BALTIC COASTAL ZONE
Journal of Ecology and Protection of the Coastline
40th academic year of the University
Vol. 14 pp. 57-74 2010

ISBN 1643-0115

Original research paper

Received: 9.02.2010
Accepted: 16.08.2010

ACCUMULATION AND RETRANSLOCATION OF NITROGEN AND PHOSPHORUS IN THE FOLIAGE OF *PINUS SYLVESTRIS* L. AND *BETULA PUBESCENS* IN CHOSEN WOODLAND ECOSYSTEMS OF THE SLOVINSKI NATIONAL PARK

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Abstract

The study of foliage was carried out in two different forest ecosystems: *Vaccinio uliginosi-Betuletum pubescentis* and *Empetro nigri-Pinetum* in the Slovinski National Park in the period of 2002-2005. The largest volume of nitrogen and phosphorus in the litter of coniferous needles was found in early summer at the moment of maximum growth. An average concentration of nitrogen in examined needles was between 1.296% and 1.358% N in *Vaccinio uliginosi-Betuletum pubescentis* and from 1.010% to 1.118% N in *Empetro nigri-Pinetum*. The decrease of biogenes concentration in plant tissues was observed in the autumn months as a result of lower demand and recession of biogenes connected with storage of valuable elements in the fatter parts of the trees. In the fall season, a gradual recession of nutrients from the litter of coniferous needles was observed. In *Vaccinio uliginosi-Betuletum pubescentis* insignificant quantity of nitrogen recesses (average 5.6%) from the new and one year old litter of coniferous needles, including 47.2% N-NH_4 and 78.6% N-NO_3 and about 21.8% P, including 11.7% P-PO_4. In *Empetro nigri-Pinetum* more intensive recession of biogenes was found from the litter of coniferous needles of common pine than in *Vaccinio uliginosi-Betuletum pubescentis*. On average 11.5% T-N is translocated, including 41.4% N-NH_4 and 23.8% N-NO_3 as well as 22.3% P, including 11.8% P-PO_4.

Key words: nutrient cycling, phosphorus, nitrogen, N:P, *Pinus sylvestris*, *Betula pubescens*, Slovinski National Park

INTRODUCTION

The nutrient concentration in the leaves of forest trees varies during the year. In nutrition of trees covering poor habitats, the phenomenon of elements translocation plays a very important role (Clark 1983, Headley et al. 1985, Fife and Nambiar 1982, Nambiar and Fife 1987, 1991, Helmisaari 1992). During the period of intensive growth, biogenes from older leaves can translocate to the younger ones (Rapp et al. 1979, Fife and Nambiar 1982, 1984, Miller 1984, Schachtman et al. 1998). A deficit of nutrients can be compensated by their fast circulation or activation of the reserve stored by plants during the autumn period (Dziadowiec and Kwiatkowska 1980, Berg et al. 1982). Retranslocation may be regulated by soil nutrient supply, the size of nutrient reserves and age of trees (Munson et al. 1995, Malik and Timmer 1998, Hawkins et al. 1999, Saur et al. 2000). The quantity of available nutrients in soil has an impact on the growth and development of plant cover (Attiwill and Adams 1993, Pugnaire 2001). The growth of available nitrogen in soil intensifies accumulation of this biogene by plants, at the same time weakening the retranslocation process (Salifu and Timmer 2001). Rainfall has a big impact on translocation of biogenes to the soil solution, and by increasing the moisture of the soil washes out soluble nitrogen and phosphorus compounds from its organic levels. Effectiveness of their utilization by trees depends both on environmental factors (rainfall and washing out deep into the soil, soil reaction, its absorption ability) and physiology of particular species. Economic management of biogenes is especially important for ecosystems with their small quantities.

Concentration of nutrients in the assimilation system of trees indicates their nutritional status (Pastor et al. 1984, De Vries and Heij 1991, Schachtman et al. 1998), while their deficiencies observed especially in their forest stands reflect their insufficient quantity in the soil (Prescott et al. 1992, Wang and Klinka 1997). The status of mineral nutrition of plants depends not only on concentration of particular mineral constituents, but also on their mutual balance (Biały 1983). Analysis of quantity proportions between particular elements both in soils and in plants can reflect, among others, the nutritional status of the plants (Van der Burg 1990), the correct character of processes within the plant (Ostrowska and Porębska 2002) and indirectly, its health status (Szczubiałka 1981). Absorption of majority of elements by a plant is a process which is metabolically regulated (Chapin 1980, Pugnaire and Chapin 1993), and their accumulation is also connected with development and aging processes within them (Malzahn 2002, Ostrowska and Porębska 2002). Absorption of ammonium, nitrate and phosphate ions by plants differs during the vegetation season, and their increase, strictly dependent on biomass production, is a result of the photosynthesis and assimilation of NH_4^+ and NO_3^- ions from the solum (Starck 2006).

