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Succession changes in diversity and assemblages composition of planthoppers and leafhoppers in natural ancient peat bogs in Belarus

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Abstract Succession has a strong influence on species diversity and composition of terrestrial ecosystems. Peat bogs are among them. They have a large area in Belarus compared to other Central European countries. While in several studies have analyzed the effects of succession on vegetation in peat bog ecosystems, the response of peatland insects to succession has not been investigated yet. To address this issue were sampled Auchenorrhyncha abundance and environmental parameters on the ancient and one of the largest natural peat bog along a successional gradient from the margin to the bog dome. The results provide evidence that succession of peat bogs has influence on planthoppers and leafhoppers abundance, diversity and species composition. Along the successional gradient from younger towards older successional stages an increase abundance of specialized peat bog species, chamebionts, oligophagous and monophagous was observed. On the contrary, the younger stages of natural peat bog succession offer favorable conditions to eurytopic, polyphagous and chortobiont planthoppers and leafhoppers. The highest abundance and species richness of Auchenorrhyncha were in the lagg zone followed by early stages of natural peat bog succession. The highest diversity was in the middle stages of succession. A determinant of Auchenorrhyncha diversity was the cover of ericaceous dwarf shrubs. Linear models shrub cover and number of plants species had a positive effect on planthoppers and leafhoppers diversity and a negative effect on their abundance. Amount of ericaceous dwarf shrubs within the peat bog could be as a measure of heterogeneity.

Keywords Succession · Auchenorrhyncha · Assemblages · Diversity · Peat bog

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Introduction

Peat bogs in the southern boreal and temperate zones form characteristic habitat islands in the surrounding landscape and occur as isolated and discrete patches of “edaphic forest tundra” and so are azonal or extrazonal ecosystems relative to the surroundings. Some of the islands of habitat are ancient and have persisted since early Holocene periglacial periods, about 12,000–13,000 years ago, when the climatic conditions were much cooler. The peat bogs of Europe contain many arthropods common to the subarctic forest-tundra biome (Spitzer and Danks 2006). The recent habitat island structure of central European bogs is a unique product of the ecological succession in the Holocene (Spitzer et al. 1999). Many bog inhabitants have specific habitat requirements, such as acidic and nutrient-poor conditions, specific cold-adapted or bog-restricted foodplants, and aquatic or aquatic-edge habitats (Spitzer and Danks 2006).

Unfortunately, peat bogs and other wetlands are very sensitive and endangered ecosystems in Central Europe (Succow 2000). Belarus is one of the few countries in Central Europe with a big area of natural bogs (Bragg et al. 2003). The size of some bogs is very considerable and varies from several hectares up to several thousand hectares. Belarusian peat bogs are important ecosystems for biodiversity conservation.

Climate of the Atlantic period (Holocene Thermal Maximum) was the most suitable for the emergence of peat bogs on the territory of contemporary Belarus. However, many of the most ancient peat bogs began to form in the Younger Dryas (11,000 years ago) (Geltman 1982). Several studies examined the effects of succession on vegetation in peat bog ecosystems (Geltman 1982; Belenki and Kurzo 1988; Yelovicheva et al. 2008). The differences in recent vegetation are reflected in the subfossil plant assemblages. Studies of the botanical composition of the peat showed that in peatlands cotton grass, pine and sphagnum in plant cover dominated in the early stages of succession. Later, the ericaceous dwarf shrubs appeared. They were composed of the periglacial vegetation and migrated to the Peat bog because of global warming in the Atlantic period. Due to peat deposits, peat bogs have a convex relief. Peat layer in the central part can reach up to 3–7 m. Ombrotrophic heather subclimax communities are formed here (Pidoplichko 1961).

The historical development and nature of individual bogs are reflected by differences among their insects, which are of great biogeographical and ecological interest. The environmental sensitivity of bogs also makes insects valuable as bioindicators. Evidence from current and past insect biodiversity helps researchers interpret the biogeography and successional dynamics of these habitats (Spitzer and Danks 2006). The presence and survival of the tyrphobiontic and tyrphophilous relict insect species seem to be good evidence of the long-term constancy of the peatland environment during the Holocene period.

One of the most appropriate objects for such researches can be Auchenorrhyncha. The planthoppers and leafhoppers feed on plant sap and occur in high abundance and species richness in most terrestrial ecosystems. Their functional significance is poorly known, but due to their high abundances in the herb layer as well as in tree canopies, their biomass in relation to other arthropod groups is high, and thus, they are likely to form an important component of terrestrial food webs (Nickel 2003). In Europe, most studies are concentrated on peat bogs Auchenorrhyncha species composition (Rabeler 1931; Maavara 1957; Freese and Biedermann 2005; Nickel and Gärtner 2009; Holzinger and Schlosser 2013; Sushko and Borodin 2009), while studies of successional influences on bogs fauna are still rare (Spitzer et al. 1999).

The aim of this study was to characterize the diversity and species composition of Auchenorrhyncha assembages of main successional stages in peat bogs.

Materials and methods

Study site

The research was carried out between 2010 and 2013 on the peat bog "Moch" (4602 hectares) which is one of the largest peat bogs in Belarus (Coordinates: 55°37′N28°06′E). Today "Moch" remains one of the few bogs preserved in natural conditions. The national conservation status of the peat bog is national hydrological reserve. Its surface is convex. There is a slope and peak–plateau. It is located at the edges of the border zone (lagg zone), which is periodically flooded due to a lower position. Peat bog "Moch" began to form in the Younger Dryas, and is one of the oldest in Belarus (Belenki and Kurzo 1988).

