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Vegetation landscapes of a small-scale river valley in the light of the GIS analysis

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Abstract: The aim of the study was to evaluate the correlations between the morphological characters of a small-scale river valley and ecological elements (vegetation and local flora) occurring in the valley using the GIS and statistical methods. The model object was a ca. 4 km-long break section of the Sopot river (IV rank river, the Tanew river tributary), crossing the escarpment zone of the Central Roztocze Highlands, SE Poland. The 3-meter resolution DEM was generated by the Topo to Raster tool with content digitized from a 1:10000 topographic map as the input data supplemented with information from field studies. This included a map of plant communities at the scale of 1:5000 and floristic charting for each 200-m long section of the river valley, separately for the right and left riverbanks. The correlation analyses were based on the DEM and its derivatives, and were conducted in primary fields, i.e. the sections of the valley. Primary and secondary morphological parameters of the valley (slope, aspect, SRAD and TWI) shape the course of the trend line for the share of species representing various Ellenberg indicator values (L, W, Tr, R, D, H). The study has confirmed that GIS methods are very useful in ecological research at different spatial scales and on different levels of biological organization: vegetation landscape, plant communities and local flora.

Key words: vegetation landscape, plant communities, Ellenberg indicator values, morphology, river valley, GIS, DEM

Introduction

For the last three decades, application of Geographical Information Systems (GIS) to environmental studies was universal and indispensable (Kistowski 2000). A dominant role of terrain shape in the component hierarchy has been widely assumed in comprehensive landscape research (Armand 1980, Richling 1992, Krysiak 1999). Relief determines physical and biological processes occurring within it and its vegetation cover. The subjects of natural (biological, geographic) studies are landforms or landscape complexes, i.e. geocomplexes (Klingseisen et al. 2008), and spatial and functional systems of plant communities, i.e. phytocomplexes (sensu J.M. Matuszkiewicz 1978), or even occurrence of individual species. Research is carried out at different spatial scales: from global phenomena/processes occurring around the Earth, through the regional and local (landscape) level, to those that occur in a micro- and nanoscale (e.g. Moore et al. 1991, White, Mladenoff 1994, Cherrill et al. 1995, Kienast et al. 1996, Ravan, Roy 1997, Mann et al. 1999, Hong, Su-fang 2005, Boylen et al. 2006, Mendas 2010, Dunn et al. 2011). Regardless of the scale of the study, some spatial elements remain unchanged. One of them is the terrain which parameters are the basis for the development research methods and techniques referred to as terrain analysis (Urbański 2008).
An excellent object to study the relationship between the abiotic environment and vegetation cover are river valleys, which integrate the structure, dynamics and function of all landscape components (Forman, Godron

1981, Ward et al. 2002). The most important factors determining the spatial distribution of plant communities (toposequence) and formation of plant landscapes of river valleys include: relief, character of the bed-rock, water relations (water drainage, water management, moisture level, water quality) and physico-chemical characteristics of soil. The aim of our study was: (1) to answer the question how to translate collected field data on plant communities, floristic diversity and ecological requirements of vascular plant species into GIS and obtain objective data (2) to evaluate the correlations between the morphological characters of a small-scale river valley (IV rank river) and ecological elements (vegetation and local flora) occurring in the valley, using the GIS and statistical methods.

Study site

The model object was a ca. 4 km long break section (i.e. between the 14th and 18th km of the river flow) of the Sopot river, the greatest right-side tributary of the upper Tanew river, crossing the escarpment zone of the Central Roztocze Highlands (fig. 1). The area constitutes the central part of the Roztocze macroregion, south-eastern Poland (Kondracki 2002). The valley was formed of the Miocene formations (content of $CaCO_3$ – 2.5-89%) in the upper part of the study area and Quaternary formations (both the mineral and organic ones) in the lower part of the valley. A characteristic feature of the 'strict' zone of the river break is a large slope of the riverbed (over the length of 1.1 km – 19.1‰; over the length of 4 km – 5.3‰, on average), a large depression of the valley bottom (≥20 m) and presence of numerous rock faults, which altogether give it a mountainous character. Additionally, in the study section of the valley there are ca. 130 springs, the majority of which are small outflows with efficiency of ≤1 $dm^3 \cdot s^{-1}$. The established changeability of mineralization of spring and soil waters is almost nine-fold. Four types of soil complexes were distinguished within the study area: (1) acid and oligotrophic habitats formed of podzol soils on the steep slopes of the valley, as well as slightly acidic to neutral and alkaline, meso- and eutrophic habitats of (2) mineral (semi-hydrogenic and alluvial) soils of the valley bottoms with the draining function of the watercourse; (3) organic soils in depressions with stagnant water; and (4) organic soils associated with the existence of a perched water-level up to 4 m above the river water-table (Czarnecka, Janiec 2000, 2002, 2006, Janiec, Czarnecka 2001).
Since 1958, following the decision of the ministry of forestry and timber industry, the most valuable part of the valley has been protected as a strict/partial landscape reserve called 'Czartowe Pole' ('The Devil's Field'). 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' = 'Solska Primeval Forest').

