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Chapter IX

Mateusz Stelmaszczyk, Jarosław Chormański, Mateusz Grygoruk,
Ignacy Kardel, Tomasz Okruszko, Helena Bartoszuk

Groundwater chemistry variation in wetland vegetation habitats of the "Red Bog Strict Protected Area"

INTRODUCTION

The Biebrza valley (located in north-east part of Poland) is one of the last valuable ecosystems for biodiversity of European natural lowland wetlands. The natural and primeval character of the Biebrza valley is reflected in occurrence of rare wetland plant communities and fauna species (WASSEN 2002). This uniqueness was a reasonable cause to protect this area in an official way. In 1925 first nature reserve was established ("Red Bog Reserve"), and in 1993 the Biebrza National Park was created.

The diversity of plant communities in the Biebrza valley is essentially regulated by the hydrology which directly affects the chemical characteristic of waters feeding the plants. Changing water levels, e.g. due to the drainage works, can cause drastic irreversible change in the vegetation cover. It is widely known that hydrological regime creates proper habitat conditions for wetland plant communities and their sustaining in good condition (BANASZUK et al. 1994; DEMBEK et al. 1997; FIAŁKOWSKI et al. 1994; FIAŁKOWSKI, URBAN 1997; HERBICH 1998; OŚWIT 1991). Less investigation was done to define the influence of water chemical characteristic on creating unique habitat conditions for rare wetland plant communities (especially bog plant communities). In this paper authors investigated linkages between groundwater chemical characteristic and occurrence of wetland plant communities in the Red Bog Strict Protected Area (RB SPA). The main aim of the research was to study patterns in water quality characteristic obtained for two layers, for peat layer and mineral layer, and recognition of correlations between ionic characteristic and occurring vegetation.

STUDY AREA

Biebrza National Park (BNP) covers a large part of the Biebrza River valley, situated in north-eastern part of Poland. BNP is the biggest among Polish national parks. Its total area is 59223 ha. The core area is surrounded by 66824 ha of the Park protection buffer-zone. Most of the Biebrza valley's peatlands are protected. The Biebrza River valley was divided into three basins using a relation of the higher order morphologic features. The most valuable feature of the Biebrza Marshes is its perfectly formed and well-preserved diagonal and longitudinal ecological zonation. The value of Biebrza National Park was held in high esteem by classifying it as the one of the Nature 2000 areas (http://www.biebrza.org.pl/).

Red Bog

Peatlands of RB SPA is the second biggest raised bog in Poland regarding its area and, probably, the only big lowland bog of this type preserved in natural state in the entire country. Due to the wide-spread endanger of wetland habitats by eutrophication and drying up, investigation of ecological relationships on the relatively slightly transformed sites is gaining importance and contribute to the unique value of the Red Bog on the European scale. Due to relatively vast area, a complete gradient from raised bog in the centre, throughout transitional peatland, to fen in the southern part is observed in the RB SPA. Additionally, the vegetation-habitat zones, which differentiation is related to trophic level and hydrological conditions, are composed in the very clear sequence (OKRUSZKO 1991). The area of Red Bog provides a mosaic of unique spots of boreal pine forest, alder communities and fern birch forest. Some open sedge meadows are present in eastern and southern part of studied area, where the birch and willow shrubs succession is also noted. The most important factor of the Red Bog's habitats development is groundwater and rain supply spatially diversified in the Red Bog Area. The diversity of water supply origin which corresponds to groundwater chemistry (WASSEN et al. 2002), makes development of Red Bog's ecosystems hard to foreseen.

The groundwater monitoring network was established in 16 measurement locations (Fig. 1) that represented the most typical wetland habitats of Red Bog and its close neighbourhood. There were 31 piezometers supplied with 17 Divers®, which recorded groundwater level and in some places also additional parameters (temperature, EC, pH) in 6-hour time step. Additionally, the piezometric head was measured manually approximately every 14 days. Due to undertaken groundwater level research method, groundwater head data was collected and verified basing on standard manual measurements. In presented approach authors used results of preliminary vegetation recognition on the area of RB SPA. Vegetation composition was characterized by recording of vegetation relevés according to Braun-Blanquet scale (species, cover, abundance etc.). Vegetation recognition of the RB SPA was done during two years, 2007 and 2008, during the June – September month period.

Groundwater sampling points were placed in few vegetation types starting from bog pine forest (Gazy2, RB2), through pine forest (RB11), fern birch forest (Gazy1, Gazy3 and RB23), communities from *Alnion glutinosae* alliance – alder swamp forest (Gazy4, RB12, RB13, RB14, RB15) and birch shrubs (RB3), and ending on meadows and tall sedges communities (RB21, RB22, RB24, and RB25) (Table 1).

Table 1

Vegetation types present in chosen groundwater sampling locations

Location	Vegetation type
Gazy 1	Community *Betula pubescens-Thelypteris palustris* – fern birch forest
Gazy 2	*Vaccinio uliginosi-Pinetum sylvestris* – raised bog pine forest
Gazy 3	Community *Betula pubescens-Thelypteris palustris* – fern birch forest
Gazy 4	*Sphagno squarrosi-Alnetum* – alder swamp forest
RB 2	*Carici chorrdorhizae-Pinetum* – mossy bog pine forest
RB 3	*Betulo-Salicetum repentis* – association of shrub birch
RB 11	*Vaccinio myrtilli-Pinetum typ.*
RB 12	*Ribeso nigri-Alnetum* – alder swamp forest
RB 13	*Ribeso nigri-Alnetum* – alder swamp forest
RB 14	*Ribeso nigri-Alnetum* – alder swamp forest
RB 15	*Sphagno squarrosi-Alnetum* – alder swamp forest
RB 21	Meadow community with *Molinia caerulea, Carex buxbaumi, Carex panicea*
RB 22	Plant community with *Calamagrostis canescens*
RB 23	Community *Betula pubescens-Thelypteris palustris* – fern birch forest
RB 24	Plant community of *Deschampsia caespitosa*
RB 25	Plant community of *Deschampsia caespitosa*

