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Biodiversity indexes in relation to soil properties in upland fir forests (*Abietetum albae*)

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Abstract. The aim of this study was to present the relationship between soil properties and biodiversity indexes in upland fir (*Abies alba*) forest associations (*Abietetum albae*). Our study was conducted in six areas representing the growth conditions of upland fir forests and the research plots were located in the Roztoczański and Świętokrzyski National Parks as well as Przedbórz, Radomsko, Piotrków and Janów Lubelski Forest District. On every plot, the topography was described, soil cores were examined and samples for laboratory analysis were taken. The following characteristics were determined for the soil samples: pH, C, N, Ca, Mg, Na and K content, particle size, exchangeable acidity, aluminum content and hydrolytic acidity. Additionally, enzyme activity in the soil samples (urease and dehydrogenase) was measured. In each test area, the stand characteristics were measured (diameter at breast height and height), floristic characteristics were described and the biodiversity indexes (Shannon, Simpson and Margalef indexes) were calculated. Different soil types (Gleysols, Brunic Arenosols, Gleyic Podzols and Hyperdistric Cambisols) were recorded for the investigated forest stands and the soils were categorized according to soil texture, C content, enzyme activity and different humus types (moder-mor, moder, moder-mull). The upland mixed coniferous forest sites were characterized by lower biodiversity indexes (2.6 Shannon index; 0.72 Simpson index; 4.9 Margalef index) while the upland mixed broadleaf forest sites showed higher indexes (3.3 Shannon index; 0.87 Simpson index; 9.4 Margalef index). The site index obtained for the fir stands confirmed these results.

Keywords: forest sites, biodiversity indexes, soil properties, *Abietetum albae*

1. Introduction and aim of the study

The ability to shape the species diversity of forest ecosystems is conditioned by site factors. As the fertility of forest sites increases, so usually does the species diversity of vascular plants of the forest floor (Puchalski, Prusinkiewicz 1990). One of the factors that is taken into account in assessing the trophism and humidity of a site is forest floor vegetations. The so-called differential species with relevant ecological requirements allow to determine a partial diagnosis of a site in a typological system, also known as the ecological system (Sikorska 2006; Lasota, Błońska 2013; CILP 2012). The relationship of forest floor vegetation to the surface horizons of the soil and plants' reaction to this expressed by the spatial structure of their occurrence can make them good bioindicators (Roo-Zielińska 2004).

The aim of this study is to look for the relationships between soil features and the empirical indicators of plant cover species diversity, trophism and moisture content, which were formulated as the result of studies carried out in upland fir forests (*Abietetum albae*) in six selected sites of southeastern and central Poland. We hypothesised that the biodiversity indicators determined based on the vegetation in upland fir forest plots differ depending on the type of forest habitat in which the association developed. The upland mixed fir forest is a protected association under the NATURA 2000 programme, located in the area of the South Poland Uplands Divide and the Brandenburgian and Greater Poland Divide (the area of the Trzebnicki Ridge) (Macicka, Wilczyńska 1985; Frost, Łabaj 2004; Świerkosz et al. 2014; Barć et al. 2015). In this paper, the structure of the forest floor plant cover and the indexes calculated on this basis were compared to the physical, chemical and biochemical properties of the soil's humus horizon.

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2. Materials and methods

The study was conducted in six selected plots of upland fir forests (*Abietetum albae*) located in southern and central Poland forest reserves (Table 1). The tree stands selected for the study were over 80 years of age, similar in terms of canopy density (0.7–0.8), and having well-developed forest floor vegetation of species recognised as typical for upland fir forests (Matuszkiewicz 2001). Soil tests, a detailed list of forest floor vegetation and tree measurements were made of each analysed stand in July. A deep (up to 1.5 m) pit was dug in the soil in the central part of each plot to take samples for further laboratory analysis. Soil samples from the surface humus horizons were taken as a pooled sample from the open pit and four sites around the pit (within a radius of up to 10 m). Using the Braun–Blanquet method, a vegetation survey of a 10 are area was conducted in each study plot. Trees with a diameter at breast height of more than 7 cm located within a circular area of 0.25 ha were measured. On the basis of the upper height, age and model proposed by Zasada (1995), the bonitation of the fir was determined by their predicted height at 100 years of age (B_{100}). The scale proposed by Zarzycki et al. (2002) was used to determine the values of the ecological index numbers of vascular plants in Poland.

