

Macrophytic communities inhabiting the Huveaune (South-East France), a river subject to natural and anthropic disturbances

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Abstract

Few studies have dealt so far with the macrophytic communities inhabiting the small Mediterranean rivers in South-East France. In order to fill this gap, it was proposed to assess the effects of natural and anthropic disturbances on the biodiversity in the lowland River Huveaune (South-East France). The Mediterranean climate in this region results in strong seasonal variations in the hydrological regime: there is a long dry period and sudden episodes of flooding occur, which greatly affect the plant community dynamics. The River Huveaune is severely polluted by organic matter. Two stations were set up, one in an upstream reference sector and the other in a downstream polluted sector. The standard sampling area of 100 m² was divided into plots 4 m² in size, some of which included part of the river and part of a bank. In addition, plant inventories were drawn up over distances of 50 and 100 m. Seventeen sampling campaigns were carried out from April 2002 to October 2003, resulting in the first systematic list of macrophyte species occurring in small Mediterranean rivers in South-Eastern France. The great variability of the hydrological factors involved leads to considerable spatial and temporal variations in the biodiversity. The upstream station was found to be less severely disturbed and to show a wider range of macrophytes than the downstream station: bryophytes predominate upstream and phanerogams and macroalgae, downstream. The Macrophyte Biological Index for River (IBMR) was tested and found to be a valid means of water quality assessment in small Mediterranean rivers.

Introduction

Aquatic and emergent macrophyte communities typically show a longitudinal pattern of zonation in rivers (Butcher, 1933; Haury & Muller, 1991) and can provide useful biotypological tools. Macrophytes can indicate the quality of river environments (Bernez, 1999) and are often used for monitoring heavy metals and other pollutants present in the water and submerged sediments (Sawidis et al., 1995). The communities affect processes such as the sedimentation and the

hydrological and underwater light regimes, as well as depending on these processes (Dawson, 1978, 1988; Cazaubon, 1986; Haury & Peltre, 1993; Daniel & Haury, 1996; Westlake, 1996; Khedr & El-Demerdash, 1997). Apart from a few studies on the dynamics of macrophyte populations in the River Durance (Fayolle, 1998) and invasive plants in the Provence-Alpes-Côte d'Azur region (Salanon, 2000; Dandelot et al., 2002), only a few fragmentary data are available about macrophytes in small Mediterranean rivers in South-East France (Comte, 2001). The aim of the present study

focusing on a single river with variable levels of water quality was to determine the particularities of the small Mediterranean river macrophyte communities in South-East France, and to ascertain whether the standard Biological Macrophyte Index for Rivers (IBMR) is applicable to these river systems

Study sites

The River Huveaune was chosen for this study because its morphology and its hydrological regime are typical of most small Mediterranean rivers. This river arises in the calcareous Sainte-Baume hills (Var) at an altitude of 600 m, and covers 51 km, reaching the Mediterranean in Marseille; its catchment basin is 500 km² in size. The floods are strongly dependent on the precipitation: low water levels occur from June to September, and there are two periods of heavy rain and high water levels, in autumn and spring. In 2003, the average flow rate near the downstream station was 1.1 m³ s⁻¹ (min = 0.3 m³ s⁻¹ in August; max = 2.7 m³ s⁻¹ in December). The pollution and disturbances occurring along the river valley are mainly due to human activities (agriculture, urban and industrial wastes and building activities on the banks).

The upstream station was located 4 km downstream from the source, at an altitude of 250 m (at Saint-Zacharie, near the Moulin Blanc). The average width of the riverbed at this point is 6 m. It is bordered on the left bank by a leisure centre. Sand, wood and stones from a building site on the right bank have been thrown into the river. Bank side trees reduce the light reaching the channel. At this station, the slope is gentle, the average depth is 18 cm and the current velocity is 0.2 m s⁻¹.

The downstream station (altitude: 10 m) was located in the commune of Aubagne. The tree canopy is much less developed here. At this station, the width of the riverbed is 13 m, the slope is gentle, the average depth is 19 cm and the current velocity is 0.3 m s⁻¹. The river is bordered on the right bank by a road and on the left bank by a sports complex. Sewage from drainpipes flows into the river. Just before our study (March 2002), the bed was completely dredged, which destroyed most of the vegetation.

