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DRAINAGE IMPACT ON PLANT COVER AND HYDROLOGY OF AUKŠTUMALA RAISED BOG (WESTERN LITHUANIA)

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Abstract

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One-third of the former Aukštumala raised bog (western Lithuania) has been preserved as Telmological Reserve since 1995, while the remaining territory is still under active industrial peat mining or are abandoned peat harvesting fields. The present study was carried out in 2013 and aimed to assess long-term human impact on the structure of plant cover and hydrology of Aukštumala raised bog. On the basis of vegetation assessment (Twinspan analysis), four habitat types were identified: i) active raised bog, ii) degraded raised bog drained by ditches, iii) contact zone of the bog and the peat mining fields and iv) recently burnt areas. The largest anthropogenic impact on vegetation cover was found in the degraded raised bog drained by the ditches and in the burnt area, where the proportion of plant species atypical to ombrotrophic raised bogs was the highest. Water electrical conductivity negatively correlated ($r = -0.57$) with bog water level, whereas correlation between pH and bog water level was weaker ($r = -0.38$). Water level in the active raised bog was significantly higher than in the rest three habitat types. Electrical conductivity values in the active raised bog were significantly lower compared to the degraded raised bog and burned area habitats. In order to recreate favourable conditions for peat accumulation and natural functioning of bog ecosystem, mean bog water level should be raised at least up to -32 cm (the optimum water level assigned for most of the typical ombrotrophic species fell into the range of -20 – -32 cm).

Keywords: Aukštumala Telmological Reserve, degradation, drainage, raised bog vegetation, Lithuania.

INTRODUCTION

Peatlands in Lithuania cover about 646 000 ha; however, only 178 000 ha may be considered as undisturbed (Povilaitis et al., 2011; Taminskas et al., 2011). Spatial distribution of disturbed peatlands is related to geomorphologic conditions and agricultural traditions in different regions of the country. The biggest drainage works have been carried out on the plains of western and central Lithuania, whereas a hilly landscape in the eastern part of the country has been drained less (Sinkevičius, 2001). In the Nemunas delta region (western Lithuania) large-scale land reclamation works were implemented already at the 19th century to regulate water regime in very fertile lands. Therefore, natural fens in this area have almost disappeared and most of large raised bogs are strongly affected by drainage (Basalykas, 1958).

In the case of pristine peatlands, the succession normally progresses towards decreasing base saturation and increasing water and peat acidity. This long-term trend towards ombrotrophy may be regarded as the final stage of peatland development (Rydin & Jeglum, 2006). Despite of the fact that active raised bogs are usually rather stable ecosystems, their further development towards degradation often follows as human activity accelerates succession process and turns them into bog woodlands or degraded raised bogs (Joosten & Clarke, 2002).

Different types of mires react to drainage in different ways. In fens, the area of the influence of drains on decreased ground water level in adjacent areas is much more prominent because of fen geomorphology and inability of the upper peat layer to retain water. According to Tanovitskaya et al. (2009), in raised bogs, during the first years after reclamation works, the zone of drainage influence is evident within 50 m from draining ditch. With gradual habitat desiccation, the vegetation cover of the raised bog loses its water-retaining properties and the zone of drainage influence expands. Decreased bog water level affects water acidity and availability of oxygen and nutrients, thus notably accelerating peat mineralization process, which leads to bog ecosystem degradation (Witte et al., 2004).

Since the end of the 19th century, Aukštumala raised bog and other peatlands of the Nemunas River Delta have been subject to a lot of investigations in various fields. Aukštumala is the first raised bog in the world described in the monograph by German botanist Weber (1902). The main concepts of raised bog ecology and botany were described in this book as well as the data on geological and paleogeographical development of raised bogs were published, the ecology and vegetation of Aukštumala raised bog were discussed. C. A. Weber is often credited for his role in developing the modern concept of raised bog (Couwenberg & Joosten, 2002).

Currently, 2417 ha of the former Aukštumala raised bog has been turned into the peat mining fields and the remaining part (1285 ha) has been declared as the Telmological Reserve. Although the status of the Reserve protects the western part of Aukštumala raised bog from further peat excavation, however, it does not protect this area from negative influence of draining. The areas adjacent to peat mining fields are drained most intensively, but ditches surround all the territory of the Reserve and cross it in several places as well. Already Weber (1902) stated that drainage has influence on thickness, chemical and physical peculiarities of the peat layer and vegetation structure.

The current study addresses the following questions: i) how do drainage and peat extraction impact the structure of plant cover and hydrology of Aukštumala raised bog?; ii) how does water level influence distribution of ombrotrophic species.

INVESTIGATION AREA

Aukštumala raised bog (1285 ha) is situated in the Nemunas Delta Plain (western Lithuania; 55° 24′ N, 21° 20′ E) (Fig. 1).

According to Kunskas (2005), the morphogenesis of certain parts of Aukštumala raised bog bottom is different: the western part includes glaciolimnic lagoon and old valley sedimentation areas, whereas the eastern part – morainic and glacioaqueous hollow relief, late ice lake terraces and the Holocene paludification. The mean thickness of peat deposit is 6.1 m, yet the greatest thickness may reach 9.0 m (Vidmantas, 1966; Liužinas, 1995). A thin (up to 1 m) layer of gyttja is usually underlying the peat deposit (Mažeika, 2006). Weber (1902) pointed out that the uppermost and the thickest of all peat layers of the raised bog is moss (*Sphagnum*) peat, which thickness varies between 3 and 5 m.

