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VARIABILITY OF NITROGEN AND PHOSPHORUS CONCENTRATION AND THE NET PRIMARY PRODUCTION OF *VACCINIUM VITIS-IDAEA* L. AND *VACCINIUM MYRTILLUS* L. IN CHOSEN WOODLAND ECOSYSTEMS OF THE SŁOWIŃSKI NATIONAL PARK

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COMMUNICATION

Keywords: Nitrogen, phosphorus, N:P, C:N, C:P, net primary production, bilberry, crowberry.

Abstract: *Vaccinio uliginosi-Betuletum pubescentis* and *Empetro nigri-Pinetum* are characteristic of their diverse frequency and density *Vaccinium vitis-idaea* L. and *Vaccinium myrtillus* L. on the forest floor. The examined berry under-shrubs show differences in content of nitrogen and phosphorous compounds and the volume of the over-ground net primary production. An average content of the examined biogenes in leaves of the bilberry (*Vaccinium myrtillus*) within the area of the Słowiński National Park was 1.311% N, 0.102% P and 40.8% C in *Vaccinio uliginosi-Betuletum pubescentis* and 1.159% N, 0.095% P and 38.7% C in *Empetro nigri-Pinetum*. Red bilberry leaves are thought to contain nitrogen, phosphorus and carbon in such propotions: 1.083% N, 0.097% P and 44.70% C in *Vaccinio uliginosi-Betuletum pubescentis* and 0.868% N, 0.085% P and 44.70% C in *Empetro nigri-Pinetum*. The variable concentration of nitrogen and phosphorus in sprouts of the examined species of berries shows a positive correlation of those elements. The over-ground net primary production of *Vaccinium myrtillus* is 534.905 kg/ha in *Vaccinio uliginosi-Betuletum pubescentis* and 216.594 kg/ha within the coastal crowberry coniferous forest. *Vaccinium vitis-idaea* in *Empetro nigri-Pinetum* reaches 155.283 kg/ha of over-ground net primary production and only 113.220 kg/ha in *Vaccinio uliginosi-Betuletum pubescentis*.

INTRODUCTION

Nitrogen and phosphorus belong to more important elements among nutrients on which the growth of plants depends in the forest ecosystems [6, 9, 13, 20, 52]. Seasonal variability of the environment and variability of plants requirements during their life span decide on dynamic character of the plant – environment relations. Intake of most elements by plants is a metabolically regulated process [8, 42] and their concentration is connected with the processes of growth and aging occurring in them [28, 34]. The humus of forest soils constitutes a source of nutritional (biogenic) elements for plants [12, 28, 39].

Many factors, such as air and soil humidity, availability of nutrients [17] rainfall as well as character of vegetation have impact on concentration of mineral components in plants. Scarcity of soil humidity strongly enhances the nitrogen content in leaves, and with increasing soil humidity, the content of nitrogen and phosphorus usually decreases [54]. Intake of ammonium, nitrate and phosphorous ions by plants is differentiated during a vegetation season, and their rise strictly dependent on biomass, is a result of a photosynthesis and assimilation of NH_4^+ and NO_3^- ions from the subsoil [45]. The volume of chemical components in leaves of bilberry (*Vaccinium myrtillus* L.), as in the red bilberry (*Vaccinium vitis-idaea* L.), is connected with phenological stages of plants development [20]. The status of mineral nutrition of plants depends not only on concentration of particular mineral components, but also on mutual balance between them [5]. Analysis of quantitative proportions between individual elements both in the soil and in the plants, can be the evidence, among others, of the status of their nutrition [7], regularity of the course of physiological processes in a plant [34] and indirectly, of its health status [47]. Changeable environmental conditions disable maintenance of optimum C:N proportion in plants. Plants use a big volume of nutritional ingredients included in the soil. Availability of these components is a main factor which controls biomass production and stability of ecosystems [48]. Increase of biomass production depends especially on the fecundity of forest community [49], the structure of the undercover, the role of a given species in the ecosystem [30], and rapidity of biogenes in soil and plant tissues [8]. In the undercover of pinewoods and mixed woods, the bilberry is a dominant species. In *Vaccinio myrtilli-Pinetum*, it reaches ecological optimum, which is the biggest frequency, density, biomass, production and intake surface of the leaves [30]. Nearly in all forest communities *Vaccinium myrtillus* returns large volumes of potassium, calcium, magnesium, manganese and iron to soil surface along with fallen leaves, which enriches the habitat with elements vital for adequate functioning of forest ecosystems. *Vaccinium vitis-idaea* populations, in comparison to other species of the kind, are characteristic of the highest phenological diversity [15] and only in some complexes they undergo annual, full developmental cycle. *Vaccinium vitis-idaea* most often appears in fresh coniferous forest (*Vaccinio myrtilli-Pinetum*), and the highest coverage ratio is reached in the coastal crowberry coniferous forest (*Empetro nigri-Pinetum*) [23].

