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CONTENTS OF NITROGEN AND PHOSPHORUS COMPOUNDS IN GROUNDWATERS OF SELECTED FOREST ASSOCIATIONS IN SŁOWIŃSKI NATIONAL PARK

AGNIESZKA PARZYCH

Environmental Chemistry Research Unit, Institute of Biology and Environmental Protection,
Pomeranian University in Słupsk, ul. Arciszewskiego 22, 76-200 Słupsk,
Corresponding author e-mail: parzycha1@op.pl

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Abstract: The study of groundwaters was carried out in two different forest ecosystems of Słowiński National Park: *Vaccinio uliginosi-Betuletum pubescentis* and *Empetro nigri-Pinetum* in the period of 2002–2005. Differences were found in the position of the groundwater table and in the concentrations of nitrogen and phosphorus compounds in the investigated forest associations. In the *Vaccinio uliginosi-Betuletum pubescentis* association the groundwater table was found on average at a depth of -73.3 cm, while in *Empetro nigri-Pinetum* at -90.2 cm. No statistically significant effect of precipitation on the position of the groundwater table was found in this study. Statistical calculations (U Mann-Whitney test) for groundwaters in the analyzed forest associations showed statistically significant differences in the dynamics of concentrations of total nitrogen (T-N), organic nitrogen (Norg.), nitrate nitrogen (N-NO_3), total phosphorus (T-P), organic phosphorus (Porg.) and the level of groundwaters.

INTRODUCTION

Contamination of groundwater with nitrogen and phosphorus compounds is a global problem. Their content in groundwater is a result of not only the activity of man, but also an effect of natural processes occurring in the soil. The chemical composition of groundwaters is closely related with the age and type of soil, as well as their management [20, 30, 33]. It fluctuates under the influence of precipitation [14, 17, 21, 24], mineral composition of the soil [9], as well as intensity of migration of nitrogen and phosphorus compounds in the soil profile [20]. Groundwater has different chemical compositions in dune, in peat bogs, still other on agricultural lands [3, 5, 9, 15, 23, 26] and in forest ecosystems [8, 11, 13, 21, 28]. Water quality is also dependent on the natural matter decomposition processes occurring in soils [16]. The effect of weather conditions, particularly differences in the volume of precipitation, results in a considerable variation of groundwater levels. Areas with high groundwater tables are most sensitive to differences in weather conditions [21]. Frequent and significant fluctuations in groundwater levels influence their chemical composition [30]. Dynamics of groundwaters in Słowiński National Park (SNP) is dependent not only on precipitation [13], but also on water levels in adjacent lakes and the Baltic

Sea. In turn, water level in these lakes is dependent mainly on the water level in the sea. At storm winds blowing from the north-west and the north the levels of waters of the Baltic are raised, causing discharge of these waters to lakes, at the simultaneous, continuous inflow of river waters. All these factors cause a considerable elevation of water levels in lakes, contributing to an increase in groundwater levels and frequent flooding of parts of stands located at lower altitudes. It can be stated that the increase in groundwater levels in SPN is caused by a constant, slow increase in the Baltic level [25] and negligence in dredging and maintenance of the drainage ditch network [22].

The aim of this study was (1) to determine to what extent the dynamics of the groundwater table position affects the formation of the chemical composition of groundwater, and (2) to determine the effect of weather on the dynamics of nitrogen and phosphorus and the formation of groundwater table in selected forest ecosystems. To this end, the four-year cycle of regular testing measurements of concentrations of nitrogen and phosphorus compounds in groundwaters and measurements of the position of groundwater levels have been done.

SAMPLING SITES

In the analyses two different forest ecosystems located in the central part of Mierzeja Łebska sand bar, in the south-western part of Smołdziński Forest Protection District were selected. From the west they adjoin Lakes Gardno and Dołgie Wielkie, from the south through a zone of low moor peat bogs they are adjacent to a moraine upland surrounded by Gardno-Łebsko and Łupawa-Łebsko Channels. From the east they are surrounded by waters of Lake Łebsko (Fig. 1). Hydrographic relations in Słowiński National Park are

