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Relationships between macrophytic vegetation and physical features of river habitats: the need for a morphological approach

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Abstract

The aim of this paper is to study the relationships between the physical features of rivers and the distribution of macrophyte vegetation. Field work was undertaken at 207 stations along the Scorff River and its tributaries, a salmon river system in southern Brittany (western France). The physical features were considered using a principal component analysis (PCA). Stepwise multiple regression models made it possible to assess their relationships with the botanical data. The first five axes of the physical PCA (used as explicative variables) were initially linked to the most frequently surveyed species, then to their eco-morphological types, and, finally to Arber's (1920. Water Plants. A Study of Aquatic Angiosperms. Cambridge Univ. Press, Cambridge, 414 pp) morphological classification. It was concluded that plant morphology was closely related to these environmental factors. This could contribute to the development of predictive models for plant distribution and could increase the knowledge of reference vegetation related to bioindication systems.

Introduction

The sensitivity of aquatic macrophytes to chemical pollution in rivers has been amply demonstrated by many authors (Kolher, 1971; Haslam, 1987; Trémolières et al., 1994; Daniel & Haury, 1995; Ali et al., 1999). However, the properties of a good indicator of water quality must involve not only its sensitivity to pollution, but its selectivity as well (Murtaugh, 1996). This second aspect has received much less attention in bio-indicator surveys based on aquatic macrophytic vegetation (Kelly & Whitton, 1998). Studies on the subject generally aim at either establishing degradation sequences (Carbiener et al., 1990), or elaborating a synthetic index, based on specific scores (Haury et al., 1996; Holmes et al., 1999). Both approaches need to establish reference situations for plant communities, or for the distribution of species. It is neither obvious nor simple to define references situations in running waters. The degradation sequences usually proposed follow the longitudinal gradient of the river. However, it is not possible for such vegetation references to be the same in the upstream section and in the downstream section of the river. It is also difficult to integrate smaller scale variations in physical features: for example, pool – riffle sequences, or local variations in incident light.

Butcher (1933) had already observed that the chief factor governing the distribution and abundance of aquatic macrophytes in English streams was water current. Others factors that he recognised as important included bottom substrate and light availability. In a survey of 17 Florida streams (with low current velocity and relatively homogeneous substrate), Canfield & Hoyer (1988) observed that nutrients were not related to the abundance of aquatic macrophytes. Instead, shading by riparian vegetation seemed to be the dominant factor. These physical factors are even capable of hiding the effects of heavy point pollution on aquatic plant communities (Daniel & Haury, 1996b; Demars & Harper, 1998; Bernez et al., 2001). Thus, a reliable bioindication system for water quality requires characterisation of the relationships between the physical features of the river, and its macrophytic vegetation.

We hypothesised that this relationship was mainly determined by the morphological traits of the aquatic macrophytes. The aim of this paper is to test the relationships between the physical features of running waters and macrophytic vegetation and to assess the relevance of considering the morphological characteristics of the aquatic plants for a better understanding of these relationships.

Materials and methods

The study was based on field work along the Scorff River and its tributaries, a salmon river system in southern Brittany (France). Schist and granite are the predominant geological substrata in the river basin (Daniel & Haury, 1996a). In total 207 stations (each a 50 m stretch) were sampled in order to represent the variability of the physical features of the river, with a stratified sampling plan based on stream order (from 1 to 5), light and water current. Vegetation relevés (with an estimation of cover) were recorded from within each station in July 1994. Aquatic macrophytes studied included all the plants growing in the usually submerged part of the channel (Holmes & Whitton, 1977): macroalgae, bryophytes (taxonomy according to Smith (1978) for the mosses and Smith (1990) for the liverworts) and spermatophyta (taxonomy according to Tutin et al. (1968–1993)). Physical features were recorded on the same date for each station, and included depth, width, size of substrate (visual cover estimation), water velocity, water surface appearance (laminar, riffle or turbulent) and incident light (using the canopy cover estimation).

Taxa were classified according to the ecomorphological types proposed by Den Hartog and Van Der Velde (1988), with the addition of two other classes: helophytes (Raunkiaer, 1905) and bryides (Mäkirinta, 1978). The morphological classification proposed by Arber (1920) was adapted to the flora studied (Table 1) and used in the analysis as well.

A principal component analysis (PCA) was made to assess the general structure of the physical variables of the habitat – software: SPAD (CISIA, 1999). Stepwise multiple regression models – software: SYSTAT (Wilkinson, 1997) – were then established in order to quantify the relationships between the physical features and the aquatic macrophyte taxa, the ecomorphological classification and the Arber morphological classification, successively. For these analyses, the first five factorial axes of the previous PCA were used as predictive variables. The factorial axes were integrated into the models one at a time and selected according to the Fisher statistic (probability limit of acceptance: 0.10). The coefficients of regression made it possible to compare the models. The major advantage of this approach was the statistical independence of the explicative variables (the factorial axes of the PCA).