The objectives of this paper are:

1. systematic measurement of concentration of nitrogen and phosphorous compounds (inorganic and total form) in leaves, stems and fruit of *Vaccinium myrtillus* and *Vaccinium vitis-idaea* in two different forest ecosystems of the Słowiński National Park in the period of 2002–2005,
2. comparison of variability concentration of N and P in the shoots of bilberry and cowberry in researched forest ecosystems,
3. comparison of their frequency, density and the volume of over-ground net primary production.

MATERIAL AND METHODS

Sampling sites

The research was held at the Słowiński National Park situated in northern Poland, in a region affected by the Baltic Sea. The research areas are situated 1.5 km from the coastal

line of the Baltic Sea, along the road running from the Smołdziński Forest to Czołpino, at a distance of 600 m one from the other. Location of the sampling sites and their surroundings with more detailed characteristics in presented in Figure 1.

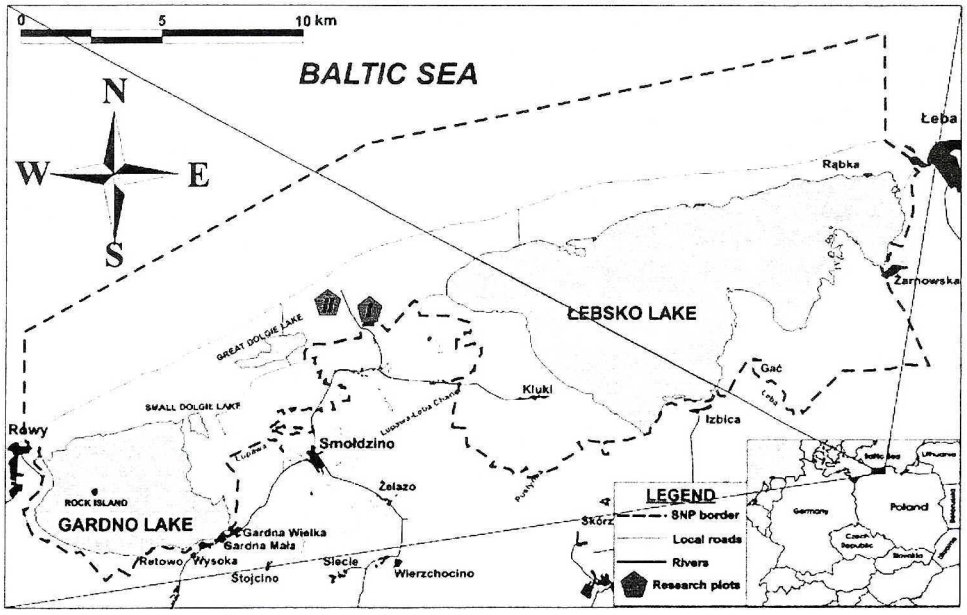

Fig. 1. Situation plan of the Słowiński National Park; locations of the study sites: I – research plot I (*Vu-Bp*), II – research plot II (*En-P*)

The research was held in two separate forest complexes of SNP: *Vaccinio uliginosi-Betuletum pubescentis,* Libbert 1933 and in *Empetro nigri-Pinetum*, (Libb. et Siss. 1939 n.n.) Wojt. 1964. *Vaccinio uliginosi-Betuletum pubescentis* (*Vu-Bp*) covers the Podzol Soil developed on the fossil peat soil, and *Empetro nigri-Pinetum* (*En-P*) covers poor barren Podzol Soil. The forest stand of the examined forest areas is diverse as to species and age. *Vu-B*p is a loose pine and birch forest stand of 18–19 m in height. Contribution of the 60 year old common pine (*Pinus sylvestris* L.) to the forest stand is 25% (128 trees), and the 47 year old downy birch (*Betula pubescens*) 75% (392 trees). *En-P* with 715 trees is covered by a 140 the year old pine forest stand (*Pinus sylvestris* L.) with low (7 m) distorted canopies and inclined trunks [38, 40]. The *Vu-Bp* of forest stands is of natural origin, the *En-P* formation is the result of artificial afforestation. Choosing the researched plots the first were taken into consideration the natural resources among them the situation the level of ground water.

Sampling and analytical procedure

Measurement of frequency, density, biomass and net primary production (NPP) of the over-ground part of the *Vaccinium vitis-idaea* and *Vaccinium myrtillus* under-shrubs was performed in July and August 2005 applying the Traczyk's method [51]. In the years 2002–2005, systematic measurement of concentration of nitrogen and phosphorous compounds in leaves, stems and berry fruit was performed. The plant samples were taken

