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Assessment of flora diversity in a minor river valley using ecological indicator values, Geographical Information Systems and Digital Elevation Models

Research Article

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Abstract: Ellenberg indicator values (EIV) have been widely used to estimate habitat variables from floristic data and to predict vegetation composition based on habitat properties. Geographical Information Systems (GIS) and Digital Elevation Models (DEM) are valuable tools for studying the relationships between topographic and ecological characters of river systems. A 3-meter resolution DEM was derived for a. 3-km-long break section of the Szum River (SE Poland) from a 1:10,000 topographic map. Data on the diversity and ecological requirements of the local vascular flora were obtained while making floristic charts for 32 sections of the river valley (each 200 m long) and physical and chemical soil measurements; next, the data were translated into EIV. The correlations of the primary and secondary topographic attributes of the valley, species richness, and EIV (adapted for the Polish vascular flora) were assessed for all species recognized in each valley section. The total area and proportion of a flat area, mean slope, slope curvature, solar radiation (SRAD), and topographic wetness index (TWI) are the most important factors influencing local flora richness and diversity. The highest correlations were found for three ecological indicators, namely light, soil moisture, and soil organic content. The DEM seems to be useful in determination of correlations between topographic and ecological attributes along a minor river valley.

Keywords: *Species richness • Species diversity • Vascular plants • River landscape • Edaphic factors • Topographic attributes • Solar radiation • Wetness index*

1. Introduction

River systems integrate the structure, dynamics, and function of all components of the landscape [1]. Habitat complexes of river valleys are characterized by considerable heterogeneity defined as variability of spatial and temporal patterns and processes [2]. Environmental heterogeneity of the riparian landscape is a result of river fluvial activity (erosion, transport, sedimentation), organic-matter dynamics, climatic factors, and hydrological relationships between all abiotic and biotic environmental elements [3-10]. The vegetation landscape of the river valley is characterized by specific zonal toposequence of plant communities [6,9,11]. Biodiversity of river systems may be considered at various levels of organization – from the physico-geographical region to the habitat patch, *i.e.*, from the macro- to nanoscale [3,11-14].

Over the last decades, Geographical Information Systems (GIS) and Digital Elevation Models (DEM) have been widely used to study the relationships between topographic and ecological features of different landscapes, including river systems [15-21]. DEM derivatives related to species occurrence [22] and vegetation diversity [23] are also analyzed. Multivariate canonical analyses are currently in common use for identifying repeatable patterns in species distribution in terms of environmental factors [9,22,24-28].

The aim of this study was: (1) to find correlations between the morphological characters of a small-scale river valley (IV rank river) and ecological elements (local flora and its requirements) occurring in the valley,

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using the GIS and multivariate statistical analysis, and (2) to evaluate the usefulness of the DEM for studying the relationships between topographic and ecological attributes of the riparian landscape.

2. Experimental Procedures

2.1 Study site

The model object of the study was a break section (approximately 3 km) of the Szum River, together with the mouth section of its left tributary, the Miedzianka River, crossing the escarpment zone of the Central Roztocze Highlands, South East Poland (Figure 1). The Szum River is a 24 km-long stream with a catchment area of approximately 84 km^2 and flows ranging from 401 to 616 dm^3·s^{-1} [6]. The river section studied is characterized by a variable course and terrace asymmetry (Figure 1). The valley is composed of formations of various origin and age: upper Cretaceous gaizes and marls, the Miocene lithotamnic limestones, lithotamnic-detritic marls, Pleistocene sands and clay sands as well as Holocene alluvial sands, sandy-clay deluvia and peats [29]. Different types of soils have been described in the study area: (1) acidic and oligotrophic podzol soils on the steep slopes of the valley; (2) slightly acidic to neutral and alkaline, meso- and eutrophic semi-hydrogenic and alluvial soils of the valley bottoms; (3) organic soils in closed depressions with stagnant water [6,30].

About 81% of the study area (37.5 ha) is wooded. Given the great differentiation of abiotic factors, 48 plant associations and communities (12 forest and 36 non-forest) have been identified. Among these are habitats protected in Poland (16 types), and some that are important at the EU scale (3 types). Additionally, among the 378 vascular taxa of 72 botanic families, there are 21 species under strict protection, 9 under partial protection, 25 plants threatened at the regional

