Hydrobiologia (2006) 570:159–164
J.M. Caffrey, A. Dutartre, J. Haury, K.J. Murphy & P.M. Wade (eds), Macrophytes in Aquatic Ecosystems: From Biology to Management
DOI 10.1007/s10750-006-0176-2

Comparison of different biological indices for the assessment of river quality: application to the upper river Moselle (France)

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Key words: chemical survey, macroinvertebrates, macrophytes, indices, water quality

Abstract

The aim of our study was to assess the water quality of the upper Moselle river by using biological indices. Simultaneous physico-chemical surveys were also undertaken from May 1999 to April 2000. Twelve sampling sites were selected in order to provide a wide range of potential pollution. Chemical analysis did not reveal any major problem of pollution. However a lower water quality resulting from domestic pollution was established for some sampling sites. A biological monitoring combining both macroinvertebrates and macrophytes was performed. Biological indices based on plant community structure and macrophyte composition were not pertinent tools, whereas simple indices based on taxonomic richness of particular groups of macroinvertebrates were strongly correlated with several chemical parameters, showing that such simple biological variables should represent powerful indicators of ecosystem degradation.

Introduction

Biological monitoring often appears to be more appropriate in the assessment of pollution of aquatic ecosystems than traditional chemical evaluation of water quality. As aquatic organisms may integrate effects of perturbations, numerous methods have been proposed to assess both water and biological quality. In particular, methods based on benthic macroinvertebrate communities have been frequently used. Water quality monitoring using aquatic macrophytes has been developed in Europe over the past two decades (Harding, 1981; Holmes & Newbold, 1984; Carbiener et al., 1990, Robach et al., 1996; Dawson et al., 2000; Haury et al., 2002). Six approaches were identified to assess the quality of aquatic ecosystems through macrophyte communities (Demars & Harper, 1998): (1) identification of community assemblages, (2) biomass measurements, (3) classification based on the drainage order combination, (4) ecomorphology, (5) phytosociology and (6) identification of communities using weightings to indicator species. Even though diversity indices based on macroinvertebrate communities are widely used (Guérold, 2000), they have rarely been employed to assess the impact of water pollution on macrophyte communities (Small et al., 1996; Baattrup-Pedersen & Riis, 1999; Thiébaut et al., 2002).

The aim of the study was to assess the pollution of rivers by using biological approaches based both on macroinvertebrate and aquatic macrophyte communities and to compare their response to water pollution.

Description of sites studied

The study area is located in the upper Moselle river (North Eastern, France) which is the main tributary of the Rhine river. The catchment of the upper Moselle river is 3706 km^2. The river drains granite and metamorphic bedrocks. Twelve sampling sites were selected along a longitudinal gradient, in order to provide a diversity of potential polluted sites. Eight sites (sites: Bussang, Fresse, Rupt, Mitreuches, Eloyes, Archette, Igney, Velle) were located on the upper part of the Moselle river and four sites (sites: Bresse, Saulxures, Zainvillers, Cleurie) along its main tributary, the Moselotte river. Sites were nearly shadeless and their substrate was composed of peebles. The mean current velocity of these twelve sites was 0.63 m/s and the mean water depth was 0.52 m.

Materials and methods

Chemical analyses

At each site, 500 ml of water was collected seven times in the year at different flow conditions. Oxygen, conductivity and pH were measured in the field using a multiparameter instrument (WTW 340i). The following parameters were analysed in laboratory (within 24 h of sample collection). Alkalinity was measured by titration. Main cations (Ca, Mg, Na, K) were analysed using atomic absorption spectrophotometry. Sulfate, chloride, nitrite-nitrogen (NNO_2) and nitrate-nitrogen (NNO_3) were determined in the laboratory by ion chromatography. Ammonium nitrogen (NNH_4) and soluble reactive phosphorus (SRP) were analysed using spectrophotometry. Nitrogen (N) (Kjeldahl) and total phosphorus (TP) were determined after digestion with acid and analysed using standard method. The biological oxygen demand (BOD) and the chemical oxygen demand (DCO) were measured following the procedures described in the French norms (respectively NFT 90-103 and NFT 90-101).

A Principal Components Analysis (PCA) based on the mean physico-chemical variables was realised to test for space and time variability (software ADE-4, version 2001, CNRS Lyon).

Biological monitoring and aquatic macrophyte communities

The botanical survey was conducted in June and September 1999. A standard length of watercourse (100 m) was selected. All macrophytes present were recorded, together with the estimated percentage cover of each species. Organisms were identified to species or to the lowest practical taxonomic level. A Canonical Correspondence Analysis (CCA) using CANOCO, was established between aquatic macrophytes and the main chemical variables. The following indices were tested on macrophyte data: taxonomic richness *S*, abundance *Q*, Shannon diversity index (Shannon & Weaver, 1963), Margalef's diversity index (Margalef, 1958), Simpson's index (Simpson, 1949). Pearson's correlation coefficient was used between indices and physio-chemical parameters using Statistica (Version 5.5, StatSoft).