from several sites of each research area; then, they were combined, taking into consideration the species diversity. Plant samples were taken several times during four vegetation seasons (2002–2005). After having transported them to the laboratory, the plant material was cleaned of the mineral particles of the soil, separated into individual species, leaves were separated from stems and fruit. After initial preparation, the plants were dried to a solid mass at the temperature of 65°C, which was then homogenized in a mill. T-N was determined by Kjedhal's method after mineralization in the mixture of H_2SO_4 and H_2O_2 [11]. Organic carbon was determined by Alten's method. N-NH_4^+ and N-NO_3^- were determined spectrophotometricaly (UV-VIS 1202, Shimadzu, Japan) with Nessler's reagent and sodium salicylate, respectively. Both T-P and P-PO_4^{3-} were determined spectrophotometricaly according to molybdate method with ascorbic acid as reducing agent (T-P after mineralization in the mixture of H_2SO_4 and H_2O_2). Both inorganic nitrogen and phosphorus were determined after extraction with 1% K_2SO_4 [33]. The limit of detection and quantification of the method depend on the purity of the reagents used. In the case of spectrophotometric determinations the calibration solutions were prepared basing on Merck standards with the nominal PO_4^{3-}, NO_3^- and NH_4^+ concentrations as follows: 1002 ± 5 mg/dm^3, 1004 ± 2 mg/dm^3 and 1001 ± 2 mg/dm^3. The limit of quantification for PO_4^{3-}, NO_3^- and NH_4^+ was 0.01 mg/dm^3, 0.02 mg/dm^3 and 0.005 mg/dm^3, respectively. The QA/QC ratio was carried out by analyzing field samples fortified with the analytes of interest. The repeatability of methodology calculated according to the formulas presented by Konieczka *et al.* [26] reached RSD(PO_4^{3-}) = 1.4%, RSD(NO_3^-) = 1.6%, RSD(NH_4^+) = 1.4%, RSD(T-N) = 2.1% and RSD(T-P) = 1.8%.

Other variables (soil-related)

In order to assess possible relation between trophic state of investigated habitats and soil properties focused on total nitrogen and phosphorus abundance in the *Vaccinio uliginosi-Betuletum pubescentis* and *Empetro nigri-Pinetum* were investigated as well (Tab. 1). Among possible soil layers only rooting zones rich in nutrients (AEes in *Vu-Bp* and *En-P*) were evaluated in this study.

Table 1. Characteristic of soil properties in the *Vaccinio uliginosi-Betuletum pubescentis* and *Empetro nigri-Pinetum* in 2002–2005 [34]

	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
N [%]	1.06	0.06	0.02	0.03	2.85	1.07	0.03	0.02	0.01
P [%]	0.111	0.007	0.003	0.002	0.206	0.139	0.003	0.002	0.002
C [%]	27.1	0.95	0.24	0.08	36.6	39.1	0.63	0.23	0.006

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 [25]

RESULTS AND DISCUSSION

The examined forest ecosystems of SNP are characteristic of uneven distribution of examined species of berries on the forest floor. The under-shrubs of bilberry (*Vaccinium*

myrtillus) have the highest frequency (43%) in the marshy birch wood (*Vu-Bp*), reaching a density of 52.7 sprouts per 1 m^2 and the highest individual increase of 1.015 g (Tab. 2). The net primary production (NPP) of *Vaccinium myrtillus* under-shrubs in *Vu-Bp* constituted as much as 534.905 kg/ha (48.68% of the whole production of the ground cover). *Vaccinium myrtillus* is characteristic of a slightly lower participation in the crowberry coniferous forest (*En-P*), in which it reaches the frequency of 23%, which constitutes 37.8 sprouts per 1 m^2. In this complex, it reaches significantly lower individual increase (0.573 g), net primary production (216.594 kg/ha), having only 19.21% participation in the over-ground production of the ground cover. The under-shrubs of the red bilberry (*Vaccinium vitis-idaea*) have slightly different distribution of frequency in the coastal crowberry coniferous forest (*En-P*), reaching the frequency of 54% and density of 57.3 sprouts per 1 m^2. The high frequency does not reflect the size of individual increase. *Vaccinium vitis-idaea* in the pine coniferous forest complex (*En-P*) reaches only 0.271 g of average increase and 155.283 kg/ha of net primary production, which constitutes 19.21% of the over-ground production of the ground cover. The research results confirm a thesis that *Vaccinium vitis-idaea* has the highest cover ratio in the coastal crowberry coniferous forest (*Empetro nigri-Pinetum*), [23]. The under-shrubs of the red bilberry are characteristic of a visibly lower frequency in the complex of marshy birch coniferous forest (*Vu-Bp*). Their frequency is maintained at the level of 32%, which constitutes 30.6 sprouts per 1 m^2. Much better development conditions in *Vaccinio uliginosi-Betuletum pubescentis* make that species reach much higher individual increase (0.370 g) than in *Empetro nigri-Pinetum*. The total net primary production (113.220 kg/ha) is, however, lower than in a pine coniferous forest (*En-P*) due to the lower frequency and density of that species (Tab. 2). The plants of the layer of the ground cover of the pine coniferous forest (*En-P*) reached density of 232.2 sprouts per 1 m^2 of the surface area [35], which is characteristic of dry pine forests [3].