The sequence of successional stages is provided by Razumovsky (1981). Vegetation surveys were also conducted according to the method of Brown (1954). 12 sites were selected (with a size of 250 m^2 each and a homogeneous vegetation structure) and stratified to three main successional stages (young, middle, and old): (1) lagg zone (LZ) at the bog margin, open and swampy (*Eriophorum vaginatum* + *Rhynchospora alba*–*Sphagnum angustifolium*)—young successional stages; (2) bog slope (PB), pine bog, wet (*Pinus sylvestris*–*Eriophorum vaginatum*–*Ledum palustre*–*Sphagnum magellanicum* + *S. angustifolium*)—middle successional stages; (3) bog slope, open bog (OBS), less wet (*Eriophorum vaginatum*–*Ledum palustre*–*Chamaedaphne calyculata*–*Empetrum nigrum*–*Calluna vulgaris*–*Oxycoccus palustris* + *Andromeda polyfolia* + *Vaccinium uliginosum*–*Sphagnum magellanicum* + *S. angustifolium* + *S. fuscum*)—middle successional stages; (4) dome (DM), open, exposed and dry (*Eriophorum vaginatum*–*Calluna vulgaris* + *Ledum palustre*–*Sphagnum fuscum*)—subclimax (old stages) (Fig. 1). Vegetation was sampled during July 2010 in all sites. In each site four vegetation parameters were recorded: cover (%) of dwarf shrubs, herbs, the number of species of vascular plants and the presence of trees (Table 1). Sites had a minimum distance of 50 m from each other.

Auchenorrhyncha survey

Auchenorrhyncha assemblages and relative abundances were estimated by using a transect method. All study plots were paced off in loops, and within a band of 1 m (total observed area per plot: 250 m^2). One sample consisted of five subsamples. Each was 50 net sweeps. For statistical analysis, data of the samplings in each site were summed up to obtain one dataset per site. Surveys were conducted during the main activity period of adult planthoppers and leafhoppers between May and the end of September. For the collection of planthoppers and leafhoppers entomogical sweep-net (diameter 30 cm) was used. Sweep-netting was done for a large proportion of the existing studies on central European Auchenorrhyncha (Nickel 2003). In sites with similar height and structure of the vegetation and even surface, standardized sweep-netting provides good results, which can be compared within the same study and on similar plots. Sweeping with a net in dense vegetation is difficult, but in peat bog habitats with homogeneous scattered vegetation this method is appropriate.

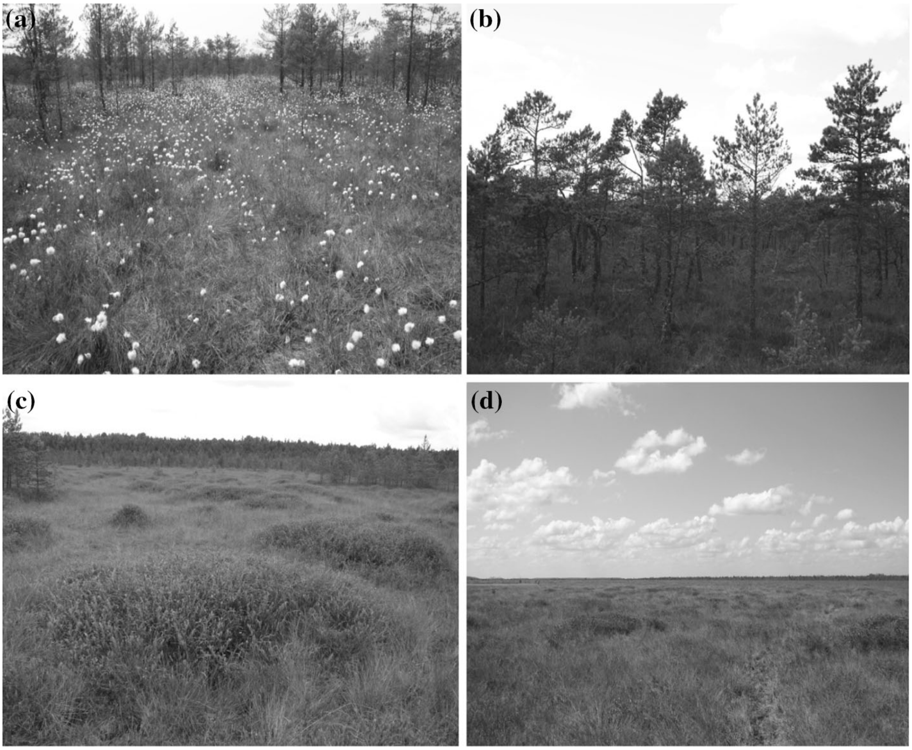

Fig. 1 Typical stands of **a** cotton grass—young successional stages (LZ); **b** pine and dwarf-shrub—middle successional stages (PB), **c** dwarf-shrub—middle successional stages (OBS), **d** heath—old successional stages (DM) within the study area of "Moch" peat bog, Belarus. *Habitat symbols* lagg zone (LZ), pine bog (PB), open bog spaces (OBS), dome (D)

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

Environmental variable	LZ	PB	OBS	D
Presence of trees (−, +)	−	+	−	−
Dwarf shrubs cover (%)	10.8 ± 2	57.9 ± 11	59.4 ± 16	56.1 ± 7
Herbs cover (%)	68.8 ± 6	12.1 ± 4	28.5 ± 18	24.7 ± 2
Number of vascular plants species	3	10	9	7
The total number of sites per habitat type	3	3	3	3

Habitat symbols lagg zone—young successional stages (LZ), pine bog—middle successional stages (PB), open bog—middle successional stages (OBS), dome—old successional stages (DM)

The nomenclature of Auchenorrhyncha follows Nickel (2003). The ecological terminology is that of Spitzer and Danks (2006): tyrphobiontic species are stenotopic and obligatory associated with peat bogs in the temperate zone, tyrphophilous taxa are more abundant on bogs than in adjacent habitats, and tyrphoneutral species are eurytopic and widely distributed in various habitats. According to Borodin (2004) there are four basic life form of peat bog Auchenorrhyncha by host plant species: chortobionic species (associated with herbs), chamebiontic species (associated with dwarf shrubs), tamnobiontic species (associated with bushes), dendrobiontic species (associated with trees).

The food plants, diet width and ecological types of Auchenorrhyncha follow Borodin (2004), Nickel and Remane (2002).

Data analysis

Differences of abundance and species richness among the Auchenorrhyncha assemblages three successional stages 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. The relationship between Shannon diversity and total Auchenorrhyncha abundance to environmental variables were tested with generalized linear models (GLM) on $\log10\ (x + 1)$ transformed data to meet model assumptions (Zuur et al. 2009, 2010). The statistical analyses were conducted using R 2.12.2 (R Development Core Team 2011).