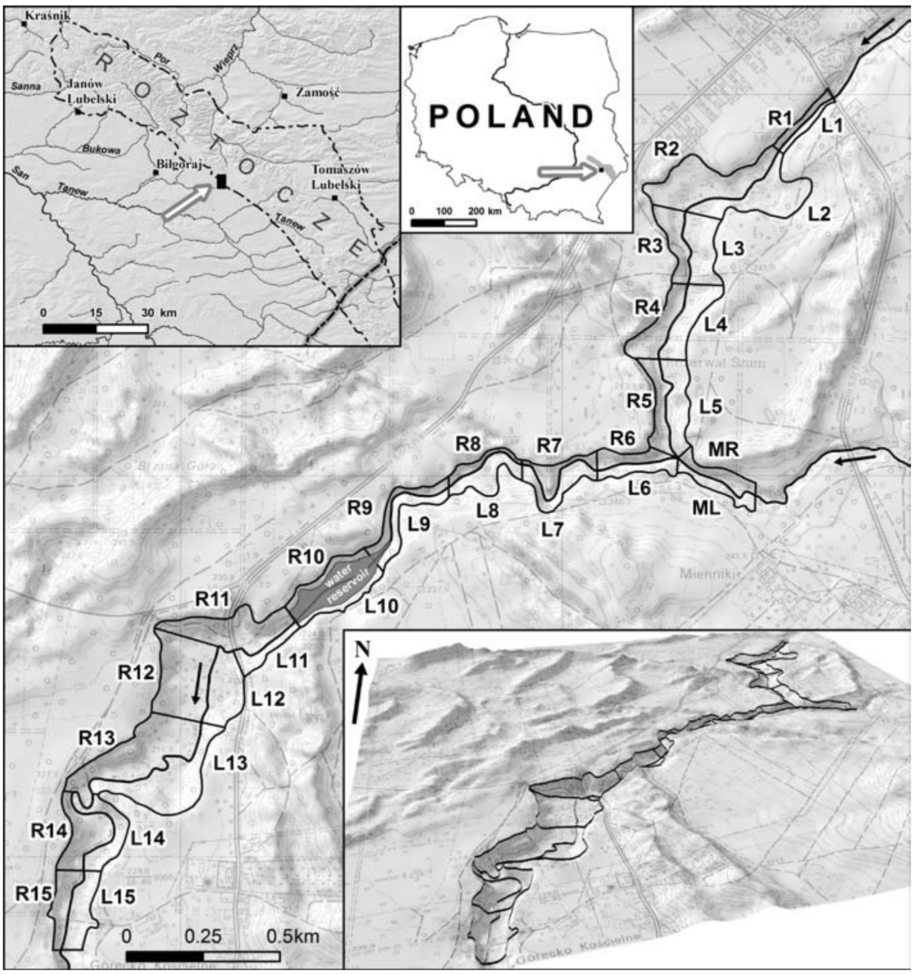

Figure 1. The study section of the Szum River valley on the background of the Roztocze Highlands. R1-R15 – sections on the right riverbank, L1-L15 – sections on the left riverbank, MR, ML – mouth sections on the right and left banks of the Miedzianka River, respectively. Vertical exaggeration = 3.

scale, and 2 species included into the Polish Red Data Book [31]. In 1958, a partial landscape reserve called 'The Szum' ('The Hum') was established, covering 16.96 ha (at present 18.17 ha) and preserving the most valuable break part of the valley with a mountainous character with forests on the slopes and river terrace. The study object was also included into the Natura 2000 network within both types of protected sites: Special Protected Area (PLB 060012 'Roztocze') and Special Area of Conservation (PLH 060018 'Puszcza Solska' = 'The Solska Primeval Forest').

2.2 Data and tools

Field studies were carried out at the level of local vascular flora and abiotic conditions. Floristic charting was done for each 200m-long section along the river valley course separately for the left and right riverbanks; 32 sections in total were analyzed (Figure 1). To establish the frequency and abundance of each vascular plant species in individual valley sections, a simplified, combined scale was used, where: 1 – means sporadic species, *i.e.* single individuals or small, scarce clumps of plants; 2 – rare and non-abundant species, *i.e.* bigger clumps or patches of plants (covering <10% of the section area); 3 – frequent and abundant species (covering 10-50% of the section area); 4 – common and very abundant species (covering >50% of the section area). To estimate the real habitat conditions in the study area and the ecological scale of particular plant species, we also used additional materials collected earlier [6,30,31, Czarnecka, unpbl. data]: a map of vegetation growing in the valley as well as phytosociological relevés in different types of plant communities (120 in total), and soil pits (33 in total) distributed proportionally to the area and the diversity of the identified communities. The types of soils and their physico-chemical properties were determined on the basis of analyses of 160 samples of mineral and organic formations. Using commonly accepted methods [32,33], the following properties were determined: the content of organic matter and/or organic carbon, active acidity, calcium carbonate, and basic nutrients (Ca, K, Na, Ma, Fe, P, and N in the form of ammonia and nitrate).

The analysis of the area was based on the DEM and its derivatives, and was conducted in basic fields, *i.e.* in 32 sections, for which precise floristic charting was performed. Spatial data were obtained from topographic maps at the 1:10,000 scale by successive digitization of contour lines, elevation points, valley edges, and their height. Break lines were also taken into account, since such data significantly improve the quality of the DEM. The DEM was generated with a resolution of 3 m [34]. Based on the DEM, topographic attributes were calculated [35,36]: primary – slope, aspect, and total, planar (contour), and vertical (profile) curvature; and secondary – solar radiation (SRAD), and the topographic wetness index (TWI); for the thematic maps of the model and its derivatives see Figure 2.

