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PROPERTIES OF FOREST SOILS UNDER *VACCINIO ULIGINOSI--BETULETUM PUBESCENTIS* AND *EMPETRO NIGRI-PINETUM* IN THE SLOVINSKI NATIONAL PARK

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Abstract

The study on properties of proper podzol soils was carried out in two different forest ecosystems: *Vaccinio uliginosi-Betuletum pubescentis* and *Empetro nigri-Pinetum* in the Slovinski National Park (17°15´E, 54°44´N). Analysed soils are acid and strongly acid, with soil pH decreasing with the depth of the genetic soil horizon. Average soil moisture content is significantly related with contents of organic matter and volumetric density. This is confirmed by means and high values of Spearman's correlation coefficient, amounting to $R=0.72$ ($p<0.05$, $n=50$) in the genetic profile of *Vaccinio uliginosi-Betuletum pubescentis* and $R=0.83$ ($p<0.05$, $n=50$) in the *Empetro nigri-Pinetum* oraz -0.42 ($p<0.05$, $n=50$, *Vaccinio uliginosi-Betuletum pubescentis*) and -0.73 ($p<0.05$, $n=50$, *Empetro nigri-Pinetum*). Maximum contents of nitrogen, phosphorus and carbon were observed in mineral peat soil of *Vaccinio uliginosi-Betuletum pubescentis* and in upper organic levels of the analysed soil profiles. This is a very important source of biogenic elements, especially for stands, providing a better supply of biogens for forest plants.

Key words: forest, soil, nitrogen, phosphorus, carbon, C:N, C:P, N:P

INTRODUCTION

Soils belong to a group of factors determining ecological identity of forest ecosystems. Studies on soils in National Parks, as protected areas, supplies an extensive body of basic information on the functioning of the entire natural environment in a given area (Klimowicz and Dębicki 2004). Forest ecosystems which developed on poor podzol soils have very limited resources of biogenic substances, accumulated mainly in organic and humus soil horizons.

Among biogenic compounds nitrogen and phosphorus are major factors determining fertility of forest soils. Most nitrogen, as much as 95-98%, is found in the form of organic compounds (Bielek 1998, Binkley and Högberg 1997), primarily incorporated into soil humus. In mineral soils its highest amounts are found in organic levels and its content decreases with the depth of the soil profile (Dobrzański and Zawadzki 1981). Organic nitrogen compounds are degraded and its final products are mineral forms of nitrogen (Brożek 1985). The process of their release in the soil is dependent on site conditions, particularly soil moisture content (Gotkiewicz 1983). They are crucial for nitrogen nutrients for plants (Binkley and Högberg 1997, Brożek 1986, Curtin and Wen 1999, Puchalski and Prusinkiewicz 1975). Nitrogen compounds in soil undergo changes – mineral nitrogen compounds are transformed into organic forms and vice versa (Dobrzański and Zawadzki 1981). These transformations are very dynamic (Czępińska-Kamińska et al. 1999), exhibiting seasonal variation.

Phosphorus, similarly as nitrogen, is found in soil in the form of both organic and inorganic compounds, mostly unavailable to plants (Ciereszko 2005). Its distribution in soil profiles depends first of all on the course of soil-forming processes (Brogowski and Okołowicz 1986, Cassagne et al. 2000, Konecka-Betley et al. 1985, 1999) and on the genesis of parent rock (Czępińska-Kamińska 1992). The organic pool accounts most typically for 30-50% of total phosphorus content in the soil. The biggest amounts of this form are found in organic and humus horizons, while the lowest content is recorded in the parent rock (Raczuk 1998, Sądej 2000). Only phosphorus in the form of ions, i.e. $H_2PO_4^-$ and HPO_4^{2-}, is directly available to plants (Ciereszko 2005, Puchalski and Prusinkiewicz 1975). The amount of phosphorus in soil changes depending on the structure and age of stands (Wachowska-Serwatka 1966). Availability of many elements essential to plants increases with an increase in the organic matter content (Potarzycki 2003, Stevenson 1985).

The aim of the study was to determine and compare selected physical and chemical properties, particularly concentrations of nitrogen and phosphorus in podzol soils of two different forest associations in the Slovinski National Park and to investigate the effect of precipitation and groundwater levels on the fluctuations in concentrations of N and P compounds.