The diagnosis of forest site type was determined according to forest management principles (CILP 2012). Half of the analysed areas were categorised as upland mixed coniferous (BMwyż) and half as fresh mixed broadleaf (LMśw) or upland mixed broadleaf (LMwyż). The relatively varied edaphic conditions in which the *Abietetum albae* association plots developed reflect the geological formations and types and subtypes of soils present (Table 1). The detailed characteristics of soil properties of the studied upland forest plots and the definition of the soil habitat index is found in the work of Lasota et al. (2011).

The methods used to determine the basic soil properties are those commonly used in soil science (Ostrowska et al. 1991), that is,

- soil pH analysis in distilled water (pH_{H2O}) and in 1M KCl (pH_{KCl}) with the potentiometric method,
- particle size according to the PTG 2008 classification of particle size with the Bouyoucos–Casagrande areometric method modified by Prószyński,
- total organic carbon content (Corg.) and total nitrogen (N) using the Leco CNS 2000 auto-analyser, based on the C:N ratio,
- colorimetric hydrogen and exchangeable aluminium in an extract of 1M KCl,
- colorimetric hydrolytic acidity (Y) in an extract of 1M $(CH_3COO)_2Ca$,
- the content of interchangeable forms of Ca, K, Mg and Na in an extract of 1M CH_3COONH_4 with the ASA method,
- soluble phosphorus (P) with the Bray and Kurtz method.

In addition, the activity of selected soil enzymes was determined in naturally humidified samples from the first humus-mineral horizon. The enzymatic activity of dehydrogenases was determined with the Lenhard method according to

Table 1. Characteristics of reserach plots of upland fir forest *Abietetum albae*

Research plots	Forest District/ National Park	Reserve	Elevation asl [m]; exposition; slope	Type and subtype of soil	Parent material	Site type Species composition
AbP1	Janów Lubelski	Lasy Janowskie	214; SW; 1	Albic Brunic Arenosol	glacial sand on boulder clay	LMśw; 5 So, 5 Jd pjd Św
AbP2	Piotrków	Wielkopole	227; NE; 3	Haplic Stagnosol	aeolian sand on boulder clay	BMwyżśw; 10 Jd
AbP3	Przedbórz	Czarna Rózga	231; 0	Gleyic Podzol	alluvial sand	BMwyżśw; 10 Jd, pjd So
AbP4	Radomsko	Kobiele Wielkie	251; 0	Haplic Stagnosol	aeolian silt on boulder clay	BMwyżśw; 8 Jd, 1 So, 1 Db
AbP5	Świętokrzyski PN	Sztymber	384; NE; 13	Haplic Cambisol	loess on quartzit	LMwyżśw; 9 Jd, 1 Bk pjd Brz
AbP6	Roztoczański PN	Czerkies	254; NE; 2	Haplic Stagnosol	alluvial sand	LMwyżśw; 10 Jd

TSL – type of forest site, LMśw – fresh mixed deciduous forest, BMwyżśw – fresh upland mixed coniferous forest, So – pine, Jd – fir, Db – oak, Bk – beech, Brz – birch

Casida et al. (Alef, Nannipieri 1995) and expressed as μmol TFFkg^{-1}·h^{-1}. Urease activity was determined with the Tabatabai and Bremner method, expressed as mmol NH_4^+·kg^{-1}·h^{-1} (Alef, Nannipieri 1995).

For each plot, numerical ratios were determined based on the floristic data. The first indicator is the number of vascular plants, which is the sum of vascular plant species occurring in the plots where phytosociological surveys were conducted. Three floristic biodiversity indicators were calculated in the study: Margalef (Sienkiewicz 2010), Shannon and Simpson (Nagendra 2002). To calculate them, the Braun–Blanquet scale was transformed into percentages; thus 'r' and '+' coverage were replaced by 0.1%, 1–5%, 2–17.5%, 3–37.5%, 4–62.5% and 5–87.5%.

The Margalef index (MRI) was calculated using the following equation:

$$MRI = (S - 1)/logN$$

where
S is the number of all species,
N is the abundance of individuals expressed in percentage.

The Shannon (SHDI) and Simpson (SIDI) indexes were calculated using the following equations:

$$SHDI = 1 - \sum p_i \times ln\, p_i$$

$$SIDI = 1 - \sum p_i \times p_i$$

where
p_i is the share (proportion) of i species in relationship to the sum of the shares of all species in the association.