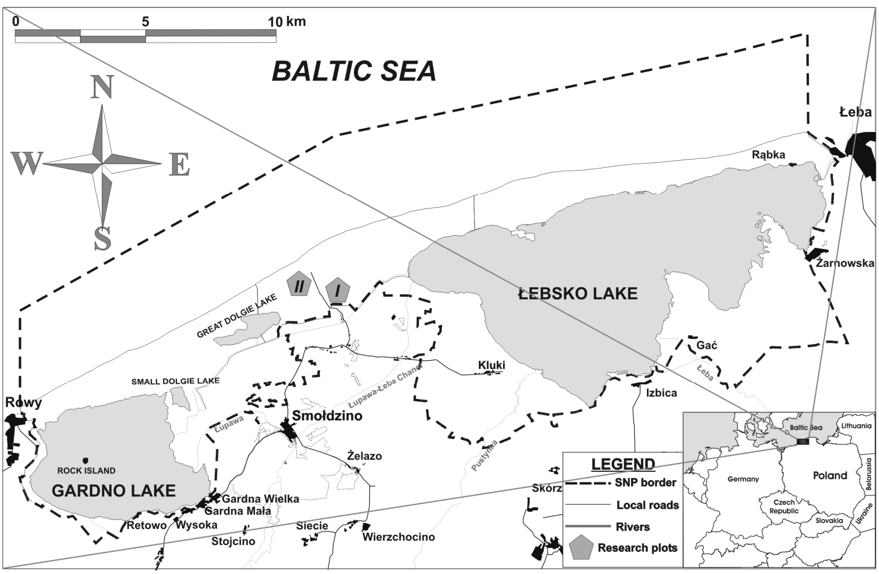

Fig. 1. Situation plan of the Słowiński National Park – locations of the study sites.
I – research plot I (*Vaccinio uliginosi–Betuletum pubescentis, Vu-Bp)* – pine-birch forest,
II – research plot II (*Empetro nigri–Pinetum, En-P*) – pine forest

modified by a specific network of small watercourses and drainage ditches, the Łeba, Łupawa and Pustynka rivers and lakes connected with the Baltic through the channel. Within the boundaries of Słowiński National Park there are 13 channels of a total length of 58 km [12]. In Smołdziński Forest Protection District, located in the northern part of Gardno-Łebsko Lowland, water relations are regulated by Gardno-Łebsko and Łupawa-Łebsko Channels.

One experimental plot was covered by a loose pine-birch stand (*Vaccinio uliginosi-Betuletum pubescentis, Vu-Bp)* formed on typical podsolic soils deposited on fossil peat soil: Ol, Ofh, AEes, Bhfe, C, Otni. The other experimental plot was covered by an old pine stand (*Empetro nigri-Pinetum, En-P)* growing on infertile typical podsolic soils: Ol, Ofh, AEes, Bhfe, C. The selection of these experimental plots resulted from the uniform effect of atmospheric conditions as well as the type of soil and vegetation cover.

RESEARCH METHODS

In order to follow groundwater levels in the central parts of the investigated forest plots observation wells were installed (PCV pipes of 100 mm in diameter), in which levels of groundwater were measured and groundwater samples were collected every 5–7 weeks in the vegetation seasons of 2002–2005. After they were transported to the laboratory the samples were filtered and next subjected to chemical analyses. In groundwater samples the following parameters were determined: total nitrogen (T-N), ammonia nitrogen (N-NH_4), nitrate nitrogen (N-NO_3), total phosphorus (T-P), phosphate phosphorus (P-PO_4) as well as pH (Tab. 1), [7]. All analyses were performed three times.

Table 1. Analytical methods for chemical parameters in groundwater

Determination		Methodology of determination
Total nitrogen	T-N	Kjedhal's method[1], after mineralization in the mixture of H_2SO_4 and H_2O_2
Ammonia nitrogen	N-NH_4	spectrophotometrically[2] (with Nessler's reagent)
Nitrate nitrogen	N-NO_3	spectrophotometrically[2] (with sodium salicylate)
Total phosphorus	T-P	spectrophotometrically[2] (molybdate method, with ascorbic acid as reducing agent), after mineralization in the mixture of H_2SO_4 and H_2O_2
Phosphate phosphorus	P-PO_4	spectrophotometrically[2] (molybdate method, with ascorbic acid as reducing agent)
Reaction	pH	potentiometrically[3]

[1] apparatus Parnas-Wagner, [2] spectrophotometr Shimadzu (UV-1202 UV-VIS), [3] glass electrode: Eurosensor ESAgP-341W

RESULTS AND DISCUSSION

Dynamics of groundwater level

Fluctuations of groundwater table are affected by weather conditions. Total precipitation in the investigated years varied considerably. The biggest amount of rainfall was recorded

