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# Trophic conditions of forest soils of the Pieniny National Park, southern Poland

*Abstract*: The primary objective of this study was to characterise the edaphic conditions of forest areas in the Pieniny National Park (PNP), and to describe the dependencies between properties of forest soils and types of forest plant communities. The "Soil Trophic Index" (SIGg) for mountainous areas was applied. The evaluation of the trophism for 74 forest monitoring employed the soil trophic index for mountainous areas SIGg or SIGgo. Plant communities in the forest monitoring areas were classified according to the Braun-Blanquet's phytosociological method. Soils of PNP present in the forest monitoring areas were mostly classified as eutrophic brown soils (72.9%), rendzinas (10.8%), brown rendzinas (5.41%), and rubble initial soils (5.41%). Pararendzinas, dystrophic brown soils, and gley soils were less common (total below 5.5%). In the forest monitoring areas of PNP, eutrophic soils predominate over mesotrophic soils. High SIGg index of the soils is caused by high values of acidity and nitrogen content. The Carpathian beech forest *Dentario glandulosae-Fagetum* and thermophilic beech forest *Carici albae-Fagetum* associations are characterised by high naturalness and compatibility of theoretical habitats. The soils of the Carpathian fir forest *Dentario glandulosae-Fagetum abietetosum* subcommunity is characterised by a higher share of silt and clay particles and lower acidity as compared to the Carpathian beech forest *Dentario glandulosae-Fagetum typicum* subcommunity. The soils of the forest monitoring areas in PNP stand out in terms of their fertility against forest soils in other mountainous areas in Poland.

*Keywords*: Carpathian soil, soil trophic index, forest plant community

## INTRODUCTION

The soil cover of the Pieniny National Park (PNP) is characterised by variability particularly resulting from the variability of the bedrock, land relief, hydrological conditions, and modern morphogenetic and pedogenetic processes. These are also the primary factors determining the variability of the trophism of forest and meadow habitats in the Park. They are characterised by species richness and strong variability of plant communities caused among others by the natural variability of the soil cover and humidity conditions of the habitat (Kaźmierczakowa, red. 2004, Bodziarczyk et al. 2016).

Detailed research on the soil cover in the Park (PPN) was initiated in the 1960's by a team supervised by Adamczyk (Adamczyk et al. 1980, 1982). Later publications and cartographic studies, also partially referring to the vegetation cover, updated information on the soil cover for modern classifications (Niemyska-Łukaszuk et al. 2002, 2004; Skiba et al. 2002, Kaźmierczakowa, red. 2004).

In the years 2014–2016, detailed field research was conducted regarding the soil conditions in circular forest monitoring areas in PNP, providing the basis for the preparation of a large-scale map of forest soils of the Park (Zaleski et al. 2016). The forest monitoring areas are dominated by fertile meso- and eutrophic soils, particularly brown soils (58%) and rendzinas of different subtypes (approximately 37%) (Zaleski et al. 2016). Common parameters of the soils include: neutral or alkaline reaction, and loamy or clayey grain composition of decayed rock. Forest soils of the Park, however, even within the same type, are characterised by a variability of the thickness of particular genetic horizons, contribution of skeleton fractions, and content of organic matter (Zaleski et al. 2016). This largely determines the edaphic conditions in the forest areas of the Park.

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The objective of this paper was to characterise the edaphic conditions of the forest areas of the Pieniny National Park, and to determine the dependencies between properties of forest soils and types of forest plant communities. The research was conducted on the soils of permanent forest monitoring areas, distributed systematically-randomly in the area of PNP (Zaleski et al. 2016). The study employed the Soil Trophic Index for mountainous areas (SIGg) introduced by Brożek et al. (2015). Numerical trophic soil indices have been improved and modified for many years in forestry, and are commonly used in the diagnosis of forest habitats (Brożek and Zwydak 2003, Brożek 2001, 2007; Brożek et al. 2011 a, b).