Table 2. Frequency, density of the plants and net productivity *Vaccinium myrtillus* and *Vaccinium vitis-idaea*

Forest association	Species	Frequency [%]	Density of the plants, D		Number of shoot	Average individual growth [Gi], [g]	Net productivity	
			on [m^2]	[%]			[kg/ha]	[%]
Vu-Bp	*Vaccinium myrtillus*	43	52.7	37.24	527	1.015	534.905	48.68
	Vaccinium vitis-idaea	32	30.6	21.63	306	0.370	113.220	10.39
En-P	*Vaccinium myrtillus*	23	37.8	16.3	378	0.573	216.594	26.70
	Vaccinium vitis-idaea	54	57.3	24.5	573	0.271	155.283	19.21

The trophic status [16], weather conditions and density as well as frequency of the berry species have big impact on the production yield of the forest ground cover. Relatively low rainfall (579 mm) was a negative factor, which had substantial impact on the limitation of production of ground cover of the examined ecosystems. Substantial lowering of the level of underground water during the vegetation season of 2005 had negative impact on the development and growth of plant cover at SNP, and in consequence on

productivity of berries [37]. The level of underground waters during intensive period of growth of the plants (from June to September) remained on average at the level of -91.3 cm in *Vaccinio uliginosi-Betuletum pubescentis* and -112.7 cm in *Empetro nigri-Pinetum*, therefore being inaccessible for the examined under-shrubs under consideration [35].

According to the research done by Kimsa [23], *Vaccinium vitis-idaea* reaches the highest production of biomass in a mixed forest *Pino Quercetum* (2151.6 kg/ha), and the lowest in *TC* (0.2 kg/ha). The research done by Gerdol [18] indicates that NPP *Vaccinium myrtillus* in *Hyperico richeri-Vaccinietum* remains at the level of 2670 kg/ha and 70 kg/ha in *Empetrum Vaccinietum*. The volume of over-ground net primary production of *Vaccinium vitis-idaea* and *Vaccinium myrtillus* under-shrubs reflects, among others, average volume of ions absorbable by the plants [1].

An average content of examined biogenes in the leaves of bilberry (*Vaccinium myrtillus*) at the area of the SNP was 1.311% N, 0.102% P and 40.8% C in *Vaccinio uliginosi-Betuletum pubescentis* (Tab. 3) and 1.159% N, 0.095% P and 38.7% C in *Empetro nigri-Pinetum*. Higher concentration of N was found in the leaves, and that of P in stems of *Vaccinium myrtillus* in both examined forest complexes. Bilberry stored in its stem on average 1.023% N and 0.112% P in *Vu-Bp* and 0.914% N and 0.114% P in *En-P*. An average nitrogen content in both species of the examined berries was substantially higher in *Vu-Bp* than in *En-P* (Tab. 3), while average content of phosphorus and carbon showed much smaller difference. Higher concentration of the above mentioned biogenes in the berries of the complex of *Vaccinio uliginosi-Betuletum pubescentis* is the result of much higher content of the above mentioned elements at top genetic levels of such soils (Tab. 1) [35]. It confirms that the regularity of biogenes layout in plant tissues is closely dependent on the soil richness. [32, 41]. In both forest complexes, the content of nitrogen was the highest in the leaves of both species of berries (Tab. 3), and the lowest in stems in the case of red bilberry, and in the fruits in the case of bilberry. Such distinctive relations were not found as to the content of phosphorus. Only in the case of bilberry in both forest complexes, its highest content was found in the stems, and the lowest in the fruits thereof. The stems of the red bilberry contained the lowest volume of phosphorous compounds. A slightly higher concentration of nitrogen (1.75–2.01% N) and phosphorus (0.096–0.153%

Table 3. The selected chemical properties in *Vaccinium vitis-idaea* and *Vaccinium myrtillus* (2002–2005), calculated in dry mass

Forest association	Species		N [%]	P [%]	C [%]	C:N	C:P	N:P
Vu-Bp	Vaccinium vitis-idaea	leaves	1.083	0.097	44.70	41.27	460.82	11.16
		stem	0.870	0.083	42.40	48.74	510.84	10.48
		fruit	0.997	0.113	–	–	–	8.82
	Vaccinium myrtillus	leaves	1.311	0.102	40.80	31.12	400.00	12.85
		stem	1.023	0.112	44.40	43.40	396.43	9.13
		fruit	0.920	0.076	–	–	–	12.10
En-P	*Vaccinium vitis-idaea*	leaves	0.868	0.085	44.70	51.49	525.88	10.21
		stem	0.734	0.077	40.20	54.77	522.08	9.53
		fruit	0.887	0.078	–	–	–	11.37
	Vaccinium myrtillus	leaves	1.159	0.095	38.70	33.39	407.37	12.20
		stem	0.914	0.114	43.00	47.04	377.19	8.02
		fruit	0.914	0.082	–	–	–	11.15

P) in leaves of *Vaccinium myrtillus* was found by Gerdol [18] during research held in Italy than in the forest complexes of SNP. The plant growth is limited especially by concentration of nitrogen and phosphorus in the soil [9, 21, 35].