To calculate the diversity of the Auchenorrhyncha assemblages I used Simpson (D) and Shannon–Wiener indices (H′). Evenness was estimated using Pielou's evenness indices (J). Hierarchical cluster analysis (Single link method) was employed in the analysis of habitat similarity. Calculations were performed using the Past® software (Hammer et al. 2001).

Principal component analysis (PCA) 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. Species occurring as singletons were omitted from ordination analysis as well as sites where only one individual was detected. Post hoc Tukey HSD tests were used to examine pairwise differences between axis 1 and 2 of the PCA ordinations. Calculations were performed using the MVSP software package (MVSP 2002).

Results

Vegetation

Vegetation parameters differed substantially among successional stages (Table 1). Cover of grasses was the largest in the young successional stages reaching values of 68.8 %. In the later successional stages cover of dwarf-shrub increased (56.1–59.4 %). Heather had the highest cover among other ericaceous dwarf shrubs in old stages of succession (86 %). Trees occurred predominantly in the pine bog habitat. They were very sparse.

Auchenorrhyncha capture statistics

A total of 40 species of Auchenorrhyncha belonging to 5 families (Cixiidae, Delphacidae, Issidae, Cercopidae и Cicadellidae) were collected. The highest number of species was recorded from Cicadellidae family (26). Other families were represented by smaller numbers of species: Cercopidae—6, Delphacidae—4, Cixiidae—3, Issidae—1.

The assemblages of planthoppers and leafhoppers comprised from 17 to 28 species. The highest number of species (28) was captured in the lagg zone (early successional stage) in

Table 2 The main parameters of Auchenorrhyncha assemblages

Parameters	Habitats			
	LZ	PB	OBS	DM
Number of species	28	27	23	17
Number of families	5	5	5	5
Number of species represented by 1–2 specimens	13	15	12	6
% of species represented by 1–2 specimens	48.15	55.55	52.17	35.29
Number of species with abundance >5 %	3	4	8	6
% of specimens of species with abundance >5 %	11.11	14.81	34.78	35.29
Shannon–Wiener index (H′)	1.525	2.356	2.453	2.243
Simpson index (D)	0.422	0.157	0.124	0.146
Pielou index (J)	0.170	0.390	0.505	0.554

the nearby pine forest (27) on the bog slope (middle successional stage). The lowest species richness (17) was recorded in the subclimax habitats of dome (Table 2).

Almost half of the species (48.15–55.55 %) was represented by 1–2 individuals in habitats of early and middle successional stages. The number of such species is reduced (35.29 %) in the old stages (Table 2). Two species *Neophilaenus lineatus* (23.95–62.64 %) and *Lepyronia coleoptrata* (11.89–16.24 %) were collected from all sites in high abundance. They were also the only abundant species in habitats on the edge of the peat bog. In the middle successional stages such species as *Cixius similis, Ommatidiotus dissimilis* increased, *Aphrophora alni, Ulopa reticulata,* and *Idiodonus cruentatus* were recorded in high abundances. At the habitats of the dome a similar ratio of species is retained. Only the numbers of *Ulopa reticulata* were higher (Table 4).

Auchenorrhyncha species composition, abundance and diversity

Auchenorrhyncha abundance significantly differed among the successional stages (ANOVA, $F = 10.91$, $p = 0.016$). Planthoppers and leafhoppers abundance was the highest in the early successional stages (LZ) (Fig. 2).

The changes in planthoppers and leafhoppers assemblages of various successional stages are reflected by the diversity indices. The middle successional stages showed the highest average Shannon–Wiener index value ($H' = 2.356$–2.453), whereas the lowest value was recorded from the youngest sites ($H' = 1.525$). The Pielou evenness index (0.170) was minimum in the youngest sites as well. Dominance peaked for early successional stages ($D = 0.422$), with the lowest value for the middle successional stage ($D = 0.124$). In the old successional stages the Shannon–Wiener index ($H' = 2.243$) slightly decreased, but evenness were the highest (0.554) (Table 2; Fig. 3).

The cluster analysis showed a similarity among Auchenorrhyncha assemblages of middle and old successional stages (PB, OBS and DM). On the other hand the assemblages of lagg zone (early stages) and ones of dome (subclimax) were the least similar (Fig. 4).

The principal components analysis revealed the groups of species associated with particular habitats. The first two axes of the PCA ordination explained 80.70 and 11.39 % of the variation. The cumulative percentage of variance explained by the two first axes was 82.09 %. In the PCA-diagram from left to right, habitats ranged from young (LZ) along the edge of bogs to middle (PB and OBS) on the slope and to the old (D). This corresponds to the succession gradient (Fig. 5).

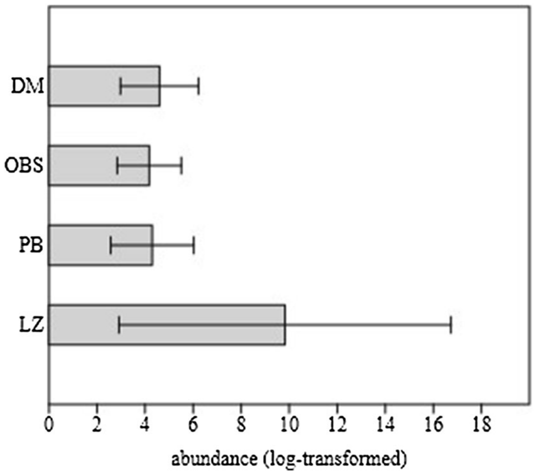

Fig. 2 Differences in the total abundance (number of individuals) of Auchenorrhyncha among successional stages along a peat bog successional gradient. *Habitat symbols* lagg zone—young successional stages (LZ), pine bog—middle successional stages (PB), open bog—middle successional stages (OBS), dome—old successional stages (DM)