## MATERIALS AND METHODS

The scope of research covered conducting field works within 373 forest monitoring areas distributed in nodes of a regular grid with a square side of 200 m, and – additionally – in selected small patches of soils located outside the grid. Fully analysed soil pits were performed in 100 areas, and extended reach drilling in 277 areas. A total of 582 soil samples were collected for analyses from genetic horizons, including 117 organic and 465 mineral horizons. In all forest monitoring areas, the systematic classification of soils was determined (type and subtype of soil) according to the Polish Soil Classification (SgP 2011). A soil map was prepared based on data obtained from soil pits and extended reach drillings.

The evaluation of soil trophism in the forest monitoring areas was performed based on the value of the Trophic Soil Index for mountainous areas SIGg or SIGgo (for soils with organic horizon > 20 cm) calculated according to formula 1 or 2:

$$SIGg = (W_{CZSg} + W_{S1g} + W_{Yg} + W_{Ng}) \cdot W_{kl} \quad (1)$$

$$SIGgo = (W_{S1g} + W_{Yg} + W_{Ng}) \cdot 1.333 \cdot W_{kl} \quad (2)$$

where:

$W_{CZSg}$ – index of resources of fraction q< 0.02 mm in 1 $m^3$ of soil

$W_{S1g}$ – index of resources of alkaline cations in 1 $m^3$ of soil

$W_{Yg}$ – index of recalculated acidity in 1 $m^3$ of soil

$W_{Ng}$ – index of recalculated nitrogen $N^2 \cdot C^{-1}$ in the first mineral humic horizon

$W_{kl}$ – reduction (climatic) index expressed as a ratio of 650/height of location of a point in m a.s.l., considered for areas located above 650 m a.s.l.; for areas located below that height $W_{kl} = 1$.

SIG calculations involved the designation of 74 forest areas evenly distributed in PNP (Fig. 1). The following was determined in the designated genetic horizons of soils: grain composition according to PN-R-04032, pH (in $H_2O$ and 1 $mol \cdot dm^{-3}$ KCl), total carbon (TC), and total nitrogen (TN) in analyser CNS Leco 2000, content of alkaline cations (Ca, Mg, K, Na) after extraction in 1 $mol \cdot dm^{-3}$ $CH_3COONH_4$ with pH 7.0, hydrolytic acidity after extraction in 0.5 $mol \cdot dm^{-3}$ $(CH_3COO)_2Ca$ by means of the Kappen's method, and content of $CaCO_3$ by means of the Scheibler's method.

In all permanent forest monitoring areas, phytosociological relevés were performed in 2012 by means of the Braun-Blanquet's method (Bodziarczyk et al. 2016). They were used for the phytosociological diagnosis of the analysed vegetation patches. The analysis concerned values of all parameters used in the determination of the SIGg index for mountainous areas. The obtained SIGg values were used for the evaluation of the spatial variability of habitat conditions of PNP and comparison between particular forest plant communities. Names of plant communities were adopted following Matuszkiewicz (2013), and supplemented according to a more detailed study concerning plant communities of the Pieniny National Park (Bodziarczyk and Pancer-Koteja 2004).

The results were processed statistically considering measures such as: minimum and maximum values, standard deviation and median, and arithmetic mean. A normality test (Shapiro-Wilk W test) was performed in Statistica 10.0 software. Because the analysed variables did not show a normal distribution, a non-parametric Kruskal-Wallis test was performed for the purpose of verification of differences between soils overgrown by different forest plant communities and between different subtypes of soils.

## RESULTS AND DISCUSSION

Soils of the forest monitoring areas in the Pieniny National Park for which the trophic soil index (SIGg) was calculated were represented by the following types of soils: eutrophic brown soils (72.9%), rendzinas (10.8%), brown rendzinas (5.41%), and rubble initial soils (5.41%). Pararendzinas, dystrophic brown soils, and gley soils were less common, with contributions not exceeding 3%. Such a selection of analysed types of soils for the determination of trophism is a reflection of the actual contribution of particular soil units in all 373 forest monitoring areas (Fig. 1) (Zaleski et al. 2016).

