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Are aquatic Hemiptera good indicators of environmental river conditions?

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Abstract Aquatic Hemiptera are barely used as "indicators" because they are considered ubiquitous organisms of great dispersal capacity and a wide range of occupied habitats. Here, we address this topic analyzing the environmental factors determining the distribution of the species found in a northeastern Moroccan basin with a strong altitudinal gradient, as well as their capability of establishing assemblages and the niche breadth for each species. Between 2014 and 2017, we sampled 55 contrasted sites representing the heterogeneity of aquatic ecosystems in the study area, where we collected a total of 27 species. The relationships between the species and environmental variables were evaluated using the STATICO methods, showing a distribution mainly influenced by the changes in flow velocity and conductivity. The Bray–Curtis dissimilarity index identified four assemblages: (a) a running species group in upper freshwater streams; (b) a middle stream group preferring less flow velocity and moderate mineralization; (c) a third group, near to the mouth, occupying moderate running or lentic brackish waters; and (d) a fourth group linked with hypersaline standing environments. The use of Indicator Species Analysis (IndVal) found few but representative species for each assemblage. The OMI

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applied showed that the majority of species had a high niche breadth and, consequently, a low specialization. Our results highlighted the overall poor habitat requirement and very ubiquitous character of most species found. Only some of them, mainly the endemism *Aphelocheirus pemae*, can be considered key for biodiversity conservation purposes because of their low niche breadth and high indicator value.

Keywords Aquatic Hemiptera · Species inventory · Biotic indicators · Conservation · STATICO and OMI methods · Niche breadth · Moulouya River Basin · Morocco

Introduction

The Mediterranean basin is among the most important biodiversity hot spots worldwide (Myers et al. 2000). Within this, Maghrebian region is one of the richest and diversified, with a mosaic of environmental conditions that have resulted in a wide variety of habitats and, consequently, a very singular biota (Dakki et al. 2015). The most emblematic Moroccan river, the largest from the Maghrebian region flowing toward the Mediterranean, is the Wadi Moulouya. Its basin includes a great part of the Oriental Region of Morocco, and together the Oriental Region covers 16.78% of the surface of the Moroccan country. The study zone comprises a multitude of protected areas such as RAMSAR Sites (e.g., the Nador Lagoon, the mouth of the Moulouya, Three Forks Cape, Mohamed V Dam, etc.) or "SIBEs" (zones of biological and ecological interest, e.g., Beni Snassen Park, Gourougou, Oued el Bared, Bou Iblane, Jbel Krouz, etc.), hosting a high number of endemism (Franchimont and Saadaoui, 2001).

Unfortunately, accelerated by the climate change effects, most aquatic ecosystems of the Oriental Region and Moulouya basin are seriously threatened by human activities like water abstraction, habitat loss, industrial and domestic effluents or agricultural runoff (Mabrouki et al. 2016a, 2017a; Taybi et al. 2016a). Therefore, it is not enough the consideration of these areas as protected. Further actions are needed to preserve these ecosystems, as well as their biodiversity (García et al. 2010). One of the most important actions is to contribute to the knowledge of such aquatic biodiversity and its distribution, including their value as biotic indicators. This is crucial to manage and preserve this group of insects and their habitats.

Several bio-assessment studies on aquatic ecosystems in Oriental Region of Morocco focused on the macroinvertebrates community have improved our knowledge of species occurrence and distribution (Mabrouki et al. 2016b, 2017b, 2018a, b, 2019a, b; Taybi et al. 2016b, 2017a, b, 2018a, 2019, 2020). Within macroinvertebrates, the order Hemiptera comprises a significant component of the world's aquatic insect biodiversity. These insects are notable for utilizing an exceptionally broad range of habitats, from marine and intertidal to the Arctic and high alpine, across a global elevational range of 0–4700 m. (Polhemus and Polhemus 2008). Most species may be found in almost aquatic biotopes, and many exhibit striking morphological adaptations to their aquatic environment, making them excellent subjects for ecological and biogeographic studies (Millán et al. 1988; Carbonell et al. 2011a).

Hemipterans constitute a very heterogeneous taxonomic group of aquatic insects which share the same propensity to live in the water (Nepomorpha, except species belonging to the family Ochteridae), or just using the water surface (Gerromorpha), in both cases with overall well disperser species which breadth atmospheric oxygen (Nieser et al. 1994; Csabai et al. 2012; May, 2019). These particularities led grow the idea that aquatic Hemiptera are bad biotic indicators, being considered ubiquitous organisms with a high capacity to colonize a wide range of habitats, including those of anthropogenic origin (Millán et al. 2002). However, several studies related their distribution with water conductivity or pH, by the features of the aquatic habitat, mainly referred to its lotic or lentic character, presence of vegetation and type of substrate (Moreno et al. 1997; López and Hernández; 2001; Karaouzas and Gritzalis, 2006; Carbonell et al. 2011a; Annani et al. 2012).

Thus, aquatic Hemiptera are rarely used as bioindicators comparing to other insect groups, namely Plecoptera, Trichoptera, Ephemeroptera, who are at the top of taxa used as sensitive surrogates of pollution and habitat degradation (Tachet et al. 2010). Their general high dispersal capacity and atmospheric oxygen consumption, abovementioned, complicate the interpretation of their spatial distribution too (Carbonell et al. 2011a), consequently, their use as "indicators." Only the species of the Aphelocheiridae family are contemplated as good indicators due to their low tolerance to pollution (Carbonell et al. 2011b; Millán et al. 2016). Their interest as indicators comes from the ecophysiological characteristics the species of this family have, in particular, the plastron-type breathing system which allows them to live permanently in the benthic zone of well-oxygenated and pristine running waters (Seymour et al. 2015).

