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Using Direct and Indirect Methods to Assess Changes in Riparian Habitats

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Abstract: Hydrological regime disturbances in riparian ecosystems affect the interactions between soil properties and vegetation. The proper assessment of changes occurring in river valley forests is a basis for planning in sustainable forest management. The existing habitat conditions in plant communities can be assessed by both direct and indirect measurements. The aim of the study was to compare the results obtained with direct and indirect methods of data collection. We also evaluated the validity of the studied variables. Our study was based on data from plots established in 90-year-old forests in the Odra river valley (SW Poland). Habitat features, such as soil moisture (F), nitrogen (N), and soil reaction (R), were expressed directly using field measurements and indirectly using Ellenberg's indicator values, calculated based on the presence/absence of species in a plot (aEIVs) as well as on species cover (wEIVs). Only in the case of nitrogen did the use of both methods of estimating habitat features give the same results for selected riverside forests. In ordination and regressive analyses, use of direct or indirect methods strongly influences the results of calculations. Analyses conducted on the basis of selected parameters indicate a significant decrease in soil moisture and a change in soil reaction in the riparian forest located on the edge of the floodplain, which indicates that the habitat transformation has already begun. We concluded that the use of Ellenberg's indicator values (EIVs) for monitoring riparian habitats has numerous disadvantages, and therefore data based on direct measurement should be preferred.

Keywords: riparian forest; environmental changes; soil moisture; Ellenberg's indicator values; field measurements

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1. Introduction

In the past, riparian forests occupied vast areas in the valleys of major rivers of temperate Europe. In Poland, in the natural succession of vegetation in valleys there is riparian willow forests (Ass. *Salicetum albo-fragilis*), then riparian ash-alder forests (Ass. *Fraxino-Alnetum*) or riparian ash-elm forests (Ass. *Ficario-Ulmetum minoris*), which turn into oak-hornbeam forest (Ass. *Galio sylvatici-Carpinetum betuli*) [1]. The dynamics of vegetative structure and composition in riverside forests reflects the hydrological connectivity with the river, the groundwater level on the floodplain in equilibrium with the river water table, and adaptation to the natural water regime. Periodic flooding raises the moisture content of the surface layer of soils, accelerates soil formation from alluvial sediments, and facilitates diaspore dispersal and the establishment of *Salix* sp. tree stands [2–4].

Ecosystems located along river valleys have various ecological roles. They diminish the strength of floods, thus protecting nearby areas, accelerate the process of water self-cleaning and preserve many unique plant and animal species [5]. Furthermore, riparian forests are the most diverse and productive in nature [6].

These fertile habitats have been modified by human activity for centuries [7] and are facing disadvantageous changes caused by river regulation, backwater elimination, artificial drying of areas adjacent to the riverside [2,8], logging of forest stands [9,10], or alien plant invasions [11]. This situation calls for preservation and restoration of riparian ecosystems [12–14]. The current condition of the natural environment requires monitoring, particularly the interactions between vegetation, soil and water.

The phytoindication method based on Ellenberg's indicator values (EIVs) [15] is most frequently used to evaluate habitat conditions in plant communities. In this system the ecological optima of particular plant species are expressed as ordinal numbers. Mean values of Ellenberg's values calculated for patches of vegetation make it possible to estimate particular habitat conditions [16]. Using Ellenberg's system as a surrogate for directly measured environmental variables saves time and lowers the cost of research [17]. Numerous research papers confirm the utility and validity of the above-mentioned method based on confirmed correlations between mean Ellenberg's index values and results of physical and chemical field measures [18–21]. Nonetheless, there are also problems connected with the use of indicator analyses [22,23].

The most common anthropogenic cause of riparian forests drying out is construction of levees and dams, which leads to changes in the hydrological regime related to the soil transition from dominant ground-water supply to supply of precipitation water. This leads to the drying out of topsoil, development of the cambic horizon, and humus accumulation [4,24]. The effects of these processes are observed in the gradual changes in the floristic composition of the understorey, consisting in decline of hygrophytic species (typical for riparian forests) and encroachment of mesophytic species typical for oak-hornbeam forests [25]. Changed habitat conditions also aid in the spread of some woody species, which do not tolerate water flooding [26].

