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Macrophytes as a tool for assessing the trophic status of a river: a case study of the upper Oum Er Rbia Basin (Morocco)

by

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Abstract

Macrophytes are one of the main components of the aquatic ecosystem. They are used in several countries as metrics for the ecological assessment of hydrosystems. The objective of our study was to evaluate the suitability of the Macrophyte Biological Index for Rivers (IBMR) to determine a trophic level in the upper Oum Er Rbia basin (Morocco) and to understand physicochemical parameters of water that govern the distribution of macrophyte species. CCA analysis was used to relate the distribution of macrophytes to hydrochemical parameters of water. The CCA analysis shows that the distribution of macrophytes was more correlated with abiotic parameters (EC, WT and DO) than nutrient parameters (PO_4-P, NO_3-N, NO_2-N, NH_3-N and COD_{Mn}). The recorded values of IBMR in the upper Oum Er Rbia basin indicate that the trophic level of the studied rivers ranged from "moderate" to "very high". Pearson's correlation coefficient showed that the IBMR is more correlated with the abiotic parameters such as WT and EC and does not show any significant correlation with the content of PO_4-P and NH_3-N in water, which makes the IBMR index unreliable for assessing the trophic status related to phosphate and ammonia concentrations in our lotic waters.

Key words: IBMR index, macrophyte, trophic state, upper Oum Er Rbia basin, ecological assessment

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1. Introduction

Aquatic macrophytes are a characteristic constituent of rivers and streams due to their multidimensional role in such lotic systems (Sukhodolova et al. 2017; Zhang et al. 2019). They are defined by their ability to increase the diversity of ecological niches and they provide a habitat structure for other taxonomic groups such as periphyton, macroinvertebrates, fish and birds (Altena et al. 2016; Celewicz-Goldyn & Kuczynska-Kippen 2017; Rodrigues et al. 2019; Roussel et al. 1998). Through the process of nutrient exchange between the sediment and the water column, macrophytes can affect flow velocity (O'Hare 2015; Old et al. 2014), water quality and the nature of substrate (Cotton et al. 2006; Madsen et al. 2001). The ability of macrophytes to grow, survive and reproduce under prevailing environmental stressors has increasingly made them the subject of research in various countries with the objective to develop multiple metrics to assess the ecological status of their hydrosystems. Several countries have developed their own macrophyte indices to assess the trophic state corresponding to trophic classes determined by the content of ammonium and orthophosphate in lotic waters (Carbiener et al. 1995): Mean Trophic Rank (MTR) in the United Kingdom (Dawson et al. 1999; Holmes et al. 1999), Trophic Index with Macrophytes (TIM) in Germany (Schneider & Melzer 2003) and Macrophyte Biological Index for Rivers (IBMR) in France (Haury et al. 2006). These indices are based on the hypothesis that the distribution of macrophytes in lotic waters depends mainly on phosphate and/or nitrogenous compounds. The Macrophyte Biological Index for Rivers (IBMR) is based on the study of macrophytes to determine the trophic status and organic pollution in French rivers, a method that has been used by several countries in the Mediterranean region such as Italy, Portugal, Spain, Greece and Slovenia (Szoszkiewicz et al. 2006). Despite Morocco's location in the Mediterranean region, only a few studies have been focused on assessing the ecological status of watercourses using macrophyte metrics (Bentaibi et al. 2017). The present study attempts to apply the IBMR method to assess the trophic status of the upper Oum Er Rbia basin (center of northern Morocco) in order to test its suitability in the Moroccan context and to investigate the structure of macrophyte communities and their relationships with river physicochemical parameters.

2. Materials and methods

2.1. Study area and sampling sites

The Oum Er Rbia watershed is a river basin of strategic importance to Morocco, which covers an area of 50 000 km^2. The basin supplies water to a strategic economic zone of Morocco, supports important economic activities and hosts a large part of the country's population as well as offers high

