WATER CHEMICAL RELATIONS AND WATER TABLE OF NORTH HUNGARIAN MIRES

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Abstract: The water chemical and physical features (pH, conductivity, Na^+, K^+, Ca^{2+}, Mg^{2+} concentration, water table) of five mires (Nyírjes lake at Sirok, Kis-Mohos and Nagy-Mohos at Kelemér, Bábtava and Nyíres lake in the Bereg region) were investigated in North Hungary. The description of water chemical relations of these mires is new result. The pH of these mires was low, the means were between 3.29 and 5.92. The mean corrected conductivity ranged between 11.08 and 176.6 μScm^{-1}. The concentrations of measured cations were high, e.g. the mean Na^+ concentration was between 3.47 and 12.71 $mgdm^{-3}$ and the mean Ca^{2+} concentration was between 7.96 and 10.21 $mgdm^{-3}$. The mires of Sirok, Kelemér, and the Bereg region are separated on the basis of most variables. The mires of Bereg are less acidic and more rich in cations than the mires in Kelemér. The mire of Sirok (Nyírjes lake) was more similar to those of Kelemér than to the mires of the Bereg region. There was no clear trend in sampling periods, but the most diverse group structure was found in September.

Key words: mire, surface water chemistry, water table

INTRODUCTION

Water chemical measurements have a long history in the Northern Hemisphere, mainly in North America and in Scandinavian countries (e.g. Gignac 1990, Gignac and Vitt 1990, Malmer 1986, Sjörs 1950, 1952, Vitt and Chee 1990, Vitt and Slack 1975), but there are some data from Great Britain (Boatman *et al.* 1975, Gorham and Pearsall 1956), from the Alps (e.g. Bargazza and Gerdol 1999, Gerdol 1990), and also from the Carpathian Region (e.g. Březina *et al.* 1963, Rybníček 1970, Hájek and Hekera 2004, Hájek *et al.* 2002, Hájková *et al.* 2004), as well. The first studies mainly characterized the features of the surface water of different mire types. These studies have also shown that pH, electrical conductivity, magnesium, sodium, and calcium concentrations in surface waters help to distinguish mire waters derived from precipitation or geogenous recharge. The connection between surface water chemistry and local distribution of species was widely examined in the last decades (eg. Albinsson

1997, Gignac 1993, Gignac *et al.* 1991, Hájková and Hájek 2004, Rydin 1986, 1993). The species and communities of different mire types are influenced by three main factors: chemistry of surface water, height above water table and shade conditions (e.g. Bargazza and Gerdol 1996, 1999, Gignac and Vitt 1990, Gignac 1992, 1993, Hájková *et al.* 2004, Sjörs 1952).

Mires, especially the *Sphagnum* dominated mires are rare habitats in Hungary. There are numerous investigations of flora, fauna, vegetation, and history of these mires (e.g. Borics 2001, Boros 1924, 1926, 1964, Czenthe 1985, Jakab *et al.* 1998, Lájer 1998*a*, *b*, Máthé and Kovács 1958, Mahunka 1991, Megyeri 1958, 1962, 1965, Nagy 2002, Nagy *et al.* 1998, Pócs *et al.* 1958, Simon 1953, Uherkovics 1979, 1981, Willis *et al.* 1997, Zólyomi 1931), but only a few have been published on water chemical data. Megyeri (1958, 1962, 1965) investigated the invertebrate fauna of peat moss dominated mires (e.g. Bábtava, Nyíres lake, Nádas lake, Nyírjes lake, Mohos lakes, Kis lake near Egerbakta) and he measured pH conductivity and ion concentrations at his sampling points. The algological investigations of mires also provided some water chemical data (e.g. Borics 2001, Uherkovics 1979, 1981). In the late 1980s Gyulai *et al.* (1988) made some measurements in the Kelemér mires. Nagy *et al.* (2016) measured pH, conductivity, redox-potential, concentration of the NH_4^+, K^+ and PO_3^- in Bábtava, Nyírjes lake, and Mohos lakes between 2009 and 2015.

Though all mires are protected by law in Hungary since 2001 ("Ex-lege" Mire Protection), our knowledge about their water chemical features is still poor. The publication of water chemical data from 2000 is also interesting because there are no published data from this period. The aims of this study are (1) to provide data about the surface water of the largest Hungarian peat moss dominated mires, (2) to compare the features of the surface water of these mires, (c) to investigate the temporal differences of the surface water.

MATERIAL AND METHODS

Study area

The most important peat moss dominated mires can be found in North Hungary, they are situated in the northern part of the Great Hungarian Plain (in the Bereg region), in the Putnok Hills and in the Mátra Mts (Fig. 1).

In the northern part of the Great Hungarian Plane the bed of the Tisza River gradually shifted from the eastern part of the plain towards southwest leaving a labyrinth of oxbow lakes and channels behind, from which Bábtava (BABT) and Nyíres lake (NYTB) have the highest conservational importance. In the end of the 1980s the *Sphagnum* dominated associations were in poor conditions because of drainage. To prevent the escalation of the drying processes many conservation actions were carried out in the 1980s: the draining canals were blocked, oak forests were planted in the buffer zone, usage of chemicals was prohibited in the surrounding agricultural lands, and water replenishers were built to increase the water supply of the mires (Simon 1992).

BABT is an about 700 m long and 80 m wide, silted oxbow lake. Simon (1960) described twelve communities, from which the most important peat moss dominated communities are *Eriophoro vaginati-Sphagnetum* and *Carici lasiocarpae-Sphagnetum*. *Sphagnum palustre* is the dominant peat moss on this mire, and there are also important populations of *S. angustifolium*, *S. fallax*, *S. flexuosum*, and *S. fimbriatum*.

The main damaging effect on the mire was the burning in 1967, when parts of the alder and willow communities and reed marshes were wiped out (e.g. Simon 1992). In their place, open water surfaces established, which are shrinking year after year as the succession of vegetation proceeds.

NYTB is a C-shaped, *ca* 750 m long and 80 m wide, silted backwater. On the vegetation map of Simon (1960), fourteen communities were distinguished; the most important is the open *Eriophoro vaginati-Sphagnetum*. The most frequent peat moss in the central open part is *S. flexuosum* and *S. fallax. Sphagnum palustre* and *S. magellanicum* mostly disappeared, they grow only in few patches. In the alder dominated parts *S. fimbriatum* is the most frequent species with some

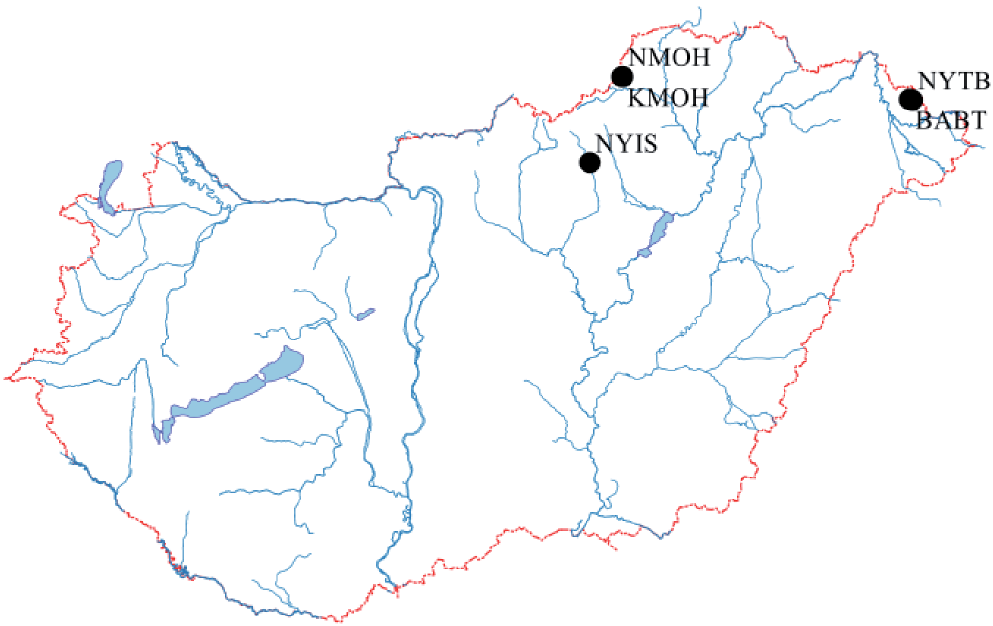


Fig. 1. Distribution of investigated mires (BABT = Bábtava, KMOH = Kis-Mohos, NMOH = Nagy-Mohos, NYIS = Nyírjes lake, NYTB = Nyíres lake).

cushions of *S. squarrosum*. Currently the largest problem is the degradation of the mire vegetation indicated by the increasing dominance of *Juncus effusus.*

Kis-Mohos (KMOH) and Nagy-Mohos (NMOH) are situated in the Putnok Hills, near Kelemér village, at 296 m and 294 m above sea level. They can be found only a few hundred metres from each other and they are surrounded by *Quercetum petraeae-cerris* and *Querco-Carpinetum* forests. They are belted by a lag zone and different willow communities. In the inner part *Betulo pubescentis-Sphagnetum* community is dominant. In the innermost part open associations (e.g. *Carici lasiocarpae-Sphagnetum*, *Eriophoro angustifolii-Sphagnetum*, *Eriophoro vaginati-Sphagnetum*) can be found. The most frequent peat mosses are *Sphagnum angustifolium, S. fallax*, *S. flexuosum*, *S. fimbriatum*, *S. magellanicum*, and *S. palustre* (Szurdoki and Nagy 2002).

