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Research Article

Longitudinal distribution of macroinvertebrate in a very wet North African Basin: Oued Melloulou (Morocco)

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Abstract – Melloulou River, which is located in Middle Atlas of Morocco, is a good example of a very wet and poorly known basin, and therefore of special conservation concern. The aim of this study was to draw up an initial inventory of the benthic macroinvertebrates taxa, and to analyze its longitudinal distribution in the basin, particularly searching for the main abiotic factors addressing its zonation for improving future management and conservation actions. The study allowed identifying 161 taxa belonging to 127 genera and 80 families, most new records for northeast Morocco. The biotypology, which was studied by using Foucart' Factorial Correspondence Analysis (FCA), Partial Triadic analysis (PTA), and IndVal showed a longitudinal distribution of macroinvertebrates mainly governed by altitude, slope and current velocity. The studied biota revealed the presence of three assemblages and an important number of ubiquitous species not included in any group. The first group is located in the upper courses of Melloulou River representing a community proper of a crenon-rhithron zone; the second occurs in the middle and lower courses, and clearly reflects the community of a large potamon; the third one is a mixture of taxa capable to colonize the entire study area. Our finding, highlight the singular aquatic biodiversity occurring in the Melloulou River and its extraordinary changing water dynamic over time, which are key factors for future monitoring, as well as managing and conservation actions.

Keywords: Pluvio-nival basins / biodiversity hotspot / longitudinal zonation / Partial Triadic Analysis / Foucart' factorial correspondence analysis / macroinvertebrates assemblages

1 Introduction

Rapid population declines and extinctions of species following the widespread destruction of natural habitats have been reported around the world (Brook *et al.*, 2003). This, currently known as "biodiversity crisis", is one of the main problems facing humanity (Koh *et al.*, 2004), and especially important in freshwater ecosystems, considered worldwide highly threatened (Sala *et al.*, 2000), and particularly those from semiarid zones (Gutiérrez-Cánovas *et al.*, 2019).

The Maghrebian territory, located in the western and arid part of the Mediterranean Basin, a recognized biodiversity hotspot (Myers *et al.*, 2000), harbors a great variety of freshwater ecosystems, many of them mineralized and with a temporary pattern (Dakki and Menioui, 2016; Gutiérrez-Cánovas *et al.*, 2019). However, it is also possible to find some rare rivers of pluvio-nival origin, confined to small areas at high altitude. In these isolated ecosystems, and in a global change framework, the pressure of desertification processes (Morocco is essentially an arid country, with 45 to 55% of its area occupied by desert), as well as the overexploitation of the water resource (Mokhtari *et al.*, 2014) is overall much higher. Thereby, detecting aquatic biodiversity composition and the ecological factors addressing the main patterns and processes of such fragile lotic community is of crucial concern and a decisive step for the management and conservation purposes.

Frequently, high altitude zones in the Mediterranean region represent a good example of these kinds of basins. Compared to the surrounding areas, the heavy rainfall gives these wet massifs the form of "water tower" from both hydrogeological and the hydrographic perspectives, and the main water supply for median and low reaches. The scientific and socio-economic interests of the included aquatic ecosystems are no longer

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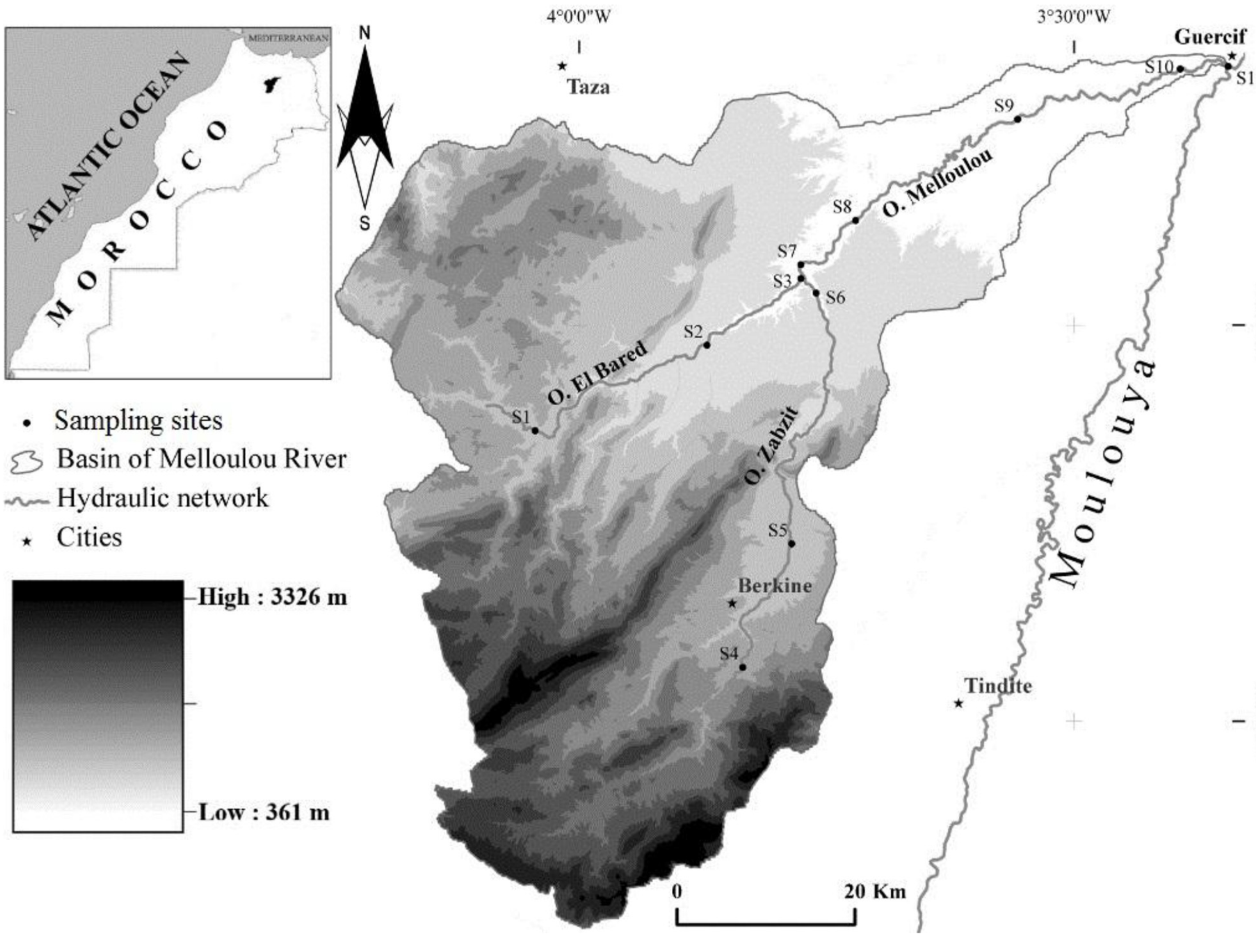