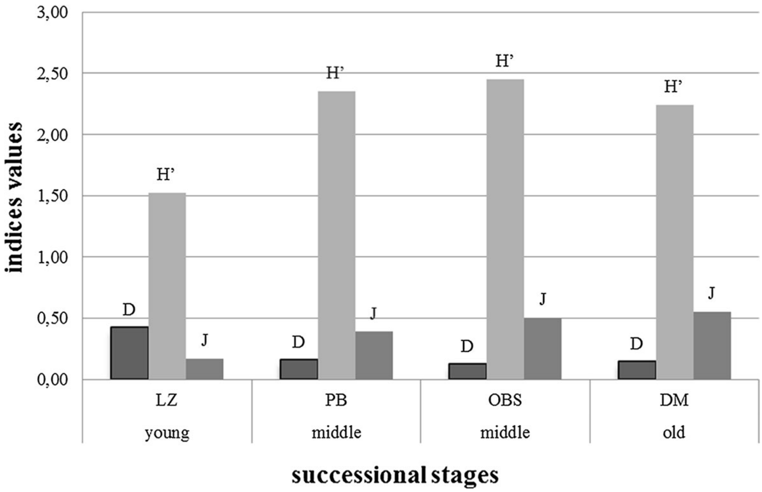

Fig. 3 Differences in a Simpson (D), and Shannon (H′) diversity and evenness (J) indices of Auchenorrhyncha among successional stages along a peat bog successional gradient. *Habitat symbols* lagg zone (LZ), pine forest (PB), open bog (OBS), dome (DM)

Many species showed clear preferences for certain habitats. Preference for the lagg zone (early stages of succession) was shown by chortobiontic tyrphophilous species, which have trophic relationship with *Eriophorum vaginatum* and *Carex* sp. (*Pentastiridius leporinus, Ommatidiotus dissimilis, Stroggylocephalus livens, Cicadula quadrinotata, Macustus grisescens,* and *Sorhoanus xanthoneurus*) and by eurytopic species such as *Neophilaenus lineatus.* On the other hand, specialized peat bogs species *Cixius similis, Ophiola russeola* and *O. cornicula*, feeding on ericaceous dwarf shrubs, seemed to be more associated with later successional stages (PB, OBS). At the same time several dendrobiontic species such as *Colladonus torneellus, Allygus mixtus,* and *Thamnotettix confinis* preferred only pine bog habitat.

The tyrphobionts and some tyrphophilous taxa are the best bioindicators of successional change of peat bogs (Spitzer et al. 1999). Within the early stages of succession six tyrphophilous species (*Pentastiridius leporinus, Kelisia vittipennis, Ommatidiotus dissimilis,*

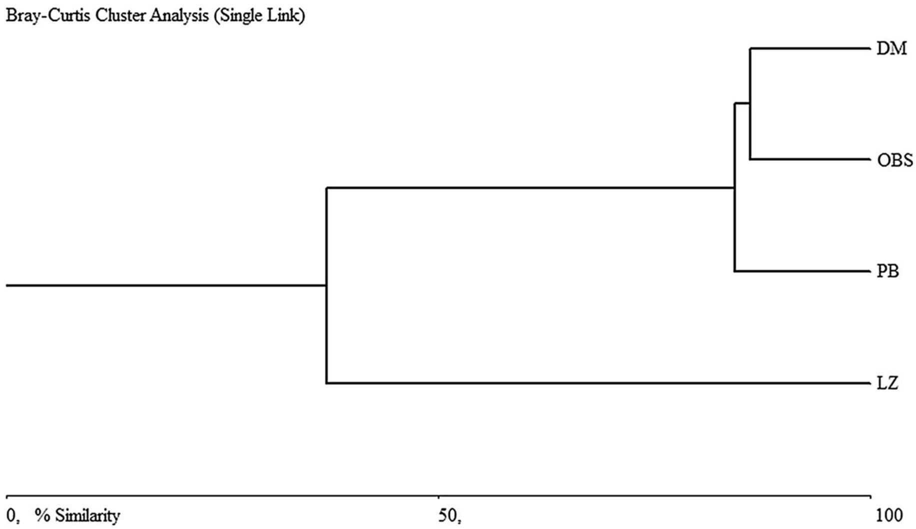

Fig. 4 Comparison of species compositions of planthoppers and leafhoppers is re-corded in different habitats in the peat bog (Single link method). *Habitat symbols* lagg zone—young successional stages (LZ), pine bog—middle successional stages (PB), open bog—middle successional stages (OBS), dome—old successional stages (DM)

Stroggylocephalus livens, Cicadula quadrinotata and *Sorhoanus xanthoneurus*) could be regarded as indicator species. *Cixius similis* and *Ophiola russeola* were recorded probably as indicator species for the middle succession stages. Within the habitats of the old stages of succession (DM) only inhabitant of heather *Ulopa reticulata* could be regarded as indicator species. Potential indicator was specialized peat bog species *Ophiola cornicula*, which was found more or less at every site of later successional stages and could not be used as indicators of old or middle stages (Fig. 5).

The significant predictors variable in the generalized linear model for Shannon diversity were dwarf shrubs cover and number of plants species. The significant predictors variable for planthoppers and leafhoppers abundance were dwarf shrubs cover and vegetation species richness which had a negative effect (Table 3).

Changes in the ecological groups of planthoppers and leafhoppers

In the early stages of succession the highest abundance were eurytopic species (65.19 %). In other successional stages of their proportion is much lower (32.33–34.05 %). On the other hand, the proportion of highly specialized peat bog species increases in a range from young (10.44 %) to old (41.84 %) stages of succession. Eleven of these species (tyrphobionts and tyrphophilous) were recorded. Compared to the other wetland areas in Central Europe (Nickel and Remane 2002, Borodin 2004), this is an average number. In addition hygrophilous and mesophilic grassland species were captured, but their abundance lower (Fig. 6).

Cotton grass dominates in flooded areas of the lagg zone. In the less moist areas located on a slope, ericaceous dwarf shrubs prevail in vegetation. On the almost dry dome the diversity of ericaceous dwarf shrubs species decreases hence the heather prevails there. It has importance for Auchenorrhyncha species, as all of them are phytophagous.