In 1882, in the south-eastern part of Aukštumala raised bog, a peat mining factory was built, and since then manual peat excavation activities have been launched (Purvinas, 2006). The greatest changes in the raised bog took place in 1968, following installation of protective embankments, water pumping stations, roads and ditches. The intensive reclamation resulted in drainage of about 2/3 of the total bog area, which was subsequently designated for industrial peat-cutting (Letukaitė et al., 2007).

At the beginning of the 20th century, Weber (1902) categorized Aukštumala raised bog vegetation by its growing place into: i) the plateau; ii) raised bog pools; iii) stream valleys; iv) marginal slope and v) vegetation of surroundings. However, the last three habitat types could hardly be found today because of the intensive drainage in the former lag zone. Pakalnis et al. (2009) indicated that after more than 100 years of peat mining activity, the following changes in the vegetation cover of the remained part of Aukštumala raised bog were ascertained: i) expansion of dwarf-shrubs (dominated by *Calluna vulgaris* (L.) Hull) in the communities of open raised bog; ii) penetration of trees (*Betula pubescens* Ehrh. and tall-stemmed *Pinus sylvestris* L.) into *Ledo-Sphagnetum magellanici* Sukopp 1959 em. Neuhäusl 1969 communities; iii) extinction of *Sphagnum* mosses and formation of lichen cover in the communities of open raised bog.

The main threat to natural habitats of the Aukštumala Telmological Reserve is posed by an

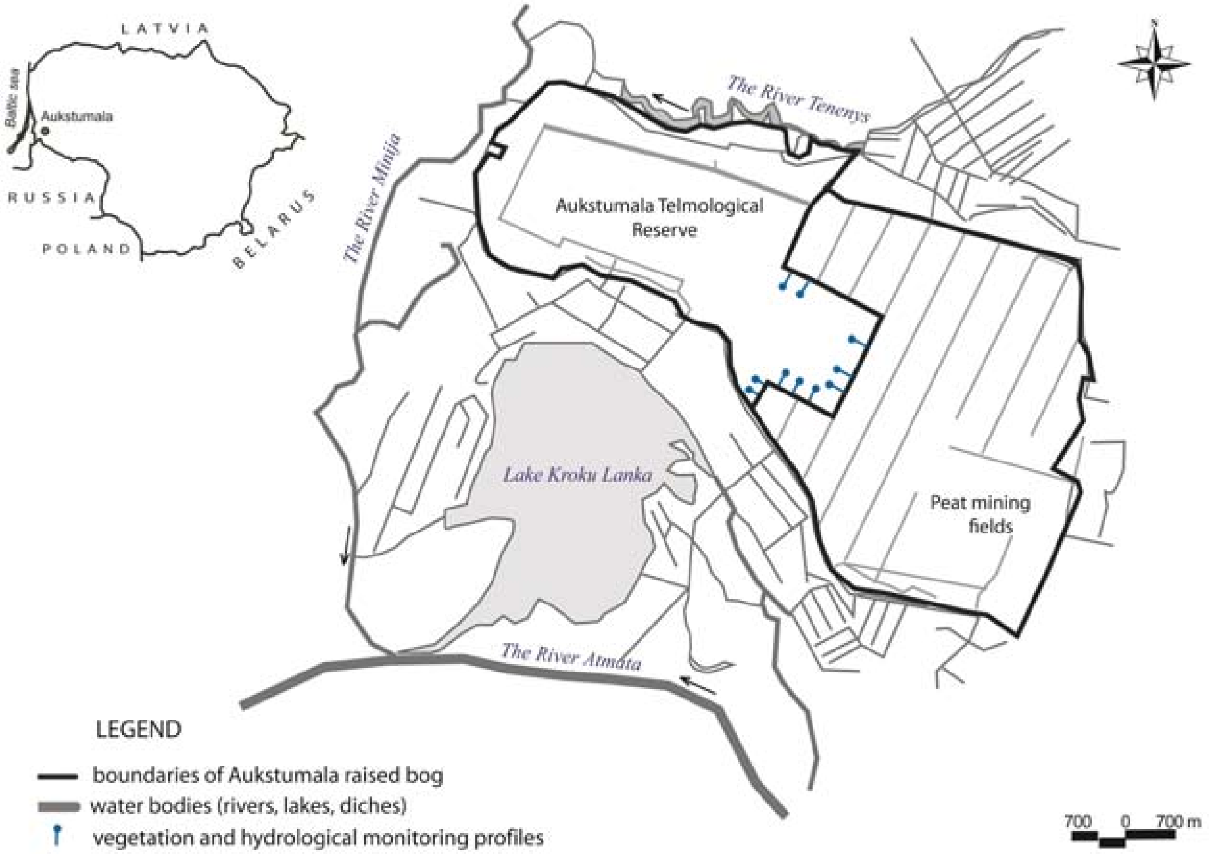


Fig. 1. Location of Aukštumala raised bog with localization of vegetation and hydrological monitoring profiles

old drainage system in the active raised bog and continuous peat mining in the neighbouring peat excavation zone. The contact zone of the Telmological Reserve and peat-cutting fields is about 6 km long; and about 30–60 ha of the Reserve is under the influence of intensive drainage (deep ditches) (Jarašius et al., 2010).