In the present study, we investigated the habitat features in selected riverside forests located at an increasing distance from the river bed. We used specific physico-chemical soil properties (moisture, nitrogen, soil reaction) assessed by direct measurements and indirectly by means of EIVs, based on the presence/absence of species in a plot (arithmetic mean) and calculated as species cover (weighted mean). The objectives of this study were to: (1) compare the results obtained with direct and indirect methods of data collection; (2) determine how the analyzed environmental factors obtained with various methods influence the composition and diversity of the studied forest community; and (3) determine the possibility of using the studied variables in the monitoring of riparian habitats.

2. Materials and Methods

2.1. Study Area

The study was carried out in 2011 in forests located in the Odra river valley within Lower Silesia, Poland (51°20′ N; 16°28′ E). This region has a moderate climate dominated by oceanic influence, characterized by warm summers (July: mean 18 °C), warm winters (January: mean −1.4 °C), a mean annual temperature about 8 °C, and a mean annual precipitation of about 550 mm [27]. In the mid twentieth century, as a result of changes in the hydrological conditions of the Odra (hydroelectric power plant), in the riverside forests analyzed the groundwater level permanently decreased as a result of reduced overbank flooding. The soils developed from loamy and silty sediments in the Holocene, in which quite often there are layers of sand [24,25].

We selected three tree stands, each with an area of around 5 ha: site I riparian forest (Ass. *Ficario Ulmetum-minoris*) on the floodplain, at a distance of 500 m from the Odra (elevation 93.2 m.a.s.l.), immediately adjacent to the old river bed; site II riparian forest located at a distance of 550 m (93.3 m.a.s.l.), bordering site I on the edge of the floodplain and adjacent to site III; and site III oak-hornbeam forest (Ass. *Galio sylvatici-Carpinetum betuli*), distance around 800 m (93.7 m.a.s.l). In the profiles located at site I and site II the groundwater level was at the depth 100 cm and 150 cm below the ground level, respectively, and in the profile at site III groundwater was not recorded to a depth of 150 cm during the period of their digging (July 2016 with evenly annually distributed rainfall).

All sites used in this study have been used as timber forests since at least the eighteenth century. In the forest stand of floodplains *Tilia cordata* Mill. is dominated by *Ulmus minor* Mill., *Alnus incana* (L.) Moench, and *Acer campestre* L. In site III standing timber is composed primarily of *Carpinus betulus* L. with some *T. cordata*. A detailed description of the vegetation can be found in Kawałko et al. [25]. The age of maturity of those stands was established as 140 years; currently 90 years. Management operations consist of thinning every 10 years after reaching a middle stage of stand maturity. The last thinning was performed in the year 2012.

2.2. Data Collection

Ten randomly selected study plots (10 m × 10 m) were established in each site, where five relevés in April/May and five in July were taken. We visually estimated the percentage cover (5% estimation intervals) of vascular plant species in the study plots. Vascular plant nomenclature was based on Tutin et al. [28].

Furthermore, in April in the four corners of each square soil samples were taken from a layer of 5–15 cm depth and pooled into one sample. After the samples were dried the pH in H_2O (potentiometrically, volume ratio 1:2.5) and content of total nitrogen (N) (modified Kjeldahl method using Büchi analyzer) were measured. In the driest period of the growing season, for each study plot the soil samples were collected in Kopecky's cylinders. Water properties (including field water capacity; FWC) were conducted in laboratory conditions with the application of sand blocks and sand-kaolinite blocks [29]. We are aware that soil texture significantly affects soil retention; however, we chose the FWC for the analysis, as it is not regulated by gravity flow, but by transpiration and evaporation. FWC is the degree of soil moisture that remains after rainfall or flooding, and after the flood has subsided. If the FWC is high, the amount of water available to plants will also develop well. Thus, it can be assumed that the FWC is an indicator of the amount of water in soil.