Results

Physical features of the habitat analysis

The first five axes of the PCA (with eigenvalues greater than 1) together accounted for 75% of the total inertia of the data set (Fig. 1). The first axis (26% inertia) corresponded to the water velocity

Table 1. Biological classification adapted from Arber (1920)

Without roots	A
Live unattached in the water	*Lemna* sp.
Rooted in the soil and all leaves submerged	B
Rooted in the soil and floating leaves differentiated	C
Rooted in the soil and sometimes with aerial leaves	D

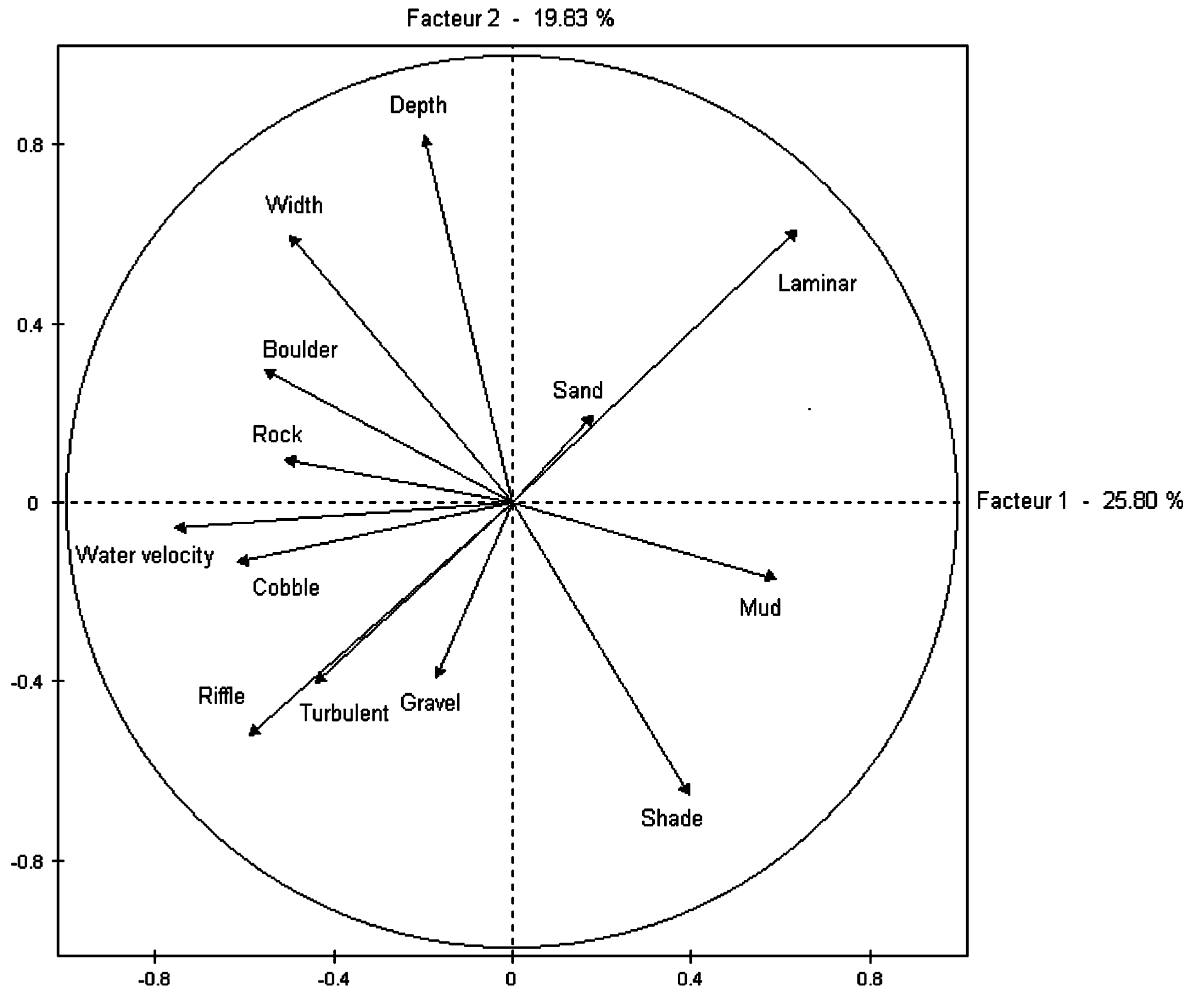

Figure 1. Representation of the first factorial plan of the principal component analysis involving the physical features of the habitat as active variables.

