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A new method to assess water trophy and organic pollution – the Macrophyte Biological Index for Rivers (IBMR): its application to different types of river and pollution

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Abstract

The paper presents a new index for assessing water trophy and organic pollution. It is based on only true aquatic macrophytes – being calculated on species score, coefficient of ecological amplitude and degree of cover. The method was tested in an acidic lowland river and an alkaline mountain river, and is shown to be validated by bio-indication scales based on macrophyte communities. The practical interest is discussed regarding the Water Framework Directive.

Introduction

Numerous papers dealing with mineralisation, trophy, and organic pollution in rivers have already demonstrated the possibility of establishing biotypologies based on flora (Grasmück et al., 1995) or phytosociological communities (Carbiener et al., 1990; Muller, 1990), and of developing indices to assess river water quality (e.g., Newbold & Holmes, 1987; Haslam, 1987). An alternative method would be to take biological traits into account (e.g., Ali et al., 1999). Such approaches to the subject have been reviewed by Haury et al. (2000) and confirmed the possibility of using macrophytes for the assessment of water quality in different rivers or ecoregions. Three main methods are, thus, currently available for assessing eutrophication in running waters: Mean Trophic Rank (MTR: Dawson et al., 1999; Holmes et al., 1999), Trophic Index with Macrophytes (TIM: Schneider, 2000) and the present Macrophyte Biological Index for Rivers (IBMR or MBIR). The latter represents an improvement of an earlier system published by the Group of Scientific Interest 'Macrophytes of inland waters' (Haury et al., 1996).

In order to assess its particular value, the index was calculated for different rivers impacted by fish-farms and domestic effluent. The results obtained were compared with the bio-indication scales of the trophic level based on the macrophyte communities established in both alkaline and acid watercourses by Robach et al. (1996). Future developments in the use of river macrophytes to implement the Water Framework Directive (WFD) are discussed.

Study sites

The River *Scorff* is a lowland river in Brittany, flowing over granite and schists bedrocks. On the main river, sources of pollution consist of urban effluent from a village, a sewage treatment plant, and two fish-farms. On its *St Sauveur* tributary, another treatment plant and a smaller fish-farm are present. The River *Nive des Aldudes* is a Pyrenean mountain water course flowing over alkaline substrata, and with pollution coming from seven fish-farms and two sewage treatment plants. Surveys were conducted in 2000 on 25 stretches of the *Scorff* and its tributary, and on 32 stretches of the *Nive des Aldudes*. Water analyses showed increases in ammonium and orthophosphate concentrations downstream from the fish-farms, the treatment plants and the village effluent sources.

A macrophyte-based classification of bio-indication was already available from two other areas: (i) the streams on the sandstone hills of the Northern Vosges (maximum altitude: 580 m) present an afforested catchment with slightly mineralised acidic stream water (pH: 4.5–7.2; conductivity: 40–130 μS/cm); and (ii) Rhine plain of French Alsace where groundwater-fed streams flow through a calcareous floodplain with highly mineralised bicarbonated stream water (pH: 7.5–8.2; conductivity: 400–1000 μS/cm).

Materials and methods

European literature and floras, in addition to our own studies of river vegetation, provided a provisional list of French river macrophytes (which included cyanobacteria, fungal growth and bacteria clumps in sewage effluent, macroalgae, bryophytes, pteridophytes and higher plants). There were certain difficulties encountered in selecting appropriate species. An initial attempt included hygrophytes, helophytes and subaquatic bryophyta (Haury et al., 1996), although this resulted in poor relationships with water quality (Bernez et al., 2001). Following detailed consideration, some 206 aquatic macrophytes were retained.[1]

Haury et al. (2000) indicated the properties that seemed to be important in assessing the aptness of the main taxa and plant communities to act as bio-indicators. However, comparisons between ecoregions have shown that, depending on whether the water is acid or alkaline, species or communities can react to different concentrations of N and P. The same is true along continental gradients (Robach et al., 1996). It is therefore, only possible to devise relative bio-indication scales. Such scales are based on ecological profiles provided by a National data base, on previously described biotypologies (Trémolières et al., 1994; Robach et al., 1996; Haury et al., 2001), and on the judgements of various experts.

