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Explorative statistical analysis of water chemistry data obtained from the southern part of Lake Fertő (Hungary)

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Abstract: The aim of the present study was to distinguish and compare areas with different chemical properties within the Hungarian part of Lake Fertő/Neusiedler See and to determine the parameters that influence the similarity of its sampling locations. Uni- and multivariate data analyses were applied to the data of 15 parameters the majority of which were chemical, with some biological for the time period 1994-2010 from 14 sampling sites. The sampling locations were first clustered then grouped. Four groups could be distinguished: open water, areas in front of the reed belt, channels within the reed belt, and a single sampling site within the reed stands. Using Wilks' λ distribution it was determined that most of the main ions, pH, dissolved oxygen and chemical oxygen demand have a greater effect on the formation of cluster groups than calcium and those parameters standing in close relation to the nutrient cycle. The results clearly show that Lake Fertő cannot be considered to be one homogenous system.

Keywords: cluster analysis, Lake Fertő, spatial variability, water quality, Wilks' λ distribution.

1. INTRODUCTION

Conserving the water quality of surface waters is such an important aim that national borders should perhaps be disregarded in its pursuit. A good example is Lake Fertő/Neusiedler See, which is situated on the Hungarian-Austrian border. However, even today its monitoring is conducted separately by the two countries. The datasets obtained from monitoring are highly complex in most cases. As a result, these are often difficult to interpret and draw meaningful conclusions from. The application of multivariate statistical methods, e.g. cluster analysis (CA) and discriminant analysis (DA), could help in easing these problems. There are tools which are commonly used to analyze water quality data, to describe the quality of the water body the data originated from and to optimize monitoring (Zhou et al. 2007). Using these methods on the time series of the Hungarian part of Lake Fertő the lake's heterogeneity (mosaic structure) was examined, and the question was raised of whether it would be possible to distinguish areas with different chemical properties within the lake also, that of which parameters are the ones that mostly determine the grouping of the sampling sites and what kind of differences could be observed between these groups.

2. THE STUDY AREA

Lake Fertő is Europe's western-most and largest steppe lake, with a surface area of 309 km². It is an extremely shallow, well-mixed lake with regulated outflow and large water level fluctuation (Dokulil and Herzig, 2009). Taken as a whole, 54% of the lake is covered by reeds, while regarding only the Hungarian side (75 km²), the coverage is 85%. Many inner ponds are located on the lake's Hungarian side (Dinka et al., 2004). Lake Fertő is a wetland (which is one of the most endangered ecosystems). Accordingly it is protected by many international conventions, such as UNESCO biosphere

reserve, IUCN's¹ protection zone or World Heritage status (Dinka et al., 2004). The lake's water balance is unstable. Most of its input comes from precipitation, besides which the Wulka and the Rákos streams provide input. Its output is mainly via evaporation. The air is almost constantly in motion, and because of the orographic effects the dominant wind direction is NW, which is followed by the SE direction as far as strength is concerned. Sediment is stirred up at wind speeds of 2 m s⁻¹ or more (Löffler, 1979).

3. MATERIALS AND METHODS

The sampling and the lab work was performed by the Hydrometeorological Station of the North-Danubian Water Authority. Monthly sampling is carried out from April to October or November. The data analysis was conducted on the data from the time interval 1994-2010, 14 sampling sites (SS) (**Figure 1A**). Regarding the SS, there are several representing the open water (Nos. 2, 4, 14), one near the reeds (No. 1), one from an inner pond (No. 5), one from each channel (direction N-S, Nos. 6-9; direction E-W, Nos. 10-13) and one from within the reeds (No. 3).

The sampled parameters which suited the conditions of the methods applied² are the following: pH, dissolved O₂ (DO), chemical oxygen demand – potassium-permanganate (COD^P), total phosphorus (TP), NO₂-N, NO₃-N, K⁺, Na⁺, Ca²⁺, Mg²⁺, Cl⁻, SO₄²⁻, CO₃²⁻, HCO₃⁻ (mg l⁻¹), chlorophyll-a (chl-a) (µg l⁻¹). Specifically, there were 92 time points, yielding 19,320 data altogether.