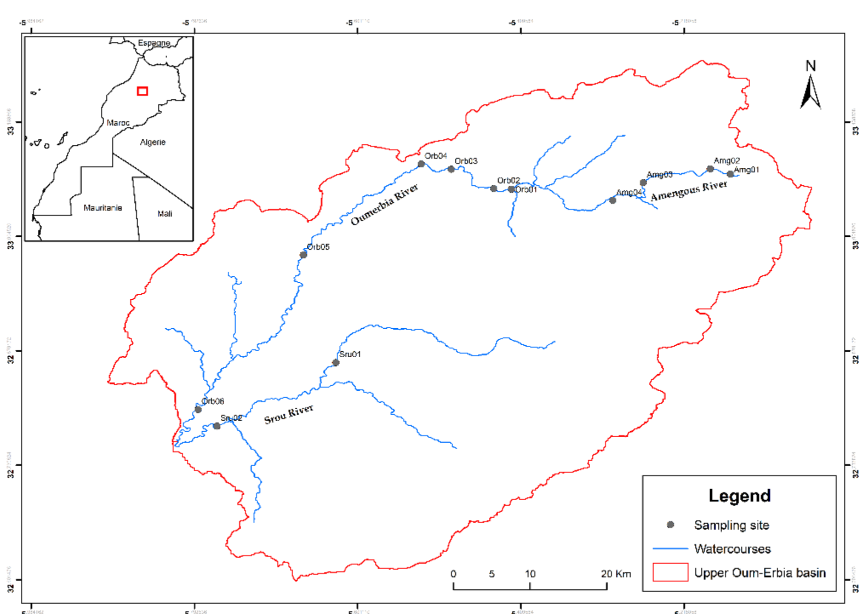

Figure 1

Location of surveyed sites

quality habitats for rare, threatened and endemic flora and fauna species. The basin currently faces various natural and technical constraints, mainly concerning the sustainability and availability of water in terms of its quantity and quality (ISKANE Ingeniérie, 2009). The upper Oum Er Rbia basin is part of the Oum Er Rbia watershed that originates in the Middle Atlas where a dozen springs contribute to its hydrological origin (Fig. 1). In the upper reaches of these sources, the river system consists of the Oued Fellat and its tributaries. The Oued Fellat consists of the Oued Amengous in the east and the Oued Senoual in the south. It receives the Oued Admer Izm and the Oued Ouiouane before joining the Oued Bou Idji at the sources of the Oum Er Rbia. It then takes the name Oum Er Rbia. Downstream from the city of Khénifra, it receives its first tributaries: the Oued Srou and the Oued Ouaoumana. A total of 12 representative sites were established in the study area. Only streams that meet the criteria of the Macrophyte Biological Index for Rivers (IBMR) standard have been selected: four sampling sites in the Amengous River (Amg01, Amg02, Amg03 and Amg04), six sampling sites in the Oum Er Rbia River (Orb01, Orb02, Orb03, Orb04, Orb05 and Orb06) and two sampling sites in the Srou River (Sru01 and Sru02).

2.2. Macrophyte surveys

Macrophytes that contribute to the calculation of the IBMR index were surveyed at each sampling site during five periods (July 2018, September 2018, November 2018, March 2019 and June 2019) in order to assess the presence and abundance of species during the growing season. Data on the peak growing season were used to calculate the IBMR index. Each site was surveyed along a distance of 100 m and the river banks were thoroughly inventoried. Submerged, floating, and emergent vascular plants, as well as filamentous algae and bryophytes contributing to the calculation of the IBMR index were taken into account. Macrophyte taxa were identified at the species level, except for some filamentous algae which were identified at the genus level. The identification was carried out according to Fennane (Fennane et al. 1999; 2007; 2014), Laplace-Treyture (Laplace-Treyture et al. 2014) and Coudreuse (Coudreuse et al. 2005).

2.3. Environmental factors

During the sampling period, the following abiotic water parameters were measured in situ at each survey site: water temperature (WT), pH (pH), dissolved oxygen (DO) and electrical conductivity (EC) using a portable multiparameter BANTI P900. Nitrite (NO_2-N), ammonia (NH_3-N) and phosphate (PO_4-P) were measured in situ by HANNA CHECKER mini-photometers HI707, HI715, and HI713, respectively. Nitrate (NO_3-N) was measured in the laboratory by the spectrophotometric method based on the reaction of nitrate with sodium salicylate in a sulfuric acid medium. Oxidizable organic matter (COD_{Mn}) was determined by the method based on the quantity of potassium permanganate ($KMnO_4$) required for the total oxidation of organic matter dissolved in water (Rodier 2009).