MATERIALS AND METHODS

Study site

The studies were carried out in two different forest ecosystems in the Slovinski National Park (SNP), (Fig. 1). The vegetation of sample plot I belongs to the group of *Vaccinio uliginosi-Betuletum pubescentis* (*Vu-Bp*) with 60-years-old pines (*Pinus sylvestris* L.) and 47-years-old mossy birches (*Betula pubescens*) and it covers proper podzol on mineral peat soil (Ol-Ofh-AEes-Bhfe-C-Otni). The vegetation of sample plot II covering proper podzol (Ol-Ofh-AEes-Bhfe-C) belongs to the group of *Empetro nigri-Pinetum* (*En-P*) with a 140-years-old pine stand (*Pinus sylvestris* L.). Analysed forest associations are found within the range of a high and variable groundwater level (Table 1), which influences soil properties, particularly the dynamics of nitrogen and phosphorus compounds in selected forest ecosystems.

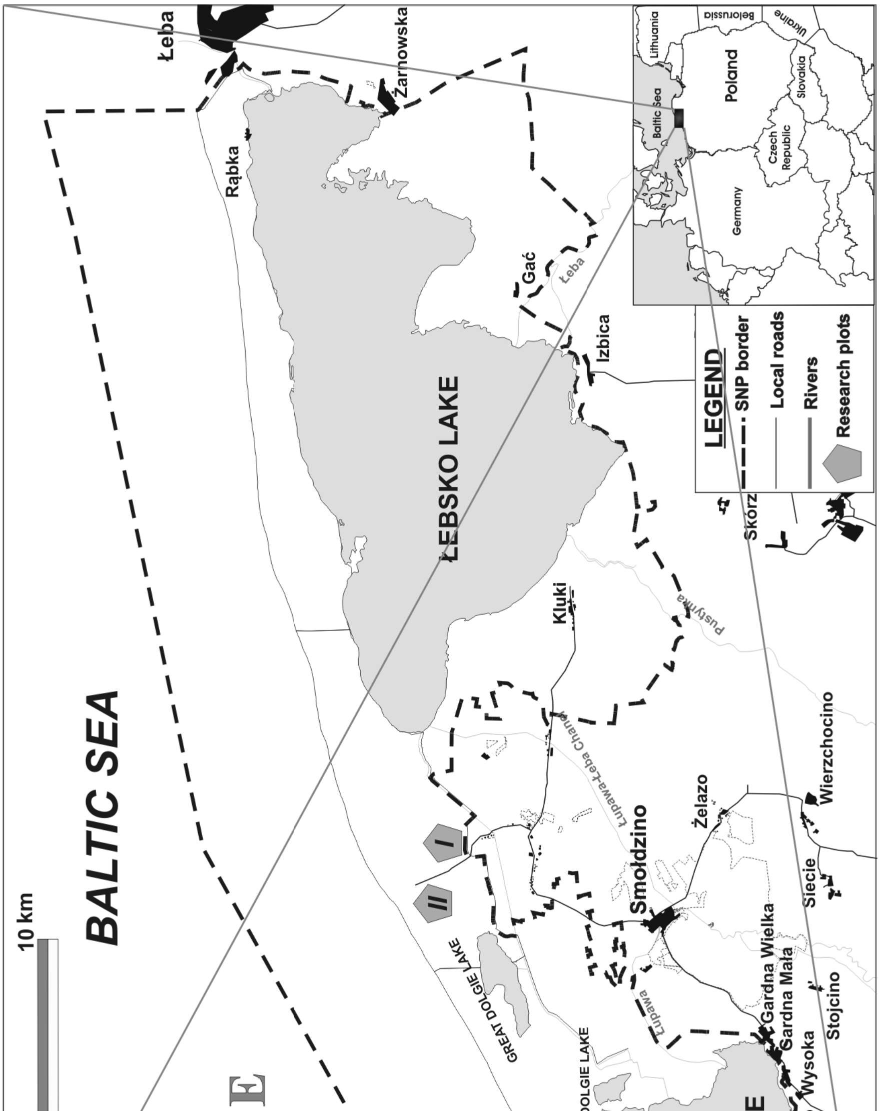

Fig. 1. Situation plan of the Slovinski National Park – locations of the study sites I – research plot I (*Vu-Bp*), II – research plot II (*En-P*)

Table 1

Precipitation and average underground water levels in the period of 2002-2005

		2002	2003	2004	2005	Mean
Precipitation [mm]		682	552	848	579	665
Average underground water 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)