For calculation of the terrain attributes, tools were used from the ArcToolbox of the ArcGIS 10 program and the Spatial Analyst extension. The DEM was generated using the Topo to Raster tool. The Raster Slope was expressed in degrees and was calculated using the Slope tool. Conceptually, the tool fits a plane to the z-values of a 3 × 3 cell neighbourhood around the processing or centre cell. The slope value of this plane is calculated using the average maximum technique. The Raster Aspect was expressed in degrees from the north and clockwise, ranging from 0 to 360. The value of −1 is used to identify flat surfaces such as flood plains, or fluvial terraces. The aspect map of the study area was classified into nine classes: flat, N, NE, E, SE, S, SW, W, and NW, using an Aspect tool. The Aspect tool fits a plane to the z-values of a 3 × 3 cell neighbourhood around the processing or centre cell. The direction the plane faces is the aspect for the processing cell. Rasters with curvatures were calculated on default settings of the Curvature tool. Insolation (SRAD) was calculated for the period of 1 year with the Solar radiation tool, which calculates insolation across a landscape or for specific locations, based on methods from the hemispherical viewshed algorithm. For the TWI, we used a script from the esri website which calculates the TWI. In this case, the TWI is a function of the natural logarithm of ratio of local upslope contributing area and slope.

Subsequently, each of these was analysed for each section using the Zonal Statistics tool, with which a statistic (majority, maximum, mean, median, minimum, minority, range, standard deviation, sum, variety) was calculated for each zone defined by a zone dataset (in our case, these were particular sections), based on values from the other datasets (DEM, slope aspect, planar, vertical and total curvature, solar radiation, and the topographic wetness index). A single output value was computed for every zone in the input zone dataset.

In the next step, the correlations between the topographic attributes of the valleys, species richness, and the ecological indicator values (EIV) were calculated for all the species recognized in each section. The theoretical and methodological basis of the original Ellenberg system [37,38] was adapted for the Polish vascular flora by Zarzycki *et al.* [39] who used sufficient data on the ecology, number of localities, dynamic tendencies, *etc.*, only from the territory of Poland; thus, the range of a given habitat factor might be slightly different than that in Central Europe as a whole. It must be emphasised that the system describes the Polish

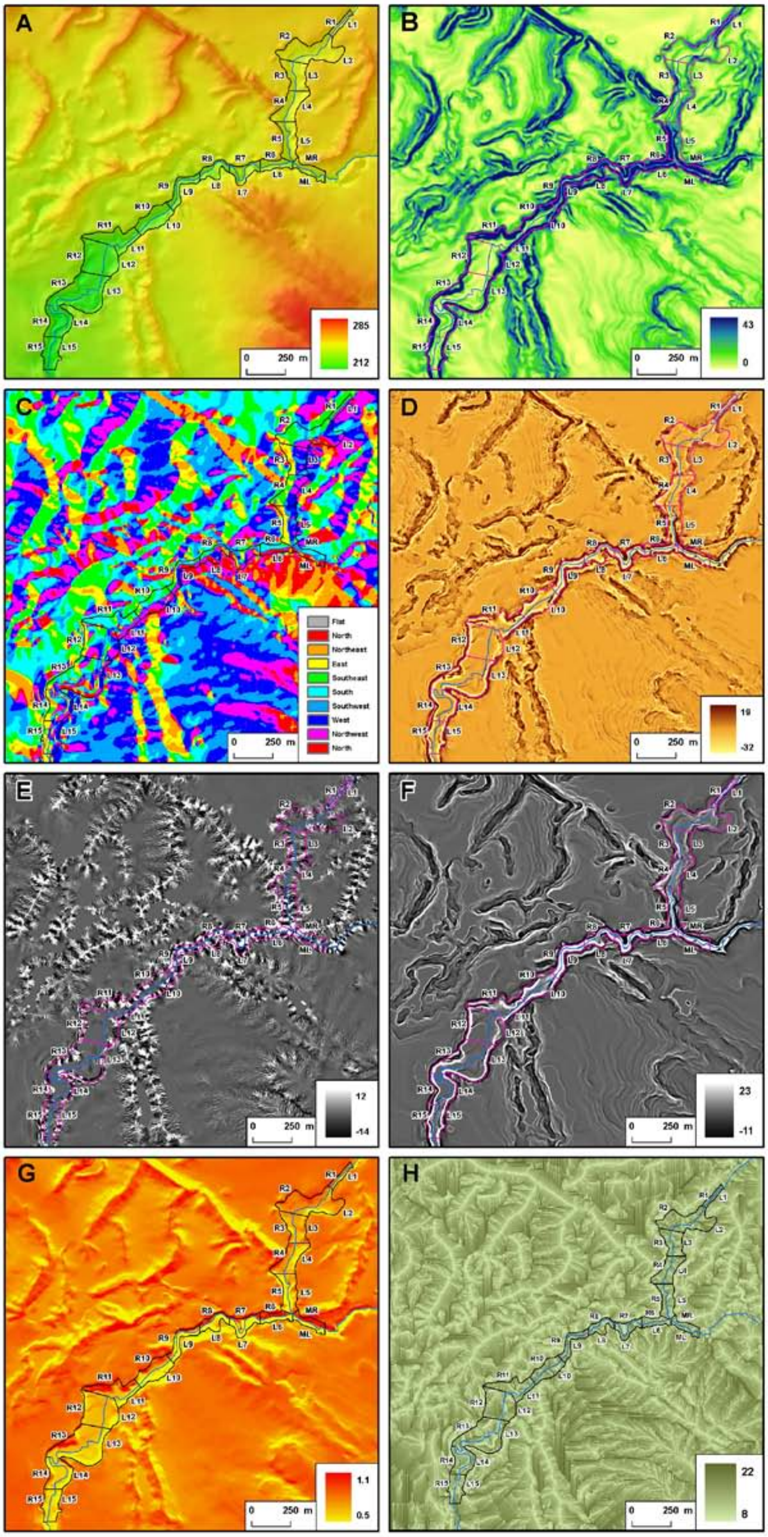

Figure 2. Thematic maps employed in the analysis of the Szum River valley: A – altitude in meters, B – slope in degrees, C – aspect, D – total curvature E – planar curvature, F – vertical curvature, G – solar radiation (SRAD) in megawatt hours per square meter, H – topographic wettnes index (TWI).