MATERIALS AND METHODS

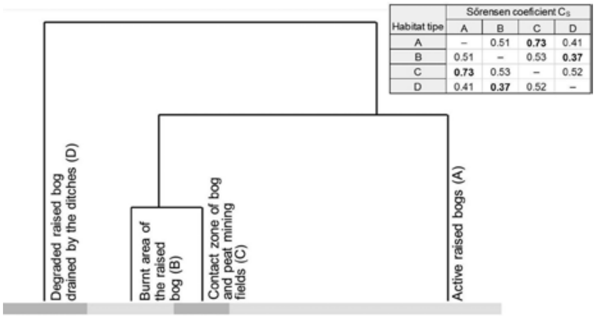
This paper summarizes the data on the investigation of vegetation cover and hydrology of the Aukštumala Telmological Reserve, carried out in 2013. To assess the drainage effect on the hydrology of the Reserve, a hydrological monitoring system was installed (ten profiles with nine water level measurement wells in each). All profiles (170 m length each) were installed perpendicularly to the contact zone of the Reserve and peat mining fields, regardless microrelief. The first well of each profile was installed 10 m from the contact zone. The distance between the rest wells was 20 m. For the installation of water level measurement wells, perforated PVC tubes (diameter 50 mm, length 2 m, perforated along the full length) were inserted into 1.8 m peat deposit. To stop peat filling, the tube from the base was covered with nylon material. The top of the well was capped. The water level measurement was carried out with monthly interval during vegetation season in May–October, 2013. Bog water pH and electrical conductivity (EC), sampled from water level measurement wells in August, 2013, were measured using HI-991300 – CONDUCTIVITY/TDS/PH METRE.

Phytocoenotic relevés of raised bog vegetation were performed applying the principles of Zürich-Montpellier phytosociological vegetation research approach (Braun-Blanquet, 1964). During the investigation, 84 phytosociological relevés (10 × 10 m) were made. The central point of each relevé was a bog water level (BWL) measurement well. Nomenclature of the plant communities followed Matuszkiewicz (2001). Nomenclature of vascular plant species followed Gudžinskas (1999) and bryophytes were described after Jukonienė (2003) and Naujalis et al. (1995). Habitats of European Importance were identified according to the criteria of the Annex II of EU Habitat directive (European comission, 2013). Ecological groups of plants (typical and atypical ombrotrophic species) were distinguished according to Ellenberg et al. (2001) scale for Nitrogen. Plant species indicating extremely infertile (1, 2 indicator groups) sites were considered as typical ombrotrophic species. Phytosociological data were statistically analysed with the aid of *JUICE 7.0*. Some outliers were excluded from the analyses. Sorensen similarity indices (C_S) were calculated (Bray & Curtis, 1957; Kent, 2012) and modified TWINSPAN classification (Hill, 1979) was used to compare plant communities and define the types of habitats. Differences between hydrological and hydrochemical mean parameters in the determined types of habitats were calculated using one-way ANOVA followed by Tukey's test for significance ($p < 0.05$). Hydrological data were statistically analysed with *STATISTICA* 6. Pearson correlation analysis was used to outline the relationship between differences in water chemical parameters (pH, EC) and BWL.

RESULTS

Analysis of vegetation cover

Of the 84 phytosociological relevés, a total of 76 plant species were recorded, 43% of which were typical to raised bogs. Based on TWINSPAN cluster analysis, four clusters were distinguished and named after relatively predominant habitat type: i) active raised bog (55 relevés); ii) degraded raised bog drained by the ditches (11 relevés); iii) the contact zone of the bog and peat mining fields (7 relevés) and iv) burned area of the raised bog (11 relevés) (Fig. 2). First two habitat types were qualified as habitats of the European importance: 7110 *Active raised bogs; 7120 Degraded raised bogs still capable of natural regeneration.



Habitat tipe	Sőrensen coeficient C_S			
	A	B	C	D
A	–	0.51	**0.73**	0.41
B	0.51	–	0.53	**0.37**
C	**0.73**	0.53	–	0.52
D	0.41	**0.37**	0.52	–

Fig. 2. Types of habitats in Aukštumala raised bog based on TWINSPAN cluster analysis. A – active raised bog; B – burned area of the raised bog; C – contact zone of the bog and the peat mining fields; D – degraded raised bog drained by the ditches

In the active zone of the raised bog, 43 plant species were recorded (Table 1, Fig. 3). Of these, 72% were typical to ombrotrophic raised bogs. This type of the habitat was represented by the ass. *Sphagnetum magellanici* (Malc. 1929) Kästner et Flössner 1933, and characterized by treeless plant communities with well-expressed *Sphagnum* moss (73% ± 14.4) and sparse herb coverage (33% ± 16). Most abundant species were *Sphagnum magellanicum, S. fuscum*, *Rhynchospora alba* and *Eriophorum vaginatum*. A large fraction of species (*Carex rostrata, Drosera anglica, Scheuchzeria palustris, Trichophorum cespitosum, Cephalozia connivens, Sphagnum cuspidatum, S. fallax, S. rubellum* and *S. tenellum*) were found only in this type of the habitat.

Forty one plant species were recorded in the degraded raised bog drained by the ditches (Table 1, Fig. 3). Trees and shrubs were abundant in this zone, whereas the moss layer was sparse (38% ± 24.1). *Pinus sylvestris, Ledum palustre* and *Vaccinium vitis-idaea* were the main vegetation components leading to identification of this type of vegetation closest to the ass. *Ledo-Sphagnetum magellanici* Sukopp 1959 em. Neuhäusl 1969. However, in more dry areas, a high proportion (61%) of the inventoried species such as mesotrophic *Sorbus aucuparia, Deschampsia flexuosa, Lycopodium annotinum, Moehringia trinervia, Luzula multiflora, Dryopteris dilatata and Trientalis europaea* as well as eutrophic *Solanum dulcamara* and *Urtica dioica* were not typical for ombrotrophic bogs.