(±) – standard deviation

Analytical methods

Analyses were conducted during four successive vegetation seasons in the years 2002-2005. Soil outcrop was prepared and described on each sample plot. Experimental material was collected from around a dozen randomly selected positions in each forest plot, and next they were combined, forming mixed samples. After pretreatment the following parameters were determined in soil samples according to the methodology described by Ostrowska et al. (1991) and Bednarek et al. (2005):

- pH in H_2O and in 1M KCl by potentiometry,
- actual moisture content by gravimetry,
- organic carbon using Tyurin's method,
- exchangeable aluminum (Al^{3+}) using Sokolov's methods,
- hydrolytic acidity (Hh) and sum of bases (S): (Ca^{2+}+Mg^{2+}+K^{+}+Na^{+}) by Kappen's methods, from which total breakthrough capacity (T) and the degree of base saturation (V) were calculated,
- total nitrogen (T-N) using the Kjedahl method and total phosphorus (T-P) by the molybdate method (after mineralization in a mixture of H_2SO_4 and H_2O_2).

Atmospheric conditions in 2002-2005

Precipitation was measured at the weather station at Gaci (in the SNP), while the groundwater level was recorded in water traps established in sample plots (*Vu-Bp* and *En-P*) on the dates of soil samples. Mean annual precipitation values and the position of the water table are given in Table 1.

Statistical methods

Statistical analysis of results included the calculation of standard deviation and Spearman's correlation coefficient (R) at the significance level $p=0.05$ between physical and chemical parameters of tested soil profiles, the amount of precipitation and groundwater levels as well as a comparison of the dynamics of total nitrogen and total phosphorus concentrations (T-N and T-P) in soils covered by *Vaccinio uliginosi-Betuletum pubescentis* and *Empetro nigri-Pinetum* in the years 2002-2005, using a non-parametric Mann-Whitney U-test.

RESULTS AND DISCUSSION

Physico-chemical properties

Tested soils had an acid and strongly acid reaction. The highest acidity was found for organic and humus horizons in both analysed forest plots, where pH values ranged from 4.18 to 4.87 (pH_{H2O}). Acidity of organic horizons covered by *Empetro nigri-Pinetum* was slightly higher (Table 2). Acidity decreased with depth, which was manifested by an increase in pH to 5.35 in the parent rock of *Vu-Bp* and to 5.64 in the parent rock horizon of *En-P*. Similar values of pH for forest soils, both in aquatic environment and in KCl solution, were recorded by Szołtyk and Walendziak (1998) as well as Czępińska-Kamińska et al. (1999). The value of soil pH is an indicator of nutrient availability, nitrification processes, the occurrence of toxic aluminum ions, and at the same time an indicator and factor in most biological and chemical processes (Kowalkowski 2002). However, the degree of soil acidification to pH=6 has an advantageous effect on availability of nitrogen and phosphorus by forest vegetation (Puchalski and Prusinkiewicz 1975). The concentration of Al^{3+} ions increases with an increase in soil acidity. Such a dependence was also observed by other researchers (Gworek et al. 2000). The highest concentration of aluminum ions was observed in organic horizons of both examined profiles, reaching slightly higher values in soil under pine coniferous forest (*En-P*), (Table 2).

High variation in the 4-years cycle of the study was observed for moisture content of genetic sol horizons, which is evidenced by the high values of coefficients of variation (CV, Table 2). Considerable moisture contents were recorded for Ofh horizons lying immediately below the ectohumus horizon, which is connected with the effect of precipitation (Parzych et al. 2008) and higher water capacity of soil. In lower sections of soil profiles moisture content increases with depth, due to an increased contact with groundwater (Parzych and Trojanowski 2007). Mean moisture content of soil is closely related with organic matter content and bulk density. This is evidenced by high and average values of Spearman's correlation coefficient, i.e. $R=0.72$ ($p<0.05$, $n=50$) in the *Vu-Bp* profile and $R=0.83$ ($p<0.05$, $n=50$) in the *En-P* profile, as well as -0.42 ($p<0.05$, $n=50$, *Vu-Bp*) and -0.73 ($p<0.05$, $n=50$, *En-P*), respectively.