populations of plants on the background of local climatic and edaphic conditions. The EIVs used in the study valley were calibrated [40-43], adjusting them to the range of habitat conditions found during the field and laboratory studies.

The first of the two main groups of conditions, *i.e.* climatic factors (continentality – C, light – L, and temperature – T) was the same in both elaborations [37-39], while the second group (= edaphic factors) differed from each other both in the list of indicators as well as in the scale degrees (Table 1). Among the climatic factors, we focused on only one – the L value ranging from 1 (deep shade) to 5 (full light). The indicator values for temperature (T) and continentality (C) were purposely not taken into account, as their value is constant in such a small area. We took into account 5 indicator values describing the most typical habitat conditions of the species. Soil moisture (W) and soil/water pH (R), are common indicators for the Ellenberg's and Zarzycki's system, although different in numbers of degrees [37-39]. In our case, the W value shows a moisture scale from very dry habitats (degree 1) to wet (degree 5) and aquatic ones (6), while the R value indicates the amplitude of habitat acidity from highly acidic soils, pH < 4 (degree 1) to alkaline soils, pH > 7 (degree 5).

Some new ecological indicators in the edaphic group were elaborated for Polish vascular plants [39]: Tr – trophy value, D – soil granulometric value, H – organic matter content value (see Table 1). The trophy value was elaborated for vascular plants of Poland by Zarzycki *et al*. [39] to replace the 'Stickstoffzahl (N-Zahl)' = 'nitrogen figure' (N) provided by Ellenberg [37,38]. The Tr value means the content of different nutrients, particularly N, K, Mg, Ca, and P making habitats (soils or waters) differently fertile and ranging from extremely poor (extremely oligotrophic – grade 1) to very rich (extremely fertile – grade 5). The D value points to a different character of soil dispersion: from rock crevices (1) and rock debris (2), through sandy soils (3), clay and dusty deposits (4) to clay and loam substratum (5). The H value indicates the humus and/or organic matter content in soil; grade 1 means soil poor in organic matter, 2 – mineral-humic soil, and 3 – soil rich in organic matter.

2.3 Statistical analysis

The mean value for a specific indicator in each section was calculated using a modified formula for the weighted average:

$$W_A = \frac{\sum_{i=1}^{n}(A_i^2 \times I_i)}{\sum_{i=1}^{n} A_i^2}$$

where: W_A – weighted average,

A_i – abundance of cover of the i-th species in a given section of the valley,

I_i – ecological indicator value for the i-th species,

n – number of species in the section.

According to the Shapiro-Wilk test, a majority of the values of the topographic attributes do not have a normal distribution. Spearman's rank correlation coefficients (r) were calculated between the number of species and the mean value for a specific indicator in each section and: the primary topographic attributes – the mean slope, total area of a given section, proportion of the flat area (*i.e.* ≤2° of terrain slope), proportion of slope area (>2° of terrain slope), planar curvature, vertical curvature and total curvature, as well as minimum, maximum, mean, and sum values of the primary and secondary topographic attributes. The correlation analysis was performed for the entire valley section studied and separately for both riverbanks, due to the varied slope aspect and terrace asymmetry (cf. Figure 1). All statistics were calculated with the use of Statistica PL.

Multivariate ordination methods in Canoco version 4.5 [24,25] were used to analyse the relationships between weighted averages for particular EIV of local

Indicator	Ellenberg [37]	Ellenberg *et al*. [38]	Zarzycki *et al*. [39]
L – light value	9-grade scale	9-grade scale	5-grade scale
W – soil moisture	8-grade scale	12-grade scale	6-grade scale
N – nitrogen value	6-grade scale	9-grade scale	---
Tr – trophy value	---	---	5-grade scale
R – soil/water acidity	5-grade scale	9-grade scale	5-grade scale
D – soil granulometry	---	---	5-grade scale
H – organic matter content value	---	---	3-grade scale

Table 1. The comparison of ecological indicator value systems for Central European and Polish vascular species. For further explanations see the text.

--- not elaborated in a given system

vascular flora and topographic attributes of the valley. According to the length of the gradient from a preliminary Detrended Correspondence Analysis (DCA), a linear model was used – Principal Components Analysis (PCA). To find the minimum number of statistically significant variables, a manual procedure with 499 Monte Carlo significance permutation tests was used. The eigenvalues and percentages of floristic and topographic variance explained by the first two axes were calculated. The pattern obtained from the classification was transferred onto a graph with sample groups marked in the PCA.

