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Using statistical tests on relative ecological indicator values to compare vegetation units – Different approaches and weighting methods

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ABSTRACT

Relative ecological indicators are frequently used tools in vegetation analyses. Despite their ordinal nature, it has been shown that average indicator values can characterize an area well, and can provide useful ecological information. Several different averaging methods have been tested against the indicated environmental parameters, but only very slight differences could be found between their reliability. Different statistical tests, including parametric and non-parametric tests, are also often applied on relative ecological indicators. Similarly to the weighting methods, there are several ways to provide source data for the tests from raw indicator values but the possible differences in the reliability of the resulting statistical layouts have never been looked at. In the present study we have chosen the Hungarian adaptation of Ellenberg's indicator for soil moisture as a model system and examined a total of 8 different statistical layouts. Raw indicator values were obtained from vegetation surveys of 16 appropriately chosen sites and were processed in two fundamentally different ways. In the first approach, average indicator values were calculated for each sampling quadrat of the sites and these averages were used as source data for ANOVA tests. The calculation of the averages was carried out in four different ways according to the weighting methods. In the second approach, site specific species lists were compiled using the quadrats of each site and the raw indicator value populations deriving from these lists were analyzed with Kruskal–Wallis tests. Again, four weighting methods were used, but instead of averaging, the indicator value of each species within a site was repeated as many times as its weight required. Finally, the reliability of each method was assessed by comparing the results with the actual soil moisture relations of the sites, determined with physical measurements. According to our results, it can be said that false positive results are rare with any type of the methods but the amount of false negative results varied among the methods considerably. The most reliable method was the Kruskal–Wallis test when performed on frequency weighted raw indicator value populations. This method could best reproduce the original soil moisture relations and could yield the most convincing *p*-values; therefore we can recommend using this method in studies where sets of relative ecological indicator values are intended to be compared with statistical tests.

1. Introduction

Relative ecological indicators express the realized optimum of plant species on ordinal scales defined along environmental gradients (Ewald, 2003). Originally, the system was developed for the flora of Central Europe by Heinz Ellenberg and included the following 7 environmental factors: soil moisture, soil acidity, productivity/nutrients, continentality, soil salt content, temperature and light (Ellenberg, 1952; Ellenberg et al., 1992). The system has been adapted to several regions outside its first definition and has become a wide-spread tool of applied plant ecology, forestry and agriculture (Borhidi, 1993; Diekmann, 2003; Dzwonko, 2001).

The most common applications of relative ecological indicators are to compare the habitat conditions of two or more different areas or to monitor the changes of the vegetation of a permanent plot (Diekmann, 2003; ter Braak and Wiertz, 1994; Tölgyesi and Körmöczi, 2012). Comparing relative indicator values, however, has its difficulties. Owing to the ordinal nature of their scales, several statistical operations cannot be applied to them without further considerations. Möller (1992) recommends the median values of the sites as statistically sound tools for comparisons but several studies have shown that mean indicator values characterize an area well and they can provide useful ecological information (Lengyel et al., 2012; ter Braak and Barendregt, 1986; ter Braak

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and Gremmen, 1987). According to Ellenberg et al. (1992) there are three basic ways to calculate mean ecological indicator values. (i) The qualitative method uses only the presence/absence data of the species and results in unweighted averages. (ii) The quantitative method uses the percent cover values of the species as weights and results in weighted averages. (iii) The ordinal method also results in weighted averages but the weights are developed by projecting the percent cover values to an ordinal scale. For example Allen (1992) recommends a 6-grade scale, while van der Maarel (1979) uses a 10-grade scale. There have also been proposals for abundance-independent weighting methods to improve the accuracy of the average values. Schaffers and Sykora (2000) called attention to the general phenomenon that the frequency distributions of indicator values are rather uneven, which creates a tendency for mean values to converge to the value most common in the regional species pool. In practice, this means that the more extreme a value is, the less species belong to it in the flora. Therefore, supplying every indicator value with a weight that appropriately downweights common values and upweights rare values can prevent the average value of an extreme habitat from shifting toward intermediate values.

Surprisingly, apart from some special cases, the correlation between average indicator values and the values of the indicated environmental parameters do not change significantly with any type of the main two weighting methods compared with the unweighted one (Diekmann, 2003; Käfer and Witte, 2004; Klaus et al., 2012). The abundance independent weighting method does not improve the correlation considerably, though it has some beneficial effects such as improving the linearity of mean values along the gradient of the indicated environmental parameter. Therefore, Schaffers and Sykora (2000) recommend the use of this weighting as a standard method, especially when quantitative statements about environmental conditions are to be made.

