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Effect of vegetation cover on the abundance and diversity of ladybirds (Coccinellidae) assemblages in a peat bog

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Abstract
Predaceous ladybirds are important natural enemies of many insect pests in terrestrial ecosystems such as peatlands, which are habitats for specialized cold-adapted plants. Ladybird assemblages of pristine peat bogs have not yet been assessed. In total, 15 ladybird species were recorded in peat bog in Belarus by using entomological sweep net. The present study shows low diversity, evenness and species richness of ladybird assemblages. However, a small number of species were present in high numbers. These are *Coccinella hieroglyphica*, *Chilocorus bipustulatus*, *Coccinulla qutuordecimpustulata* and *Hippodamia tredecimpunctata*. Ladybird abundance was positively related to shrub cover and number of vascular plant species, and negatively related to herb cover. In terms of ladybird diversity, only shrub cover had a significant negative effect.

Keywords Ladybirds · Species assemblages · Diversity · Peat bog · Belarus

Introduction

Predaceous ladybirds play an important role in food chains of terrestrial ecosystems as natural enemies of pest insect species, especially whiteflies, aphids, mealybugs, scale insect, and mites (Hodek and Honěk 2009; Roy et al. 2016). Many aphids and mealy bugs are strongly associated with specialized peat bog plants. Examples are *Aphis vaccinii* (Börner, 1940) (feeds on *Vaccinium uliginosum* L., *V. vitis-idaea* L., and *Oxycoccus palustris* L.), *Acyrthosiphon knechteli* (Börner, 1950) (feeds on *V. uliginosum, V. vitis-idaea,* and *O. palustris*), *Aulacorthum flavum* F.P. Muller, 1958 (feeds on *V. uliginosum*), *Macrosiphum nasonovi* Mordvilko, 1919 (feeds on *V. uliginosum,* and *O. palustris*) (Buga and Borodin 1999). Specialized peat bog plants are not only foods for herbivore insects, they also provide favorable environmental conditions for grass–shrub layer dwellers (Sushko 2017b), including ladybirds.

Today, the importance of the conservation of peat bogs is widely recognized. As of today 62% of European mires and peatlands have been destroyed due to human activities (Bragg et al. 2003). As a result, there is insufficient information on the fauna of pristine bogs in general and on insect species in particular. Belarus has maintained more than 50% of its peatlands in a relatively natural condition (Bragg et al. 2003). Therefore, Belarusian peat bogs are unique field sites for ecological studies. Ladybird assemblages of the pristine peat bogs are poorly studied. Information on this subject is only available from a few papers (Peus 1928; Maavara 1957; Spungis 2008; Sushko 2017a).

The present study is aimed at describing the ladybird assemblages associated with six main habitats in peat bog. The second aim was to examine environmental factors affecting ladybird diversity and abundance. Particular emphasis was given to predatory species that can be valuable in biological control and thus should be considered among primary protection goals in peatland management.

Materials and methods

Sampling sites

This research was carried out in 2015–2017 in a 19,984 ha "Yelnia" peat bog in Belarus (55°34'N27°55′ E). This is one of the largest peat bog in Central Europe with international conservation status (Kozulin et al. 2005). Its dome is about

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Table 1 Site characteristics shown as means (±SE) of the vegetation structure

Environmental variable	Habitats					
	LZ[a]	PB[b]	HOL[c]	HUM[d]	OBS[e]	D[f]
Presence of trees (−,+)	–	+	–	–	–	–
Plant height (cm)	37.5 ± 3	40.4 ± 8	28.3 ± 9	38.3 ± 6	41.4 ± 8	39.7 ± 7
Total plant cover (%)	68.6 ± 2	77.2 ± 11	67.9 ± 9	72.3 ± 9	84.3 ± 18	62.7 ± 9
Shrub cover (%)	7.4 ± 4	64.8 ± 5	7.2 ± 2	58.1 ± 4	62.4 ± 12	59.3 ± 5
Herb cover (%)	65.5 ± 3	10.4 ± 9	57.3 ± 3	14.3 ± 2	24.4 ± 8	22.7 ± 2
Number of species of vascular plants	3	10	2	8	9	7
Total number of sites per habitat type	3	3	3	3	3	3

[a] lagg zone
[b] pine bog
[c] hollow
[d] hummock
[e] open bog
[f] dome

7 m higher than the peripheral parts. The peat layer can be as deep as 8.3 m but is 3.8 m on average. There is a slope, a peak, and a plateau, located at the edges of the border zone (lagg zone) and periodically flooded due to lower elevation. For the study of ladybirds, six of the most typical peat bog habitats were selected in a transection from the edge to the dome of the peat bog: lagg zone at the bog margins, pine bog, hollows on the slope, hummocks on the slope, open bog on the slope, open bog on the dome.