Fig. 1. Location of the Melloulou River basin and sampling sites selected for this study.

demonstrated as an area with rich and varied natural resources, which generally support the presence of an interesting aquatic biodiversity (Chillasse *et al.*, 2001; Guareschi *et al.*, 2012). However, these very confined and inaccessible basins are often unknown, particularly their macroinvetebrate community.

Macroinvertebrates play a key role in freshwater ecosystems and they reflect specific features of the basins where they live, consequently, their study is decisive for the knowledge of natural conditions and the functions of river systems (Bruno *et al.*, 2014). Several studies have provided deep knowledge regarding the structure and function of the aquatic macroinvertebrates in Mediterranean areas (*e.g.*, Moreno *et al.*, 1997; Morais *et al.*, 2004; Millán *et al.*, 2006; Bonada *et al.*, 2008; Mellado Díaz *et al.*, 2008; Bonada and Resh, 2013; Gutiérrez-Cánovas *et al.*, 2019). In North Africa, since mid-80s, different hydrobiological works concerning the structure of some benthic communities in the most emblematic rivers were published (*e.g.*, Dakki, 1987; Bouzidi and Guidicelli 1994; Boumaiza and Thomas, 1995; Lounaci *et al.*, 2000; Berrahou *et al.*, 2001; Arab *et al.*, 2004). Nevertheless, pluvio-nival basins remained unknown in Maghreb despite of their great ecological and conservation concerns. Furthermore, no works up to our knowledge focused on the complete macroinvertebrate species community.

The aim of this research is to identify the species composition of aquatic macroinvertebrates of the Melloulou River basin and to identify the main drivers determining their distribution and assemblage patterns in this very dynamic fluvial system. The knowledge of the macroinvertebrate community and its distributional pattern in this singular basin, as a model of the rare and isolated Mediterranean wet basins, will provide to managers and researchers crucial information to improve the exploitation of resources in parallel with conservation purposes. Furthermore, we want to discover the real contribution of this area to the global aquatic biodiversity of North Morocco and the Maghreb, as a hotspot of highly endemic species typical of wet environments.

2 Material and methods

2.1 Study area

The Melloulou River (Fig. 1) is located in the Eastern Middle Atlas. It extends for an area of 2476 km^2. It is the most important tributary of the Moulouya River, one of the largest basins in Morocco and the largest Maghrebian river flowing in the Mediterranean Sea. It is a very orographically intricate sub-basin that receives precipitation as snow in winter; the latter can stay until early summer in surrounding mountains (López Lara *et al.*, 2007). The climate of this basin varies from Mediterranean humid and sub-humid forests at high areas in the west and south, to semi-arid and arid Mediterranean sparse shrublands further northeast in the Guercif plain, where the rainfall rarely exceeds 185 mm and temperatures frequently reaches 47 °C, at the confluence with the Moulouya River (see more details in Mabrouki *et al.*, 2017a). Additionally, the Melloulou River basin has two main tributaries: Oued Zabzit and Oued El Bared; the latter was listed in the '*Master Plan of Protected Areas of Morocco'* as a *'Site of Biological and Ecological Interest'* (AEFCS, 1996).

2.2 Macroinvertebrate data

Aquatic macroinvertebrates were bimonthly and sampled during three campaigns, between March and August 2014, on 11 pristine localities (Fig. 1) selected by their natural environmental conditions following a previous study on the physicochemistry of Melloulou River (Mabrouki *et al.*, 2017a).

In each locality, macroinvertebrates were collected using a Surber sampler (surface of 20 × 25 cm and 0.4 mm mesh net), and eight samples were taken covering the whole micro-habitats heterogeneity represented within each locality (mainly determined by the type of substrate, macrophyte cover and flow velocity). Complementary, aerial adults (required to identify most taxa to species level) were directly captured in the immediate riparian zone with the help of an entomological hand net and a Japanese umbrella.

2.3 Mesological descriptors

In addition to the macroinvertebrate sampling, a physico-chemical (tree measures per sampling site) and environmental characterization was taken at each sampling locality (altitude, slope, thermal amplitude of the atmosphere, water temperature, distance to the spring, flow velocity, bioclimatic zones and Emberger quotient). There is a general consensus among researchers concerning the importance of these variables to understand macroinvertebrate distribution in semiarid Mediterranean river basins (*e.g.*, Dakki, 1987; El Agbani *et al.*, 1992; Bouzidi and Guidicelli, 1994; Millán *et al.*, 2006; Zouggaghe and Moali, 2009; Belmar *et al.*, 2012; Taybi, 2016; Mabrouki *et al.*, 2019a; Gutiérrez-Cánovas *et al.*, 2019).