Retranslocation can be divided into two phenomena: autumnal nutrient withdrawal from senescing foliage, and nutrient translocation from the living foliage during aging. *Pinus sylvestris* L. and *Betula pubescens* are two of the most important trees species in Poland. The objectives of this paper are: (i) systematic measurement of concentration of nitrogen and phosphorous compounds (inorganic and total form) in the litter of common pine needles (new needles, 1-year and 2, 3-years and leaves of a downy birch in two different forest ecosystems of the Slovinski National Park in the period of 2002-2005, (ii) evaluation and comparison of the volume of nitrogen and phosporus retranslocation in the needles and leaves during spring and autumn seasons.

MATERIALS AND METHODS

Study site

The studies were carried out on the territory of two different forest ecosystems in the Slovinski National Park (SNP). SNP is located in northern Poland, in the region characterized by the Baltic Sea proximity, with very small human activity and relatively free of industrial air pollution sources. Due to close vicinity of the Baltic Sea the climate is temperate with mean annual temperatures near 7.3°C and with an annual precipitation averaging 700 mm (Matuszkiewicz 2002). The research forest plots are located 1.5 km from the coastline of the Baltic Sea at a distance of 600 m from each other. Location of the sampling sites and their surroundings with more detailed characteristics is presented in Figure 1.

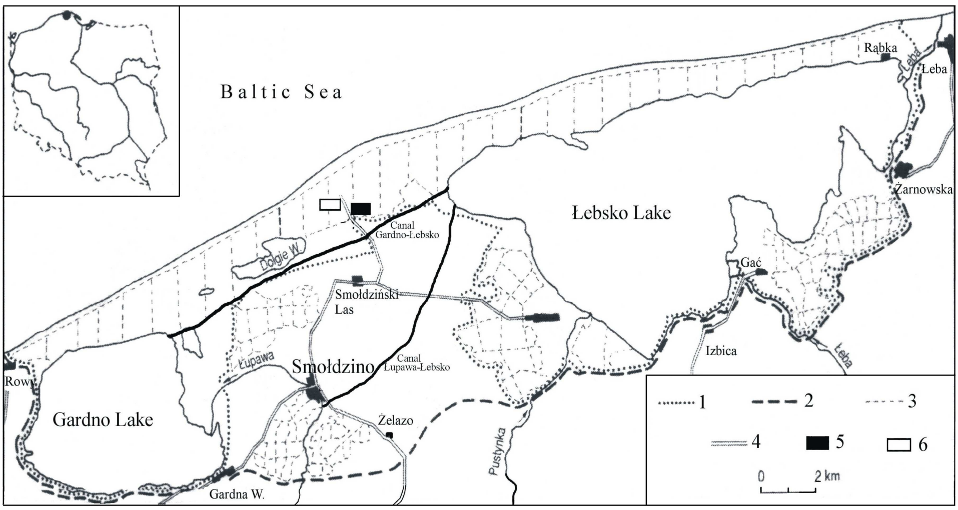

Fig. 1. Situation plan of the Slovinski National Park
1– limits of area, 2 – limits of Park's administrative area, 3 – limits of forestall areas, 4 – ways, 5 – research plot I (*Vu-Bp*), 6 – research plot II (*En-P*)

The vegetation of the research plot I belongs to the group of *Vaccinio uliginosi–Betuletum pubescentis* (*Vu-Bp*) and covers proper podsol on mineral peat soil. The vegetation of the research plot II covering proper podsol belongs to the group of *Empetro nigri-Pinetum* (*En-P*). Studied forest stands are diversified by species and age. Research plot I is overgrown by loose pine-birch stand of 18-19 m height. The participation of a common 60-years old pine (*Pinus sylvestris* L.) in the stand is equal to 25% (128 trees), while 47-years old mossy birch (*Betula pubescens*) – 75% (392 trees). Research plot II with 715 trees is afforested by uniform, 140-years old pine stand (*Pinus sylvestris* L.) characterized by low (7 m), deformed crowns and leant trunks (Plan ochrony... 2003).

Plant sampling

The plant material was collected from March to November it the 2002-2005 period from 10 *ad hoc* selected *Pinus sylvestris* in *Vu-Bp* and *En-P* and *Betula pubescens* in *Vu-Bp.* For examination, the leaves (needles) growing at the height of about 2 m above the ground level were collected. The collected plant material was combined with consideration of species diversity. After having been taken into laboratory, the plant material was cleaned of contaminations, the needles were separated into the ones from this year (new needles), 1-, 2- and 3-years old ones. At one time, the length of 300 fresh pine tree needles was measured at each survey area (Puchalski and Prusinkiewicz 1975) with accuracy up to 1 mm. After initial preparation, the plant material was oven-dried for 72 h at 65°C, and homogenized in a grinder.

