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PERFORMANCE OF MACROINVERTEBRATES-BASED BIOTIC INDICES FOR ASSESSING WATER QUALITY IN MARTIL RIVER BASIN, NORTHERN MOROCCO

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Abstract

To explore the spatiotemporal variation of benthic communities and assess their response to anthropogenic pressures and climatic variability, a seasonal biomonitoring of benthic macroinvertebrates in the Martil Basin was carried out. Macroinvertebrates were sampled seasonally at 19 sites from autumn 2015 to spring 2018, and the performance of the Iberian Biological Monitoring Working Party (IBMWP), the Standardized Global Biological Index (IBGN), the Average Score Per Taxon (ASPT), and the Family Biotic Index (FBI) indices were assessed. The results showed a clear decline in taxa richness from the upper to the lower river sections. The overall water quality of the Martil River Basin ranged from moderate to poor, but the different indices produced various classification outcomes. The IBMWP index showed highest correlation with taxonomic richness being the most appropriate for assessing the water quality. Notwithstanding, we suggest that biotic indices should be included as an essential tool for assessing the water quality in Moroccan streams, for maintaining the ecological integrity.

Keywords: biotic indices, Martil Basin, Mediterranean ecosystems, Morocco, water quality

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1. Introduction

Freshwater has always been a key factor for agricultural, industrial and domestic development (Arifi et al., 2018). Most water bodies have been subjected to increasing pollution loads, greatly affecting their water quality and ecosystem health status, causing physicochemical and flow-regime alteration and habitat loss. These physicochemical and hydromorphological changes are major drivers of the distribution of aquatic fauna in surface waters and especially in countries that are undergoing significant anthropogenic development (Hepp et al., 2013; Prommi and Payakka, 2015).

Understanding the interactions between anthropogenic threats, habitat and ecological response, including in particular the structure of benthic communities in Mediterranean areas, is a major challenge for the conservation of freshwaters and their biota (Bonada and Resh, 2013; Bruno et al., 2014; Cooper et al., 2013). It has also been well documented that Mediterranean rivers are subject to temporal climatic variability, alternating between wet and, often extreme, dry periods, which means that greater fluctuations in water quality, water availability and aquatic biodiversity can be expected (Aktaş, 2014; Bêche and Resh, 2007; Munné and Prat, 2011).

Water quality monitoring refers to the acquisition of quantitative and qualitative information using an integrated approach for evaluating the physical, chemical and biological characters of water in relation to human activities, ecological conditions and designated water uses (Norris and Thoms, 1999). Currently, numerous biotic indices have been

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developed, based on aquatic taxa, to evaluating water quality and classify the ecological status of water bodies (Aazami et al., 2015). A range of aquatic organisms have been selected as bioindicators of water quality and ecological integrity. Among them, macroinvertebrates have been recognized as suitable indicators of the overall ecosystem health (Nguyen et al., 2017). Macroinvertebrates are the middle link of the food chain in streams playing a central role in energy flow and material cycling (Li et al., 2015). They represent an extremely diverse group of aquatic animals, with several advantages as bio-indicators and a wide range of responses to multiple natural and human-induced stressors such as organic pollutants, sediments, and toxicants, reflecting stream conditions over a long time period (Cairns and Pratt, 1993; Mophin-Kani and Murugesan, 2014). Apart from responding to human stressors, the structure and composition of benthic communities vary temporally with the seasons and spatially in different parts of the Basin (Alvarez-Cabria et al., 2010).

Macroinvertebrates based biotic indices have been developed based on the degree of ecological sensitivity of each taxon (Armitage et al., 1983; Mophin-Kani and Murugesan, 2014; Nguyen et al., 2017), by combining numerical expressions of macroinvertebrate diversity and qualitative data on their ecological sensitivity with respect to different disturbance situations (Czerniawska-kusza, 2005). A great variety of macroinvertebrates-based biotic indices has been developed to assess levels of pollution and other human influences in Mediterranean streams (Prommi and Payakka, 2015; Sedeño-Díaz and Kohlmnan, 2012), such as the Average Score Per Taxon (ASPT) (Armitage et al., 1983), the Family Biotic Index (FBI) (Hilsenhoff, 1988), the Ephemeroptera, Plecoptera and Trichoptera (EPT) (Lenat, 1988), the Iberian Biological Monitoring Working Party (IBMWP) (Alba-Tercedor et al., 2002), the Standardized Global Biological Index (IBGN) (AFNOR, 2004).