Two criteria were considered for each macrophyte taxon. The **scores (CSi)** ranged from 0 (heavy organic pollution and heterotrophic taxa) to 20 (oligotrophy). They gave the overall value for «water quality» as determined by two nutrients – orthophosphate and ammonium, and heavy organic pollution, as indicated by the presence of sewage fungi. The species distribution range across four trophy classes (oligotrophic, mesotrophic, eutrophic, hypertrophic) was recorded using a **coefficient of ecological amplitude (Ei)**: Coefficient 1, representing wide amplitude, covered three classes of trophy, and coefficient 3, representing a very limited amplitude, was restricted to just one class.

Surveys should be conducted by trained surveyors in the appropriate season. They should be conducted along 50–100 m-long stretches, which include both swift and slow flowing habitats. Percentage cover (exact numeral) is estimated in the field for all the macrophyte taxa (**i**), and classed

[1] Electronic supplementary material is available for this article at http://dx.doi.org/10.1007/s10750-006-0175-3 and accessible for authorised users.

according to a **scale of cover (Ki)**, going from 1 to 5 (1: <0,1%; 2: 0,1–<1%; 3: 1–<10%; 4: 10–<50%; 5: ≥50%), so enabling inclusion in the subsequent calculation of the index.

$$IBMR = \frac{\sum_i Ei * Ki * CSi}{\sum_i Ei * Ki}$$

By comparison with the previous French index (Haury et al., 1996), macrophyte scores were modified to fit to a scale of five levels of trophic status (decreasing from oligotrophic to hypertrophic): IBMR > 14 = Very good; 14 ≥ IBMR > 12 = Good; 12 ≥ IBMR > 10 = Moderate; 10 ≥ IBMR > 8 = Poor; 8 ≥ IBMR = Bad.

The ranking system for bio-indication was based on both botanical censuses and physico-chemical analyses of the stream water. Statistical analyses enabled us to propose an alphabetic system (A–F for hard water and A′–D′ for acidic water) based on ammonium and phosphate ion concentrations (Robach et al., 1996: Table 1). The trophic level, expressed as soluble reactive phosphorus of the water, was usually higher in acidic than in alkaline water.

Results

Application of IBMR to the rivers Scorff *and* Nive des Aldudes

The IBMR showed changes at and below all point sources of pollution (Fig. 1). For the *Scorff* a general degradation of water quality was apparent from upstream to downstream. For the *Nive des Aldudes*, the general trophic level remained the same, while heavy organic pollution was observed downstream the first fish-farm, giving rise to bacterial clumps.

The IBMR and the ranking system for bio-indication

In hard water the IBMR index varied from 15.9 (corresponding to Group A) to 6.8 (Group F), whist in acidic water the range was from 15.6 to 10.5 (Table 2). In acidic water the index showed a significant difference between oligo-mesotrophic (A′B′) and meso-eutrophic communities (C′D′). In alkaline water the index distinguished three groups: the first corresponded to an oligotrophic level (IBMR > 15); the second grouped

Table 1. Bio-indication ranking system for eutrophication in the running hard water of the Alsace plain (A–F) and soft water of the Northern Vosges mountains (A′–D′): macrophyte communities and trophic level (P- PO_4^{3-}, N-NH_4^+) (from Robach et al., 1996)