2.3. Data Analysis

In the analyses, we decided to use Ellenberg indicator values, which are often used due to the possibility of assessing habitat features without direct measurements [16]. This system can be used to identify environmental factors based on the species composition of vegetation [18]. In our study, we used the Ellenberg indicator values for soil moisture (F), soil reaction (R) and nitrogen (N) [18]. Soil moisture (F) takes values from 1 on dry soils to 9 on wet soils. Soil reaction (R) ranges from strong acidity (1) to alkaline soils (9). Nitrogen takes values from 1 on the poorest soils to 9 on nitrogen-rich soils [18]. In our study, we decided to choose three types of forest communities which strongly differ in environmental gradients, particularly soil moisture. The species defined in the Ellenberg system as indifferent were omitted from the calculations. The means of Ellenberg indicator values (EIVs) were calculated as weighted averages based on the presence/absence of species in a plot (aEIVs) as well as weighted means based on species cover (wEIVs).

The compatibility of data with a normal distribution was tested with the Shapiro-Wilk W test. The homogeneity of variances was checked using the Levene's test. The variables for which a normal distribution was obtained were studied with parametric methods: the Pearson correlation coefficient and analysis of variance (ANOVA) with Tukey's HSD test. The data for which a normal distribution was not found and/or the assumption of variance homogeneity was not met were tested using non-parametric methods: the Spearman correlation (Rs) and the Kruskal-Wallis test.

In order to determine the influence of habitat conditions on the number of species, multiple regression analysis was performed. The calculations were conducted for ln-transformed and standardized data. A model was constructed using all analysis effects. Model verification was based on assessing the significance of linear regression and the significance of partial regression coefficients, the lack of multicollinearity between independent variables, the assumption of homoscedasticity, normal distribution of residuals, and no autocorrelation of residual calculated using Durbin-Watson statistics. Variance analysis in regression was used to determine the variation explained by the obtained model. The analyses were conducted using STATISTICA software [30].

To reveal the main environmental gradients on the basis of the species composition of vegetation, detrended correspondence analysis (DCA) was conducted. The length of the gradient represented by the first DCA canonical axis was 4.7 Standard Deviation (SD); therefore to determine the influence of the study environmental factors on vegetation canonical correspondence analysis (CCA) was used. The significance of the variables was tested with the Monte Carlo permutation test with stepwise variable selection. All ordination analyses were performed using the CANOCO v5.03 software [31]

3. Results

3.1. Habitat Properties Determined Using Direct and Indirect Methods

Research results showed significant differences in the habitat properties of selected communities (Table 1). In the first studied habitat feature—moisture—the riparian forest on the edge of the floodplain (site II) was assessed as dried out in two methods: direct, expressed as field water capacity FWC ($F = 630.40$; $p < 0.0001$); and indirect, using weighted mean of moisture index F according to Ellenberg ($F = 5.37$; $p = 0.011$). No significant differences between mean arithmetic values of Ellenberg's moisture index were found between the two riparian habitats ($H = 9.39$; $p = 0.09$).

Table 1. Mean values (±standard error SE) of calculated and measured soil properties. wEIVs = weighted mean of Ellenberg's indicator values; aEIVs = arithmetic mean of Ellenberg's indicator values; FWC = field water capacity (%); F = moisture; R = soil reaction; N = nitrogen; Ntot = total nitrogen concentration (%). Different letters in rows indicate significant differences between sites determined in Tukey HSD test or Kruskal-Wallis test with $p \leq 0.05$ ($n = 10$ for each site).