Longitude, latitude and altitude were also measured directly on the field using an "Altimeter PRO" GPS. The bioclimatic floors of Emberger quotient was developed by us from the map established at the scientific institute of Rabat by Brignon and Sauvage (1962). The Emberger quotient, the thermal amplitude (Mm), and the slope were calculated from 1/50000 map. Kilometers at the source were measured directly by ARCGIS software, version 10.2. The average slope, thermal amplitude, bioclimatic stages and current velocity were transformed into modalities (see Table S1).

2.4 Statistical methods

Each campaign provided two cross tables, one for macroinvertebrates and sampling sites and the other for abiotic factors and sampling sites (Tables S1 and S2). The aim of this procedure is to identify a spatial species-samples typology pattern as well as its variability through the different campaigns. The analysis of such tables raises some problems that conventional multivariate analysis (FCA, PCA, MCA) do not address satisfactorily, so we used multi-tables statistical analyses more adapted to these problems and previously used by several researchers called (Thioulouse and Chessel, 1987; Blanc *et al.*, 1998).

Thus, for the multidimensional data, we opted for the Partial Triadic Analysis (PTA), which works with a PCA logic and the FCA of Foucart. The purpose was to find a spatial structure (typology) common to all campaigns and to study the temporal stability around this average structure. For this, it relies first on the search for an average of tables called "compromise" that we analyze, then for the reproducibility of the compromise by each of the initial tables (Blanc *et al.*, 1998). By choosing an FCA strategy on the same dataset, it is explicitly stated that we want to make a typology of the macroinvertebrate response curves at the longitudinal gradient (study of the compromise) and that we also look for a temporal evolution of this typology (study of the reproducibility of the compromise). In our case, we have limited to the study of the average spatial typology of benthic invertebrates.

We also used Foucart' FCA analysis, based on a logic of FCA, which allows approaching three-dimensional data type: species–sampling sites–campaigns. It lets demonstrating the effectiveness of this method as an objective way to organize sampling sites according to the similarities between their stands and to appreciate how species react to environmental factors (Blanc and Beaudou, 1998; Blanc, 2000; Taybi, 2016; Mabrouki *et al.*, 2019a).

To avoid a biased structural analysis, only specimens identified to the species rank were kept, and within them, those with very low occurrences (minimum frequency in all sampling sites and per campaign = 3) were not considered. Thus, 111 taxa were retained for further analysis (see Table S1).

In order to homogenize the variances and minimize the non-normality effects, all macroinvertebrate abundance data were undergone a log transformation ($\log(x+1)$). We started with an overall analysis of the data set consisting of 33 surveys (11 sampling sites × 3 campaigns)/111 species (see Tables S1 and S2).

To link the sampling sites according to faunistic similarities and to identify the environmental variables driving the spatial distribution of the benthic fauna, a *mesological typology* was established using the 13 parameters (Table S1) formerly mentioned.

To answer the question of a possible relationship between environmental factors and the population of benthic invertebrates during the three campaigns; we used a Coinertia analysis. The Coinertia analysis is especially recommended when the environmental variables are qualitative (Dolédec and Chessel, 1987).

The study of the fauna–environment relationship thus involves the coupling of the global faunal table with the table of environmental variables. The study of fauna-environment relationship involves thus the coupling of the global faunal table (11 sampling sites × 3 campaigns = 33 surveys × 111 species) with the table of environmental variables (33 surveys × 13 variables).

The relevance of the Coinertia analysis is verified by a Monte-Carlo permutation test (Manly, 1991) on 1000 random permutations (Fig. 2). The observed value (Rv = 0.78) corresponds to the correlation coefficient between the two wildlife and environment tables. This value (with a p-value = 0.001) is higher than the values obtained by random draws (randomization), which indicates that the two structures (environment and benthic settlements) are significantly linked: there is indeed a co-structure. A search for a global mesological structure of the environment from these abiotic descriptors is therefore justified. Additionally, the sites were classified according to their environmental characteristics by hierarchical grouping using the Bray-Curtis dissimilarity method (Clark and Warwick, 2001).

The Indicator Value analysis (IndVal, Dufrêne and Legendre, 1997) was carried out to identify indicator species for each. This analysis consists in calculating the indicator value of the species and testing its significance by a permutation test, in this case the Monte Carlo test. This test makes possible to check whether the preference of a species for a previously found assemblage group is clearly greater than that suggested by a random distribution (Dufrêne and Legendre, 1997).

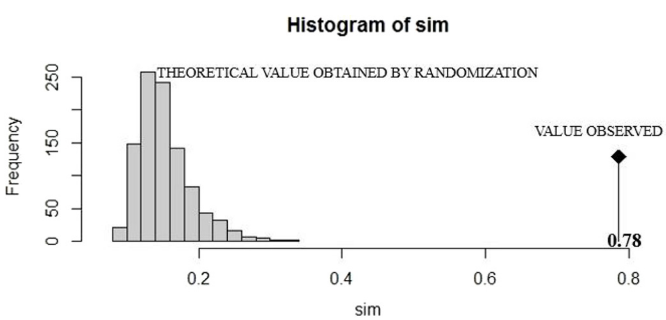

Fig. 2. Coinertia permutation test from faunistic and environmental tables of Melloulou River basin.

3 Results

This study allowed the identification of 161 species listed in 127 genera and 80 families (see Table S2). Almost all identified taxa are new to the Melloulou River basin and 53 are also new to the Moulouya River basin and/or Oriental Morocco. Furthermore, 37species are endemic in the broadest sense, i.e., only present in Morocco, Magreb and/or Ibero-African territories.