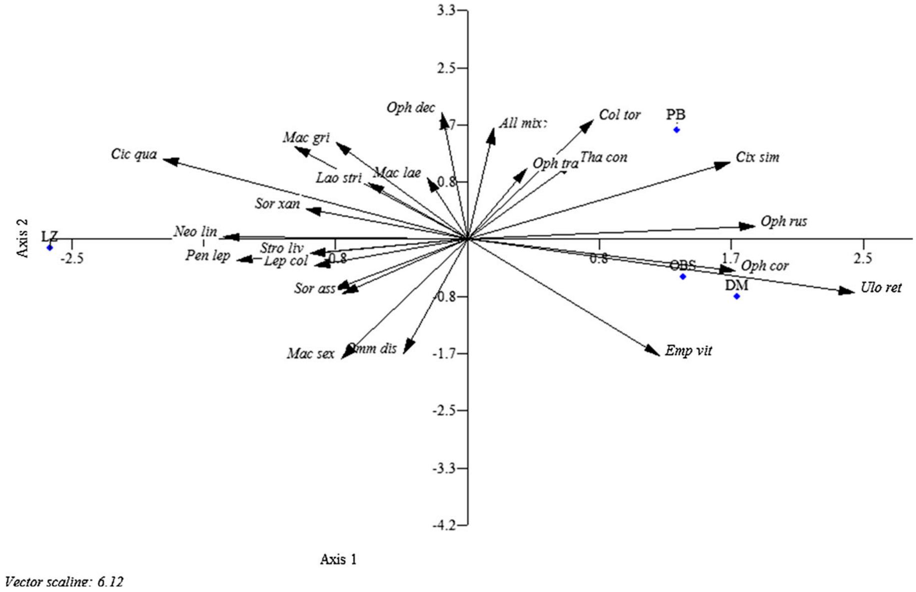

Fig. 5 PCA biplot for sites and for species. *Habitat symbols* lagg zone—young successional stages (LZ), pine bog—middle successional stages (PB), open bog—middle successional stages (OBS), dome—old successional stages (DM). *All mix = Allygus mixtus, Cic qua = Cicadula quadrinotata,Cix sim = Cixius similis, Col tor = Colladonus torneellus, Emp vit = Empoasca vitis, Idi cru = Idiodonus cruentatus, Lao str = Laodelphax striatella, Lep col = Lepyronia coleoptrata, Mac lae = Macrosteles laevis, Mac sex = M. sexnotatus, Mac gri = Macustus grisescens, Neo lin = Neophilaenus lineatus, Omm dis = Ommatidiotus dissimilis, Oph cor = Ophiola cornicula, Oph dec = O. decumana, Oph rus = O. russeola, Pen lep = Pentastiridius leporinus, Sor xan = Sorhoanus xanthoneurus, Sor ass = S. assimilis, Str liv = Stroggylocephalus livens, Tha con = Thamnotettix confinis, Ulo ret = Ulopa reticulata*

Auchenorrhyncha prevailing at edge of the peat bog, followed by young stages of succession, feed on *Eriophorum vaginatum* (8 species) and on *Carex* sp. (11 species). In the pine bog and open habitats on the slopes the number of such species is much smaller (8). On the other hand, the number of species, feeding on ericaceous dwarf shrubs, increases (4). On the dome (old stages of succession) there is even a smaller number of species, feeding on sedges. In addition, there is the highest number of heather feeders (Fig. 7).

Polyphagous species (57.67–86.31 %) dominated in all habitats. These are such species as *Lepyronia coleoptrata, Neophilaenus lineatus, Aphrophora alni, Idiodonus cruentatus, Philaenus spumarius* and others. On the slope and the dome (middle and old succession stages) their number decreases. Compared to the lagg zone, here where a higher percentage of oligophagous species (22.83–29.19 %). The majority are feeding on *Calluna vulgaris* and *Vaccinium* sp. A higher percentage of monophagous was recorded on the dome followed by old stages of peat bog succession (19.56 %). On the other hand, the greatest number of monophagous species were found in the lagg zone (young succession stages). Among them were monophagous *Eriophorum vaginatum* such as *Kelisia vittipennis, Ommatidiotus dissimilis, Stroggylocephalus livens, Cicadula quadrinotata, Sorhoanus xanthoneurus* (Fig. 8).

Table 3 Composition of Auchenorrhyncha assemblages of different habitats on the peat bog "Moch" (NW Belarus)

Species/family	Percentage of total abundance of sampling site				Food plants	Diet width
	LZ	PB	OBS	DM		
Cixiidae						
Cixius distinguendus Kirschbaum 1868	0.23				Dwp	po
C. similis Kirschbaum, 1868**	0.93	21.08	16.77	14.67	*Betula, Pinus, Vaccinium*	o2
Pentastiridius leporinus (Linnaeus, 1761)*	0.93				*Phragmites australis, Carex, Eriophorum*	m1
Delphacidae						
Kelisia vittipennis (J. Sahlberg, 1868)*	1.16	0.54	0.60	1.09	*Eriophorum, Carex*	m2
Delphax crassicornis (Panzer, 1796)	0.70	0.54			*Phragmites australis*	m1
Laodelphax striatella (Fallén, 1826)	0.46	0.54	0.60		Poaceae	po
Javesella pellucida (Fabricius, 1794)	0.46				Poaceae, Cyperaceae	po
Issidae						
Ommatidiotus dissimilis (Fallén, 1806)*	2.78	2.16	5.39	4.89	*Eriophorum vaginatum*	m1
Cercopidae						
Lepyronia coleoptrata (Linnaeus, 1758)	16.24	11.89	14.37	13.04	Mainly Poaceae, dch.	po
Neophilaenus exclamationis (Thunberg, 1784)		0.54			*Festuca ovina, Deschampsia flexuosa*	o1
N. lineatus (Linnaeus, 1758)	62.65	29.73	23.95	28.26	Poaceae, Cyperaceae, Juncaceae	po
Aphrophora alni (Fallén, 1805)	1.86	4.86	6.59	4.89	Ad.: Dwp, Nym.: dch	po
A. pectoralis Matsumura, 1903		0.54			*Salix caprea, S. purpurea* a.o.	m2
Philaenus spumarius (Linnaeus, 1758)	0.70	2.70	2.99	1.63	Mainly dch	po
Cicadellidae						
Ulopa reticulata (Fabricius, 1794)*		4.86	5.99	12.50	*Calluna vulgaris*	m1
Aphrodes bicinctus (Schrank, 1776)	0.23				Fabaceae (a.o.)	o1
Stroggylocephalus agrestis (Fallén, 1806)	0.23				*Carex*	m2
S. livens (Zetterstedt, 1838)*	0.23				*Carex, Eriophorum*	m2
Cicadella viridis (Linnaeus, 1758)	0.23				*Juncus, Carex* a.o.	po
Kybos strigilifer (Ossiannilsson, 1941)		0.54	1.20	0.00	*Salix* grey-leaved	m2