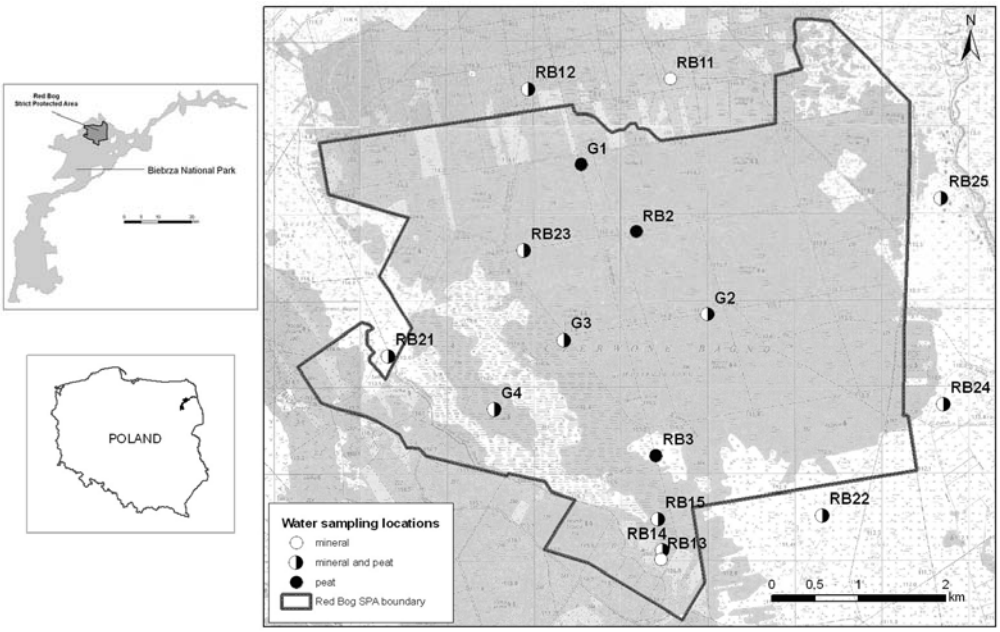

Fig. 1. Sampling points localizations on a study area – Red Bog Strict Protected Area

MATERIALS AND METHODS

The groundwater hydro-chemical monitoring of the Red Bog Strict Protected Area was carried out for two years (2007 - 2008). The water chemical characteristic was determined for two layers, for peat layer and mineral layer laying beneath peat stratum. There were chosen 16 separate locations (Fig. 1) in which water sampling were carried out. Almost in all locations two piezometers were installed that allowed water sampling from first peat stratum (14 piezometers) and from mineral stratum laying beneath it (13 piezometers). Water chemical analyses were done in one month interval. Analysis of electroconductivity (EC), alkalinity (HCO_3^-) and pH were done directly in the field. The water samples were collected to the polyethylene containers and transported in mobile refrigerator to the laboratory in Warsaw. In the laboratory anions (NO_3^-, NO_2^-, PO_4^{3-}, Cl^-, SO_4^{2-}) and cations (NH_4^+, Ca^{2+}, Mg^{2+}, Br^+, Li^+, Na^+, K^+, F^+) concentration was determined using High Performance Liquid Chromatography (HPLC). Moreover, concentration of total nitrogen (TN), inorganic carbon (IC) and total organic carbon (TOC) was determined using SKALAR continuous-flow analyzer.

Collected chemical data were statistically analyzed using STATISTICA 8 software. Verification of the data was done by computing basic statistics (minimum, maximum, mean and standard deviation). In this paper the basic statistics calculated for chemical data set will not be widely discussed. This part of the work was done to check the whole collected chemical data. This looking over of the chemical characteristics of the chosen locations allowed to make an assumption that in the data set taken for further analysis there are no outstanding values, caused e.g. by malfunctions in water samples collection or analysis shortcomings. The main statistical analysis was done using Principal Component Analysis (PCA) method. This multivariate analysis method consist of transformation of observed variables in new, not observed and at the same time not correlated variables called principal components. Every new principal component is a linear function of input variables, and components are ordered in a way that variances of each next component (which represent information about chemical characteristics) are smaller and smaller. In PCA method sum of the variances of input variables is equal to the sum of variances of new components which means that there is no lost of original information about water chemical characteristic (STANISZ 2007; CHATFIELD, COLLINS 1980).

Owing to the usage of PCA analysis it was possible to define groundwater characteristics for monitored locations in the RB SPA. In the PCA method few first components consist of majority of information about water characteristic, which leads to reduction of factors taken into account in further analysis (CATTELL 1965). This does not cause significant loss of input information. There are two methods of components quantity selection to more detailed analysis, by Kaiser criterion or by scree test (CATTELL 1966). First is basing on the eigenvalues of the new components, rejecting components with eigenvalues smaller than 1, so those which represent less information than one original variable. Second method is a graphical one, rejecting components which are on the right side from the point on which low decrease of eigenvalues starts. In presented situation (Table 2) both methods recommend to study mainly first five new components. Scree plot for PCA analysis done for the groundwater samples from mineral layer is clearer than for the peat layer. For peat layer this method suggests to further analysis even more than five components. Despite above-mentioned in further analysis authors focused only on three first components. Those components describe a large majority of variability of groundwater chemical characteristics (64.7% for peat layer and 70.2% for mineral). Moreover those three components are characterized by the most of the strong correlations with original chemical water parameters, which leads to obtaining the most useful interpretation of the results. In presented approach, in further detail analyses authors used cases with correlations between water chemical parameters and principal components higher than 0.6. In such environmental researches as presented, it can be assumed that below that level of correlation there are no statistically significant dependences between variables.