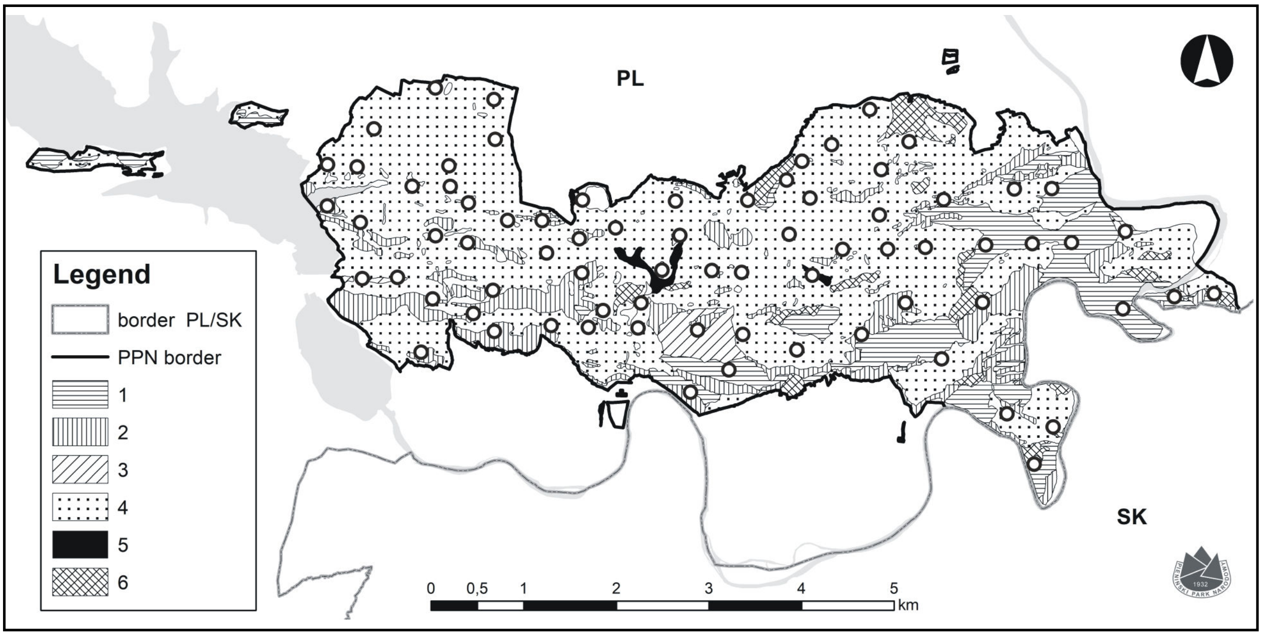


FIGURE 1. Soil Map of the Pieniny National Park. Dominant soils types according to the Polish Soil Classification (2011) are marked on the map: 1 – raw rocky and raw debris soils, 2 – proper rendzinas, 3 – pararendzinas, 4 – eutrophic brown earths, 5 – acid brown earths, 6 – brown rendzinas; black rings mark monitoring areas

Soil parameters considered in the calculation of the SIGg index were characterised by quite high variability. The variability coefficients for particular parameters amounted to: 46.5% ($C_{ZSVg}$), 51% ($S_{1Vg}$), 89.8% ($Y_{Vg}/C_{ZSVg}$), and 53.7% ($N^2 \cdot C^{-1}$), respectively. Mean reserve of floatable fractions amounted to 534 $kg \cdot m^{-3}$. This suggests that the soils were on average characterised by high values of the index of content of floatable fractions ($W_{CZSg}$=9 on a 10-grade scale) (Table). In the soils of Pieniny, the high reserve of floatable fractions results from the heavy grain structure of weathered rocks, dominated by loamy and dusty formations (Zaleski et al. 2016).

The analysed soils were on average characterised by very high values of content of total cations ($W_{S1g}$=9 on a 10-grade scale). The value of mean recalculated acidity for the soils of Pieniny corresponded with the maximum value ($W_{Yg}$=10) of the index in the applied methodology of calculation of SIGg (Brożek et al. 2015). Content of recalculated nitrogen was characterised by relatively high values averaging 0.026. Such a value corresponds with maximum values of the index of recalculated nitrogen ($W_{Ng}$=10). High content of nitrogen in the soils results from the character of organic matter, dominated by well decomposed mull. High content of mean resources of alkaline cations and low mean content of recalculated acidity result from the mineralogical composition of the parent material and soil slope covers, and presence of primary and secondary carbonates in the soil profile (Birkenmajer 1981, Adamczyk et al.1980, 1982; Niemyska-Łukaszuk et al. 2002, 2004; Skiba et al. 2002, Zaleski et al. 2006, Zaleski et al. 2016).

