BIOINDICATION USING VEGETATION OF THREE REGULATED RIVERS UNDER AGRO - INDUSTRIAL PRESSURE IN WESTERN FRANCE

I. BERNEZ*, J. COUDREUSE*, H. DANIEL**, J. HAURY*, D. LE COEUR***
*UMR "EQHC" Agrocampus Rennes 65 rue de Saint Brieuc, F-35 042 Rennes Cedex
**UMR "SAGAH", INRA-INH-Univ. Angers, 2 rue Le Nôtre, F-49045 Angers Cedex
***SAD Armorique, 65 rue de Saint Brieuc, F-35 042 Rennes Cedex
e-mail: Ivan.Bernez@agrocampus-rennes.fr

ABSTRACT - The longitudinal changes of richness and composition of aquatic plants have been studied from headwaters to the fifth stream order in three near-by rivers of Western Brittany (France), the Orne, Sélune and Rance. All rivers were regulated years ago with dams located on the lower third of the studies river stretches. A shifting evolution of the macrophyte richness was revealed in a previous study along the river continuum, related to habitat heterogeneity, influences of regulated sectors and geological changes. Nutrient enrichment and organic pollution influences were the main secondary gradients. On this basis we improved a methodology to complete a biotic index used in Europe for water trophy assessment, following the European water frame work directive, the IBMR based on aquatic plant survey: a validation with classical statistical tests and a comparison to a canonical analysis were performed. Finally this approach permitted to make a proposition of adaptation of the index to the local particularities of each three high anthropised rivers.
KEY WORDS - Bioindication, macrophyte, regulated river, agricultural impact, water quality, river continuum.

INTRODUCTION

In a context of increase of anthropogenic enrichment in river ecosystems, the European water framework directive has contributed to the development and use of biological indicators of water quality. Since the seventies, macrophytic vegetation of rivers has been used to assess their nutrient status (Haslam, 1978), and many countries have developed their indexes (Kohler, 1982; Daniel & Haury, 1996; Holmes *et al.*, 1999; Schneider & Melzer, 2003; Haury *et al.*, 2004) or have used macrophytes as indicators (Romero & Onainda, 1995). In the same time, important works have been carried out on the description of the communities related to the multiple environmental factors (and not only chemicals) involved in the taxa distribution

(Onaindia *et al.*, 1996; Demars & Harper, 1998; Riis *et al.*, 2000; Bornette *et al.*, 2001; Barendregt and Bio, 2003; Bernez *et al.*, 2004).

In a previous study (Bernez *et al.*, 2004), we analysed the combined effects of environmental factors and river regulation on macrophyte richness and composition from three near-by river systems located in western France: each of a similar size and river valley land-use (in terms of agro-industry, agriculture and population pressures), but differing in their geological characteristics and flow regime due to regulation by dams. The aim of this present work is to test a biological index based on aquatic plant community composition, the IBMR (a french index meaning "Biological Macrophytical Index in Rivers"), a tool for water trophy survey, and it is done on these three anthropised rivers in Western France.

Material and Methods

Study area

All three river basins rise at low altitude with spring sources at 120-250 m, and flow for 70-100 km into the English Channel (Table 1 and Figure 1). The main rivers were studied in their continental part from their sources to the mouth. Damming occurs in the last downstream third of all the studied watercourses. Dam systems were different between rivers. Land-use within the three river basins are dominated by agro-industrial activities and intensive farming: Phosphates and Nitrogen forms levels were very high along the whole river courses, and the lake influences are proved physically and chemically by a classical up/downstream comparison (Figure 1, Table 1 and Bernez *et al.*, 2004, 2002 for more details). The distribution of the vegetation was influenced in order of a higher impact by hydrological (position on the river basin, slope), physical (substrate quality, habitat type), geology and chemical water quality (Table 2). The three rivers plant communities gave a different reaction with many similarities concerning non-chemical parameters (Table 2).

Sampling and bioindicating methods

Macrophytes were studied by surveying 50 m long sites, into the river bed. A hierarchical sampling was performed: A total of 23 stations (15 upstream: 5 in the hydro-peaking channel: 3 downstream the compensation), 19 (13:6) and 27 (15:12) were studied on rivers Orne, Selune and Rance, respectively (Table 1); this distribution was established for each physically homogeneous river reach: the reaches were identified according to a combination of geological background, slope and stream order (see the distribution of these sections along the river courses in Figure 1). All three main rivers were surveyed from the headwaters to the fifth stream order. Surveys were performed in July and September 1995 for the Orne and Rance and 1996 for the Sélune and included all taxa within the channel. Plant identification was done on the field or at the laboratory when needed, it included Spermatophytes, Bryophytes and macro-algae.