In the contact zone of the bog and peat mining fields, 25 plant species were recorded (Table 1, Fig. 3). Of these, 80% are typical to ombrotrophic bogs. Communities with dense *Pinus sylvestris*, *Calluna vulgaris* and *Empetrum nigrum* cover and sparse moss coverage (10% ± 10.5) have penetrated into the raised bog along a narrow (20–60 m wide) stripe. Only two *Sphagnum* species (*S. magellanicum, S. capillifolium)* were recorded. The structure of vegetation was closest to ass. *Ledo-Sphagnetum magellanici* Sukopp 1959 em. Neuhäusl 1969.

Table 1. Plant cover composition and mean frequency (%) of plant species in different types of habitats in the Aukštumala Telmological Reserve, Šilutė district, Lithuania, 2013. For definition of the habitat types see Fig. 2

		Habitat type			
		A	B	C	D
Total number of relevés		55	11	7	11
Coverage (%)	Tree layer	12	6	38	47
	Shrub layer	0	0	0	28
	Dwarf shrub layer	55	69	64	43
	Herb layer	33	21	11	28
	Bryophyte layer	73	29	9	38
Average number of species per relevé		13	11	14	15
Total number of species in the habitat type		42	29	24	41
Trees					
Betula pendula Roth b*		7	.	57	9
c**		42	91	14	.
Betula pubescens Ehrh. b		9	27	43	91
c		56	.	29	.
Pinus sylvestris L. b		13	.	86	82
c		62	.	14	.
Shrubs					
Frangula alnus Mill.		4	.	29	82
Ribes rubrum L.		.	.	.	18
Sorbus aucuparia L.		.	.	.	64
Viburnum opulus L.		.	.	.	18
Herbs and dwarf shrubs					
Andromeda polifolia L.		91	64	86	36
Bidens tripartita L.		.	9	.	.
Calamagrostis epigejos (L.) Roth		.	18	.	.
Calamagrostis sp.		.	18	.	.
Calluna vulgaris (L.) Hull		80	82	86	27
Carex rostrata Stokes		5	.	.	.
Cerastium sylvaticum Waldst.et Kit.		.	9	.	.
Circaea alpina L.		.	.	.	9
Conyza canadensis (L.) Cronquist		.	18	.	.
Cystopteris fragilis (L.) Bernh.		.	.	.	18
Deschampsia flexuosa (L.) Trin.		.	.	.	45
Drosera anglica Huds		24	.	.	.
Drosera rotundifolia L.		44	.	14	.
Dryopteris dilatata (Hoffm.) A. Gray		.	.	.	18
Empetrum nigrum L.		35	.	86	18
Epilobium angustifolium L.		.	73	.	.
Eriophorum angustifolium Honck.		2	.	.	.
Eriophorum vaginatum L.		87	18	57	36
Galium aparine L.		.	.	.	9
Geum urbanum L.		.	.	.	9
Ledum palustre L.		16	9	71	73
Luzula multiflora (Ehrh.) Lej.		.	.	.	9
Lycopodium annotinum L.		.	.	.	27
Maianthemum bifolium (L.) F.W. Schmidt		.	.	.	18
Moehringia trinervia (L.) Clairv.		.	.	.	18

Table 1 continued

	Habitat type			
	A	B	C	D
Molinia caerulea (L.) Moench	.	.	29	91
Mycelis muralis (L.) Dumort.	.	9	.	18
Oxycoccus palustris Pers.	58	9	57	27
Rhynchosphora alba (L.) Vahl	84	36	.	9
Rubus caesius L.	.	9	.	.
Rubus chamaemorus L.	44	45	71	45
Rubus idaeus L.	.	.	.	27
Rumex acetosella L.	.	18	.	.
Scheuchzeria palustris L.	5	.	.	.
Senecio sylvaticus L.	.	18	.	.
Solanum dulcamara L.	.	.	.	9
Trichophorum cespitosum (L.) C. Hartm.	2	.	.	.
Trientalis europaea L.	.	.	.	18
Urtica dioica L.	.	.	.	9
Vaccinium myrtillus L.	.	.	.	73
Vaccinium uliginosum L.	4	.	29	36
Vaccinium vitis-idaea L.	.	.	.	91
Bryophytes				
Aulacomnium androgynum (Hedw.) Schwaegr.	4	.	.	.
Aulacomnium palustre (Hedw.) Schwaegr.	45	27	.	18
Brachythecium mildeanum (Schimp.) Schimp. ex Milde	4	.	.	.
Brachythecium oedipodium (Mitt.) Jaeg.	.	.	.	18
Cephalozia bicuspidate (L.) Dumort.	2	.	.	.
Cephalozia connivens (Dicks.) Lindb.	2	9	.	.
Dicranella cerviculata (Hedw.) Schimp.	2	9	57	.
Dicranum polysetum Sw.	7	9	86	82
Dicranum scoparium Hedw.	2	.	57	.
Funaria hygrometrica Hedw.	2	82	57	.
Hypnum cupressiforme Hedw.	5	.	29	.
Lophocolea heterophylla (Schrad.) Dumort.	2	.	.	.
Marchantia polymorpha L.	2	64	.	.
Mylia anomala (Hook.) Gray	5	.	.	.
Plagiothecium sp.	2	.	.	.
Pleurozium schreberi (Brid.) Mitt.	11	9	100	73
Pohlia nutans (Hedw.) Lindb.	2	27	86	.
Polytrichum commune Hedw.	.	36	.	.
Polytrichum strictum Sm.	36	82	71	.
Sphagnum angustifolium (C.E.O. Jensen ex Russow) C.E.O. Jensen	.	.	.	9
Sphagnum capillifolium (Ehrh.) Hedw.	65	.	29	9
Sphagnum cuspidatum Ehrh. ex Hoffm.	7	.	.	.
Sphagnum fallax (H. Klinggr.) H. Klinggr.	33	.	.	.
Sphagnum fuscum (Schimp.) H. Klinggr.	51	.	14	.
Sphagnum magellanicum Brid.	96	.	14	36
Sphagnum rubelum Wilson	20	.	.	.
Sphagnum tenellum (Brid.) Pers. ex Brid.	5	.	.	.