Table 2

Eigenvalues of correlation matrix (PCA analysis on data from peat and mineral layer)

Value No.	Peat stratum				Mineral stratum			
	Eigen-value	Cumu-lative eigen-value	Total variance [%]	Cumu-lative [%]	Eigen-value	Cumu-lative eigen-value	Total variance [%]	Cumu-lative [%]
1	6.17	6.17	32.46	32.46	6.89	6.89	36.29	36.29
2	3.47	9.64	18.28	50.75	3.54	10.44	18.65	54.94
3	2.64	12.28	13.91	64.66	2.90	13.33	15.24	70.18
4	1.84	14.13	9.69	74.35	2.05	15.38	10.78	80.96
5	1.61	15.74	8.48	82.83	1.83	17.21	9.64	90.60
6	0.96	16.70	5.08	87.90	0.78	18.00	4.11	94.72
7	0.88	17.58	4.64	92.55	0.44	18.43	2.30	97.02
8	0.68	18.27	3.59	96.13	0.25	18.68	1.32	98.34
9	0.28	18.55	1.48	97.61	0.15	18.83	0.79	99.13
10	0.20	18.75	1.07	98.68	0.10	18.93	0.53	99.65
11	0.12	18.87	0.62	99.30	0.05	18.99	0.27	99.93
12	0.09	18.95	0.46	99.76	0.01	19.00	0.07	100.0
13	0.05	19.00	0.24	100.0	-	-	-	-

RESULTS

HYDROLOGY OF RED BOG

Groundwater level monitoring during a period of hydrological year 2008 allows to characterize hydrological condition of RB SPA. Fig. 2 and Table 3 show piezometer head's statistics of: magnitude of water level fluctuation, number of days with water level above and below of ground surface as well as average piezometric head in both peat and mineral layers. The average hydrological conditions for habitat of forest on peat soil (e.g. location Gazy 2, where the habitat of bog-pine forest is typical for raised bog) are more stable than in open meadows (e.g. location RB21) which are covered by mosaic of birch and willow shrubs and sedge meadows. Presented index of number of days with groundwater occurrence above/below the ground level, describe essential conditions for unique plant communities presence, such as alder forest (CHORMANSKI et al. 2009).

In particular areas of the RB SPA dominant sources of water supply can be observed. In northern part of the area (RB12, Gazy 1, RB2), lower magnitude of groundwater level fluctuation is the result of water feeding from the sandy aquifer of outwash plain, where the velocity of groundwater flow is much higher than that in peat. In western and south-eastern part of the RB SPA, bigger magnitude of groundwater fluctuation could be the result of high potential evapotranspiration (RB14), percolation to sandy aquifer (RB15, RB21 – what is observed in significant difference in piezometric head in both peat and mineral layers) either the impact of neighbourhood's drainage system (RB24). In case of the RB SPA it can also indicate main directions and paths of the groundflow, that comes from the side of outwash plain to south-east (ZLOTOSZEWSKA-NIEDZIALEK, FALKOWSKI 2009), when in dry periods, groundwater level – even due to high evapotranspiration – does not decline. Therefore, in particular locations (RB22, RB23, RB25) higher groundwater supply from deeper, sandy aquifer can be expected.

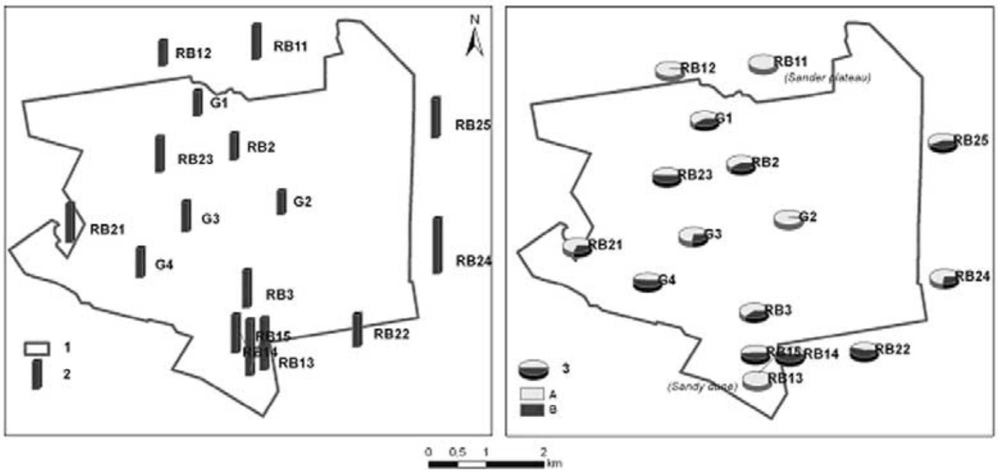

Fig. 2. Hydrological equilibrium of the Red Bog during hydrological year of 2008; 1 – RB SPA boundary, 2 – magnitude of groundwater level, 3 – balance between the number of days with groundwater head below (A) and above (B) the ground level