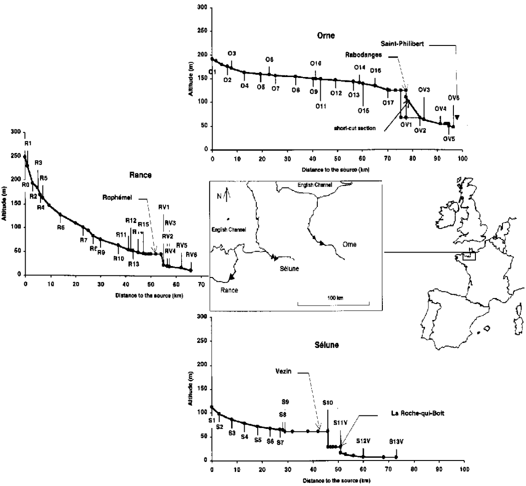

FIGURE 1 - Localisation and longitudinal profiles of the rivers Orne, Sélune and Rance and the hierarchical sampling effort based on slope, geology, drain order changes.

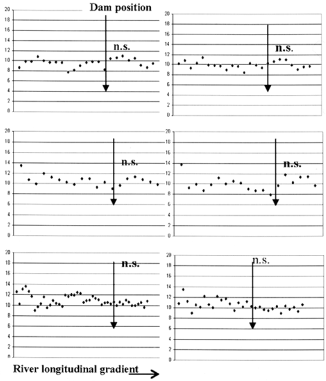

FIGURE 2 - Longitudinal variation of the results of the biological index, IBMR (0: bad trophy quality to 20: very good) in June (left) and September (right) for the three rivers Orne (top), Sélune (middle) and Rance (down). The vertical arrows give the positions of the three hydroelectric dam systems and a non-parametric test is used to compare the upstream values of the index to the downstream values, n.s.: no significatively different.

The french biotic index using macrophytes, the IBMR (Indice Biologique Macrophytique en Rivière) is a way of calculating the water quality in term of trophy from an aquatic plant community sample list according to a reference quotation of each taxa (0: bad to 20: very good) weighted by a coefficient of ubiquity (1: tolerant to 3: specialist), for more details see Haury *et al.*, 2004.

DATA ANALYSIS

Non-parametric Wilkoxon rank tests were applied for comparing the results of the biological index in a upstream and downstream comparison, because of the greater differences of water quality (chemical and physical) observed in each three cases (TABLE 1). The quality value of the index is expressed by a mean value of the quotation of the taxa present at each station in a range of 0 to 20 (0: bad quality; 20: very good quality), Haury *et al.*, 2004. Number of taxa involved in the calculus of the index is considered and the proportion of ubiquist *versus* specialist taxa.

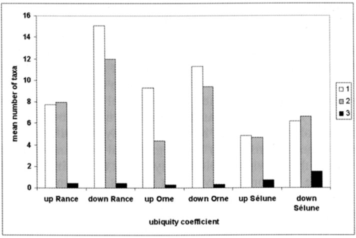

FIGURE 3 - Mean richness in ubiquist (1), intermediate (2) and specialist (3) taxa that were used in the biological index calculus for the three rivers divided in upstream and downstream sectors from their dams or dams systems.

RESULTS

The FIGURE 2 shows for each river, at two periods of the summer, the low shift of the index values along the river course from headwaters to the downstream regulated sectors. The rank of the minimum and maximum values are 7.8/11.4, 7.9/13.7 and 8.9/13.6 for the rivers Orne, Sélune and Rance and mean values of the three water courses are 9.8+/-0.8, 10.4+/-1.2 and 10.7+/-1 respectively. No significant differences were found in the three upstream-downstream comparisons using a non-parametric test, on the graph, arrows give the position of the dam on the longitudinal river course.