The purpose of this study was: (1) to assess water quality variation at selected sites in the Martil River Basin, using macroinvertebrates-based biotic indices (IBMWP, IBGN, ASPT, FBI; (2) to analyse the composition and the distribution of macroinvertebrate assemblages at the family level of the river's upper, middle and lower sections and (3) to compare the response of each of the four biotic indices to the Martil Basin's stress gradients, for determining the most suitable index for the particular hydrological and climatic conditions of Morocco. Considering that the water quality monitoring programmes in the country are mainly based on physicochemical measurements, our study is a crucial step towards upgrading to integrated physicochemical-biological monitoring schemes, advancing towards the sustainable management of the water and biological resources in Morocco.

2. Material and methods

2.1. Study area

The Martil River Basin is located at the northwestern part of Morocco (latitudes between 35°10' and 35°45'N; longitudes between 5°17' and 5°38'W). It is part of the Tangier-Tetouan-Al Hoceima Region (Karrouchi et al., 2016) (Fig. 1). This Basin belongs to the Rifain domain, surrounded to the North by the chains overlooking the Strait of Gibraltar, to the West by the Gharb plains, to the South by the Atlas Mountains and to the East by the Mediterranean Sea.

The Martil River Basin occupies an area of 1259 km^2, with altitudes ranging from 0 m to 1782 m (average altitude 424 m) (Karrouchi et al., 2016).

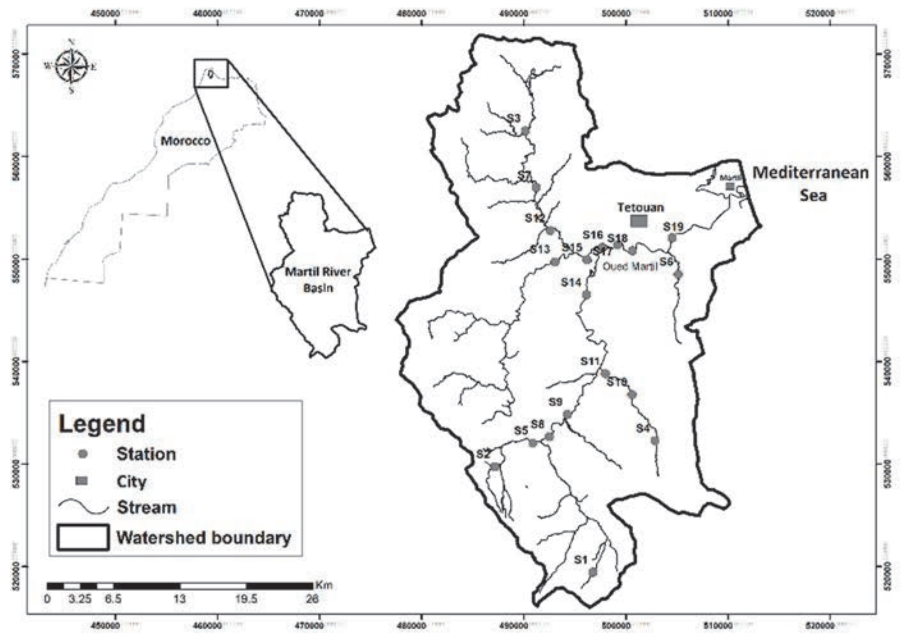

Fig. 1. Study area; the Martil River Basin, Morocco, and the location of the 19 sampling sites

The climate of the study area is mainly Mediterranean with an oceanic influence, characterized by two different seasons with cold winters and hot summers (Karrouk, 1990). The average annual precipitation varies between 500 and 750 mm/year (El Ouadini et al., 1996).

The basin's highlands are occupied by relatively dense forest cover. The middle parts of the basin are generally occupied by limited agricultural land (Oualad Mansour et al., 2009), and the lowlands are characterized by high population density and industrial activities with a proliferation of quarries and industrial units of tanneries, brickworks, cement units, and marble factories resulting in the release of large quantities of pollutants into the rivers without any prior treatment (MEMEE, 2013).

2.2. Macroinvertebrates sampling and identification

Seasonal monitoring was carried out at nineteen sampling sites throughout in ten seasons between Autumn 2015 and Spring 2018, except for the Autumn 2016, when there was a severe period of drought that caused most streams to dry up. Macroinvertebrates were sampled at each site using two sampling techniques, Surber net (20 × 20 cm) for rocky substrate and standard hand net (25 x 25 cm) used by kicking and sweeping from all available microhabitats that are representative of the site. The duration of each sampling (from 30 to 60 min) is determined depending on the available microhabitats (riffles, pools, runs, vegetated and edges) and sample takes an average of 10-15 minutes per microhabitat type to get sufficient samples representative of the site. Organisms were afterwards collected, separated from debris and finally placed in a plastic box containing 95% alcohol. Back in the laboratory, individuals were sorted and identified to the family level under a binocular microscope with relevant identification keys (Sansoni, 1992; Tachet et al., 2002), subsequently conserved in 70% alcohol to produce a full list of taxa present.