3.1 Mesological structure

The compromise of the PTA of Melloulou River (Fig. 3) shows that there is a stable average structure between the three campaigns. The F1 axis, with 65.3% of the total information, expresses an upstream-down gradient, mainly explained by elevation and other parameters highly correlated with it (distance to the source, thermal amplitude). Sampling sites of high-altitude, with low thermal amplitudes (S1, S2, S3 and S4) were grouped on the negative side of the F1 axis, while the low-altitude sampling sites, with much higher thermal

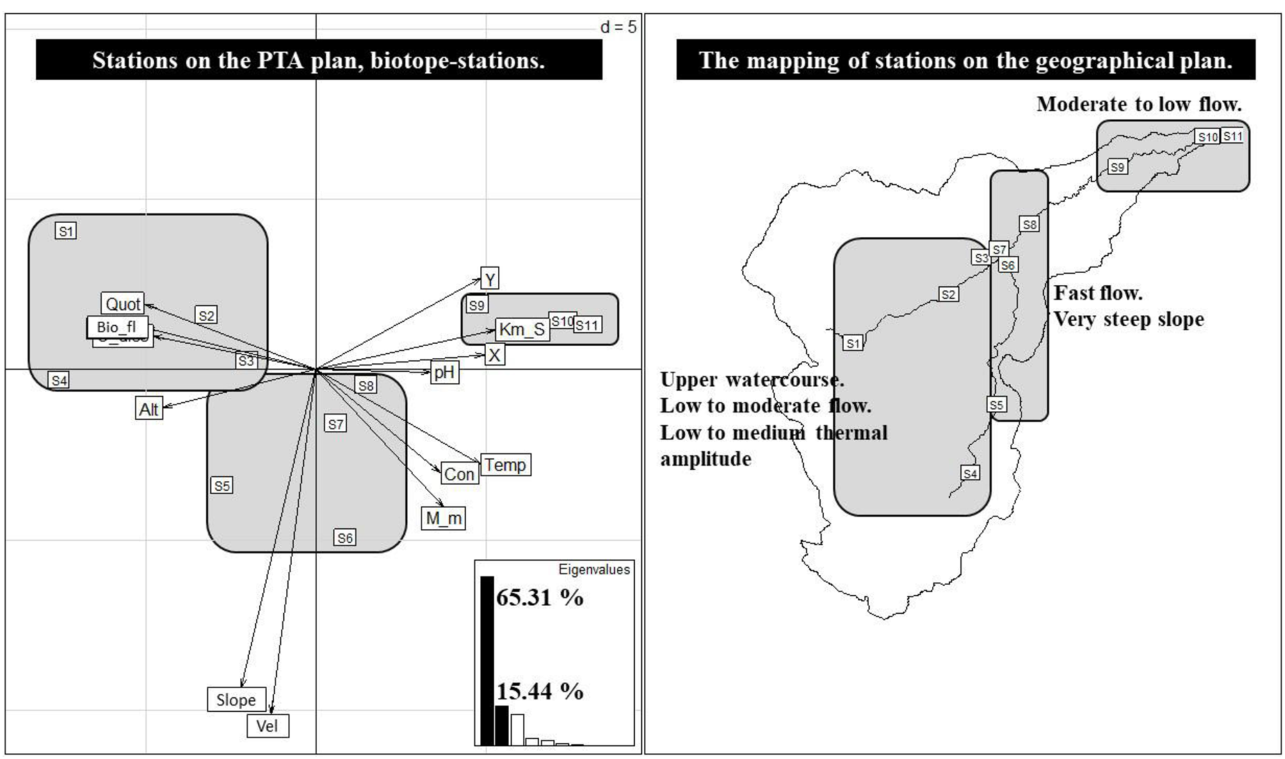

Fig. 3. Typological synthesis test of the Melloulou River basin using the explanatory mesological variables of the first two factorial axes of the Partial Triadic Analysis. (Alt: altitude; Slope: the mean slope; Vel: current velocity; Bio-fl: bioclimatic floors; Y: latitude; X: longitude; DO: dissolved oxygen; Con: conductivity; pH: hydrogen potential; Temp: temperature; Km_S: kilometers at the source; M-m: thermal amplitude; Quot: the Emberger quotient).