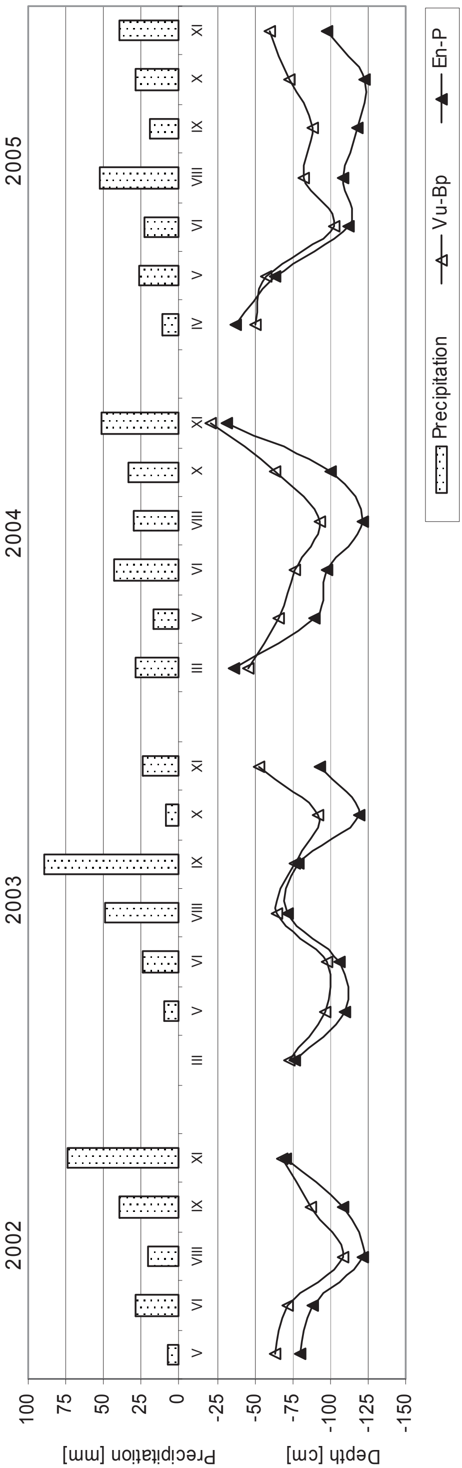

Fig. 2. Fluctuations of groundwater level and 14-days precipitation sums in 2002–2005

in 2004 (848 mm), while the lowest in 2003 (552 mm), (Tab. 2). Much smaller variation was observed for mean annual temperatures (7.73°C) and humidity values (83.90%). Fluctuations in groundwater levels changed cyclically within the course of a year. In both examined wells the rhythm of these fluctuations was very similar [19]. The highest water tables were recorded in the spring and autumn periods (March, April and November), while the lowest in the summer (June, August), (Fig. 2).

Similar trends in the position of the groundwater table, were found by Pierzgalski *et al.* [21] in Białowieski National Park as well as by Kowalkowski and Jóźwiak in Świętokrzyski National Park [13]. Despite the similar rhythm of the fluctuations certain differences appeared in the position of groundwater levels. In *Vaccinio uliginosi-Betuletum pubescentis* the groundwater table was typically found at a depth of -73.3 cm, while in *Empetro nigri-Pinetum* it was at -90.2 cm (Tab. 2).

Much bigger amplitudes of water table fluctuations were observed in *En-P*, on average by 25%. Such a situation is a consequence of a smaller water capacity of the mineral genetic layers affected by groundwaters. The presence of fossil soil in *Vu-Bp* within groundwaters, having a considerable water capacity, promotes water retention, and thus smaller amplitudes of fluctuations in water table. According to Uggla and Uggla [32] organic soils (particularly peat soils) have a high water capacity, amounting to as much as over 90% volume.

Mean values of the minimum position of the groundwater table remained at -100.5 cm in the case of *Vaccinio uliginosi-Betuletum pubescentis* and they were higher than mean mini-

Table 2. Atmospheric condition and average groundwater level in 2002–2005

		2002	2003	2004	2005	Average
Precipitation [mm]		682	552	848	579	665
Air temperature [°C]		-	7.69	7.68	7.81	7.73
Air humidity [%]		-	83.5	84.5	83.6	83.9
Average groundwater level [cm]	Vu-Bp	79.8(±18.0)	79.1(±17.2)	60.8(±24.9)	73.7(±18.7)	73.3(±20.1)
	En-P	93.8(±20.9)	93.6(±18.5)	79.3(±36.9)	94.3(±31.7)	90.2(±28.4)

Note: (±) – standard deviation,

mum in *Empetro nigri-Pinetum* (-120.0 cm) by 19%. Mean values of the maximum position of the analyzed groundwater tables were lower in pine coniferous forest on average by 12%, amounting to -53.0 cm (Tab. 3). The high mean level of groundwaters indicates their high contribution to the fluctuations in soil moisture content within the analyzed soil profiles [17].