The highest sorption capacity was found for organic horizons (32.44-28.55 me/100g) and humus-eluvial horizons (11.58-12.51 me/100 g) of the investigated soil profiles (Table 2). The capacity of these horizons to adsorb and exchange cations results in a situation when ectohumuses form a certain filter trapping many components released into the soil in a variety of ways (Pokojska 1992). A much lower sorption capacity is observed for mineral horizons. In case of the examined soil profiles values of sorption capacity decreased with depth, in parent rock amounting to 1.95 me/100 g (*Vu-Bp*) and 1.85 me/100 g (*En-P*). In the fossil soil horizon the total exchangeable ca-

Table 2

Average values of acidity, moisture content and sorption properties of analysed soils

Genetic soil horizon	pH H_2O	pH KCl	Moisture content [%] (CV)	S	Hh	T	V [%]	Al^{3+} [me/100g]
				[me/100 g]				
Soil under *Vaccinio uliginosi-Betuletum pubescentis*								
Ol	4.44	3.63	16.33 (39.88)	14.74	16.95	31.69	46.51	1.80
Ofh	4.62	3.83	23.06 (36.56)	11.15	17.40	28.55	39.05	1.90
AEes	4.87	4.02	4.73 (29.99)	2.20	10.31	12.51	17.58	0.63
Bhfe	5.17	4.42	4.32 (64.18)	2.00	2.40	4.40	45.45	0.54
C_1	5.37	4.63	10.60 (40.83)	1.15	1.35	2.50	46.00	0.28
C_2	5.35	4.66	18.40 (32.60)	1.05	0.90	1.95	53.85	0.12
Otni	5.34	4.69	36.72 (38.75)	41.40	7.43	48.83	84.79	0.10
Soil under *Empetro nigri-Pinetum*								
Ol	4.18	3.46	21.52 (32.99)	12.61	19.83	32.44	38.87	2.15
Ofh	4.19	3.37	32.31 (24.54)	9.20	22.65	31.65	29.07	2.10
AEes	4.80	4.03	5.74 (74.39)	6.55	5.03	11.58	56.59	0.26
Bhfe	5.19	4.34	6.07 (69.69)	1.20	1.50	2.70	44.44	0.17
C_1	5.41	4.66	9.65 (60.51)	1.05	1.16	2.21	47.45	0.10
C_2	5.77	4.85	13.36 (43.64)	0.95	0.90	1.85	51.35	0.09
C_3	5.64	4.96	17.26 (35.92)	0.40	0.75	1.15	34.78	0.09

Ol – fresh forest litter subhorizon, Ofh – detritus subhorizon, AEes – albic horizon with humic horizon feature, Bhfe – spodic horizon, C – mother rock, Otni – histic horizon of buried peat soil (Konecka-Bentley et al. 1999), CV – coefficient of variation [%], S – sum of bases according to Kappen: (Ca^{2+}+Mg^{2+}+K^{+}+Na^{+}), Hh – hydrolytic acidity according to Kappen, T – total breakthrough capacity, V – degree of base saturation pacity reaches the highest value (48.83 me/100 g). Analysed soils are also characterised by slight sums of base cations (S) in the sorption complex (Table 2). The highest amounts of base cations are found in the fossil soil horizon (41.40 me/100g) and in the organic horizons (9.20-14.74 me/100g), as well as humus-eluvial horizons (2.20-6.55 me/100g) of the analysed soil profiles, resulting from biological accumulation (Dziadowiec 1990, Pokojska 1992). Hydrolytic acidity (Hh) of analysed soils decreases with the depth of the profiles (Table 2). The highest acidity was observed in organic horizons of pine coniferous forest (*En-P*). As a result of the conducted analyses it was found that hydrolytic acidity depends on soil reaction and contents of organic compounds. The lower the pH value and the higher the humus content, the highest the value of hydrolytic acidity. This is confirmed by the highly significant values of Spearman's correlation coefficient, i.e., $R=-0.92$ (*Vu-Bp*) and $R=-0.93$ (*En-P*) for pH and Hh at $p<0.05$, $n=50$, and $R=0.78$ (*Vu-Bp*) and $R=0.98$ (*En-P*) for pH and organic matter content at $p<0.05$, $n=50$.