2.3. Biotic indices

Four biotic indices were selected to compare their performance in the Martil River Basin (Table 1). The assessment of biological water quality in this study was based on the following indices:

IBMWP (Iberian Biomonitoring Working Party) (Alba-Tercedor et al., 2002): The IBMWP index is used to evaluate the water quality, based on macroinvertebrates sensitivity to pollution. For the application of this index. IBMWP is calculated by attributing a score from 1 to 10 based on each taxon's tolerance to pollution (Armitage et al., 1983; O'Callaghan and Kelly-quinn, 2013; Poquet et al., 2009). The scores of all taxa are then summed and the final IBMWP score is categorized into one of five water quality classes (Alba-Tercedor et al., 2002; Poquet et al., 2015).

IBGN (Standardized Global Biological Index) (AFNOR, 2004): The IBGN index ranges from 0 to 20, within a five-class system. The index's macroinvertebrate list contains 152 taxa, 38 of which belong to 9 indicator groups. The IBGN is then calculated from a double input analysis table, depending on both the number of taxa and the indicator groups (AFNOR, 2004; Benzena and Bachir, 2018; Guilpart et al., 2012).

ASPT (The average score per taxon) (Armitage et al., 1983): The ASPT index is calculated by dividing the IBMWP value by the number of families present in the sample. The ASPT score ranges from 0 to 10; high scores indicate of a clean site containing large numbers of high scoring taxa, while low scores correspond to small numbers of taxa indicating the existence of pollution (Armitage et al. 1983; Arslan et al., 2016; Mandaville, 2002).

FBI (Family Biotic Index) (Hilsenhoff, 1988): The FBI index is calculated by multiplying tolerance values of indicator families by their abundances, summing the results and dividing them by the total number of macroinvertebrate individuals in the sample (Mandaville, 2002; O'Callaghan and Kelly-quinn, 2013). The tolerance values increase as water quality decreases, ranging from 0 to 10 based on their sensitivity to pollution (Hilsenhoff, 1988; Ojija et al., 2017).

2.4. Statistical analysis

Kolmogorov-Smirnov test was applied to determine whether or not each biotic index calculated over the 19 sites at all sampling seasons follow a normal distribution. Since normality was not achieved for all indices, the Spearman's Rank correlation was applied to measure the degree of association among the various biotic indices.

Table 1. Scores and categories of biotic indices used for the classification of samples in the Martil River Basin.

IBMWP		*IBGN*		*ASPT*		*FBI*	
Score	***Category***	***Score***	***Category***	***Score***	***Category***	***Score***	***Category***
> 101	Good	17-20	Very good	> 6	Clean water	0.00-3.75	Excellent
61-100	Moderate	13-16	Good	5-6	Doubtful quality	3.76-4.25	Very good
36-60	Poor	9-12	Moderate	4-5	Probable moderate pollution	4.26-5.00	Good
16-35	Bad	5-8	Poor	< 4	Probable severe pollution	5.01-5.75	Fair
< 16	Very bad	> 4	Bad			5.76-6.50	Fairly poor
						6.51-7.25	Poor
						7.26-10	Very poor

Simple linear regression was applied to explore the relationship between taxonomic richness and the indices selected. Correlation and regression analysis were conducted using the IBM SPSS v21 software.

3. Results and discussion

3.1. Macroinvertebrate assemblages

In total, more than 29 513 macroinvertebrate individuals were sorted and identified across all nineteen sites distributed among 13 orders (Rhynchobdellida, Gastropoda, Veneroida, Amphipoda, Isopoda, Branchiopoda, Ephemeroptera, Plecoptera, Odonata, Hemiptera, Coleoptera, Trichoptera, Diptera) and 79 families which belong to three phylums (Annelida, Mollusca, and Arthropoda). Arthropoda were found to be the most dominant group, containing the majority of families (89%), followed by Mollusca (10%) and Annelida (1%).

The most predominant orders were Diptera (16 families), followed by Coleoptera (13 families), Trichoptera (10 families) and Hemiptera (10 families). Plecoptera, and Odonata were represented by 7 families for each one of them, Ephemeroptera (6 families) while Gasteropoda contains 5 families. Amphipoda, Branchiopoda, Isopoda, Rhynchobdellida, and Veneroida show few taxa consisting of one family for each one (Fig. 2).