Chemical analysis

After homogenization of the subdivided plant material, total nitrogen (T-N), ammonia nitrogen ($N\text{-}NH_4^+$), nitrate nitrogen ($N\text{-}NO_3^-$), total phosphorus (T-P) and phosphate phosphorus ($P\text{-}PO_4^{3-}$) were determined. T-N was determined with Kjedhal's method after mineralization in the mixture of H_2SO_4 and H_2O_2 (CMA 1973). $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ were determined spectrophotometrically (UV-VIS 1202, Shimadzu, Japan) with Nessler's reagent and sodium salicylate, respectively. Both T-P and $P\text{-}PO_4^{3-}$ were determined spectrophotometrically 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 (Ostrowska et al. 1991). Since the limit of detection and quantification of the method depends on the purity of the reagents used, in 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 $mg \cdot dm^{-3}$, 1004±2 $mg \cdot dm^{-3}$ and 1001±2 $mg \cdot dm^{-3}$. The limit of quantification for PO_4^{3-}, NO_3^- and NH_4^+ was 0.01 $mg \cdot dm^{-3}$, 0.02 $mg \cdot dm^{-3}$ and 0.005 $mg \cdot dm^{-3}$, respectively. QA/QC was carried out by analyzing field samples fortified with analytes of interest. In general, the determined concentration fell within 15-20% of the true value, which is comparable to results presented before by Polkowska et al. (2002). The repeatability of methodology calculated according to the formulas presented by Konieczka et al. (2004) reached $RSD(P\text{-}PO_4^{3-})$=1.4%, $RSD(N\text{-}NO_3^-)$=1.6%, $RSD(N\text{-}NH_4^+)$=1.4%, RSD(T-N)=2.1% and RSD (T-P)=1.8%. The analytical results were transformed to the form of deposition and expressed in $kg \cdot ha^{-1} \cdot year^{-1}$ in order to assess the annual nutrient's deposition on a surface area basis.

Other variables (environmental and soil-related)

Rainfall, air humidity and air temperature were recorded in the Gać meteorological station located inside the boundaries of SNP. Average values of major climatic conditions in both locations for the study period are shown in Table 1.

Table 1

Atmospheric conditions in the period between 2002 and 2005

	2002	2003	2004	2005	Mean
Rainfall [mm]	682	552	848	579	665
Air temperature [^oC]	-	7.69	7.68	7.81	7.73
Air humidity [%]	-	83.5	84.5	83.6	83.9

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 (Table 2). Among of possible soil layers only rooting zones abundance with nutrients (Otni in *Vu-Bp* and C in *En-P*) were evaluated in this study.

Table 2

Characteristic of soil properties in the *Vaccinio uliginosi-Betuletum pubescentis* and *Empetro nigri-Pinetum* in 2002-2005 (Parzych 2008)

Soil horizon	*Vaccinio uliginosi-Betuletum pubescentis*					*Empetro nigri-Pinetum*			
	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

Note: Ol – fresh forest litter subhorizon, Ofh – detritus subhorizon, AEes – albic horizon with mic horizon feature, Bhfe – spodic horizon, C – mother rock, Otni – histic horizon of buried peat soil (Konecka-Betley et al. 1999)

RESULTS AND DISCUSSION

The nutrient accumulations and fluctuations in the leaves

Concentration of nitrogen and phosphorus in the litter of coniferous needles of the examined forest ecosystems shows diversity within a forest community, during a vegetative season and depending on the age of the litter of coniferous needles. Much higher concentration of biogenes was found in the litter of coniferous needles

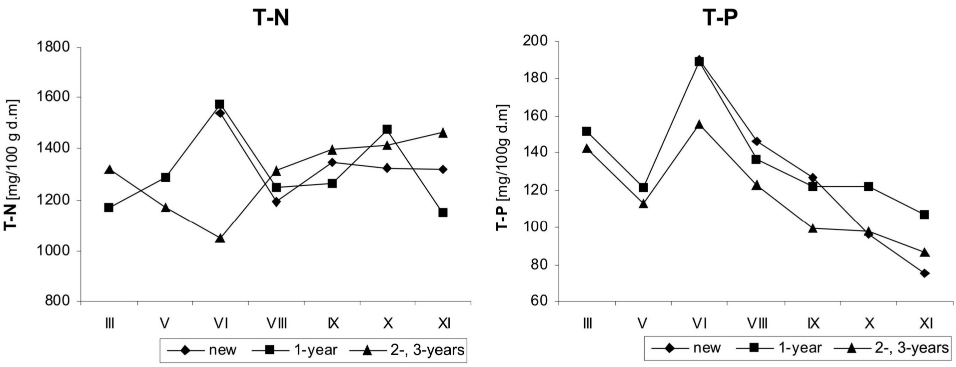

Fig. 2. The concentration of total nitrogen (T-N) and total phosphorus (T-P) in pinus needles in the *Vaccinio uliginosi-Betuletum pubescentis*

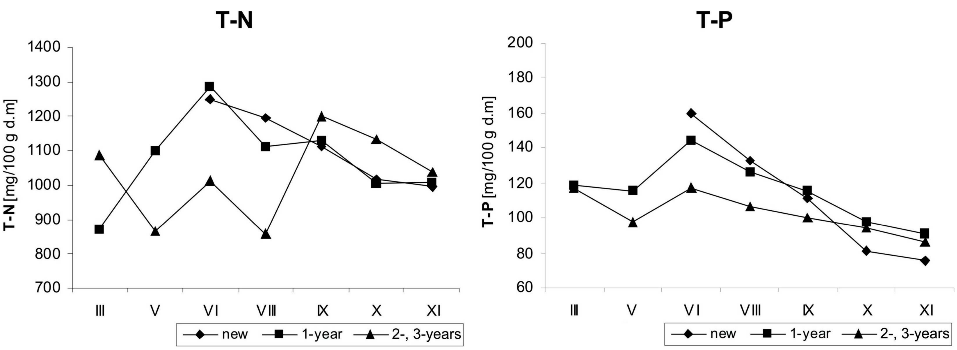

Fig. 3. The concentration of total nitrogen (T-N) and total phosphorus (T-P) in pinus nedlees in the *Empetro nigri-Pinetum*