The degree of saturation with base cations (V), ($Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}$) is an important indicator of soil quality. In organic horizons under *Vu-Bp* it is on average by 25.9% higher than V of organic horizons under *En-P* (Table 2). The value of parameter V decreased in both sample plots with an increase in the degree of humification of organic residue accumulated in successive organic horizons (Ol, Ofh). Such a dependence was also observed in her studies by Pokojska (1992). In the *Vu-Bp* profile the degree of base saturation (V) decreased from the Ol to the AEes horizon, followed by a gradual increase in successive mineral horizons, reaching maximum saturation in the fossil soil horizon (84.79%). A slightly different situation was observed in the soil profile under *En-P,* maximum V was found in the AEes (56.59 %) and in the C horizons (51.35%). What is more, the higher the saturation of soil with exchangeable bases, the lower the proportion of H^{+} and Al^{3+} cations, and thus the lower the value of acidity.

Chemical properties

The highest concentrations of nitrogen, phosphorus and carbon compounds were recorded in the fossil soil horizon (Otni) under *Vaccinio uliginosi-Betuletum pubescentis* and in the upper organic horizons of both examined soil profiles (Table 3). Concentration of the above mentioned elements decreases gradually with the depth of the profiles, reaching the lowest values in the parent rock horizon.

Nitrogen content in upper organic horizons was slightly higher than 1% in both forest associations. Much lower amounts of nitrogen were found in mineral horizons. In case of *Vu-Bp* higher amounts of nitrogen were found than in respective mineral horizons under *En-P*. An over 2 times higher concentration of total nitrogen (T-N) was contained in the humus-eluvial horizon – AEes under *Vaccinio uliginosi-Betuletum pubescentis*. The biggest reserves of nitrogen, 69.26 t/ha (94%), were contained in fossil soil, while in the humus-eluvial layer they amounted to 1.01 t/ha under *Vaccinio uliginosi-Betuletum pubescentis.* In *Empetro nigri-Pinetum* the biggest nitrogen resources were accumulated in the detritus subhorizon, amounting to 0.92 t/ha. Much higher reserves of nitrogen in the soil profile of pine and birch forest than those of

Table 3

Selected chemical properties of analysed soils

Forest association	Genetic soil horizon	N [%]	P [%]	C [%]	C : N	N : P	C : P	Reserves [t/ha]		
								N	P	C
Vu-Bp	Ol	1.069(±158)	0.1130(±23)	27.60(±2.7)	25.8	9.5	244.2	0.43	0.045	11.04
	Ofh	1.011(±318)	0.1090(±24)	26.60(±3.1)	26.3	9.3	244.0	0.89	0.096	23.41
	AEes	0.064(±19)	0.0074(±2)	0.95(±1.8)	14.8	8.6	128.4	1.01	0.117	15.07
	Bhfe	0.021(±7)	0.0032(±0.7)	0.24(±0.4)	11.4	6.6	75.0	0.73	0.112	8.40
	C_1	0.016(±6)	0.0022(±0.5)	0.10(±0.0)	6.2	7.3	45.4	0.57	0.078	3.56
	C_2	0.026(±13)	0.0032(±0.7)	0.06(±0.0)	2.3	8.1	18.7	0.99	0.123	2.30
	Otni	2.849(±612)	0.2067(±50)	36.60(±4.2)	12.8	13.7	177.1	69.26	5.027	890.11
								Σ=73.88	Σ=5.598	Σ=953.89
En-P	Ol	1.071(±132)	0.1410(±21)	38.50(±2.9)	35.9	7.5	273.0	0.26	0.034	9.24
	Ofh	1.078(±251)	0.1370(±35)	39.60(±3.3)	36.7	7.9	289.1	0.92	0.116	33.66
	AEes	0.028(±12)	0.0031(±0.8)	0.63(±1.3)	22.5	9.0	203.2	0.45	0.049	10.09
	Bhfe	0.015(±4)	0.0017(±0.4)	0.23(±0.3)	15.3	8.8	135.3	0.44	0.050	6.83
	C_1	0.013(±4)	0.0018(±0.5)	0.10(±0.0)	7.1	7.7	55.6	0.36	0.050	2.81
	C_2	0.012(±3)	0.0019(±0.6)	0.06(±0.0)	5.0	6.3	31.6	0.42	0.066	2.09
	C_3	0.013(±3)	0.0019(±0.3)	0.02(±0.0)	1.5	6.8	10.5	0.60	0.088	0.93
								Σ=3.45	Σ=0.453	Σ=65.65

(±) – standard deviation

pine coniferous forest result in a much better condition of that stand, as it is manifested, among other things, by bigger tree heights.