Table 3. Characteristics of groundwater level in the 2002–2005

Forest association	2002			2003			2004			2005			2002-2005	
	min.	max.	ampl.	min.	max.	ampl.	min.	max.	ampl.	min.	max.	ampl.	Av. min.	Av. max.
	[cm]													
Vu-Bp	-108	-64	44	-98	-53	45	-93	-21	72	-103	-51	52	100.5	47.3
En-P	-122	-71	51	-119	-72	47	-121	-31	90	-118	-38	80	120.0	53.0

The slight effect on the variation in groundwater levels was found for precipitation in the investigated vegetation seasons. In both examined forest ecosystems statistically non-significant dependencies were found between the amount of precipitation and groundwater levels. Probably this results from the fact that in the vegetation season as a consequence of the lowering of the groundwater table the vegetation of the forest floor utilises solely precipitation. Moreover, a considerable part of precipitation is evaporated. An enhanced activity of trees in the vegetation period is also of some importance [21, 30], as well as type of the plants [31]. According to Johnson *et al.,* [11] as well as Bliss and Comerford [2], plants exert a significant effect on groundwater table in forest. After partial removing of plants the groundwater level is rising. According to Alley *et al.,* [1] fluctuations of the groundwater table are the result of the changeability of their supply. Variation in the groundwater levels over a considerable area of the Park results mainly from the variable water levels in near lakes and in the Baltic Sea [25].

Nitrogen, phosphorus compounds and pH in groundwater

Groundwaters in the examined forest ecosystems showed a similar dynamics, by varying abundance of nitrogen and phosphorus compounds. Much bigger amounts of biogens were observed in groundwaters in *Vaccinio uliginosi-Betuletum pubescentis*, which results from the presence of fossil soil, abundant in biogens, in the genetic profile (Tab. 4).

Table 4. Characteristics of soil properties in *Vu–Bp* and *En–P*

	Vaccinio uliginosi–Betuletum pubescentis					*Empetro nigri–Pinetum*			
Soil horizon	O (Ol+Ofh)	AEes	Bhfe	C	Otni	O (Ol+Ofh)	AEes	Bhfe	C
Depth [cm]	8-0	0-13	13-41	41-104	104-150	8-0	0-18	18-48	48-150
T-N [%]	1.06	0.06	0.02	0.03	2.85	1.07	0.03	0.02	0.01
T-P [%]	0.111	0.007	0.003	0.002	0.206	0.139	0.003	0.002	0.002

Groundwaters within the organic genetic horizon (Otni) wash out high amounts of nitrogen and phosphorus compounds. Groundwaters in pine-birch forest contained on average by 56% more total nitrogen (T-N) than waters in pine coniferous forest, mean 4.5 mg/dm^3 (Tab. 5).

Table 5. Characteristics of nitrogen and phosphorus content and pH in groundwater in 2002–2005

	Average	Minimum	Maximum	Mediane	CV [%]
T-N [mg/dm^3]	4.50(±1.09)^a 2.89(±0.63)^b	2.95^a 1.77^b	6.66^a 4.13^b	4.13^a 2.77^b	29.99^a 25.57^b
$N\text{-}NH_4$ [mg/dm^3]	1.33(±0.54)^a 1.37(±0.29)^b	0.45^a 0.97^b	2.42^a 1.90^b	1.21^a 1.38^b	47.64^a 22.00^b
$N\text{-}NO_3$ [mg/dm^3]	1.41(±0.83)^a 0.78(±0.32)^b	0.25^a 0.28^b	3.38^a 1.36^b	1.29^a 0.74^b	67.89^a 42.22^b
Norg. [mg/dm^3]	1.75(±1.05)^a 0.74(±0.31)^b	0.20^a 0.05^b	3.49^a 1.66^b	1.34^a 0.67^b	63.16^a 41.76^b
T-P [mg/dm^3]	2.11(±0.95)^a 1.55(±0.48)^b	0.87^a 0.82^b	4.01^a 2.71^b	1.78^a 1.40^b	44.75^a 30.76^b
$P\text{-}PO_4$ [mg/dm^3]	0.80(±0.50)^a 0.78(±0.55)^b	0.17^a 0.23^b	2.44^a 2.12^b	0.74^a 0.52^b	62.99^a 71.72^b
Porg. [mg/dm^3]	1.24(±0.81)^a 0.77(±0.33)^b	0.44^a 0.12^b	3.53^a 1.23^b	1.05^a 0.83^b	65.29^a 44.49^b
pH	6.38(±0.34)^a 6.43(±0.52)^b	5.65^a 5.00^b	6.90^a 7.13^b	6.40^a 6.47^b	5.33^a 8.05^b

Note: (±) – standard deviation, CV – coefficient of variation, a – groundwater in *Vu-Bp*, b – groundwater in *En-P*

Nitrate ions and total phosphorus were also found in great abundance, by 80% and 36% more, respectively, than in the case of *Empetro nigri-Pinetum*. A mean nitrate concentration in groundwater was 0.78 mg/dm^3 in *En-P* and 1.41 mg/dm^3 in *Vu-Bp*. Only ammonia nitrogen and phosphate phosphorus were generally found in the same amounts in the groundwaters of the examined forest plots. A mean concentration of $N\text{-}NH_4$ remained at a level of 1.33–1.37 mg/dm^3, while $P\text{-}PO_4$ was on average found at 0.78–0.80 mg/dm^3. A similar content of phosphates in groundwater (0.24–0.70 mg/dm^3) was reported by Sapek *et al.*, [29]. Low concentrations of mineral compounds of nitrogen and phosphorus in SNP groundwater are most probably a result of intensive absorption by the forest plants.