With respect to seasonal variations of the total sampled sites from Martil Basin, our results show that the taxa richness recorded a maximum of 51 families in Spring 2017 and a minimum of 37 families in winter 2018. In terms of abundance, the greatest number of taxa was recorded during spring 2018 (4550 individuals), whereas Autumn 2015 registered the lowest number of taxa (2149 individuals).

The maximum and minimum numbers of families were collected at site S1 (35 families) in Spring 2017 and at site S18 (1 family) in winter 2018, with an average of 21 and 5 families per season respectively. Sites S4, S10, S12, S13, S14, S15, S16, S18 and S19 had the lowest number of families with (0 taxa) during floods or droughts.

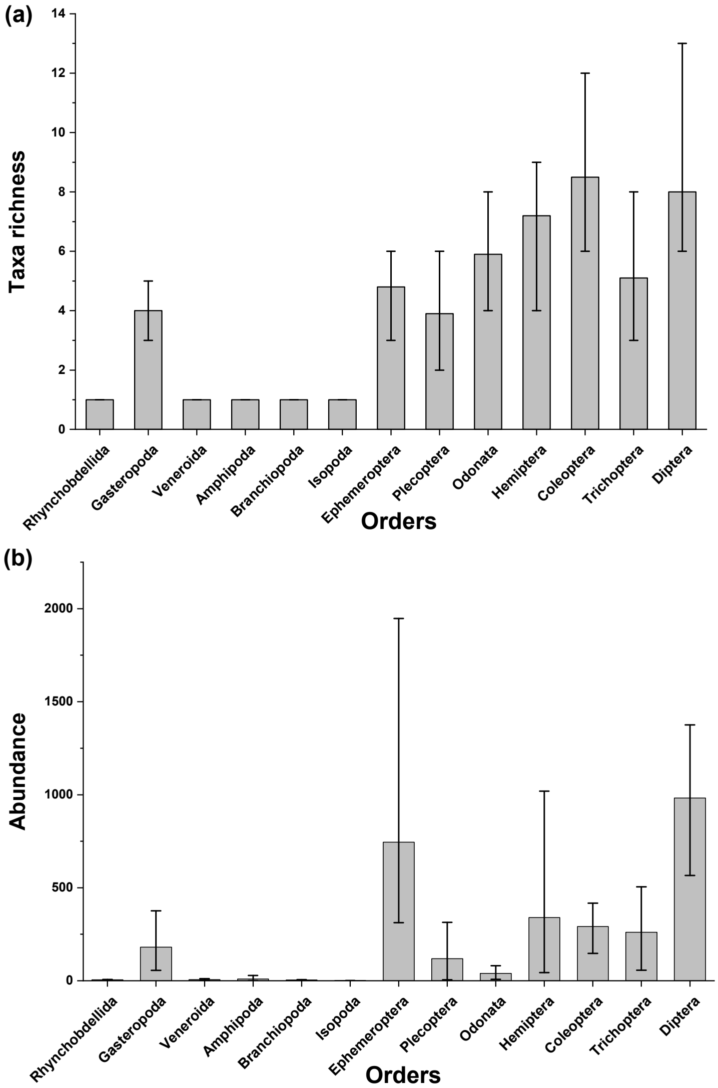

Fig. 2. Seasonal variation of taxa richness (a) and abundance (b) of macroinvertebrates taxonomic groups during our study period at Martil Basin

Simuliidae was the most abundant family, accounting for 22% of the total of individuals sampled, followed by Baetidae and Chironomidae, (22% and 10%, respectively). Baetidae, Caenidae, Chironomidae, Corixidae, Notonectidae, Physidae, and Simuliidae were the most frequently occurring families among the 19 sampling sites.

The deterioration of river water quality in northern Morocco is caused by a multitude of natural and human-induced stressors. Those of natural origin are associated to the hydro-climatic conditions of the region, including environmental variability within a Mediterranean climate, which determines a specific regime of the river systems, which is characterized by steep slopes, and short and abrupt watercourses, inducing fluvial dynamics controlled by sequential and seasonal flooding and drought events over an annual cycle.

The strong seasonality and hydrological conditions, especially in intermittent Mediterranean streams where riffles dry up, play a major role in the control of available habitats transforming stream fragments into a series of pools in the river bed, imposing large changes in community structure of the benthic fauna (Bonada et al., 2006; Gasith and Resh, 1999; Obolewski et al., 2016; Robson et al., 2012). Those of anthropogenic origin are caused by domestic, industrial and agricultural effluents affecting the water quality.