Biological monitoring and macroinvertebrate communities

At each site, four samples of macroinvertebrates were taken in May 1999, using a modified Surber sampler (0.084 m^2, 353 μm mesh). Only organisms belonging to Epheromeptera, Plecoptera and Trichoptera orders (EPT) were taken into consideration. Organisms were identified to the lowest practical taxonomic level. Different indices based on macroinvertebrate biodiversity were tested: Ephemeropta richness, Plecoptera richness, Trichoptera richness, Ephemeroptera, Plecoptera, Trichoptera richness (EPT), Shannon–Wiener and Margalef diversity indices applied to EPT. Pearson's correlation coefficient was used between indices and physio-chemical parameters using Statistica (Version 5.5, StatSoft).

Results

Physico-chemical composition

The PCA performed on chemical analysis showed that the Moselle river and its main tributary, the Moselotte river, was classically characterised by an increasing gradient of mineralisation from upstream to downstream as the first axis explains 55.6% of the variance. The second axis which explains 34.8% of the variance, corresponded to a domestic pollution gradient (Fig. 1a). Chemical analysis did not reveal any major problem of pollution except during high flow in October (Fig. 1b)

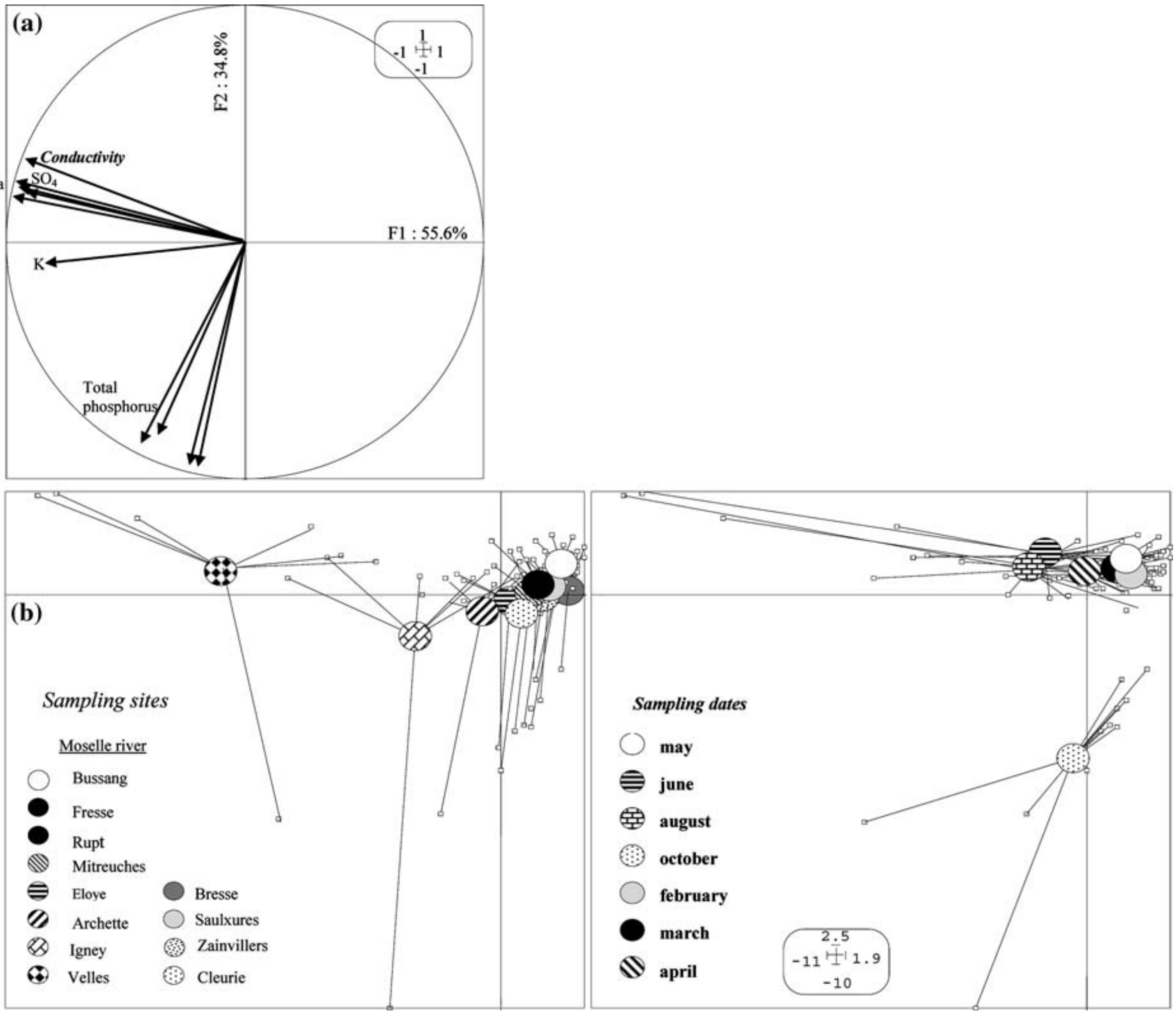

Figure 1. Principal component analysis (PCA) of physico-chemical variables. (a) Correlation circle showing the position of the variables on the F1F2 plane. (b) Ordination of the 12 selected sites on the F1F2 plane. (c) Position of the sampling date on the F1F2 plane. Circles denote the weighted average of all sample taken from a given sampling site. Line link sample (small square) to weighted average.

Aquatic plant communities