Material and methods

Field studies were carried out both at the level of vegetation and local vascular flora (Faliński 1990-1991, Matuszkiewicz 2005, Dzwonko 2007). A map of plant communities was prepared at the scale of 1:5000 (Czarnecka, unpbl. data). Simultaneously, the method of phytosociological relevés was employed and precise floristic charting was done for each 200-m long section of the river valley, separately for the left and right riverbanks. The frequency and abundance of each vascular plant species in a particular valley section was evaluated according to the simplified, combined scale, developed for the purpose of the study: 1 – sporadic species (single individuals or very small, scarce clumps of plants); 2 – rare and not-abundant species (represented by a few bigger aggregations of plants or scattered, 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). Using the computer programme ArcView 3.3, the areas of different plant communities were estimated and percent participation of particular plant associations, in the total area of the study site was calculated. Vascular plants nomenclature followed Mirek et al. (2002) and plant communities were distinguished after W. Matuszkiewicz (2005).
The analysis of the area was based on the Digital Elevation Model (DEM) according to Kraak & Ormeling (1998), with a resolution of 3 m. Spatial data were obtained from topographic maps at the 1:10 000 scale by successive

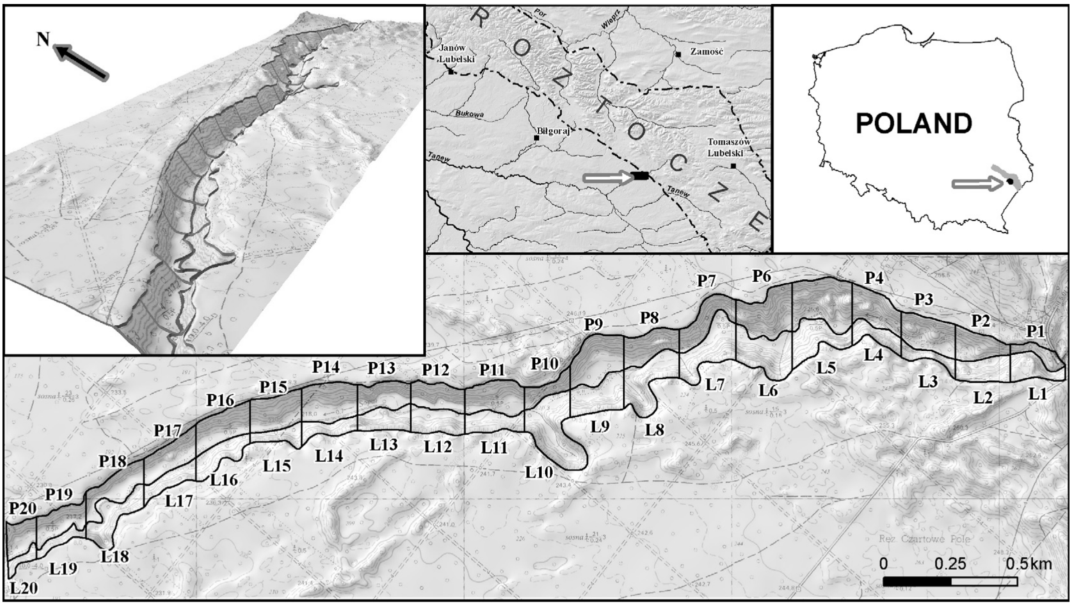

Fig. 1. The study section of the Sopot river valley on the background of the Roztocze Highlands

digitization of contour lines, elevation points, valley edges and their height. In addition to the information about the terrain shape provided by the contour lines, elevation points and discontinuity lines (here: the edges of the Sopot river valley), the topographic maps of the area also included information about the relative height of the latter. The Topo to Raster tool was used to generate the DEM. Based on the DEM, topographic attributes were calculated in the form of rasters (Gallant, Wilson 2000, Urbański 2008): primary – slope, aspect, planar and vertical curvature; and secondary – mean solar radiation (SRAD), and the topographic wetness index (TWI). Subsequently, each raster was analysed by calculation of zone statistics. The zones were the individual sections of the valley in which field observations were carried out. Statistics for each section were calculated using the Zonal Statistics tool. The whole operation was carried out using the ArcGIS 9.3.1 software.

