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Bioindication with Ellenberg's indicator values: A comparison with measured parameters in Central European oak forests

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ABSTRACT

Ellenberg's indicator values (EIVs), as bioindicators of primary environmental traits, are commonly applied in Europe; however, a problem exists with the appropriate interpretation of bioindication results in terms of ecological gradients. Very few studies have tested the predictive values of EIVs using validation data sets. In this study, we compared the results of bioindications of nitrogen content, soil reaction, light availability and soil moisture with measured environmental traits in Central European oak forests and assessed the ability of EIVs to predict environmental traits based on validation data sets. Additionally, the regression trees method was applied to determine which environmental traits influenced the values of EIVs. The results reveal that numerous linear correlations exist between the mean values of EIVs and measured traits. However, the correlations were rather low. The established regressions allow realistic predictions in case of Ca content and light conditions, while they did not perform satisfactory in case of moisture and nitrogen. The relatively low correlations were the result of several factors. Among these, the values of EIVs for species are inter-correlated, which might distort the results, especially for soil moisture and light availability. Moreover, the average values of EIVs assigned as an indication of particular environmental trait could be influenced by multiple ecological factors acting together and this could bias bioindication. The regression tree method, as a more flexible one, was able to detect such effect influencing average values of EIVs, while the linear method was not able to reveal it.

1. Introduction

The theory of ecological niches of species provides the basis for the use of bioindication, where species composition of a given community allows conclusions to be made about the environment. One of the most frequently used systems of bioindication of primary environmental traits in Europe is based on Ellenberg's indicator values (EIVs, Ellenberg et al., 1992), where realized ecological optima of plant species are expressed as ordinal numbers. Weighted average values of EIVs calculated for a vegetation sample are used as surrogates for measured environmental variables (Diekmann, 2003). In the view of purely mathematical criteria, the weighted average method is not appropriate, as EIVs are expressed on an ordinal scale. However, (Ter Braak and Barendregt (1986) postulated that the ordinal nature of Ellenberg's scale is far less important than the shape of species response curves, which should be symmetrical. In this case, mean and median values usually do not differ widely (Diekmann, 2003). Moreover, median values produce additional stochastic noise caused by their rough scaling; therefore, there is practically no substantial argument against the use of weighted average values (Seidling and Fischer, 2008). Several studies have demonstrated that calculated weighted mean EIVs are often a good estimate of actual environmental conditions (Diekmann, 2003). The mean EIVs are known to be robust in response to changes in sampling area (Otýpková, 2009) and incompleteness of species lists in the plant community (Ewald, 2003a). Therefore, forestry uses bioindication with mean values of EIVs as a relevant indicator of site productivity (Bergès et al., 2006) and for validation of the prediction of water relationships in soils (Häring et al., 2013). They are also used as a surrogate of environmental variables in modeling biodiversity (Merunková and Chytrý, 2012), herb biomass production (Wagner et al., 2007; Axmanová et al., 2012) and bioindication of atmospheric deposition (Van Dobben et al.,

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1999). EIVs are also commonly used to aid the interpretation of vegetation ordination results (Persson, 1981), and to model species distribution (Brunet et al., 2000; Erdős et al., 2013). Moreover, most floristic data available in the European vegetation databases are not accompanied by environmental data, and EIVs provide an opportunity to approximate environmental parameters (Tichý et al., 2010). This approximation is particularly important when analyzing historical data, which can provide evidence of changes in environmental traits over time. If no previous measurements are available, bioindicators are indispensable and allow the assessment of the dimension of environmental change (Zonneveld, 1983).

Despite their common application, the reliability of bioindications based on EIVs has been criticized for several reasons. For example, EIVs are not systematically derived from field measurements, but mainly result from the field experience of plant ecologists, i.e., observations of species occurrences at different sites. They are thus rather subjective, and any data set bias might lead to an inaccurate assessment of habitat quality (Økland, 1999). The direct comparison of results of bioindication using EIVs with measured environmental variables reveals that problems exist with the appropriate interpretation of bioindication in terms of ecological gradients (e.g., Schaffers and Sýkora, 2000; Wamelink et al., 2002, 2005). Results of studies suggest that the EIVs for nitrogen values more accurately reflect productivity, as these are correlated with not only available nitrogen, but also phosphorus and potassium, as well as biomass production (Hill and Carey, 1997; Schaffers and Sýkora, 2000; Wagner et al., 2007; Axmanová et al., 2012). Moreover, soil pH is not a nutrient itself; however, it affects the general availability of nutrients and other elements in the soil and therefore influences productivity (Wagner et al., 2007). Some soil elements are much better correlated with the mean EIV for soil reactions; in particular, this is true for the amount or saturation of exchangeable Ca^{2+} (Schaffers and Sýkora, 2000). For EIVs for moisture, it has been suggested that the lowest values of measured water content give better correlations with mean EIVs than mean water content. This indicates that plant susceptibility to periodic or occasional drought is more important to their long-term performance in the field than tolerance to occasional periods of high soil moisture content (Scheffer and Sykora, 2000). The lack of a significant effect of flooding on bioindication with EIVs appears to support this hypothesis (Follner et al., 2010). Additionally, one can assume that the smaller the length of gradient, the weaker the performance of corresponding indicator values (Diekmann 1995, 2003). For short gradients, the mean EIVs do not differ greatly, and might be more affected by random fluctuations in species composition than by the underlying gradient (Diekmann, 2003).