Table 3

Hydrological statistics and average piezometric head in peat and mineral layers of the particular measurement locations in the Red Bog during hydrologic year of 2008

Location	Magnitude of water level fluctuation [m]	Number of days with water level below ground level	Number of days with water level above ground level	Average piezometric head in peat layer [m a.s.l.]	Average piezometric head in fine mineral layer [m a.s.l.]
Gazy 1	0.49	218	148		
Gazy 2	0.46	358	8	113.72	113.73
Gazy 3	0.59	266	100	113.60	113.64
Gazy 4	0.57	177	189	113.29	113.31
RB2	0.51	218	148	113.91	113.90
RB3	0.73	225	141		
RB11	0.67	366	0		
RB12	0.49	362	4	114.36	114.34
RB13	1.09	366	0		
RB14	1.01	163	203	112.54	112.54
RB15	0.74	188	178	112.76	112.71
RB21	0.75	251	115	113.51	113.47
RB22	0.64	170	196	112.24	112.24
RB23	0.69	181	185	113.85	113.83
RB24	1.07	264	102	112.29	112.29
RB25	0.76	207	159	112.84	112.82

PCA ANALYSIS FOR THE GROUNDWATER FROM PEAT LAYER

Figure 3 represents correlations among original variables projected into space defined by first three components. If the original variable is laying closer to the circle edge, more original information will be represented by the two components building coordinate system. The closer two original variables are laying to each other on the plot, the higher is the positive correlation between them. When two vectors between two variables and centre of a coordinate system are perpendicular to each other the variables are regarded as uncorrelated. And when vectors are in one line, but on the opposite side of the coordinate system the variables are negatively correlated. High positive correlations are shown between nitrogen ions (NH_4^+, NO_3^-, NO_2^-) and total nitrogen, and between calcium, magnesium, sodium, electroconductivity, alkalinity and inorganic carbon and between sulfates and phosphates (Fig. 3). High negative correlations are shown between nitrogen ions, total nitrogen and fluorides. Two groups of variables a) pH, calcium, magnesium, sodium, electroconductivity, alkalinity and inorganic carbon and b) fluorides, nitrogen ions and total nitrogen are more or less uncorrelated to each other. First group of variables is well represented by first component and the second group by the second component.

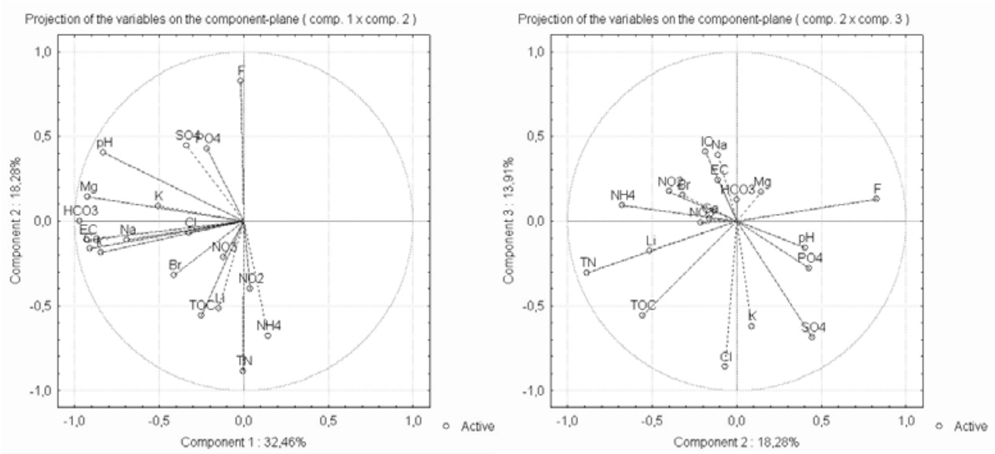

Fig. 3. Projection of the variables in a plane of principal component 1 and 2 and component 2 and 3 (for peat layer)

Values of linear correlation coefficients between following first five components and water chemical parameters are set in the Table 4. First component is strongly negatively correlated right up to seven parameters (correlation coefficient higher than 0.69). The highest correlations show EC, HCO_3^-, Ca^{2+} and Mg^{2+}. The second component is strongly negatively correlated with NH_4^+ and TN and positively with F^+ (correlation coefficient higher than 0.68). The third component is strongly negatively correlated with three parameters: Cl^-, SO_4^{2-} and K^+ (correlation coefficient higher than 0.62). Fourth and fifth components are strongly correlated only with one parameter, nitrogen ions: nitrate and nitrite, respectively.

Figure 4 and Fig. 5 show projection of the cases – location of water sampling points – in a plane of first, second and third component. By comparing this information with correlation coefficients of variables (water chemical parameters) and selected components, it becames possible to determine the chemical characteristic of chosen locations, which are habitats of different plant communities. The component plane is divided into four parts, each part is related to different chemical characteristic. As authors mentioned above, first component is strongly negatively correlated with parameters such as pH, HCO_3^-, EC, Na^+, Mg^{2+}, Ca^{2+} and IC (Fig. 4), so locations which have first component coordinates higher than zero will be characterized by low values of those parameters, while locations which have first component coordinates lower than zero will be characterized by high values of those parameters. Locations Gazy 2 (covered by raised bog), RB2 (mossy bog pine forest) and RB3 (birch shrubs) have the lowest mean values of parameters strongly correlated with first component among observed (pH< 6.3, HCO_3^-< 120.3 mg/dm^3, EC< 242.6 µS, Na^+< 5.3 mg/dm^3, Mg^{2+}< 4.8 mg/dm^3, Ca^{2+}< 77.6 mg/dm^3, IC< 22.2 mg/dm^3). Whereas locations Gazy 4 (alder swamp forest) and RB24 (tall sedges vegetation) have the highest values of those parameters (pH> 6.7, HCO_3^-> 388.9

mg/dm^3, EC> 509.0 µS, Na^+> 9.9 mg/dm^3, Mg^{2+}> 12.6 mg/dm^3, Ca^{2+}> 151.2 mg/dm^3, IC> 56.4 mg/dm^3).