In the frame of managing and conservation of these insects and their habitats, as well as to unravel their role as a biological indicator, we have checked: (1) whether there are clear environmental factors addressing the distribution of the species found in the Moulouya basin and Oriental Region from Morocco; (2) whether different aquatic Hemiptera assemblages occurred; (3) the existence of indicator species for each assemblage; and (4) the niche breadth of the species found. We hypothesized that despite the high dispersal capacity and air oxygen consumption of the species belonging to this group, they will be spatially distributed and assembled largely due to the influence of the main environmental factors of the study area, in our case the persistence and variability of water flow, as well as the changes in the mineralization of water bodies.

Materials and methods

Study area

The watershed of the Moulouya (Fig. 1), with a surface near to 43,412 km^2, covers much of the Moroccan Oriental Region. With a length of 600 km, the Moulouya is the largest Moroccan river flowing into the Mediterranean. Moulouya River has a hydrological regime of Mediterranean type, characterized by high water flow in late winter and early spring, low water flow in summer. The main tributaries are the Oued Ansegmir, Oued Melloulou, Oued Za all permanent, with very irregular hydrological regimes, severe summer low water and violent floods in other seasons. Other tributaries are intermittent, with frequent flashfloods every year (Berrahou et al. 2001; Mabrouki et al. 2016a, 2017a). Furthermore, the conductivity in the drainage systems of the Moulouya basin considerably fluctuates in time and space, increasing generally from up- to downstream (Taybi, 2016). This, together with the subhumid, semiarid, arid and Saharan climates, characteristic of the study area (Mabrouki et al. 2016b) confers this basin a wide variety of aquatic ecosystems, ranging from springs and headwater streams to big rivers, ponds, pools, wetlands (e.g., many RAMSAR sites as Nador lagoon, Moulouya's mouth, Mohamed V dam), saline lagoons and salt-pans (Chavanon et al. 2004).

Biological dataset

Field surveys were conducted from 2014 to 2017, sampling 55 localities along the Moulouya River Basin and Oriental Region of Morocco (see Appendix for the complete list of localities). Sampling sites were selected to cover all of the different environmental conditions and water-body types (mouth rivers and streams, irrigation channels, lagoons, ponds, salt marshes and salt-pans) observed in Morocco. All the sampling campaigns were carried out between ten in the morning and noon, following the same protocol. These sampling sites were visited at least three times. We collected relative esteems of macroinvertebrate taxa, but mainly focusing on Hemiptera in the different microhabitats prospected at each locality. Macroinvertebrates were taken by kick nets, landing nets, clamps, "Surber" samplers (with a surface of 20 × 25 cm × 8 samples = 0.40m^2). All were equipped with a 500 mm mesh net. We were sampling each locality until apparently no new taxa were found. We confirmed the field identification in the laboratory using specialized literature (e.g., Jansson, 1986; Nieser et al, 1994; Günther, 2004).

Environmental data

In situ, we measured pH, conductivity, dissolved oxygen concentration with portable equipment (WTW, MPP350). Water temperature was obtained using a mercury thermometer sensitive to 0.1 °C, and flow speed was measured through the time taken by a floating body (cork stopper) to cover a minimum distance of one meter. Elevation was calculated using a GPS device (Garmin eTrex 10). Other parameters including the biological oxygen demand, ammonium sulfate, orthophosphate concentrations were measured in the laboratory from water samples in the laboratory (Tab. 1).