All the 208 taxa observed into the rivers were considered in the index. The FIGURE 3 shows the mean number of taxa involved in the index calculus by rank of ubiquity (1: tolerant to 3: specialist), this ubiquity coefficient is used to weight the taxa quotations too. The three rivers have a strong proportion of non-specialist taxa, reinforced downstream from the dams. The Sélune river has the highest mean richness value of specialist in its regulated sectors.

DISCUSSION

This study shows the difficulty of application of a global biological index on three rivers under agro-industrial pressure. A key of the problem is the weighted coefficient of ubiquity, as shown with the FIGURE 3: too many non-sensitive taxa are considered in the calculus of the index (FIGURE 3), what is not consistent with the bioindication concept (Haslam, 1995), more sensibility should be reached if only specialist taxa are selected; a second value like a percentage of ubiquist taxa of the plant record could give a complementary information: the two approaches should be distinct. Previous works with the first version of the index on the river Rance had given a similar conclusion (Bernez *et al.*, 2001).

The fact that these river plant communities are first sensitive to physical factors, and secondly to chemical's, even in a context of important variation of trophy (TABLE 1), could explain the lack of response of the index. Other organic pollution, as fish-farm effluents, on rivers of the same region and of the same size, have given the same results (Daniel, 1998; Daniel *et al.*, 2004). This trend is observed but rarely considered because of the difficulty to integrate it in a model, as bioindication tools. More has to be done in a way of a differentiation of community response that is sensible to biogeographical and landscape changes; the difficulty is to find the relevant level of study to link trophy impact to river plants: that is probably the local or site level, that permits experimental investigations, considering regional, biogeographical aspects as a boundary factor or fixed condition (Barendregt & Bio, 2003).

An other aspect is the consideration of the river continuum, with the non-independence of the communities along the river course: it could influence in smoothing the value of the index. For example, the drift possibility, linked to some biological traits as reproduction modes, has to be integrated in a comprehensive model of bioindication. We expected that a disruption of big hydroelectric dam lakes gave better results, because of an observed very contrasted flora and strong variations with environmental factors: no shift in the up-downstream comparison of index values appeared, when observed communities were very different in term of composition and richness (Bernez *et al.*, 2004). One way to link trophy impact to river plants is to consider local condition, where the chemical factors seemed to be important: middle and lower area in north-Spain rivers gave responses to trophy degradation, because of a possibility to fix physical conditions in the comparison, when upper reaches did not offer this possibility (Onaindia, 1996). Future works using river plants as bioindicators of the water trophy quality should integrate more statistical evaluation (Murtaugh, 1996) and that should be possible because of the increasing interests and the increase of surveys.

AKNOWLEDGMENTS

Thanks to EDF-Electricité de France-and the French Water agencies of Loire-Bretagne and Seine-Normandie for funding this research, to the french foreign Affairs Ministry for the "Lavoisier" Fellowship, to Laurent Beillard for some figures, to Bernard I. Gérard West for the revision of the english and to Valérie Pousse and Silvia Casertano for the "riassunto italiano".

RIASSUNTO

I mutamenti longitudinali delle piante acquatiche in ricchezza e composizione sono stati studiati dai corsi superiori fino al quinto ordine di corso d'acqua in tre fiumi vicini nella Bretagna occidentale (Francia), l'Orne, il Sélune e il Rance. Tutti i fiumi sono stati regolati anni fa da dighe situate sulla terza parte inferiore dei corsi fluviali esaminati. In uno studio precedente si era osservato un mutamento evolutivo della ricchezza in macrofiti lungo il continuum fluviale, legato all'eterogeneità del-

l'habitat, a influenze dei settori regolati e ai mutamenti geologici. L'arricchimento nutritivo e l'influenza dell'inquinamento organico sono stati i principali gradienti secondari. Su questa base abbiamo messo a punto una metodologia per completare un indice biotico usato in Europa per la valutazione del trofismo dell'acqua, seguendo la direttiva quadro europea sulle acque, l'IBMR basato su un esame delle piante acquatiche: è stata eseguita una verifica con test statistici classici e le segnature d'ordine delle piante. L'indice non ha fornito una reazione significativa alle variazioni nella qualità dell'acqua: ciò dimostra che (i) l'estrapolazione dei valori biologici di qualità su un territorio ampio non è evidente e (ii) i fattori fisici, che hanno un impatto soprattutto (prima delle sostanze chimiche) sulla distribuzione della vegetazione nei fiumi, non consentono di utilizzare le piante per l'indicazione del trofismo dell'acqua. Infine questo approccio permette di proporre un adattamento dell'indice alle particolarità locali di ognuno dei tre fiumi altamente antropicizzati.