Table 4

Principal component-variable correlations for two strata (component coordinates of the variables, based on correlations)

Variable	Peat stratum					Mineral stratum				
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 1	PC 2	PC 3	PC 4	PC 5
pH	***-0,83***	0,40	-0,16	-0,14	-0,02	***0,83***	0,22	-0,14	-0,28	0,21
EC	***-0,93***	-0,11	0,24	0,07	-0,12	***-0,87***	0,38	0,08	0,16	0,01
HCO_3^-	***-0,97***	-0,00	0,13	0,01	0,05	***-0,93***	0,23	0,07	0,09	0,17
F^+	-0,02	***0,83***	0,13	0,39	-0,12	-0,03	0,34	***0,82***	0,34	-0,00
Br^+	-0,41	-0,32	0,15	0,54	0,02	-0,55	-0,32	-0,05	***-0,61***	-0,29
Cl^-	-0,32	-0,07	***-0,86***	-0,07	-0,10	***0,68***	0,15	-0,50	0,30	-0,15
NO_2^-	0,04	-0,40	0,17	-0,14	***-0,75***	0,08	0,33	0,31	-0,58	0,59
NO_3^-	-0,12	-0,21	-0,01	***-0,83***	-0,29	***0,71***	0,35	0,48	-0,29	-0,08
PO_4^{3-}	-0,22	0,43	-0,28	0,48	-0,59	0,10	-0,55	0,43	-0,35	0,52
SO_4^{2-}	-0,34	0,45	***-0,69***	0,15	0,01	***0,79***	0,26	0,16	-0,10	-0,48
Li^+	-0,15	-0,51	-0,18	0,35	0,56	-0,24	-0,08	-0,12	***-0,66***	***-0,63***
Na^+	***-0,69***	-0,11	0,39	-0,16	0,14	-0,50	***0,75***	-0,00	-0,35	-0,02
NH_4^+	0,14	***-0,68***	0,09	0,38	-0,41	-0,38	-0,54	0,48	0,03	0,13
K^+	-0,51	0,09	***-0,62***	-0,31	0,07	0,15	0,53	***0,65***	0,33	-0,33
Mg^{2+}	***-0,92***	0,14	0,17	-0,08	0,13	-0,57	***0,72***	0,00	-0,31	-0,15
Ca^{2+}	***-0,91***	-0,16	0,02	0,06	-0,11	-0,37	0,22	***-0,80***	0,04	0,22
TN	-0,00	***-0,89***	-0,31	0,05	0,13	-0,45	***-0,74***	0,30	0,01	-0,29
IC	***-0,84***	-0,18	0,41	0,03	-0,02	***-0,89***	0,37	-0,01	0,16	0,18
TOC	-0,25	-0,56	-0,56	0,13	-0,12	***-0,86***	-0,27	0,06	0,10	-0,28

Differences among locations due to second component are subjected to ammonium, total nitrogen (strong negative correlation) and fluorides (strong positive correlation). Locations Gazy 1 (fern birch forest) and RB12 (alder swamp forest) are characterized by the highest concentrations of fluorides and the lowest concentrations of ammonium and total nitrogen among observed (F^+> 0.4 mg/dm^3, NH_4^+< 3.3 mg/dm^3, TN< 1.4 mg/dm^3). The third component is strongly negatively correlated with three parameters: Cl^-, SO_4^{2-} and K^+ (Fig. 5). Locations Gazy 1 (fern birch forest) and Gazy 4 (alder swamp forest) are characterized by low concentrations of those parameters (Cl^-< 4.6 mg/dm^3, SO_4^{2-}< 2.2 mg/dm^3, K^+< 4.2 mg/dm^3), and locations RB12 (alder swamp forest) and RB24 (tall sedges vegetation) by high concentrations of those parameters (Cl^-> 7.2 mg/dm^3, SO_4^{2-} > 12.9 mg/dm^3, K^+> 8.0 mg/dm^3).

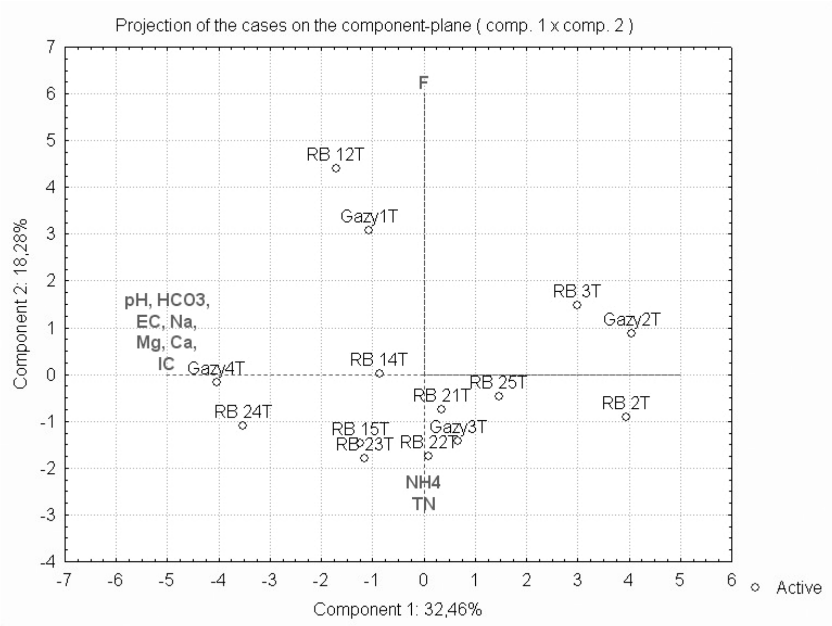

Fig. 4. Projection of the sampling locations in a plane of principal component 1 and 2 (for peat layer)