Table 3

Average nutrient concentration in needles of *Pinus sylvestris* and leaves of *Betula pubescens* in the period between 2002 and 2005

Forest association	Species		N [%]	P [%]	C [%]	C:N	C:P	N:P
Vu-Bp	*Betula pubescens*	leaves	1.702	0.128	47.40	27.85	370.31	13.39
	Pinus sylvestris	new needles	1.358	0.132	55.20	40.65	418.18	10.28
		1-year needles	1.306	0.136	54.60	41.81	401.47	9.60
		2-3-years needles	1.296	0.117	53.12	40.98	454.02	11.08
En-P	*Pinus sylvestris*	new needles	1.118	0.116	54.84	49.05	472.76	9.64
		1-year needles	1.082	0.116	54.30	50.18	468.10	9.33
		2-3-years needles	1.010	0.102	52.11	51.59	510.88	9.90

of *Vaccinio uliginosi-Betuletum pubescentis* than *Empetro nigri-Pinetum* (Fig. 2 and 3, Table 3). It is probably an effect of the presence of nutrient rich fossil soil within the area of the tree roots in a soil profile of that forest complex (Table 2). It can be supported by the fact that the quantity of the nutrients available in the soil has an impact on growth and development of the plant cover (Attiwill and Adams 1993, Pugnaire 2001). The largest quantity of nitrogen and phosphorus in the plant cover was found early summer during the period of maximum growth of the plants (Fig. 2 and 3). From June, the content of N and P most often decreased due to the growth of mass, fructification and the substantial rainfall in the period of summer. The highest rainfall was in October (95.3) and July (85.1), the lowest in spring: April (25.9) and March (34.9), Parzych (2008).

The average annual rainfall in the years 2002-2005 was 665 mm (Table 1). The shortage of moisture in the soil has substantial effect on the growth of nitrogen in leaves, while with higher moisture, the level of nitrogen usually decreases. A similar variation of nutrients concentration in leaves during vegetation season was described by other researchers (Wachowska-Serwatka and Marczonek 1968, Chapin and Kedrowski 1983, Pugnaire and Chapin 1993, Regina and Tarazona 2001, Xue and Luo 2002). Lowering of concentration of the above mentioned biogenes in plant tissues was observed in the autumn months, which was a result of lower demand of plants and recess of biogenes in the autumn season, connected with storage of important elements in thicker parts of the trees. A similar phenomenon was observed by Stachurski and Zimka in the pine dominated forest ecosystems (Stachurski and Zimka 1981, Zimka and Stachurski 1980). The abundance of tested biogenes in the litter of coniferous needles was strictly limited by the age of the needles (Table 3). The largest concentration of nitrogen was found in new (this year) needles of both forest complexes, on average by 3-4% higher than in older needles, and the lowest concentration in 2 and 3 years old ones. In the case of phosphorus, the highest concentration was in 1 year old needles of *Vaccinio uliginosi-Betuletum pubescentis* and this year needles as well as 1 year old needles of *Empetro nigri-Pinetum*. Similar regularity was found in pine forests of Poland by Szczubiałka (1981).

Average concentration of nitrogen in the examined litter of coniferous needles was between 1.296% and 1.358% N in *Vu-Bp* and from 1.010% to 1.118% N in *En-P* (Table 3). According to Ostrowska and Porębska (2002) concentration of nitrogen and phosphorus in the leaves of forest tree species varies from 1.3 to 3.1% N and from 0.1 to 0.4% P. Nitrogen concentration of the needles of pine in the 2002-2005 period did not exceed physiological maximum (1.8%), which is regarded by some researchers as the critical number indicating negative influence of air on trees (De Vries and Heij 1991). Nitrogen supply (>1.3%) appeared sufficient only in *Vaccinio uliginosi-Betuletum pubescentis* (Table 3). In *Empetro nigri-Pinetum* deficiency of that element was found (<1.3% N). In conditions of nitrogen deficit, a limited growth of plants is visible (Starck 2006), which can be evidenced by a small size of the pine trees, reaching in this tree system only 7 m of height on average, as well as small length of the needles (on average 48.8 mm). However, no acute deficiency of biogenes was found in the tested coniferous litter, which can be evidenced by <1% N and <0.1% P (Gawliński 1991). Lower than average concentration of macroelements of pine forest systems of the Baltic Sea region was confirmed by the results of research held by Małachowska et al. (2006). Average concentration of N (1.702%) and P (0.128%) in the leaves of downy birch appeared to be sufficient, which was visible not only in the percentage content of those elements (Table 3), but also in much better biological and cultivating condition of the forest system (average height of the trees is 18-19 m).