Nyírjes lake (NYIS) is the mire of the Mátra Mts, situated near Sirok village, on the northern slope of Darnó Hill, at about 250 m above sea level. This mire developed in a basin of about 9000 m^2, and has no visible surface water supply. The Nyírjes lake is belted with a lag zone, which is full with water during the whole period. The main communities from outside inwards are the following: *Scirpeto-Phragmitetum*, *Salicetum cinereae*, *Salici cinereae-Sphagnetum*, and *Carici lasiocarpae-Sphagnetum*. The most frequent peat mosses are *Sphagnum angustifolium*, *S. fallax*, *S. fimbriatum*, and *S. palustre* (Szurdoki and Nagy 2002).

Data collection

All five investigated mires were sampled three times in 2000, in June, September, and November.

Water sampling units were collected from small shallow pits or from artificially made holes. The sampling points were not fixed, but samples were taken from similar parts of the mires during the sampling periods. The sampling units were collected from peat moss dominated communities (*Carici lasiocarpae-Sphagnetum*, *Eriophoro angustifolii-Sphagnetum*, *Eriophoro vaginati-Sphagnetum*, *Betulo pubescentis-Sphagnetum*, *Salici cinereae-Sphagnetum*) where the water table was lower than 40 cm. Altogether 80 samples (27 from BABT, 8 from NYTB, 21 from KMOH, 9 from NMOH and 15 from NYIS) were collected in each sampling period.

Height above water table (HWT) was measured with perforated tube, following the dipwell method described by Brooks and Stoneman (1997). Surface water conductivity and pH were measured in situ using portable instruments (pH: Hanna Checker 1, conductivity: Cole-Palmer 1980-20 Measurements). The readings were standardized to 20 °C (pH, conductivity) and conductivity was corrected with hydrogen ions (Sjörs 1952). Afterwards, water was placed in plastic bottles and 0.5 ml of 65% HNO_3 was added to 100 ml of sample to preserve. Since most water samples were turbid due to colloidal suspensions, filtration was necessary. Metallic elements (Na^+, K^+, Ca^{2+}, Mg^{2+}) were measured with flame spectral analysis. The sampling units collected from the same mire, same community, and places with same dominant peat mosses were mixed before flame spectral analysis. Altogether 28 samples (9 from BABT, 4 from NYTB, 7 from KMOH, 3 from NMOH and 5 from NYIS) were taken in each sampling period.

Statistical analysis

The water conditions of the mires were compared based on the measurements of the different periods separately and also based on the measurements of the whole period (merging the data of the three sampling periods), indicated as "total average" in Results. Besides, the differences between the periods within the mires were also analysed.

For data analyses univariate statistical and multivariate methods were used. One-way ANOVA or Kruskal–Wallis test was used for comparing temporal and spatial variation of environmental variables. For multiple comparison Tukey's Post Hoc test or Dunn's test was calculated (Zar 1999). To compare mires and sampling periods and to determine the main gradients non-metric multidimensional scaling (NMDS with Bray–Curtis distance) was applied (Borcard *et al.* 2011). To test the multivariate difference between mires and sampling periods permutational multivariate variance analysis (based on Bray–Curtis distance and 999 permutations) was calculated (Borcard *et al.* 2011).

Statistical analyses were calculated with R 3.4.2 (R Core Team 2017). Tukey's Post Hoc test was calculated with "glht" function (multcomp 1.4-7 package, Hothorn *et al.* 2017) and Dunn's test with "dunn.test" function (dunn.test 1.3.5 package, Dinno 2017). The NMDS was calculated with "metamds" function and the permutational multivariate variance analysis (permanova) with the "adonis" function of vegan 2.4-3 package (Oksanen *et al.* 2017), respectively.

The nomenclature follows Hill *et al.* (2006) for mosses and Simon (2000) for vascular plants and associations.

RESULTS

Height above water table (HWT; Table 1, Fig. 2)

HWT ranged between 1 cm (NMOH) and 35 cm (BABT) from June 2000 to November 2000 and the total average HWT of mires ranged between 8.6

cm (NYTB) and 15.51 cm (NYIS). The water table was highest in NMOH and NYTB, the lowest in BABT and NMOH. There was a significant difference in HWT between mires on the basis of all data and also in all sampling period. The water table was quite stable during the year, the summer means are only slightly higher in most investigated mires. From five investigated mires only BABT and NYIS showed significant difference between sampling dates, these mires were wetter during November.

Table1. Mean, standard deviation, median, maximum and minimum values of height above water table (HWT) in the five investigated mires during the whole period and in June, September, and November (BABT = Bábtava, KMOH = Kis-Mohos, NMOH = Nagy-Mohos, NYIS = Nyírjes lake, NYTB = Nyíres lake).

	BABT	KMOH	NMOH	NYIS	NYTB
			Whole period		
mean (cm)	14.30	12.07	9.92	15.51	8.60
± SD	5.89	5.38	5.29	4.82	4.25
median (cm)	14	13	9	15	8.5
minimum (cm)	4	2	1	7	2
maximum (cm)	35	23	22	30	19
			June 2000		
mean (cm)	14.89	11.00	8.54	17.36	8.38
± SD	4.55	5.48	5.48	5.30	4.60
median (cm)	14	14	7	15	8.5
minimum (cm)	8	2	2	12	3
maximum (cm)	24	17	21	30	17
			September 2000		
mean (cm)	16.81	13.78	11.96	17.07	8.00
± SD	6.83	3.63	5.24	3.13	3.63
median (cm)	16	15	12	16	8.5
minimum (cm)	6	7	4	14	2
maximum (cm)	35	18	22	24	12
			November 2000		
mean (cm)	11.19	11.44	9.25	12.60	9.50
± SD	4.74	6.77	4.71	4.72	4.93
median (cm)	11	11	9	11	8
minimum (cm)	4	3	1	7	6
maximum (cm)	22	23	16	22	19