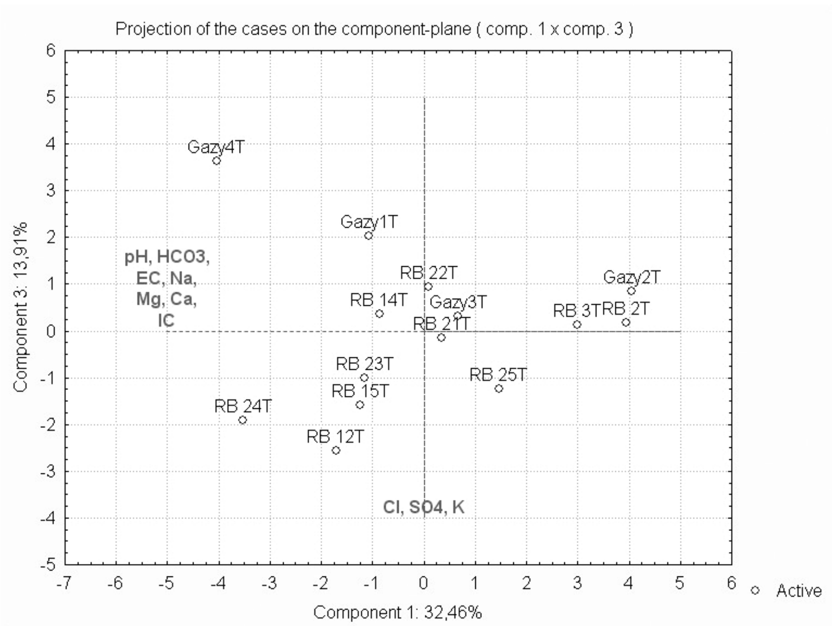

Fig. 5. Projection of the sampling locations in a plane of principal component 1 and 3 (for peat layer)

PCA ANALYSIS FOR THE GROUNDWATER FROM MINERAL LAYER

As shown on the Fig. 6 it is possible to distinguish few positively correlated groups of groundwater chemical parameters from mineral layer. Strong high positive correlations are present between: a) sodium and magnesium; b) ammonium and total nitrogen; c) alkalinity, electroconductivity and inorganic carbon; d) pH, sulfates, nitrates, and chlorides. Chemical parameters from group a) and d) and group b) and c) are almost uncorrelated with each other. Parameters from group d) pH, sulfates, nitrates, and chlorides show strong negative correlation with bromide and total organic carbon.

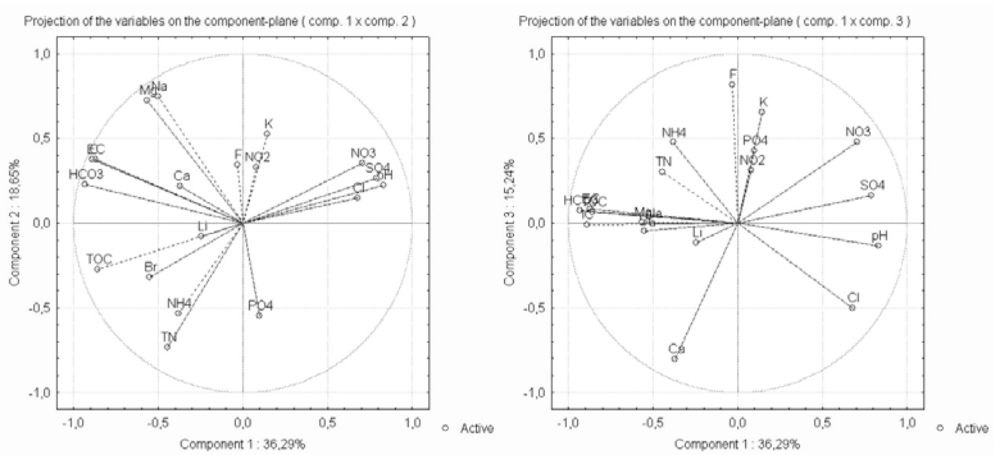

Fig. 6. Projection of the variables in a plane of principal component 1 and 2 and component 2 and 3 (for mineral layer)

While examining the results for the mineral layer (Table 4) it is clear that first component is strongly correlated (correlation coefficient higher than 0.68) right up to eight parameters, negatively with EC, HCO_3^-, IC, TOC, and positively with pH, NO_3^-, SO_4^{2-}, Cl^-. Moreover, second and third components are strongly correlated with three variables each (correlation coefficient higher than 0.72 and 0.65, respectively). Second component positively to Na^+ and Mg^{2+} and negatively to TN, third component positively to K^+ and F^+ and negatively to Ca^{2+}. The fourth and fifth components are strongly correlated only with two trace elements: bromide and lithium.