The content of phosphorus in needles of *Pinus sylvestris* was between 0.117% and 0.136% P in *Vaccinio uliginosi-Betuletum pubescentis* and 0.102-0.116% P in *Empetro nigri-Pinetum*. These levels are recognized as correct by the Center for Coordination of assimilation apparatus, acting within ICP-Forest (Stefan et al. 1997).

The C:N ratio in the litter of coniferous needles of common pine is on average 41 in *Vu-Bp*, and 50 in the pine wood. Slightly higher levels of the carbon/nitrogen ratio in the pine wood than in the leafy forest find confirmation in literature. According to the research by McGroddy et al. (2004) C:N ratio in leafy forests of the moderate zone is 35.1 on average, and 59.5 in coniferous ones. Similar levels of C:N ratio (28-65) were also found by Gifford (2000), examining the green eucalyptus leaves (Australia). According to the data found in the literature of the subject, the recurring C:N ratio in plants is between about 5 in algae and over 100 in trees (Raven et al. 2004). The values of the C:N ratio in the plant cover of the examined forest complexes of the Slovinski National Park are within the values provided in the literature of the subject. The C:P ratio is from 370.31 to 454.02 in *Vu-Bp* and from 472.76 to 510.88 in *En-P* (Table 3).

Much higher values the C:P ratio was found by McGroddy et al. (2004) in leafy forests: average 922.3, and in coniferous forests 1231.8. Enwezor (1976) examining the various plant materials, found the C:P ratio value between 112 and 501. That figure, in the plant cover, depends on concentration of the above mentioned elements in soil. The N:P ratio in the coniferous litter of the needles of the common pine is between 9.60 and 11.08 in *Vu-Bp* and from 9.33 to 9.90 in *En-P*. The highest average value of the N:P ratio was found in the leaves of the downy birch (Table 3). According to Güsewell and Koerselman (2002) N:P in the plants in natural sites most often has the values from 12 to 13, and according to the research work of Malzahn (2002) the optimum supply of nitrogen and phosphorus in threes is with a ratio of 7-10. According to Zhiguo et al. (2007) the maximum increase of the plants and maximum supply with nutrients is at the N:P ratio approximating 9.5. Besides, the value of the N:P ratio is characteristic for a given species (Townsend et al. 2006). According to Güsewell (2004), in the plant cover during vegetation season, it can have values of 10-20. Concentration of nitrogen and phosphorus in the examined litter of coniferous needles was limited at the same time by ammonia nitrogen and nitrate nitrogen. The largest quantity of mineral forms of nitrogen was found in the early summer period, and then their proportional loss was found (Fig. 4 and 5). Similar relations were found in the case of concentration of phosphate ions (Fig. 6). In *Vu-Bp* slightly higher concentration of mineral forms of nitrogen was found in the litter of coniferous needles of *Pinus sylvestris* than in *En-P*, especially during the first half of the vegetation period (Fig. 4 and 5). Only in the case of P-PO_4, no differences were found in the litter of coniferous needles in *Vu-Bp* and *En-P*.

Nitrogen and phosphorus in plant tissues appear mainly in the form of organic connections, therefore concentration of mineral forms of nitrogen and phosphorus con-

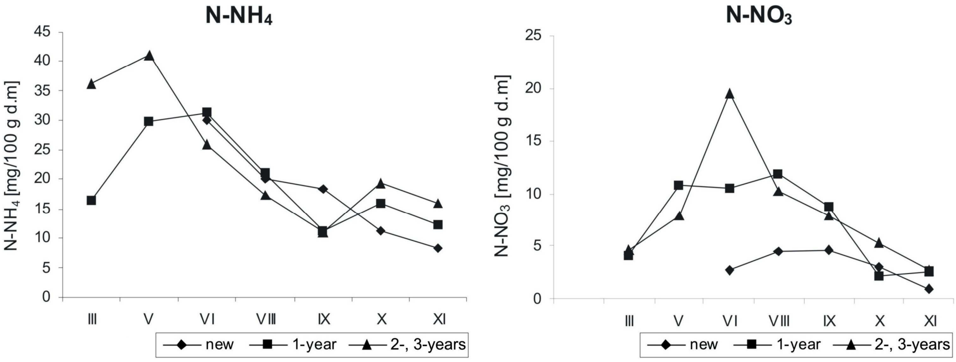

Fig. 4. Monthly average changes of N-NH_4 and N-NO_3 in pinus needles in *Vu-Bp* (2002-2005)

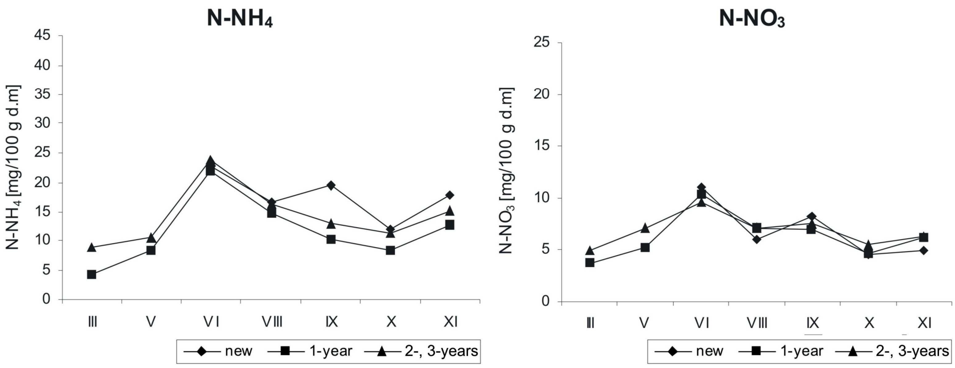

Fig. 5. Monthly average changes of N-NH_4 and N-NO_3 in pinus needles in *En-P* (2002-2005)