Materials and methods

A standard sampling unit with an area of 100 m², including a 0.5 m wide belt above the water level on each of the two banks, was used to study the macrophytic communities. Each station was divided into plots of 4 m², some of which included part of the river and part of a bank. A detailed inventory of the flora was drawn in each plot and the percentage rate of cover of each macrophyte taxon was assessed visually. For this purpose, each plot was divided into 16 sub-plots 2500 cm² in size. A value of 2% was allotted to all the species having a cover amounting to less than 6%. To make sure that no information was lost, surveys were carried out over a distance of 50 then 100 m, using the standardized IBMR procedure (AFNOR, 2003).

The following physical characteristics of the habitat were determined in each plot: the depth, the granulometry of the substrate (fine = slime, silt, sands; coarse = gravels, pebbles and boulders) and the current velocity (FLO-MATE, portable Model 2000). In addition, 15 abiotic parameters of the water were analyzed either on the field (the temperature and conductivity: multisonde VTW analyzer) or at the laboratory (chemical parameters, using the SEQ EAU protocol recommended by the French water agency).

A multivariate PCA analysis was applied to the data (ADE 4 program by Thioulouse et al., 1997).

The quality of the water was assessed using the IBMR (Haury et al., 2002; AFNOR, 2003). IBMR is an index which can be used to rate the quality of water based on quantitative data on the macrophytes (the percentage rates of macrophytic cover). The 5-level trophic quality grid corresponding to the IBMR gives the quality of the water based on the scores calculated.

The IBMR was calculated using the following formula:

$$\text{IBMR} = \sum E_i \cdot K_i \cdot C_{si} / \sum E_i \cdot K_i$$

i = contributive species

C_{si} = specific trophic size from 0 to 20

E_i = coefficient of eury-stenoecie

K_i = coefficient of abundance (1–5 depending on the cover)

Seventeen sampling campaigns were carried out at each station from April 2002 to October 2003, at approximately monthly intervals, from April to October, and every two months from the end of October to March.

Results

Abiotic parameters

The water was slightly cooler upstream than downstream, apart from periods of flooding: the water temperature ranged between 11 and 21 °C. In both stations, the depth was shallow and the water velocity slow. The water was slightly alkaline and strongly mineralized. The values corresponding to the conductivity, chlorides, sulfates and nitrates, mineral and organic matter in suspension and 5-day biological oxygen requirements (BDO5) increased considerably in the downstream stretch, which is more severely polluted than the upstream one (Table 1).

The substrate granulometry was finer downstream (fine = 37%, coarse = 63%) than

upstream (fine = 13%, coarse = 87%) which, together with the high level of organic matter, favoured the proliferation of plants, such as particular macroalgae and phanerogams in particular.

Biotic parameters

Macrophytic richness

Sixty-nine taxa in all including hydrophytes, helophytes, wet bank plants and terrestrial species were observed growing at the two stations. The specific richness differed between the two stations: 60 taxa upstream, 37 downstream (including 28 common ones). This was mainly due to the greater bryophyte richness upstream (26 taxa) than downstream (4 taxa), while the species of phanerogams detected were equally numerous at both stations (30 upstream; 30 downstream) (Table 2).

However, the taxonomic richness varied depending on the year and the season (Fig. 1a, b). In 2003, the numbers of taxa decreased upstream (34 taxa in 2002; 29 taxa in 2003), where some bryophytes and cyanobacteria disappeared in summer and autumn (*Cinclidotus aquaticus* (Hedw.) B. & S., *Bryum* cf. *pseudotriquetrum* (Hedw.) Gaertn., *Didymodon insulanus* (De Not.) M. Hill, *Didymodon luridus* Hornsch. ex Spreng., *Didymodon tophaceus* (Brid.) Lisa, *Brachythecium rutabulum* (Hedw.) B., S. & G., *Bryum gemmiparum* De Not.), while downstream, the numbers increased (15 taxa in 2002; 21 taxa in 2003) due to colonization by additional species of filamentous macroalgae (*Cladophora* sp.), bryophytes (*Cinclidotus fontinaloides* (Hedw.) P. Beauv., *Bryum* sp.) and phanerogams (*Epilobium hirsutum* L., *Mentha aquatica* L. & *Solanum dulcamara* L.).