On Fig. 7 and Fig. 8 are shown projections of locations of water sampling points in a plane of first three components. Locations Gazy 4 (covered by alder swamp forest) have first component coordinates lower than zero so it will be characterized by low values of pH, NO_3^-, SO_4^{2-} and Cl^- (due to their positive correlation with first component) and high values of EC, HCO_3^-, IC and TOC (due to their negative correlation with first component). For this specific location water chemical characteristic is as follow: pH= 6.9, NO_3^-= 0.6 mg/dm^3, SO_4^{2-}= 0.6 mg/dm^3, Cl^-= 2.5 mg/dm^3, EC= 726.3 µS, HCO_3^-= 599.8 mg/dm^3, IC= 116.0 mg/dm^3, TOC= 115.6 mg/dm^3. Locations RB11 (pine forest) and RB12, RB13 (alder swamp forests) have first component coordinates higher than zero so they can be distinguished by high concentrations of pH, NO_3^-, SO_4^{2-} and Cl^- parameters (pH> 7.2, NO_3^-> 0.9 mg/dm^3, SO_4^{2-}> 8.5 mg/dm^3, Cl^-> 8.8 mg/dm^3) and low concentrations of EC, HCO_3^-, IC and TOC (EC< 413.6 µS, HCO_3^-< 280.6 mg/dm^3, IC< 35.8 mg/dm^3, TOC< 62.2 mg/dm^3). Differences among locations due to second component are subjected to sodium and magnesium (because of strong positive correlation) and total nitrogen (because of strong negative correlation). Locations Gazy 4 and RB12 (alder swamp forests) are characterized by high values of sodium and magnesium (Na^+> 5.4 mg/dm^3, Mg^{2+}> 9.0 mg/dm^3) and low values of total nitrogen (TN< 2.0 mg/dm^3). Whereas locations Gazy 2 (raised bog pine forest), Gazy 3 (fern birch forest) and RB25 (tall sedge vegetation) with second component coordinates lower than zero are characterized by low values of sodium and magnesium (Na^+< 4.3 mg/dm^3, Mg^{2+}< 8.8 mg/dm^3) and high values of total nitrogen (TN> 3.5 mg/dm^3). The third component is correlated with three parameters, positively with potassium and fluorides and negatively with calcium. Due to third component locations RB12 and RB13 (alder swamp forests) are positively correlated with potassium and fluorides and negatively with calcium, whereas location RB11 (pine forest) in the opposite way, negatively with potassium and fluorides and positively with calcium. Locations RB12 and RB13 are characterized by high concentrations of K^+ and F^+ (K^+> 4.1 mg/dm^3, F^+> 0.25 mg/dm^3) and low of Ca^{2+} (Ca^{2+}< 90.6 mg/dm^3). Location RB11 are characterized by low concentrations of K^+ and F^+ (K^+= 2.3 mg/dm^3, F^+= 0.06 mg/dm^3) and high of Ca^{2+} (Ca^{2+}= 188.2 mg/dm^3).

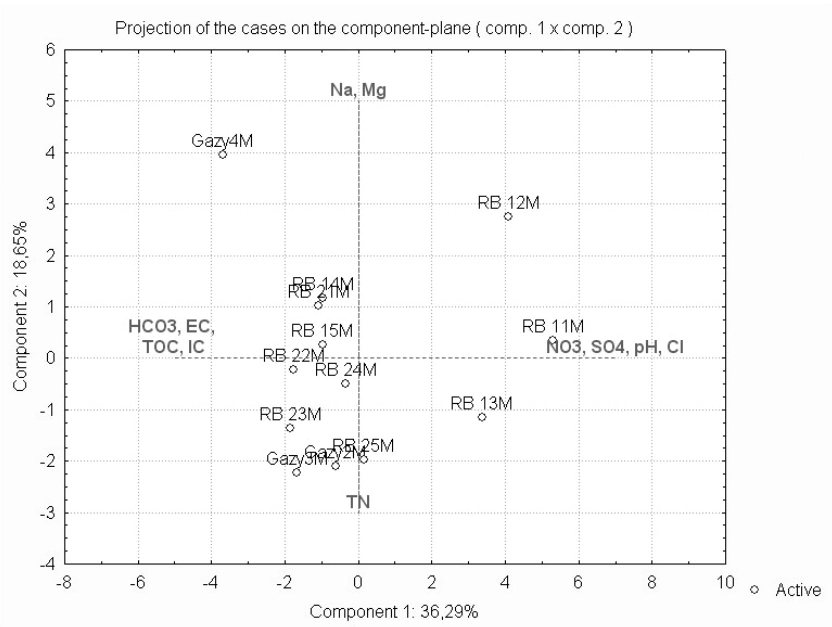

Fig. 7. Projection of the sampling locations in a plane of principal component 1 and 2 (for mineral layer)

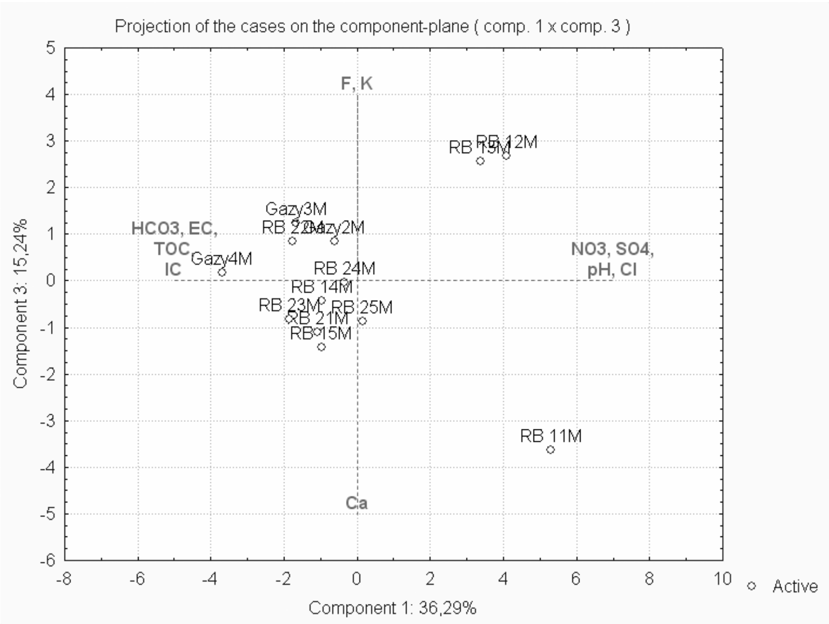

Fig. 8. Projection of the sampling locations in a plane of principal component 1 and 3 (for mineral layer)