Vegetation

Vegetation surveys were executed using the method of Brown (1954). The following plant associations were selected: 1) lagg zone (LZ) (plant association: *Eriophorum vaginatum* L. – *O. palustris* – *Sphagnum angustifolium* (Warnstorf) C.E.O. Jensen), 2) pine bog (PB) (plant association: *Pinus sylvestris* L. – *E. vaginatum* – *Ledum palustre* (L.) – *V. uliginosum* – *S. magellanicum* Brid), 3) hollows (HOL) (plant association: *Rhynchospora alba* (L.) Vahl. – *S. cuspidatum* Ehrh. ex Hoffm.), 4) hummocks (HUM) (plant association: *E. vaginatum* – *O. palustris* – *Andromeda polifolia* (L.) – *L. palustre* – *V. uliginosum* – *S. magellanicum* – *S. angustifolium*), 5) open bog (OBS) (plant association: *E. vaginatum* – *L. palustre* – *Chamaedaphne calyculata* (L.) Moench. – *Empetrum nigrum* L. – *Calluna vulgaris* (L.) Hull. – *O. palustris* – *V. uliginosum* – *S. magellanicum*), 6) dome (D) (plant association: *E. vaginatum* – *C. vulgaris* – *S. fuscum* Kling.).

In each habitat, 3 sites of 250 m^2 with homogeneous, vegetation were surveyed (18 sites in total). Six vegetation parameters were recorded in each site: plant height (cm), total plant cover (%), cover (%) of shrubs and herbs, the number of

Table 2 The main parameters of ladybird assemblages

Parameters	Habitats					
	LZ[a]	PB[b]	HOL[c]	HUM[d]	OBS[e]	D[f]
Number of observed species	9	10	9	6	9	5
Chao1	10.2	10.1	10.0	6.3	11.0	6.0
Estimate standard error	1.5	0.2	1.8	0.6	2.8	1.4
Jackknife 1	11.8	12.4	12.0	7.0	12.0	6.4
Estimate standard error	2.7	2.4	2.4	1.4	2.8	0.7
Shannon index (H′)	1.938	1.555	2.058	1.466	1.623	1.127

[a] lagg zone
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[c] hollow
[d] hummock
[e] open bog
[f] dome

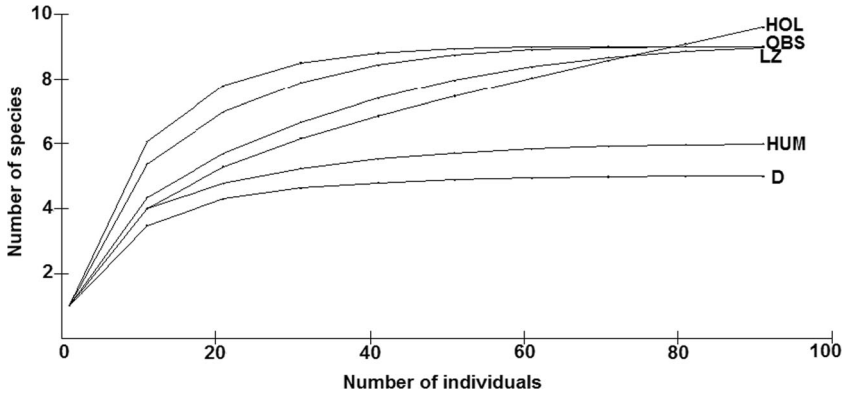

Fig. 1 Individual-based rarefaction curves showing the estimated number of ladybird species as a function of the number of individuals in the sampled sites

species of vascular plants and the presence of trees (Table 1). Sites had a minimum distance of 100 m from each other.

Open and swampy lagg zone and hollows showed a higher percentage of herbs cover and lower plant species richness (Table 1). The most common vascular plants species of these sites are *E. vaginatum, Carex limosa* L., and *Rhynchospora alba.* Pine bogs, open bogs showed the higher percentage of ericaceous dwarf shrubs cover and higher plants species richness. The hummocks, which may vary in diameter from 20 to 30 cm to several meters, are mainly composed of cotton grass, cranberry, whortleberry, Labrador tea, bog rosemary and common sundew. These plants are typical for pine bogs and open bogs, while the dome showed the higher percentage of heather in dwarf shrubs cover and a slight decrease of plants species richness.