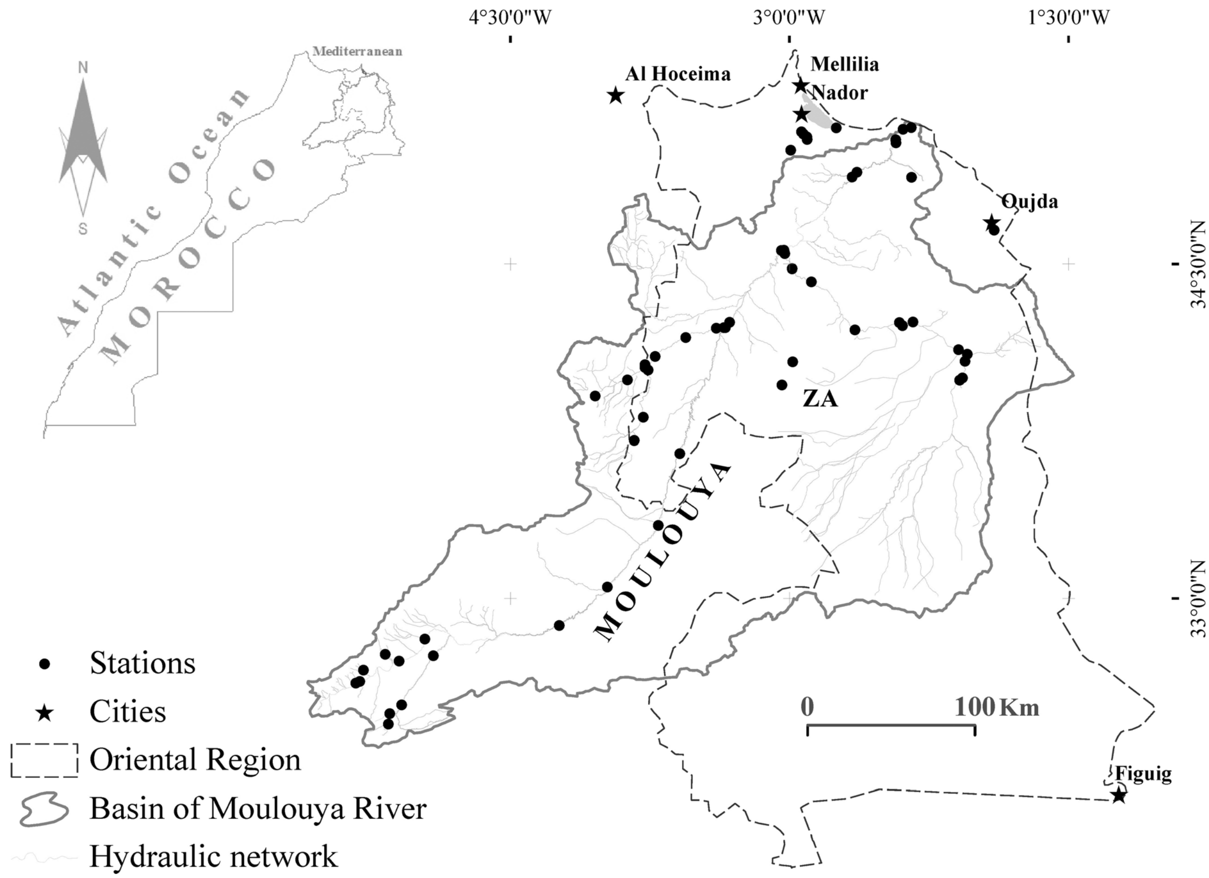

Fig. 1 Study area showing the sampling sites

Table 1 Environmental variables measured in sampled sites

Environmental variables	Units	Code
pH	–	pH
Temperature	°c	Temp
Conductivity	µs cm^{-1}	Con
Dissolved oxygen concentration	mg l^{-1}	O_diss
Ammonium	mg l^{-1}	N_NH
Sulfate	mg l^{-1}	SO
Orthophosphate	mg l^{-1}	PO
Biological oxygen demand	mg l^{-1}	DBO5
Altitude	m	ALT
Flow speed (ordinal variable)	0 (0–15 cm), 1(15–50 cm), 2(> 50 cm)	FS

Data analyses

Co-inertia analysis

The co-inertia analysis is a tables coupling method, based on the duality scheme defined by Escoufier (1987). It allows for combining different types of multivariate basic analyses (principal component analysis—PCA; correspondence analysis—FCA or CA; multiple correspondence analysis—MCA). With this method, it is possible to describe the common structure to two tables of data in order to study the species–environment costructure (Dolédec and Chessel 1994). The analysis was performed on a pair of global tables (55 × 3) wildlife–environment (165 sampling sites—25 species) × (165 sampling sites—ten environmental variables). The relevance of the co-inertia analysis was verified by a Monte Carlo permutation test (Manly 1991) on 1000 random permutations. Species with low occurrences (< 3) were taken into account in the final taxonomic inventory but not included in the analyses.

STATICO method

In our study, we place ourselves in the case of three-dimensional data where several variables were measured three times in the same locality. The data cube thus constituted can be considered as a chronological sequence of three tables with two inputs (stations x surveys). The STATICO method (for STATIS and Co-Inertia) allows the simultaneous processing of this series of three pairs of tables (Thioulouse et al. 2004; Slimani et al. 2017). The main goal of this method is to search for the structure common to the three tables, called "compromise" by the best combination of such tables giving the best image of the permanent spatial structure of the variable species relationship. More precisely, if we consider n stations on which we have identified p species and measured q variables at K different dates, STATICO makes it possible to obtain an average image of the species–variable relationship, to study the evolution of this relationship in the time and to characterize the typology of the stations studied as a function of this temporal evolution. STATICO, interpreted as any conventional main component analysis, combines the logic of two methods: the multitables and more particularly of the partial triadic analysis and secondly, the co-inertia couplings (Simier et al. 1999).

Classification and Indicator values (IndVal)

Sampling sites were classified by hierarchical grouping according to their environmental characteristics using the Bray–Curtis dissimilarity method.

IndVal consists of calculating the indicator value of each species based on its relative abundance and occurrence frequency in each of a priori defined group. We tested the significance by the Monte Carlo test to verify whether the preference of a species (key species) for a type of habitat is significantly higher than the suggested by a random distribution (Dufrêne and Legendre 1997). However, indicator species analysis is often limited to singleton identification of species. Combinations of species as indicators could provide more information about ecological conditions as suggested by De Cáceres and Legendre (2009) and, consequently, the best indicator of habitats and more information on the ecology of such habitats. Thus, they proposed, as alternative to singleton test, species pairs or trios tests. In this study, we limited the analysis to singleton and pairs of species. This has the advantage according to the latter of limiting the complexity in the identification of the indicator species, to avoid very large numbers of possibilities, which can reduce the reliability of the analysis.

OMI method

In order to approach the problem of the niche separation and its width descriptively, the choice was made on an analysis technique which did not impose any initial hypothesis on the shape of the response curve (better representation of "realized" niches) and assigning an equivalent weight to rich and poor sites in species or individuals (many monospecific sites). It is the Outlying Mean Index (OMI). This method also helps to identify important environmental factors for the structure and organization of communities by separating species according to the characteristics of the habitat they occupy. The principle is based on measuring the marginality or specialization of species, i.e., it measures the distance between the average habitat of a given species and the average habitat conditions of the study area (corresponding to the distribution of a hypothetical species uniformly distributed in all conditions). The analysis places species on habitat gradients to maximize their OMIs. Each niche deduced from the OMI analysis can then be broken down into three elements: a) an index of marginality or specialization (OMI: position of the niche); b) a tolerance index (Tol: width of the niche), and c) a residual tolerance index (rtol: efficiency of environmental variables in the definition of the niche). This method was used due to its demonstrated suitability for the study of multidimensional niche breadths in the presence of strong limiting factors, e.g., water conductivity (Dolédec et al. 2000).