Reduced concentrations of nitrates and phosphates in forest groundwaters were demonstrated by Sánchez-Pérez *et al.*, [27, 28] and Groffman *et al.*, [6].

A much greater dynamics of nitrogen and phosphorus compounds in groundwaters of pine-birch coniferous forest results in much higher values of standard deviation and coefficients of variation (CV).

For nitrogen and phosphorus compounds contained in groundwaters, the values of standard deviations fell within the range of 1.09–0.81 (*Vu-Bp*) and 0.63–0.29 (*En-P*). The biggest variation of concentrations in groundwaters of *Vaccinio uliginosi-Betuletum pubescentis* was observed for nitrate ions (67.9%), while in *Empetro nigri-Pinetum* it was for phosphate ions (71.7%). The high variation in concentrations of individual ions in the period of 2002–2005 caused changes in pH (Tab. 5). Minimally higher mean acidity was found for groundwaters of pine-birch forest (*Vu-Bp*).

The concentrations of ammonia, nitrate and phosphate ions varied in the tested groundwaters. It resulted from the mutual relationships between ions, as in waters of *Vaccinio uliginosi-Betuletum pubescentis* nitrate ions predominated over ammonia ions, thus they were slightly more acidic (Tab. 6).

Table 6. Ratios of dissolved ions and total forms of nitrogen and phosphorus in groundwater in 2002–2005

Forest association	$\frac{N\text{-}NH_4}{N\text{-}NO_3}$	$\frac{N\text{-}NH_4 + N\text{-}NO_3}{P\text{-}PO_4}$	$\frac{T\text{-}N}{T\text{-}P}$
Vu-Bp	0.94	3.41	2.13
En-P	1.75	2.76	1.80

Such a situation may indicate a higher requirement of that vegetation cover for ammonia ions. In the groundwater of the areas used (meadows) $N\text{-}NH_4$ is most often a dominating form of nitrogen [21]. The concentration of ammonium and nitrate nitrogen in SNP groundwater is repeatedly lower than it was stated by Jaszczyński *et al.*, [10] in groundwater of pastures and several times lower than showed by Chen *et al.*, [3] in waters under the areas used for agriculture. Moreover, dissolved nitrogen compounds are found in much bigger quantities than phosphate ions available to plants. The ratio of total nitrogen (T-N) to total phosphorus (T-P) in groundwaters of *Vu-Bp* was by approx. 18% bigger than that ratio in groundwaters of *En-P*, amounting to 2.13.

Factorial analysis was performed in order to identify factors determining the chemical composition of groundwaters. The Principal Component Analysis (PCA) was used to distinguish three independent explanatory factors each, explaining over 66% variance in their chemical composition.

In *Vaccinio uliginosi-Betuletum pubescentis* the first factor (nitrogen-phosphorus), explaining 31% variation, grouped biogens characterised by very high positive factorial weights (Tab. 7).

An increase in the concentration of total nitrogen was accompanied by an increase in the concentrations of total and organic phosphorus. The second factor (nitrate), explaining 20%, grouped nitrate ions and groundwater levels with high negative factorial weights. The lowering groundwater level resulted in a reduction of concentrations of dissolved nitrates and to a slight extent contributed to an increase in the concentrations of ammonia and phosphate ions. Their increase with a lowering of groundwater levels was

Table 7. Results of principal component analysis on groundwater and 7-day sum of precipitation, n = 25.

Parameter	*Vu-Bp*			*En-P*		
	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3
	nitrogen-phosphorus	nitrate	precipitation	nitrogen	phosphorus (mineral)	phosphorus (organic)
T-N	**0.94**	0.14	0.25	**0.95**	0.11	0.17
$N\text{-}NH_4$	0.31	0.36	0.36	**0.80**	0.01	-0.09
$N\text{-}NO_3$	0.24	**-0.81**	0.10	0.49	0.29	0.29
Norg.	0.62	0.54	-0.03	0.68	-0.08	0.12
T-P	**0.90**	0.02	-0.41	0.12	**0.96**	-0.03
$P\text{-}PO_4$	0.46	0.31	-0.17	0.26	**0.80**	0.46
Porg.	**0.80**	-0.13	-0.27	-0.19	0.05	**-0.86**
pH	0.27	0.66	0.23	0.13	-0.37	0.45
groundwater level	-0.25	**-0.70**	0.10	-0.50	-0.30	-0.03
N:P	-0.43	0.20	**0.81**	0.50	**-0.74**	0.35
Precipitation [mm]	-0.07	0.24	**-0.86**	-0.12	0.20	0.67
Variance output	3.4	2.23	1.91	2.89	2.52	1.85
Participation of variance output	**31**	**20**	**18**	**26**	**23**	**17**
	69%			**66%**		

also observed by Sapek *et al.*, [29], as well as by Szymczyk *et al.*, [30]. Among biogenic compounds only $N\text{-}NO_3$ within this factor participated in the formation of the chemical composition of groundwaters in *Vaccinio uliginosi-Betuletum pubescentis.* The third factor (precipitation) explained 18% variation. It includes 7-day sums of precipitation with a high negative weight and the N:P ratio with a high positive weight. This means that the N:P ratio is higher at lower precipitation.