Percentage macrophytic cover

The percentage macrophytic cover (mean average) was comparable on the whole at both stations (32.5% upstream and 39.6% downstream) but the composition of the communities differed: bryophytes predominated upstream, and phanerogams and macroalgae downstream (Fig. 2a).

Annual changes were observed at the downstream station: the overall cover was greater in 2003 (50%) than in 2002 (32%), while no significant changes occurred upstream (34% in 2002 versus 29% in 2003). Some seasonal differences

Table 1. Average values and standard deviations of the main physicochemical components of the water at the two stations studied on the River Huveaune (σ = standard deviation)

	Upstream		Downstream	
	Mean	σ	Mean	σ
Temperature (°C)	15	2.1	16.9	3.4
Conductivity ($\mu\text{S cm}^{-1}$)	550	15.6	735	83.5
Dissolved oxygen (mg l^{-1})	9	0.6	9.7	3.3
Chlorides (mg l^{-1})	36.6	24.2	60.5	38.3
SO_4^{2-} (mg l^{-1})	39.5	15.7	161.8	23
NO_2^- (mg l^{-1})	0.01	0	0.02	0.01
NO_3^- (mg l^{-1})	1.38	0.6	7.8	2.2
NH_4^+ (mg l^{-1})	0.07	0.06	0.1	0.07
PO_4^{3-} (mg l^{-1})	0.02	0.02	0.07	0.05
BDO5 (mg l^{-1})	1.4	0.8	3.2	2.2
Mineral matter in suspension (mg l^{-1})	0.5	0.8	2.2	2.7
Organic matter in suspension (mg l^{-1})	0.3	0.3	1	0.5
PH	7.2	0.3	7.3	0.3
Current velocity (m s^{-1})	0.2	0.1	0.3	0.2
Depth (cm)	18.6	3.5	18.9	8.7

Table 2. List of the macrophytes present at both stations studied on the River Huveaune; A = algac, B = bryophytes, Ph = phanerogams, C = clumps of cyanobacteria

Species	Huveaune	
	Ust	Dst
Hydrophytes		
A <i>Cladophora</i> sp.	+	+
A <i>Hildenbrandia rivularis</i> (Liebm.) Breb.	+	+
C <i>Nostoc</i> sp.	+	–
A <i>Vaucheria</i> sp.	+	+
B <i>Amblystegium riparium</i> (Hedw.) B., S. & G.	+	–
B <i>Cinclidotus aquaticus</i> (Hedw.) B. & S.	+	–
B <i>Cinclidotus fontinaloides</i> (Hedw.) P. Beauv.	–	+
B <i>Fissidens crassipes</i> Wils. ex B., S. & G. subsp. <i>warnstorffii</i> (Fleisch.) Brugg. Nann.	+	+
B <i>Fontinalis antipyretica</i> Hedw.	+	–
B <i>Rhynchostegium riparioides</i> (Hedw.) Card.	+	–
Ph <i>Glyceria fluitans</i> (L.) R. Br.	+	–
Total	10	5
Helophytes		
Ph <i>Apium nodiflorum</i> (L.) Lag.	+	+
Ph <i>Carex pendula</i> Hudson	+	–
Ph <i>Carex pseudocyperus</i> L.	–	+
Ph <i>Cyperus eragrostis</i> Lam	–	+
Ph <i>Cyperus longus</i> L.	–	+
Ph <i>Glyceria plicata</i> (Fries) Fries	–	+
Ph <i>Lycopus europaeus</i> L.	+	+
Ph <i>Mentha aquatica</i> L.	+	+
Ph <i>Nasturtium officinale</i> R. Br.	+	+
Ph <i>Phalaris arundinacea</i> L.	+	+
Ph <i>Phragmites australis</i> (Cav.) Trin. ex Steudel	+	+
Ph <i>Polygonum hydropiper</i> L.	+	+
Ph <i>Polygonum mite</i> Schrank	–	+
Ph <i>Polygonum persicaria</i> L.	+	+
Ph <i>Veronica anagallis-aquatica</i> L.	+	+
Total	10	14
Species of wet banks		
B <i>Bryum gemmiparum</i> De Not.	+	–
B <i>Bryum</i> cf. <i>pseudotriquetrum</i> (Hedw.) Gaertn., Meyer & Scherb	+	–
B <i>Cratoneuron commutatum</i> (Hedw.) G. Roth	+	–
B <i>Cratoneuron filicinum</i> (Hedw.) Spruce	+	–
B <i>Conocephalum conicum</i> (L.) Dum.	+	–