3. Results

3.1 Species richness *vs*. topographic attributes

The number of vascular species in the particular valley sections is variable (mean ± standard deviation = 102 ± 39), ranging from 41 (section L9) to 222 (R15). Species richness in the entire valley section studied increases significantly only with the rise of the total area of a given section ($r = 0.41$; $P < 0.05$). The decline in species richness is not significantly related to the increase in the mean slope ($r = -0.32$) or sum total curvature ($r = -0.22$). None of the analysed topographic attributes is significant for the left bank of the valley separately (cf. Figures 1, 2). In turn, for the right bank of the river the following significant attributes were found ($P < 0.05$): the sum vertical curvature ($r = 0.58$), mean TWI (0.53), and sum total curvature ($r = -0.52$).

3.2 Species diversity *vs*. topographic attributes

The highest Spearman's correlations were found for the L, W, and H indicators (Table 2). The increase in mean slope in the individual valley sections contributed significantly to the decline in the proportion of photophilous ($r = -0.80$) and hygrophilous species ($r = -0.74$) as well as species requiring substantial or high contents of organic matter ($r = -0.79$). In turn, the total area of the section and the proportion of the flat area contributed to higher radiation on the terrain surface, and higher levels of wetness and organic matter content, thereby exerting a highly positive effect on the proportion of species with higher requirements for light ($r = 0.50$ and 0.54), humidity ($r = 0.61$ and 0.65), and soil fertility ($r = 0.66$ and 0.71) respectively, for the total and flat area. High significant correlations were also obtained for the mean SRAD ($0.36 < r < 0.75$) and the sum SRAD ($0.54 < r < 0.84$).

The higher the mean curvature in the vertical plane of the valley slope (that is, where convexes are not balanced by concaves), the significantly lower the number of species with higher values of L ($r = -0.56$), W ($r = -0.44$), and H ($r = -0.44$) indicators. The relationships differed between the valley banks; they were generally stronger and more significant for the left than for the right riverbank (Table 2, Figure 2). Two of the remaining edaphic indicators, that is, soil trophy (Tr) and reaction (R) exhibited less frequent and lower Spearman's correlations with the topographic attributes of the valley. The soil trophy value (Tr) increased only with the increasing proportion of slope concaves ($0.38 < r < 0.40$), and declined together with the total curvature ($-0.38 < r < -0.40$); correlations were higher for the left bank, but absent for the right one. In turn, some examples were found for soil reaction (R) which also increased along with the increasing sum total curvature ($r = 0.36$) and decreased with the increasing sum vertical curvature ($r = -0.35$). For the right bank of the valley, there was a positive effect of the increased mean TWI on L, W, R, and H values. In contrast, increases in the mean and sum planar curvature on the right bank decreased the R value. None of the topographic attributes analysed exerted a significant effect on soil size distribution, *i.e.* soil granulometry (D) for the entire valley section under investigation or separately for each of the two banks (Table 2).

The PCA analysis (Figure 3) confirmed the great significance of the total area (TA) and flat area (FA) of a given section (terrain slope ≤2°), the sum SRAD and sum TWI (cf. Figure 2) for the species richness (NS) and the proportion of species requiring higher light value (L), humidity value (W), and humus content (H) in the soil. This analysis also showed a weaker correlation of the above-mentioned ecological indicator values with the slope area (SA) of a given section (terrain slope >2°). From the remaining three ecological indicators, R and D are positively correlated with both first axes, while Tr is negatively correlated with axis 1 and positively with axis 2. The length of the vector for the mean slope (SL_mean) and its opposite sign to that of the above-mentioned vectors for the total area of a section (TA), flat area (FA), and sum SRAD and sum TWI proves that the factor exerts an opposite effect on the proportion of species requiring substantial or high amounts of light, moisture, and organic matter contents. Vectors for sum and mean vertical curvatures on the one hand, and for planar curvatures (CP_mean and CP_sum) and total curvature (CT_mean and CT_sum) on the other hand have opposite signs and are generally poorly correlated with axes 1 and 2, which implies that these topographic attributes have no great significance for species richness and diversity.

The cumulative percentages of floristic and topographic variance of species data explained by the

Topo-	Ecological indicator values													
graphic	L			W			Tr			R		H		
attributes	All	Left	Right	All	Left	Right	All	Left	Right	All	Right	All	Left	Right
TA	0.50**	0.55*		0.61***	0.85***							0.66***	0.80***	0.60*
FA	0.54**	0.57*		0.65***	0.73**	0.57*						0.71***	0.75***	0.70**
SL_mean	-0.80***	-0.80***	-0.81***	-0.74***	-0.84***	-0.67**						-0.79***	-0.83***	-0.81***
CP_mean		0.68**			0.50*	-0.68**	-0.38*				-0.54*			-0.72**
CP_sum		0.52*				-0.68**					-0.53*			-0.68**
CV_mean	-0.56***	-0.68**	-0.52*	-0.44*	-0.80***		0.38*					-0.44*	-0.76***	
CV_sum		-0.52*					0.40*	0.59*		-0.36*				
CT_mean	0.55**	0.69**		0.41*	0.79***		-0.40*					0.42*	0.75***	
CT_sum		0.55*					-0.38*	-0.56*		0.36*				
SRAD_mean	0.36*	0.74**			0.75***								0.72**	
SRAD_sum	0.54**	0.56*		0.63***	0.84***							0.69***	0.81***	0.60*
TWI_mean			0.75***			0.71**			0.59*		0.73**			0.73**
TWI_SUM	0.49**	0.55*		0.60***	0.84***							0.65***	0.80***	0.60*

Table 2. Statistically significant correlation coefficients between topographic attributes and ecological indicator values of vascular flora in the Szum River valley. Significance level: *0.01 < P ≤0.05, **0.0001 < P ≤0.01, ***P ≤0.0001. For other details see text.