* Second tree layer; ** Trees in the shrub layer

In 2013, two years after the fire, a total of 29 plant species were recorded in the investigated area of the burned bog (Table 1, Fig. 3). Only 52% of the inventoried species were typical to ombrotrophic raised bogs. Pioneer moss species such as *Marchantia polymorpha* and *Funaria hygrometrica* were dominant. In the herb layer, the ruderal species *Chamerion angustifolium* and alien species *Conyza canadensis* were commonly found. A *Sphagnum* layer was almost absent (burnt out) in this zone, and typical oligotrophic species *Andromeda polifolia, Oxycoccus palustris*, *Rhynchosphora alba* and *Polytrichum strictum* occurred sparsely (Table 1).

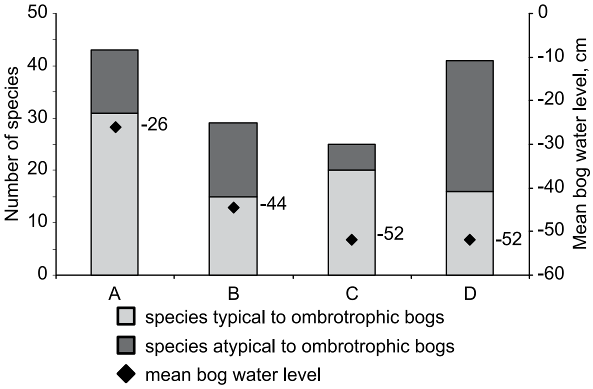


Fig. 3. Distribution of plant species typical and atypical to ombrotrophic bogs and mean water level in four different habitats in the Aukštumala Telmological Reserve

Hydrological and hydrochemical analysis

In all 84 water level measurement wells, the water level ranged between 15 and 94 cm below the bog surface (Fig. 4); pH ranged between 4.0 and 6.2, and EC – from 44 to 140 µS·cm^{-1} (Table 2). It was ascertained that the water level moderately negatively correlated with EC (r = -0.57; p < 0.05) (Fig. 5), while the correlation of water level with pH was weaker (r = -0.38; p < 0.05). The comparison of hydrological and hydrochemical parameters in four distinguished types of plant habitats showed that water level in the active raised bog habitat was significantly (at p < 0.05) higher than in other three habitat types (Table 2, Fig. 4), while among the rest three types the differences were insignificant (at p > 0.05). EC values in active raised bog habitat were significantly (at p < 0.05) lower compared to degraded raised bog and burned area habitats (Table 2). Significant differences in mean pH values between different habitats were not found.

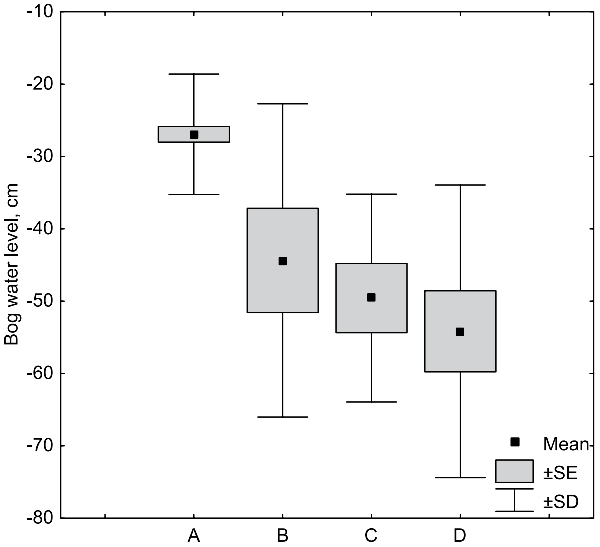


Fig. 4. Differences in bog water level in four different habitats in the Aukštumala Telmological Reserve. For habitat definition see Fig. 2

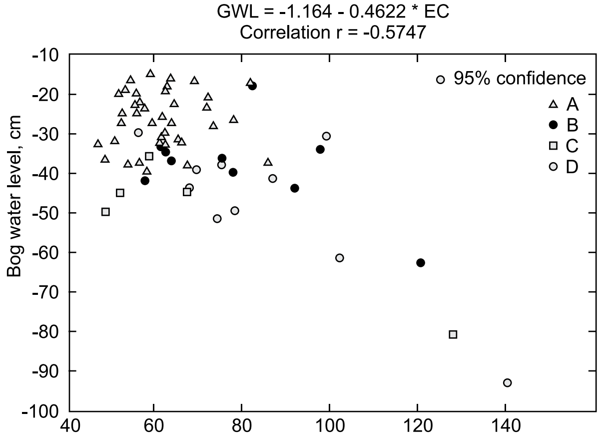


Fig. 5. Correlation between bog water level and electrical conductivity (EC µS·cm^{-1}) in the Aukštumala Telmological Reserve. A, B, C, D – different types of habitats. For habitat definition see Fig. 2

According to our hydrological data, the highest mean bog water level in all habitats was recorded in May and had a tendency to decrease during the summer season (Table 3). However, water level fluctuation amplitudes in four habitats were different. The most constant bog water level was recorded in active raised bog habitat; the average seasonal bog water level amplitude was 12 ± 6.4 cm. In the rest three habitat types, seasonal bog water level amplitude was higher with the largest fluctuation recorded in the degraded raised bog habitat (Table 3). Moreover,