Moreover, EIVs are internally correlated. A positive correlation exists between EIVs for moisture and nitrogen, as well as for light and nitrogen (Cornwell and Grubb, 2003) and pH and nitrogen (Wagner et al., 2007). In the forests of Germany, calciphilous species have an advantage in habitats that provide more nitrogen and light, but less moisture. Additionally, in terms of climate, they have a slight preference for warmer sites and their distribution extends further into the continent (Ewald, 2003b). Species adapted to leached acidic soils usually have a range of distribution in oceanic climates (Chytrý, 1995). Such inter-correlations between EIVs might bias the results of bioindication (Pakeman et al., 2008). In long-term fertilization experiments in grasslands, EIVs for continentality and moisture changed, even though moisture and climate were not manipulated (Chytrý et al., 2009). This effect was the result of inter-correlations of EIVs; on fertilized plots, nutrient-demanding species appeared, which simultaneously had lower values for continentality and higher for moisture (Chytrý et al., 2009).

Bioindication with EIVs is often used for the evaluation of habitat and/or vegetation traits in relatively short environmental gradients, in certain vegetation types and even plant associations, e.g. *Peucedano-Pinetum* pine forest (Matuszkiewicz et al., 2013), nutrient-poor pine forest (Reinecke et al., 2014), beech forests (Carranza et al., 2012) or thermophilous oak woods (Hédl et al., 2010). Unfortunately, no attempts have been made to validate the predictive values of EIVs with a validation data set in forest ecosystems. Such a lack of knowledge could potentially lead to misinterpretation of indication with EIVs. Additionally, only a few attempts have been made to evaluate the relationship between forest floor biomass and EIVs for nitrogen (Axmanová et al., 2012). Moreover, the EIVs, originally designed for the flora of Germany, are often applied in countries in the sub-continental part of Central Europe e.g., in the Czech Republic, Poland and Slovakia. Although some species show differences in their ecological behavior in different geographical areas, only a limited number of studies have correlated mean EIVs with measured traits (Dzwonko, 2001; Gégout and Krizova, 2003; Hájková et al., 2008; Balkovič et al., 2012).

To examine the reliability of bioindication, the average values of EIVs are correlated with mean values of measured environmental variables. If the relationship is weak or absent, bioindication is assumed to have performed poorly, but one could also conclude that an incorrect parameter was measured (Diekmann, 2003). There are reasons why bioindication could perform better than instrumental measurements of ecological factors. Plants used for bioindication can be supposed to accurately 'measure' what is relevant for them, while measurements depend on arbitrary choices of the researcher (e.g. sampling procedures, analytical methods, choice of measured factors). In addition, plants integrate all relevant factors in time and space whereas actual measurements provide snapshots (Zonneveld, 1983; Zelený and Schaffers, 2012). However, evaluating what provides the best results, bioindication or instrumental measurements, is difficult when traits of vegetation (e.g. species composition, species richness) are response variables. Some studies reveal that average values of EIVs could be a better predicator of plant species occurrence than measured variables (Dupré and Diekmann, 1998; Smart et al., 2010). Nevertheless, the problem of circular reasoning exists when attempting to explain vegetation pattern using bioindication with EIVs. This happens because the average values of EIVs are derived from two information sources: (1) values of EIVs for a particular species, specifying ecological behavior of a species; and (2) species composition of the vegetation sample for which the average values of EIVs were calculated. In this situation, the first source contains external information. However, since the data related to composition of vegetation samples are used to calculate the average values of EIVs, the average EIVs preserve the information about the vegetation sample, e.g. about its compositional similarity to other samples. Zelený and Schaffers (2012) called this problem the similarity issue and demonstrated that this issue can bias the results of a study related to species richness, differences between groups of vegetation samples, and ordination of vegetation. Therefore, the similarity issue can be potentially bias observations concerning that fact that average EIVs exhibit better performance than the measured variables; they need, at least, re-evaluation with the use of a specially developed statistical approach (Zelený and Schaffers, 2012).

In this study, we correlated and regressed the values of measured environmental factors and forest floor biomass productivity with mean EIVs for light availability, moisture, soil reaction and nitrogen in forest floor vegetation in Central European oak forests. This allowed us to determine which environmental gradient or gradients are reflected in bioindication with EIVs in the studied forest types. Second, based on established regression, we also examined the ability of EIVs to predict values of physical and chemical environment traits, using a validation data set. Third, we examined the potentially complex and non-linear relationships between mean