Table 2. (Continued)

B <i>Didymodon tophaceus</i> (Brid.) Lisa	+	–
B <i>Eurhynchium hians</i> (Hedw.) Sande Lac.	+	–
B <i>Fissidens taxifolius</i> Hedw.	+	–
B <i>Fissidens viridulus</i> (SW.) Wahlenb.	+	–
B <i>Lunularia cruciata</i> (L.) Lindb.	+	–
B <i>Marchantia polymorpha</i> L.	+	–
B <i>Pellia endiviifolia</i> (Dicks.) Dum	+	+
B <i>Plagiomnium undulatum</i> (Hedw.) T. Kop.	+	–
B <i>Pohlia wahlenbergii</i> (Web. & Mohr) Andr. var. <i>calcareae</i> (Warnst.) Warburg	+	–
Ph <i>Bidens tripartita</i> L.	+	+
Ph <i>Brachypodium sylvaticum</i> (Hudson) Beauv.	+	–
Ph <i>Calystegia sepium</i> (L.) R. Br.	+	+
Ph <i>Equisetum arvense</i> L.	+	–
Ph <i>Equisetum telmateia</i> Ehrh.	+	+
Ph <i>Epilobium hirsutum</i> L.	+	+
Ph <i>Epilobium parviflorum</i> Schreber	+	–
Ph <i>Eupatorium cannabinum</i> L.	+	+
Ph <i>Juncus</i> sp.	–	+
Ph <i>Mentha suaveolens</i> Ehrh.	+	–
Ph <i>Polypogon viridis</i> (Gouan) Breistr.	+	+
Ph <i>Ranunculus ficaria</i> L.	+	–
Ph <i>Samolus valerandi</i> L.	+	+
Ph <i>Scrophularia auriculata</i> L.	+	+
Ph <i>Solanum dulcamara</i> L.	+	+
Total	28	11
Terrestrial species		
B <i>Brachythecium rutabulum</i> (Hedw.) B., S. & G.	+	–
B <i>Bryum</i> cf. <i>radiculosum</i> Brid.	+	–
B <i>Bryum</i> sp.	+	+
B <i>Didymodon insulanus</i> (De Not.) M. Hill	+	–
B <i>Didymodon luridus</i> Hornsch. ex Spreng.	+	–
B <i>Scorpiurium circinatum</i> (Brid.) Fleisch. & Loeske	+	–
B <i>Trichostomum crispulum</i> Bruch	+	–
Ph <i>Galium aparine</i> L.	+	+
Ph <i>Galium album</i> Miller	+	+
Ph <i>Lactuca serriola</i> L.	–	+
Ph <i>Plantago major</i> L.	–	+
Ph <i>Rumex crispus</i> L.	+	+
Ph <i>Rumex</i> sp.	+	–
Ph <i>Urtica dioica</i> L.	+	+
Total	12	7
Total of all species	60	37