Collection of ladybirds

Ladybirds were sampled by an entomological net (diameter 30 cm) in transects of 50 m long and 5 m wide (250 m^2 per site). In each transect exactly 50 sweeps were done between 10:00 AM and 1:00 PM twice each month. For statistical analysis, samples from each site were pooled to obtain one dataset per habitat. Sampling was done during the main activity period of adult ladybirds between May and the end of September.

Data analysis

Differences between species richness and abundances among ladybird assemblages were tested with analysis of variance (ANOVA) using permutation tests (the level of significance $p < 0.05$). The data were $\log_2$ transformed. Multiple comparisons of means were done by Tukey HSD post hoc tests.

Statistical nonparametric estimators Chao 1 and Jackknife 1 were used for calculating and extrapolating species richness. The estimators were calculated using the software SPADE (Chao et al. 2015). Rank–relative abundance curves and individual-based rarefaction curves were used to compare the patterns of species abundance among the ladybird assemblages for each site by pooling the samplings of the three years (Magurran 2004).

Alpha diversity was calculated using the Shannon diversity index (H'). SHE analysis of diversity was conducted to decompose the Shannon diversity value in a measure of species richness and evenness, to allow the interpretation of changes in diversity (Magurran 2004). SHE analysis was done using the software package PAST (Hammer et al. 2001).

Correspondence analysis (CA) was used to ordinate the relationship among species and their habitats (Jongman et al. 1995). The data were $\log_2$ transformed. The acronyms of scientific species names in the ordination represent the first three letters of both the genus- and the species (Table 3).

The relationship between Shannon diversity and total ladybird abundance to environmental variables were tested with generalized linear models (GLM) (Zuur et al. 2009). Possible intercorrelations of all measured environment variables were examined by Spearman rank-correlation (r_s). In cases of high intercorrelation among variables ($r_s > 0.6$), one of them was excluded from the analyses.

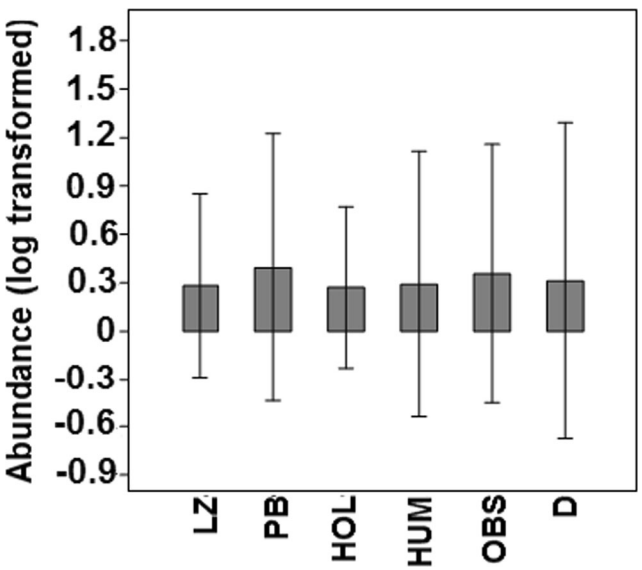

Fig. 2 Differences in total abundance (log-transformed) in ladybird assemblages. Habitat symbols: lagg zone (LZ); pine forest (PB); hollow (HOL); hummock (HUM); open bog spaces (OBS); dome (D)

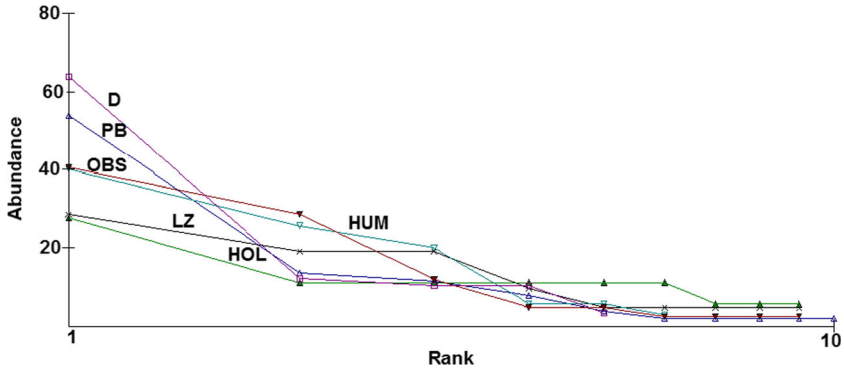

Fig. 3 Rank-abundance curves of ladybird assemblages. The y axis shows the relative abundance of species, whereas the x axis ranks each species in order from most to least abundant. Relative abundance is plotted on a $\log_{10}$ scale. Habitat symbols: lagg zone (LZ); pine forest (PB); hollow (HOL); hummock (HUM); open bog spaces (OBS); dome (D)