Table 2. Bog water level, pH, electrical conductivity (µS·cm^{-1}) in four different habitats identified in the Aukštumala Telmological Reserve. Within lines, values labelled with different letters are significantly different at $p \leq 0.05$; n.s. – non-significant difference (Tukey HSD test, ANOVA). For definition of the habitat types see Fig. 2

Parameter	Habitat types							
	A		B		C		D	
Number of relevés	55		11		7		11	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Bog water level, cm	-26 a	± 8.4	-44 b	± 22.5	-52 b	± 16.0	-52 b	± 20.2
pH	4.4 n.s.	± 0.17	4.6 n.s.	± 0.24	4.6 n.s.	± 0.38	4.6 n.s.	± 0.61
EC, µS·cm^{-1}	60 a	± 9.7	79 b	± 14.4	74 ab	± 24.1	84 b	± 21.9

Table 3. Bog water level fluctuation during vegetation period (May–October) in the Aukštumala Telmological Reserve, 2013. Within lines, values labelled with different letters are significantly different at $p \leq 0.05$ (Tukey HSD test, ANOVA). For definition of the habitat types see Fig. 2

Months	Habitat type							
	A		B		C		D	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	Mean water level fluctuation amplitudes							
May–October	12 a	±6.4	21 a	±14.0	18 a	±8.8	34 b	±15.5
	Mean bog water level during the vegetation season (May–October)							
May	-23 a	±7.7	-41 b	±25.1	-44 b	±16.1	-36 ab	±14.0
June	-25 a	±7.0	-50 b	±27.2	-49 b	±15.9	-45 b	±17.3
July	-26 a	±7.1	-49 b	±21.9	-55 b	±18.7	-48 b	±16.7
August	-29 a	±8.6	-50 b	±21.3	-56 b	±14.1	-57 b	±24.6
September	-29 a	±11.7	-39 a	±19.5	-58 b	±14.0	-69 b	±23.6
October	-23 a	±7.6	-38 ab	±19.9	-47 bc	±16.9	-56 c	±24.7
Mean	-26 a	±8.4	-44 b	±22.5	-52 b	±16.0	-52 b	±20.2

monthly bog water level values in active raised bog (A) habitat were in most cases significantly higher ($p < 0.05$) compared to the rest three habitat types (B, C, D); the differences were the most prominent during summer season (June–August) (Table 3).

In the active raised bog, the mean bog water level was 26 ± 8.4 cm below the surface (Table 1) and fluctuated from -15 cm in treeless communities to -49 cm in communities with well-expressed tree coverage. The mean water pH was 4.4 ± 0.2, falling into the range of pH values typical to ombrotrophic bogs. The mean EC value was 60 ± 10 µS·m^{-1} (Table 3).

In the zone of degraded raised bog drained by the ditches, the mean water level was 52 ± 20.2 cm below the surface, mean water pH was 4.6 ± 0.61 and mean EC value was 84 ± 21.9 µS·m^{-1} (Table 3). At the driest sites, the lowest recorded water level was -93 cm, while water pH and EC values were above average: 6.2 and 140 µS·m^{-1}, respectively. In the contact zone of peat mining fields and the bog, the mean water level was -52 ± 16.0 cm, mean water pH was 4.6 ± 0.38 and mean EC value was 74 ± 24.1 µS·m^{-1} (Table 3). At the driest sites, the lowest recorded water level was -80 cm, while water pH and EC values also were above average: 5.5 and 127 µS·m^{-1}, respectively. At the burned sites, the mean water level was -44 ± 22.5 cm, mean water pH was 4.6 ± 0.24 and mean EC value was 79 ± 14.4 µS·m^{-1} (Table 3). At the driest sites, the lowest recorded water level was -93 cm, while water pH and EC values also were above average: 5.0 and 97 µS·m^{-1}, respectively.

The occurrence of ombrotrophic bog plant species (*Sphagnum magellanicum*, *S. capillifolium*, *S. cuspidatum*, *S. fallax*, *S. fuscum*, *S. rubellum*, *S. tenellum*, *Calluna vulgaris*, *Drosera rotundifolia*, *Eriophorum vaginatum*, *Oxycoccus palustris*, *Polytrichum strictum* and *Rhynchospora alba*) was analysed in relation to a bog water level. Mean water level ranged between 20 and 32 cm below the peat surface in the relevés, where the above-listed plant species were found (Fig. 6). However, the lowest bog water level values were different for the analysed species. For example, mean water level for *Sphagnum* mosses ranged between -20 cm and -27 cm with a maximum of -50 cm in case of *Sphagnum magellanicum*. The mean water level for hygrophilous *Sphagnum* species (*Sphagnum cuspidatum, S. tenellum* and *S. fallax)* ranged between -20 and -24 cm with a maximum of -38 cm. Whereas, mean water level for *Polytrichum strictum, Eriophorum vaginatum, Oxycoccus palustris* and *Calluna vulgaris* was deeper (-29 – -32 cm) with a maximum of -80 cm in some relevés (Fig. 6).