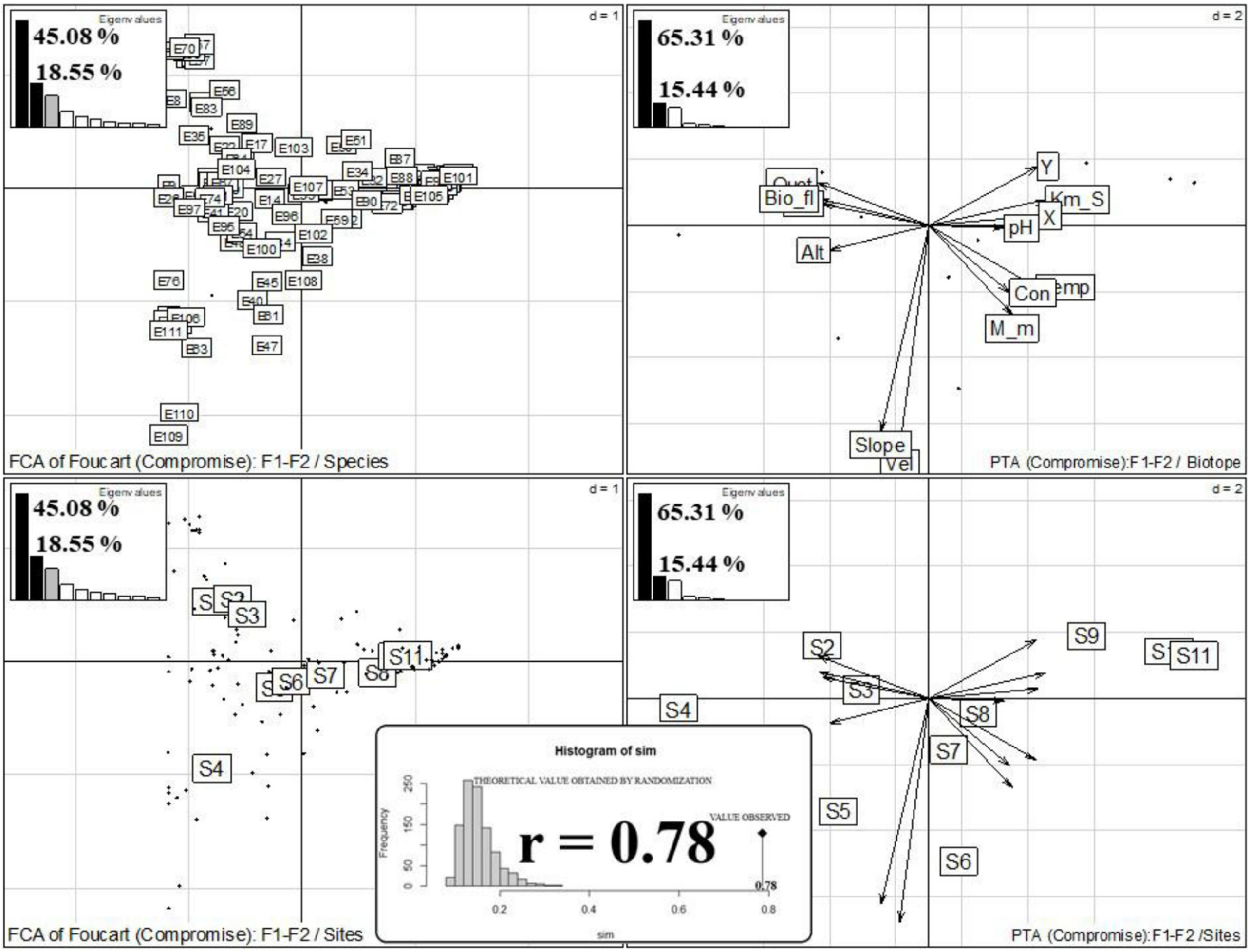

Fig. 4. Projections of the sampling sites on the F1-F2 plane of the Foucart' FCA compromise and the Partial Triadic Analysis. Left: The sampling sites seen by the species. Right: The sampling sites viewed by the environmental variables; RV: correlation coefficient between the coordinates of the macroinvertebrate and environmental data.

amplitudes (S9, S10 and S11) were grouped on the positive side of this axis. The F2 axis, which represents only 15.4% of the total information, expresses two redundant parameters, the current velocity and the riverbed slope, which show high values in four sampling sites (S5, S6, S7 and S8), separating them from the two other groups.

3.2 Biotypological structure

The results of the analysis are illustrated in Figure 4, providing the projection of both communities (represented by their sampling sites) and species on the factorial plan of the two first axes, cumulating about 64% (respectively 45.08% and 18.55%) of the total inertia.

The F1-F2 plane of the PTA on the table of the mesological variables assigned to the sampling sites, also showing an upstream-down organization on the F1 axis, and again sampling sites defined by the mesological analysis with the macroinvertebrates in perfect agreement.

To clarify the possible relationship between the biotypological structure and the mesological one, we compared the coordinates of the sampling sites (seen by the macroinvertebrates) on the first three factorial axes (F1 axis: 45.08% of total inertia; F2 axis 18.55%; F3 axis 13.48%) derived from Foucart' FCA) to the values of the mesological parameters (Table 1 in Supplementary Material) that can influence the distribution of the fauna.

Ten environmental parameters had a good correlation with the FI axis (Fig. 5). In descending order of correlation, we found the bioclimatic floor ($r = -0.93$), kilometer at the source ($r = 0.91$), the Emberger quotient and the temperature of the water ($r = -0.90$ and $r = 0.90$) as the most correlated variables. Slope had a fairly good correlation with the F2 axis ($r = -0.68$), whereas current velocity ($r = -0.80$) was correlated with the F3 axis.

These correlations are also well illustrated using a visual comparison between the biological and mesological typologies of the 11 sapling sites on the two first axes (F1-F2 plans) of the two analyses. However, in the biotypology, all downstream sites (S5 to S11) were grouped and organized in upstream-down gradient, while in the mesological typology, despite upstream-down organization was also observed, the F2 axis segregates two sampling sites (S5 and S6) with higher slope and/or flow velocity, key factors of this axis.

Table 1. IndVal results for the groups (only the most significant species were showed).

Group	Species	Indicator value	*P*-value
	E008 *Protonemura talboti*	100	0.005
	E011 *Perla* cf *pallida*	100	0.005
A	E012 *Brachyptera algirica*	100	0.005
	E005 *Ancylus fluviatilus*	89.4	0.022
	E035 *Hydropsyche* sp	89.4	0.022
B	E038 *Tinodes algiricus*	89.4	0.023
	E108 *Limnophora* sp	89.4	0.023
	E077 *Platycnemis subdilatata*	100	0.006
	E004 *Physella acuta*	89.4	0.029
	E007 *Atyaephyra desmarestii*	89.4	0.029
C	E044 *Allotrichia pallicornis*	89.4	0.029
	E069 *Micronecta scholtzi*	89.4	0.029
	E080 *Ischnura graellsii*	89.4	0.029
	E082 *Anax imperator*	89.4	0.029
	E085 *Gomphus simillimus*	89.4	0.029