The following variables were included in Generalized Linear Models: cover of shrubs and herbs, the number of species of vascular plants and the presence of trees. The statistical analyses were done in R 2.12.2 (R Development Core Team 2011).

Results

Ladybird species richness, abundance and diversity

In total, 672 individuals of 15 ladybird species were recorded. Non-parametric species richness estimators Chao 1 and Jackknife 1 provided good average expected species richness, which was close to the actual overall richness recorded in the study area (Table 2). The estimator indicated that the total number of ladybird species in the study areas was 6.0–12.4 species suggesting that the observed total of 5–10 species represented 99.00% to 80.64% of the actual richness (Table 2). All the rarefaction curves, which show the estimated number of species as a function of the number of sampled individuals, the asymptote was reached, except for hollows (Fig. 1).

The ladybird assemblages comprised 6 to 10 species depending on the habitat type. The lowest number of species was

Table 3 Composition of ladybird assemblages of different habitats in the peat bog

Species	*Abbreviations*	Habitats					
		LZ[a]	PB[b]	HOL[c]	HUM[d]	OBS[e]	D[f]
		relative abundance, %					
Scimnus suturalis Thunberg, 1795	*Sci sut*	0.00	1.92	0.00	0.00	0.00	0.00
Hyperaspis reppensis (Herbst, 1783)	*Hyp rep*	4.76	0.00	11.11	2.86	2.38	0.00
Chilocorus bipustulatus (Linnaeus, 1758)	*Chis bip*	19.05	13.46	27.78	25.71	40.48	12.07
Ch. renipustulatus (Scriba, 1790)	*Chi ren*	0.00	1.92	11.11	0.00	2.38	0.00
Exohomus quadripustulata (Linnaeus, 1758)	*Exo qua*	0.00	1.92	5.56	0.00	0.00	0.00
Coccinulla qutuordecimpustulata (Linnaeus, 1758)	*Coc qut*	28.57	7.69	0.00	5.71	4.76	3.45
Anisosticta novemdecimpunctata (Linnaeus, 1758)	*Ani nov*	4.76	0.00	11.11	0.00	2.38	0.00
Calvia decemguttata (Linnaeus, 1767)	*Cal dec*	0.00	1.92	0.00	0.00	0.00	0.00
Halyzia sedecimguttata (Linnaeus, 1758)	*Hal sed*	4.76	0.00	5.56	0.00	0.00	0.00
Anatis ocellata (Linnaeus, 1758)	*Ana oce*	0.00	1.92	0.00	0.00	0.00	0.00
Hippodamia tredecimpunctata (Linnaeus, 1758)	*Hip tre*	4.76	11.54	0.00	20.00	11.90	10.34
H. variegata (Goeze, 1777)	*Hip var*	0.00	0.00	0.00	0.00	2.38	0.00
Coccinella hieroglyphica Linnaeus, 1758	*Coc hie*	19.05	53.85	11.11	40.00	28.57	63.79
C. quinquepunctata Linnaeus, 1758	*Coc qui*	4.76	0.00	5.56	0.00	0.00	0.00
C. septempunctata Linnaeus, 1758	*Coc sep*	9.52	3.85	11.11	5.71	4.76	10.34

[a] lagg zone
[b] pine bog
[c] hollow
[d] hummock
[e] open bog
[f] dome

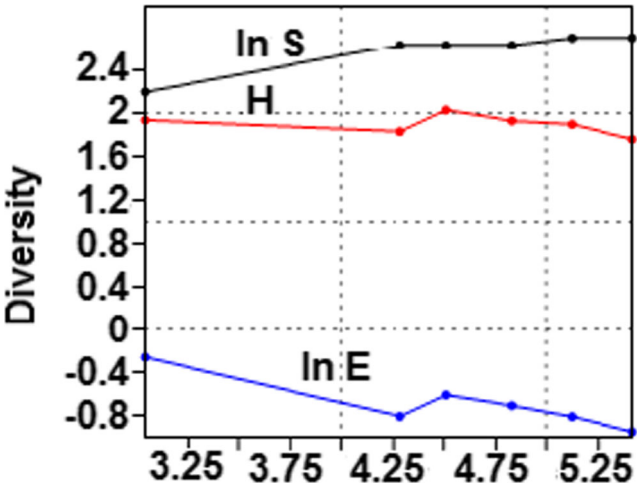

Fig. 4 SHE analysis of diversity for ladybird assemblages. ln S natural logarithm of species richness; ln E natural logarithm of evenness; H diversity (Shannon-Winner index)