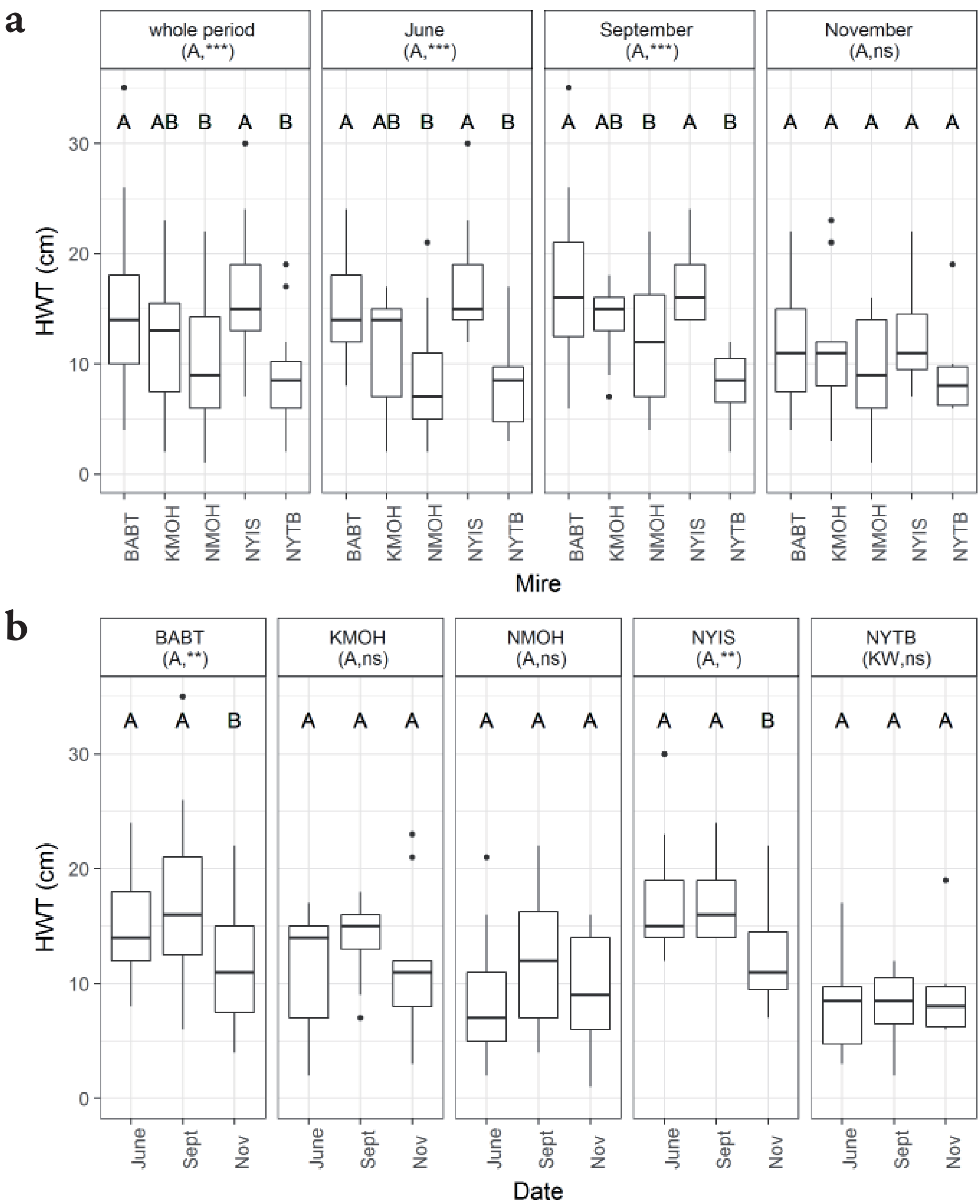


Fig. 2. Variation in the height above water table (HWT) in the investigated mires during the whole period, June, September and November (a) and during sampling periods in investigated mires (b) (BABT = Bábtava, KMOH = Kis-Mohos, NMOH = Nagy-Mohos, NYIS = Nyírjes lake, NYTB = Nyíres lake). Boxes define 25 and 75 percentiles; thick horizontal lines show the median; whiskers define 10 and 90 percentiles; points are outliers. In the bracket, under the sampling period (a) and mire's name (b) the used univariate statistical test and the level of significance are detailed (A = ANOVA, KW = Kruskal–Wallis test, *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, ns = non significant). The capital letters above box and whisker plots refer to the results of post hoc tests (Tukey's test when ANOVA and Dunn's test when Kruskal–Wallis test was calculated).

pH (Table 2, Fig. 3)

The measured pH values ranged between 3.29 (BABT) and 5.92 (BABT) from June 2000 to November 2000 and the total average pH of mires ranged between 3.77 (KMOH) and 4.41 (BABT). The difference was significant between mires on the basis of all data and in June and September, but there was no significant difference between them in November. The mires near Kelemér (NMOH and KMOH) were the most acidic and mires of the Bereg Plain were the less acidic in most sampling period. The clear trend was not detected during the year, however three from the five investigated mires showed significant difference in sampling dates. The range was the largest in BABT, in the case of all three sampling dates.

Table 2. Mean, standard deviation, median, maximum and minimum values of pH of surface water in the five investigated mires during the whole period and June, September, and November (BABT = Bábtava, KMOH = Kis-Mohos, NMOH = Nagy-Mohos, NYIS = Nyírjes lake, NYTB = Nyíres lake).

	BABT	KMOH	NMOH	NYIS	NYTB
		Whole period			
mean	4.41	3.77	3.82	3.96	4.19
± SD	0.64	0.31	0.24	0.15	0.54
median	4.36	3.7	3.78	3.94	4.035
minimum	3.29	3.41	3.33	3.72	3.6
maximum	5.92	4.5	4.58	4.48	5.52
		June 2000			
mean	4.46	3.76	3.89	4.07	3.95
± SD	0.45	0.19	0.23	0.18	0.38
median	4.48	3.77	3.805	3.98	3.845
minimum	3.83	3.41	3.52	3.92	3.6
maximum	5.79	4.1	4.58	4.48	4.7
		September 2000			
mean	4.83	3.68	3.83	3.97	4.50
± SD	0.64	0.31	0.21	0.12	0.70
median	4.67	3.57	3.75	3.95	4.33
minimum	3.91	3.47	3.6	3.81	3.84
maximum	5.92	4.5	4.35	4.21	5.52
		November 2000			
mean	3.95	3.87	3.75	3.87	4.19
± SD	0.50	0.40	0.25	0.09	0.45
median	3.85	3.75	3.72	3.88	4.105
minimum	3.29	3.43	3.33	3.72	3.73
maximum	5	4.46	4.54	4.03	4.87

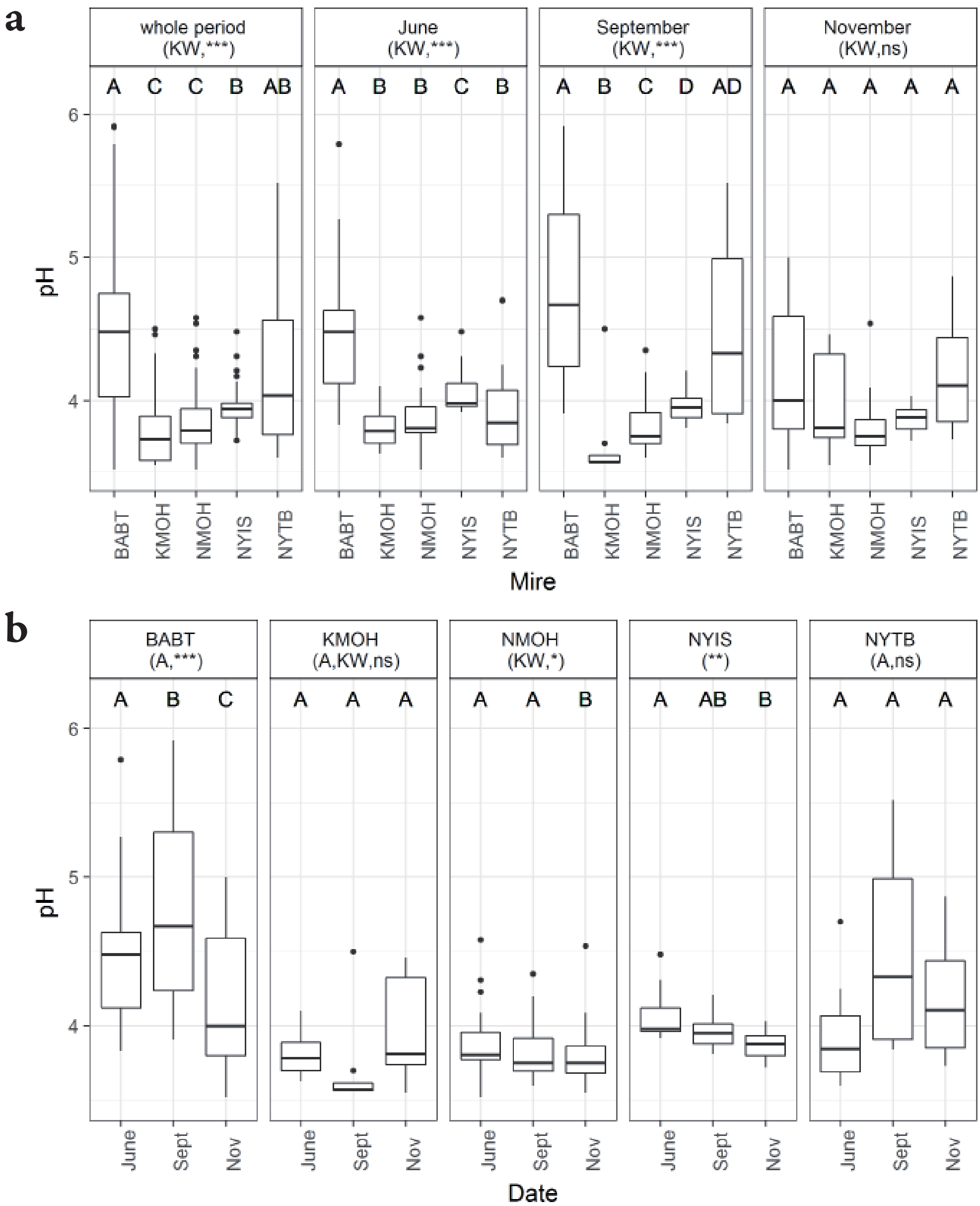


Fig. 3. Variation in the pH of surface water of the investigated mires during the whole period, June, September, and November (a) and during the sampling periods in the investigated mires (b) (BABT = Bábtava, KMOH = Kis-Mohos, NMOH = Nagy-Mohos, NYIS = Nyírjes lake, NYTB = Nyíres lake). Boxes define 25 and 75 percentiles; thick horizontal lines show the median; whiskers define 10 and 90 percentiles; points are outliers. In the bracket, under the sampling period (a) and mire's name (b) the used univariate statistical test and the level of significance were detailed (A = ANOVA, KW = Kruskal–Wallis test, *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, ns = non significant). The capital letters above box and whisker plots refer to the results of post hoc tests (Tukey's test when ANOVA and Dunn's test when Kruskal–Wallis test was calculated).

Corrected conductivity (Table 3, Fig. 4)

The conductivity ranged between 11.08 µScm^{-1} (BABT) and 176.6 µScm^{-1} (BABT) from June 2000 to November 2000 and the total average conductivity of mires ranged between 39.70 µScm^{-1} (NYIS) and 78.66 µScm^{-1} (NYTB). There was significant difference between mires, and the mires of Bereg (BABT and NYTB) separated from the other three mires on the basis of all data. However the range of conductivity was slightly different between sampling periods, the differences between mires were similar. BABT has significantly higher conductivity values than those of the Mohos lakes (KMOH, NMOH) and NYIS. On the basis of Dunn's test NYTB was placed in different groups in all sampling periods. The

Table 3. Mean, standard deviation, median, and maximum and minimum values of corrected conductivity of surface water in the five investigated mires in whole period and June, September, and November (BABT = Bábtava, KMOH = Kis-Mohos, NMOH = Nagy-Mohos, NYIS = Nyírjes lake, NYTB = Nyíres lake).