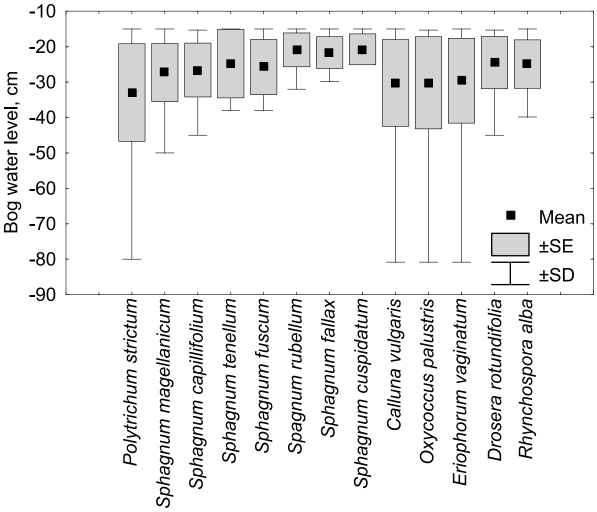


Fig. 6. Ombrotrophic plant species tolerance to bog water level in the Aukštumala Telmological Reserve in 2013

DISCUSSION

In Lithuania, raised bog communities belong to three phytosociological classes: Cl. *Oxycocco–Sphagnetea*, Br.-Bl. et R.Tx. 1943, Cl. *Vaccinietea uliginosi* Lohm. et R. Tx. 1955, Cl. *Scheuzerio–Caricetea* (Nordh. 1937) R.Tx 1937, whereas the most frequent associations are *Sphagnetum magellanici*, *Ledo-Sphagnetum magellanici* and *Caricetum limosae nigrae* (Grigaitė, 1993). In the present study, communities of the ass. *Sphagnetum magellanici* and the ass. *Ledo-Sphagnetum magellanici* were identified in the periphery of the Aukštumala TR. The ass. *Sphagnetum magellanici* occurred at sites where the influence of anthropogenic activity was minimal, whereas, the ass. *Ledo-Sphagnetum magellanici* was found where the negative impact of drainage was obvious. Normally, in an undisturbed raised bog, communities of the ass. *Ledo-Sphagnetum magellanici* are distributed on the marginal slopes of the bog with a constantly high water level (Grigaitė, 1993). In Aukštumala, the ass. *Ledo-Sphagnetum magellanici* mostly occurred in the degraded raised bog habitats drained by the ditches and in the contact zone of the bog and the peat mining fields.

According to Witte et al. (2004), the decrease of water level increases the rates of peat mineralization. During this process, the nutrients are released, making the peat more eutrophic. Hence, ombrotrophic plant species characteristic of nutrient-poor sites are constantly replaced by more adaptable ones. This was evident in the most damaged areas of the Aukštumala TR: a fraction of typical ombrotrophic species was low both in the degraded raised bog drained by the ditches and in the burned area. Despite the generally lower bog water level in the contact zone of the bog and the peat mining fields, the fraction of typical ombrotrophic species was very similar to that in the active raised bog. However, the increased coverage of tree and dwarf–shrub layer in this zone already indicates the incipient changes in the composition of plant communities and generally unfavourable conditions for peat accumulation. If hydrological conditions for peat accumulation are recreated, further succession of the degraded raised bog will most likely be towards active raised bogs or transition mires (Joosten & Clarke, 2002), therefore, the development of the damaged habitats in the Aukštumala TR largely depends on its further management.

According to Weber (1902), at the end of the 19th century, the plant cover of the Aukštumala plateau (i.e. active raised bog) was composed of a dense carpet of *Sphagnum* and *Trichophorum cespitosum*. Nowadays, the red-listed species *T. cespitosum* forms some fragments of the ass. *Eriophoro-Trichophoretum cespitosi* (Zlatnik 1928; Rudolf et al. 1928). Rübel 1933 em. Diers. 1975 in the least anthropogenically affected western and central parts of the Aukštumala TR. However, *T. cespitosum* is likely getting extinct in the peripheral drained zones of the Aukštumala TR, as it was found only in one relevé during our study.

Hydrological and hydrochemical characteristics of ombrotrophic peat bogs depend on climatic conditions and geographical situation of the region (Wieder & Vit, 2006; Rydin & Jeglum, 2006). Grigaitė (1993) was pointed out that in Lithuania bog water level in pristine communities of the ass. *Ledo-Pinetum sylvestris* and the ass. *Sphagnetum magellanici* usually doesn't fall below -20 – -30 cm. When water level falls below -50 cm, the osmotic water starts to evaporate from the peat layer accelerating its mineralization processes (Povilaitis et al., 2011). Hydrological monitoring data presented by Ruseckas & Grigaliūnas (2008) showed that water level in the pristine (central) part of Kamanos raised bog (northern Lithuania) varied from 4.5 cm to 30 cm, whereas in active drainage zone, the water level fluctuated from 8 cm to 51 cm below the bog surface. According to Shouten (2002), the average water level in the communities dominated by *Sphagmum magallanicum* was from -10 to -15 cm and decreased to -30 cm in the dry season, whereas in disturbed or burnt areas dominated by *Calluna vulgaris*, the average water levels were below -20 cm throughout the year, falling to an average minimum value of almost -50 cm. In Aukštumala case, the mean water table in the active raised bog habitat was 26 ± 8,4 cm below the bog surface, whereas in the damaged habitats B, C and D it ranged between -44 ± 22.5 cm and -52 ± 20.2 cm, and fell down to -93 cm close to the deep draining ditches. The obtained data on water level in relatively undamaged habitats of the Aukštumala TR were in agreement with the data ascertained by other researchers (Grigaitė, 1993; Shouten, 2002; Ruseckas & Grigaliūnas, 2008). Our data also showed that hydrological optimum for most of the typical ombrotrophic species varied from -20 to -32 cm (Fig. 6); therefore, aiming to create favourable conditions for peat accumulation, the mean bog water level should be raised at least up to -32 cm.

Our results correspond with the data presented by other researchers (Balysava, 1974; Eggelsmann, 1984) that seasonal water level fluctuations in undisturbed bogs of Europe may be within 20–30 cm. The data obtained in the Aukštumala TR showed that water level amplitude during the vegetation season in active raised bog habitat (A) was 12 ± 6.3 cm (Table 2). Eggelsman (1984) and Nicholson et al. (1989) indicated that drainage tends to have an increasing effect on the fluctuation of the water level. According to our study, seasonal water level amplitude in disturbed habitats was more evident (B – 21 ± 14.0 cm, C – 18 ± 8.9 cm, D – 34 ± 15.5) (Table 2).