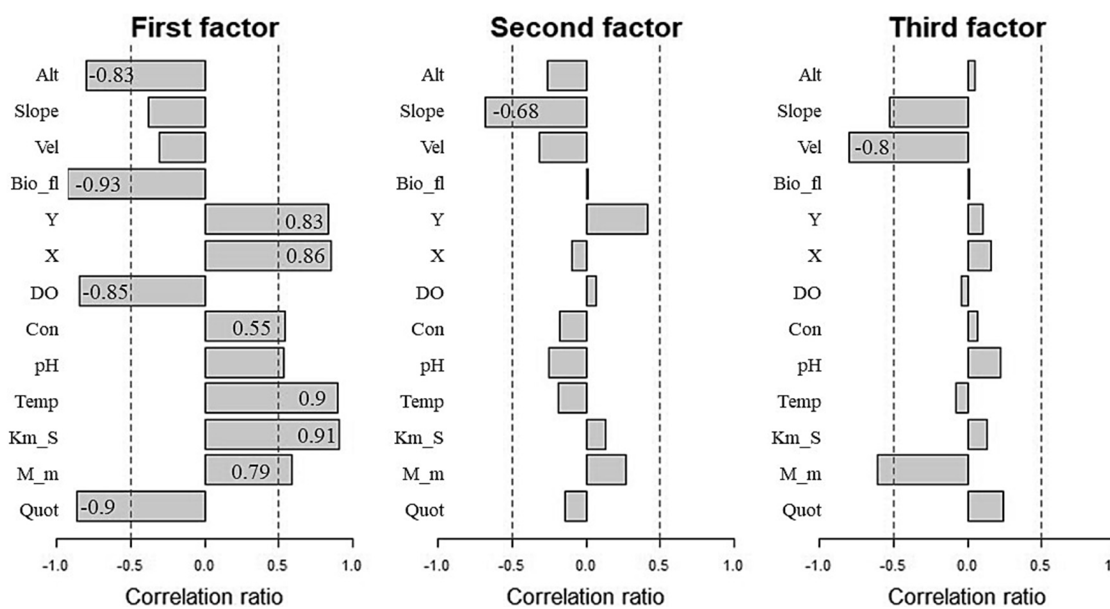

Fig. 5. Correlation report between the mesological parameters and the first three axes of Foucart' AFC.

3.3 Ordination and clustering classification

The hierarchical classification (Fig. 6) as well as the spatial ordination of the taxa along the first factorial axis of Foucart FCA (Fig. 7) defined three faunal groups. In Table 1 appears the indicator species for each of the groups:

Group A. It is composed by 42 taxa, most of them (36) being specific to the two studied springs (S1 and S2); some of these taxa are stenothermic and rheophilic, with high frequency in fresh and clean waters. The species that are significantly indicative of this group (with an IndVal index equal to 100) are *Protonemura talboti* (E8), *Perla* cf *pallida* (E11) and *Brachyptera algirica* (E12).

Group B. The species in this group are restricted to medium and high altitude sampling sites. It is composed by *Caenis pusilla* (E19), *Rhitrogena* sp1 (E28), *Hydroptila* sp cf *mendli* (E41), *Hydropsyche fezana* (E31), *Choroterpes volubilis* (E22), *Rhitrogena* sp2 (E29), *Habrophlebia fusca* (E20), *Rhyacophila munda* (E30), *Oxyethira cf falcata* (E40), *Ithitrichia clavata* (E45), *Tinodes algiricus* (E38) and *Cheleocholeon dimorphicum* (E17). These species are moderately stenothermic, generally preferring slow-to-moderate-flow waters. Significantly indicative species of this group (with an IndVal index greater than 89) are *Tinodes algiricus* (E38) and *Limnophora* sp.

Group C. The taxa constituting this group are eurythermal or strictly thermophilic, preferring low or medium river

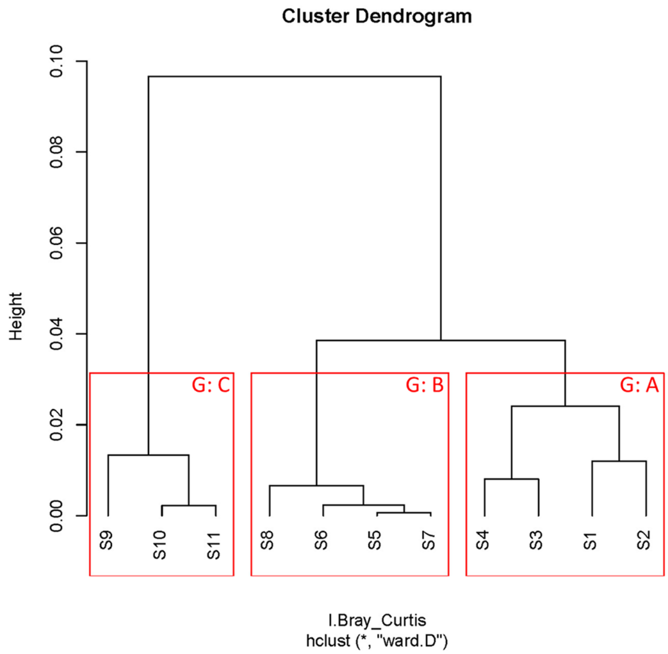

Fig. 6. Hierarchical classification of the studied sampling sites based on the environmental parameters using Bray-Curtis dissimilarity method showing the three typological groups (G: A, B and C) by their macroinvertebrate taxa similarity.

sections with worm summer waters and good representativeness of habitats favorable to limnophilic forms. The indicator species of this group are numerous, but the most significant one (with an IndVal index greater than 89) was *Platycnemis subdilatata* (E77).