In addition, the trophic (Tr) and moisture content (W) indexes were calculated for each plot based on the ecological numbers of vascular plants developed by Zarzycki et al. (2002), taking into account the methodology proposed by Różański (1984). These indexes express the average weighted trophic (W_{TR}) or moisture content (W_W), with the weight representing the degree of coverage of particular species.

A site soil index (SIG) was used in the analysis, which was calculated using the four parameters characterising the soil's pedon, that is, the total content of the floating fraction, the sum of the alkaline exchange cations, total acidity in relation to the amount of floating fraction in a 1.5-m^3 block of soil and the quotient of nitrogen in the C:N ratio in the first humus-mineral horizon (Brożek et al. 2007, 2011).

3. Results

The basic properties of the humus-mineral soil horizon of the analysed plots of upland fir forests are presented in Table 2. These plots exhibit large variation in organic carbon and nitrogen content, organic matter decomposition expressed by the C:N ratio as well as the level of acidification, content of exchangeable aluminium and alkaline cations.

The plant characteristics of the studied *Abietetum albae* association plots varied with the wide variability of the features of the soil's humus horizons. These plots have a varied number of vascular plant (4–15) and moss species (2–8) (Fig. 1). Higher numbers of vascular plant species (14–15) are found in upland fir forest plots that developed in fresh broadleaf forest (LMśw) or upland fresh broadleaf forest (LMwyżśw) sites compared to plots occupying the poorer upland mixed coniferous forest site (BMwyżśw), where only 4–7 species of vascular plants were recorded on the forest floor. The plots are characterised by a well-developed moss layer, typical for this association. Fourteen species of bryophytes were identified in six research sites. Figure 1 shows the ratio of the number of vascular plant species and bryophytes. The area of each *Abietetum albae* study plot had numerous *Polytrichastrum formosum*, whilst *Thuidium tamariscinum* and *Pleurozium schreberi* as well as the smaller *Plagiothecium denticulatum* were also found in five of the six plots (Table 4).

The Shannon, Simpson and Margalef indexes, as well as the number of vascular plants, were confronted with the properties of the soil deposits. The upland fir forest study plots are characterised by a high diversity of flora (Table 3). The biodiversity indexes divided the area into two groups, identical to the trophic sites expressed by the forest site type and the productivity determined by the fir bonitation. The first of these – more fertile, with higher values of diversity indexes – covers areas AbP1, AbP5 and AbP6, which are mixed forest sites. These areas are characterised by Shannon values of 3.2–3.3, Simpson values of 0.86–0.88 and Margalef values of 8.9–9.7. The higher productivity of mixed forest sites is confirmed by the more favourable fir bonitation rates (B_{100} of 31–34.4 m). The areas of AbP2, AbP3 and AbP4 (categorised as upland fresh mixed coniferous sites) were characterised by lower biodiversity index values (2.3–2.7, 0.62–0.79 and 4.2–5.4) and lower fir bonitation (B_{100} of 22.9–30.1 m). This division was not reflected by the number of vascular plants, whose scope extended in a wide range from 4 (AbP3) to 15 (AbP1 and AbP6) (Table 3).

The trophic index of the analysed fir forest plots is from 2.46 to 3.00. Three of the study plots are characterised by low trophic rates (2.46–2.50), three others are slightly higher (2.90–3.00). In one case, the indexes thus calculated did not coincide either with the site types identified in the typological system or with the sites soil index values (Table 3). The second of the calculated values based on the ecological numbers of vascular plants –moisture content – is in the range of 2.00–3.45. The lowest value of this index was