Phosphorus is not uniformly distributed in soil profiles. The biggest concentration of phosphorus compounds, similarly as in case of nitrogen, was found in the fossil soil horizon (approx. 0.21%), (Table 3). Organic subhorizons under *Empetro nigri-Pinetum* contained on average by 25% more phosphorus compounds than the subhorizons of *Vaccinio uliginosi-Betuletum pubescentis*. Maximum phosphorus reserves are accumulated in the fossil soil horizon (approx. 5 t/ha), while considerable amounts are found in the organic and humus-eluvial horizons of both soil profiles (0.034-0.116 t/ha).

Organic matter is accumulated mainly in organic and humus horizons (Table 3). Much bigger amounts of organic carbon were recorded in organic horizons under *Empetro nigri-Pinetum,* in the ectohumus subhorizon, being on average by 40%, and in the detritus subhorizon being on average by 48% higher than in the respective horizons under *Vaccinio uliginosi-Betuletum pubescentis*. According to Czępińska-Kamińska et al. (1999), carbon content in organic horizons of forest soils ranges most typically from 25.9 to 36.0%, while in humus horizons it is from 0.75 to 2.11%. Carbon content decreases with the depth of analysed soil profiles. In humus-eluvial horizons it takes values from 0.95% in case of *Vaccinio uliginosi-Betuletum pubescentis* to 0.63% for *Empetro nigri-Pinetum.* The lowest carbon content was found in parent rock of both examined soil profiles (0.02-0.06%).

The biggest reserves of organic carbon are accumulated in fossil soil (890.11 t/ha) and in upper organic horizons (34.45 t/ha) of *Vaccinio uliginosi-Betuletum pubescentis* as well as organic horizons (42.90 t/ha) of *Empetro nigri-Pinetum* (Table 3). Carbon resources accumulated in the Ol and Ofh horizons of pine coniferous forest were by 20% bigger than those in pine and birch forest. A higher accumulation of carbon in case of *Empetro nigri-Pinetum* than in *Vaccinio uliginosi-Betuletum pubescentis* may be the consequence of slower processes of organic matter mineralisation or it may result from the presence of a much older stand. Investigations by Dovydenko (2004) confirmed that carbon content in soil increases with the age of a stand. According to Zwoliński (1998), the organic layer of pine coniferous forests (50- to 60-years old) contains most frequently 42 t/ha carbon and in older stands the content remains similar (almost constant). The presence of fossil soil in the soil profile under *Vaccinio uliginosi-Betuletum pubescentis* has a differentiating effect on resources of nitrogen, phosphorus and carbon in analysed soils.

The C:N ratio decreases with the depth of soil profiles. In the Ofh subhorizons it was observed to increase slightly, which may have been caused by the rapid depletion of nitrogen from the ectohumus horizon. The value of the C:N ratio in organic and humus-eluvial subhorizons distinctly differentiates analysed soils (Table 3). The lower it is, the more fertile a given forest soil is. A much wider C:N ratio was found in the organic subhorizons under *Empetro nigri-Pinetum*, which may have resulted from much slower processes of mineralisation and humification of organic matter (Wachowska-Serwatka 1966), as well as a varied chemical composition of plant debris. According to Raczuk (Van der Welle et al. 2003), slowing down of humification in podzol soils may result in a strongly acid reaction of surface genetic horizons. Studies by Enwezor (1976) and by Paul and Clark (1989) confirmed that mineralisation of organic nitrogen increases with a reduction of the C:N ratio. When this ratio is too wide (over 32:1), mineralisation of organic matter is slowed down and available nitrogen is absorbed by microorganisms. When this ratio is narrower, mineralisation of nitrogen, which is not used by plants, is intensified (Thompson et Troeh 1978). Results recorded in this study are also confirmed by the findings reported by Królikowski (1935). Values of C:N ratios in organic horizons are generally higher in more acid soils under coniferous stands (such as *Empetro nigri-Pinetum*) than in soils under mixed stands (such as *Vaccinio uliginosi-Betuletum pubescentis*). The C:N ratio in the O horizon under oligotrophic coniferous forest vegetation most frequently ranges from 25 to 40 (Zawadzki 1999).