	Site I	Site II	Site III
	Moisture		
F wEIVs	2.03 ± 0.20 b	1.59 ± 0.13 ab	1.20 ± 0.20 a
F aEIVs	4.21 ± 0.13 b	4.03 ± 0.09 b	3.35 ± 0.22 a
FWC	49.63 ± 0.40 c	45.51 ± 0.24 b	32.41 ± 0.41 a
	Soil reaction		
R wEIVs	2.35 ± 0.25 b	1.67 ± 0.12 ab	1.32 ± 0.20 a
R aEIVs	4.24 ± 0.21 ab	4.39 ± 0.10 b	3.47 ± 0.25 a
pH	5.37 ± 0.06 b	5.19 ± 0.07 b	4.66 ± 0.10 a
	Nitrogen		
N wEIVs	5.08 ± 0.09 b	5.06 ± 0.09 b	1.52 ± 0.24 a
N aEIVs	5.33 ± 0.08 b	5.31 ± 0.14 b	3.71 ± 0.26 a
Ntot	0.40 ± 0.03 b	0.33 ± 0.02 b	0.25 ± 0.02 a

Analysis of the second tested feature—soil reaction—showed a decrease in soil pH along with the drying process. This dependency was observed for weighted mean values of soil reaction index ($F = 5.37$; $p = 0.011$) and soil pH expressed directly (pH: $H = 17.68$; $p = 0.0001$). For mean arithmetic values of the soil reaction index the study showed an increase of value in site II ($F = 8.49$; $p = 0.001$).

For the last analysed feature—nitrogen—all methods of expressing the studied variables gave similar results (N: $H = 13.67$; $p = 0.001$; N weight.: $F = 169.31$; $p < 0.0001$; N arithmet.: $F = 27.11$; $p < 0.0001$), showing significant differences between study communities.

The comparison of the relationship between arithmetic means and weighted mean values of Ellenberg's ecological values showed a relation for all studied features: moisture F ($Rs = 0.713$; $p < 0.001$); soil reaction R ($Rs = 0.665$; $p < 0.001$); and nitrogen N ($Rs = 0.878$; $p < 0.001$).

The analysis of dependencies between Ellenberg's indicator values expressed in both methods and soil properties showed certain discrepancies (Table 2). The arithmetic mean of moisture index F, the study recorded a slightly stronger correlation with field water capacity as compared to the relation between weighted mean of F and FWC. At the same time, no significant dependencies between soil pH and mean arithmetic soil reaction index R was noted. Both the weighted mean and arithmetic mean of the N index were correlated with nitrogen content determined indirectly.

Table 2. Spearman's rank correlation coefficient values between the studied indices. wEIVs = weighted mean of Ellenberg's indicator values; aEIVs = arithmetic mean of Ellenberg's indicator values; FWC = field water capacity (%); F = moisture; R = soil reaction; N = nitrogen; Ntot = total nitrogen concentration (%). Correlation coefficients are significant at * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$ (n = 30).

	F wEIVs	R wEIVs	N wEIVs	F aEIVs	R aEIVs	N aEIVs	N tot	pH	FWC
F wEIVs									
R wEIVs	0.783 ***								
N wEIVs	0.476 **	0.372 *							
F aEIVs	0.713 ***	0.624 ***	0.539 **						
R aEIVs	0.622 ***	0.665 ***	0.527 **	0.663 ***					
N aEIVs	0.461 **	0.388 *	0.878 ***	0.61 ***	0.554 **				
Ntot	0.255	0.464 **	0.447 *	0.235	0.232	0.496 **			
pH	0.378 *	0.503 **	0.519 **	0.340	0.311	0.543 **	0.815 ***		
FWC	0.542 **	0.553 **	0.668 ***	0.629 ***	0.368 *	0.71 **	0.590 ***	0.665 ***	

The comparison of dependencies between particular variables showed a cross-correlation between most of the variables studied (Table 2).

3.2. The Influence of the Studied Environmental Variables on Results of Ordination Analyses

Weighted means of Ellenberg's indicator values used in CCA analysis with the Monte Carlo permutation test showed that total variation is at the level 2.63, explanatory variables account for 31.7% and adjusted explained variation is at the level of 23.9% (Table 3).

Table 3. Results of all the variables selected in forward selection of variables in the three canonical correspondence analysis (CCA) analyses. wEIVs = weighted mean of Ellenberg's indicator values; aEIVs = arithmetic mean of Ellenberg's indicator values; FWC = field water capacity (%); F = moisture; R = soil reaction; N = nitrogen; Ntot = total nitrogen concentration (%); Explains (%)–percentage of explained variability in species data; pseudo–F statistic obtained by the Monte Carlo permutation test; *p*–type I error probability.