2.4. Data analysis

Canonical Correspondence Analysis (CCA) from CANOCO 5 was employed to study the relationships between macrophyte species and physicochemical parameters.

The IBMR calculations were performed on the basis of contributing aquatic taxa observed at the study sites. The IBMR index was expressed by a score ranging from 0 to 20, which assesses the degree of eutrophication related to the content of nitrogen and phosphorus in water. The IBMR standard is based on the floristic reference list including 208 taxa. Three coefficients were assigned to each of these taxa (CSi, Ei, Ki):

$$IBMR = \frac{\sum_i^n Ei \times Ki \times CSi}{\sum_i^n Ei \times Ki}$$

where i = contributing taxa, n = total number of contributing taxa, CSi = specific score reflecting the affinity of a macrophyte for trophic conditions, varying from 0 (dystrophic/hypereutrophic) to 20 (oligotrophic), Ei = stenoecy factor reflecting the degree of bioindication or ecological plasticity, varying from 1 (euryoecy) to 3 (stenoecy), Ki = abundance class that reflects the adaptation of each taxa to specific environmental conditions, varying from 1 to 5 (1: < 0.1%; 2: from 0.1 to < 1%; 3: 1 to < 10%; 4: 10 to < 50%; 5: > 50%).

According to the above-mentioned formula, the value of the index is based on the integration of the ecological importance of each species in the population, weighted by its development and bioindication capacity. The results of the index represent the trophic level of a watercourse (Table 1).

Pearson's correlation coefficient was calculated to explore the effect of physicochemical parameters on IBMR values for the study area.

Table 1

The IBMR ranges with the corresponding trophic status (AFNOR 2003)

IBMR	> 14	12 < X ≤ 14	10 < X ≤ 12	8 < X ≤ 10	≤ 8
trophic status	very low	low	moderate	high	very high

3. Results

3.1. Macrophyte composition

A total of 17 contributing taxa belonging to 15 families, forming different associations and communities, were identified at all sampling sites. Hydrophytes dominated, representing 70.6% (12 taxa) of the recorded species. Helophytes and hygrophytes together represented 23.5% (4 taxa) of all species. Bryophytes represented by one moss species accounted for about 5.9% (Table 2).

3.2. Physicochemical parameters

Water analysis carried out during the study period revealed physicochemical gradients along the surveyed watercourses, especially along the Amengous and Oum Er Rbia rivers where considerable fluctuations were recorded from the upper to lower river zones. The pH of water was alkaline at the sampling sites, ranging from 7.70 to 8.12. Electrical Conductivity (EC) was high in the Oum Er Rbia River and in the Srou River, reaching the maximum value at Orb06 (2339.33 µS cm^{-1}) and Sru02 (4100 µS cm^{-1}). High dissolved oxygen (DO) concentrations were generally measured upstream. Average values of the measured nutrient parameters in the Amengous River (PO_4-P = 415 µg l^{-1}; NH_3-N = 50 µg l^{-1}; NO_2-N = 96.77 µg l^{-1}; NO_3-N = 7.67mg l^{-1}) and the Srou River (PO_4-P = 355 µg l^{-1}; NH_3-N = 111.25 µg l^{-1}; NO_2-N = 134.06 µg l^{-1}; NO_3-N = 3.64 mg l^{-1}) were higher than those for the Oum Er Rbia River (PO_4-P = 275.83 µg l^{-1}; NH_3-N = 15.14 µg l^{-1}; NO_2-N = 115.3 µg l^{-1}; NO_3-N = 5.90 mg l^{-1}). Progressive increases in water temperature (WT) and oxidizable organic matter (COD_{Mn}) values were recorded as one traveled downstream (Table 3).

3.3. Relationships between water parameters and macrophytes

According to Canonical Correspondence Analysis (CCA) performed based on the full observation period, environmental parameters explained 68.2% of the observed species distribution. The eigenvalues were 0.576 and 0.274 for axis 1 and 2, respectively. The taxon-environment correlation of the two canonical axes was 0.870 and 0.791, respectively, which showed a

Table 2

List of macrophyte contributive species that were recorded in the upper Oum Erbia basin