As it can be seen, the accuracy of different averaging methods is well-studied, but according to our knowledge no study has ever been conducted to examine the reliability of the different statistical layouts used on Ellenberg indicator values. Such tests, however, are widely used in applied vegetation science (Zeleny and Schaffers, 2012). In the literature one can find examples for the use of parametric tests like the *t*-test and the ANOVA test (e.g. Spiegelberger et al., 2006), as well as non-parametric tests like the Mann–Whitney test and the Kruskal–Wallis test (e.g. Zwaenepoel et al., 2006), and in some cases mean indicator values are weighted with species abundance measures (e.g. Roovers et al., 2005) but in other cases they are not (e.g. van Dobben et al., 1999).

In the present study we have chosen a relative ecological indicator, Borhidi's indicator for soil moisture (*F* value), which is the adaptation of Ellenberg's indicator for soil moisture to the Hungarian flora (Borhidi, 1995), and aimed to investigate whether there are differences in the efficiency of different statistical layouts and tried to find the most reliable one for comparing vegetation units. For this purpose we selected 16 appropriately chosen study sites and examined, which statistical layout can best reproduce their humidity relations, previously determined with physical measurements.

2. Materials and methods

2.1. Study sites

The study was carried out on the lowlands of Central Hungary, in the Kiskunság National Park. Considering the purposes, study sites were needed with different water supplies but otherwise with environmental conditions as similar as possible. The sites had to be relatively close to each other to ensure synchronized water supply fluctuations, thus eliminating the need for multiple soil moisture measurements. Areas under severe human influence had to be avoided as it may cause competitive release, making the original indicator values of certain species less usable (Kowarik and Seidling, 1989). The presence of severe disturbance – natural or anthropogenic – would have also been disadvantageous because the vegetation of such areas does not primarily indicate specific soil conditions but reflect the disturbance regime (Briemle, 1997). Using average indicator values on heterogeneous plots can result in misleading results (Diekmann, 2003), therefore special attention was paid to choose study sites with as homogeneous vegetation as possible. To ensure differential water supplies, the sites were chosen so that they were located on different elevations.

Considering the above criteria, eight study sites were chosen in a sand dune range, called Fülöpháza Sand Dunes. Four of them were in hilltop position (dry dune sites, DD1-4, 109–111 m a.s.l.) and four in dune slacks (wet dune sites, WD1-4, 100–101 m a.s.l.). DD sites are covered with sparse xeric vegetation, since their only water source is falling precipitation and their soil has a very poor water holding capacity. The vegetation of the WD sites is denser and taller since they receive some extra water from the adjacent sandhills in the form of leaking moisture at thaw and after rain, and, in addition, they are less exposed to the drying effect of the wind. The water table, however, is still several meters below their deepest points. For a detailed description of the vegetation and the environmental conditions of the Fülöpháza Sand Dunes see Molnár (2003). A set of eight other study sites were chosen in the adjacent Turjánvidék, which is a mosaic of low-lying (92–93 m a.s.l.) wetland and steppe patches. The water table at the wetland sites (wet mosaic sites, WM1-4) is close to the soil surface and the vegetation can be characterized with tall sedge and grass species. The steppe patches (dry mosaic sites, DM1-4) were located 0.5–1.0 m higher than the WM sites and were apparently dryer habitats with shorter vegetation rich in herbaceous plants. More information on the vegetation and the environmental conditions of the Turjánvidék is given by Biró et al. (2007) and Járai-Komlódi (1958).

2.2. Data collection

All field samplings and surveys were carried out in late May 2012. Seven random soil samples were taken from every study site for soil moisture measurements (a total of 112 samples). After removing the litter layer, cylindrical cores were collected from the upper 20 cm of the soil. The cores were analyzed at the University of Szeged, Hungary. The mass of the cores was measured with gravimetry, then they were baked at 90 °C for 2 days and the remaining dry matter was measured again. The difference was the water content, which was then expressed in percents of the original mass. No rain had fallen within 10 days before the samplings, so the soil moisture contents reflected real microclimatic conditions. Vegetation surveys were carried out on 5 (DM and WM sites) or 7 (DD and WD sites) randomly chosen 2 m × 2 m quadrats (a total of 96 quadrats). The DD and WD sites seemed to have less homogeneous vegetation than the WM and WD sites; this is why the larger number of quadrats. Every species in the quadrats was identified and their percent cover was also assessed.

2.3. Data analysis

Average relative soil moisture contents were analyzed with ANOVA, which was followed by Tukey's pairwise comparisons. First, the four groups were tested for within-group differences, which meant four separate tests. If a test detected significant differences, the group was split accordingly and the new groups were used in all subsequent analyses. As a second step, between-group differences were tested to see if the original assumption for the soil