TemaNord 2003:547: 206-211

Selecting potential type-specific lakes of reference in implementing the E.U. Water Framework Directive

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Keywords: benthic macroinvertebrates, E.U. Water Framework Directive, lake typology, type-specific lakes of reference

Introduction

The E.U. Water Framework Directive (WFD) requires the description of type-specific reference conditions to assess the current ecological status of the aquatic ecosystems in comparison. Several methods for establishing reference conditions are proposed in the WFD of which spatially based or survey approaches are recognised as the most straightforward ones (REFCOND 2003). However, the current strong ecological degradation of most of the aquatic ecosystems in Europe makes undisturbed water bodies of reference difficult to locate. Recent discussions across official working groups led to the idea that water bodies of reference should be defined as the less disturbed as possible for a given type and not necessarily as water bodies exhibiting pristine conditions. Consequently statistical methods have to be established which enable to assess and identify such type-specific water bodies of reference among a set of water bodies. In this paper, we present a multivariate method developed using a data base of benthic macroinvertebrates collected in 31 lakes from Brandenburg (N-E Germany).

Material and methods

A total of 31 lakes located in Brandenburg (N-E Germany) were prospected during two sampling campaigns in autumn 2001 and in spring 2002. Each lake was divided into 6 sectors. In each sector, six samples were taken from the sublittoral to the littoriprofundal zone (1.5 to 6 m depth) using a Ekman-Birge grab sampler. Sediments were rinsed directly in the field after sampling, using a sieve of 355 µm mesh size. Additional information about sampling and laboratory methods together with a list of the 261 taxa recorded in the 31 studied lakes are given in Garcia *et al.* (2002a, b) and Brauns *et al.* (2004).

The identification of lake types based on the hydromorphological characteristics of the lakes, required by the WFD previously to any ecological assessment, was done using a cluster analysis. The Canberra metric (Lance and Williams 1967) was used to calculate the distances. The Unweighted Pair-Group Method (UPGMA) was used as clustering method to compute the hierarchy.

The assessment of the ecological status of the lakes based on the benthic macroinvertebrate assemblages, and the identification of type-specific lakes of reference, was done using multivariate statistical analysis. Two methods were performed for the analysis of the data : a Canonical

Correspondence Analysis (CCA, Ter Braak 1986) and a Co-Inertia analysis (CoI, Doledec and Chessel 1994).

Results

Definition of lake types

The abiotic factors to be used to define lake types are provided in the annex II of the WFD as a set of obligatory and optional factors (Directive 2000/60/CE). From the set of obligatory factors, the altitude, latitude, longitude, geology and size were *de facto* removed because the 31 studied lakes share common geomorphological characteristics as follow : altitude lower than 200 m, location in the E.U. Ecoregion “Central plains”, catchment area mainly calcareous, and lake surface area comprised between 1 and 10 km². Consequently, maximum water depth was the only obligatory factor considered. From the set of optional factors proposed in the annex II of the WFD, four factors were considered : mean water depth, lake shape, residence time and mixis characteristics of water. The exposure of the lake to the dominant south-westerly winds was additionally considered. From the highly correlated maximum water depth and mean water depth, we only selected mean water depth for further analyses. For each factors, modalities were defined according to the characteristics exhibited by the lakes. Finally, five factors subdivided into three modalities each were selected for creating the typology (Table 1).

Table 1 : Factors and modalities used for creating the typology.

Mean depth (m)	Residence Time (years)	Mixis type	Shape (length / width)	Wind exposure (° / SW)
<2	<1	Polymictic	Round	0
2-9	1-5	Monomictic	Oval	45
>9	>5	Dimictic	Long	90

Based on these five factors, the cluster analysis classified the 31 studied lakes into four lake types. Mixis and water residence time initially separate a group of 15 lakes independent of a river network (groundwater lakes) from a group of 15 lakes connected to a river network (riverine lakes). Groundwater lakes are characterised by a dimictic mixis type, and a residence time exceeding one year. They are also the deeper lakes with a mean water depth over 9 m. Riverine lakes are characterised by a polymictic mixis type and a faster turn-over of their water mass which never takes longer than one year. Considering secondarily the shape and the mean depth, the cluster analysis leads to a further finer classification into a total of four groups. The initial group of groundwater lakes is subdivided into circle-shaped lakes (6 lakes), defining lake type I, and into oval-shaped lakes (9 lakes), defining lake type II. The initial group of riverine lakes is subdivided into moderately deep lakes (12 lakes) exhibiting a range of mean depths from 2 to 9 m, and into shallow lakes (4 lakes) characterized by a mean depth lower than 2 m. These two categories define respectively lake types III and IV.