31 of the analysed soils were located above 650 m a.s.l. This forces the application of the reduction climatic index lowering values due to mountainous climate conditions in the calculation of SIGg (Brożek et al. 2015).

The reduction climatic index was applied for 41.9% of total analysed soils. In spite of that, the mean trophic soil index (SIGg = 34.6) was within the range of the category of eutrophic soils (SIGg = 34–40) (Table). The contribution of eutrophic soils amounted to 67.6%. They were dominated by the following soils: typical eutrophic brown soils (56%), endoeutric eutrophic brown soils (22%), typical brown rendzinas (6%), and rubble rendzinas (6%). Pseudogley eutrophic brown soils, typical rendzinas, and typical pseudogley eutrophic chernozem rendzinas were less common. Somewhat less fertile mesotrophic soils (SIGg = 24–33) accounted for 32.4%. In typological terms, they belonged to different units. The group was dominated by typical eutrophic brown soils (33%), endoeutric brown soils (25%), and typical rendzinas (21%). Typical pararendzinas, typical dystrophic brown soils, typical brown rendzinas, rubble rendzinas, and typical gley soils reached a lower contribution (Table).

It is worth emphasising that soils characterised by the lowest componential SIG indices ($W_{CZSg}$=2, TABLE. Statistical analysis components of componential indexes, SIGg index and selected location parameters of the forest monitoring areas in PNP

| Statistical parameter | Elevation | Slope | Czs vg Content of the Ø< 0.02 mm fraction | S vg Total exchangeable alkaline cations | Yvg/$CZ_{svg}$ Recalculated acidity | $N^2/C$ Recalculated nitrogen | Indices | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | m a.s.l. | degree ° | kg·m$^{-3}$ | mol· m$^{-3}$ | | | $W_{CZSg}$ | $W_{S1g}$ | $W_{Yg}$ | $W_{Ng}$ | $SIG_g$ |
| All monitoring areas | | | | | | | | | | | |
| arithmetic mean | 649.07 | 22.4 | 534.17 | 173.08 | 0.072 | 0.026 | 8.27 | 8.84 | 9.78 | 9.45 | 34.63 |
| stand. dev. | 84.51 | 10.4 | 248.49 | 88.21 | 0.064 | 0.014 | 1.20 | 0.79 | 0.53 | 1.06 | 3.32 |
| minimum | 468.06 | 2 | 43.20 | 5.56 | 0.003 | 0.005 | 2 | 4 | 7 | 4 | 24.07 |
| maximum | 838.00 | 44 | 1030.38 | 449.42 | 0.415 | 0.103 | 10 | 10 | 10 | 10 | 39 |
| median | 636.40 | 21 | 566.00 | 171.98 | 0.054 | 0.024 | 9 | 9 | 10 | 10 | 36 |
| n | 74 | 74 | 73 | 74 | 74 | 74 | 73 | 74 | 74 | 74 | 74 |
| Thermophilic beech forest *Carici-albae Fagetu*m | | | | | | | | | | | |
| arithmetic mean | 602.19 | 32.9 | 575.99 | 222.44 | 0.047 | 0.031 | 8.63 | 9.13 | 10.00 | 9.63 | 36.24 |
| stand. dev. | 98.09 | 8.7 | 191.55 | 107.27 | 0.030 | 0.017 | 0.74 | 0.35 | 0.00 | 0.74 | 2.20 |
| minimum | 468.06 | 17 | 195.30 | 119.61 | 0.007 | 0.015 | 7 | 9 | 10 | 8 | 32.68 |
| maximum | 748.18 | 44 | 841.45 | 449.42 | 0.081 | 0.065 | 9 | 10 | 10 | 10 | 38 |
| median | 576.52 | 34.5 | 599.73 | 195.44 | 0.044 | 0.025 | 9 | 9 | 10 | 10 | 37.1 |
| n | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Carpathian beech forest *Dentario glandulosae-Fagetum* | | | | | | | | | | | |
| arithmetic mean | 684.71 | 19.4 | 469.00 | 139.02 | 0.106 | 0.028 | 8.10 | 8.67 | 9.57 | 9.33 | 33.07 |
| stand. dev. | 69.82 | 10.5 | 216.03 | 73.70 | 0.087 | 0.021 | 1.09 | 1.11 | 0.75 | 0.97 | 4.01 |
| minimum | 559.45 | 2 | 95.16 | 5.56 | 0.022 | 0.009 | 5 | 4 | 7 | 7 | 24.07 |
| maximum | 790.26 | 40 | 789.10 | 331.37 | 0.415 | 0.103 | 9 | 9 | 10 | 10 | 38 |
| median | 681.77 | 16 | 469.41 | 135.17 | 0.078 | 0.022 | 8 | 9 | 10 | 10 | 34.94 |
| n | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 |
| Thermophilic Carpathian fir forest *Dentario glandulosae-Fagetum abietetosu*m | | | | | | | | | | | |
| arithmetic mean | 643.94 | 18.3 | 700.93 | 200.47 | 0.042 | 0.024 | 8.80 | 8.70 | 10.00 | 8.90 | 35.22 |
| stand. dev. | 75.57 | 9.6 | 172.12 | 99.92 | 0.026 | 0.012 | 0.42 | 1.34 | 0.00 | 1.85 | 3.45 |
| minimum | 558.28 | 5 | 401.73 | 9.01 | 0.009 | 0.005 | 8 | 5 | 10 | 4 | 28.74 |
| maximum | 785.24 | 34 | 876.47 | 353.58 | 0.090 | 0.044 | 9 | 10 | 10 | 10 | 38 |
| median | 626.40 | 19 | 728.58 | 209.86 | 0.038 | 0.022 | 9 | 9 | 10 | 9.5 | 37 |
| n | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