Table 2. Selected physical and chemical properties of humus-mineral horizon

		AbP1	AbP2	AbP3	AbP4	AbP5	AbP6
Texstural group		pl	pl	pl	pyz	pyz	pl
Sand		90	92	89	47	38	90
Silt		8	7	9	46	52	9
Clay	[%]	2	1	2	7	10	1
Corg.		1.23	3	5.11	4.34	7.44	0.55
Nt		0.03	0.1	0.11	0.2	0.44	0.03
C/N		35	31	45	22	17	16
pH_{H2O}		3.52	3.66	3.58	3.98	4.26	4.12
pH_{KCl}		2.92	2.82	2.65	3.11	3.25	3.38
H		2.8	2.48	5.51	8.16	8.47	2.02
Al	$cmol(+) \cdot kg^{-1}$	2.47	2.2	4.9	7.9	7.98	1.93
Y		7.34	10.53	38.12	17.04	25.16	4.05
Ca		1.18	7.38	5.31	7.89	49.54	1.9
K		1.04	2.32	2.51	6.15	9.9	0.99
Mg	$mg \cdot kg^{-1}$	0.3	0.64	0.48	6.15	4.79	0.22
Na		0.27	0.66	0.43	0.55	0.66	0.21
P		0.88	1.26	1.12	13.48	4.83	5.81

pl – sand, pyz – silt, Y – hydrolitic acidity

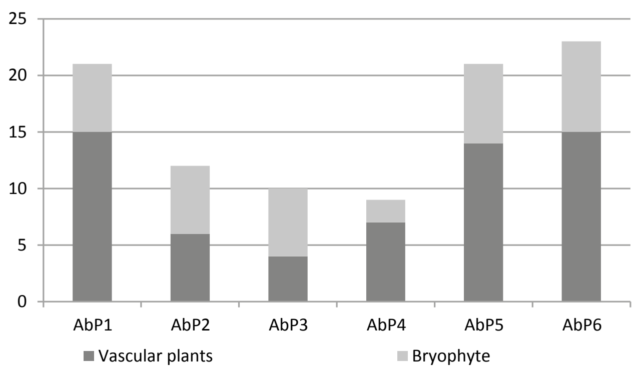

Figure 1. The ratio of the number of vascular plant species to mosses on the investigated plots

calculated for the AbP4 area, whose soils consists of Haplic Stagnosols characterised by fine grain size, whereas the highest values were calculated for AbP1 and AbP2, which had sands on boulder clay.

The enzymatic activity of dehydrogenases and urease was determined for the accumulated humus horizon. The enzymatic activity of the examined soils was strongly differentiated. The dehydrogenase activity was in the range of 3.3–20.7 µg TFF $1g^{-1}24\ h^{-1}$. The highest activity of dehydrogenase was found for the soil of plot AbP5, where the habitat was defined as upland fresh broadleaf forest (LMwyżśw). The urease activity ranged from 3.7 to 17.8 µg $N–NH_4\ g^{-1}\ 2\ h^{-1}$. The highest activity of urease was noted for plot AbP2, categorised as an upland fresh mixed coniferous forest habitat (BMwyżśw).

4. Discussion

The presented analysis confirms the large diversity of site conditions in which upland fir forests form. The small number of areas in the plots of well-preserved upland fir forests provides the whole spectrum of soil conditions of this association (from Podzols through Arenosols, Haplic

Table 3. Selected soil and vegetations indexes in the investigated upland fir forest

Index	SHDI	SIDI	MRI	LRN	W_{TR}	W_W	AU	ADh	SIG	B_{100}
AbP1	3.3	0.87	8.9	15	2.93	3.45	13.4	3.3	24	31.0
AbP2	2.7	0.76	5.0	6	3.00	3.45	17.8	12.0	31	30.1
AbP3	2.7	0.79	4.2	4	2.50	3.25	7.5	6.4	17	28.1
AbP4	2.3	0.62	5.4	7	2.46	2.00	8.5	18.9	24	22.9
AbP5	3.2	0.88	9.7	14	2.9	3.17	13.0	20.7	33	32.7
AbP6	3.3	0.86	9.6	15	2.46	2.66	3.7	11.2	13	34.4

SHDI – Shannon biodiversity index, SIDI – Simpson biodiversity index, MRI – Margalef index, LRN – amount of vascular plant species, W_{TR} – trophic index calculated on the basis of ecological value vascular plant, W_W – moisture index calculated on the basis of ecological value vascular plant, AU – urease activity [mmol NH_4^+ $kg^{-1} h^{-1}$], ADh – dehydrogenase activity [µg TPF $kg^{-1} h^{-1}$], SIG – trophic soil index, B_{100} – site index