Explanations: All – all sections of the valley, Left – left sections of the valley, Right – right sections of the valley, TA – total area, FL – flat area, SL_mean – mean slope, CP_mean – mean planar curvature, CP_sum – sum planar curvature, CV_mean – mean vertical curvature, CV_sum – sum vertical curvature, CT_mean – mean total curvature, CT_sum – sum total curvature, SRAD_mean – mean solar radiation (SRAD), SRAD_sum – sum solar radiation, TWI_mean – mean topographic wetnes index (TWI), TWI_sum – sum topographic wetnes index.

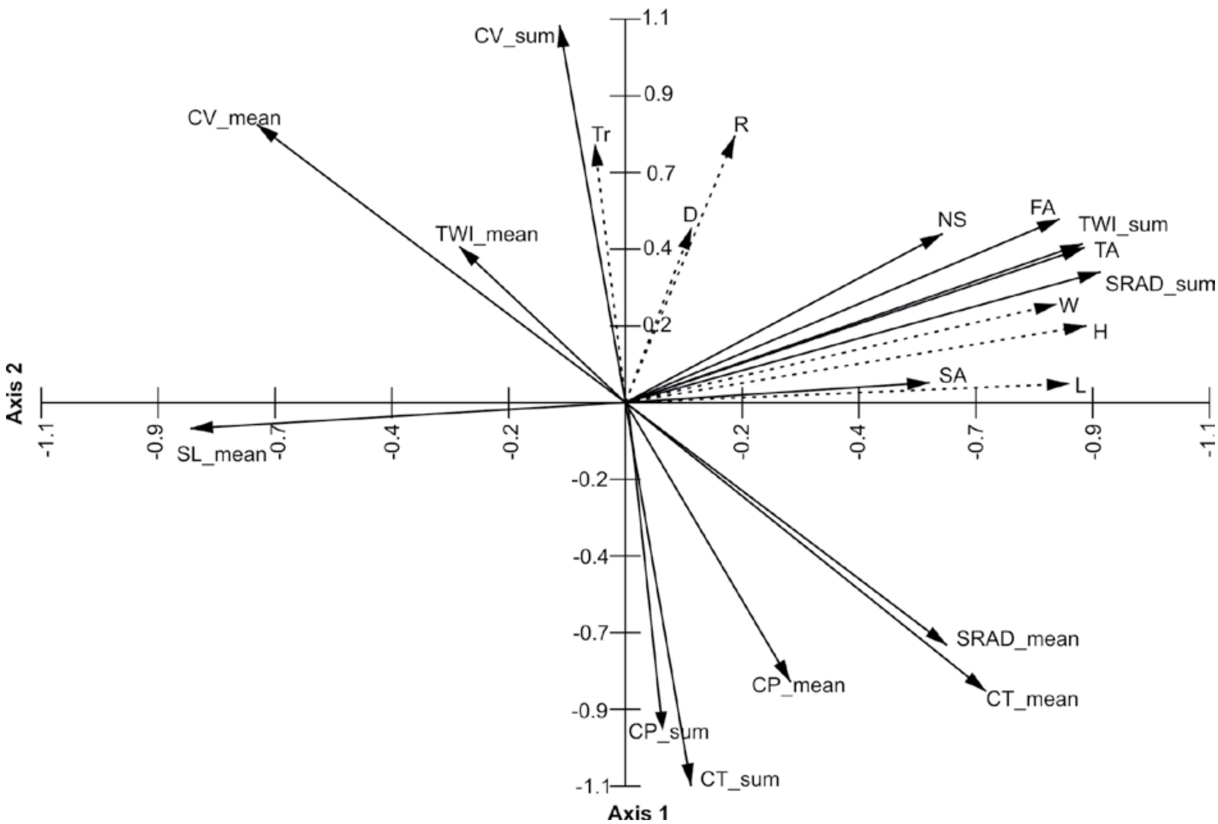

Figure 3. Ordination diagram showing the result of the PCA for species richness, ecological indicator values and topographic attributes of the Szum River valley. Eigenvalues: Axis 1 – 6.188, Axis 2 – 5.169. Cumulative percentages: Axis 1 – 41.256, Axis 2 – 75.714. NS – number of species, SA – slope area; remaining abbrevations as in Table 2.

first PCA axis are lower than those explained by the second axis (41.26 *vs*. 75.71). The sum values of the Monte Carlo test show that axis 1 explained 66.5% of all variables analysed for all 32 valley sections (F ratio = 29.826, P = 0.01380).