	BABT	KMOH	NMOH	NYIS	NYTB
Whole period					
mean (µScm^{-1})	71.46	45.85	43.55	39.70	78.66
± SD	29.38	25.53	23.36	16.82	36.68
median (µScm^{-1})	70.26	39.86	39.09	38.52	68.64
minimum (µScm^{-1})	11.08	14.81	10.49	13.15	21.67
maximum (µScm^{-1})	176.06	101.87	163.3	79.47	151.86
June 2000					
mean (µScm^{-1})	63.80	40.07	44.09	29.53	47.18
± SD	19.00	14.48	18.75	17.97	14.40
median (µScm^{-1})	64.64	43.49	40.02	24.75	48.44
minimum (µScm^{-1})	31.56	20.68	13.75	13.15	21.67
maximum (µScm^{-1})	97.82	58.99	79.92	79.47	70.46
September 2000					
mean (µScm^{-1})	76.65	48.84	37.55	47.02	125.35
± SD	28.86	30.50	16.19	12.25	18.70
median (µScm^{-1})	73.21	39.86	35.06	45.93	123.99
minimum (µScm^{-1})	41.41	19.07	13.11	20.41	99.50
maximum (µScm^{-1})	154.65	101.87	73.93	66.88	151.86
November 2000					
mean (µScm^{-1})	74.98	48.63	48.75	39.85	73.93
± SD	39.83	30.37	31.52	16.99	15.63
median (µScm^{-1})	71.83	37.92	42.65	36.89	70.46
minimum (µScm^{-1})	11.08	14.81	10.49	15.56	58.07
maximum (µScm^{-1})	176.06	99.26	163.30	70.05	97.99

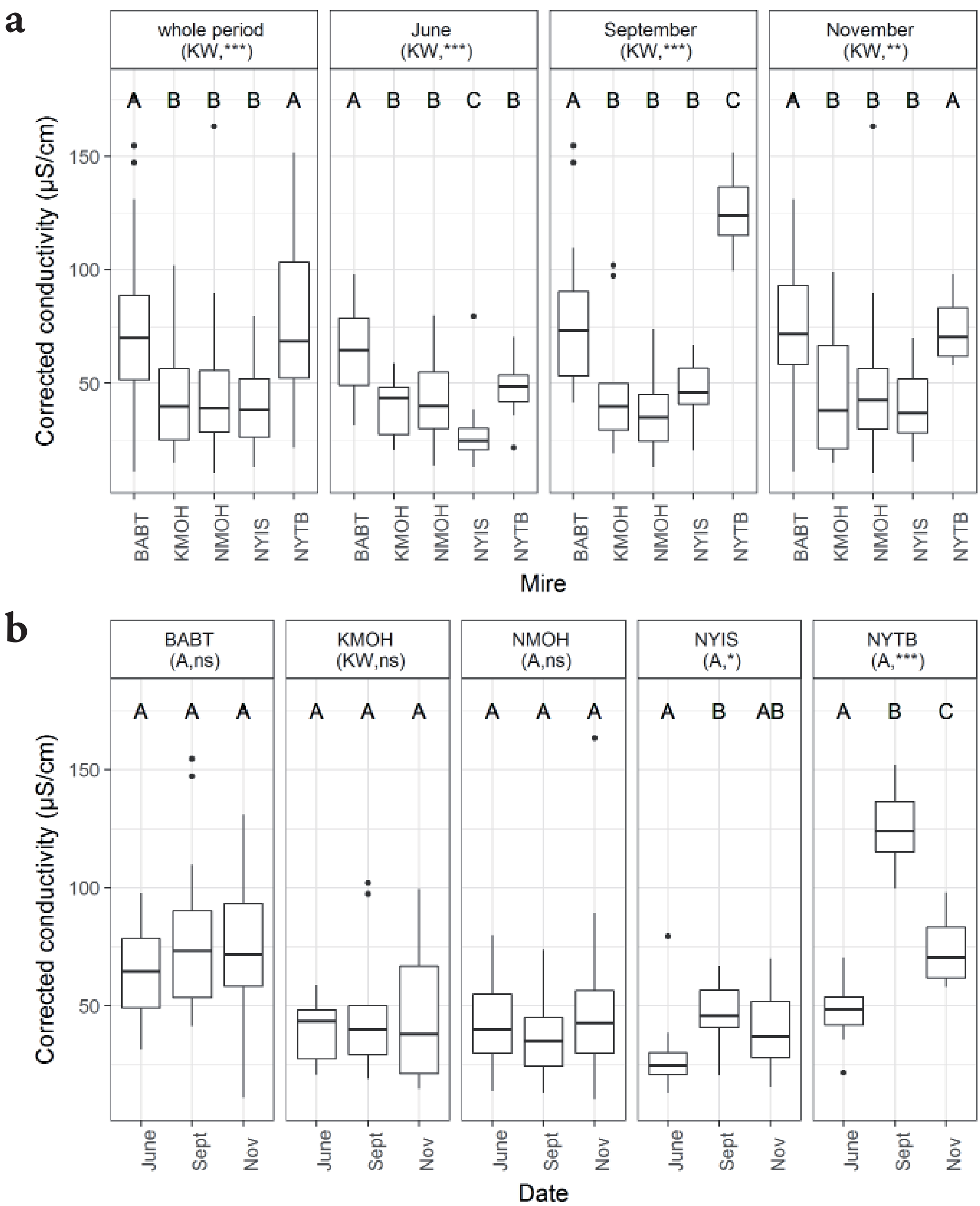


Fig. 4. Variation in the corrected conductivity of surface water of the investigated mires during the whole period, June, September, and November (a) and in the sampling periods in the investigated mires (b) (BABT = Bábtava, KMOH = Kis-Mohos, NMOH = Nagy-Mohos, NYIS = Nyírjes lake, NYTB = Nyíres lake). Boxes define 25 and 75 percentiles; thick horizontal lines show the median; whiskers define 10 and 90 percentiles; points are outliers. In the bracket, next to the sampling period (a) and mire's name (b) the used univariate statistical test and the level of significance are detailed (A = ANOVA, KW = Kruskal-Wallis test, *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, ns = non significant). The capital letters above box and whisker plots refer to the results of post hoc tests (Tukey's test when ANOVA and Dunn's test when Kruskal–Wallis test was calculated).

conductivity was stable during the year in BABT, NMOH, and KMOH, but there was a strong and significant difference between sampling dates in NYTB. There was only a week, but significant difference in NYIS between sampling periods.

Cations

Na^+ concentration (Table 4, Fig. 5)

The concentration of Na^+ ion varied between 2.28 (NYIS) and 19.37 (BABT) mgdm^{-3} from June 2000 to November 2000, and the total means of mires ranged between 3.47 (NYIS) and 12.71 mgdm^{-3} (NYTB). There was a significant differ-

Table 4. Mean, standard deviation, median, and maximum and minimum values of Na^+ concentration of surface water in the five investigated mires in whole period and June, September, and November (BABT = Bábtava, KMOH = Kis-Mohos, NMOH = Nagy-Mohos, NYIS = Nyírjes lake, NYTB = Nyíres lake).

	BABT	KMOH	NMOH	NYIS	NYTB
Whole period					
mean (mgdm^{-3})	11.75	5.64	4.95	3.47	12.71
± SD	3.15	1.87	1.24	0.97	2.99
median (mgdm^{-3})	11.24	4.84	4.995	3.42	13.19
minimum (mgdm^{-3})	8.03	3.91	3.09	2.28	8.95
maximum (mgdm^{-3})	19.37	10.11	8.21	5.93	15.72
June 2000					
mean (mgdm^{-3})	9.55	4.29	3.92	3.55	9.29
± SD	1.214	0.42	0.67	1.53	0.371
median (mgdm^{-3})	9.13	4.12	3.91	2.85	9.29
minimum (mgdm^{-3})	8.03	3.91	3.09	2.51	8.95
maximum (mgdm^{-3})	11.24	4.84	5.04	5.93	9.64
September 2000					
mean (mgdm^{-3})	11.97	7.02	4.82	3.1	15.53
± SD	2.54	2.38	0.97	0.75	0.15
median (mgdm^{-3})	12.1	6.11	5	2.96	15.53
minimum (mgdm^{-3})	9	4.84	3.43	2.28	15.39
maximum (mgdm^{-3})	15.75	10.11	6.32	4.33	15.67
November 2000					
mean (mgdm^{-3})	13.74	5.60	6.11	3.79	14.45
± SD	3.66	1.12	0.93	0.44	1.39
median (mgdm^{-3})	14.31	5.03	6.045	3.65	14.455
minimum (mgdm^{-3})	8.23	4.68	4.91	3.31	13.19
maximum (mgdm^{-3})	19.37	7.08	8.21	4.56	15.72