Concentration of nitrogen and phosphorus in leaves of the red bilberry (*Vaccinium vitis-idaea*) remained on average at the level of 1.083% N and 0.097% P in *Vaccinio uliginosi-Betuletum pubescentis* and 0.868% N and 0.085% P in *Empetro nigri-Pinetum*. An average concentration of examined biogenes in stems of the red bilberry was lower and remained at the level of 0.870% N and 0.083% P in *Vu-Bp* and 0.734% N and 0.077% P in *En-P* (Tab. 3). Concentration of nitrogen and phosphorus in fruits of the examined berries was higher in *Vu-Bp* complex than in *En-P*. In *Vaccinio uliginosi-Betuletum pubescentis* higher volumes of biogenes were found in *Vaccinium vitis-idaea*, and in *Empetro nigri-Pinetum* in *Vaccinium myrtillus*. The *Vaccinium vitis-idaea* under-shrubs showed slightly higher concentration of carbon in leaves (44.7% C) than in stem (40.2–42.4% C) in both examined forest complexes. The reverse situation was observed in the case of bilberry. Higher concentration of C as well as P in stems than in leaves both in *Vaccinio uliginosi-Betuletum pubescentis* and in *Empetro nigri-Pinetum* (Tab. 3) can be the result of the economic management of such biogenes. It protects the shrubs of the bilberry against the loss of such elements during the period of autumn leaves shedding. Such situation most frequently takes place in poor habitats such as pine coniferous forests.

The dynamics of concentration of N and P in sprouts of the examined berries shows positive correlation of those elements (Figs 2 and 3). The graphs below indicate, that variations of nitrogen and phosphorus during the four examined vegetation seasons are vitally interrelated, which can be confirmed by the values of the Pearsons correlation coefficient. Slightly lower values of R coefficient were reached in the shoots of the berries in *Vaccinio uliginosi-Betuletum pubescentis*. Literature confirms existence of positive correlation between N and P in plants. Positive, important correlation of N and P in the leaves of the trees was evidenced by Pugnaire [41], in shoots of moor grass (*Molinia caerulea*), by Güsewell [21] and Garten [17] in various fragments of plants.

An analysis of quantitative relations between particular elements in the under-shrubs of berries provides valuable information on their nutritional status. The N:P relation remained within the limits of 8.02–12.85 in *Vaccinium myrtillus* and 8.82–11.37 in *Vaccinium vitis-idaea*. In each of the analyzed cases, the N:P ratio was each time higher in leaves than in stems of the berries in examined forest complexes (Tab. 3). According to Zhiguo

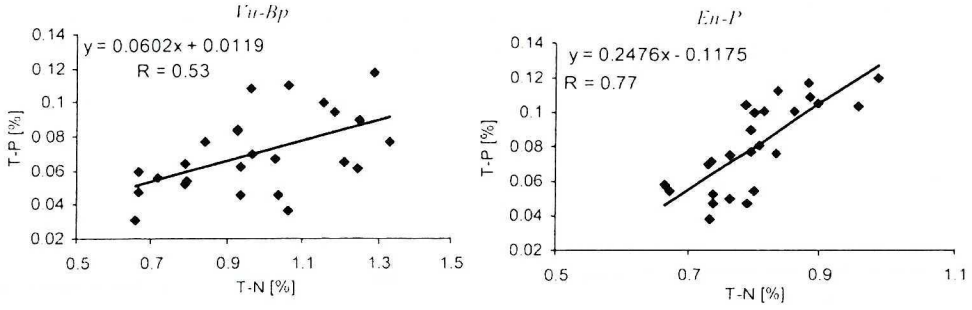

Fig. 2. Relationships between concentration of nitrogen and phosphorus in shoots *Vaccinium vitis-idaea* in *Vu-Bp* and *En-P*, R – Pearson's correlation coefficients, $p < 0.05$, $n = 25$, $R_{crit} = 0.323$

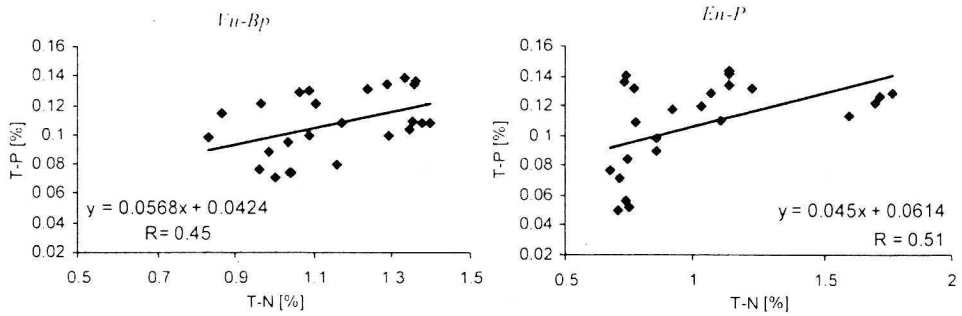

Fig. 3. Relationships between concentration of nitrogen and phosphorus in shoots *Vaccinium myrtillus* in *Vu-Bp* and *En-P*, R – Pearson's correlation coefficients, $p < 0.05$, $n = 25$, $R_{crit} = 0.323$

et al., [56] the maximum growth of plants and maximum supply of nutrients occurs at the N:P relation approximating 9.5. Consequently, the value of the N:P ratio is characteristic for each species [50]. According to Güsewell [21] during the vegetation period it can have the values of 10–20. According to Koerselman and Meuleman [24] the N:P correlation > 16 in *Vaccinium myrtillus* leaves indicates substantial deficit of phosphorus.