$W_{S1g}$<6, $W_{Ng}$<7) were in two cases a substrate for fertile Carpathian beech forest *Dentario glandulosae-Fagetum abietetosum* fir forest subcommunity in floristically poor variant, in one case for a patch of typical *Dentario glandulosae-Fagetum typicum*, and in one case for a patch with parameters less distinctive in terms of phytosociological criteria, categorised to the *Fagion* association. The only typical dystrophic brown soil in the analysed group occurred in the typical patch of fertile Carpathian beech forest *Dentario glandulosae-Fagetum typicum*. Similar brown soils with loamy grain structure and saturation with alkaline cations higher than 50% usually constitute substrate for eutrophic or mesotrophic deciduous forests, hence the specification of the soil unit in the Polish Soil Classification (2011) as dystrophic is unfortunate.

The comparison of the components of the trophic soil index in groups of soils ascribed to the described plant communities showed variability, usually not supported by statistically significant differences. Mean reserve of floatable fractions, however, was the highest ($C_{ZSVg}$ = 701 kg·m$^{-3}$) in the soils of fertile Carpathian beech forest in fir subcommunity *Dentario glandulosae-Fagetum abietetosum* (Table). Lower values of the parameter (576 kg·m$^{-3}$ and 469 kg·m$^{-3}$) were calculated for the soils of thermophilic beech forest *Carici albae-Fagetum typicum* (with no contribution of fir) and fertile Carpathian beech forest *Dentario glandulosae-Fagetum typicum*. The highest mean resources of alkaline cations concerned soils under patches of thermophilic beech forest (222 $mol \cdot m^{-3}$) and fertile Carpathian beech forest in fir subcommunity (200 $mol \cdot m^{-3}$)and its typical form (139 $mol \cdot m^{-3}$). In terms of mean recalculated acidity, relatively low values were calculated for the soils of thermophilic beech forest and fertile Carpathian beech forest in fir subcommunity, but somewhat higher acidity (0.10) characterised patches typical of fertile Carpathian beech forest (Table). It should be emphasised, however, that differences in recalculated acidity are low, and all mean values are typical of forest eutrophic soils. Mean values of recalculated nitrogen in the soils of all plant communities exceed the threshold value ($N^2 \cdot C^{-1} > 0.02$) of the highest componential SIGg index ($W_{Ng}$=10).