Table 3 continued

Species/family	Percentage of total abundance of sampling site				Food plants	Diet width
	LZ	PB	OBS	DM		
Empoasca vitis (Göthe, 1875)		0.54	2.99	1.63	Dwp	po
Linnavuoriana sexmaculata (Hardy, 1850)			0.60		*Salix*	m2
Balclutha punctata (Fabricius, 1775)	0.70	0.54	1.20	0.54	Poaceae	o1
Macrosteles cristatus (Ribaut, 1927)	0.23				Poaceae	po
M. laevis (Ribaut, 1927)	0.23	0.54	0.60		Poaceae	po
M. sexnotatus (Fallén, 1806)	0.70		0.60	0.54	Poaceae, Juncaceae, Cyperaceae	po
Idiodonus cruentatus (Panzer, 1799)	2.32	4.86	5.39	5.98	Nym.: vhp; Ad.: trees, shrubs	po
Colladonus torneellus (Zetterstedt, 1828)		1.62	0.60	0.54	*Melica uniflora*, woody plants	po
Allygus mixtus (Fabricius, 1794)		0.54			Nym.: Poaceae; Ad.: Dwp	po
Cicadula quadrinotata (Fabricius, 1794)*	2.09	0.54			*Carex, Eriophorum*	m2
Thamnotettix confinis (Zetterstedt, 1828)		1.08		1.09	Ad.: Dwp; Nym.: vhp	po
Macustus grisescens (Zetterstedt, 1828)*	0.46	0.54			Poaceae, *Carex* a.o., *Molinia caerulea, Eriophorum vaginatum*	o2
Ophiola cornicula (Marshall, 1866)*		2.16	2.99	3.80	*Calluna vulgaris, Vaccinium* spp.	o1
O. decumana (Kontkanen, 1949)	0.23	1.08	0.60		*Polygonum aviculare, Rumex acetosella* (a.o.)	o1
O. transversa (Fallén, 1826)		0.54	0.60		*Achillea millefolium*	m1
O. russeola (Fallén, 1826)*		3.24	3.59	3.80	*Calluna vulgaris, Vaccinium oxycoccos*	o1
Paralimnus phragmitis (Boheman, 1847)	0.23				*Phragmites australis*	m1
Arthaldeus pascuellus (Fallén, 1826)	0.23				Poaceae	o1
Sorhoanus assimilis (Fallén, 1806)	0.46		0.60		*Carex rostrata, C. panicea, C. nigra*	m2
S. xanthoneurus (Fieber, 1869)*	2.09	1.62	1.20	1.09	*Eriophorum vaginatum*	m1

Habitat symbols lagg zone (LZ), pine forest (PB), open bog (OBS), dome (DM), m1—1st degree monophagous, 1 plant species monophag, m2—2nd degree monophagous, 1 plant genus monophag, *o1* 1st degree oligophagous, 1 plant family oligophag, o2 2nd degree oligophagous, two plant families or less than five species of less than five families oligophag, *po* polyphagous, *Dwp* Deciduous woody plants, *dch* dicotyledonoush herbs, *vhp* various herbaceous plants

* Tyrphophilous species, ** Tyrphobiontic species

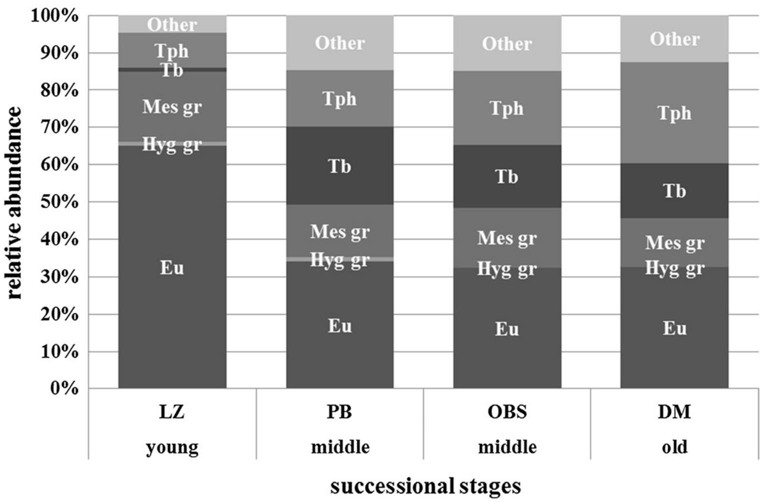

Fig. 6 Differences in ecological types of Auchenorrhyncha (after Borodin 2004) among successional stages along a peat bog successional gradient (percentage of total specimens). Ecological types: *Eu* eurytopic species, *Hyg gr* hygrophilous grassland species, *Mes gr* mesophilic grassland species, *Tb* tyrphobiontic species, *Tph* tyrphophilous species. *Habitat symbols* lagg zone (LZ), pine bog (PB), open bog (OBS), dome (DM)