REFERENCES

BARENDREGT, A. and BIO A.M.F., 2003 - *Relevant variables to predict macrophyte communities in running waters*. Ecol. Model. **160:** 205-217.

BERNEZ, I., DANIEL H. and HAURY J., 2001 - *Etude des variations des communautés végétales aquatiques sous l'effet de perturbations anthropiques en rivière régulée*. Bull. Fr. Pêche Piscic. **357/358:** 169-189.

BERNEZ, I., DANIEL H. and HAURY J., 2004 - *Combined effects of environmental factors and regulation on macrophyte vegetation along three rivers in Western France*. River Res. Applic. **20:** 43-59.

BERNEZ, I., HAURY J. and FERREIRA M.T., 2002 - *Downstream effects of a hydro-electric reservoir on aquatic plant assemblages*. The Scientific World Journal **2:** 740-750.

BORNETTE, G., PIEGAY H., CITTERIO A., AMOROS C. and GODREAU V., 2001 - *Aquatic plant diversity in four river floodplains: a comparison at two hierarchical levels*. Biodivers. Conserv. **10:** 1683-1701.

DANIEL, H. 1998 - Evaluation de la qualité des cours d'eau par la végétation macrophytique-Travail *in situ* et expérimental dans le Massif armoricain sur les pollutions par les macronutriements. Thèse Ecole Nat. Sup. Agron. Rennes, Rennes.

DANIEL, H., BERNEZ I. and HAURY J., 2004 - *Relationships between macrophytic vegetation and physical features of river habitats: the need for a morphological approach*. Hydrobiologia: in press.

DANIEL, H. and HAURY J., 1996 - *Les macrophytes aquatiques: une métrique de l'environnement en rivière*. Cybium **20** (3) sup: 129-142.

DEMARS, B.O.L. and HARPER D.M., 1998 - *The aquatic macrophytes of an English lowland river system: assessing response to nutrient enrichment*. Hydrobiologia **384:** 75-88.

HASLAM, S.M., 1978 - River plants. Cambridge University Press, Cambridge, 396 pp.

HASLAM, S.M., 1995 - *Cultural variation in river quality and macrophyte response*. Acta bot. Gallica 142 (6): 595-599.

HAURY, J., PELTRE M.C., TRÉMOLIÈRES M., BARBE J., THIÉBAUT G., BERNEZ I., DANIEL H., CHATENET P., HAAN-ARCHIPOF G., MULLER S., DUTARTRE A., LAPLACE-TREYTURE C., CAZAUBON A. and LAMBERT-SERVIEN E., 2004 - *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*. Hydrobiologia: in press.

HOLMES, N.T.H., NEWMAN J.R., CHADD J.R., ROUEN K.J., SAINT L. and DAWSON F.H., 1999 - Mean Trophic Rank: a user's manual. Research & Development, Technical report E38. Environment Agency, Bristol: 134 pp.

KOHLER, A. 1982 - *Wasserpflanzen als Belastungsindikatoren.* Decheniana-Beihefte **26:** 31-42.

MURTAUGH, P.A. 1996 - *The statistical evaluation of ecological indicators.* Ecological Applications **6:** 132-139.

ONAINDIA, M., de BIKUNA B.G. and BENITO I., 1996 - *Aquatic plants in relation to environmental factors in Northern Spain.* J. Env. Manage. **47:** 123-137.

RIIS, T., SAND-JENSEN K. and VESTERGAARD O., 2000 - *Plant communities in lowland Danish streams: species composition and environmental factors.* Aquat. Bot. **66:** 255-272.

ROMERO, I. and ONAINDIA M., 1995 - *Fullgrown aquatic macrophytes as indicators of river water quality in the northwest Iberian Peninsula.* Ann. Bot. Fennici **32:** 91-99.

SCHNEIDER, S. and MELZER A., 2003 - *The Trophic Index of Macrophytes (TIM)-a new tool for indicating the trophic state of running waters.* Internat. Rev. Hydrobiol. **88:** 49-67.