The final evaluation of the trophism of the analysed soils suggests that the soils of thermophilic beech forest *Carici albae-Fagetum typicum* with no contribution of fir (SIGg=36.2) and fertile Carpathian beech forest in fir subcommunity *Dentario glandulosae-Fagetum abietetosum* (SIGg=35.2) belong to eutrophic habitats of mountainous forests. Soils in typical patches of fertile Carpathian beech forest *Dentario glandulosae-Fagetum typicum* (SIGg=33.07) can be described as mesotrophic, corresponding in typological terms with more fertile habitats of mixed mountainous forest and mountainous forest. *Dentario glandulosae-Fagetum* and *Carici albae-Fagetum* communitues are the main forest plant communities of the Park. They occupy a total of 85% of the forest area. Fertile Carpathian beech forest in the Park is characterised by more uniform floristic composition than thermophilic beech forest (Bodziarczyk and Pancer-Koteja 2004). Apart from that community, part of forest plant communities in forest monitoring areas are non-uniform patches with a transitional or mosaic character. Part of data on soils from the permanent areas was therefore limited by credible comparison of the reported plant communities. The only statistically significant differences between mean values of soil parameters – SIGg components – were evidenced in the comparison of fertile Carpathian beech forest in fir subcommunity with the typical form of the beech forest characterised by lower than in the case of fir subcommunity reserve of floatable fractions and higher recalculated acidity. The association of thermophilic beech forests *Carici albae-Fagetum* with southern expositions with high slope inclination (averaging 33°) observed in the analysed groups of soils (although not statistically significant (Table), is in accordance with the patterns determined earlier (Różański and Bodziarczyk 1995).

The comparison of parameters of the forest soils of the monitoring areas of PNP considered in the estimation of trophism by means of the SIG method with mean parameters of 180 soils representing full variability of the lithological-climatic conditions of the remaining Polish mountain ranges – from Bieszczady to Góry Izerskie (Brożek et al. 2016) shows evident distinctiveness of the soils of PNP (Fig. 2).