Pearson correlations

The OMI analysis should be performed on a restricted set of variables, eliminating the most redundant variables. Therefore, a calculation of Pearson's correlations between habitat variables was achieved and the most redundant variables were eliminated. The dataset used in the OMI analysis, therefore, consisted of five environmental variables and 25 species of Hemiptera (165 sampling sites—25 species) × (165 stations—five environmental variables).

The analyses of the data were carried out using the software R in version 3.5.1, under the Ade4, indicspecies and vegan packages, for ease of reading, the marginality is calculated by 100—OMI.

Results

Species inventory

A total of 27 species of aquatic and semiaquatic Hemiptera were identified belonging to nine families (Table 2), representing 41.5% of the total Moroccan fauna. Five species are endemisms, being *Aphelocheirus pemae* and *Hebrus atlas* only known from Morocco, *Microvelia vidali* and *Velia ioannis* from Maghreb, *Parasigara favieri* from Maghreb and Iberian Peninsula. Furthermore, we detected one alien species, *Trichocorixa verticalis verticalis*, from the Atlantic coast of North America (Table 2).

Spatiotemporal distribution

From the co-inertia analysis, we obtained a low coefficient correlation of the vectors (RV = 0.35, see Fig. 2), but highly significant ($p < 0.001$), mining that the observed value was higher than the values obtained by random draws (Monte Carlo randomization). This result points out that the environmental and biotic structures were significantly related, showing a coexistence structure, so a STATICO analysis was therefore justified.

The results of the STATICO analysis demonstrated the dominance of the first axis (interstructure, Fig. 3a), with 80.77% of the co-inertia, showing the costructure observed during the three campaigns. The compromise analysis provided a histogram of eigenvalues (Fig. 3b–d) highlighting two predominant dimensions represented by the factorial axes F1 and F2, which, respectively, reflect 60.87% and 14.59% (75.46% of the total information).

On the factorial map of the environmental parameters of the compromise analysis, the first axis (horizontal) describes a gradient of mineralization and temperature, which decreases from left to right, and this gradient is negatively correlated with altitude; the latter has a moderate contribution to the formation of the F1 axis. The second axis (vertical) expresses a water current speed gradient, which increases from top to bottom. The species were consequently organized according to these two gradients: those from strongly mineralized and temperate water at the left of the F1 axis, such as *Sigara selecta* and *Trichocorixa verticalis verticalis*; and those from low mineralized and cool waters at the right of the F1 axis, as *Hydrometra stagnorum, Nepa cinerea* or *Velia ioannis*. The second axis seems to segregate the species according to the speed of the water, isolating *Aphelocheirus pemae*, which prefers high to moderate current velocity and well-oxygenated waters (see "Introduction" section), at the down part of the axis, against the species preferring depositional habitats of lotic environments or standing waters at the top of this axis, such as *Aquarius cinereus, Micronecta scholtzi* or *Naucoris maculatus*.

Assemblages and indicator species

The classification gave four groups of assemblages (Fig. 4) shared as follows:

- G1 (20 sites): running freshwater upper watercourses.
- G2 (9 sites): running low mineralized waters in the middle river reaches.
- G3 (10 sites): moderate running and/or standing low mineralized waters, downstream.
- G4 (16 sites): standing strongly mineralized water.

Indicator values (IndVal) of taxa or combinations of taxa are presented in Table 3. Six singleton indicator species and nine pairs were found in the four groups found.

Table 2 Species checklist, code, number of individuals and estimated abundance percentages for each species of Hemiptera. Taxa were ordered alphabetically

Code	Species	No. individuals	Percentage of total
Adeb	*Anisops debilis perplexus* Poisson, 1929	30	1.03
Apem	*Aphelocheirus pemae* Millán, L'Mohdi & Carbonell, 2016[a]	31	1.07
Acin	*Aquarius cinereus* (Puton 1869)	213	7.34
Anaj	*Aquarius najas* (De Geer, 1773)	60	2.07
Caff	*Corixa affinis* Leach, 1817	16	0.55
Cpun	*Corixa punctata* Illiger, 1807	17	0.59
Hatl	*Hebrus atlas* Kment, Jindra & Berchi, 2016[a]	30	1.03
Hver	*Heliocorisa vermiculata* (Puton, 1874) [d]	10	0.34
Hsta	*Hydrometra stagnorum* (Linnaeus,1758)	209	7.2
Mvit	*Mesovelia vittegera* (Horvath, 1895)	83	2.86
Msch	*Micronecta scholtzi* (Fieber, 1860)	525	18.08
Mvid	*Micronecta vidali* (Poisson, 1938)[b]	36	1.24
Mpyg	*Microvelia pygmaea* (Dufour, 1833)	91	3.13
Nmac	*Naucoris maculatus* Fabricius, 1798	122	4.2
Ncin	*Nepa cinerea* Linnaeus, 1758	239	8.23
Ngla	*Notonecta glauca* (Latreille, 1802)	14	0.48
Nmac	*Notonecta maculata* (Fabricius, 1794)	99	3.41
Nmer*	*Notonecta meridionalis* (Poisson, 1926)	–	–
Pfav	*Parasigara favieri* (Poisson, 1939)[c]	106	3.65
Pmin	*Plea minutisima* (Leach, 1817)	81	2.79
Rnig*	*Rhagovelia nigricans* (Burmeister, 1835)	–	–
Slat	*Sigara lateralis* (Leach, 1817)	32	1.1
Sscr	*Sigara scripta* (Rambur, 1840)	22	0.76
Ssel	*Sigara selecta* (Fieber, 1848)	365	12.57
Ssta	*Sigara stagnalis* (Leach, 1817)	116	4
Tver	*Trichocorixa verticalis verticalis* (Fieber, 1851)[c]	308	10.61
Vioa	*Velia ioannis* Tamanini, 1971[b]	48	1.65