Ecological status of the lakes and identification of type-specific lakes of reference

A CCA based on a data set of 131 benthic taxa and 11 environmental factors, reflecting both the level of eutrophication and the hydromorphological characteristics of the lakes, was performed. As a result, the CCA provided a first lake typology based on the benthic macroinvertebrates assemblages (Fig. 1), where the 31 lakes appear mainly ordinated along the first axis (F1 : 62.1% of the total inertia explained). As shown by the correlations of the 11 explanatory variables with the two first axis of the CCA (Table 2), the first axis is mainly defined as a gradient of degradation. Secchi depth and conductivity, two variables reflecting the level of eutrophication of the lake, are highly correlated with F1 (0.77 and -0.67) as well as phosphor and chlorophyll a contents (-0.61). Variables reflecting lake types, as mixis type, residence time of water and mean depth, are also highly correlated with F1 (0.64, 0.65 and 0.53). Consequently, the first axis of the CCA could additionally be interpreted as reflecting type-specific benthic macroinvertebrate assemblages as suggested by the ordination of the four lake types along F1. However, the observed overlap between lake types and the level of degradation of the 31 lakes constitutes an artefact, since lakes closely connected to a river network tend to be more disturbed than groundwater lakes because of the heavy degree of anthropogenic influence to which most the rivers in Europe have been exposed. The CCA is then mainly reflecting the level of eutrophication of the lakes, while lake types are for a part expressed on the second axis, as shown by the correlation of the two variables shape and wind exposure with F2 (Table 2).

Table 2 : Correlation of each explanatory variable with the two first axis of the CCA. Highest correlations in bold.

Variables	**Correlation/F1**	**Correlation/F2**
Secchi Depth	**0.77**	0.04
Conductivity	**-0.67**	0.25
Mixis Type	**0.65**	-0.26
Residence Time	**0.64**	-0.25
Phosphor	**-0.61**	-0.01
Chlorophyll a	**-0.61**	**-0.44**
Mean Depth	**0.53**	-0.13
pH	0.32	-0.13
Alkalinity	-0.22	**0.44**
Shape	-0.03	**0.40**
Wind Exposure	0.01	**0.38**

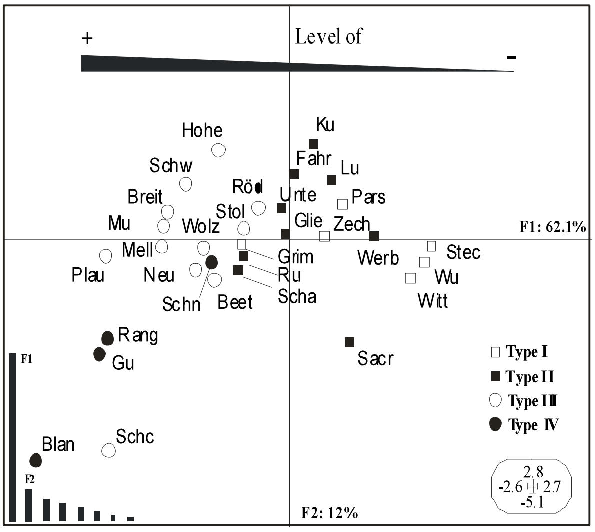

Fig. 1 : Canonical correspondance analysis (CCA). 136 taxa, 11 abiotic variables. Plot of the faunistic sample scores on the F1xF2 factorial plan.