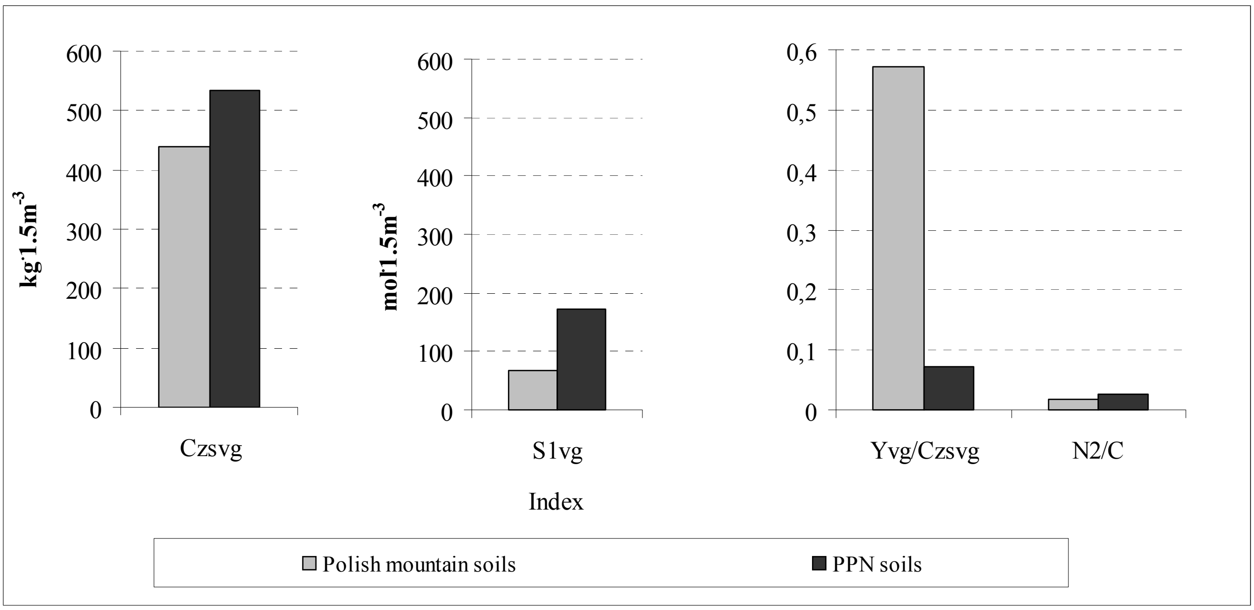


FIGURE 2. Componential indices of the Trophic Soil Index (SIGg) of soils of the Pieniny National Park (n=74) and the remaining mountain forest soils of Poland (n=180) (source: Brożek et al. 2016)

It is manifested the most in more than 2.5 times higher mean reserve of alkaline cations and very low recalculated acidity the value of which for the soils of PNP constitutes less than 13% of the mean value for mountainous forest soils. Less considerable differences occur for mean values of recalculated nitrogen and reserve of floatable fractions which in the soils of PNP were higher by 54.8% and 21.6% respectively than the mean value for mountainous soils in Poland. The high value of the SIGg index in the soils of PNP corresponds well with plant communities, suggesting proper adjustment of the vegetation to the soil environment.

## CONCLUSIONS

In the forest monitoring areas in the Pieniny National Park, eutrophic soils are largely predominant. High evaluation of the fertility of the soils results from high values of indices of recalculated acidity and recalculated nitrogen.

The soils of fertile Carpathian beech forest in fir subcommunity *Dentario glandulosae-Fagetum abietetosum* are characterised by a higher reserve of floatable fractions and lower recalculated acidity in comparison to the soils of the typical form of fertile Carpathian beech forest *Dentario glandulosae-Fagetum typicum*. The soils of forest monitoring areas of the Pieniny National Park are characterised by higher fertility than forest soils from other mountainous regions in Poland.

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# Trofizm gleb leśnych Pienińskiego Parku Narodowego

*Streszczenie*: Celem niniejszej pracy była charakterystyka warunków edaficznych obszarów leśnych Pienińskim Parku Narodowym (PPN) oraz opis zależności pomiędzy właściwościami gleb a typami zbiorowisk leśnych. W opracowaniu wykorzystano siedliskowy indeks glebowy dla obszarów górskich (SIGg). Ocenę trofizmu wykonano dla 74 gleb na powierzchniach monitoringowych w oparciu o wartość siedliskowego indeksu glebowego dla obszarów górskich SIGg lub SIGgo. Na powierzchniach monitoringowych wykonano również zdjęcia fitosocjologiczne metodą Braun-Blanqueta. Gleby leśne PPN badane na powierzchniach monitoringowych, reprezentowane były przez następujące typy gleb: brunatne eutroficzne (72,9 %), rędziny właściwe (10,8%), rędziny brunatne (5,41%) i gleby inicjalne rumoszowe (5,41%). Mniej licznie reprezentowane były pararędziny, gleby brunatne dystroficzne i gleby glejowe – łącznie mniej niż 5,5%. W obrębie leśnych powierzchni monitoringowych w PPN przeważają gleby eutroficzne z niewielkim udziałem gleb mezotroficznych. Duża żyzność tych gleb wynika z wartości wskaźników kwasowości przeliczonej i azotu przeliczonego. Stanowiska żyznej buczyny karpackiej *Dentario glandulosae-Fagetum* i ciepłolubnej buczyny *Carici albae-Fagetum* cechuje duża naturalność i zgodność z siedliskiem. Gleby żyznej buczyny karpackiej w podzespole jodłowym *Dentario glandulosae-Fagetum abietetosum* wyróżniają się większym zapasem części spławialnych i mniejszą kwasowością przeliczoną w porównaniu do gleb typowej postaci żyznej buczyny karpackiej *Dentario glandulosae-Fagetum typicum*. Gleby leśnych powierzchni monitoringowych PPN wyróżniają się większą żyznością niż leśne gleby innych górskich regionów w Polsce.

*Słowa kluczowe*: gleby Karpat, siedliskowy indeks glebowy, zbiorowiska leśne