The methods applied were cluster analysis (using Ward's method, and squared Euclidean distance; Kovács et al., 2006, 2008, 2012) and Wilks' lambda distribution to determine which parameter influences the cluster groups conformation the most (Hatvani et al., 2011). In this method the smaller the value of lambda ($0 > \lambda < 1$) for a certain parameter, the more it

¹ International Union for Conservation of Nature and Natural Resources

² Parameters have to be measured at all sampling sites at all investigated time points

determines the cluster groups. As a verification tool, discriminant analysis was used. All of these methods were applied to z-scale standardized data. To aid the visualization of the differences between the cluster groups box-and-whiskers diagrams were used (Hatvani et al., 2009).

4. RESULTS AND DISCUSSIONS

4.1. Spatial variations in water quality

CA was conducted on 92 time points and 15 parameters in order to group the similar SS for every point in time. Each group thus obtained received a code and these codes were clustered again to obtain the most characteristic groups for the whole time interval (**Figure 1B**).

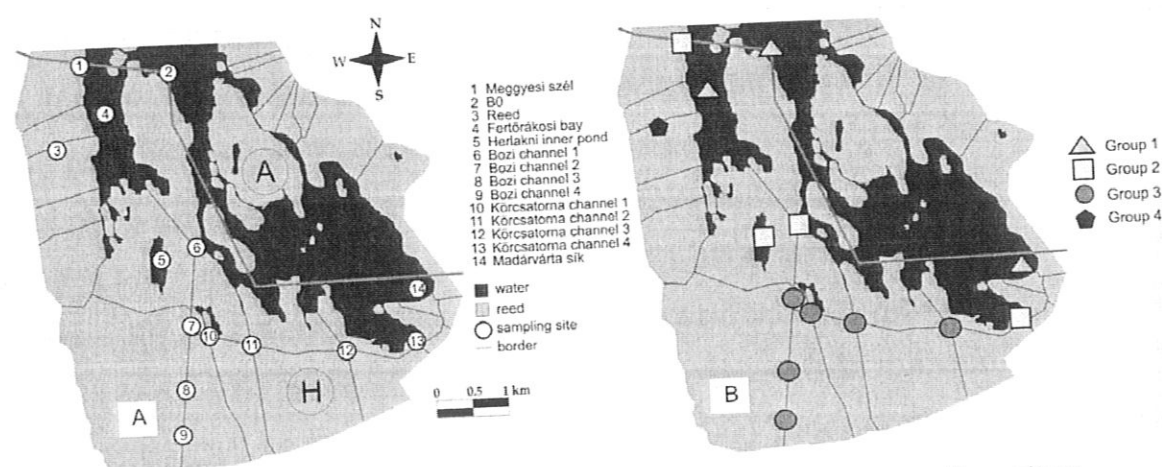


Figure 1: The location (A) and groups (B) of the sampling sites

Four groups could be distinguished. First one covered the open water area, the second the sedimentation zone in front of a certain the reed belt (including the SSs located in the channels, which displayed resemblance to the open water, and the inner pond). The third group contained the SSs of the channels, while the fourth contained the sole SS from within the reed stands. Discriminant analysis pointed out that the original groups were correctly identified in 70.3% of the cases. Naturally, this value does not reach 100.0% because at certain sampling events unusual events such as

extreme wind and water level conditions affected the groups conformation. This value confirms that the water quality of Lake Fertő varies significantly over time and space.

4.2. Parameters influencing the grouping of the sampling locations

For each cluster result a Wilks' lambda distribution was calculated. The average values were as follows: pH (0.16), DO (0.19), HCO_3^- (0.20), Cl^- (0.21), CO_3^{2-} (0.21), Mg^{2+} (0.22), K^+ (0.22), COD^p (0.22), Na^+ (0.25), SO_4^{2-} (0.25), Ca^{2+} (0.37), chl-a (0.39), TP (0.46), $\text{NO}_3\text{-N}$ (0.46), $\text{NO}_2\text{-N}$ (0.48).

As a next step, the obtained Wilks' λ quotients (92 x the number of parameters) were clustered, and two groups were obtained. The main anions and cations (except Ca^{2+}) with pH, COD^p and DO (average 0.21) influenced the formation of the cluster groups the most. Parameters in close relation to the nutrient cycle and calcium, however, had a smaller influence (average 0.43).

4.3. Differences between the groups

The groups obtained from the 92 time points were compared using boxplots. The median of pH, DO and CO_3^{2-} in the open water (cluster group (G) 1) was higher than the one in the channels (G3) or in the reed stands (G4) (**Figure 2A, B, C**). All three displayed a similar pattern.