Dominant or characteristic species	Steps	Trophic level	N-NH_4^+ (μg/l)		P-PO_4^{3-} (μg/l)	
			Mean	SD	Mean	SD
Potamogeton coloratus	**A**	Oligotrophic strict	14	7.3	7	1.7
Berula erecta	**B**	Oligo-mesotrophic	22	13.8	13	5.5
Callitriche obtusangula, B. erecta, Elodea Canadensis	**C**	Mesotrophic	45	27.8	15	6.8
Zannichellia palustris, Groenlandia densa Nasturtium officinale	**D**	Meso-eutrophic	34	31.3	29	23.6
Oenanthe fluviatilis, Ceratophyllum demersum, Ranunculus fluitans	**E**	Eutrophic	61	40	40	33
Potamogeton nodosus P. lucens, P. pectinatus	**F**	Hypertrophic Meso-saprobic	255	107	191	116
Potamogeton polygonifolius	**A′**	Oligotrophic	43	13	20	26
P. polygonifolius, Ranunculus peltatus, Callitriche hamulata, C. platycarpa	**B′**	Oligo-mesotrophic	49	14	22	11
C. hamulata, E. canadensis, O. fluviatilis, Myriophyllum alterniflorum, P. alpinus	**C′**	Mesotrophic	86	35	53	19
C. hamulata, C.obtusangula	**D′**	Eutrophic	170	109	139	46