The ordination diagram shows varied significance of the topographic attributes analysed in the individual sectors of the valley studied (Figures 1, 2, 4). The following sections are most positively correlated with axis 1 (in decreasing order): R17, R6, R16, R15, L6 whereas sections L17, L13, L11, and L18, exhibit the strongest correlation with axis 2. For sections of the first group, the most important topographic attributes are the total and flat areas. In the case of sections R10 and R14, the mean planar and sum total curvatures are the most significant factors of habitat quality; in section L17 the sum vertical curvature and the mean vertical curvature and mean TWI in sections L10 and L14 are the most significant. In turn, the slope area may be regarded a significant factor for sections L5, R12, ML, L15, L10 and L14, and mean SRAD for section L7, R8 and L9. The central location of some sections in relation to axes 1 and 2 (*i.e.* R19, L19, R18) indicates that all the value attributes analysed are equally significant. The first two axes of the PCA ordination explain 35.92% and 28.10% of topographic variance in the study valley sections, respectively.

4. Discussion

Through retention of sediments and nutrients, river valleys provide some of the most diverse and species-rich habitats. In many regions, riparian landscapes constitute a rather small proportion of the total watershed area, but they play a prominent ecological role [3,4,7-11,13,14,19,31].

Geospatial tools, particularly GIS and DEM, have been widely used in studying the relationships between topographic and ecological characters of river systems [15-21, and others]. Among the topographic attributes, two feature groups have usually been taken into account [35,36]: primary – slope, aspect, and planar and vertical curvature; and secondary – solar radiation (SRAD) and the topographic wetness index (TWI). On the other hand, ecological indicator values [37,38] are widely used in assessment of vegetation, both to estimate soil variables from floristic data and to predict vegetation composition

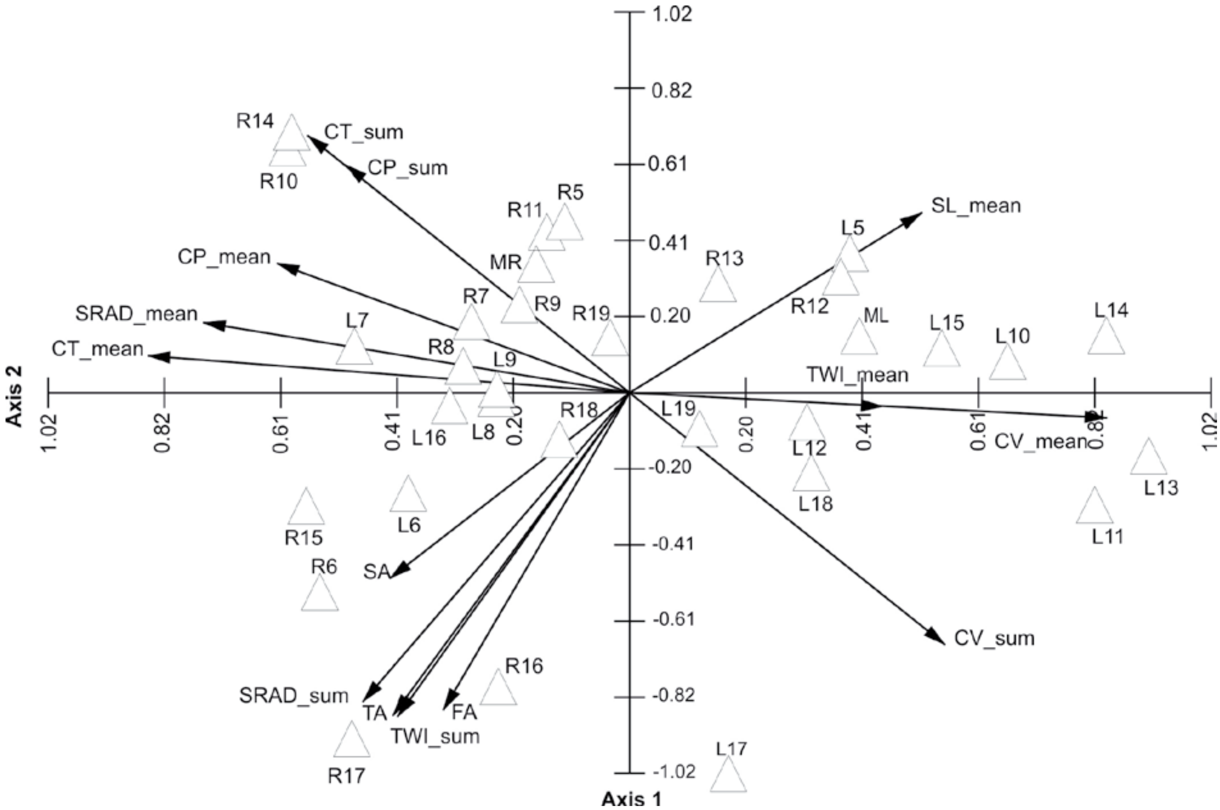

Figure 4. Ordination diagram showing the result of the PCA for particular sections and topographic attributes of the Szum River valley. Eigenvalues: Axis 1 – 7.903, Axis 2 – 6.183. Cumulative percentages: Axis 1 – 35.924, Axis 2 – 64.029. SA – slope area; remaining abbrevations as in Table 2.

from given soil properties [26,27,40-45]. According to Lawesson *et al.* [43], the wide success of the Ellenberg system is probably associated with the fact that for a majority of species autecological characteristics and life history in general are not too different throughout Europe. It is also believed that using indicator species, instead of physical and chemical measures, saves time, makes it possible to estimate past environmental factors, and gives a synthetic measure of environmental fluctuations in space and time, especially light intensity and soil humidity [46].