[a]Moroccan endemic

[b]Maghrebian endemic

[c]Iberomaghrebian endemic

[d]Alien species. (*Species with low occurrences (< 3) were not considered in further analyses)

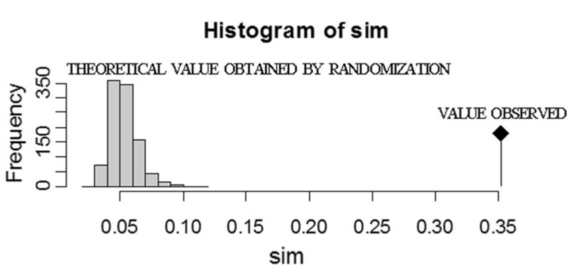

Fig. 2 Permutation test on the co-inertia of the global table fauna–environment

Ecological niches

The results of the OMI analysis are shown in Table 4 and Figs. 5 and 6.

Twelve of the 25 species analyzed showed significant marginality, suggesting an average influence (12/25) of the environmental variables retained on the species distribution. The overall test on the average marginality of all species is also very significant ($p < 0.001$).

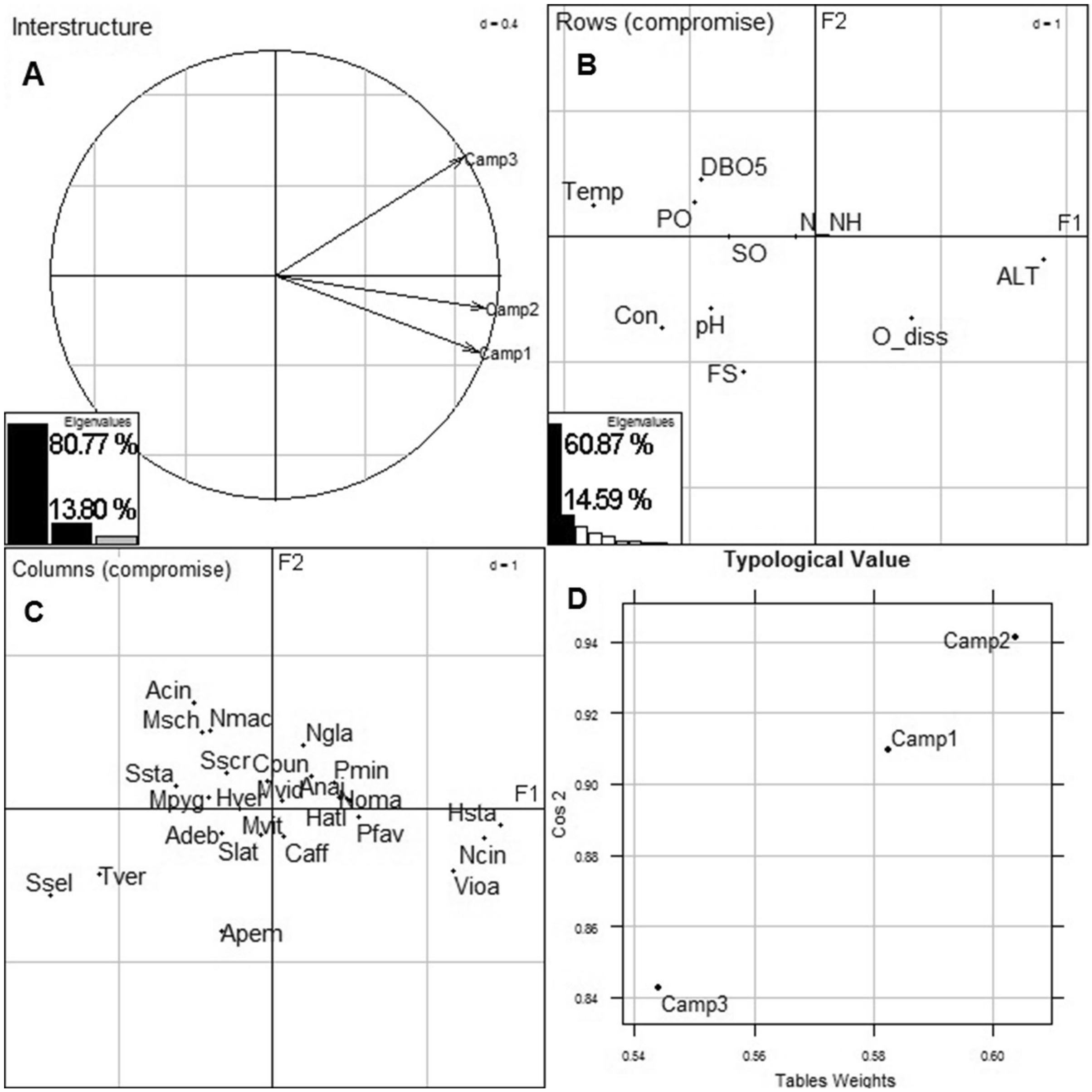

Fig. 3 Interstructure and compromise of STATICO on the Hemiptera dataset. A) Projections of the three table campaigns of co-inertia on the axes 1 and 2 of the interstructure, with its histogram of the eigenvalues. B) Coordinates of the variables on the 1–2 plan of the compromise, with its histogram of eigenvalues underlining the existence of a two-dimensional average structure. C) Species' coordinates on the plan 1–2 of the compromise. Species are identified by their codes. D) Typology of the weights of the three tables (campaigns)

Aphelocheirus pemae (Apem) was the most marginal species (OMI = 95), therefore the most demanding with respect to the abiotic variables selected for this study, also the least tolerant (tol = 0.1), which is, the one with the smallest niche, and it records only a low residual tolerance (rtol = 4.9. In the second position of habitat specialization comes *Velia ioannis* (Vioa) (OMI = 59.5), but its tolerance is higher than *A. pemae* (tol = 19.7) showing a wider niche breadth. The least marginal species were *Sigara stagnalis* (Ssta), *Aquarius cinereus* (Acin) and *Nepa cinerea* (Ncin) (see Table 4).