TABLE 1 - General characteristics of the rivers and dams positions, and number of sampling sites coupled to Mean and standard deviation of abiotic characteristics for the groups of sampling sites upstream and downstream from the three reservoirs. Significant upstream-downstream comparisons are given by Wilcoxson rank tests (* $p<0.05$; ** $p<0.01$; *** $p<0.001$ are significant differences with the associated probability). For producing this table, seasonal data for different sites at different dates was pooled. Table modified and adapted from Bernez *et al.* (2004).

	Orne		**S lune**		**Rance**	
River length studied (km)	100		70		70	
Dam position (km) / stream order	75 / 3		50 / 4		50 / 4	
Compensation dam position (km)	90		Closed to the previous		No compensation dam	
Between dams channel length (km)	11		0.5		No compensation dam	
Downstream channel length (km)	15		15		15	
Number of sampling site Upstream (Downstream)	15(5+3)		13(6)		15(12)	
	Upstream	**Downstream**	**Upstream**	**Downstream**	**Upstream**	**Downstream**
	n–34	n–12	n=26	n–12	n–34	n=20
Velocity m/s	0.24 0.13	**0.43–0.20** **	0.27–0.11	**0.42–0.16****	0.38-0.11	**0.17–0.08** ***
Width m	15.5–8.7	**20.7–2.9** **	4.9 3.6	**20.4–3.2** ***	4.4–1.8	**10.8–3.5** ***
Silt % (<1mm)	29.7–26.3	**4.0–2.7** **	36.7 24.4	10.6 13.5 *	6.3–6.9	2.6-3.4
Sand % (1-5 mm)	10.7–9.5	5.9–3.9*	4.7–4.5	10.4–6.9	10.8–6.4	**4.1–3.4** **
Block % (>500 mm)	5.9–5.6	32.2–20.5 *	4.6–4.6	35.5–17.2 *	4.8–7.3	3.5–2.9
Conductivity S.cm-1	597.6 46.4	450.1 17.5*	238.8–35.6	235.3 12.7	458.5 223.7	336.0–30.0
pH	7.7–0.2	**7.8–0.1** **	7.2–0.2	**7.5–0.2** **	6.9 0.1	**7.7–0.4** ***
Alkalinity meq/l	3.7–1.0	**2.3–0.3** **	1.9–0.4	2.0–0.6	0.7–0.2	**1.4–0.2** ***
Temp.¡C	16.6–0.7	**18.6–0.9** **	14.1–2.4	18.0–1.1 *	14.2–0.8	**16.3–0.8** ***
PO4 mg/l	0.43–0.13	0.31–0.11*	0.35–0.28	0.08–0.05 *	0.34–0.29	**0.10–0.07****
NO3 mg/l	29.5–8.5	18.3–1.4**	29.7–7.7	34.9–6.7	30.8–4.0	**16.2–4.6** ***
NH4 mg/l	0.12–0.10	0.09–0.10	0.06–0.05	0.04-0.03	0.02–0.02	0.18–0.27

TABLE 2 - Abiotic variables forward selected by the canonical correspondence analyses of aquatic plant taxa from the rivers Orne, Sélune and Rance, and their correlation with the first two canonical axes. *significant correlation at $p<0.05$. Table modified and adapted from Bernez *et al.* (2004).

		Forward selection		Correlation with canonical axes	
	Selected Variables	F-ratio	P-value	Axis1	Axis2
Orne	Distance from the source	4.234	0.005	-0.77*	-0.46*
	Pool habitat	2.69	0.005	0.51*	-0.44*
	Nitrates (NO3)	1.665	0.005	0.29*	0.55*
	Conductivity	1.515	0.01	0.74*	0.24
	Downstream from the dam	1.504	0.015	-0.67*	-0.02
S lune	Distance from the source	3.991	0.005	-0.85*	0.17
	Riffle habitat	2.401	0.005	-0.14	-0.42*
	Slope	2.14	0.005	0.45*	0.21
	Depth	2.11	0.01	-0.29*	0.41*
	Downstream from the dam	1.87	0.01	-0.74*	-0.05
Rance	Downstream from the dam	7.632	0.005	-0.89*	0.07
	Distance from the source	3.194	0.005	-0.85*	-0.32*
	Ammonium (NH4)	2.47	0.005	-0.27*	-0.43*
	Slope	2.169	0.005	0.62*	0.31*
	Phosphates (PO4)	2.01	0.005	0.22	0.49*
	Calcareous substratum	1.93	0.03	-0.36*	-0.25