As a result, benthic assemblages are constantly changing in the presence of these disturbances expressing their ecological responses through a reorganization of their benthic communities. Within our study period, taxonomic richness peaked in Spring and decreased during summer, Autumn and winter. In this context, the number of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa showed substantial seasonal variation, while Chironomidae showed moderate seasonal stability (Chi et al., 2017; Maloney and Feminella, 2006). Moreover. the results of Bonada et al. (2006) suggested that the changes in community structure with loss of EPT richness, relative to Odonata, Coleoptera, and Heteroptera (OCH) richness is explained by the loss of longitudinal connectivity when riffles become dry and the streams are limited into a series of pools which represent a refuge for some tolerant lentic taxa (OCH) but not for the majority of sensitive lotic taxa (EPT) in Mediterranean hydrosystems.

3.2. Comparison of the performance of biotic indices

The seasonal variation of the IBMWP index showed significant fluctuation among the sites studied (Fig. 3). This index showed highest values in Spring with the maximum score (189) observed at site S1. Based on the IBMWP index, 7% of samples in the Martil River Basin were classified as good, 26% were classified as moderate, 33% were classified as poor and 10% had bad quality status. The IBMWP index indicates a strong quality decrease from the upstream to the downstream of the Basin.

As regards the values of IBGN (Fig. 4), this index showed highest values in Spring 2017 with the maximum score (17) observed at site S1. Based on the IBGN index, only 1% of samples were classified as very good quality, 4% were classified as good, 23% were classified as moderate, and, 44% were classified as poor and 28% had bad quality status.

The ASPT index showed highest values in winter 2016 with the maximum score (6.33) observed at site S15. Based on the ASPT index, 2% of samples in the Martil River Basin were classified as clean water quality, 21% were classified as doubtful quality, 41% were classified as probable moderate pollution and 36% had a probable severe pollution quality (Fig. 5).

FBI index showed highest values in summer 2017 with the maximum score (0.125) observed at S17. Based on this index, 57% of samples were classified as very good, 15% were classified as good, 15% were classified as fair, 10% was classified as fairly poor, 2% were classified as fairly poor and 1% had very poor quality status (Fig. 6).

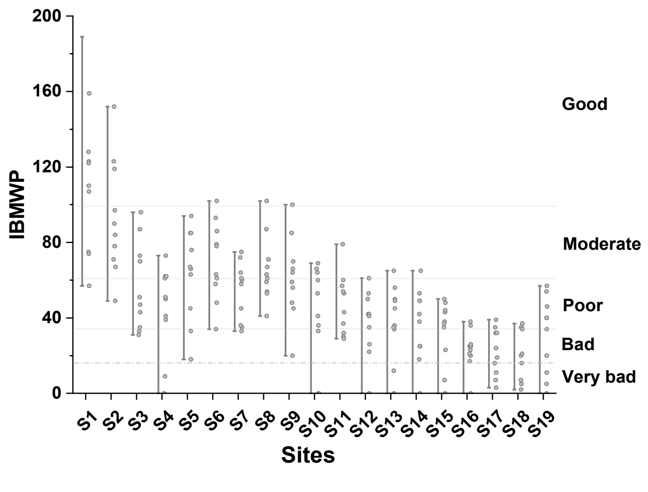

Fig. 3. Scatterplot showing the seasonal variation of the IBMWP index at each of the 19 sites sampled in the Martil River Basin. The vertical line indicates the rating scale of the index

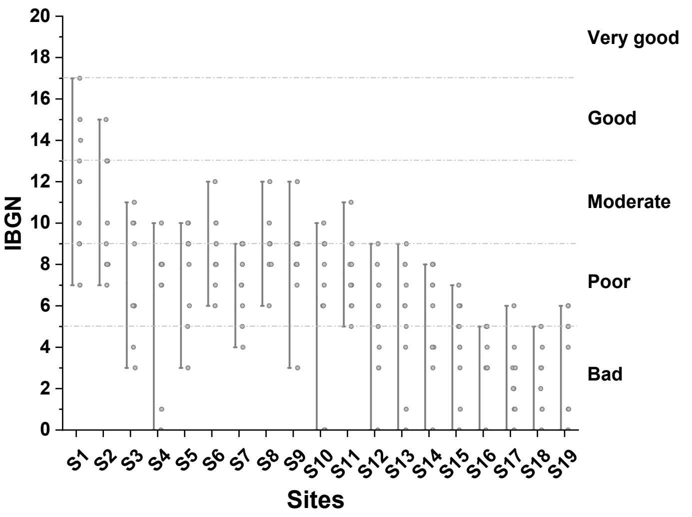

Fig. 4. Scatterplot showing the seasonal variation of the IBGN index at each of the 19 sites sampled in the Martil River Basin. The vertical line indicates the rating scale of the index