The highest tolerances are recorded, respectively, by *Naucoris maculatus* (Nmac, tol = 38.3), *Nepa*

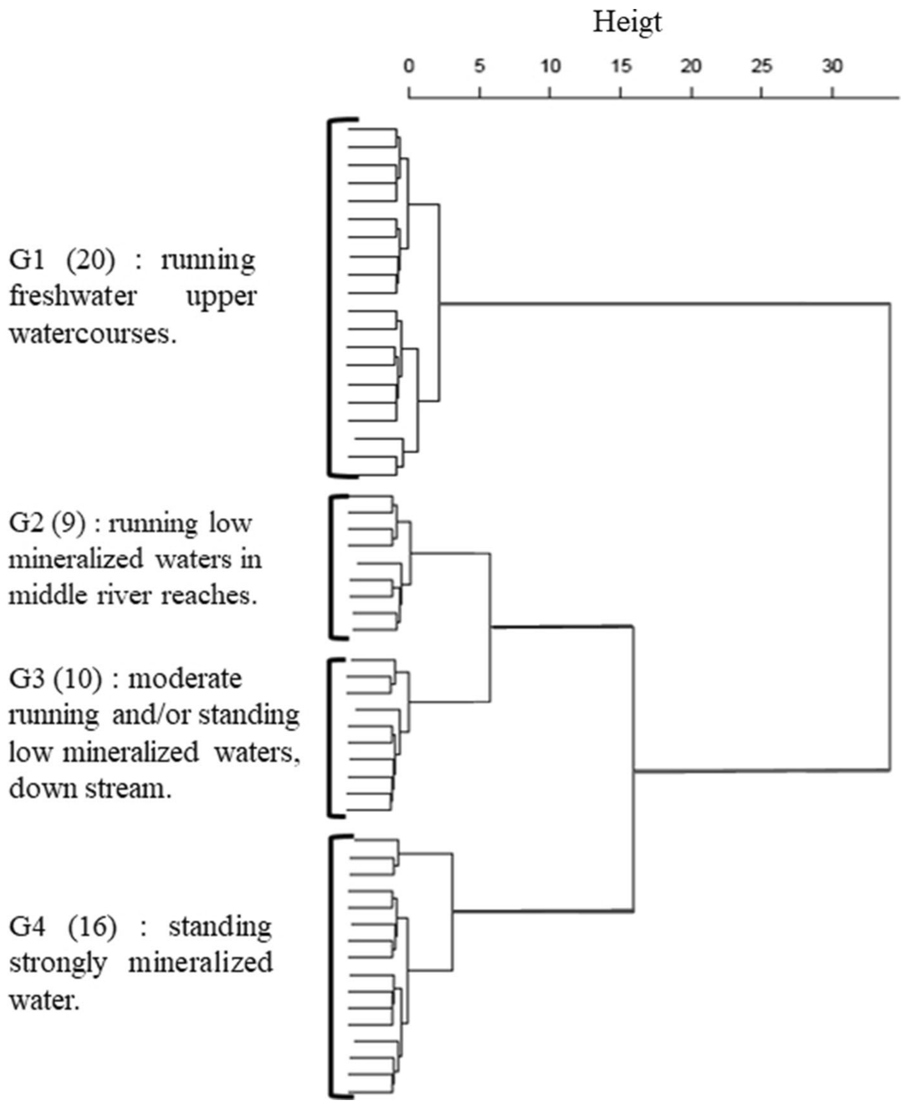

Fig. 4 Dendrogram showing the four groups obtained according to the Bray–Curtis dissimilarity index. Number of sites in parentheses

cinerea (Ncin, tol = 39.5) and *Aquarius cinereus* (Acin, tol = 40.9), indicating their wide distribution, i.e., the largest ecological niches.

The 12 species having a significant marginality are presented in Fig. 5 according to their specialization (marginality) and tolerance. The figure shows that aquatic Hemiptera in Oriental Region of Morocco (except *Aphelocheirus pemae*) overall have low habitat specificity and high plasticity (niche breadth).

The F1 axis expresses, unsurprisingly, the mineralization gradient, indicating that the *Velia ioannis* (Vioa) niche is linked to the low mineralized mountainous streams and that the *Sigara selecta* (Ssel) and *Trichocorixa verticalis verticalis* (Tver) niches are related to highly mineralized hydrosystems (Fig. 6).

Discussion

The 27 species of aquatic Hemiptera identified in this study represent a relatively low richness comparing to that found in other Mediterranean basins with similar environmental characteristics (e.g., Carbonell et al. 2011a). The dominance of running water in the sampling sites prospected could be the main cause of this poor richness, pointing a first indicator quality of