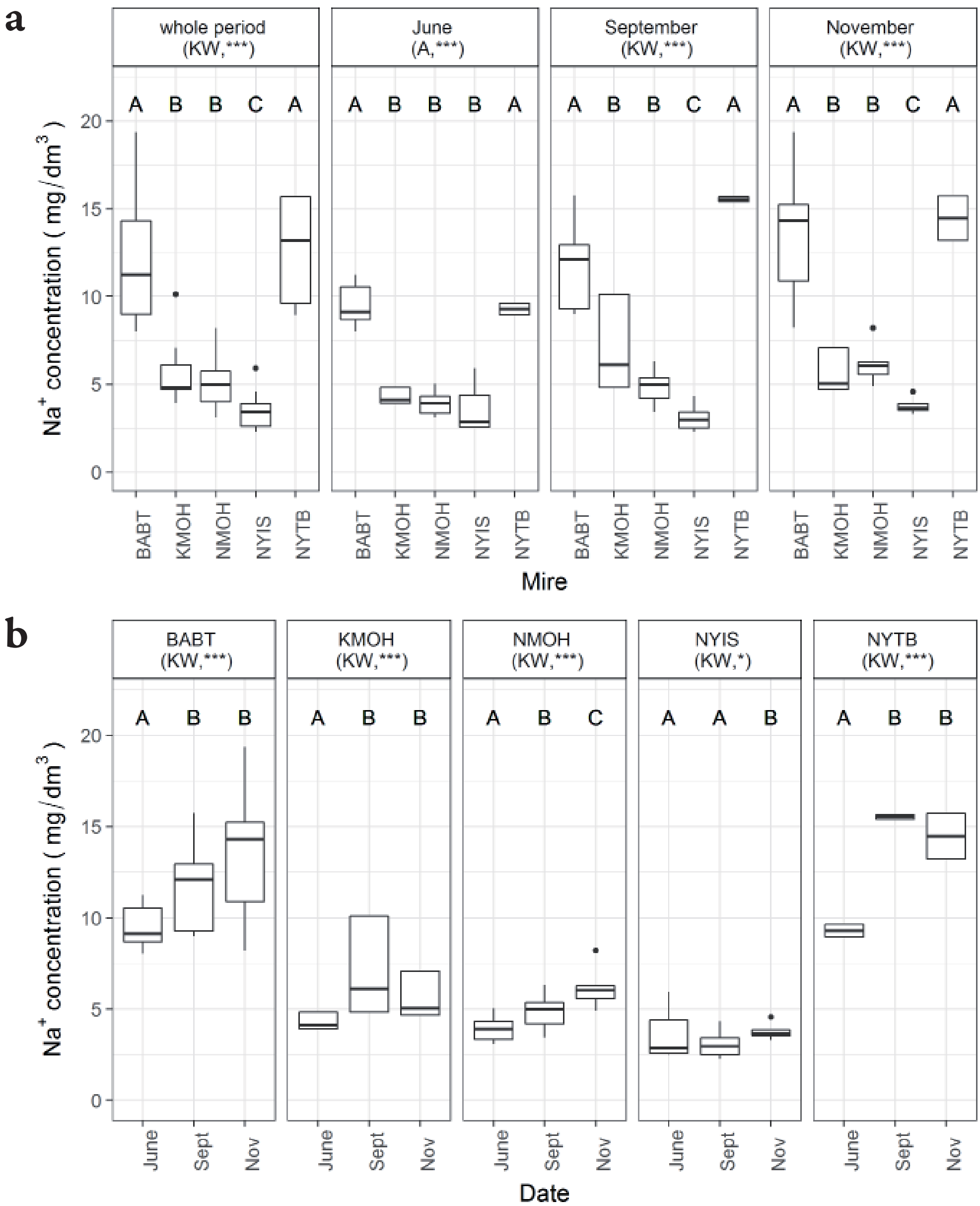


Fig. 5. Variation in the Na^+ concentration of the surface water of the investigated mires in the whole period, June, September, and November (a) and in the sampling periods in the investigated mires (b) (BABT = Bábtava, KMOH = Kis-Mohos, NMOH = Nagy-Mohos, NYIS = Nyírjes lake, NYTB = Nyíres lake). Boxes define 25 and 75 percentiles; thick horizontal lines show the median; whiskers define 10 and 90 percentiles; points are outliers. In the bracket, under the sampling period (a) and mire's name (b) the used univariate statistical test and the level of significance are detailed (A = ANOVA, KW = Kruskal–Wallis test, *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, ns = non significant). The capital letters above box and whisker plots refer to the results of post hoc tests (Tukey's test when ANOVA and Dunn's test when Kruskal–Wallis test was calculated).

ence between mires. The three groups of the mires are recognizable. NYIS is separated both from the group of the Bereg's mires and the group of the Kelemér's mires. The lower spring values definitely differ from summer and autumn values, in most investigated mires. In the case of NYIS the Na concentration varied only slightly during the year, the difference was hardly significant.

K^+ concentration (Table 5, Fig. 6)

The K^+ ion concentration ranged between 1.79 and 15.63 $mgdm^{-1}$ from June 2000 to November 2000 and the total means of mires varied between 3.28 (NYIS) and 7.59 (BABT). Only the NYIS differs significantly from the four other mires

Table 5. Mean, standard deviation, median, and maximum and minimum values of K^+ concentration of surface water in the five investigated mires in the whole period and June, September, and November (BABT = Bábtava, KMOH = Kis-Mohos, NMOH = Nagy-Mohos, NYIS = Nyírjes lake, NYTB = Nyíres lake).

	BABT	KMOH	NMOH	NYIS	NYTB
Whole period					
mean ($mgdm^{-3}$)	7.59	7.71	7.07	3.28	6.07
± SD	3.28	1.91	2.85	1.10	1.49
median ($mgdm^{-3}$)	6.99	6.99	6.37	3.1	5.5
minimum ($mgdm^{-3}$)	3.26	5.3	3.43	1.79	4.18
maximum ($mgdm^{-3}$)	15.63	10.61	17.47	5.44	8.71
June 2000					
mean ($mgdm^{-3}$)	7.59	6.25	5.30	3.31	4.84
± SD	2.66	0.91	1.39	1.41	0.71
median ($mgdm^{-3}$)	7.72	6.08	5.04	2.59	4.84
minimum ($mgdm^{-3}$)	4.54	5.30	3.43	2.07	4.18
maximum ($mgdm^{-3}$)	13.20	7.38	8.18	5.44	5.50
September 2000					
mean ($mgdm^{-3}$)	5.98	9.26	7.27	3.64	7.48
± SD	2.55	1.71	1.57	0.94	1.35
median ($mgdm^{-3}$)	5.34	10.17	7.36	3.68	7.48
minimum ($mgdm^{-3}$)	3.26	6.99	5.28	2.47	6.25
maximum ($mgdm^{-3}$)	11.85	10.61	9.56	5.20	8.71
November 2000					
mean ($mgdm^{-3}$)	9.15	7.61	8.65	2.89	6.30
± SD	3.78	1.73	3.85	0.93	1.00
median ($mgdm^{-3}$)	7.61	6.59	7.68	2.78	6.30
minimum ($mgdm^{-3}$)	4.85	6.34	4.89	1.79	5.38
maximum ($mgdm^{-3}$)	15.63	9.91	17.47	4.42	7.21