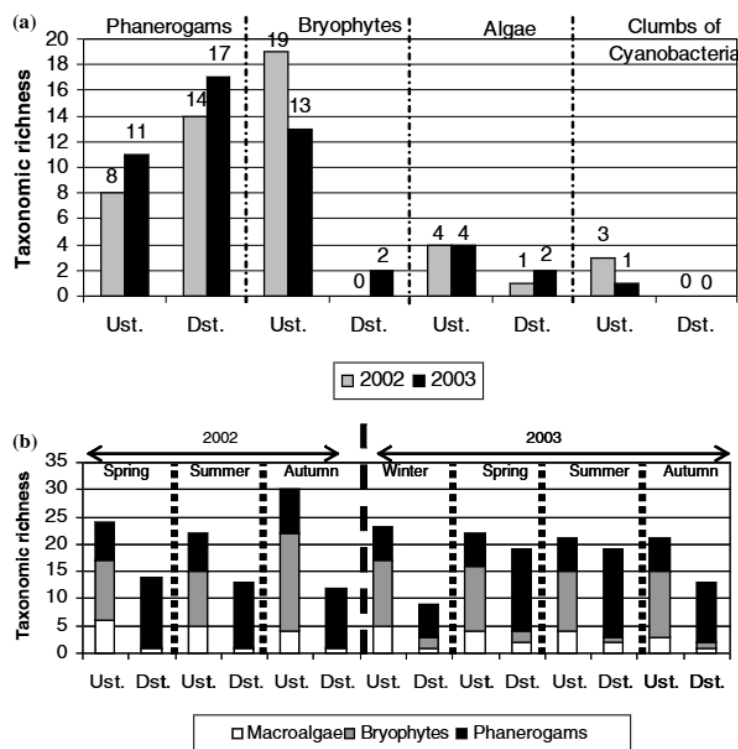


Figure 1. (a) Annual variations in the taxonomic richness of the different divisions of macrophytes at the two stations: upstream (Ust) and downstream (Dst). (b) Seasonal variations in the taxonomic richness of the various divisions of macrophytes upstream (Ust) and downstream (Dst).

were observed downstream, however (Fig. 2b): two maxima occurred in summer and autumn 2003, corresponding to a small increase in the phanerogams cover and above all, to a remarkable proliferation of macroalgae. In the last 2003 surveys, a quantitative change was observed downstream, while the upstream sector showed greater stability (Fig. 3a, b).

The results of the PCA (Fig. 4a, b) corroborate these tendencies. Axis 1 (inertia = 40%) distinguishes the bryophytic communities (upstream) from those with phanerogams and macroalgae (downstream). Axis 2 (inertia = 11%) shows that summer 2003 corresponded to the maximum macrophyte cover downstream, where macroalgae and phanerogams proliferated as the result of the increase in solar radiation and temperature, exacerbated by the sparsity of the canopy. Upstream, the differences between summer 2002 and the 2003 heat wave were much slighter because of the shady environment.

Aquatic macrophytes: metrics of the environment in a Mediterranean river

The use of IBMR shows a downstream degradation of the quality of the River Huveaune water. The trophic quality of the water was passable to good upstream (9.7–12.5) and mainly poor (sometimes bad or passable) downstream (7.7–10.6) with small annual variations and little temporal (seasonal and monthly) instability (Fig. 5). During the flood periods, the scores dropped sharply (to 9.3 upstream and 7.5 downstream).

Discussion

In terms of the community dynamics, the taxonomic richness and plant cover at the two study sites varied in both space and time. This variability was linked to the physical factors at work