DISCUSSION

Summarizing obtained results authors pointed few clear relationships that can be found between vegetation types and water chemical characteristic. Starting from the results of water quality for peat layer, some patterns of water chemistry specific for bog pine forest, fern birch forest and alder swamp forest can be observed. Areas covered by unique bog pine forest are subjected to lower values of pH, electroconductivity, alkalinity and low concentrations of Na^+, Mg^{2+} and Ca^{2+} ions. Opposite, the habitat of alder swamp forest is characterized by the highest values of base cations. However vegetation from *Alnion glutinosae* alliance is not uniform and may cause some divergences in interpretation of water quality results. It is impossible to fully specify water quality characteristic appropriate for *Alnion glutinosae* vegetation while thinking about that alliance as a whole. As shown in the results, two plant communities from *Alnion glutinosae* alliance can occur in areas distinguished by opposite chemical characteristic. *Sphagno squarrosi-Alnetum* occurs in habitats with lower SO_4^{2-}, Cl^-, and K^+ ions concentrations whereas the most typical alder swamp forest – *Ribeso nigri-Alnetum* – occurs in places where higher values of SO_4^{2-}, Cl^-, and K^+ ions can be measured. Similarly as a *Sphagno squarrosi-Alnetum* plant community, the fern birch forest prefers habitats with lower values of SO_4^{2-}, Cl^-, and K^+ ions concentrations. Moreover, lower concentrations of total nitrogen, and NH_4^+ and higher concentrations of F^+ ions are characteristic for fern birch forest. Those patterns are reflected when looking into water quality results from mineral layer. There are not significant differences in linkages between vegetation types and specific characteristics of groundwater quality parameters when comparing the water from peat and mineral layer.

It can be assumed that on the RB SPA the water chemical characteristic differs due to the water supply. Although the aim of this paper was not to define the ways and directions of water supplies of Red Bog area, authors found some patterns in a spatial distribution of waters characterized by similar chemical characteristics. Among samples collected from the peat layer it can be observed that waters from the center of the research area and waters from the edges, both from north and south part of the research area, have opposite chemical characteristic. In the center part waters are more acidic (lower pH) and with lower values of electroconductivity, alkalinity and Na^{+}, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^{-}, and K^{+} ions concentrations. Inversely, the further from the centre of the RB SPA the higher values of above listed parameters. This chemical diversification of waters from center and edges of RB SPA can be confirmed when looking into hydrological measurements. During measurement time the magnitude of groundwater level was smaller in the central part of the area than in the edges. This reflects in vegetation occurring on the RB SPA. Vegetation with lower tolerance to water levels fluctuations is present in central part (e.g. bog pine forest) while in the edges occurs vegetation more flexible to water changes (e.g. vegetation from *Alnion glutinosae* alliance or sedge communities).

CONCLUSIONS

Usage of PCA, multivariate analysis method, made possible assessment of linkages between habitats of vegetation types and specific characteristics of groundwater quality parameters defined for two water types, from peat and mineral stratum. The most significant differences between habitats of different wetland plant communities (e.g. raised bogs and tall sedges vegetation) were caused by the differences in pH, alkalinity, and electroconductivity, and differences in the concentration of Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^{-}, Na^{+} and K^{+} ions. Looking into details of the results it is possible to notice that some of the locations covered by the same vegetation type are characterized by different values of water quality parameters (e.g. in a case of vegetation from *Alnion glutinosae* alliance). At this point it is essential to mention that for creating proper habitat conditions for occurring specific vegetation types might be responsible, besides water chemical characteristic, an external factor that was not taken into account in this work. It can be that no chemical water characteristic is the crucial set of parameters but e.g. water table fluctuations or management (herbivores impact). Considering ecological approach, proceeding succession has to be kept in mind. It is probable that differences in vegetation occurring on specific habitats would be more distinct with the passage of time.

At the end of the paper authors remark that the period of groundwater monitoring is very short and should be lengthened to confirm obtained results of groundwater quality characteristics for monitored locations. It is worth to mention that RB SPA was closed for any research activity before, what made impossible to have the dataset longer. Therefore, monitoring will be prolonged for the next year as the last year, as it was planed in the carried project: "Biodiversity protection of Red Bog – the relict of raised bogs in Central Europe".

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Mateusz Stelmaszczyk[1], Jarosław Chormański[1], Mateusz Grygoruk[1], Ignacy Kardel[1], Tomasz Okruszko[1], Helena Bartoszuk[2]

[1] Warsaw University of Life Sciences
Department of Hydraulic Engineering and Environmental Restoration
Nowoursynowska Str. 159
02-776 Warsaw, Poland
e-mail: M.Stelmaszczyk@levis.sggw.pl

[2] Biebrza National Park
Osowiec-Twierdza 8,
19-110 Goniądz, Poland