Deep bog water level accelerates peat mineralization processes (Witte et al., 2004). Our data showed that bog water level negatively correlated with bog water EC and pH. Electrical conductivity measurement is a convenient proxy for a total ionic concentration assessment. Increased values of EC indicate accelerated mineralization process in peat bogs (Rydin & Jeglum, 2006). Electrical conductivity within raised bog waters is usually less than 80 μS·cm^{-1} (Banaś & Gos, 2004). Shouten (2002) pointed out that the average EC in ombrotrophic bogs varies from 52 μS·m^{-1} in *Sphagnum magellanicum*-dominated communities to 65 μS·cm^{-1} in *Rhynchosphora alba*-dominated communities, whereas in degraded *Calluna vulgaris*-dominated bog communities, EC values may increase up to 116 μS·cm^{-1}. The mean EC value found by us in active raised bog habitats was 60 ± 9.7 μS·cm $^{-1}$ and did not exceed the typical values of ombrotrophic bogs, while in some of the damaged habitats (B and D) the EC values were significantly higher.

The complete absence of bicarbonate alkalinity below pH 5.5 is a fundamental dividing point in the habitat limits of many peatland plant species. Peatlands with a surface water having pH less than 5.5 are dominated by oligotrophic *Sphagnum* species (Wieder & Vit, 2006). The pH in ombrotrophic bogs is usually below 4.2, yet because of seasonal variation it can sometimes reach higher values (Rydin & Jeglum, 2006). Grigaitė (1993) pointed out that in Lithuanian ombrotrophic bogs pH values do not exceed 4.8. In the present study, the mean pH value in the active raised bog habitat (A) was 4.4 and only in a few cases reached 4.9. In all three anthropogenically affected habitats (B, C and D), the mean pH values were a little (non-significant difference) higher – 4.6, although at the most mineralized sites the values reached up to 6.2, thus notably exceeding pH values typical for ombrotrophic bogs and clearly showing a shift in growing conditions, which led to the development of eutrophic plant communities in certain areas (habitat D).

CONCLUSIONS

Peat mining and permanent drainage have a large negative impact on vegetation of Aukštumala raised bog. The biggest changes in vegetation structure (towards domination of the atypical ombrotrophic species) were ascertained due to increased depth to bog water level and large amplitude of its seasonal fluctuations in the disturbed habitats, where mineralization of the upper peat layer is evident.

Proper management actions aimed to prevent water runoff may help to contribute to restore natural hydrology and stop further degradation of the raised bog leading to its subsequent self-recovery. In order to recreate favourable conditions for peat accumulation and natural functioning of the bog ecosystem, the water level should be raised at least up to -30 cm. The present investigation showed that the optimum water level for most of the typical ombrotrophic species in Aukštumala TR fell into the range of -20 – -32 cm. Composition of the bog communities is clearly dependent on the bog water level, which in active raised bog habitat was significantly higher as compared to the rest (damaged) habitats. Electrical conductivity values in active raised bog were significantly lower compared to degraded raised bog and burned area habitats. Moreover, the bog water level correlated with its hydrochemical parameters such as electrical conductivity and pH.

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ANTROPOGENINIŲ VEIKSNIŲ ĮTAKA AUKŠTUMALOS TELMOLOGINIO DRAUSTINIO AUGALIJAI PERIFERINĖJE PELKĖS DALYJE

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Santrauka

Straipsnyje Aukštumalos aukštapelkės (Šilutės r.) pavyzdžiu nagrinėjama durpių kasybos įtaka pažeistų aukštapelkių augalijai ir hidrologiniam režimui. Daugiau kaip 100 metų trunkantys durpių kasybos darbai rytinėje pelkės dalyje turi neigiamą sausinamąją įtaką neeksploatuojamai aukštapelkės daliai. Pelkės būklės įvertinimui buvo sukurta hidrologinio monitoringo sistema, susidedanti iš 84 vandens lygio matavimo šulinėlių, kuriuose tirti vandens lygio svyravimai bei nustatomos pH ir elektrinio laidumo (EC) reikšmės. Šių tyrimų rezultatai buvo siejami su šalia šulinėlių (10 × 10 m plote) vykdytais fitocenotiniais aprašymais.

Atlikus fitocenotinių duomenų analizę išskirtos keturios aprašymų grupės, išsiskiriančios skirtinga augalinės dangos sudėtimi: aktyvios aukštapelkės, sausinamaisiais grioviais sausintos degradavusios aukštapelkės, durpyno ir pelkės kontakto zona bei degvietė. Daugiausiai netipingų aukštapelkėm rūšių aptikta grioviais sausintoje degradavusioje aukštapelkėje bei degvietėje.

Palyginus keturių išskirtų grupių hidrologinius parametrus nustatyta, kad pagal vandens lygį statistiškai reikšmingai ($p > 0,05$) išsiskyrė aktyvių aukštapelkių grupė. Pagal pH ir EC reikšmes šios grupės nesiskyrė. Analizuojant vandens lygio įtaką cheminiams jo parametrams nustatyta, kad gruntinio vandens lygis turi didesnę įtaką elektriniam laidumui (r = -0,59) nei pH (r = -0,38). Aktyvias aukštapelkes formuojantiems durpojams optimalios hidrologinės sąlygos stebėtos esant -15 – -35 cm gruntiniam vandens lygiui.