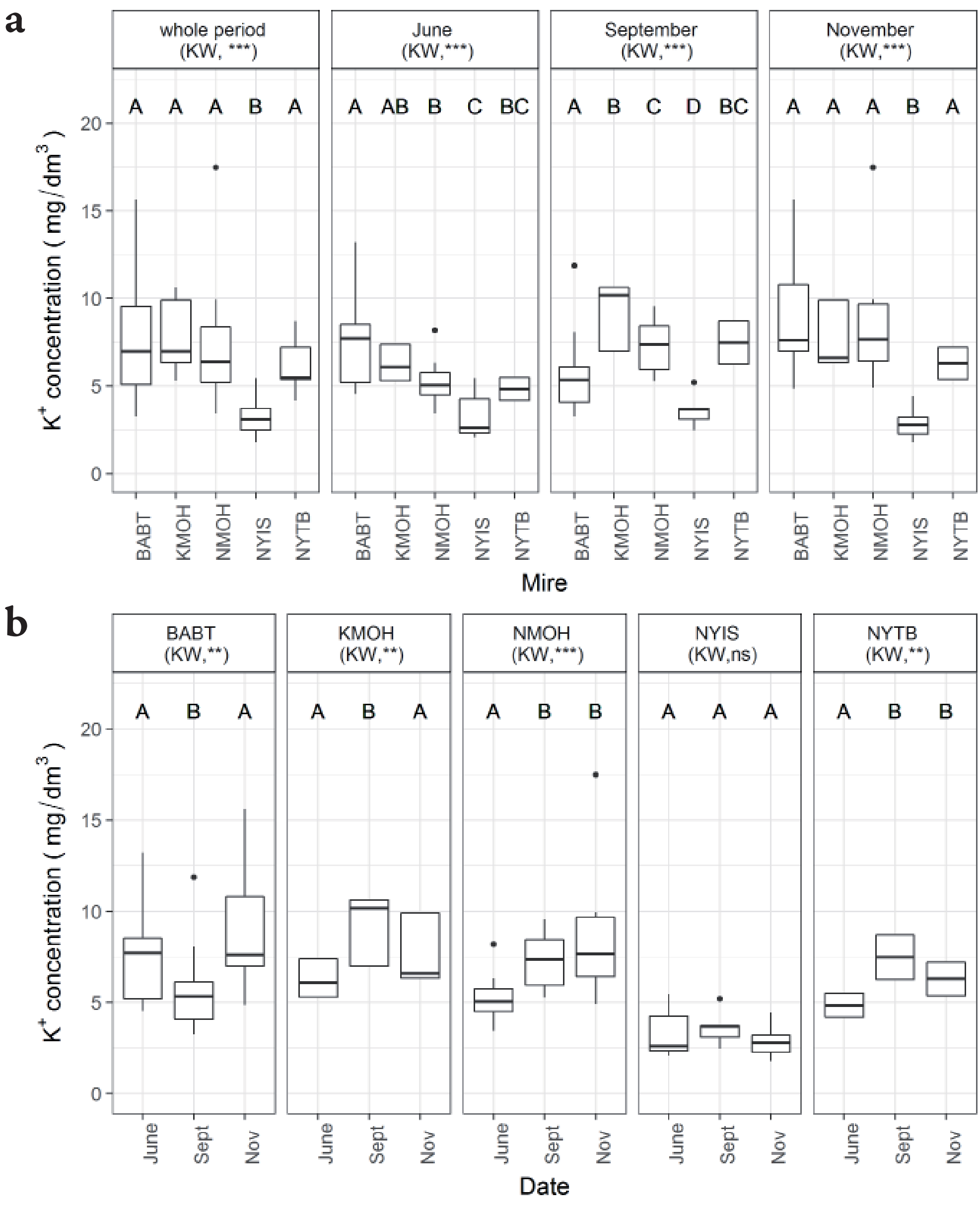


Fig. 6. Variation in the K^+ concentration of surface water of the investigated mires in the whole period, June, September, and November (a) and in the sampling periods in the investigated mires (b) (BABT = Bábtava, KMOH = Kis-Mohos, NMOH = Nagy-Mohos, NYIS = Nyírjes lake, NYTB = Nyíres lake). Boxes define 25 and 75 percentiles; thick horizontal lines show the median; whiskers define 10 and 90 percentiles; points are outliers. In the bracket, under the sampling period (a) and mire's name (b) the used univariate statistical test and the level of significance are detailed (A = ANOVA, KW = Kruskal–Wallis test, *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, ns = non significant). The capital letters above box and whisker plots refer to the results of post hoc tests (Tukey's test when ANOVA and Dunn's test when Kruskal–Wallis test was calculated).

on the basis of the whole period dataset. The difference between mires was largest in September. The clear trend was not detected during the whole year, however four from the five investigated mires showed significant difference between sampling dates. The K^+ ion concentration values were the lowest in NYIS during the whole period and this low concentration was quite stable.

Ca^{2+} concentration (Table 6, Fig. 7)

The Ca^{2+} ion concentration ranged between 4.95 (KMOH) and 15.00 (KMOH) mgdm^{-3} from June 2000 to November 2000 and the total means of mires varied between 7.96 (BABT) and 10.21 (NYIS). On the basis of the whole dataset

Table 6. Mean, standard deviation, median, and maximum and minimum values of Ca^{2+} concentration of surface water in the five investigated mires in the whole period and June, September, and November (BABT = Bábtava, KMOH = Kis-Mohos, NMOH = Nagy-Mohos, NYIS = Nyírjes lake, NYTB = Nyíres lake).

	BABT	KMOH	NMOH	NYIS	NYTB
			Whole period		
mean (mgdm^{-3})	7.96	9.67	10.06	9.07	10.21
± SD	1.81	2.99	2.16	1.53	2.06
median (mgdm^{-3})	7.54	9.59	10.15	8.29	10.5
minimum (mgdm^{-3})	5.55	4.95	5.34	6.83	7.2
maximum (mgdm^{-3})	13.1	15	13.1	11.4	13.1
			June 2000		
mean (mgdm^{-3})	7.83	8.89	11.30	9.73	8.12
± SD	2.15	0.72	1.36	1.11	0.98
median (mgdm^{-3})	7.28	8.95	11.75	9.97	8.12
minimum (mgdm^{-3})	5.55	8.02	9.09	8.51	7.20
maximum (mgdm^{-3})	13.10	9.69	13.10	11.20	9.04
			September 2000		
mean (mgdm^{-3})	8.32	13.13	10.93	9.16	11.80
± SD	1.56	1.42	1.56	1.70	1.42
median (mgdm^{-3})	8.15	12.50	10.75	8.08	11.80
minimum (mgdm^{-3})	6.29	11.90	8.90	7.56	10.50
maximum (mgdm^{-3})	11.00	15.00	12.80	11.40	13.10
			November 2000		
mean (mgdm^{-3})	7.75	6.98	7.95	8.50	11.40
± SD	1.69	2.06	1.75	1.50	0.99
median (mgdm^{-3})	7.60	6.39	8.03	8.23	11.40
minimum (mgdm^{-3})	5.70	4.95	5.34	6.83	10.50
maximum (mgdm^{-3})	11.50	9.59	11.10	11.20	12.30

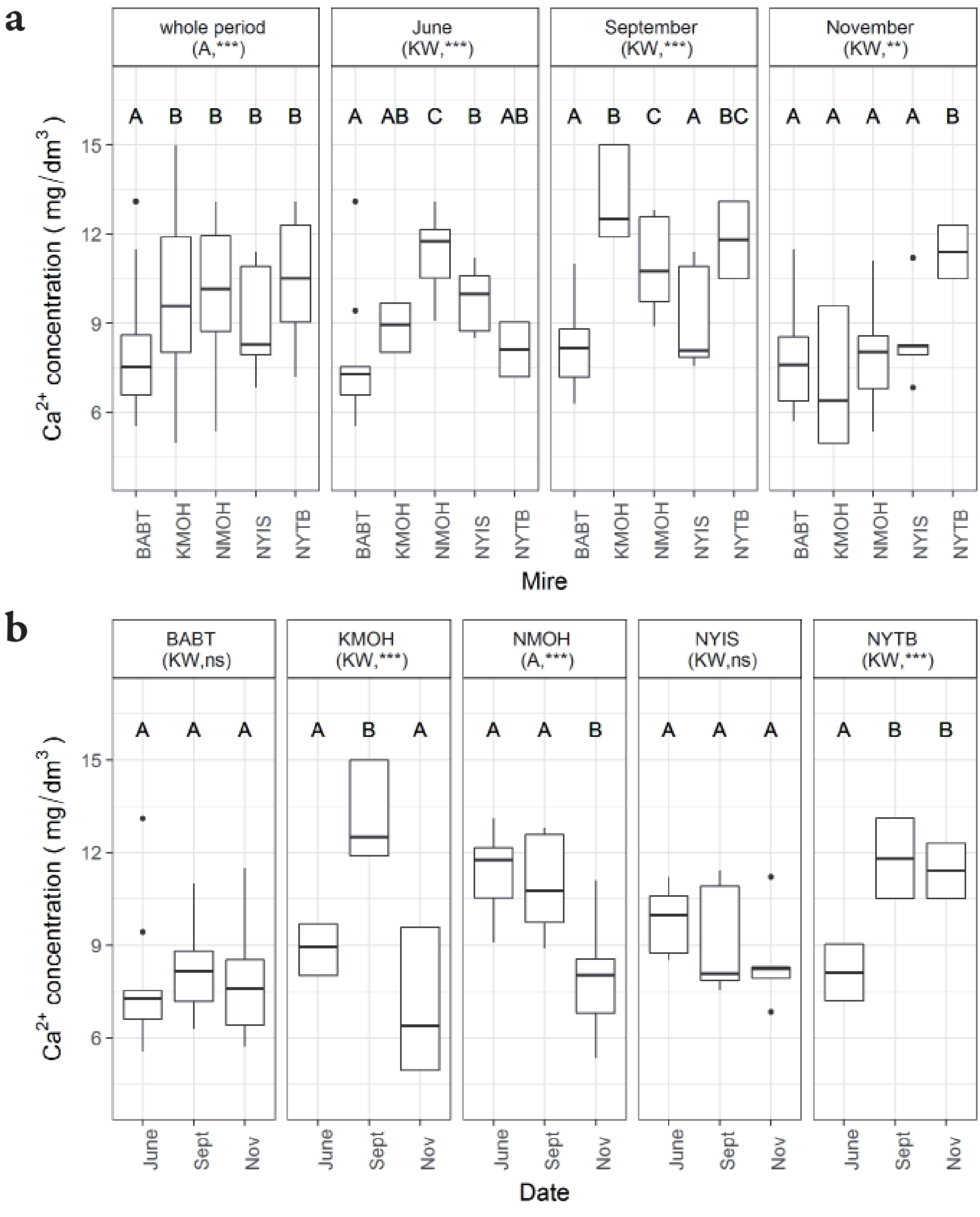


Fig. 7. Variation in the Ca^{2+} concentration of surface water of the investigated mires in the whole period, June, September, and November (a) and between sampling periods in the investigated mires (b) (BABT = Bábtava, KMOH = Kis-Mohos, NMOH = Nagy-Mohos, NYIS = Nyírjes lake, NYTB = Nyíres lake). Boxes define 25 and 75 percentiles; thick horizontal lines show the median; whiskers define 10 and 90 percentiles; points are outliers. In the bracket, under the sampling period (a) and mire's name (b) the used univariate statistical test and the level of significance were detailed (A = ANOVA, KW = Kruskal–Wallis test, *** = $p < 0.001$, ** = $p < 0.01$, * 7 $p < 0.05$, ns = non significant). The capital letters above box and whisker plots refer to the results of post hoc tests (Tukey's test when ANOVA and Dunn's test when Kruskal–Wallis test was calculated).

only the BABT showing lower concentration of Ca^{2+} ions differs significantly from the four other mires. The most pronounced difference between mires was detected in September. The clear trend was not recorded during the year, however three from the five investigated mires showed significant difference between sampling dates. NYTB, NMOH, and KMOH showed different changes between sampling periods.