(factorial coordinate: −0.75) and the laminar appearance of the water (+0.63). The second axis was mainly explained by several variables (depth – factorial coordinate: +0.82, incident light – +0.65 and width – +0.60) corresponding to the longitudinal gradient of the river. The predominant bank materials were moderately correlated to these first two axes, whereas the specific size substrates appeared on the next factors. Sandy substrate stations contrasted with boulder and cobble substrate stations with the 3rd and 4th axes, respectively. The 5th axis was mainly explained by a differentiation of the mud substrate stations.

Regression models for the aquatic macrophytes taxa

Stepwise multiple regression models using factorial axes of the PCA were performed for the 40 taxa recorded with a frequency greater than 5%. Several models appeared significant (Table 2). The plants growing in swiftly flowing water had generally the best-fitted statistical models, for example: *Fontinalis antipyretica, Rhynchostegium riparioides, Callitriche hamulata*. The first axis corresponding to water flow was used in almost all the cases, except for riparian plants (such as *Iris pseudacorus*) and those growing in deep stations (*Nuphar lutea*).

Table 2. Stepwise multiple regression models using factorial axes of the PCA for the 40 taxa

Taxa	*R*	*F*1	*F*2	*F*3	*F*4	*F*5
Lemanea sp.	0.58**	−0.94**		−0.76**		
Fontinalis antipyretica	0.57**	−1.37**	0.67**			
Rhynchostegium riparioides	0.57**	−1.84**	−0.43*	−1.13**		
Vaucheria sp.	0.56**	−1.28**	0.75**			0.78*
Callitriche hamulata	0.56**	−1.98**	1.11**		1.15**	
Phalaris arundinacea	0.55**	−0.33**	1.6**			0.53*
Fissidens gr. *pusillus*	0.54**	−0.45**		−0.6**	−0.66**	
Sparganium emersum	0.54**		1.03**			
Chiloscyphus polyanthos s.l.	0.52**	−1.1**	−0.32*	−0.83**	−0.62**	
Octodiceras fontanum	0.51**	−0.48**	0.63**		0.55**	1**
Ranunculus penicillatus	0.49**	−4.5**	2.98**	2.1**	2.06*	
Other macro-algae	0.43**	−1.04**	1.87**			
Callitriche obtusangula	0.43**	−0.67**	0.98**			
Potamogeton alpinus	0.43**	−0.91**	0.64**		0.51*	
Amblystegium fluviatile	0.42**	−0.31**		−0.29**	−0.17*	−0.24**
Mentha aquatica	0.4**	0.28**		−0.31**	0.29*	−0.42**
Nuphar lutea	0.39**		0.7**		−0.39**	
Amblystegium riparium	0.38**	−0.93**				
Apium nodiflorum	0.37**	1.5**	−1.48**	1.57**		
Riccardia chamaedryfolia	0.35**	−0.39**	−0.35**	−0.29*	−0.38*	0.5**
Glyceria fluitans	0.31**	1.07**				−1.14**
Galium palustre	0.31**	0.27**		−0.19**		
Myriophyllum alterniflorum	0.3**	−0.37**	0.52**			
Equisetum fluviatile	0.3**	0.03**			−0.05**	−0.09**
Porella pinnata	0.3**	−0.45**				0.43*
Lemna minor	0.28**		0.74**	0.48*		
Scapania undulata	0.27**		−0.48**	−0.95**		
Callitriche stagnalis	0.26**	0.36**				
Polygonum hydropiper	0.24**		0.04	0.05**	0.06*	
Callitriche platycarpa	0.23**		0.63**			
Sparganium erectum	0.22**	0.46*			0.76*	−1.12**
Hildenbrandia sp.	0.21**	−0.35**				
Myosotis gr. *Scorpioïdes*	0.21**	0.24**			0.31*	
Oenanthe crocata	0.2**	−0.7*	−0.93**			
Alisma plantago-aquatica	0.19**	−0.02**			0.03*	
Ranunculus peltatus	0.13*		0.43*			
Iris pseudacorus	0.12*				0.14*	
Batrachospermum sp.	/					
Brachythecium rivulare	/					
Apium inundatum	/					

R: regression coefficients; *F*1–*F*5: equation parameters; **: $p < 0.05$; *: $0.05 < p < 0.10$; empty case: $p > 0.10$.

The second factor (correlated mainly with water depth) was usually integrated into the models as well. Its positive values were associated with the downstream hydrophytes and its negative values, either with the rheophilous bryophytes (*Riccardia chamaedrifolia*), or with some helophyte, widely distributed in small brook riffle (*Oenanthe crocata*, *Apium nodiflorum*). The 3rd and 4th axes were integrated into the models in the case of some bryophytes associated with large-size substrata and for plants associated with sand substrata (*Ranunculus penicillatus*, *Lemna minor*, *Apium nodiflorum*). The 5th factor was rarely integrated; it led to a better determination of the abundance of species usually associated with fine substrates (e.g. *Phalaris arundinacea*, *Glyceria fluitans*).