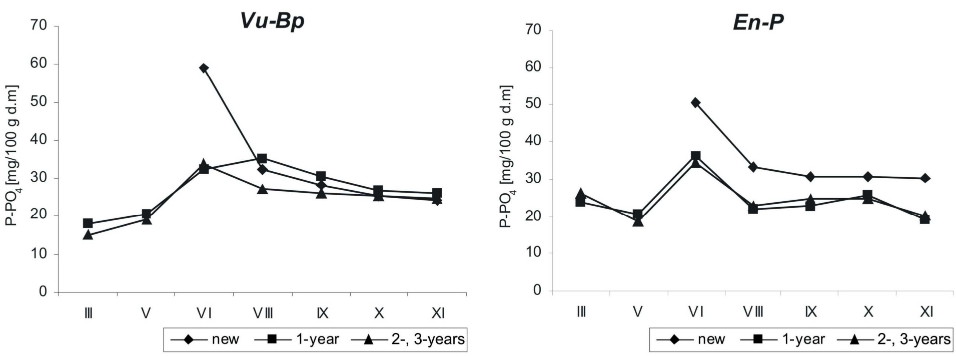

Fig. 6. Monthly average changes of P-PO_4 in pinus needles in *Vu-Bp* and *En-P* (2002-2005)

stitute only a minor part of general forms. Mineral forms of nitrogen and phosphorus absorbed by the plants are processed into complex organic compounds (Kabata-Pendias and Pendias 1993). The N-NH_4 concentration in *Vaccinio uliginosi-Betuletum pubescentis* has average values from 17.7 mg/100 g in new coniferous litter to 25.3 mg/100 g

Table 4
Average available nutrient concentration [mg/100 g d.m.] in the needles of *Pinus sylvestris* and leaves of *Betula pubescens* in 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	*Betula pubescens*	leaves	25.3	24.2	13.4	53.2	7.7	6.5	4.6	60.0	36.1	36.7	12.9	35.9
	Pinus sylvestris	new needles	17.7	16.7	9.1	51.4	3.1	2.9	1.6	52.1	35.9	28.8	13.4	37.3
		1-year	19.5	16.2	19.1	47.0	7.5	7.0	4.5	61.0	25.4	24.9	5.4	21.5
		2-3-years	23.1	19.4	11.5	49.8	5.3	7.6	6.6	125.1	24.7	24.8	6.4	26.0
En-P	*Pinus sylvestris*	new needles	15.6	15.9	6.1	39.4	7.0	6.1	3.4	49.4	33.1	30.7	10.8	32.6
		1-year	10.9	8.30	6.2	57.1	6.5	5.7	3.9	60.1	24.1	23.4	6.6	27.3
		2-3-years	13.2	11.7	5.8	44.0	6.9	6.5	3.0	43.1	23.9	23.5	6.2	26.1

Vu-Bp – *Vaccinio uliginosi-Betuletum pubescentis*, *En-P* – *Empetro nigri-Pinetum*, Av. – average, Med. – medians, SD – standard deviation, CV – coefficient of variation in the leaves of downy birch, and in *En-P* from 10.9 mg/100 g in 1-year old needles to 15,6 mg/100 g in new needles (Table 4).

Concentration of nitrate ions in *Vaccinio uliginosi-Betuletum pubescentis* was from two to five times lower from the content of ammonia ions. The lowest concentration of N-NO_3 was found in this year needles of the common pine – 3.1 mg/100 g, and the highest in the leaves of the downy birch – 7.7 mg/100 g in the phytocenosis *Vu-Bp*. Slightly different distribution of concentration of nitrates was characteristic for the litter of coniferous needles in the pine wood (*En-P*). The highest concentration of N-NO_3 was found in the new needles – 7.01 mg/100 g, and the smallest in 1-year old – 6.5 mg/100 g. Concentration of phosphorous ions in the examined leaves had average levels from 23.9 mg/100 g in 2-, 3-years old litter of coniferous needles of *En-P* to 36.1 mg/100 g in the leaves of downy birch (*Vu-Bp*). Dynamics of examined ions in the litter of coniferous needles of the pine is visible in the level of variation rates (Table 4). The largest variation the nitrate ions showed in the examined plant cover. Their content was strictly connected with rainfall which could substantially wash out N-NO_3 from plant tissues (Hansen 1996, Walna et al. 2003, Parzych et al. 2008). More intensive rainfall in the autumn period has an impact on substantial wash out of nitrates from assimilation apparatus *Vaccinio uliginosi-Betuletum pubescentis*, which is reflected in the increase of concentration of such ions in sub tree head rainfall *Vu-Bp* (Parzych et al. 2008).