The next step in the analysis was determination of correlations of topographic attributes of the valley, species richness and the Ellenberg indicator values for all species recognized in each section. We have taken into account the following 6 indicator values describing the most typical habitat conditions of the species (according to Zarzycki et al. 2002): L – light value, W – soil moisture value, Tr – trophy value, R – soil/water acidity (pH) value, D – soil granulometric value, H – organic matter content value. The indicator values were adopted arbitrarily, based on the predominance of habitats representing particular value intensity not only in the whole valley, but also in its particular sections. The share of species with a specific indicator value in each section was determined 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.

The trend line equations for the studied traits and Pearson's correlation coefficients (r) were calculated.

Results

The study area is characterized by differentiated topographic and water conditions and it is almost entirely wooded (99.5%). The main character of the vegetation landscape of the steep slopes is created by the Holy Cross mixed fir forest *Abietetum polonicum* (46.1% of the study area), one of the priority habitats in the EU. A similar role is played by two forest types occupying the riverbed habitats: riverside ash-alder forest *Fraxino-Alnetum* (21.2%) and bog alder forest *Ribeso nigri-Alnetum* (14.2%). A smaller area is occupied by the following forests: oak-pine mixed forest *Querco roboris-Pinetum* (7.0%), moist mixed coniferous forest *Querco-Piceetum* (5.7%), suboceanic pine forest *Leucobryo-Pinetum* (3.2%), secondary pine communities of the class *Vaccinio-Piceetea* (0.7%) and of the class *Querco-Fagetea* (0.1%). The remaining area (0.5%) is covered by sedge and meadow vegetation. The total number of 283 vascular plant species, representing 66 botanic families and different ecological groups were noticed in the study valley section (the area of ca. 80 ha), ranging from 47 to 118 in particular sections.

Some differences were found in the course of the mean slope between the left and right valley banks (fig. 1), with a stronger correlation for the left bank. Along the river, the mean slope for the left bank slightly increases ($y = 0.2627x + 10.347$, $r^2 = 0.25$, $r = 0.50$), and slightly decreases for the right bank ($y = -0.1691x + 13.036$, $r^2 = 0.11$, $r = -0.33$); the trend lines intersect at the level of section 6. Due to the near latitudinal course of the Sopot river valley in the study section, there are substantial differences in the mean amount of solar radiation reaching the ground surface on the left (northern aspect and derivatives) and the right bank of the river (southern aspect and derivatives). The trend lines for mean SRAD run parallel to each other (fig. 2); the correlation for the left bank is slightly weaker ($y = -2227.8x + 799214$, $r^2 = 0.22$, $r = -0.47$) than for the right bank ($y = -925.25x + 917999$, $r^2 = 0.29$, $r = -0.54$).

The trend lines for the mean values of topographic wetness index (TWI) for both banks exhibit a substantially different course (fig. 3). Along the river, the trend line for the left bank falls slightly ($y = -0.0295x + 8.0115$, $r^2 = 0.04$, $r = -0.21$) and the TWI assumes the highest values in sections L6-L9 while the trend line for the right bank rises significantly ($y = 0.1179x + 6.773$, $r^2 = 0.62$, $r = 0.79$), intersecting the line for the left bank at section 9, where riverbed habitats begin to predominate over slope habitats (fig. 1). It is worth noting that the correlation for the left bank is weak, and for the right bank – very high. The course of the trend line for the TWI clearly indicates asymmetry of the valley bottom (fig. 1).

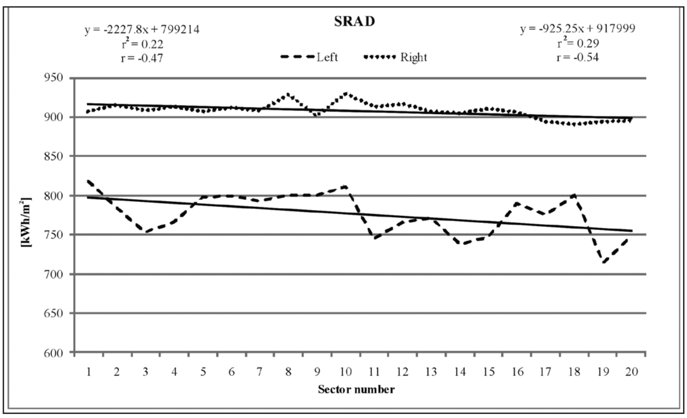

Fig. 2. Changes of values and trend line equations for mean SRAD along the study Sopot river section

The above-discussed primary and secondary morphological parameters of the valley – the slope, aspect, SRAD, and TWI – are related to the trend line for the share of species representing different Ellenberg indicator values. Along the river, the trend line for the share of species with a higher light value (L) has a slightly ascending and parallel course (the left bank: $y = 0.0066x + 2.9041$, $r^2 = 0.05$, $r = 0.23$; the right bank: $y = 0.0107x + 2.9875$, $r^2 = 0.08$, $r = 0.28$), although the correlation for both banks is weak. In turn, the trend lines for the soil moisture value (W) rise and almost coincide in the case of both valley banks, and the correlation coefficients are very high (left bank: $y = 0.035x + 3.442$, $r^2 = 0.72$, $r = 0.85$; right bank: $y = 0.0313x + 3.4916$, $r^2 = 0.58$, $r = 0.76$).