Scientific Name	Family	Amg01	Amg02	Amg03	Amg04	Orb01	Orb02	Orb03	Orb04	Orb05	Orb06	Sru01	Sru02
Vascular plants													
Myriophyllum spicatum	Haloragaceae	x	x	x	x			x					
Ranunculus aquatilis	Ranunculaceae	x	x										
Groenlandia densa	Potamogetonaceae	x	x	x	x								
Potamogeton pectinatus	Potamogetonaceae						x	x		x	x		
Nasturtium officinale	Brassicaceae	x	x	x	x	x	x	x	x	x			
Zannichellia palustris	Zannichelliaceae	x	x		x	x	x	x	x	x			
Persicaria amphibia	Polygonaceae			x									
Typha angustifolia	Typhaceae											x	
Typha longifolia	Typhaceae											x	
Agrostis stolonifera	Poaceae			x									
Algae													
Cladophora sp.	Cladophoraceae		x	x	x		x	x	x	x	x	x	x
Spirogyra sp.	Zygnemataceae		x	x		x		x		x	x		x
Vaucheria sp.	Vaucheriaceae		x	x	x	x	x	x	x	x	x	x	x
Nostoc sp.	Nostocaceae					x		x					
Diatoma sp.	Tabellariaceae	x	x				x	x		x	x	x	x
Ulva sp.	Ulvaceae						x	x	x	x	x	x	x
Bryophytes													
Brachythecium rivulare	Brachytheciaceae					x	x	x					
Total number of species in each site		6	9	8	6	6	8	11	5	8	6	6	5

Table 3

Descriptive statistics of the physicochemical parameters of the surveyed sites in the upper Oum Erbia basin

		pH	WT (°C)	EC (µS cm^{-1})	DO (mgO_2 l^{-1})	COD (Mn) (mgO_2 l^{-1})	NH_3-N (µg l^{-1})	NO_2-N (µg l^{-1})	NO_3-N (mg l-1)	PO_4-P (µg l^{-1})
Amg01	Mean	8.12	12.50	283.50	10.53	3.68	105	74.02	5.98	330
	Range	6.3–9.98	7.1–17.9	259–308	8.53–12.53	0.32–7.04	60–150	72.38–75.67	3.63–8.32	130–530
	SD	0.75	7.64	34.65	2.82	4.75	63.64	2.33	3.31	282.84
Amg02	Mean	7.92	12.98	380.50	9.65	5.04	12.5	69.19	7.51	430
	Range	7.41–8.72	8.0–16.8	321–421	7.16–13.56	0.00–11.52	0.00–30	55.93–82.64	3.73–12.47	0.00–1460
	SD	0.60	3.65	44.25	2.74	4.86	15	13.56	3.80	696.32
Amg03	Mean	7.91	15.15	404.75	8.23	5.52	62.50	126.76	9.97	485
	Range	7.51–8.59	10.3–19.6	323–459	6.30–10.54	0.00–10.88	0.00–230	85.93–171	6.24–14.64	140–870
	SD	0.48	3.80	58.64	1.75	4.49	112.06	35.23	3.47	301.16
Amg04	Mean	7.86	17.30	772.75	7.95	6.00	20	117.12	7.23	415
	Range	7.47–8.24	10.3–23.0	516–1348	6.09–10.14	0.32–10.56	0.00–80	72.38–154.6	3.16–15.60	160–850
	SD	0.33	5.24	390.63	1.67	4.28	40	41.11	5.74	319.84
Orb01	Mean	7.70	14.98	1781.50	8.87	3.60	0.00	25.50	6.64	50
	Range	7.45–8.10	13.2–15.7	1587–1974	7.72–10.67	1.92–5.12	0.00	0.00–62.51	3.33–10.50	0.00–140
	SD	0.28	1.19	162.49	1.31	1.60	0.00	26.91	3.06	66.33
Orb02	Mean	7.78	15.23	1961.50	8.77	5.92	0.00	110.86	5.88	280
	Range	7.46–8.22	12.8–16.4	1646–2308	8.0–10.32	0.96–9.60	0.00	52.64–175.7	3.31–10.02	170–510
	SD	0.32	1.65	292.73	1,07	4,23	0.00	53.50	2.99	157.06
Orb03	Mean	7.89	16.45	2188.25	8.52	6.40	32.50	124.09	6.33	162.50
	Range	7.40–8.58	13.4–19.2	1695–2597	6.71–10.83	0.96–11.52	0.00–70	39.48–239.5	4.95–8.96	60–290
	SD	0.51	2.44	371.51	1.71	4.47	37.75	84.65	1.85	96.40
Orb04	Mean	7.88	17.58	2225.25	7.46	7.60	10	156.72	4.49	395
	Range	7.68–8.26	13.5–22.2	1687–2651	6.75–8.81	1.92–10.88	0.00–40	123.03–198.6	3.85–4.97	40–630
	SD	0.26	3.70	400.76	0.92	4.16	20	31.65	0.51	264.90
Orb05	Mean	7.80	18.13	2286.67	7.56	6.82	3.33	161.63	4.56	280
	Range	7.58–8.15	13.2–21.1	1989–2763	6.50–9.02	3.20–10.24	0.00–10	129.6–178.9	4.24–4.73	20–640
	SD	0.30	4.30	416.79	1.31	3.52	5.77	27.76	0.27	321.87
Orb06	Mean	7.9	19.97	2339.33	7.21	6.29	45	113	7.55	487.50
	Range	7.77 – 8.12	12.4 – 24.4	1829 –2959	6.50 –7.98	1.92–10.88	10–90	19.74–175.7	2.36–11.23	150 –1100
	SD	0.19	6.59	572.88	0.74	4.48	34.16	72.37	4.62	419.07
Sru01	Mean	7.89	19.03	1695.67	7.39	6.93	22.50	54.28	2.39	190
	Range	7.61–8.44	10.6–23.8	695–2708	6.68–8.33	4.16–11.52	0.00–50	0.00–82.25	1.89–2.92	20–490
	SD	0.48	7.32	1006.55	0.85	4.00	20.62	37.07	0.51	223.16
Sru02	Mean	8.11	22.97	4100.00	7.77	10.35	200	213.85	4.90	520
	Range	7.71–8.63	12.3–29.2	2340–6504	6.30–9.98	5.12–13.76	160–270	62.51–417.8	0.18–9.17	350–860
	SD	0.47	9.28	2090.28	1.95	4.59	60.83	183.41	4.50	294.45