Twenty-three ubiquitous taxa, some of them being also the most abundant in this basin, did not fit with any of the groups obtained. They are considered as eurytopic, mainly eurythermal, with very diverse preferences towards flow velocity. Such profile is well expressed at least by five species: *Baetis rhodani* (E14), *Baetis pavidus* (E13), *Ecdyonurus rothschildi* (E27), *Choroterpes atlas* (E21) and *Hydropsyche pellucidula* (E34).

4 Discussion

4.1 Improving biodiversity knowledge

Due to the lack of studies on aquatic biota, the Moulouya basin and Oriental Morocco have always been underestimated in terms of biodiversity, but the extension of our research in the orographically intricate sub-basin of Melloulou River, has boosted the macroinvertebrate richness of this poorly studied area joining 38 species (31 % of the total taxa inventoried) as new for Moulouya and Oriental Morocco (see Table S2), completing a rich macroinvertebrate community of 23 species of Ephemeroptera (Mabrouki *et al.*, 2017b), at least nine of Plecoptera (Mabrouki *et al.*, 2016), 146 species of Coleoptera (Mabrouki *et al.*, 2018; Taybi *et al.*, 2017a), 47 Odonata (Taybi *et al.*, 2019), 45 Hemiptera (Taybi *et al.*, 2018), at least 41 Trichoptera (Mabrouki *et al.*, 2020), 26 Mollusca (Glöer *et al.*, 2020; Taybi *et al.*, 2017b) and nine freshwater Hirudinea (Mabrouki *et al.*, 2019b). Most of these newly recorded species exhibit pronounced geographic isolation in the Melloulou River such as *A. almohades*; *O. skoura*; *E. glaucops*; *C. volubilis*; *C. petitpierreae*; *I.* cf. *kir*; *A. incertulus*; *H. fezana* and *B. irene*. This notable increase of species occurs because Melloulou is the most distinctive sub-basin in terms of bioclimatic floors, landscape elements and surface and groundwater resources of the Moulouya River basin (Mouhdi, 1993; López Lara *et al.*, 2007; Taybi, 2016). However, the current list of aquatic macroinvertebrates identified in this area must not be the final one. Future studies, either in the eastern Middle Atlas or in other inaccessible territories of Moulouya River basin, and more focused in particular orders, could lead to the discovery of new taxa for Morocco, North Africa or even for science.

4.2 Distribution of macroinvertebrates

The longitudinal distribution of benthic macroinvertebrates in the Melloulou River basin is mainly governed by altitude, slope and current velocity. These environmental factors are recurrently pointed as main drivers for macroinvertebrate distribution in alpine basins (*e.g.* Astorga *et al.*, 2014; Jacobsen *et al.*, 2014). However, in our case, these factors do gradually not change, but abruptly, separate the fauna into two clearly different groups, one exclusively rheophilous at head water, preferring fast flowing; and the other mainly limnophilous, with a strong preference for depositional reaches, in the middle and low Melloulou River, just until the connection with the Moulouya River. Similar results were also highlighted in other areas with comparable intricate orography and bioclimatic conditions such as the Soummam River basin from Algeria (Zouggaghe and Moali, 2009). Furthermore, in Mediterranean areas current velocity is most strongly variable throughout the year comparing with temperate rivers, causing a contrasting flow pattern with important discharges in early spring or late summer, and severe low level of water by discharges in most summers (Bonada and Resh, 2013). This strong environmental change could favor the dispersion of limnophilous and opportunistic species upstream, but also an important replacement of the macroinvertebrate communities, even in the same season over time.

The results of this singular flow regime provokes a faunal segregation, but also an important overlapping of species in time (as occurred in the third campaign), generating the two above mentioned groups, clearly separated by different environmental conditions, but also a third group of species that is a mixture of the two first groups, and a set of species, difficult to fit in any of the three found groups, characterized by their opportunistic and ubiquitous behavior and capable to colonize any of the reaches of the Melloulou River basin.

The high-altitude sampling localities, with fresh water and wet bioclimate, shelter the species of the group A. The best taxa representing this stenotopic group those belonging to Plecoptera, such as *Protonemura talboti*, *Perla* cf *pallida* and *Brachyptera algirica*. Conversely, the group C, in the middle to low reaches of Melloulou River, with a prevalence of semi-arid to arid climate and, consequently, the presence of more temperate and standing waters, sustains a strongly different macroinvertebrate community, with thermophilic and, limnophilic species such as *Allotrichia pallicornis*, *Micronecta scholtzi*, *Physella acuta* and *Cloeon dipterum*. As we mentioned before, the group B represents a transition zone between the two preceding ones and shelter the hemi-