Mg^{2+} concentration (Table 7, Fig. 8)

The Mg^{2+} ion concentration ranged between 1.44 (KMOH) and 5.04 (KMOH) mgdm^{-3} from June 2000 to November 2000 and the total means of mires varied between 2.55 (BABT) and 4.88 (NYIS). Only the NYTB differs sig-

Table 7. Mean, standard deviation, median, and maximum and minimum values of Mg^{2+} concentration of surface water in the five investigated mires in the whole period and June, September, and November (BABT = Bábtava, KMOH = Kis-Mohos, NMOH = Nagy-Mohos, NYIS = Nyírjes lake, NYTB = Nyíres lake).

	BABT	KMOH	NMOH	NYIS	NYTB
Whole period					
mean (mgdm^{-3})	3.06	2.55	2.76	2.47	4.88
± SD	0.78	0.72	0.53	0.32	0.69
median (mgdm^{-3})	2.86	2.55	2.805	2.36	5.2
minimum (mgdm^{-3})	1.91	1.44	1.59	2.11	3.95
maximum (mgdm^{-3})	5.04	3.84	3.61	3.14	5.76
June 2000					
mean (mgdm^{-3})	2.85	2.31	2.96	2.51	4.09
± SD	0.79	0.19	0.32	0.28	0.15
median (mgdm^{-3})	2.55	2.23	3.01	2.64	4.09
minimum (mgdm^{-3})	2.12	2.14	2.45	2.11	3.95
maximum (mgdm^{-3})	4.62	2.55	3.44	2.83	4.23
September 2000					
mean (mgdm^{-3})	2.90	3.38	2.92	2.42	5.33
± SD	0.58	0.35	0.47	0.31	0.01
median (mgdm^{-3})	2.86	3.25	2.94	2.29	5.33
minimum (mgdm^{-3})	1.91	3.06	2.19	2.12	5.32
maximum (mgdm^{-3})	3.72	3.84	3.61	2.93	5.33
November 2000					
mean (mgdm^{-3})	3.44	1.96	2.42	2.49	5.48
± SD	0.83	0.54	0.59	0.36	0.31
median (mgdm^{-3})	3.21	1.78	2.35	2.36	5.48
minimum (mgdm^{-3})	2.33	1.44	1.59	2.11	5.20
maximum (mgdm^{-3})	5.04	2.65	3.45	3.14	5.76

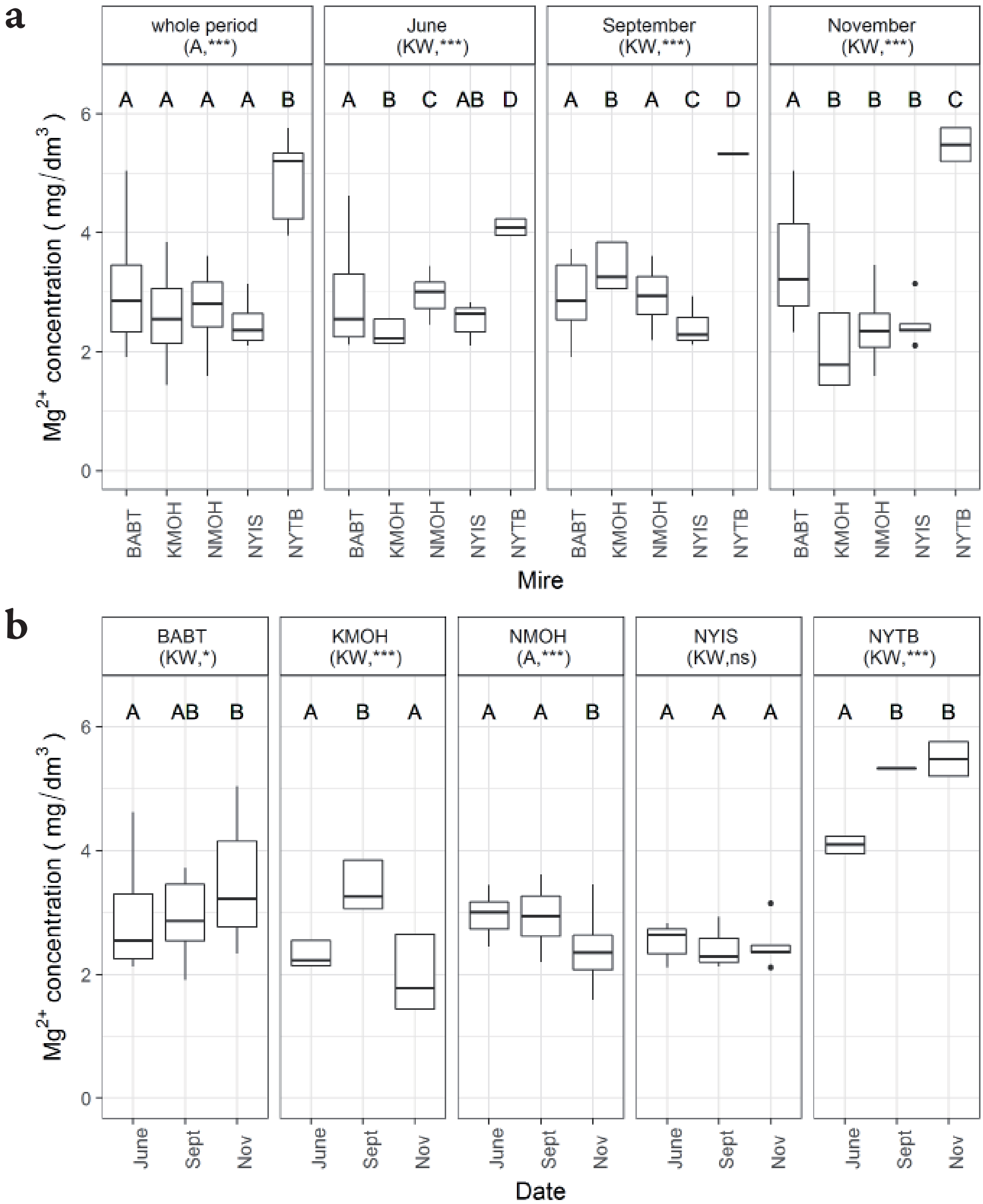


Fig. 8. Variation in the Mg^{2+} concentration of surface water of the investigated mires in the whole period, June, September, and November (a) and in the sampling periods in the investigated mires (b) (BABT = Bábtava, KMOH = Kis-Mohos, NMOH = Nagy-Mohos, NYIS = Nyírjes lake, NYTB = Nyíres lake). Boxes define 25 and 75 percentiles; thick horizontal lines show the median; whiskers define 10 and 90 percentiles; points are outliers. In the bracket, under the sampling period (a) and mire's name (b) the used univariate statistical test and the level of significance are detailed (A = ANOVA, KW = Kruskal–Wallis test, *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, ns = non significant). The capital letters above box and whisker plots refer to the results of post hoc tests (Tukey's test when ANOVA and Dunn's test when Kruskal–Wallis test was calculated).

nificantly from the four other mires on the basis of the total dataset. The difference between mires was most pronounced in September. There was not any trend during the year, however four from the five investigated mires showed significant difference between sampling dates. The Mg^{2+} ion concentration was the highest in NYTB during the year.

Multivariate analysis

The NMDS analysis (Fig. 9a) showed that the point clouds of the mires of Bereg (BABT, NYTB) partly overlap each other. They are completely separated from the points of NYIS. The mires of Kelemér (KMOH, NMOH) widely overlap each other and also overlap NYIS and Bereg's mires. The separation of the mires of Bereg and NYIS was based on conductivity, pH, sodium, and potassium ion concentration. The differentiation between BABT and NYTB and between KMOH and NMOH was based on height above water table and concentration of calcium and magnesium. There is a strong significant difference between mires on the basis of permanova (R^2 of mires 0.29293, $p = 0.000999$ ***).