strong relationship between macrophyte communities and hydrochemical variables. The cumulative percent variance of macrophyte species data for axis 1 and 2 was 14.4% and 21.3%, respectively. The Monte Carlo test was performed with 499 unrestricted permutations and showed that the additional contribution of the environmental factors is highly statistically significant (p = 0.002). The CCA ordination (Fig. 2) revealed that three major groups of parameters have the strongest relationship with the structure of macrophyte species. The first group comprises electrical conductivity (EC), water temperature (WT) and nitrite (NO_2-N), which affect five communities representing submerged macrophytes dominated by algae. The second group comprises phosphate (PO_4-P) and ammonia (NH_3-N), which affect the distribution of two communities of macrophytes in the study area. Dissolved oxygen (DO) is the third group and is most strongly correlated with four communities of macrophytes.

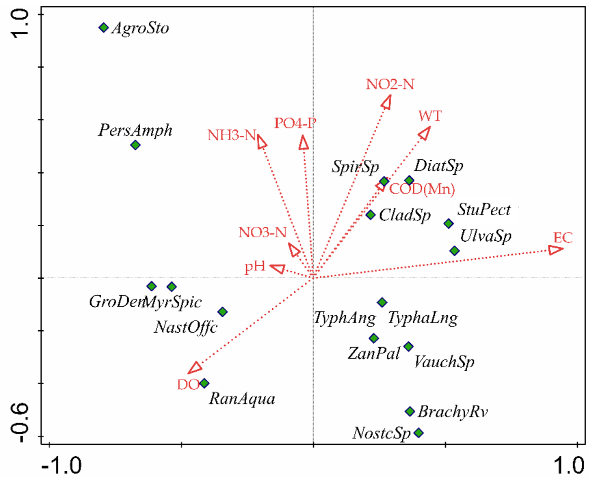

Figure 2

Canonical correspondence analysis (CCA) diagram showing the correlation between Macrophytes distribution and physicochemical parameters. *AgroSto – Agrostis stolonifera*, *PersAmph – Persicaria amphibia*, *GroDen – Groenlandia densa*, *MyrSpic – Myriophyllum spicatum*, *NastOffc – Nasturtium officinale*, *RanAqua – Ranunculus aquatilis*, *SpirSp – Spirogyra* sp., *DiatSp – Diatoma* sp., *CladSp – Cladophora* sp., *UlvaSp – Ulva* sp., *StuPect –Stuckenia pectinata*, *TyphAng – Typha angustifolia*, *TyphLng – Typha latifolia*, *ZanPal – Zannichelia palustris*, *NostcSp – Nostoc* sp., *VauchSp – Vaucheria* sp., *BrachyRv – Brachythecium rivulare*