recorded in the dome (5) and hummocks (6), whereas the highest species richness was in the pine bogs (10) (Table 2). In contrast, the highest ladybird abundance was in a dome (Fig. 2).

Rank abundance diagrams of the ladybird assemblages showed a low species evenness. Steepest plots signify assemblages (D, PB) with high dominance such as might be found in a geometric distribution, while shallower slopes (HUM, OBS, LZ, HOL) imply the higher evenness consistent with a log series model (Magurran 2004) (Fig. 3).

Coccinella hieroglyphica (63.79%–11.11%), *Chilocorus bipustulatus* (40.48%–12.07%), *Coccinulla qutuordecimpustulata* (28.57%–3.45%) and *Hippodamia tredecimpunctata* (20.00%–4.76%) were the most abundant species (Table 3). Three coccinellid species (*C. hieroglyphica*, *C. septempunctata* and *C. bipustulatus*) occurred in all habitats.

Hollows (H′ = 2.058) and lagg (H′ = 1.938) showed the highest Shannon-Wiener index, whereas the lowest value was recorded from dome (H′ = 1.127). The diversity index was slightly lower in other assemblages (H′ = 1.466–1.623). As a result, the SHE analysis shows that decrease in Shannon diversity value in the habitats covered with shrubs corresponded to reduction of evenness. Species richness in these habitats increases, but only a few species have high abundance (Fig. 4).

Ladybird species composition and response to environmental variables

CA analysis revealed groups of species associated with particular habitats (Fig. 5). The first two axes of the CA ordination explained 64.36% and 19.96% of the variation. The cumulative percentage of variance explained by the two first axes was 84.32%. *C. bipustulatus*, *H. tredecimpunctata* and *C. hieroglyphica* were associated with the habitats covered with shrubs (PB, OBS, HUM, D). *Halyzia sedecimguttata* seemed to be associated with open bog spaces of the lag zone.

The regression models explained 68.3% of the variation in Shannon diversity and 77.2% of the species abundance. Among the variables included in the GLM, shrub cover (p = 0.004) had a significant negative effect on the ladybird diversity and emerged as the most important predictors in this model.

The significant predictor variables for ladybirds abundance were shrub cover (p = 0.021), number of vascular plant species (p = 0.005) as well as herb cover (p = 0.021), which had a negative effect (Table 4).

Discussion

The results showed a high dominance of a small number of species in different habitats of the peat bog. The most abundant species (*C. hieroglyphica*, *C. bipustulatus*, *C. qutuordecimpustulata* and *H. tredecimpunctata*) are important predators of pest arthropods, and are considered key species for the control of many aphid, scale insects, and leaf

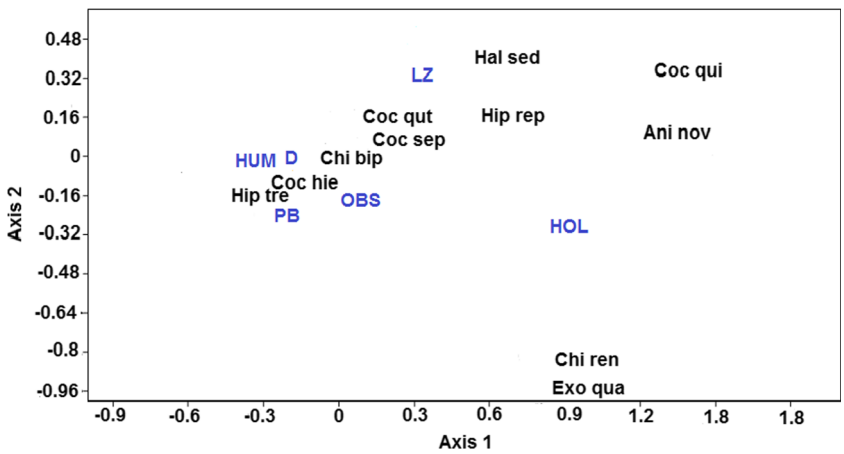

Fig. 5 Odination diagram of the correspondence analysis (CA) for assemblages of ladybirds in the analyzed habitats (Species abbreviations are given in Table 3); Habitat symbols: lagg zone (LZ); pine forest (PB); hollow (HOL); hummock (HUM); open bog spaces (OBS); dome (D)