In case of the N:P ratio the situation is different. It was found to be much wider in the organic subhorizons under *Vu-Bp*, which may be a consequence of a lower content of phosphorus in those subhorizons. This ratio decreases slightly with the depth of soil profiles, with the lowest value being recorded in the Bhfe horizon of *Vaccinio uliginosi-Betuletum pubescentis* and in the parent rock horizon under *Empetro nigri-Pinetum.* In turn, it is widest in the fossil soil horizon, in which it amounts to 13.7. The N:P ratio in soil under *Vu-Bp* exhibits a strong, positive correlation ($R=0.85$, $p<0.05$, $n=50$) with the concentration of organic matter in this profile, which was not observed in the soil profile of pine coniferous forest. In turn, the N:P ratio in case of *Empetro nigri-Pinetum* exhibits an average, negative correlation with pH ($R=-0.49$, $p<0.05$), which was not found in the profile of pine and birch forest. The existence of the above relationships differentiates analysed soil profiles. Significant dependencies between the N:P ratio and the concentration of organic matter and pH were observed in soil analyses also by Van der Welle et al. (2003).

The ratio of carbon to phosphorus is another important indicator of the trophic condition of soil. In the investigated soils it decreased with the depth of the profiles, reaching the widest values in the organic, humus and eluvial horizons as well as the

Table 4

Significant differences in nitrogen and phosphorus contents in organic horizons, albic horizons and spodic horizons under *Vu-Bp* and *En-P* in 2002-2005 according to U Mann-Whitney test's

Compound	Genetic soil horizon	Significance of differences
T-N	O (Ol+Ofh)	b.r.
	AEes	***
	Bhfe	**
T-P	O (Ol+Ofh)	***
	AEes	***
	Bhfe	***

Differences significant at: *** $p<0.001$, ** $p<0.01$, b.r. – non-significant differences, $n=50$

fossil soil horizon (Table 3). The value of the C:P ratio changed from 244.2 to 18.7 in *Vu-Bp* and from 289.1 to 10.5 in *En-P*. According to Fuller et al. (1956), the most intensive processes of phosphorus mineralisation occur in the genetic soil horizons at $C:P<200$. At $C:P>300$ phosphorus may be immobilised. Thus it may be assumed that the most intensive mineralisation of phosphorus occurs in the humus-eluvial horizons (AEes), since the C:P ratio was 128.4 (*Vaccinio uliginosi-Betuletum pubescentis*) and 203.2 (*Empetro nigri-Pinetum*). The lowest ratio of carbon to phosphorus was found in the parent rock horizon.
The Mann-Whitney U-test was applied in order to compare the dynamics of fluctuations in the concentrations of total nitrogen and phosphorus in analysed soil profiles in the years 2002-2005 (Table 4). Only the upper sections of soil profiles were compared due to the fact that the biggest concentration of plant roots was found in this horizon. Statistical analyses for the investigated forest associations showed statistically significant differences in the dynamics of total nitrogen (T-N) in the mineral horizons (AEes and Bhfe) and in the dynamics of total phosphorus (T-P) in the compared genetic soil horizons. In turn, no statistically significant differences were found in the dynamics of total nitrogen (T-N) in the organic horizons.

The effect of precipitation and groundwater on nitrogen and phosphorus contents in genetic soil horizons

The changing level of groundwater had a considerable effect on the fluctuations of concentrations of total nitrogen and phosphorus in the analysed soils (Table 1). This was evidenced by the significant values of Spearman's coefficients of correlation (Table 5). An increase in the groundwater level contributed to an increase in the concentration of nitrogen and phosphorus to the biggest extent in case of *Vaccinio uliginosi-Betuletum pubescentis* as a result of leaching of the above mentioned biogens from the fossil soil ($R=0.61$ and $R=0.67$, respectively, $p<0.05$, $n=50$). A slightly

Table 5
Spearman's correlation coefficients ($p<0.05$) between precipitation, groundwater levels and contents of total nitrogen and phosphorus in soil profiles under *Vu-Bp* and *En-P* in 2002-2005

		En-P (n=50, $r_{crit}<0.235$)			
		precipitation	u.w.l	T-N	T-P
Vu-Bp (n=50, $r_{crit}<0.235$)	precipitation	-	0.16	0.01	-0.23
	u.w.l.	0.21	-	**0.36**	**0.47**
	T-N	-0.05	**0.61**	-	**0.66**
	T-P	-0.09	**0.67**	**0.65**	-

u.w.l. – underground water level [cm], critical values of Spearman's correlation coefficient referred to Ramsey (1989) weaker effect of groundwater level was found in case of N and P concentrations in soil under *Empetro nigri-Pinetum* ($R=0.36$ and 0.47, $p<0.05$, $n=50$). Moreover, highly significant, positive dependencies were stated between concentrations of nitrogen and phosphorus in the soil profiles under *Vu-Bp* and *En-P*. Precipitation did not have a significant effect on the fluctuations in N and P contents in the compared profiles of podzol soils (Table 5). It modified significantly only moisture content in the surface of genetic soil horizons, showing no significant relationship with groundwater level. This is probably a consequence of great water requirement of plants.