The first axis of CCA is a mineralisation gradient. From the CCA ordination diagram (Fig. 2), it can be seen that alkalinity and conductivity are strongly correlated with the first CCA axis. Species with a high positive score (*Myriophyllum spicatum*, *Cladophora* sp.) on that axis were therefore restricted to downstream site (Velle) with high alkalinity and conductivity. The second axis can be interpreted as being related to the ratio of ammonium to phosphate, the idea being that these variables have on the second axis about equal canonical coefficients of opposite sign (0.51 and −0.55). The second axis is still a contrast between ammonium and phosphate concentrations. No significant correlations were established between macrophyte diversity indices and chemical variables, except for Simpson index.

Macroinvertebrate communities

EPT richness was severely depressed at some sampling sites showing that some taxonomic

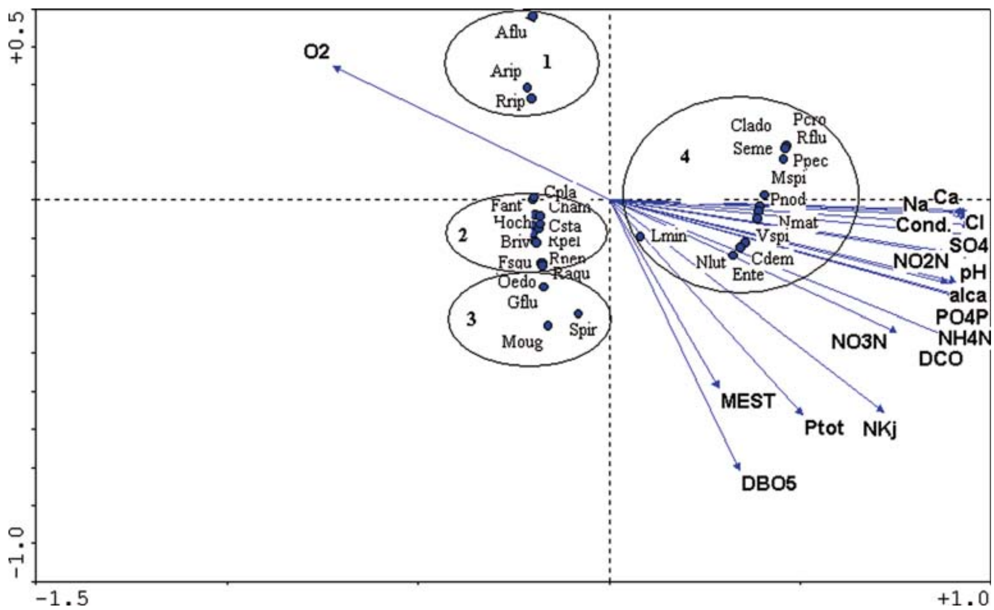

Figure 2. Canonical Correspondence Analysis between aquatic plants and chemical variables. Bryophyte: *Amblystegium fluviatile* – Aflu; *Amblystegium riparium* – Arip; *Brachythecium rivulare* – Briv; *Fontinalis antipyretica* – Fant; *Fontinalis squamosa* – Fsqu; *Hygrohypnum dilatatum* – Hdil; *Hygrohypnum ochraceum* – Hoch; *Hyocomium armoricum* – Harm; *Rhacomitrium aciculare* – Raci; *Rhynchostegium riparioides* – Rrip; *Scapania undulata* – Sund; Aquatic Vascular plants: *Callitriche stagnalis* – Csta; *Callitriche hamulata* – Cham; *Callitriche platycarpa* – Cpla; *Elodea Canadensis* – Ecan; *Glyceria fluitans* – Gflu; *Lemna mino* – Lmin; *Myriophyllum spicatum* – Msp; *Ranunculus aquatilis* – Raqua; *Ranunculus peltatus* – Rpel; *Ranunculus penicillatus* – Rpen; *Sparganium emersum* – Seme; Algae: *Cladophora* sp. – Clado; *Lemanaea fluviatilis* – Lflu; *Melosira* sp. – Melo; *Mougeotia* sp. – Moug; *Nitella flexilis* – Nflex; *Oedogonium* sp. – Oedo; *Oscillatoria* sp. – Osci; *Spirogyra* sp. – Spir; *Vaucheria* sp. – Vauc.