The C:N correlation in leaves and stems of berries was between 31.12 and 54.77. However, higher values were reached in *Empetro nigri-Pinetum* than in *Vaccinio uliginosi-Betuletum pubescentis.* According to the data found in literature, the most frequent C:N correlation in plants is between about 5 in algae and over 100 in trees [43]. The values of the C:N correlation in the plant cover of the examined forest complexes at SNP are within the limits of the values provided in literature. As far as the C:P correlation is concerned, the scope of the values was much wider and was between 377.19–525.88 (Tab. 3). Enwezor [14] during the examination of various plants found the values of the C:P correlation within the limit from 112 to 501. This value in plants depends on concentration of the above mentioned elements in soil.

The plants during vegetation season show variable demand for mineral compound of nitrogen and phosphorus. The same species in different vegetation conditions absorbs nutritional ingredients in variable proportions [22]. This diversification is one of the reasons of variable concentration of ammonium nitrate and phosphorous ions in plants. Nitrogen and phosphorus occur in plant tissues mainly in the form of organic complexes, therefore concentration of mineral forms of nitrogen and phosphorus constitutes only minor part of general forms. Mineral forms of nitrogen and phosphorus absorbed by plants are transformed into complex organic compounds.

The concentration of $N\text{-}NH_4$ in *Vaccinium vitis-idaea* has average values from 35.33 mg/100 g dry mass in leaves (CV = 26.35%) to 21.02 mg/100 g d.m. in fruits (CV = 5.42%) (Tab. 4). Slightly higher concentration of those ions was found in *Vaccinium myrtillus*. leaves and stems. Those values were between 56.74 mg/100 d.m. in *En-P* stems to 15.88 mg/100 g d.m. in fruit. The highest dynamics of concentration of ammonium ions was in *Vaccinium myrtillus* leaves (CV = 52.26% in *Vu-Bp*) and (CV = 47.18% in *En-P*). The concentration of nitrate ions in berry tissues was lower than the content of ammonium ions. The lowest concentration of $N\text{-}NO_3$ was found in *Vaccinium myrtillus* fruits in *En-P* (8.21 mg/100 g d.m., CV = 14.22%). The obtained values of $N\text{-}NO_3$ in examined plant cover are slightly lower from those found in tissues of *Phalaris arundinacea* (26–

Table 4. Average content of nitrogen and phosphorus compounds [mg/100 g d.m.] in *Vaccinium myrtillus* and *Vaccinium vitis-idaea* (2002–2005)

Forest association	Species		N-NH_4				N-NO_3				P-PO_4			
			Av.	Med.	SD	CV	Av.	Med.	SD	CV	Av.	Med.	SD	CV
Vu-Bp	*Vaccinium vitis-idaea*	leaves	34.10	32.10	8.12	25.11	20.99	20.60	7.05	33.54	23.70	20.10	11.56	48.86
		stem	34.00	29.10	12.17	35.73	15.55	15.30	4.00	25.77	22.40	20.90	11.46	51.06
		fruits	24.90	23.80	0.90	3.61	13.97	13.90	-	-	21.21	21.40	-	-
	Vaccinium myrtillus	leaves	40.30	30.40	21.05	52.26	13.97	13.60	8.94	64.00	32.60	27.90	14.75	45.93
		stem	46.70	43.70	15.15	33.88	16.01	16.70	7.72	48.25	29.50	25.30	9.40	31.81
		fruits	22.50	22.20	1.76	7.83	10.12	10.90	-	-	16.94	16.90	-	-
En-P	*Vaccinium vitis-idaea*	leaves	35.33	35.98	9.31	26.35	18.74	17.65	9.07	48.32	21.22	21.33	4.11	19.37
		stem	28.32	29.06	9.00	31.78	13.43	12.55	5.87	43.69	17.28	15.71	6.00	34.72
		fruits	21.02	21.19	1.14	5.42	10.45	10.45	0.78	7.52	18.38	18.43	0.91	4.90
	Vaccinium myrtillus	leaves	43.18	48.44	20.37	47.18	15.36	14.87	8.12	52.87	26.26	20.95	14.61	55.64
		stem	56.74	53.98	19.77	34.84	24.78	23.58	10.52	42.44	20.91	17.22	10.43	49.88
		fruits	15.88	16.33	3.58	22.54	8.21	8.06	1.17	14.22	15.22	15.24	1.00	6.61