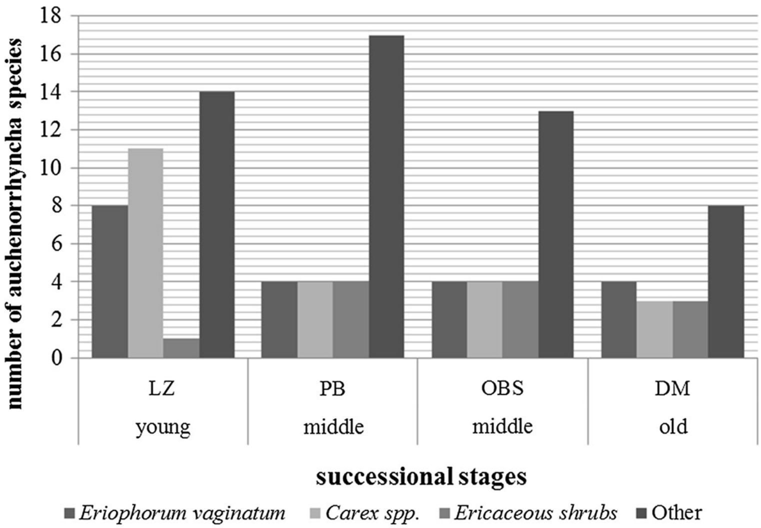

Fig. 7 Differences in a trophic preferences of Auchenorrhyncha (after Nickel 2003) among three successional stages along a peat bog successional gradient. *Habitat symbols* lagg zone (LZ), pine forest (PB), open bog (OBS), dome (DM)

Discussion

Peat bogs are known as extreme habitats for plants and certain groups of animals (Främbs et al. 2002; Spitzer and Danks 2006; Dapkus and Tamutis 2008). The number of collected Auchenorrhyncha species is not high. In this study most species were collected in low

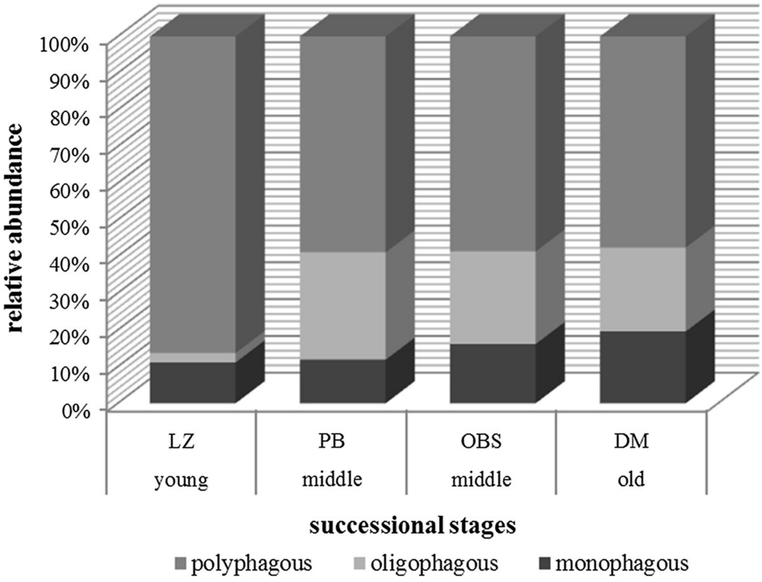

Fig. 8 Differences in a diet width (after Nickel 2003) of Auchenorrhyncha among three successional stages along a peat bog successional gradient. *Habitat symbols* lagg zone (LZ), pine forest (PB), open bog (OBS), dome (DM)

numbers. A few abundant species are dominating in assemblages. That is typical for peat bogs in other European countries as well (Maavara 1957; Nickel and Remane 2002; Freese and Biedermann 2005; Holzinger and Schlosser 2013). In total, 49 species of Auchenorrhyncha inhabit peat bogs in Belarus, which is only about 14.80 % of all planthoppers and leafhoppers species known in this country (Borodin 2004; Sushko and Borodin 2009).

Vegetation characteristics showed strong differences among the successional stages. Along the successional gradient from lagg zone towards dome an increase of vegetation composition and abundance was observed.

Lagg zone corresponding to younger successional stages showed the higher percentage of herbs cover and low plants species richness. In these stages several polyphagous and chortobiontic species had their highest abundance. This might be explained by the narrow food supply offered in those habitats for a lot of Auchenorrhyncha species. It was also detected that most species feed on cotton grass, but the number of their individuals was low (Fig. 9).

Compared to the transitional stages, the younger stages offer favorable conditions to eurytopic planthoppers and leafhoppers. On the other hand, the proportion of highly specialized peat bog species increases in a range from young to old stages of succession. The same was observed for Lepidoptera and Carabidae in the peat bogs in Czech Republic (Spitzer et al. 1999).

Vegetation characteristics of a pine bog and an open bog, followed by middle stages of peat bog succession, were similar. These stages showed the higher percentage of ericaceous dwarf shrubs cover and high plants species richness. The ericaceous dwarf shrubs offer a food poor supply for oligophagous and monophagous Auchenorrhyncha species specialized on ericaceous dwarf shrubs, which might explain low abundance of chortobionts at that stage (Fig. 9).

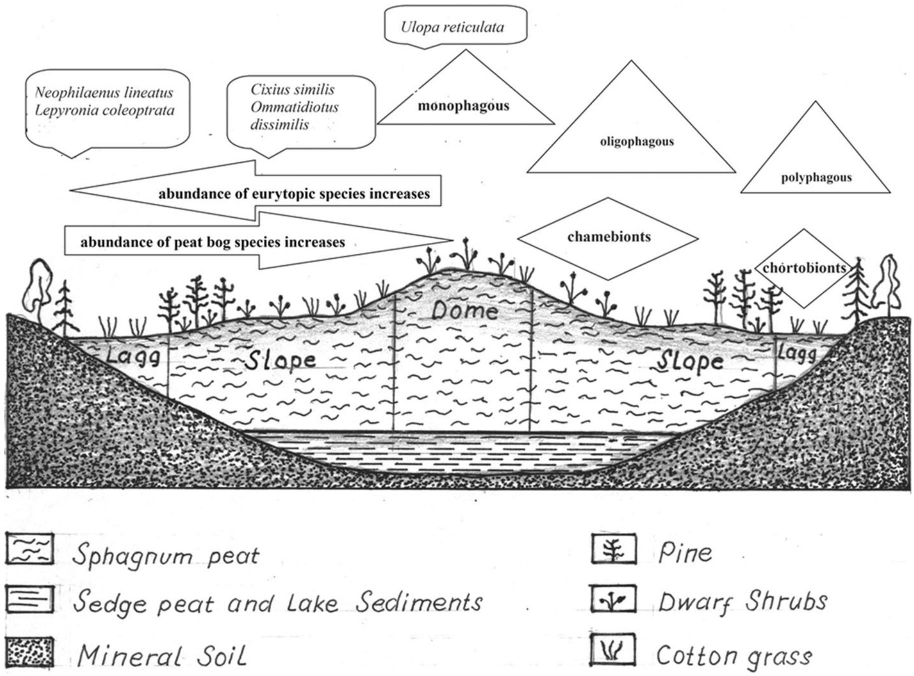

Fig. 9 The main changes in Auchenorrhyncha assembages along the successional gradient from young towards old successional stages in the peat bogs (according to Pidoplichko 1961). *Habitats* lagg zone—young successional stages; slope (pine bog and open bog)—middle successional stages; dome—old successional stages