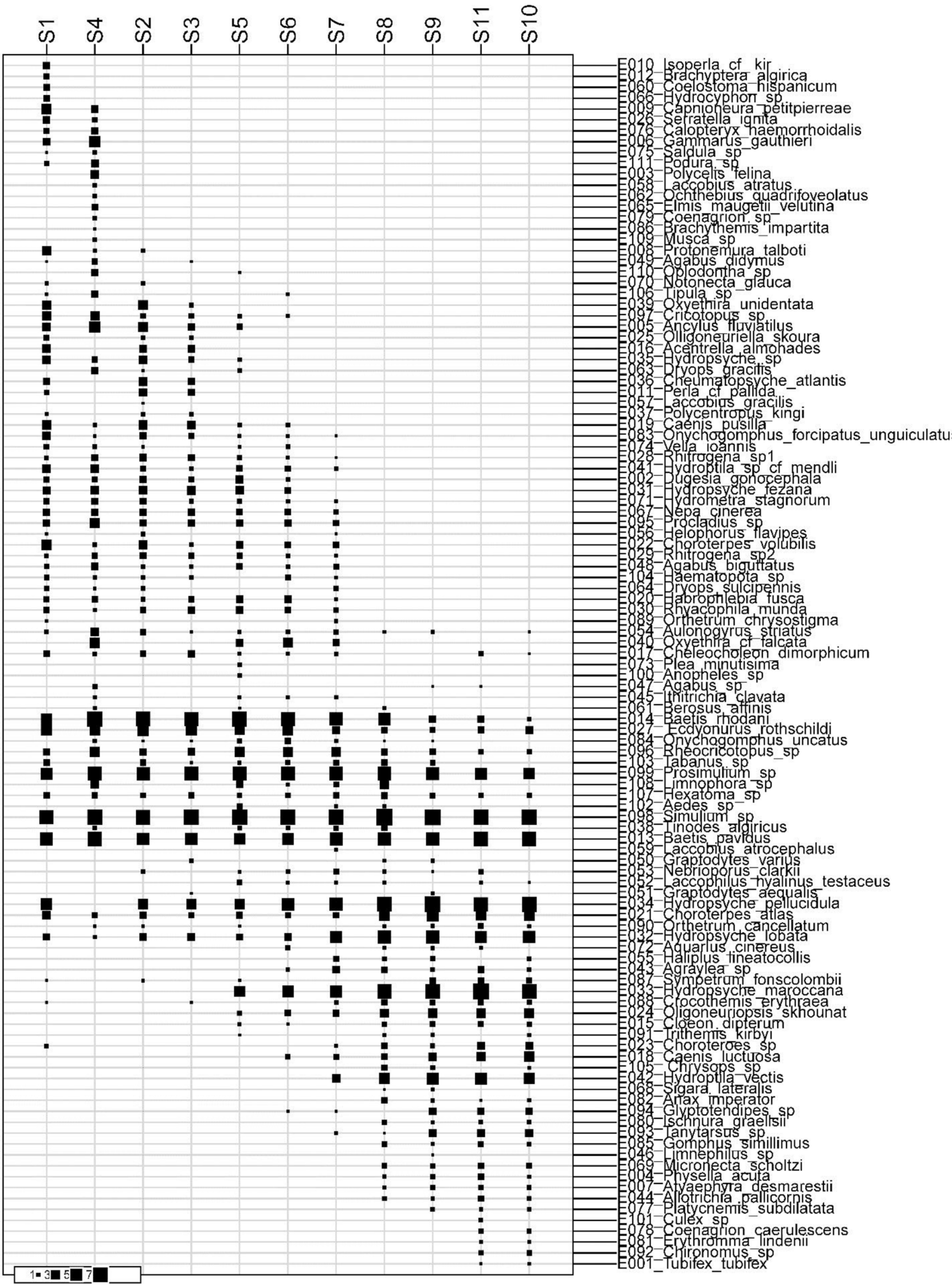

Fig. 7. Ordination of species and sampling sites along F1 axis of Foucart' FCA compromise. Black squares represent total abundance transformed into Log (x + 1).

stenothermic species with hemi-eurythermic generally preferring moderate flow waters; the representative taxa of this group are *Tinodes algiricus* and *Limnophora* sp. Concluding, macroinvertebrates taxa from the upper Melloulou represent a typical crenon-rhithron community, the middle course and the lower Melloulou presents a large community typical of potamon river section.

4.3 Management and conservation schemes

In a very changing environment, Melloulou River basin is still relatively spared from pollution, which is not the case for most of Morocco's hydrosystems, as in most of the North African territory (Garcia *et al.*, 2010; Dakki, 2014). Results of the recent monitoring progress of the water quality in the Melloulou watercourse (Mabrouki *et al.*, 2017a) showed, in general, a good natural condition, both up and down stream. However, this does not necessarily mean that the river does not need any manage for resource exploitation in parallel with conservation purposes. Riparian zone and surrounding areas modifications caused by agricultural practices, substrate extraction along the basin, upstream deforestation and downstream desertification are the main human impacts observed in the study area (Mouhdi, 1993; Mabrouki, 2017; Mabrouki *et al.*, 2017a). The effect of these impacts could be accentuated in the middle and low Melloulou River by the violent flash floods experienced, almost annually, coming from the large basin of Moulouya (Berrahou *et al.*, 2001), which could allow the arrival and expansion of alien species from this basin. Many exotic species have been spotted recently in the Moulouya River basin, including several alien fishes such as the "Mosquitofish" *Gambusia holbrooki* Girard 1859, the "mummichog" *Fundulus heteroclitus* (Linnaeus, 1766) and the "Pumpkinseed" *Lepomis gibosus* (Linnaeus, 1758). But also invertebrates, like the "Asian clam" *Corbicula fluminea* (Müller, 1774) and the "boatman" *Trichocorixa verticalis verticalis* (Fieber, 1851) (Mabrouki *et al.*, 2019c; Taybi, 2016; Taybi *et al.*, 2017b, 2020a, b). With climate change, temperature increases and frequent construction of canals and dams, these species are potentially able to disperse provoking strong changes in the native communities (Fenoglio *et al.*, 2016; Carbonell *et al.*, 2017).

The results of our study, highlighting the important contribution of the Melloulou's macroinvertebrates to the global biodiversity in North Morocco, as well as the essential role of altitude, slope and current velocity and the organization and distribution of such macroinvertebrate community should be of crucial concern for managers and conservationist. It is also so important to take into account its discharge dynamic, strongly variable and capable to change community assemblages in the same reach and season in different years. Considering these particular characteristics could help to coupling monitoring, managing and conservation purposes in this fragile and singular basin, serving also as reference for future studies in similar Mediterranean basins.

Supplementary Material

Supplementary Tables S1 and S2

The Supplementary Material is available at https://doi.org/10.1051/limn/2020016.

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