Table 3 Indicator value (IndVal) of taxa or taxon combinations of groups

Group	Taxa or combination of taxa	A	B	IndVal	*p* value	Sig
G1	*Hydrometra stagnorum*	0.6773	0.7619	0.718	0.005	**
	Parasigara favieri	0.97538	0.14286	0.373	0.013	*
	Nepa cinerea + *Hydrometra stagnorum*	0.6202	0.7143	0.666	0.005	**
	Velia ioannis	0.8333	0.4286	0.598	0.016	*
	Hydrometra stagnorum + *Velia ioannis*	0.8333	0.4286	0.598	0.016	*
	Nepa cinerea + *Velia ioannis*	0.8043	0.4286	0.587	0.019	*
G2	*Plea minutissima* + *Mesovelia vittigera*	1.0000	0.2727	0.522	0.011	*
	Mesovelia vittigera	0.8401	0.2727	0.479	0.043	*
G3	*Sigara lateralis* + *Aquarius cinereus*	0.7529	0.2857	0.464	0.047	*
G4	*Trichocorixa verticalis verticalis*	0.9812	0.3750	0.607	0.001	***
	Sigara selecta + *Trichocorixa verticalis verticalis*	0.99267	0.16667	0.407	0.001	***
	Sigara selecta	0.98414	0.18750	0.430	0.001	***
	Sigara scripta + *Aquarius cinereus*	1.0000	0.3125	0.559	0.009	**
	Sigara scripta + *Micronecta scholtzi*	0.9650	0.3125	0.549	0.015	*
	Sigara scripta + *Notonecta maculata*	1.0000	0.2500	0.500	0.016	*

A = Specificity, B = Fidelity, Sig. = Significance level

Significance codes: *** 0.001, ** 0.01, * 0.05

this group of insects, i.e., the preference of most hemipterans for standing waters. Nevertheless, the majority of species also showed a broad general distribution (Taybi et al. 2018b) as well as an ample repartition within the study area, reflecting their ubiquitous character, but also an overall high dispersal capacity, limiting their indicator value. Only five species have restricted distribution, being endemisms (see Table 2), reflecting that a small number of the species pool found are presumably capable to provide more specific characteristics associated with the water bodies where they are living, being apparently better indicators and of interest for biodiversity conservation purposes.

Although there is a whole range of environmental factor governing distribution, structure and assemblage composition of aquatic insect communities (e.g., Jacobsen et al. 2010; Mabidi et al. 2017), information about what of such environmental factors are related to the distribution and assemblages of aquatic Hemiptera is still poorly known. Here, within the strong altitudinal and water temperature gradient studied, we have found that conductivity and current velocity also play an important role in the species distribution of this group. Conductivity was also considered as one of the most important drivers of the aquatic Hemiptera distribution in several Mediterranean basins (Moreno et al. 1997; Karaouzas and Gritzalis, 2006; Carbonell et al. 2011a). The harsh environmental conditions occurring in saline ecosystems are an insurmountable barrier for many species and shape the kind of organisms that inhabit water bodies depending on their salt concentration (Millán et al. 2011). Similarly, current velocity is contemplated as crucial for the distribution of most macroinvertebrate groups, including Hemipterans (Millán et al. 2002; Mellado-Díaz et al. 2008; Carbonell et al. 2011a), in need of special adaptations to colonize running waters (Statzner and Holm 1982; Schoen et al. 2013; Schoen et al. 2013). Our study, thus, corroborates these previous results showing a certain indicator value of aquatic Hemiptera.

Analyzing the assemblages, we found four groups in a gradient of mineralization and current velocity, demonstrating that aquatic Hemiptera can be organized according to these two main factors, separating the species of the freshwater sampling sites from those preferring localities with mineralized waters in the first axis. However, the second axis dissociated Hemiptera species pool in two groups, one referred

Table 4 Niche parameters of 25 Hemiptera species

	Inertia	OMI	Tol	Rtol	***OMI***	***Tol***	***Rtol***	P value	
Ncin	4.493	0.798	1.774	1.921	**17.8**	**39.5**	**42.8**	**0.001**	
Apem	9.015	8.561	0.009	0.445	**95.0**	**0.1**	**4.9**	**0.001**	
Pfav	4.322	2.371	0.412	1.539	**54.9**	**9.5**	**35.6**	**0.016**	
Ssel	22.964	13.181	6.474	3.308	**57.4**	**28.2**	**14.4**	**0.001**	
Ssta	7.034	1.372	1.839	3.823	**19.5**	**26.1**	**54.3**	**0.048**	
Sscr	4.104	1.716	0.641	1.747	**41.8**	**15.6**	**42.6**	**0.042**	
Slat	2.395	0.983	0.1	1.312	41.0	4.2	54.8	0.129	NS
Msch	3.33	0.808	0.735	1.787	**24.3**	**22.1**	**53.7**	**0.001**	
Mvid	2.348	0.927	0.52	0.901	39.5	22.2	38.4	0.700	NS
Caff	2.228	0.128	0.208	1.893	5.7	9.3	84.9	0.969	NS
Cpun	6.819	0.36	2.716	3.744	5.3	39.8	54.9	0.558	NS
Hver	4.596	0.299	0.389	3.909	6.5	8.5	85.0	0.642	NS
Tver	10.756	4.459	2.441	3.856	**41.5**	**22.7**	**35.8**	**0.001**	
Ngla	6.363	0.649	1.013	4.701	10.2	15.9	73.9	0.160	NS
Noma	3.786	0.583	1.282	1.922	15.4	33.9	50.8	0.071	NS
Adeb	3.029	1.034	0.477	1.518	34.1	15.8	50.1	0.077	NS
Hsta	3.965	1.075	1.315	1.576	**27.1**	**33.2**	**39.7**	**0.001**	
Acin	3.402	0.63	1.39	1.382	**18.5**	**40.9**	**40.6**	**0.001**	
Anaj	3.656	0.752	1.12	1.784	20.6	30.6	48.8	0.074	NS
Nmac	4.291	0.937	1.643	1.71	**21.8**	**38.3**	**39.8**	**0.015**	
Pmin	3.373	0.231	0.559	2.583	6.8	16.6	76.6	0.437	NS
Hatl	1.987	0.748	0.395	0.845	37.6	19.9	42.5	0.223	NS
Vioa	5.948	3.541	1.172	1.235	**59.5**	**19.7**	**20.8**	**0.001**	
Mpyg	3.503	1.323	1.233	0.947	37.8	35.2	27.0	0.072	NS
Mvit	2.765	0.592	0.695	1.478	21.4	25.1	53.5	0.205	NS