groups were strongly affected. For example, no species of Plecoptera were recorded from four sampling sites. Correlation analyses between biological variables and indicators of domestic pollution revealed several significant relationships between the richness of EPT, Plecoptera, Trichoptera (Table 1). For example the richness of ETP and each taxonomic group was significantly negatively correlated with kjedahl nitrogen concentrations. In this sense, the more highly significant relationships were found with EPT and Trichoptera richness. On the contrary, diversity indices were poorly correlated with chemical parameters, showing that this metrics were less powerful indicators of pollution than richness.

Discussion

Vegetation is assumed to be more linked to the instability than to the nutrients inputs of the Moselle river (running water from the tributary and flood disturbances). The absence of correlation between diversity indices based on aquatic plants and chemical variables corroborates this situation. This is in contradiction with another study previously realised, which established a significant correlation between diversity indices (Shannon's index, Margalef's index) and phosphate and between Margalef's index and nitrogen in stable habitats of streams in the Vosges mountains (Thiébaut et al., 2002). In our study area, factors such as depth, substrata, shading, width, bed stability, singly or in some combinations, have a stronger influence on the floristic community than the water chemistry in the upper Moselle catchment. In the literature, significant correlations have been established between physical and floristic parameters (Baattrup-Pedersen & Riis, 1999). Macrophyte species diversity in streams also increases as the spatial heterogeneity and/or diversity of habitats increases. The number of species and abundance also depend on biotic variables (herbivory). Use of diversity indices

Table 1. Correlation matrix between several chemical indicators of domestic pollution and biological variables based on macroinvertebrate communities

Biological variables	N Kj		NO_3		NO_2		P tot		PO_4	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Richness										
EPT	−0.938	0.000	−0.758	0.011			−0.800	0.005	−0.788	0.007
Plecoptera	−0.771	0.009	−0.909	0.000	−0.714	0.020	−0.837	0.003	−0.777	0.008
Trichoptera	−0.928	0.000					−0.659	0.038	−0.675	0.032
Ephemeroptera	−0.698	0.025								
Diversity indices										
Shannon & Wiener							−0.676	0.032		
Margalef	−0.882	0.001								
Simpson										

based on macrophyte communities did not allow us to assess pollution status of the Moselle river, because the influence of factors other than a change in trophic status is deemed significant.

Since several decades methods based on macroinvertebrate communities have become more and more popular (De Pauw & Vanhooren, 1983; Resh & Jackson, 1993; Barbour et al., 1996; Thorne & Williams, 1997). If perturbation conditions are present for a period sufficient to induce detrimental effects at a population and consequently at a community level, it becomes possible to evaluate changes in the community composition by using simple biological variables such as richness and diversity indices. Such metrics may be simply an estimation of the taxonomic richness or diversity indices which combine abundance and richness. As previously reported by Norris & Georges (1993) they are seen as a useful way to condense complex data, making interpretation easier. In the present study, estimation of the richness of Plecoptera, Trichoptera or ETP appeared more accurate biological parameters to reveal domestic pollution than diversity indices. The use of these three taxonomic groups is interesting as many species are polluo-sensitive, relatively easy to identify at a genera or species level. In several countries such as in France, these three groups are also the best known. Contrary to other biological methods such as the IBGN index (AFNOR, 1992) commonly used in France (that need only determinations at the family level), genera/species richness evaluation provides a more important information because it represents a direct evaluation of the (bio)diversity of macroinvertebrates and its erosion when ecosystems are polluted. In this sense, it is necessary to stress that the more precise are the determinations of invertebrates the more pertinent are the biological variables (Guérold, 2000).

Conclusion

Chemical analysis did not reveal a major perturbation. However a lower water quality resulting from domestic pollution was established at some sampling sites. A number of factors, including ecological conditions, can affect macrophyte communities in streams undergoing water pollution that are not evaluated by diversity indices. In this study diversity indices based on aquatic macrophytes were not pertinent tools to assess water quality, whereas the three taxonomic groups of macroinvertebrates (EPT), appeared to be more relevant to assess domestic pollution of running waters.

Acknowledgements

This study was supported by the INERIS and by the French Ministry of Ecology and Sustainable Development and took place within the framework of the French National Program Ecotoxicity (PNETOX).

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