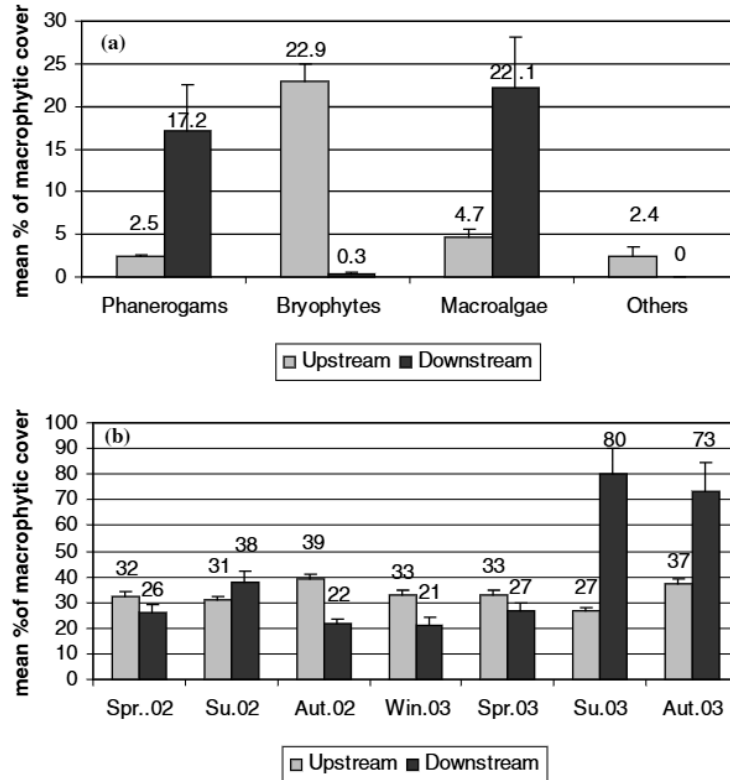


Figure 2. (a) Percentage rate of cover (mean values) of the various divisions of macrophytes upstream (Ust) and downstream (Dst). (b) Seasonal variations (Spr.: spring, Su.: summer, Aut.: autumn, Win.: winter) in the percentage rate of macrophytic cover (mean values) upstream and downstream.

in the environment, which contribute importantly to the pattern of macrophyte distribution (Butcher, 1933). In addition, the changes observed were due to disturbances of various kinds (rising and falling water level, organic pollution, scraping, channeling, etc). The main factors at work in the River Huveaune and the patterns most frequently mentioned in the literature are the longitudinal gradient, the effects of the flow rate and the light conditions (Butcher, 1933; Haslam, 1978; Weigleb, 1984; Thiébaud & Muller, 1999). The light energy received acts directly on the composition of the macrophytic communities, along with the nature of the substratum, which is one of the most decisive factors. In the River Huveaune, the substrate, which is mainly coarse upstream, is compatible with the development of bryophytes. The finer downstream sediments have favoured colonization by phanerogams.

The physicochemical quality of the water has influenced the taxonomic composition of the macrophytic stands. In the River Huveaune, some species such as *Rhynchostegium riparioides* and *Cinclidotus aquaticus* disappeared downstream (at the more polluted station), for instance. The presence downstream of some stands of the Rhodophyte *Hildenbrandia rivularis* (October 2003), which is thought to be sensitive to pollution (Cazaubon & Loudiki, 1985) and of *Nasturtium officinale* shows that these species are in fact able to resist pollution to some extent. *Cinclidotus fontinaloides*, which tolerates pollution, was present both at the sources of the Huveaune (Hébrard, 2003) and downstream, where pollutotolerant macroalgae, *Vaucheria* sp. and *Cladophora* sp., proliferated. As reported by Bernez et al. (2000) at the river Rance, polluted stations where eutrophication has occurred have a greater plant cover than others.