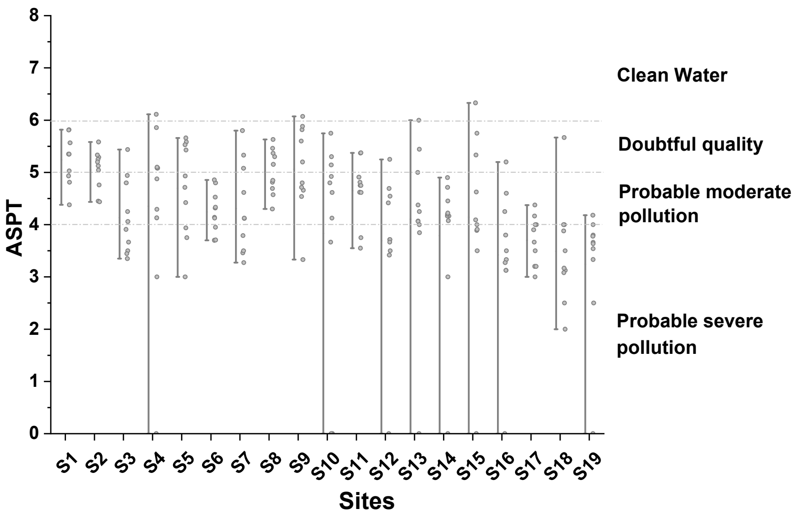

Fig. 5. Scatterplot showing the seasonal variation of the ASPT index at each of the 19 sites sampled in the Martil River Basin. The vertical line indicates the rating scale of the index

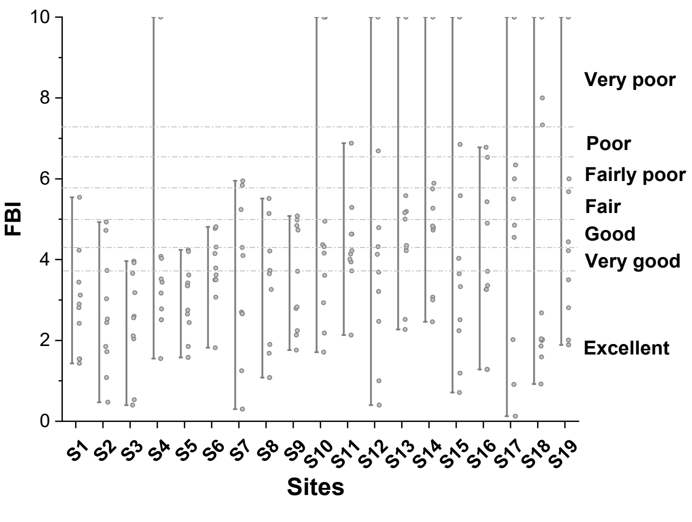

Fig. 6. Scatterplot showing the seasonal variation of the FBI index at each of the 19 sites sampled in the Martil River Basin. The vertical line indicates the rating scale of the index

The results showed significant variation in the mean scores of the four indices (IBMWP: 50.20; IBGN: 6.48), and a tendency to classify the status of the Martil River Basin as poor, while the ASPT suggests ‘probable moderate pollution’ (score 6.84). The FBI index was an exception to this, as it indicated ‘very good’ quality (score 3.84), and showed high values also at the lower section of the watershed even though they are influenced by high levels of pollution.

Statistically significant and strong correlations were observed between IBMWP and IBGN (r = 0.957, p =0.01), IBMWP and ASPT (r = 0.676, p =0.01) and between ASPT and IBGN (r = 0.676, p =0.01). Negative significant and strong correlations were observed between FBI and IBMWP (r = -0.281, p =0.01), FBI and IBGN (r = -0.659, p =0.01) and between FBI and ASPT (r = -0.55, p =0.05) (Table 2).

Moreover, Spearman’s correlations revealed a weaker relationship between FBI and the other indices, this is in agreement with studies that used benthic assemblage as indicators to estimate the ecological state of the Mediterranean rivers (Kalyoncu and Zeybek, 2010; Yorulmaz et al., 2015).