Dome corresponding to old successional stages showed the higher percentage of heather in dwarf shrubs cover and a slight decrease of plants species richness. Open bog spaces at the dome showed the highest abundance of specialized peat bog species and monophagous Auchenorrhyncha of all studied successional stages (Fig. 9).

Therefore, along the successional gradient from young towards old successional stages an increase abundance of specialized peat bog species, chamebionts, oligophagous and monophagous abundance was observed. In contrast the younger stages of natural peat bog succession offer favorable conditions to eurytopic, polyphagous and chortobiontic planthoppers and leafhoppers.

The results provide evidence that succession of peat bogs has a strong influence on planthoppers and leafhoppers abundance, diversity, and species composition. Abundance and species richness of Auchenorrhyncha were the highest in the lagg zone followed by early stages of natural peat bog succession (edge of the bog covered with cotton grass). These results provide support for previous studies, which reported higher Orthoptera (Schirmel et al. 2011) and Lepidoptera density in early stages of heathland succession (Schirmel and Fartmann 2014). Two eurytopic species (*Lepyronia coleoptrata* and *Neophilaenus lineatus*) composed here 78.89 % of all individuals.

Diversity was higher in the middle stages of succession in comparison to early and old stages. Other investigations, on the contrary, reported higher carabid diversity in the early stages of forest succession (Riley and Browne 2011) and butterflies diversity in the early stages of coastal heathland succession (Schirmel and Fartmann 2014). Compared to the transitional stages, the old successional stages had slightly reduced values of Shannon–Wiener diversity index. On the other hand, these Auchenorrhyncha assemblages and assemblages of early stages were the least similar. Minimum difference in Auchenorrhyncha species composition occurred between the middle and old stages of succession. In the early stages of succession Auchenorrhyncha assemblages there was the lowest diversity and evenness of species and the highest index of dominance.

Many species showed clear preferences for certain habitats. Preference for the early stages of succession was shown by tyrphophilous species (*Pentastiridius leporinus*, *Kelisia vittipennis*, *Ommatidiotus dissimilis*, *Stroggylocephalus livens, Cicadula quadrinotata*, *Macustus grisescens*, and *Sorhoanus xanthoneurus*) and by eurytopic species as well. In those habitats the highest abundance was represented by eurytopic species *Neophilaenus lineatus*. On the other hand, the later stages of succession offer favorable conditions to other specialized peat bogs Auchenorrhyncha species such as *Cixius similis, Ophiola russeola* and *O. cornicula*, feeding on ericaceous dwarf shrubs.

Poisson generalized models shrub cover and number of plants species had a positive effect on planthoppers and leafhoppers diversity and a negative effect on their abundance. Amount of ericaceous dwarf shrubs within the peat bog could be as a measure of heterogeneity.

Such habitats consist of a mixture of only three plant life forms (short pines, dwarf shrubs and herbs). A determinant of Auchenorrhyncha diversity was the cover of ericaceous dwarf shrubs, such as *Ledum palustre, Chamaedaphne calyculata, Calluna vulgaris, Oxycoccus palustris, Andromeda polyfolia, Vaccinium uliginosum.* They are the main larval and imaginal host plants of planthopper and leafhoppers in the middle successional stages. *Calluna vulgaris* is one of the main host plants of Auchenorrhyncha in the old successional stages.

Conservation of biodiversity of relict peat bogs is a basic priority for insect conservation in Europe (Spitzer et al. 1999). Moreover, the increasing fragmentation and uniformity of peat bog fragments following anthropogenic influence on the landscape make these questions urgent. Among the specialized peat bog species, only *Cixius similis* was recorded in greater number. The abundance of others peat bog dwellers was lower. They are very sensitive to environmental changes. It is necessary to keep hydrological conditions in bogs stable. Otherwise, some management activities in bogs should be used (Table 4).

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

Parameters	Estimate	SE	t	P
Shannon diversity ($R^2 = 0.978$)				
Shrubs cover	0.017	0.001	9.511	**0.010**
Herbs cover	−0.015	0.004	−3.520	0.072
Number of vascular plant species	0.124	0.009	13.691	**0.005**
Trees	0.270	0.129	2.084	0.172
Abundance ($R^2 = 0.889$)				
Shrubs cover	−5.367	0.146	−36.714	**0.0007**
Herbs cover	4.858	1.212	4.005	0.057
Number of vascular plants species	−37.265	3.308	−11.263	**0.007**
Trees	−75.500	44.111	−1.711	0.229

Significance $P < 0.005$ marked of bold

To conclude, the results provide evidence that succession of peat bogs has an influence on planthoppers and leafhoppers abundance, diversity and species composition. Along the successional gradient from young towards old successional stages an increase abundance of specialized peat bog species, chamebiontic, oligophagous and monophagous was observed. In contrast, the younger stages of natural peat bog succession offer favorable conditions to eurytopic, polyphagous and chortobiontic planthoppers and leafhoppers. Abundance and species richness of Auchenorrhyncha were the highest in the lagg zone followed by early stages of natural peat bog succession. Diversity was the highest in the middle stages of succession. A determinant of Auchenorrhyncha diversity was the ericaceous dwarf shrubs cover. Linear models of a shrub cover and a number of plants species had a positive effect on planthoppers and leafhoppers diversity and a negative effect on their abundance. Amount of ericaceous dwarf shrubs within the peat bog could be as a measure of heterogeneity.

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