	Explains (%)	Pseudo-F	*p*
N wEIVs	24.3	9	0.002
R wEIVs	3.5	1.3	0.07
F wEIVs	3.9	1.5	0.026
N aEIVs	19.6	6.8	0.002
F aEIVs	4.3	1.5	0.014
R aEIVs	2.9	1	0.394
FWC	23.2	8.4	0.002
pH	3	1.1	0.286
N tot	2.5	0.9	0.706

When it comes to arithmetic means of EIVs, total variation is at the level of 2.63, explanatory variables account for 26.8% and adjusted explained variation is at the level of 18.4% (Table 3).

Data expressed directly indicated that total variation is at the level 2.64, explanatory variables account for 28.7% and adjusted explained variation is at the level of 20.4% (Table 3). The permutation test result was slightly lower than the results obtained for weighted mean values of EIVs.

3.3. Determining the Vegetation-Habitat Dependency

The first multiple regression model (Table 4) obtained for species richness and weighted mean EIVs showed a strong influence of soil reaction index R (r = 0.526; $p = 0.004$) on the total number of species. As much as 70% of total variation of the "species richness" variable is explained through this model. Variance regression analysis results could lead to the conclusion that variation explained through the regression model is at the level of 25%.

Table 4. Summary of the multiple regression analysis for the dependent variable 'number of species per plot'. wEIVs = weighted mean of Ellenberg's indicator values; F = moisture; R = soil reaction; N = nitrogen. R = 0.86, $R^2 = 0.73$, adjusted R = 0.70, F = 24.00, $p < 0.0001$, standard error of estimation: 0.54.

	Standardized Coefficient	Standard Error	t	*p*
Intercept	0.000	0.099	0.000	1.000
F wEIVs	0.093	0.246	0.378	0.709
R wEIVs	0.765	0.243	3.150	0.004
N wEIVs	0.009	0.165	0.055	0.957

The second model obtained for species richness and arithmetic means of EIVs showed no significant correlation between the studied factors and dependent variable (R = 0.73, $R^2 = 0.54$, adjusted R = 0.49, F = 10.21, $p = 0.0001$, standard error of estimation: 0.71).

In the third model made for the dependent variable "species richness" and physicochemical properties of soil, there was no correlation between the studied habitat properties and the dependent variable. Comparing the result with previous ones leads to the conclusion that, for habitat features studied directly, the model proved to be less accurate (R = 0.49, $R^2 = 0.24$, adjusted R = 0.15, F = 2.74, $p = 0.06$, standard error of estimation: 0.92).

4. Discussion

4.1. Habitat Properties Estimated Using Direct and Indirect Methods.

The assessment of habitat features conducted using three methods (arithmetic mean EIVs, weighted mean EIVs, direct measurements) gave the same results only in the case of nitrogen in the studied communities. This parameter showed no significant differences between riparian habitats. Usually, for deciduous forests rich in species, estimating habitat features using arithmetic and weighted means gives similar results [19,32]. In our research mean EIVs for moisture and soil reaction, calculated based on the presence/absence of species (arithmetical averages) and based on cover (weighted averages), were different between these two methods. Many researchers have recommended averages determined by the species cover of each species in the research plot [15,21,33–35]. They assumed that a species reaches a higher cover when the environmental conditions at the site are nearer to the ecological optimum of the species [36]. The analyses of our research based on weighted mean EIVs indicate a significant decrease in moisture and a change in the soil reaction of the riparian forest located on the edge of the floodplain.

The confirmation of mean EIVs reliability is strongly related to measured environmental variables [17]. In many forest studies there was a significant association between mean EIVs for reaction and soil pH [15,17,19–21,32,37,38]. Diekmann [16] stated that among environmental factors, soil reaction is easier to measure and does not vary as much over the year as the other features. In our research we found a low correlation between soil pH and weighted averages of EIVs for soil reaction. We did not include the saturation of Ca cations. However, some authors have suggested a necessity to determine their content and stated that the relation between mean EIVs for reaction and Ca content is usually stronger than those with soil pH [21,32].