Table 4

Pearson's correlation coefficients between IBMR values and physico-chemical parameters of water (n = 36)

	IBMR	
	r	*p*
NO_2-N	−0.696*	0.012
PO_4-P	−0.230	0.472
NO_3-N	0.696*	0.012
WT	−0.844**	0.001
DO	0.694*	0.012
pH	0.372	0.234
EC	−0.806**	0.002
COD_{Mn}	−0.854**	0.000
NH_3-N	−0.330	0.295

3.4. Ecological assessment using the Macrophyte Biological Index for Rivers (IBMR)

In order to test the reliability and applicability of the IBMR index as a tool to assess the ecological status of our study area, we calculated the IBMR index for all sampling sites (Fig. 3). The results obtained indicate that the trophic level of the Amengous River ranged from "High" to "Very High", whereas the Oum Er Rbia River shows a trophic level ranging from "Moderate" to "Very High". Subsequently the correlation between the IBMR and the physicochemical parameters was tested using Pearson's coefficient (Table 4). Pearson's coefficient shows that all parameters, except for phosphate (PO_4-P) and ammonia (NH_3-N), are significantly correlated with the IBMR value.

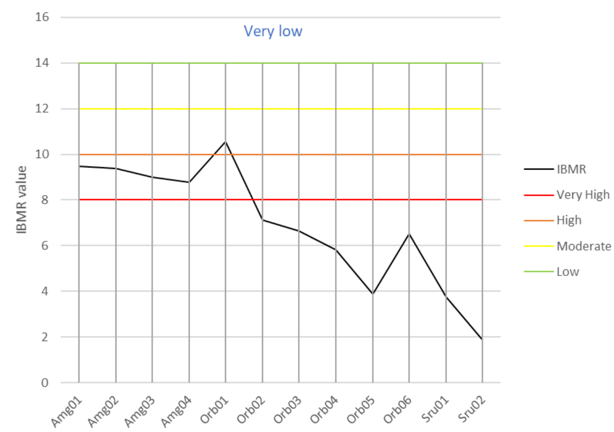

Figure 3

Graph showing the IBMR values for each site and the trophic level thresholds

4. Discussion

Physicochemical data from the water analysis show that all rivers were oxygenated throughout the study period, which mainly reflects a high metabolism of aquatic vegetation in an open hydrosystem (Hauer & Lamberti 2017). The Amengous River and the Srou River were characterized by high nutrient levels. The downstream sites of the Oum Er Rbia River were exposed to an increase in nutrient levels. Nonetheless, these values remain high, permitting the rivers to be classified into trophic levels, varying from mesotrophic to eutrophic (Environmental Protection Agency 2000; Haury & Peltre 1993; Nisbet & Verneaux 1970; O'Hare et al. 2018). These results are confirmed by the presence of species characteristic of high trophic levels such as *Myriophyllum spicatum, Zannichellia palustris* and *Groenlandia densa* (Fabris et al. 2009; Robachl et al. 1996; White & Hammond 2008), which together form a plant community in the Amengous River. Furthermore, the presence and sometimes abundance of ubiquitous Chlorophyceae, such as *Cladophora* sp. and especially *Vaucheria* sp., indicate a high trophic level and high content of ammonium and phosphate (Thiébaut & Muller, 1999). The high values of electrical conductivity (EC) in the Oum Er Rbia River and the Srou River are mainly due to various saline springs that feed these watercourses. The pH is alkaline, which is typical for eutrophic waters (López-Archilla et al. 2004). The temperature is a determining factor for the development of these algae species (*Vaucheria* sp., *Cladophora* sp. and *Spirogyra* sp.), which tend to grow in a range of 15–28°C (Pikosz & Messyasz 2016; Sheath & Cole 1992). In addition to temperature, various saline springs feeding the Oum Er Rbia River increase water mineralization and favor the growth of *Ulva* sp. The marly-limestone nature of the Oum Er Rbia riverbed and the increase in the trophic level at the downstream sites favor the development of some species (e.g. *Zannichellia palustris* and *Stuckenia pectinata*) that are characteristic of eutrophic marly-limestone environments (Haury et al. 1998). At Sru01 (downstream), the substrate is enriched with nutritive matter and the water flow is reduced, favoring the occurrence of two helophyte species (*Typha latifolia* and *Typha angustifolia*), which accumulate nutrients in their tissues and ensure the elimination of organic pollutants (Westlake et al. 2009). This explains the positive correlation between these helophytes and NO_2-N and COD_{Mn}. The negative correlation between some species and NH_3-N may be due to the alkaline reaction of water, which makes NH_3-N a plant growth inhibitor (Kohler 1976; Litav & Lehrer 1978; Wang et al. 2008; Zhu et al. 2018). The amount of dissolved oxygen in the water results from the balance between the dissolved oxygen supply associated