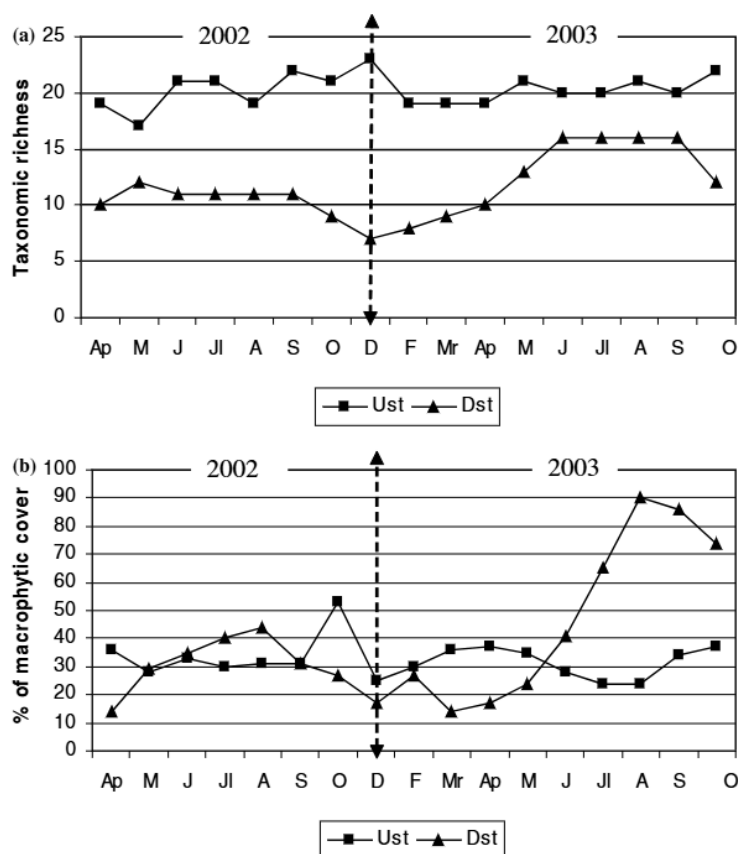


Figure 3. (a) Variations in the taxonomic richness (stations upstream and downstream) in 2002 and 2003. (b) Variations in the macrophytic cover in 2002 and 2003 (upstream and downstream).

The IBMR calculated after the floods (in April and November 2002), suggests that the biological quality of the water decreased at these times. This was not in fact the case, as several species of macrophytes were uprooted during the spates, which led to lower IBMR values. After flooding conditions of this kind, it is recommended not to use the IBMR. Therefore, in small Mediterranean rivers, hydrological disturbances of this kind should in fact be regarded as incompatible with the application of this index.

Conclusion

Based on the present analysis of the changes in composition and cover shown by the macrophytic

communities inhabiting a Mediterranean river, we have drawn up the first list of the aquatic and subaquatic species liable to colonize the small Mediterranean rivers in the South-East of France which are subject to natural and anthropic disturbances. Over 2-year study on the communities of macrophytes showed the occurrence of variations in terms of the biodiversity. The Biological Macrophyte Index for Rivers based on an accurate identification of the taxa proved to be a valid tool for the detection of pollution in the case of small Mediterranean rivers. A climatic event was found to have decisive effects: The heat wave and the drought in 2003 resulted in particularly low water levels during the summer and autumn of that year, which favoured the proliferation of macroalgae and phanerogams.