A CoI based on the same data set of 131 benthic taxa and 11 environmental factors was performed subsequently to identify the type-specific lakes of reference. On the factorial plan of the CoI (Fig. 2), environmental (dots) and faunistic (arrows) sample scores are plotted simultaneously. The abiotic typology, as defined by the cluster analysis, is also exhibited by the CoI (dots). Clearly, the first axis separates the groundwater lakes (lake types I and II) from the riverine lakes (lake types III and IV). In the same way, the second axis separates the circle-shaped lakes (lake type I) from the oval-shaped lakes (lake type II).

The location of the arrows on the factorial plan of the CoI reflects the structure and the composition of the faunal assemblages of each lake (Fig. 2). Three patterns can be recognized. A group of 13 arrows, mainly originated from lakes of lake types III and IV, end in the same sub-area of the factorial plan at the right part of the first axis (Group 1 : Schn, Rang, Mügg, Blan, Gülp, Rupp, Mell, Plau, Schc, Wolz, Breit, Beet, Schw). Such a grouping reflects the paucity and the similarity of the faunal assemblages of the 13 corresponding lakes. A second group of seven arrows originated

from lakes of lake types I and II are directed towards the pre-cited sub-area (Group 2 : Grim, Stol, Werb, Glie, Unte, Fahr, Scha). Such a location reflects the higher diversity of the faunal assemblages of these lakes by comparison to those of group 1. Finally, 11 arrows escape completely the direction of the pre-cited sub-area (Group 3 : Witt, Stec, Zech, Wumm, Pars, Lübb, Sacr, Rödd, Neue, Hohe). Such a pattern reflects lakes with unique and highly diversified assemblages.
Based on these three patterns, an assessment of the ecological status of the 31 studied lakes into the five E.U. defined categories is given (Table 3). Lakes from group 1 necessarily belong to poor and bad status. Lakes from group 2 mainly belong to moderate status. Then, lakes from group 3 belong to good and high status and can be considered as potential type-specific lakes of reference. The calculation of the log series α diversity index (Fisher 1943) supports the assessment resulting from the CoI analysis (Table 3).

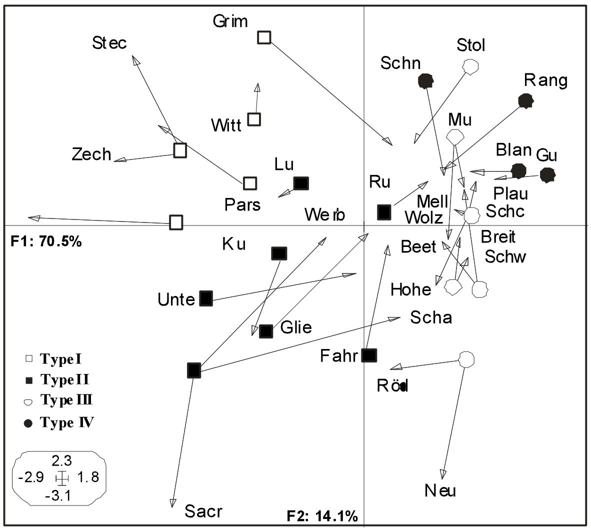

Fig. 2 : Co-Inertia analysis (CoI). 136 taxa, 11 abiotic variables. Plot of environmental (forms) and faunistic (arrows) sample scores on the F1xF2 factorial plan.

Table 3 : Comparison of the ecological status of the 31 studied lakes with their faunistic diversity. Potential type-specific lakes of reference underlined.

Type	Lake	Ecological status	Diversity (Log series α)	Type	Lake	Ecological status	Diversity (Log series α)
I	Stec	High	8.8	III	Rödd	High	7.1
I	Wumm	High	8.4	III	Neue	High	6.8
I	Pars	High	7.8	III	Stol	Moderate	7.9
I	Zech	High	7.8	III	Hohe	Moderate	4.7
I	Witt	Moderate	6.5	III	Schw	Bad	5.5
I	Grim	Poor	5.1	III	Wolz	Bad	5.1
				III	Mell	Bad	3.9
II	Küst	High	9.2	III	Mügg	Bad	3.9
II	Lübb	High	6.8	III	Plau	Bad	3.5
II	Sacr	Good	5.4	III	Beet	Bad	2.9
II	Werb	Moderate	7.7	III	Breit	Bad	2.5
II	Fahr	Moderate	7.6	III	Schc	Bad	2.2
II	Unte	Moderate	6.4				
II	Glie	Moderate	6.2	IV	Gülp	Bad	3.2
II	Rupp	Bad	5.3	IV	Schn	Bad	2.2
II	Scha	Poor	4.5	IV	Rang	Bad	1.8
				IV	Blan	Bad	1.3

Discussion

The data analysis has led to a successful assessment of the ecological status of the 31 studied lakes based on their benthic faunal assemblages. Moreover, potential type-specific lakes of reference for three of the four abiotic types previously defined by the cluster analysis were identified.

Beyond these results, the present study addresses two key problems in implementing the WFD. The first one relates with the difficulty to find undisturbed type-specific lakes of reference for each lake type. This is especially true for riverine lakes directly influenced by the long-term degradation of most of the rivers in Europe. This point is clearly highlighted in this study by the opposition of groundwater lakes and riverine lakes on the main axis of the CCA and CoI. Consequently, if find oligotrophic lakes to serve as type-specific lakes of reference for groundwater lakes is still possible (e.g. Stechlinsee), find a riverine lake exhibiting pristine conditions is more challenging. A currently discussed alternative way should be to retain as type-specific lakes of reference, the less disturbed lakes of each lake type.
The second key problem relates with statistical methods to assess ecological quality in freshwaters. In the context of the first key problem, the ecological assessment of lakes from different lake types using a CCA, consistently led to a misdiagnose. This method, called direct gradient analysis,

searches among a set of environmental factors which factor explain the most the structure of a faunistic data set. In other words, it explains the first table by the second. It is a fact for the European freshwaters that the main factor influencing the structure and the composition of the faunal assemblages is the level of eutrophication. As a result, the ordination of the lakes in the CCA is done by linear comparison of each lake with the same object of reference, the less disturbed lake of the complete set, without any consideration to the lake type. Conversely, the ecological assessment of lakes from different lake types using a CoI led to a more accurate diagnose. This method called two-tables simultaneous analysis, examine the species-environment relationships by considering the two data sets equally. As a result, the ordination of the lakes is done by comparison of each lake with the less disturbed lake of the group (lake type) to which it belongs. Simultaneously, linear relationships through the complete set of lakes is also considered by the analysis. The problem is clearly illustrated in this study by the case of the Neuendorfer See (Neue). In the CCA, the lakes are ordinated along F1 from the less disturbed one (Stec) to the more disturbed one (Blan). Neuendorfer See is placed by the analysis among the most disturbed lakes at the left side of the first axis. Then, based on the CCA, Neuendorfer See belongs to the E.U. category “poor ecological status”. However, the diversity of its fauna is one of the highest diversity recorded among lakes of lake type III. In the CoI, lakes are also ordinated according to their level of degradation, however under the constraint of the type. The arrow representing the Neuendorfer See escapes from the sub-area of the factorial plan where the degraded lakes are concentrated, highlighting the uniqueness and the richness of its faunistic assemblage by comparison to those of lakes from lake type III. Then, based on the CoI, Neuendorfer See belongs to the E.U. category “high ecological status”, which seems more exact according to its high faunistic diversity. Consequently, Neuendorfer See can be proposed as type-specific lake of reference for lake type III, because it is one of the less disturbed lakes recorded for lake type III. The same remark can be done for Röddelinsee (lake type III) and Lübbesee (lake type II).

In conclusion, it is demonstrated that the Co-Inertia analysis appears a suitable and efficient method allowing to assess the ecological status of the water bodies as well as to select potential type-specific water bodies of reference.

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Acknowledgement

We thank the Landesumweltamt Brandenburg which founded this project. The authors also greatly thanks Steffi Noack, Christian Polleichtner, Michaela Schönherr and Astrid Schwalb for their efficient help on the field and at the laboratory.