To assess the performance of each index, a linear regression analysis was applied to relate the number of taxa found over all the sampling period in our study area and biotic indices (Fig. 7). A highly significant and strong correlation exists between the taxonomic richness and the IBMWP index (r^2 = 0.92) and the IBGN index (r^2 = 0.85) by presenting good linear regressions. In contrast, the ASPT and FBI weakly correlated with taxonomic richness and showed a relatively low correlation (r^2=0.28; r^2=0.223), respectively.

Table 2. Spearman’s correlation among the four biotic indices calculated for the samples of the Martil River Basin.

	IBMWP	***IBGN***	***FBI***	***ASPT***
IBMWP	1			
IBGN	0.957**	1		
FBI	-0.281**	-0.659**	1	
ASPT	0.676**	0.676**	-0.055	1

*** The correlation is significant at level 0.01 (bilatéral)*

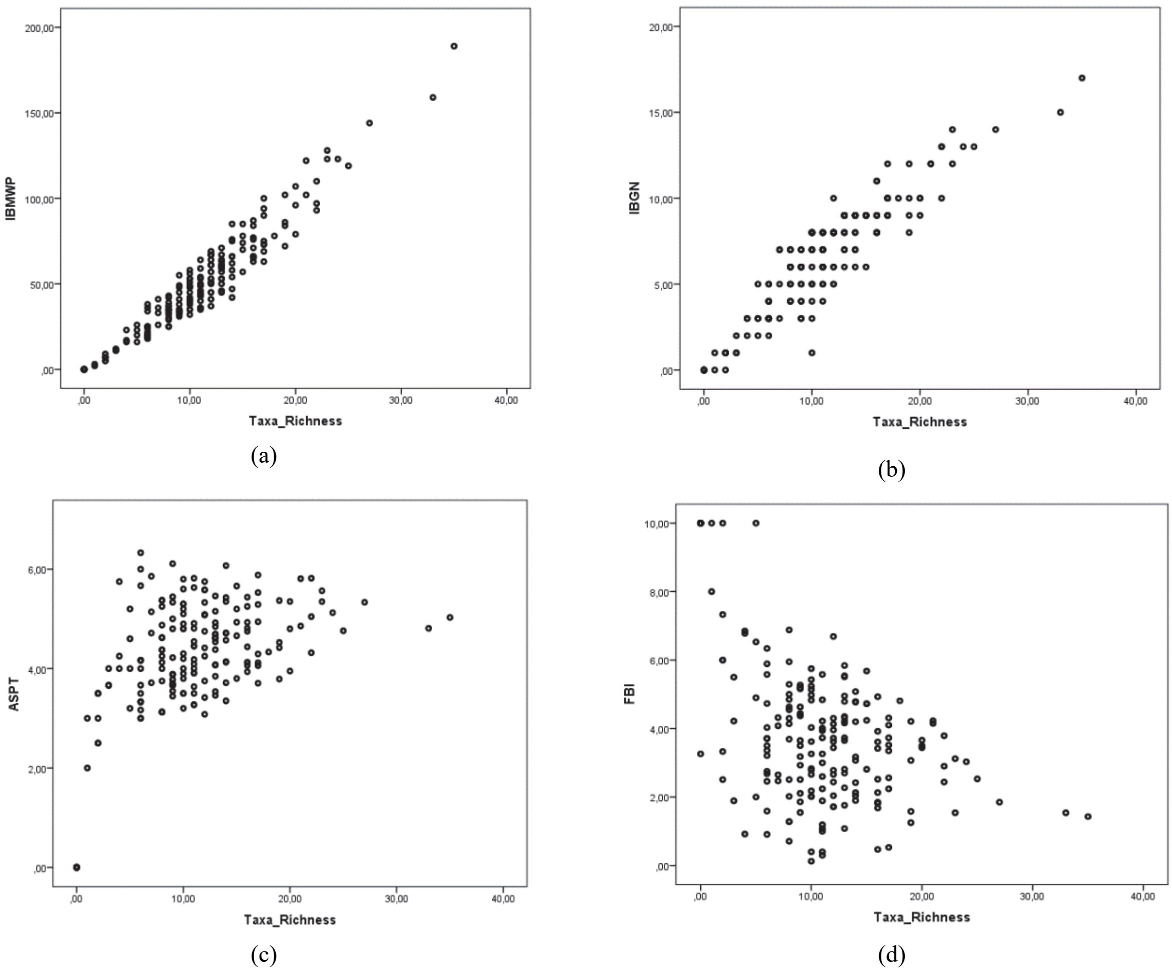

Fig. 7. Linear regression between the (a) IBMWP, (b) IBGN, (c) ASPT and (d) FBI as a function of taxa richness from the nineteen sampling sites in Martil Basin during the study period

It is worth noting that the indices had various seasonal patterns. The IBMWP and IBGN indices which are based on taxa richness had similar variation across seasons in the sites of the Martil River Basin over the study period, in accordance with the results obtained from Younes-Baraillé et al. (2005), Hamzaoui and Arab (2012) and Abbou and Fahde (2017) in other Mediterranean streams.