Vu-Bp – *Vaccinio uliginosi-Betuletum pubescentis*, *En-P* – *Empetro nigri-Pinetum*, Av. – average, Med. – medians, SD – standard deviation, CV – coefficient of variation

61 mg/100 g d.m.) Golińska and Kozłowski [19]. The highest dynamics of N-NO_3 was also characteristic of bilberry leaves in both examined forest complexes. The dynamics of nitrate ions (Tab. 4) is closely connected with rainfalls which could have significantly washed out N-NO_3 from plant tissues [36]. The concentration of phosphorus ions was also maintained at average level with the values from 23.77 mg/100 g d.m. in leaves to 17.28 mg/100 g d.m. in stems of *Vaccinium vitis-idaea* and from 32.6 mg/100 g d.m. in leaves from 15.22 mg/100 g d.m. in *Vaccinium myrtillus* fruit.

The concentration of nitrogen and phosphorus in examined species of berries indicated variation during examined vegetation seasons. The largest concentration of nitrogen in leaves and stems of *Vaccinium vitis-idaea* was in summer during their maximum growth (Fig. 4). From August, a gradual decrease of concentration of that biogene both in leaves and stems of red bilberry in both forest complexes was observed.

The lowest volume of nitrogen in plant tissues was found in the autumn months, which is a consequence of lower demand of plants for nitrogen in that period. The largest concentration of phosphorus was found in sprouts of bilberry in June, both in *Vu-Bp* and in *En-P*, and then it gradually decreased by the end of vegetation season (Fig. 5). Similar concentration of nutrients in leaves during vegetation season was described by other researchers [10, 42, 44, 54]. Over both examined forest

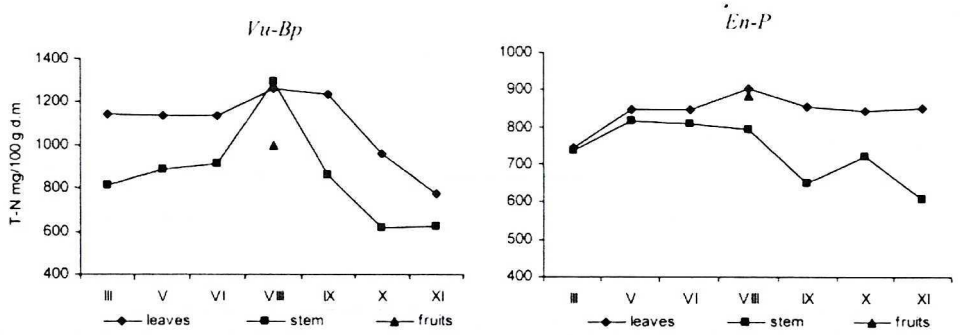

Fig. 4. Monthly average changes of total nitrogen in *Vaccinium vitis-idaea* shrubs in *Vu-Bp* and *En-P* in 2002–2005

areas, much lower concentration of P was found in the autumn season in leaves than in stems. Such status can be a consequence of retranslocation of this element from leaves to stems connected with storage of valuable biogenes in thicker parts of berries [30]. It is the evidence that the bilberry withdrawing biogenes before autumn dropping of leaves behaves as tall trees [31]. Among ions containing nitrogen N-NH_4 dominated in examined species of berries. Ammonium ions exceeded concentration of nitrates by many times (Tab. 5). Similar relations among mineral forms of nitrogen in plant cover were discovered by Andrews *et al.* [2]. In berries of examined forest complexes, mineral forms of nitrogen exceeded phosphates.

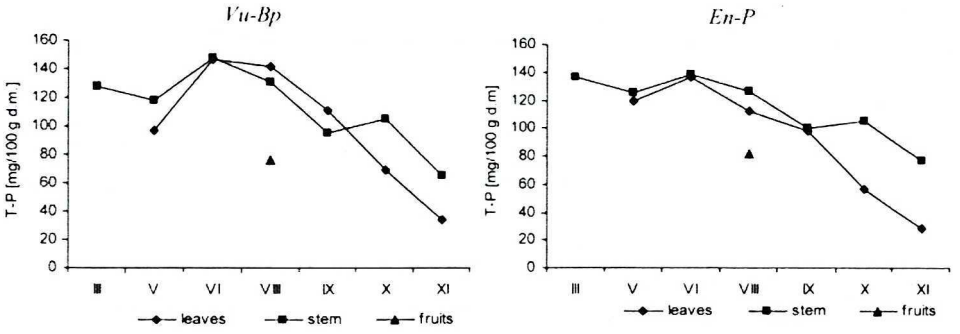

Fig. 5. Monthly average changes of total phosphorus in *Vaccinium myrtillus* shrubs in *Vu-Bp* and *En-P* in 2002–2005