CONCLUSIONS

Analysed podzol soils, formed on dunes, are characterised by an acid and strongly acid reaction, which decreases with the depth of soil profiles. A slightly higher acidity and content of available aluminum Al^{3+} were recorded in the organic horizons of pine coniferous forest (*Empetro nigri-Pinetum*). We need to stress here a higher amount of organic matter in the organic subhorizons of *Empetro nigri-Pinetum* than those in the respective subhorizons of *Vaccinio uliginosi-Betuletum pubescentis*.

Mean soil moisture content is closely related with the organic matter content and bulk density. An increase was observed in soil moisture content with an increase in the organic matter content and a decrease in bulk density. This is evidenced by the statistically significant Spearman's correlation coefficients. Actual moisture content in soil profiles varied in the analysed vegetation seasons, which is related with precipitation and changing groundwater levels. Much bigger resources of soil water available to plants were accumulated in the soil profile under *Vu-Bp.*

Nitrogen concentration in the upper organic horizons of both analysed forest ecosystems is comparable. In case of phosphorus the content of this biogen in the organic horizon of pine coniferous forest (*En-P*) was by 25% higher than the organic horizon of pine and birch forest (*Vu-Bp*).

Fluctuations in the concentrations of total nitrogen and phosphorus in the analysed soil profiles were significantly affected by groundwater levels. Precipitation modified only moisture content in surface genetic soil horizons, showing no significant relationship with groundwater level and having no significant effect on N and P content in the compared profiles of podzol soils.

The presence of fossil soil in the soil profile under *Vaccinio uliginosi-Betuletum pubescentis* to a considerable extent differentiates analysed soils. Huge amounts of organic matter accumulated in fossil soil, lying at a depth of approx. 1 m, constitute an important source of biogenic elements, particularly for the stand and vegetation with an extensive root system. Much higher resources of nitrogen and phosphorus in the soil profile of pine and birch forest (*Vu-Bp*) than those of pine coniferous forest (*En-P*) definitely contribute to a much better supply of vegetation in the analysed biogens.

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WŁAŚCIWOŚCI GLEB LEŚNYCH POD *VACCINIO ULIGINOSI-BETULETUM PUBESCENTIS* I *EMPETRO NIGRI-PINETUM* SŁOWIŃSKIEGO PARKU NARODOWEGO

Streszczenie

Badania właściwości gleb bielicowych prowadzono w dwóch różnych ekosystemach leśnych: *Vaccinio uliginosi-Betuletum pubescentis* i *Empetro nigri-Pinetum* w Słowińskim Parku Narodowym (17^{o}15´E, 54^{o}44´N). Badane gleby wykazują odczyn kwaśny i silnie kwaśny, który maleje wraz z głębokością profilu glebowego. Średnia wilgotność gleby pozostaje w ścisłym związku z zawartością materii organicznej oraz gęstością objętościową. Dowodem tego są wysokie i przeciętne wartości współczynników korelacji Spearmana, odpowiednio $R=0,72$ ($p<0,05$, $n=50$) w profilu *Vaccinio uliginosi-Betuletum pubescentis* i $R=0,83$ ($p<0,05$, $n=50$) w profilu *Empetro nigri-Pinetum* oraz -0,42 ($p<0,05$, $n=50$, *Vu-Bp*) i -0,73 ($p<0,05$, $n=50$, *En-P*). Największą koncentrację związków azotu, fosforu i węgla stwierdzono w poziomie gleby kopalnej (Otni) *Vaccinio uliginosi-Betuletum pubescentis* oraz w górnych poziomach organicznych obu badanych profili glebowych. Jest to ważne źródło pierwiastków biogenicznych dla drzewostanu i roślinności runa z rozbudowanym systemem korzeniowym.