Use of the morphological classifications

Table 3 presents the same calculations for the ecomorphological types. Nearly all the models were significant ($p < 0.05$). The first factor was used in all the cases. A good fit was possible for the bryids with only two factorial axes. However, the abundance of the helophytes could not be significantly predicted by any model.

Finally, the use of the Arber classification (adapted to our data) appeared to be the most suitable for this approach. Significant models ($p < 0.05$) were calculated for all the classes (Table 4). The comparison of the regression coefficients obtained at each step of the study confirmed the relevancy of this simple morphological typology (Fig. 2).

Discussion and conclusion

The principal variation axes of the physical features provided the main predictive variables used in the regression models. These results conform to the recognised influence of the physical river habitat on macrophytic vegetation (Butcher, 1933) and the interest of an morphological approach (Dawson et al., 1999). The results are also in line with the findings of Chambers (1987) for lake macrophyte vegetation. She suggested that the physical environment primarily determines the growth-form composition of aquatic plant communities. Thus, a simple morphological classification appears to be an effective tool for predicting a large part of the distribution of macrophytic vegetation in running waters.

These results confirm the necessity of studying not only the biological traits of the aquatic macrophytes but their links to ecological factors as well (Bornette et al., 1994; Ali et al., 1999; Willby et al., 2000). Such a morphological approach can help to determine the macrophyte carrying capacity of running water stations. Further calibration studies in other streams could lead to the development of a system defining the

Table 3. Stepwise multiple regression models using factorial axes of the PCA for the ecomorphological types

Ecomorphological types	*R*	*F*1	*F*2	*F*3	*F*4	*F*5
Bryides	0.73**	−7.66**		−4.27**		
Peplides	0.52**	−2.45**		2.87**	1.28*	
Batrachiides	0.50**	−4.82**	3.41**	2.2**	2.21*	
Elodeides	0.25**	−0.45**	0.66**			
Nympheides	0.29**	1.11**	0.59*			
Helophytes	/					

R: regression coefficients; *F*1–*F*5: equation parameters; **: $p < 0.05$; *: $0.05 < p < 0.10$; empty case: $p > 0.10$.

Table 4. Stepwise multiple regression models using factorial axes of the PCA for the biological classification adapted from Arber (1920)

Biological classification (Arber)	*R*	*F*1	*F*2	*F*3	*F*4	*F*5
A	0.77**	−10.8**	2.58**	−5.78**		
B	0.56**	−2.43**	1.77**		1.43**	
C	0.60**	−6.15**	6.55**	2.21*	2.47*	
D	0.25**	2.35**			2.42*	

R: regression coefficients; *F*1–*F*5: equation parameters; **: $p < 0.05$; *: $0.05 < p < 0.10$; empty case: $p > 0.10$.

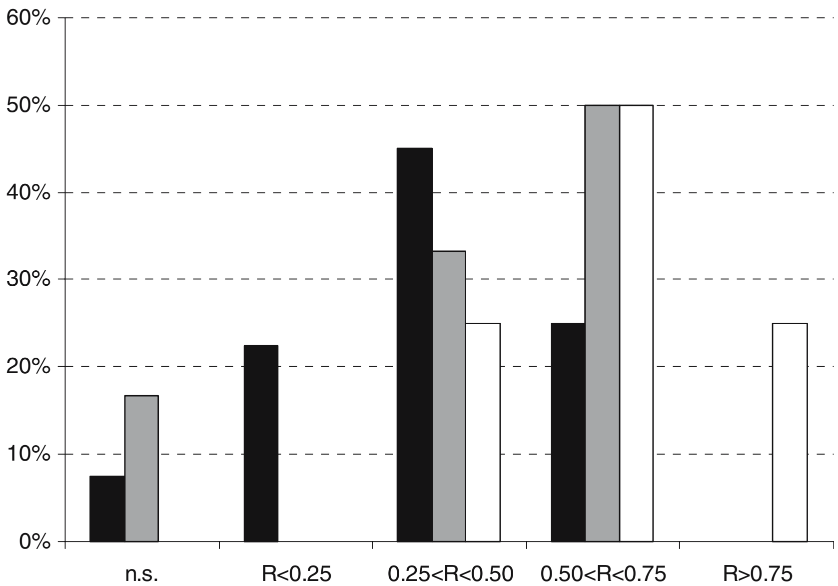

Figure 2. Frequency of the regression coefficient obtained in the stepwise multiple regression models. (Black: with the 40 taxa, grey: with the ecomorphological classification, white: with Arber classification.)

morphological groups of aquatic plants related to the physical features of the stations, which may complement and extend the capabilities of existing bioindication systems.

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