On the other hand, the relationship between the average of EIVs, both arithmetical and weighted, for moisture and field water capacity was much stronger. For the sake of comparison, studies by Diekmann [19] and Szymura [32] reported weak correlations between weighted EIVs and moisture in deciduous forests. The reason for the difference in the dependencies might be related to the season and depth of sample collection and the physico-chemical properties of soil [39,40].

In the case of nitrogen, there was a linear relation between all estimated features. It is unclear to what extent the relation is connected with N in soil, because the effects of nitrogen, and particularly phosphorus, are difficult to distinguish [15].

4.2. Validity of the Studied Variables and the Results of Statistical Analyses

Analyses conducted using mean EIVs have given good results in the case of natural and semi-natural phytocoenoses with stable plant composition [16,17]. In the case of habitat under strong human pressure the results become less reliable. When comparing the results of mean EIVs with measured features, Wamelink [37,38] stated that major problems exist with the appropriate interpretation of fitoindication in terms of ecological gradients and suggest using indication with EIVs to estimate habitat features only for the same vegetation types. On the other hand, in a certain vegetation type with a relatively short environmental gradient, it could potentially lead to misinterpretation of identification with EIVs [32,41]. Determining a cross-correlation between groups of analyzed features—for example between moisture and nitrogen, light and nitrogen [42], pH and nitrogen [17,43], which are also present in our research—may influence the results of statistical analyses.

Using direct and indirect methods for estimating habitat features led, in our case, to obtaining different results of ordination and regressive analyses. The compared permutation tests showed that the highest percentage of vegetation data variation comes from environmental factors expressed indirectly using weighted means. Those variables should, however, be used sensibly. Plants react to habitat changes with delay and mean indicator values may reflect a critical stage in plant development and not the current state [16]. Moreover, it needs to be taken into account that there is a strong linear dependency between data pertaining to vegetation and the ecological factors; especially if the gradient is short, the random variation in species composition might bias the results [16].

Multiple regression analyses showed, similarly to the results of permutation tests, that the highest reliability may be credited to the model built using weighted means. In the case of arithmetic means the study did not show any significant influence of the studied variables, and analogous results were also obtained in the case of variables expressed directly. Using arithmetic and weighted means in regression analyses seems disputable because of ordinal scaled values [44], the lack of normal distribution [45], and frequent collinearity. Additionally, the relationship between means does not always have to be linear [21]. Furthermore, calculating mean ecological optima for species may cause the so-called regression problem [46], which, in consequence, may cause invalid results of statistical analyses.

4.3. Implications for Management

With proper moisture riparian phytocoenoses show resistance to moderate anthropogenic disturbances [47]. However, the soil properties recorded in our research (moisture, soil reaction) and species composition in the riparian forest located on the edge of the floodplain suggest that the process of drying out has already begun.

The management of the riparian forest analyzed should focus on conservation of current stand composition. Natural regeneration is recommended, which is native and appropriate to the location and soil water regime [12]. However, this process depends on the number of parent trees, a minimum of 20–30 per hectare [48], and density of ground vegetation. Planting will be necessary in the case of unsuccessful germination of tree seeds. It is also possible to consider fixed-width unharvested buffer zone [49,50], which is currently standard practice in most of the major temperate and boreal timber-producing regions [51,52].

5. Conclusions

Species composition of plant phytocoenoses and quantitativeness changes of particular taxa are useful indicators in studying and monitoring environmental changes. Comparing the results obtained with direct and indirect methods of data collection, we found that only in the case of nitrogen did the use of methods of estimating habitat features give the same results for selected riverside forests. Due to some caveats in using Ellenberg's indicator values to assess the habitat condition, we concluded that data from direct measurements should be preferred.

Our analyses indicate a impact of the studied variables on the species composition of the riparian forest located on the edge of the floodplain. Moreover, we found a significant decrease in soil moisture and a change in soil acidity, which indicates that the process of overdrying of this habitat has already begun. The results obtained constitute a premise for implementation of the conservation plan for this riparian stand.

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