In *Empetro nigri-Pinetum* the first factor (nitrogen) explains 26% variation and comprises total and ammonia nitrogen with a very high and high positive factorial weight, respectively (Tab. 7). An increase in the concentration of total nitrogen was connected with an increase in the concentration of ammonia ions. The second factor explains 23% variance. It comprises total and phosphate phosphorus (having a very high and high positive factorial weight, respectively) and the N:P ratio with a high negative weight. The values of the above weights indicate that an increase in total phosphorus in groundwaters of *Empetro nigri-Pinetum* contributes to a reduction of the N:P ratio. The third factor explains 17% variance. It comprises the concentration of organic phosphorus with a high negative factorial weight. Among biogenic compounds only Porg. within this factor participates in the formation of the chemical composition of groundwaters in *Empetro nigri-Pinetum.*

The Principal Component Analysis clearly differentiates groundwaters in the analysed forest ecosystems. The level of groundwater table has a significant effect on the chemical composition of groundwaters only in *Vaccinio uliginosi-Betuletum pubescentis.* Adaptation of the PCA analysis for the characteristics of groundwater's chemical composition was suggested and described by Dragon [4], who distinguished main factors shaping the chemical composition.

In order to compare the dynamics of concentrations of nitrogen and phosphorus compounds and the level of groundwaters in *Vu-Bp* and *En-P* the U Mann-Whitney test was applied (Tab. 8).

Table 8. Results of U Mann-Whitney test of significance of nitrogen and phosphorus compounds differentiation in groundwater Vu-Bp and En-P in 2002-2005, n = 25.

Parameter	Significance of differences
T-N [mg/dm^3]	***
$N\text{-}NH_4$ [mg/dm^3]	b.r.
$N\text{-}NO_3$ [mg/dm^3]	**
Norg. [mg/dm^3]	***
T-P [mg/dm^3]	*
$P\text{-}PO_4$ [mg/dm^3]	b.r.
Porg. [mg/dm^3]	*
pH	b.r.
groundwater level [cm]	**
N:P	b.r.

Note: significant differences : *** $p < 0.001$, **$p < 0.01$, *$p < 0.05$, b.r. – no significant differences.

Statistical analyses for groundwaters of *Vaccinio uliginosi-Betuletum pubescentis* and *Empetro nigri-Pinetum* exhibited statistically significant differences in the dynamics of the concentrations of total nitrogen (T-N), organic nitrogen (Norg.) and nitrate nitrogen ($N\text{-}NO_3$). Statistically significant differences were also found for total phosphorus (T-P), organic phosphorus (Porg.) and groundwater level (tab. 8). In contrast, no significant differences were observed in the dynamics of $N\text{-}NH_4$ ions, $P\text{-}PO_4$ or pH and the N:P ratio in groundwaters of both forest associations.

CONCLUSIONS

In *Vaccinio uliginosi-Betuletum pubescentis* the groundwater table was typically found at a depth of -73.3 cm, while in *Empetro nigri-Pinetum* it was at -90.2 cm. Much bigger amplitudes in the fluctuations of groundwater levels were found in *En-P*. The presence of fossil soil in *Vu-Bp* promotes water retention, and thus lower amplitudes of fluctuations in groundwater tables. Moreover, no statistically significant effect on the position of the groundwater table was observed for precipitation.

Groundwaters in the investigated forest ecosystems had different concentrations of nitrogen and phosphorus compounds. Much bigger amounts of biogens were found in groundwaters of pine-birch forest (*Vu-Bp*) than in waters from pine coniferous forest (*En-P*). Groundwaters being within the organic genetic horizon (Otni) wash out considerable amounts of nitrogen and phosphorus compounds. They contained on average more total nitrogen (T-N) by 56% and 26% more total phosphorus (T-P) than waters from *Empetro nigri-Pinetum*.

The Principal Component Analysis (PCA) shows that the groundwater level has a significant effect only on the chemical composition of groundwaters in *Vaccinio uliginosi-Betuletum pubescentis*. Statistical calculations for groundwaters of both associations showed statistically significant differences in the dynamics of concentrations of total nitrogen (T-N), organic nitrogen (Norg.), nitrate nitrogen ($N\text{-}NO_3$), total phosphorus (T-P), organic phosphorus (Porg.) and groundwater level. In contrast, no significant differences were found in the dynamics of NH_4^+, PO_4^{3-} ions and the reaction of groundwaters in the analysed forest associations.