Among nitrogen containing ions, N-NH_4 dominated. Ammonia ions several times exceeded concentration of nitrates (Table 5). Similar relations between mineral forms

Table 5

Ratios of soluble nitrogen and phosphorus ions in *Pinus sylvestris* and *Betula pubescens* (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	*Betula pubescens*	leaves	3.25	0.92
	Pinus sylvestris	new needles	5.64	0.58
		1-year	2.59	1.06
		2-, 3-years	4.32	1.15
En-P	*Pinus sylvestris*	new needles	2.23	0.68
		1-year	1.67	0.72
		2-, 3-years	1.90	0.85

of nitrogen in plant cover were found by Andrews et al. (1999). Mineral nitrogen compounds slightly exceeded phosphate compounds only in the case of 1, 2 and 3 years old needles in *Vaccinio uliginosi-Betuletum pubescentis*.

The nutrient translocation in the leaves

The fact of relocation of biogenes from older leaves to the younger ones, was confirmed in examined coniferous litter of needles of the common pine (Fig. 2 and 3). In the early summer period connected with growth of new sprouts, the decrease of nitrogen and phosphorus in the 2-and 3-years old litter of coniferous needles was found and at the same time intensive increase of concentration of nitrogen and phosphorus compounds in new needles and 1-year old ones. In *Vaccinio uliginosi-Betuletum pubescentis* concentration of nitrogen in the 2- and 3-years old litter of coniferous needles decreases by 11.5%, and phosphorus by 20.7%, while in *Empetro nigri-Pinetum* decreases by 20.0% and 16.4% respectively. Research done by Millard (1996) shows, that retranslocation of nitrogen during the growth of young needles can remain even at the level of 32-40% N. Maximum supply of N i P in the new and 1-year old needles of *Pinus sylvestris* was found in both forest ecosystems.
Accordingly, in the autumn period, gradual recess of biogenes from the needles was discovered (Fig. 2 and 3). In oligotrophic forest ecosystems with domination of the pine tree, strong recession of N and P from the leaves is found in autumn (Stachurski and Zimka 1981, Zimka and Stachurski 1980). The trees with a small N and P content recess similar or the same quantity as the trees of a higher trophic status (Chapin and Kedrowski 1983). In *Vaccinio uliginosi-Betuletum pubescentis* minor quantities of nitrogen are recessed (average 5.6% T-N) from the new and 1-year old needles, including 47.2% $N\text{-}NH_4$ and 78.6% $N\text{-}NO_3$ and about 21.8% P, including 11.7% $P\text{-}PO_4$ (Fig. 4 and 6). The lack of recession of nitrogen from the oldest litter of coniferous needles is reflected with abundance of the organic litter which is richer in nitrogen compounds from the organic litter from the pine forest (Parzych 2008). In *Empetro nigri-Pinetum* stronger than in *Vu-Bp* recession of biogenes from the litter of coniferous needles common pine was found. On average, 11.5 % T-N is relocated, including 41.4% $N\text{-}NH_4$ and 23.8% $N\text{-}NO_3$ as well as 22.3% P, including 11.8% $P\text{-}PO_4$ (Fig. 5 and 6). In forest complexes of the Slovinski National Park the assumptions by Chapin and Kedrowski (1983) were confirmed, which refer to the volume of the recessed biogenes depending on the trophic status of the forest ecosystem. Retranslocation decreases with the increase of abundance (availability) of nutrients in the soil. Research of Stachurski and Zimka (1992) and Zimka (1989) confirm that

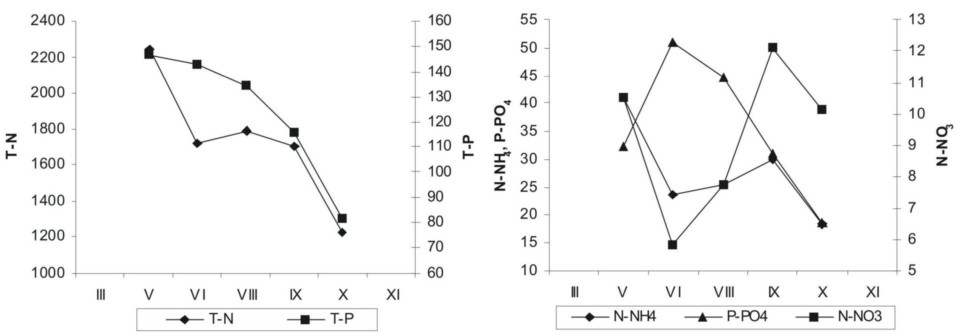

Fig. 7. The average concentration of nitrogen and phosphorus compounds (in mg/100g d.m) in the leaves of *Betula pubescens* in the *Vu-Bp* in 2002-2005

the forest plants can to certain extent decrease recession of elements under conditions of lower trophy of the habitat. Quantity feedback between recessed elements provide forest plants with fast and precise reconstruction of the photosynthetic potential in the next vegetation season. Stachurski and Zimka (1981) found in the pine forests of Poland recession of biogenes in the autumn period at the level of 75% of nitrogen and 85% phosphorus, and in leafy forests 7% N and 16% P. While Dziadowiec and Pokojska (1988) found the recession at the level of 49% N and 70% P in pine forests and 49% N and 61% P in the decidous forests.