A different course is exhibited by the trend lines for the soil trophy value – Tr: a slightly rising trend line was

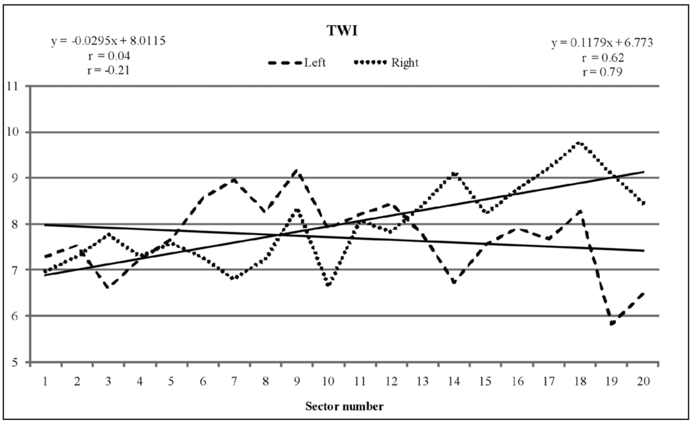

Fig. 3. Changes of values and trend line equations for mean TWI along the study Sopot river section

recorded for the left bank ($y = 0.0082x + 3.3929$, $r^2 = 0.17$, $r = 0.41$), and a slight decline was observed for the right bank ($y = -0{,}0028x + 3.5109$, $r^2 = 0.02$, $r = -0.14$); the intersection of the lines falls in section 11, and the correlation is, respectively, moderate and weak. From this section of the valley on the left riverbank, the share of meso- and eutrophic habitats of riverside ash-alder forest, floristically the richest community, increases, whereas on the right riverbank the share of rich habitats on the bottom and on the slope of the valley decreases, i.e. ash-alder forest and mixed fir forest, respectively. A similar tendency is revealed in the trend lines for the soil/water acidity value – R (the left bank: $y = 0.0048 x + 3.3701$, $r^2 = 0.08$, $r = 0.29$; the right bank: $y = -0.0012 x + 3, 4559$, $r^2 = 0.003$, $r = -0.05$), however with a weak and feeble correlation, respectively.

In the case of the soil granulometric value (D), on both banks of the valley along the river, there is a considerable increase in the share of species preferring heavier soils (clay and dusty deposits), particularly on the left bank, where the correlation is high ($y = 0.0125x + 3.9428$, $r^2 = 0.44$, $r = 0.66$); for the right bank the correlation is moderate ($y = 0.0074x + 4.0259$, $r^2 = 0.17$, $r = 0.41$). The increase in the share of soils rich in organic matter, i.e., the organic matter content value (H), along the river course is much clearer (habitats of bog alder forest and moist mixed coniferous forest). A similar trend was evaluated for both riverbanks (the left bank: $y = 0.0173x + 2.0495$, $r^2 = 0.79$, $r = 0.89$; the right bank: $y = 0.019x + 2.0617$, $r^2 = 0.73$, $r = 0.85$). The latter dependency has the highest correlation of all these analyzed in this study.

Summing-up and conclusions

1. The study break section of the Sopot river valley is characterized by a great abiotic diversity shaping the biodiversity both on the vegetation and vascular flora level.
2. Among the abiotic factors the most important for diversity of plant communities and local flora are the following: relief, Miocene and Quaternary bed-rock, water geochemistry, natural type of water economy and great changeability of mineralization of spring and soil waters.
3. Both primary and secondary morphological parameters of the valley (slope, aspect, SRAD and TWI) determine the course of the trend line for the share of species representing different Ellenberg indicator values (L, W, Tr, R, D, H).
4. The present study has confirmed that GIS and statistical methods are very useful in ecological research at different spatial scales and on different levels of biological organization: vegetation landscape, plant communities and local flora.
5. The DEM may be useful in the studies of correlations between topographic and ecological features along line structures of landscape: river valleys, sea and lake shores, ditches, roadsides, hedgerows, mid-field escarpments, etc.

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