REFERENCES

[1] Alley W.M., R.W Healy, J.W Labaugh, T.E. Reilly: *Flow and storage ingroundwater systems*, Science, **296**, 1985–1990 (2002).

[2] Bliss C.M., N.B. Comerford: *Forest harvesting influence on water table dynamics in a Florida flatwoods landscape*, Soil Science Society Journal of America, **66**, 1344–1349 (2002).

[3] Chen W.F., W.S. Lin, G.C. Chang, C.V. Chin: *Groundwater dissolved oxygen and nitrate concentrations in recharge of the Choshui Fan-delta*, Bulletin of the Central Geological Survey, **16**, 125–139 (2003).

[4] Dragon K.: *Chemizm wód podziemnych poziomu wielkopolskiej doliny kopalnej w rejonie między Obrą a Wartą, Zastosowanie metod statystycznych w badaniach naukowych III*, StatSoft Polska 55–60, www.statsoft.pl/czytelnia.html (2008).

[5] Durkowski T., L. Pieczyński: *Jakość wód gruntowych i powierzchniowych w bezpośredniej zlewni jeziora Miedwie – zbiornika wody pitnej*. W: Materiały konferencyjne nt. Woda - Środowisko – Obszary wiejskie. Wyd. IMUZ Falenty, 145–148 (2003).

[6] Groffamn P.M., A.J. Gold, R.C. Simmons: *Nitrate dynamics in riparian forests: Microbial studies*, J. Environ. Qual., **21**, 666–671 (1992).

[7] Hermanowicz W., J. Dojlido, W. Dożańska, B. Kosiorowski, J. Zerbe: *Fizyczno-chemiczne badania wody i ścieków*, Wyd. Arkady, Warszawa (1999).

[8] Hotta N., N. Tanaka, S. Sawano, K. Kuraij, K. Shiraki, M. Suzuki: *Changes in groundwater level dynamics after low-impact forest harvesting in steep, small watersheds*, J. Hydrol. **385**, 120–131 (2010).

[9] Igras J., T. Jadczyszyn: *Zawartość azotanów i fosforanów w płytkich wodach gruntowych w Polsce*, Prob. Inż. Rol., **2**, 91–101 (2008).

[10] Jaszczyński J., S. Chrzanowski, A. Sapek: *Jakość wód gruntowych pod użytkami zielonymi różnie użytkowanymi*, Woda Środ. Obsz. Wiej., **6**, 2(18), 173–189 (2006).

[11] Johnson A.C., R.T. Edwards., R. Erhardt: *Ground-water response to forest harvest: implications for hillslope stability*, J. Am. Water Res. Ass., **43**, 134–147 (2007).

[12] Kluczyński B., A. Kreft: *Ilościowy oraz biologiczny stan starodrzewów sosnowych (Pinus sylvestris L.) w Słowińskim Parku Narodowym*, Parki Nar. Rez. Przyr., **22**, 2, 197–226 (2003).

[13] Kowalkowski A., M. Jóźwiak: *Chemizm wód gruntowych i powierzchniowych w mikrozlewni*, Świętokrzyski Park Narodowy: Przyroda, Gospodarka, Kultura, Bodzentyn- Kraków, 415–426 (2000).

[14] Macioszczyk A., D. Dobrzyński: *Hydrogeochemia*, wyd. PWN, Warszawa (2002).

[15] McLay C.D.A., R. Dragten, G. Sparling, N. Selvarajah: *Predicting groundwater nitrate concentrations in a region of mixed agricultural land use: a comparison of three approaches,* Environ. Poll., **115**: 191–204 (2001).

[16] Mazurek M., Z. Zwoliński: *Funkcjonowanie wybranych geoekosystemów Polski w świetle pomiarów monitoringowych w roku hydrologicznym 1999* (2000).

[17] Muñoz-Carpena R., A. Ritter, Y.C. Li: *Dynamic factor analysis of groundwater quality trends in an agricultural area adjacent to Everglades National Park,* Journal of Contaminant Hydrology, **80,** 49–70 (2005).

[18] Parzych A.: *Dynamika koncentracji związków azotu i fosforu w dwóch odmiennych ekosystemach leśnych Słowińskiego Parku Narodowego*, Akademia Pomorska (mscr.), Słupsk (2008).

[19] Parzych A., J. Trojanowski: *Biogenic substances versus the level of ground waters in chosen woodland ecosystems of Słowiński National Park*, Ann. Pol. Chem. Soc., 423–426 (2007).