Nevertheless, it is important to highlight that IBGN was the most rigorous index, due to the influence of the pollution-sensitive EPT taxa, which represent the majority of families included as indicator groups in the IBGN index. The IBMWP was higher during dry periods since it assigns scores to the majority of macroinvertebrates families according to their sensitivity to pollution, being more stable when climate conditions change, especially with the increase of the proportions of Diptera, Coleoptera and Hemiptera, the abundance of which increases in Mediterranean streams during dry periods. The gradual changes occurs from macroinvertebrates typical of lotic habitats to those that seems to prefer lentic habitats (such as isolated pools), in which taxa with high dispersal gradient that move easily along hydrological connections (e.g., Heteroptera and Colepotera), are more frequent. (Bonada et al., 2006; Gasith and Resh, 1999; Hershkovitz and Gasith, 2013; Robson et al., 2012).

ASPT, which does not account for taxonomic richness, had varying performance among seasons. Since it is based on the abundance of taxonomic groups. The FBI index was the least sensitive to pollution, classifying the water quality in the Martin River Basin as excellent or very good quality as demonstrated in other studies in Mediterranean streams (Fagrouch et al., 2011; Gonçalves and de Menezes, 2016; Rada and Puljas, 2010; Sànchez-Montoya et al., 2010).

Finally, the strong correlation of IBMWP with taxa richness suggests that this index is the most suitable in assessing the water quality of Moroccan streams, especially that the biotic metrics based on the composition and taxa richness data is often taken as a valid tool to improve water quality rather than those based on abundance metrics which are less effective due to the strong variation of hydrologic factors in Mediterannean streams (Pinto et al., 2004; Sànchez-Montoya et al., 2010).

As highlighted by previous studies from various regions of the globe (Solimini et al., 2000), taxa richness show a significant fluctuation according to altitudinal gradient. However, the upstream areas of the Martil River Basin have a well-developed structure, with pollution sensitive families of macroinvertebrates, and higher taxonomic richness related to the integrity of the aquatic ecosystem. Mean values of biotic indices were obtained in the mean courses of the Basin reflecting a decline in taxonomic diversity due to the impacts of agricultural activities.

A significant decrease in taxonomic richness and the scores of biotic indices in the lower course of the Oued Martil, which reflects extensive pollution generated by various human activities, mainly those that are carried out along the river, and thereby affecting the entire ecological integrity of the downstream section.

4. Conclusions

From this current study, water quality is strongly influenced by anthropogenic pressures and hydro-climatic conditions. The analysis of the macroinvertebrates communities revealed that the further downstream we move, the more pollution-sensitive taxa decline or even disappear. In fact, Baetidae, Chironomidae, and Simuliidae were the largest faunal group dominating the study area which exhibited some spatiotemporal stability.

Based on the combined results of biotic indices, water quality is classified from "moderate" to "poor" quality in Martil Basin. In comparing indices sensitivity to natural and anthropogenic pressures, we found that IBMWP seems to be more suitable than other indices and better at reflecting the actual condition in northwestern Moroccan aquatic ecosystems since it is the most suitable with changes macroinvertebrate assemblages. Thus, the upper part of this river system appears to have good water quality, while the lower part has been classified as bad quality.

The performed comparative Spearman's correlation and regression analysis to assess the responses of indices to variations in water quality allows us to conclude that IBMWP reflected a positive response to the variations in taxa richness and habitat conditions and showed a good relationship with IBGN and ASPT and different performance from the FBI which was inadequate to define the water quality of Martil Basin.

However, there is a need for more intensive study on aquatic assemblages in Moroccan Basins to fully comprehend the biological and ecological traits of macroinvertebrates in order to establish a Moroccan Biotic Index or the adaptation of IBMWP according to local macroinvertebrates, the morphologic, climatic and ecological characteristics of Moroccan streams.

Different approaches used in these indices require integration throughout the Mediterranean Basin since the combined application of those biotic indices in monitoring programmes will create consistent classifications and develop the environmental management and the ecological integrity of hydrosystems.

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