The recession process is determined both by the factors of physiological and ecological character (Zimka 1989, Zimka and Stachurski 1992). The more productive the process of recovery of elements from the ageing plant leaves, the less productive is the process of the elements releasing from fallen organic matter. It slows down the processes of the elements releasing from the ground litter substantially, especially under conditions of low trophy of the habitat (Zimka 1989). According to the data found in the literature, retranslocation in *Pinus pinea* in Italy was at the level of 43% N (Rapp et al. 1979), in *Pinus nigra* in Australia at the level of 50-60% N (Miller 1984), and in the needles of *Radiata Pine* in Australia at the level of 48% N and 86% P (Fife and Nambiar 1982).

The phenomenon of translocation is a fast process, and most changes take place during the period of the leaves yellowing (Zimka 1989). In the leaves of the downy birch, nitrogen concentration decreases from May already, and phosphorus from August (Fig. 7). It is a result, above all, of the intensive growth of the plant cover connected with the increase of biomass and substantial rainfall in the summer period (Chapin and Kedrowski 1983, Pugnaire and Chapin 1993, Regina and Tarazona 2001, Xue and Luo 2002). In the autumn period (from September to October) 28.3% T-N is recessed on average, including 38.7% $N\text{-}NH_4$ and 16.6% $N\text{-}NO_3$ as well as 29.5% P, including 39.5% $P\text{-}PO_4$. Slightly higher intensity of recession of biogenes from the leaves of the downy birch than from the leaves of common pine in *Vaccinio uliginosi-Betuletum pubescentis* and *Empetro nigri-Pinetum* results from the species differences.

CONCLUSIONS

The process of translocation of nitrogen and phosphorus compounds in the forest stand of the examined forest complexes, appeared to be quite common due to the poor podzol. Concentration of nitrogen and phosphorus in the pine wood litter of coniferous needles shows variation within a given forest phytocenosis, a vegetation season and depending on the age of the litter of coniferous needles. The largest quantity of N and P compounds was found early summer during the period of maximum plant growth. Due to the processes of translocation in the spring period, substantial quantity of biogenes is relocated from older to younger litter of coniferous needles (*Pinus sylvestris*). An average concentration of nitrogen in examined litter of coniferous needles was between 1.296% and 1.358% N in *Vu-Bp* and 1.010% – 1.118% N in *En-P*. In poor *Empetro nigri-Pinetum* deficiency of nitrogen was found as well as sufficient quantity of phosphorus in the litter of coniferous needles of

Pinus sylvestris. Nitrogen deficit is visible through limited growth of plants, the evidence of which can be a small size of the pine tree – average 7 m of height. The tree stand *Vaccinio uliginosi-Betuletum pubescentis* shows much better biological and development condition than *Empetro nigri-Pinetum* tree stand, which can be evidenced by much higher trees (18-19 m) and higher concentration of nitrogen and phosphorus in the examined leaves. Lowering of the concentration of the above mentioned biogenes in plant tissues was observed in the autumn months.

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AKUMULACJA I RETRANSLOKACJA AZOTU I FOSFORU W LISTOWIU SOSNY ZWYCZAJNEJ I BRZOZY OMSZONEJ W WYBRANYCH EKOSYSTEMACH LEŚNYCH SŁOWIŃSKIEGO PARKU NARODOWEGO

Streszczenie

Badania listowia prowadzono w dwóch różnych ekosystemach leśnych: *Vaccinio uliginosi-Betuletum pubescentis* i *Empetro nigri-Pinetum* w Słowińskim Parku Narodowym w latach 2002-2005. Największe ilości azotu i fosforu w igliwiu stwierdzono wczesnym latem w czasie maksymalnego wzrostu. Średnia koncentracja azotu w badanym igliwiu mieściła się w przedziale od 1,296% do 1,358% N w *Vaccinio uliginosi-Betuletum pubescentis* oraz od 1,010% do 1,118% N w *Empetro nigri-Pinetum*. Obniżenie koncentracji biogenów w tkan-

kach roślinnych obserwowano w miesiącach jesiennych jako wynik mniejszego zapotrzebowania na nie oraz wycofywania biogenów związanych z magazynowaniem cennych pierwiastków w grubszych częściach drzew. W okresie jesiennym zaobserwowano również stopniowe wycofywanie nutrientów z igliwia. W *Vaccinio uliginosi-Betuletum pubescentis* wycofywane są nieznaczne ilości azotu (średnio 5,6%) z igliwia nowego i jednorocznego, w tym 47,2% $N\text{-}NH_4$ i 78,6% $N\text{-}NO_3$ oraz około 21,8% P, w tym 11,7% $P\text{-}PO_4$. W *Empetro nigri-Pinetum* stwierdzono silniejsze wycofywanie biogenów z igliwia sosny zwyczajnej niż w *Vaccinio uliginosi-Betuletum pubescentis*. Średnio retranslokacji ulega 11,5% T-N, w tym 41,4% $N\text{-}NH_4$ i 23,8% $N\text{-}NO_3$ oraz 22,3% P, w tym 11,8% $P\text{-}PO_4$.