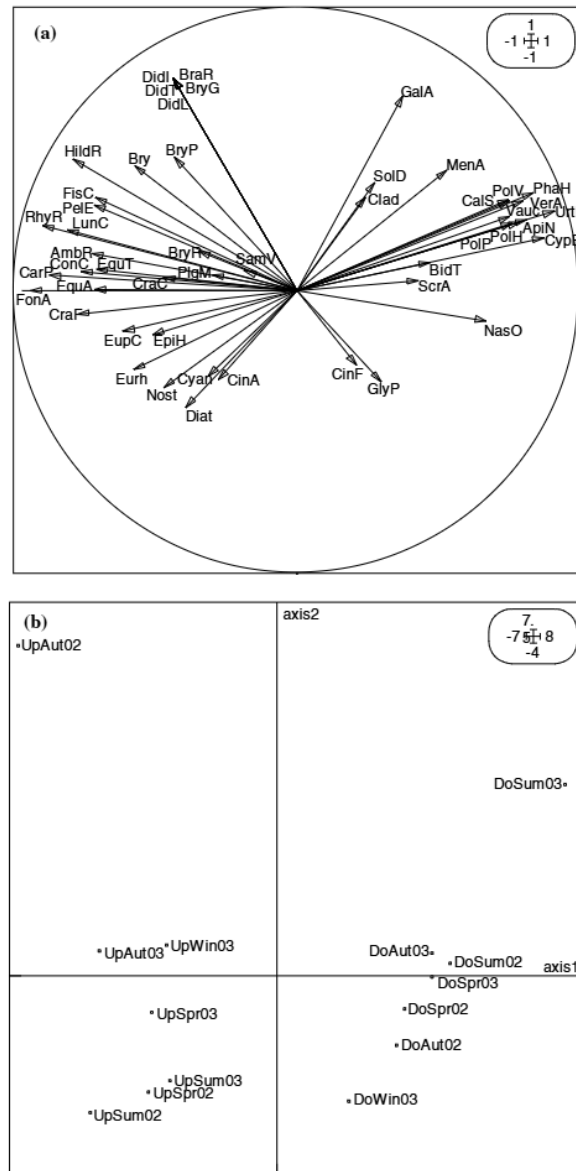


Figure 4. (a) Projection of the species points onto factorial planes I-II; AmbR = *Amblystegium riparium*, ApiN = *Apium nodiflorum*, BidT = *Bidens tripartita*, BraR = *Brachythecium rutabulum*, Bry = *Bryum* sp., BryG = *Bryum gemmiparum*, BryP = *Bryum pseudotriquetrum*, BryR = *Bryum radiculosum*, CalS = *Calystegia sepium*, CarP = *Carex pseudocyperus*, CinA = *Cinclidotus aquaticus*, CinF = *Cinclidotus fontinaloides*, Cla = *Cladophora* sp., ConC = *Conocephalum conicum*, Crac = *Cratoneuron commutatum*, CraF = *Cratoneuron filicinum*, Cyan = *Cyanobacteria*, CypE = *Cyperus eragrostis*, DidI = *Didymodon insulanus*, DidL = *Didymodon luridus*, DidT = *Didymodon tophaceus*, EpiH = *Epilobium hirsutum*, EquA = *Equisetum arvense*, EquT = *Equisetum telmateia*, EupC = *Eupatorium cannabinum*, Eurh = *Eurhynchium hians*, FisC = *Fissidens crassipes*, FonA = *Fontinalis antipyretica*, GalA = *Galium aparine*, GlyP = *Glyceria plicata*, HildR = *Hildenbrandia rivularis*, LunC = *Lunularia cruciata*, MenA = *Mentha aquatica*, NasO = *Nasturtium officinale*, Nost = *Nostoc* sp., PelE = *Pellia endiviifolia*, PhaH = *Phalaris arundinacea*, PlaM = *Plantago major*, PolH = *Polygonum hydropiper*, PolP = *Polygonum persicaria*, PolV = *Polypogon viridis*, RhyR = *Rhynchostegium riparoides*, SamV = *Samolus valerandi*, ScrA = *Scrophularia auriculata*, SolD = *Solanum dulcamara*, VauC = *Vaucheria* sp., VerA = *Veronica anagallis-aquatica*, UrtD = *Urtica dioica*. (b) Projection of the station points onto factorial planes I-II; Up = Upstream, Do = Downstream, Spr = Spring, Sum = Summer, Aut = Autumn, Win = Winter.

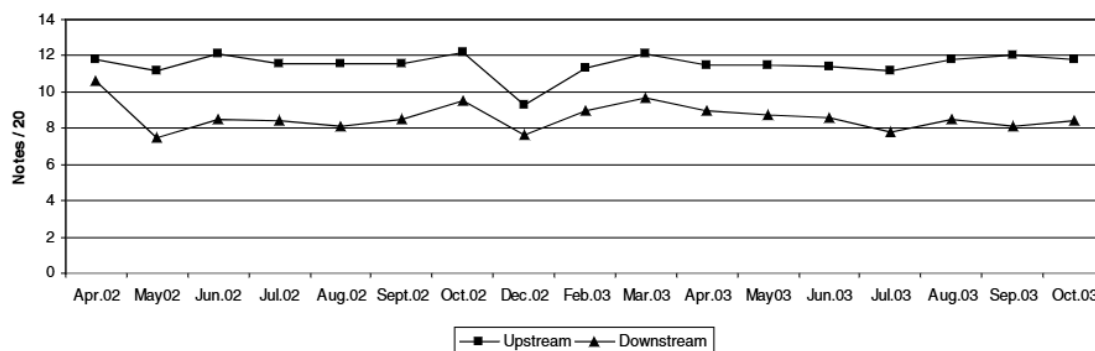


Figure 5. Variations in the IBMR at the two stations on the River Huveaune.

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