In the case of pH, the phenomenon behind the change in its values is the chemical, biological processes in the reed belt producing humic substances, which originate mostly from the decomposition of reed detritus (**Figure 2A**). The pH of the waters near the shore increases gradually towards the deeper water, after seeping through the reed belt. The water of the lake is much more alkaline in the deeper sections.

Regarding DO (**Figure 2B**) in the open water (G1), because of the frequent mixing and low nutrient input, the oxygen conditions are good. On the

contrary, in the reed channels (G3) oxygen concentrations are low or in certain cases anaerobic conditions may even occur (Dinka and Szeglet, 2001). The lack of mixing and the oxidization of organic substances decreases dissolved oxygen content. The median of DO is much higher at the sole SS in the reed stands (G4) than at the SSs in the channels. This may have happened because in the surroundings of G4 the reed stands degraded, so given the lack of shelter from the frequent NW winds allows the water here to be stirred up more frequently than in the channels. CO_3^{2-} , because of its pH dependence (Daniel, 1999), behaves similarly to it in all the groups (**Figure 2C**). The median of pH oscillates around 8.49, which is almost at the critical threshold for carbonate ions to be present. This oscillation caused carbonate concentrations to reach the highest values in the open water (G1) and the lowest in the channels (G3). COD^p increases gradually from G1 to G4 (**Figure 2D**). However this increase is influenced by the vicinity of the reeds. In G4 the water is shallow, the diurnal temperature fluctuation is high, and both of these influence the biological processes.

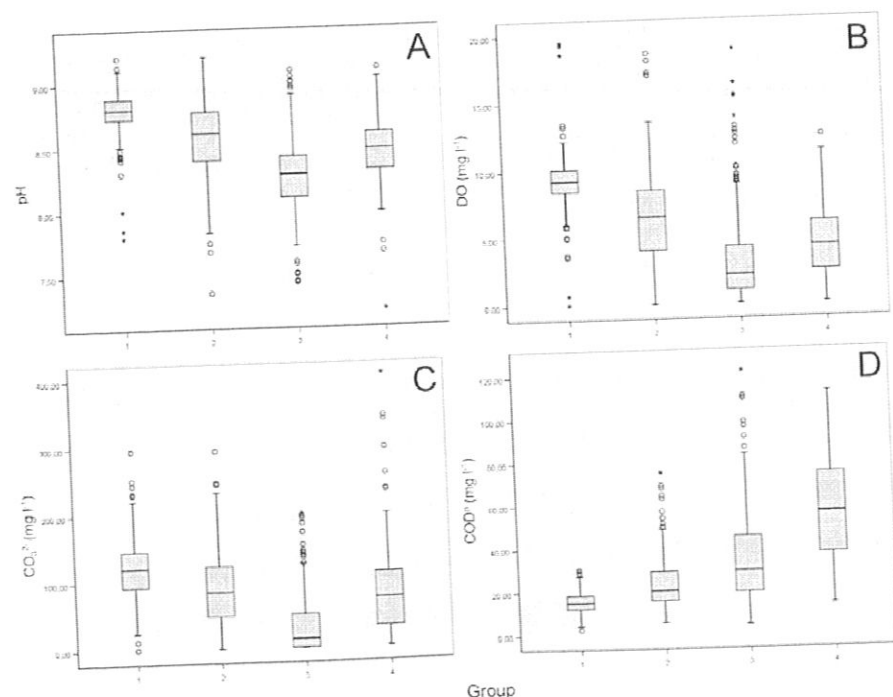


Figure 2: Box-and-whiskers plot: pH (A); DO (B); CO_3^{2-} (C); COD^p (D)

5. CONCLUSIONS

This study emphasises the fact that multivariate data analysis methods can be optimal tools in evaluating complex environmental datasets, as in the case of Lake Fertő. With CA, the most representative pattern of SS was determined, resulting in four groups (open water, sedimentation zone in front of the reed, channels, reed stands).

Using Wilks' lambda distribution it was pointed out that the main ions, pH, COD^p and DO, determine the formation of the cluster groups the most, while calcium and nutrient content (TP, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$) and chl-a were less relevant. Boxplots highlighted significant differences between the distinguished areas.

It can be stated that the water quality of the Hungarian part of Lake Fertő varies both in time and space. This is reflected in its fragmented water surface, which is the basis for its diversity.

6. ACKNOWLEDGMENTS

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