[20] Pazdro O Z.: *Hydrologia ogólna*, wyd. geologiczne, Warszawa (1983).

[21] Pierzgalski E., A. Boczoń, J. Tyszka: *Zmienność opadów i położenia wód gruntowych w Białowieskim Parku Narodowym*, Kosmos, **51**, 4 (251), 415–425 (2002).

[22] Plan Ochrony Słowińskiego Parku Narodowego. *Operat Ochrony Ekosystemów Leśnych na lata 2002-2021, t. VIII, opis ogólny, t. 9/1, opis taksacyjny lasu – Obręb Lądowy Oddziały 1-63*, Jeleniogórskie Biuro Planowania i Projektowania (2003).

[23] Rauba M.: *Zawartość związków azotu i fosforu w wodach gruntowych zlewni użytkowanej rolniczo na*

przykładzie zlewni rzeki Śliny, Ochrona Środowiska i Zasobów Naturalnych, **40**, 505–512 (2009).

[24] Ritter A., R. Muñoz-Carpena, D.D. Bosch, B. Schaffer, T.L. Potter: *Agricultural land use and hydrology affect variability of shallow groundwater nitrate concentration in South Florida*, Hydrological Processes, **21**, 2464–2473 (2007).

[25] Rotnicki K., W. Borzyszkowska: *Przyspieszony wzrost poziomu morza i jego składowe na polskim wybrzeżu Bałtyku w latach 1951-1990*. W: Ewolucja geosystemów nadmorskich południowego Bałtyku, red. R.K. Borówka, Z. Młynarczyk, A. Wojciechowski, Wyd. Nauk. Bogucki, Poznań-Szczecin, 141–160 (1999).

[26] Rozemeijer J.C., H.P. Broers, F.C. Van Geer, M.F.P. Bierkens: *Weather-induced temporal variations in nitrate concentrations in shallow groundwater*, J. Hydrol., **378**:119–127 (2009).

[27] Sánchez-Pérez J.M., M. Trémoliéres, R. Carbiener: *Une station naturelle d'épuration des phosphates et des nitrates apportés par les eaux débordement du Rhin: la forêt alluviale à frêne et orme*, C.R. Acad. Sci. Paris **112**, 395–402 (1991).

[28] Sánchez-Pérez J.M., M. Trémolieres: *Groundwater nutrient levels in the Rhine forest ecosystems depending on the hydrological regime and the soil texture*, Glob. Ecol. Biogeographical Lett., **6**, 211–217 (1997).

[29] Sapek A., B. Sapek, S. Chrzanowski, P. Nadany, M. Urbaniak: *Wymywanie fosforanów z odwodnionych gleb torfowych po ich denaturalizacji – w świetle projektu „Prowater*", Rocz. Glebozn., **40**, 3, 173–183 (2004).

[30] Szymczyk S., J. Pawluczuk, A. Stepień: *Seasonal variability of mineral nitrogen in groundwater of hydrogenic soils*, J. Elemental., **15**(4): 713–723 (2010).

[31] Takatert N., J.M. Sánchez-Pérez, M. Trémolieres: *Spatial and temporal variations of nutrient level of groundwater under alluvial flooded forest: effect of hydrology, vegetation and substrate,* Hydrol Process, **13**: 1511–1526 (1999).

[32] Uggla H., Z. Uggla: Gleboznawstwo leśne, PWRiL, Warszawa (1979).

[33] Zawadzki S.: Gleboznawstwo, PWRiL, Warszawa (1999).

ZAWARTOŚĆ ZWIĄZKÓW AZOTU I FOSFORU W WODACH GRUNTOWYCH WYBRANYCH ZESPOŁÓW LEŚNYCH SŁOWIŃSKIEGO PARKU NARODOWEGO

Badania wód gruntowych prowadzono w dwóch różnych ekosystemach leśnych Słowińskiego Parku Narodowego: *Vaccinio uliginosi-Betuletum pubescentis* i *Empetro nigri-Pinetum* w latach 2002–2005. Stwierdzono różnice w położeniu lustra wód gruntowych oraz w koncentracji związków azotu i fosforu w badanych zespołach leśnych. W *Vaccinio uliginosi-Betuletum pubescentis* lustro wód gruntowych występowało średnio na głębokości -73,3 cm, a w *Empetro nigri-Pinetum* -90,2 cm. Nie stwierdzono istotnego statystycznie wpływu opadów atmosferycznych na położenie lustra wód gruntowych. Obliczenia statystyczne (test U Manna-Whitneya) dla wód gruntowych badanych zespołów leśnych wykazały istotne statystycznie różnice w dynamice koncentracji azotu ogólnego (T-N), azotu organicznego (Norg.), azotanowego (N-NO_3), fosforu ogólnego (T-P), fosforu organicznego (Porg.) oraz poziomu wód gruntowych.