Stagnosols to the poorer subtypes of Cambisols). With the diversity of soil compositions, and especially the surface horizons of humus accumulation, the richness of the forest floor vegetation, its structure and composition varies considerably, even though the study plots have the same plant association. It is interesting to note that the analysed biodiversity indexes (Shannon, Simpson and Margalef) differed by the site groups classified to different fertility categories in the typological site classification system. The literature has examples of using biodiversity indexes in comparing different ecosystems or differently managed areas. For example, Magurran (1988) compared the values of the Shannon and Margalef indexes for oak and Sitka spruce plantations occurring in similar site conditions. The results obtained by her are consistent with an intuitive understanding of biodiversity – that it should be higher in deciduous forests than in coniferous plantations. In her study, both indexes (Shannon and Margalef) were higher in the oak forest (3.54 and 10.44, respectively) than in the spruce plantation (2.9 and 4.96, respectively). The results obtained in this study suggest the possibility of using biodiversity indicators to demarcate sites with differing fertility and forest-forming potential. The biodiversity indexes divided the areas into mixed coniferous forest sites and mixed broadleaf forests that differ in productivity expressed by the bonitation of fir. Six analysed plots are actually a small sample, but given the fact that the presented material is characterised by the entire spectrum of trophic conditions encountered in upland fir forests, it is possible to propose an indicative number of boundaries between mixed coniferous and mixed broadleaf sites. The suggested value for the Shannon index is 3.0, for the Simpson ratio is 0.8 and for the Margalef index is 7.0. Of course, one needs to check how the values of the analysed indicators will be influenced by situations where the sites are degraded or the vegetation is incompatible with soil conditions. A very small sample of the surface where the same plant association occurred was tested in the study, which matched the site conditions. In a situation where the plant cover is compatible with the biotope, it can be assumed that the characteristics of the plant cover should reflect the quality of site conditions.

Ecological index numbers yielded results that are not totally compatible with earlier analyses of floral diversity. It was assumed that an increase in biodiversity would be related to an increase in the trophism of a site and, to some extent, to an increase in its moisture content, that is, the characteristics described by the values of the ecological index numbers. The range of calculated indexes did not, however, coincide with the categories of sites highlighted in the forest typology. When analysing the results obtained, it should be remembered that the calculated average index numbers, weighted by species, are characterised by the ecological response of plants, including that resulting from intra- and extra-species competition, and not only from the actual physiological requirements of the species (Roo-Zielińska 2004). This was taken into consideration by creating the ecological number of vascular plants. The trophic index, based on the ecological index numbers, lowers the trophism of sites by about one level. Three of the study plots are characterised by lower trophic rates (2.46–2.50), which, according to Różański, correspond to the category of coniferous sites, undistinguished in upland areas. The next three plots are identified by slightly higher trophic indexes (2.90–3.00), corresponding to – according to the author – mixed coniferous sites. The indexes thus calculated do not correspond either with the types of habitats distinguished in the typological system or with the values of the soil site index (Table 3). The second of the calculated numerical indexes, based on the ecological numbers of vascular plants of Zarzycki et al. (2002), is the moisture

Table 4. List of vegetation in the research plots

	AbP1	AbP2	AbP3	AbP4	AbP5	AbP6
a1						
Abies alba	3	5	5	5	5	5
Betula verrucosa					+	
Fagus sylvatica					1	
Picea abies	+					
Pinus sylvestris	3		+	1		
Quercus robur				1		
a2						
Abies alba	3	+	+	+	3	2
Fagus sylvatica					+	+
b						
Abies alba	+	+	3	1	1	1
Carpinus betulus		r				
Fagus sylvatica				+		1
Frangula alnus		+			+	+
Picea abies	+		+			
Populus tremula					+	
Quercus robur	r	r	+			
Sorbus aucuparia		+	r	+		+
c						
Abies alba	+					+
Anemone nemorosa						+
Athyrium filix-femina	+			+	2	+
Calamagrostis arundinacea	1				r	
Calamagrostis villosa					+	
Carex pilulifera	+					
Circaea alpina						1
Dryopteris carthusiana	1	+		+	1	1
Dryopteris dilatata					+	
Dryopteris filix-mas					+	
Fagus sylvatica						
Galeobdolon luteum					+	+
Gymnocarpium dryopteris				r	+	
Luzula pilosa	+	+		+	1	+
Lycopodium annotinum	+					+