CONCLUSIONS

Forest ecosystems at the Słowiński National Park are characteristic of uneven species of berries on the forest floor. Bilberry under-shrubs (*Vaccinium myrtillus*) have the largest frequency (43%), individual growth 1.015 g and NPP (534,91 kg/ha) in marshy coniferous birch forest (*Vu-Bp*). Under-shrubs of the red bilberry (*Vaccinium vitis-idaea)* had the highest frequency (54%) at the coastal crowberry coniferous forest (*En-P*), reaching at the same time with modest individual growth (0.271 g) much larger net primary pro-

Table 5. Ratios of soluble nitrogen and phosphorus ions in *Vaccinium vitis-idaea* and *Vaccinium myrtillus* (2002–2005)

Forest association	Species		$\frac{N\text{-}NH_4}{N\text{-}NO_3}$	$\frac{N\text{-}NH_4 + N\text{-}NO_3}{P\text{-}PO_4}$
Vu-Bp	*Vaccinium vitis-idaea*	leaves	1.62	2.32
		stem	2.19	2.21
		fruit	1.78	1.83
	Vaccinium myrtillus	leaves	2.88	1.66
		stem	2.92	2.12
		fruit	2.22	1.92
En-P	*Vaccinium vitis-idaea*	leaves	1.88	2.55
		stem	2.11	2.42
		fruit	2.01	1.71
	Vaccinium myrtillus	leaves	2.81	2.23
		stem	2.29	3.89
		fruit	1.93	1.58

duction (155.28 kg/ha) than in the marshy coniferous birch forest. Frequency, density, average individual growth and low atmospheric rainfall in 2005 (579 mm) had an impact on reduction of net primary production of the examined berries. The NPP volume of *Vaccinium vitis-idaea* and *Vaccinium myrtillus* is also a reflection of average concentration of compounds of nitrogen and phosphorus absorbable by plants. The concentration of nitrogen and phosphorus in leaves of red bilberry (*Vaccinium vitis-idaea*) was on average at the level of 1.083% N and 0.097% P in *Vaccinio uliginosi-Betuletum pubescentis* and 0.868% N and 0.085% P in *Empetro nigri-Pinetum*. An average concentration of biogenes in stems of the red bilberry was slightly lower and remained at the level of 0.870% N and 0.083% P in *Vu-Bp* and 0.734% N and 0.077% P in *En-P*. The dynamics of nitrogen and phosphorus in sprouts of the examined species of berries showed positive correlation which can be evidenced by the levels of the correlation of Pearson's coefficients. The concentration of nitrogen and phosphorus in the fruits of examined berries was larger in *Vu-Bp* complex than in *En-P*. The N:P relation remained between 8.02–12.85 in *Vaccinium myrtillus* and 8.82–11.37 in *Vaccinium vitis-idaea*. In examined forest complexes, each analyzed N:P correlation was each time higher in leaves than in stems of berries.

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ZMIENNOŚĆ KONCENTRACJI AZOTU I FOSFORU ORAZ PRODUKCJA PIERWOTNA NETTO *VACCINIUM VITIS-IDAEA* L. AND *VACCINIUM MYRTILLUS* L. W WYBRANYCH EKOSYSTEMACH LEŚNYCH SŁOWIŃSKIEGO PARKU NARODOWEGO

Vaccinio uliginosi-Betuletum pubescentis i *Empetro nigri-Pinetum* charakteryzują się zróżnicowaną frekwencja i zagęszczeniem *Vaccinium vitis-idaea* L. i *Vaccinium myrtillus* L. na dnie lasu. Badane krzewinki borówek wykazują różnice w zawartości związków azotowych i fosforowych oraz wielkości nadziemnej produkcji pierwotnej netto. Średnia zawartość badanych biogenów w liściach borówki czarnej (*Vaccinium myrtillus*) na

terenie Słowińskiego Parku Narodowego wynosiła 1,311% N, 0,102% P i 40,8% C w *Vaccinio uliginosi-Betuletum pubescentis* oraz 1,159% N, 0,095% P i 38,7% C w *Empetro nigri-Pinetum*. Zawartość azotu, fosforu i węgla w liściach borówki brusznicy (*Vaccinium vitis-idaea*) wynosiła: 1,083% N, 0,097% P i 44,70% C w *Vaccinio uliginosi-Betuletum pubescentis* oraz 0,868% N, 0,085% P i 44,70% C w *Empetro nigri-Pinetum*. Zmienna koncentracja azotu i fosforu w pędach badanych gatunków borówek wykazuje dodatnią korelację tych pierwiastków. Nadziemna produkcja pierwotna netto *Vaccinium myrtillus* wynosi 534,905 kg/ha w *Vaccinio uliginosi-Betuletum pubescentis* oraz 216,594 kg/ha w nadmorskim borze bażynowym. *Vaccinium vitis-idaea* w *Empetro nigri-Pinetum* osiąga 155,283 kg/ha produkcji pierwotnej netto oraz jedynie 113,220 kg/ha w *Vaccinio uliginosi-Betuletum pubescentis*.