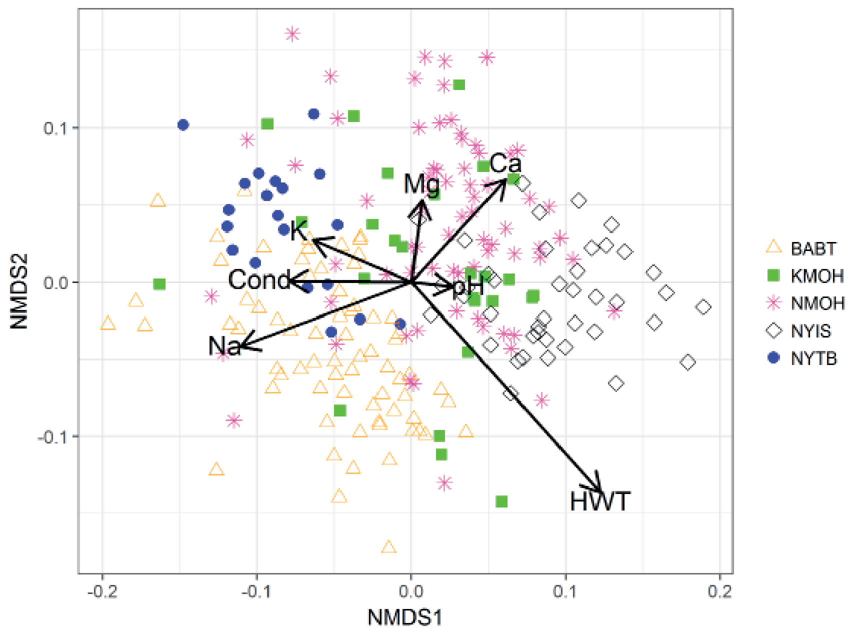
The NMDS analysis of sampling periods (Fig. 9b) showed that point clouds of the first (June) and third (November) period are separated but widely overlapping. The points of the second sampling period (September) are totally overlapping points of the two other periods. The permanova analysis of sampling periods indicated week significant difference (R^2 of periods 0.02987, $p = 0.005994$ **).

DISCUSSION

The water table in the five investigated mires is relatively close to the surface of peat moss. Tahvanainen *et al.* (2003) published HWT data from Finnish fens. They found, similarly to our results that the water table in mires is the lowest in August. The HWT was smaller in moderately rich fens (2.5–5 cm) than in poor fens (7–9.5 cm).

The pH of these mires was relatively low compared with other fens. The measured pH ranged from 3.29 to 5.92, and means ranged from 3.68 to 4.83. These low pH values refer to bog or poor fens. The pH was markedly higher, mean was 5.5 in the Western Carpathian poor fens (Hájek *et al.* 2002, Hájek and Hekera 2004) and also in a *Sphagnum* dominated mire near Bolzano (Alps, Italy), where the pH in fen vegetation ranged between 4 and 5 (Bargazza and Gerdol 1999). Tahvanainen *et al.* (2002, 2003) measured pH under 4 in Finnish bogs, and between 4 and 5 in poor and moderately poor fens. Sjörs and Gunnarson (2002) also published low pH values from Swedish bogs.

a



b

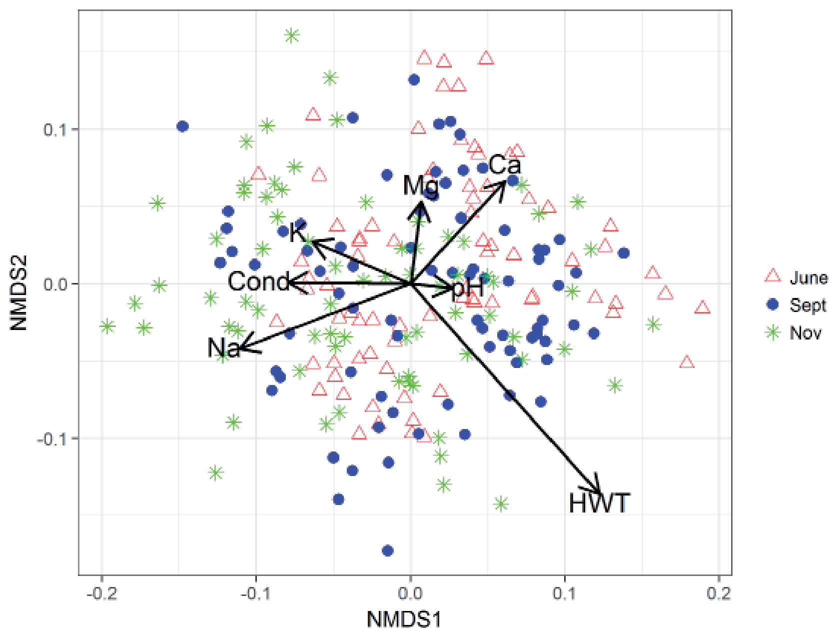


Fig. 9. NMDS of surface water samples based on water chemical variables and height above water table. The samples were grouped by mires (a) and by sampling periods (b) (BABT = Bábtava, KMOH = Kis-Mohos, NMOH = Nagy-Mohos, NYIS = Nyírjes lake, NYTB = Nyíres lake, HWT = height above water table, Cond = corrected conductivity, Na = Na^{+} concentration, K = K^{+} concentration, Ca = Ca^{2+} concentration, Mg = Mg^{2+} concentration).

The corrected conductivity of the five investigated Hungarian mires was relatively high, the means were between 29 and 125 µScm^{-1}. Similar corrected conductivity was measured in the Western Carpathians, where the mean conductivity was 53.1 µScm^{-1} in poor fens and 145 µScm^{-1} in rich fens. Bargazza and Gerdol (1999) found lower values, between 5–35 µScm^{-1}. In Finland Tahvanainen *et al.* (2002) also measured lower conductivity values.

The metallic element concentrations, similarly to conductivity, (Na^+, K^+, Ca^{2+}, Mg^{2+}) were higher in Hungarian mires than in poor fens of the Western Carpathians (Hájek and Hekera 2004, Hájek *et al.* 2002), in a *Sphagnum* dominated mire in Italy (Bargazza and Gerdol 1999), or in poor and moderately poor fens in Finland (Tahvanainen *et al*. 2002, 2003).

The deviation between mires was less pronounced in November, and the most diverse group structure was observed in September. Hájek and Hekera (2004) investigated the water chemical variables of mires during three years, and they found that the late summer-early autumn period is the best to divide fens on the basis of water chemical data. Tahvanainen *et al.* (2003) collected weekly water chemical data for a year, and they demonstrated that the largest difference between mires can be detected in early autumn.

There was not a clear trend between sampling periods in the investigated mires. Two or three variables did not differ significantly between sampling periods in mires. HWT was very stable during the year in KMOH, NMOH, and NYTB, corrected conductivity was constant in KMOH, NMOH, and BABT while pH in NYTB and NMOH, respectively. NYIS showed different picture, because there were no significant differences in the case of K^+, Ca^{2+}, and Mg^{2+} concentration. Hájek and Hekera (2004) had similar results from Western Carpathian fens, they found that pH and conductivity were the most stable variables, Na^+, K^+, Ca^{2+}, and $SO4^{2-}$ were relatively stable, and N-NO_3^-, Cl^-, Fe, PO_4^{3-}, and redox-potential temporally varied.

The ranges of measured variables were relatively narrow, there was significant difference between mires on the basis of multivariate permanova and there was also significant difference in the case of all variables (simple statistic, with whole period dataset).

The results of simple one-variable statistics and NMDS pointed out that the mires situated close to each other can be characterized by very similar water chemical and HWT values. The mires of the Bereg Plain (BABT and NYTB) have very similar values in pH, conductivity, and sodium and potassium concentrations, and their point clouds in NMDS markedly overlapped. The mires of Kelemér (KMOH and NMOH) were in the same group in the case of all variables (on the basis of whole period dataset) and their point clouds in NMDS widely overlapped. The NYIS clearly separated from the mires of Bereg and its point cloud partly overlapped those of KMOH and NMOH in NMDS. The results of one-variable statististics were interesting. NYIS formed an own group in the case of two variables (sodium and potassium concentration) and shared also groups with the Kelemér mires, with BABT (e.g. HWT), and with NYTB (e.g. pH).

***

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Összefoglaló: Észak-magyarországi tőzegmohalápokban (siroki Nyírjes-tó, keleméri Kis-Mohos és Nagy-Mohos, beregi Bábtava és Nyíres-tó) végeztünk vízkémiai vizsgálatokat (pH, konduktivitás, Na^+, K^+, Ca^{2+}, Mg^{2+} koncentráció) valamint vízszintmérést. A pH viszonylag alacsony volt a vizsgált lápokban, az átlagok 3.29 and 5.92 között változtak. A konduktivitás láponkénti átlaga 11.08 and 176.6 μScm^{-1} közötti értékeket mutatott. A kationok koncentrációja magasnak mondható, a Na^+ koncentráció láponkénti átlaga 3.47 és 12.71 $mgdm^{-3}$ a Ca^{2+} koncentrációé 7.96 és 10.21 között változott. A siroki, keleméri és beregi régiók egymástól viszonylag jól elkülönültek a legtöbb változó alapján. A beregi lápok kevésbé savanyúnak és kationokban gazdagabbnak bizonyultak a keleméri lápoknál. A siroki Nyírjes-tó a vizsgált változók tekintetében közelebb áll a keleméri lápokhoz, mint a beregiekhez. A mintavételi időpontok alapján szabályszerű változásokat nem lehetett kimutatni. A lápok közötti különbség a kora őszi mintavétel alkalmával volt a legjelentősebb.

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