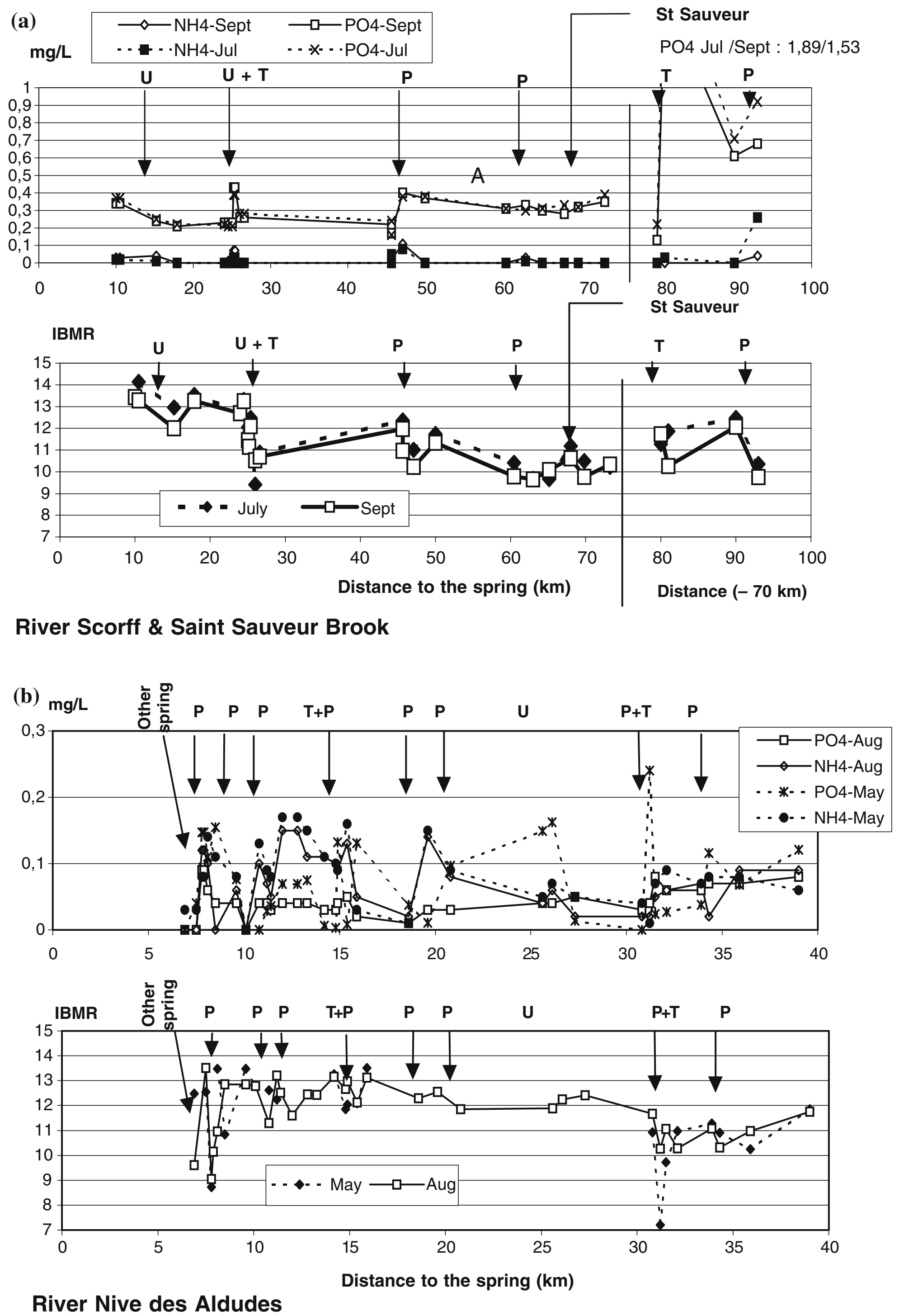

Figure. 1. Ammonium, orthophosphates and IBMR on the two rivers Legend: P: Pisciculture (fish-farm); U: urban sewage; T: sewage treatment plant. *For River Scorff and Saint Sauveur Brook, vertical line shares the tributary and broken arrow assesses the joining point. For River Nive des Aldudes, important secondary spring joins the main course not very far from the upper spring.*

Table 2. Mean and standard deviation of IBMR calculated on the macrophytes communities of the bio-indication ranking system in hard and soft water

Community	A	B	C	D	E	F
IBMR Alsace plain	15.9	12.4	10.9	9.5	8.1	6.8
SD	1.8	1.1	0.5	1.2	1.2	0.8
Community	A′	B′	C′	D′		
IBMR Northern Vosges	15.6	13.9	11.0	10.5		
SD	1.1	0.7	0.9	0.5		

meso-eutrophic communities together (B, C, even D with the IBMR circa 10); while the third group characterised eutrophic communities E and F (IBMR *circa* 7.5).

Discussion and conclusions

As demonstrated for both rivers, the IBMR effectively assesses not only trophic disruption, but also heavy organic pollutions (where heterotrophic organisms begin to be observed). This simple method can be used by field surveyors, provided they have some guidance and training from senior scientists. They will also need help in taxonomic determinations. The IBMR was widely tested throughout France in 2001 and 2002 by more than 10 separate teams of surveyors on more than 100 sites.

A comparison of the IBMR values calculated for macrophyte communities did not show any significant difference (*t* test) in alkaline and acidic water between A and A′, C and C′ and D and D′. We did, however, find a slightly significant difference between the B and B′ communities. The difference could be explained by the floral composition and the high score of the oligotrophic *Potamogeton polygonifolius* in B′, whereas B community contained only oligo-mesotrophic aquatic plants.

Some limitations are nevertheless apparent. For example, in certain rivers flowing over mobile substrata where macrophytes are scarce, the surveyed stretch ought to exceed 100 m. When only a few taxa are present, these must be strong indicators for the IBMR to be used with confidence. In deep water, the methodology must be adapted by using pin-point sampling (Dutartre et al., 1999; Dutartre, unpublished data).

The method is being standardised with the aim of setting up a method in France for assessing river quality (SEQ) which can be used for the WFD. The IBMR can already be considered to be a good index for estimating whether or not a river is affected by nutrient inputs (eutrophication) and/or heavy organic pollution. It cannot, however, be considered as the complete answer for comparing type-specific macrophyte communities. It is a relevant indicator of disturbed situations when in good agreement with the bio-indicator ranking system based on reference macrophyte communities. To get a better fit with the WFD requirements, references from unpolluted rivers should be taken into account wherever and as far as they still exist. Such reference phytocoenoses and degradation sequences still remain to be assessed in most French regions – as indeed the differences between expected and observed vegetation. Intercalibration with the MTR, Austro–German methods (Kohler & Janauer, 1995; TIM: Schneider, 2000) and the Saprobic Index (Husàk et al., 1989) ought to be the next step in implementing the WFD using macrophytes.

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