Table 4 Relationship of total ladybird diversity and abundance to environmental factors (generalized linear model with log transformed data, multiple regression)

Parameters	Estimate	Standard Error	t-test	*p*-value
Shannon diversity ($R^2 = 0.683$)				
shrub cover	−0.009	0.003	−2.939	**0.004**
herb cover	0.008	0.003	2.509	0.062
number of vascular plant species	−0.071	0.037	−1.791	0.130
presence of trees	0.087	0.408	0.213	0.841
Abundance ($R^2 = 0.772$)				
shrub cover	0.509	0.148	3.689	**0.021**
herb cover	−0.426	0.139	−2.878	**0.042**
number of vascular plant species	4.001	1.455	2.746	**0.005**
presence of trees	17,2	17.856	0.963	0.389

beetle larvae pests (Hippa et al. 1982; Drea and Gordon 1990; Hodek and Honěk 2009). It should be noted, that these species are trophically related to pests of specialized peat bog plants (mainly ericaceous shrubs), including *O. palustris,* and *V. uliginosum* (Buga and Shalapenok 1991; Buga and Borodin 1999). On the other hand, *C. bipustulatus*, *H. tredecimpunctata* and *C. hieroglyphica* were the most associated with the habitats covered with shrubs. Among collected species *C. bipustulatus* and *C. septempunctata* have been introduced worldwide for biological control (http://www.eppo.int). *C. hieroglyphica* can be used as agents for biological control of *O. palustris,* and *V. uliginosum* pests.

C. hieroglyphica is the commonest and most widespread ladybird species in European peat bogs (Peus 1928; Maavara 1957; Spungis 2008). This species has been reported as feeder of aphids, eggs and larvae of the heather leaf beetle (*Lochmaea suturalis* (Thomson, 1866)) and chrysomelids of the genera *Altica* and *Galerucella* (http://www.coleoptera.org.uk; Hippa et al. 1982), which are common and widely distributed in the Belarusian peat bogs (Sushko 2017a). There are records from heaths, marshy meadows, acid grassland and glades too (http://www.coleoptera.ksib.pl). In Great Britain *C. hieroglyphica* is strongly associated with heaths (http://www.coleoptera.org.uk).

The highest ladybird alpha-diversity was in the habitats covered predominantly with sedges. On the other hand, in habitats, where two or three species strongly dominated, diversity decreased as a result of a low evenness. These species are probably the most adapted to the ecological conditions of raised bogs. At the same time, beta-diversity analysis revealed a clear separation between the ladybird assemblages of shrub- and herbs-covered sites.

C. bipustulatus, *H. tredecimpunctata* and *C. hieroglyphica* were associated with the habitats covered with shrubs, including *O. palustris* and *V. uliginosum*. *H. sedecimguttata* seemed to be associated with open bog spaces of the lag zone and may be the main predator of cranberry pests in the boundary bog sites.

Using in biological control requires an understanding of how vegetation factors at multiple scales affect patterns of ladybird composition. The results suggest that vegetation characteristics play an important role in shaping ladybird assemblages within peat bogs. The modeling results (GLM) indicated that plant cover and number of vascular plant species, which are food for aphids, strongly influenced ladybird abundance. On the other hand, the increase of the shrubs cover caused a decrease in the ladybird diversity. As a result, the ladybird assemblages showed to increase the abundance of several specialized peat bogs species, which are the main predators of pests of heather shrubs among which plants are important for humans.

In conclusion, the results of this study showed a low diversity, evenness and species richness of ladybird assemblages and a high abundance of a small number of species such as *C. hieroglyphica*, *C. bipustulatus*, *C. qutuordecimpustulata* and *H. tredecimpunctata*, which are the main predators of arthropods, and are considered key species for the control of many pests of cranberries, bog whortleberries and other valuable peat bog plants for the humans. Among the environment factors affecting ladybird abundance were plant cover and number of vascular plant species, whereas only shrub cover had a significant effect on diversity.

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Compliance with ethical standards

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

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