with the photosynthesis activity and the surface exchange with oxygen in the air as well as the oxygen consumption necessary for respiration, biochemical and chemical reactions to degrade organic matter. The high concentration of dissolved oxygen (DO) recorded in the Amengous River can be explained by metabolic activities (photosynthesis) of the higher biomass of aquatic plants in this river (Barbe 1984; Sukhodolova et al. 2017). Our survey showed that some species were more likely to be present at high concentrations of nutrients (e.g. *Persicaria amphibia*), whereas some species characteristic of eutrophic environments (e.g. *Myriophyllum spicatum*, *Groenlandia densa*, *Zannichellia palustris*) were more closely correlated with nutrients in water. This can be explained by the effect of other factors such as water temperature, flow velocity and mineralization of water, which prevent nutrient assimilation from water and promote nutrient uptake from the sediment by macrophyte root systems (Baldy et al. 2007; Onaindia et al. 2009).

The obtained IBMR values indicate that the Oum Er Rbia River and its tributaries have a very high, high and moderate trophic state, which confirms the results discussed above concerning the physicochemical parameters and the distribution of macrophytes. Our correlation analysis shows that the IBMR index depends not only on the nutrient parameters but also on other abiotic parameters such as water temperature (WT), electrical conductivity (EC), which explain the distribution of macrophytes more effectively than nitrate (NO_3-N) and nitrite (NO_2-N) in the upper Oum Er Rbia basin. Our results support other studies carried out in several countries (Demars et al. 2012; Kargioglu et al. 2012; Manera et al. 2014; Özbay et al. 2019). The results also showed a positive correlation between the IBMR values and nitrate (NO_3-N). This may be due to the nitrification activity controlled by environmental factors such as dissolved oxygen. Sometimes, under environmental pressure, macrophyte species prefer different forms of nitrogen in water (Hauer & Lamberti 2017), which may partly explain the apparent correlation between the IBMR value and nitrogen compounds. We note that phosphate (PO_4-P) and ammonia (NH_3-N) have no significant relationship with the IBMR value, which raises a serious question about the reliability of the IBMR index for the detection of pollution related to phosphate (PO_4-P) and ammonia (NH_3-N) concentrations in the studied rivers. It appears, however, that non-nutrient parameters in the upper Oum Er Rbia basin may play an important role in determining the distribution of macrophytes even in rivers that are exposed to eutrophication and have relatively high concentrations of nutrients, which may cause the IBMR to be a misleading index in some cases.

5. Conclusion

This study is the first in the upper Oum Er Rbia basin employing a macrophyte metric such as the Macrophyte Biological Index for Rivers (IBMR) to assess the trophic state of rivers. Our results provide new data on the physicochemical parameters controlling the distribution of macrophytes in the Moroccan river system, as well as on the role played by macrophytes as a sensitive indicator of eutrophication of watercourses. Even though the IBMR index showed encouraging results regarding the trophic state of the studied rivers, the correlation between this macrophyte metric and each hydrochemical parameter showed that the IBMR is more related to abiotic parameters than nutrients. These results allow us to pose a serious question concerning the suitability and reliability of the IBMR for the assessment of pollution related to phosphate and ammonium concentrations in our hydrosystems. Finally, it is necessary to develop an indication method for Moroccan rivers, which would take into consideration all species characteristic of our watercourses and which would include different environmental factors that characterize our rivers.

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