In the light of the present study, the DEM seems to be useful in determination of the correlations between topographic and ecological attributes along a small-scale river valley. We found the following primary attributes to be the most important for the richness and diversity of the local vascular flora: the total area of the study valley section, proportion of the flat area in particular sections, mean slope, and slope curvature (especially vertical). Species richness was significantly correlated with the proportion of the flat area only for the entire valley section studied. Surprisingly, we did not find a significant positive correlation between species richness and planar curvature, despite the fact that the latter is recognized as an attribute intensifying flooding and sedimentation processes which in turn may induce changes in the physical attributes of soil, such as texture, temperature, and moisture, and also changes in community composition [7,8,10,14]. For the study sections of the river valley, the lack of a positive influence of planar curvature on the local flora is related to the mountainous character of the river and its valley. The velocity of the river along a considerable length of the course is high (even 0.65-0.88 $m \cdot s^{-1}$), and the terrace is very narrow reaching only a dozen or a few meters. Locally, the valley bottom is reduced and equals the width of the riverbed, and the incision depth exceeds 10 m. Even if the planar curvature of the contour lines has more ‘valleys’ than ‘ridges’, which indicates predominance of conditions promoting convergence over divergence of flowing water, the narrow terrace and water velocity reduce the repository role of the river curves. Therefore, there are no favourable conditions for development of rich hygrophilous and nitrophilous vegetation, *i.e.* the richest forms of riverside carrs and bog alder forests [30,31]. In turn, we found significant negative correlations between the mean and sum planar curvature and W and R values but only for the right bank of the valley. This points to the situation when 'ridges' prevail over 'valleys', which indicates predominance of conditions promoting divergence over convergence of flowing water. These habitats are overgrown with poor forms of mixed fir forest and pine forest on acidic and slightly acidic, usually sandy, soils [6,29-31].

The highest negative correlations were found for the mean slope in the individual valley sections and three of the study ecological indicator values: light (L), soil moisture (W) and organic matter content (H); the latter commonly indicating greater soil fertility. We have confirmed that the secondary topographic attributes, TWI as well as SRAD values, are significantly correlated with the number of species with higher humidity, light, and soil fertility (especially organic matter content) requirements.

While soil moisture is one of the most important determinants of vegetation composition and productivity, its exact measurement is very difficult [28]. This is the reason why the TWI derived from DEMs is commonly used and regarded as one of the most important secondary topographic attributes [28,47,48]. In the present paper, we have confirmed that the TWI, particularly the sum values, is significantly positively correlated with the proportion of species that require higher light, humidity, and humus content. In general the correlation coefficients obtained were much higher for the left than the right river bank. Solar radiation (SRAD), which affects the microclimatic conditions and influences the growth activity of plants in the study river valley, was also recognized as a very important secondary topographic attribute [48,49]. In our study, we have confirmed that the mean and sum SRAD values are significantly correlated with the share of plant species with higher light, humidity, and organic matter content requirements, particularly on the left bank of the river. The observed differences between the left and right banks of the study river are caused by terrace asymmetry for the corresponding sections of the river course [6,30]. On one side, this affects the different slope aspect: more eastern and southern (and their derivatives) for the right bank and more western and northern for the left one, and on the other side – different light and moisture conditions as a consequence of the aspect.

Primary and secondary topographic attributes, with only few exceptions, do not exert a significant effect on the values of the remaining three ecological indicators analysed: trophy (Tr), soil/water pH (R), and soil granulometry (D). Among these ecological indicator values, the soil reaction is a relatively frequent subject of studies [26,27,41-43,45]. However, some authors have criticized Ellenberg's R scale. Wamelink *et al.* [42] found during field measurements that pH values for some ecological groups of species were different than those expected from Ellenberg's scale, which strongly limits the use of the R values and requires calibration [40-43]. In turn, Schaffers and Sýkora [41] stressed the known influence of soil acidity and the calcium content on species occurrence. This may also refer to the study river valley due to the presence of the Ca-rich formations of various origin and age; among them there are Cretaceous gaizes and marls, lithotamnic limestones, detritic marls, *etc*., covered by Pleistocene and Holocene alluvial sands, sandy-clay deluvia, and peats [29]. The diverse water-bearing horizons of these formations result in approximately a nine-fold differentiation of water mineralisation [6,30,31].

The ecological indicator value system provides a very valuable tool for habitat calibration and has been recently applied for modelling plant distribution at various spatial scales. However, investigations conducted at the regional and landscape levels [23,27,40,42-45] are still much more common than studies on local sites or even single patches of plant communities, *i.e.* phytosociological releves [20,22,26,41, and the present study]. Multivariate statistics [24,25] have become a useful tool for detection of patterns of vascular species richness and distribution of their ecological groups on the background of primary and secondary topographic attributes of a given terrain, including riparian landscapes [9,10,22,26-28].

Given the ongoing improvement to collection methods and data elaboration (GIS, DEM), our hitherto performed analyses should be verified with the use of a much more accurate model generated from LIDAR or ground-based data.

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