	AbP1	AbP2	AbP3	AbP4	AbP5	AbP6
Maianthemum bifolium	2	1	1	2	+	3
Milium effusum						+
Moehringia trinervia						+
Oxalis acetosella	2	+			1	3
Phegopteris connectilis					+	
Pteridium aquilinum	2		+			1
Rubus hirtus	1				2	+
Rubus idaeus	+					+
Rubus sp.				+		
Senecio fuchsii					+	
Trientalis europaea	1	+				+
Vaccinium myrtillus	3	3	2	1	2	1
Vaccinium vitis-idaea			+			
Veronica officinalis	+					
Viola reichenbachiana	+					
d						
Eurhynchium angustirete	1				1	2
Hylocomium splendens	1					
Hypnum cupressiforme					+	
Leucobryum glaucum		1	2			
Plagiochila asplenioides					1	1
Plagiomnium affine		1				3
Plagiomnium laetum					+	
Plagiothecium denticulatum	+	+	+	+		
Pleurozium schreberi	3	3	3			1
Polytrichastrum formosum	2	2	2	1	2	2
Polytrichum commune						1
Rhizomnium punctatum						1
Sphagnum girgensohnii			+			
Thuidium tamariscinum	+	3	3		2	1

content index, which is in the range of 2.00–3.45. In the interpretation given by Różański, the range of this index suggests the existence of dry sites, which are distinguished only in lowland areas (index of <2.6); fresh sites (index in the range of 2.6–3.3); as well as moist sites (indicator of >3.3). The moisture content analysis for all plots of the upland fir forest indicates the variant of fresh site. Such a diagnosis is evidenced by the lack of diagnostic species that differentiate site typology from moist to fresh, despite the presence of features indicating gleyic processes in the case of three profiles.

In the present study, the biological quality of soil was measured by the activity of soil enzymes. Enzymatic activity is considered as a useful indicator of soil evaluation because it reflects the microbial activity and reacts well to any changes occurring (Nannipieri et al. 2002, Gianfreda et al. 2005). The analysed soils associated with the upland fir forest association are strongly differentiated in terms of enzymatic activity. The highest activity of dehydrogenases was found for soils that had a greater amount of fine fractions (silt) and a higher concentration of humus in the upper horizons. One would expect that compared to very sandy soils, these would have a more stable moisture content, that is, they would not be prone to drying out quickly. Kubista's studies (1982) indicate the importance of temperature and humidity as factors influencing the dehydrogenase activity. Also, according to Brzezińska et al. (2001), the activity of these enzymes is positively correlated with the water content of the soil. But Kucharski (1997) believes that the rate of enzymatic reactions depends on the amount of organic matter. The amount of mineral and organic colloids determines the sorption capacity as well as the microbial activity of the soil. Soils with more colloids (such as plots AbP4 and AbP5) provide better conditions for the growth and development of microorganisms. Dehydrogenase activity was the lowest in the Albic Brunic Arenosols of the lowland fresh mixed broadleaf forest site. The activity of the tested enzyme confirms the lower production capacity of this site compared to the upland mixed broadleaf site, as evidenced by the fir bonitation as evidenced by their height at 100 years of age. The second enzyme, urease, showed considerable variation of activity in the studied soils of upland fir forests but no association with the selected types of forest sites was found.

5. Conclusions

1. The upland fir forest association is characterised by a diversity of site conditions that are reflected in the biodiversity values determined by the characteristics of the forest floor cover.

2. The values of the Shannon, Simpson and Margalef biodiversity values are lower in plots of poorer upland fresh mixed coniferous sites (mean values are 2.57, 0.72 and 4.87, respectively), unlike the plots of the richer mixed broadleaf forest sites (fresh mixed broadleaf and upland fresh mixed broadleaf). These indicators are 3.27, 0.87 and 9.40, respectively, for the richer sites.

3. The indicators calculated based on the ecological numbers of vascular plants do not reflect either the division amongst trophic groups of sites or the variants of moisture content identified in the site typology.

4. The prognosis of the upper height of firs at 100 years of age in the upland fir forest association shows a strong connection to site conditions, as well as with the floristic biodiversity indicators.

Conflict of interest

The authors declare no potential conflicts of interest.

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Authors' contribution

J.L. – concept of the study, text of the article; M. W. – calculations of biodiversity indexes, data analysis, participation in writing the article; E. B. – soil data collection, enzyme analysis, participation in writing the article; S. B. – grant manager of the project enabling us to collect the data used in the article.

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