The inertia, the outlying mean index (OMI), the tolerance index (Tol), and the residual tolerance index (RTol) were computed for each species

Values in bold and italic represent the corresponding percentages of variability. The last column (Num) represents the number of random permutations (out of 1000) which yielded a higher value than the observed OMI (NS = not significant at an estimate, $P \geq 0.05$). Species are identified by their codes shown in Table 2

to habitats with no water flow to moderate renewal, the second dominated by species preferring standing and high mineralized waters. These results are similar to those obtained in previous studies on this group of macroinvertebrates in similar climate areas (Carbonell et al. 2011a; Slimani et al. 2017). Nevertheless, these outcomes are, probably, not enough to confirm aquatic Hemiptera as good indicators, at least, to consider them better indicators than other macroinvertebrates. As previously pointed, most macroinvertebrates are influenced by conductivity and current velocity, probably, in a more sensitive way (e.g., Mellado-Díaz et al. 2008); therefore, we need contemplating on other characteristics that support the value of aquatic Hemiptera as indicators.

Representative species of assemblage groups could be another possibility to evaluate the role of aquatic Hemiptera as indicators, underlying the best indicator of them. In our case, some species (single and/or species combination, see Table 3) were good representant of the assemblages found, especially those inhabiting running freshwater and standing mineralized water (G1 and G4 groups). So, despite the high dispersive distribution of species, some of them strongly represent specific characteristics of the water bodies where they are living (Moreno et al. 1997; Carbonell et al. 2011a), such as *Hydrometra stagnorum* for running waters (Millán et al. 1988) or *Sigara selecta* for saline standing waters (Barahona et al. 2005). However, the significant marginality (specificity) of 12 out of the 25 species, as well as their moderately high residual tolerances, indicates that the environmental variables studied explain only partly (average influence = 48%) the distribution of most aquatic Hemiptera in Oriental Region of Morocco. So, we considered to study the niche breadth of species hypothesizing that ubiquitous and largely widespread

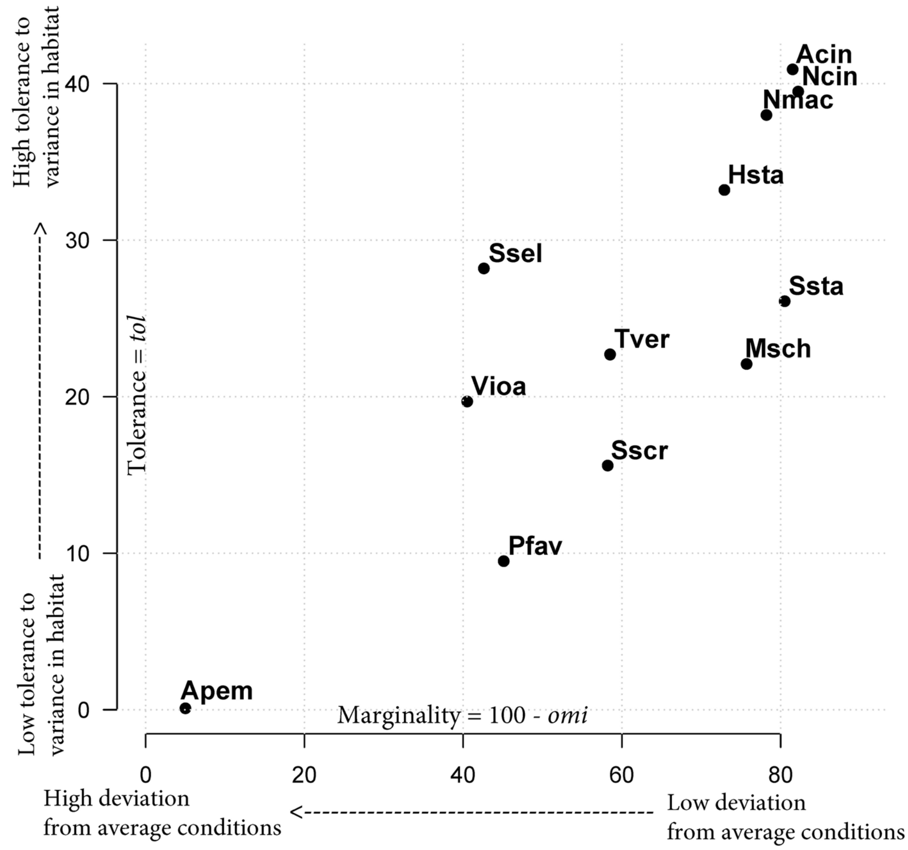

Fig. 5 Hemiptera' total marginality (i.e., ecological niche deviation from average conditions found in the environment) versus total tolerance (i.e., capacity to adjust to any variance in habitat composition). Species are identified by their codes in Table 2

species should have ample niches (Cardillo et al. 2019) and consequently a less indicator value.

Our results point out a overall high amplitude in the niche of most species showing their low specialization in the entire studied gradients, with a general preference for a moderate mineralization and low current velocity (or standing waters), but also a high species environmental tolerance that makes them capable to colonize a great variety of water bodies in this gradient of salinity and water renewal. The general high dispersal capacity and air oxygen consumption allow most species of aquatic Hemiptera to migrate when the environmental characteristics become unfavorable (Nieser et al. 1994; Velasco and Millán 1998; Polhemus and Polhemus 2008). This finding is consistent with the results obtained by Usseglio-Polatera et al. (2000), who suggested that environmental preferences and biological traits are generally homogeneous in aquatic Hemiptera. