A reference system for continental running waters: plant communities as bioindicators of increasing eutrophication in alkaline and acidic waters in north-east France

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Abstract

Two bioindication scales of the degree of eutrophication based on aquatic macrophyte communities were established in two types of running waters free of organic matter, the one in acidic “soft” waters (pH 5.5–7.0, conductivity 40–110 µS.cm⁻¹), the other in alkaline hard waters (pH 7–8, conductivity 500–900 µS.cm⁻¹). We show that the main determining factor of the macrophyte distribution is the nutrient level (trophic), especially the level of phosphate and ammonia. The acidic scale, with increasing pH, includes four stages ranging from oligotrophic to eutrophic level (traces to 300 µg.l⁻¹ N-NH₄⁺ and P-PO₄³⁻), while the alkaline scale at constant pH comprises six stages of a trophic gradient. For the most part, the floristic composition found in the two sequences is different and depends on conductivity and alkalinity variation. However, some species occur in the two scales and may reflect differences in the trophic level, depending on whether the waters are alkaline or acidic. This change of trophic level for these species is discussed.

Introduction

The occurrence of aquatic vascular macrophyte is related unambiguously to the water chemistry as shown by e.g. Kohler (1975), Wiegleb (1984), Klosowski (1985), Lachavanne (1985), Konold et al. (1990). Developing the plant species or communities as indicator method (Iserentant & de Sloover, 1976) has been an objective for surveying water quality. Until now biological methods have been carried out especially using invertebrate macrofauna, but some authors such as Newbold & Holmes (1987), Haslam (1982) and Harding in Standing Committee of Analysts (HMSO 1985–1986) have constructed biological indices based on aquatic plants for assessing water quality. More recently bioindication scales of the nutrient level (phosphorus and nitrogen) based on aquatic macrophyte communities have been performed and tested in running water streams of the Alsace floodplain (Carbiener et al. 1990) and the Vosges mountains, in Eastern France (Muller, 1990).

The aim of this paper is to compare the two bioindication scales, one in acidic water, the other in alkaline waters, in order to define a hierarchy of variables which explains the distribution of plants.

We focused on the study of distribution of species which appear in these two types of water, to determine the best ecological conditions for their occurrence.

Study Site

In the east of France, two large hydrological networks of running waters were selected in two types of geochemistry. The first concerned streams in the Alsace Rhine floodplain. Most of them are fed by groundwater which flows in a gravelly calcareous aquifer. The groundwater-fed streams present a large homogeneity of characteristics, organic matter-free, calcareous
hard water with a pH 7.5–8 and a conductivity higher than 500 $\mu$S.cm$^{-1}$. The remainder are surface waters connected to the Rhine or to the Ill, the main tributary of the Rhine in the Alsace floodplain. The second network flows in the Northern Vosges mountains on acidic substrate (sandstone), and has a pH of 5.5–7 and a conductivity between 40–110 $\mu$S.cm$^{-1}$. The variation in altitude from the spring to the bottom of valley is 100 to 150 m. Their downstream course where they reach the Alsace plain is characterized by a neutral pH and a conductivity of 150–350 $\mu$S.cm$^{-1}$. Both slightly and highly mineralized systems exhibit a large trophic range from oligotrophic to eutrophic. 129 sites were investigated, 91 in the alkaline network and 38 in the acidic network.

**Materials and methods**

**Vegetation analysis**

Vegetation surveys have been carried out more and less regularly since 1970, in the streams of the Alsace floodplain and since 1988 in those of the Vosges mountains. The vegetation was investigated using Flora Europaea (Tutin et al., 1964–1993). When no perturbation occurs, no change of vegetation was observed for many years. However, if vegetation changed, the site was considered as a new one. In each site a phytosociological relevé was recorded by the method defined by Braun-Blanquet (1964), using a coefficient of abundance-dominance. Aquatic vascular and non vascular (Bryophytes and algae) plants were listed over a minimal distance of 50 m and usually 100 m of a stream and assigned a coefficient of abundance-dominance.

**Water analysis**

In parallel with the vegetation survey, water was sampled in streams, monthly in the Alsace floodplain and every three months in the Vosges mountains. Several sites per stream were selected according to the change of vegetation. A vegetation relevé corresponded to each sample of water. pH, conductivity, dissolved oxygen and temperature were measured in situ. Phosphate, nitrate, ammonia, chloride and water hardness were analysed in the laboratory by using the procedures (APHA, 1985) previously described by Trémolières et al. (1993).

**Data analysis**

The mean of each variable was calculated over one year, integrating the yearly fluctuations. The reference year was determined by the existence of a maximum of data (>4) covering the whole year.

Statistical analyses such as c-PCA (centred Principal Component Analysis) and FDA (Factorial discriminant analysis) were applied, using the Statitcf program. A first PCA was processed on 129 sites and 7 physico-chemical variables, a second one on species affected of a coefficient of abundance. FDA was used to integrate the new variable, the plant community which we defined for each site. The objective was to compare the plant communities and to verify their classification realized a priori.

7 Classes for each variable were determined a posteriori on the whole data, in order to have an homogeneous distribution of the n sites among the classes (each class represents around n/7 sites). Thus, the distribution of a species was specified according to a given variable.

**Results**

**Water chemistry**

The running waters of acidic geochemistry in the Northern Vosges mountains have a pH which varies from 5.5 to 7 and a low conductivity from 40 to 110$\mu$S.cm$^{-1}$. The trophic level related to phosphate and ammonia changes from oligotrophic (annual mean 50 $\mu$g.l$^{-1}$ N-$\text{NH}_4^+$, 25 $\mu$g.l$^{-1}$ P-$\text{PO}_4^{3-}$) upstream to eutrophic (150 $\mu$g.l$^{-1}$ N-$\text{NH}_4^+$, 150 $\mu$g.l$^{-1}$ P-$\text{PO}_4^{3-}$) downstream. The nitrate concentrations remain almost constant around 0.5 mg.l$^{-1}$. In the Alsace floodplain, the streams consist of buffered bicarbonated water with alkaline pH (7.5–8.2) and high conductivity varying from 400 to 1000 $\mu$S.cm$^{-1}$. The nitrate nitrogen varies greatly between 0.5 and 7.5 mg.l$^{-1}$, the streams with the highest values being located in agricultural areas. Phosphate phosphorus and ammonia nitrogen range from 3 to 350 $\mu$g.l$^{-1}$ (annual mean).

**Physico-chemical variables hierarchy**

According to the results of c-PCA (129 individuals) on 7 physico-chemical variables (pH, conductivity, hardness, chloride, phosphate, ammonia, nitrate) two zones can be distinguished on the PCA ordination diagram.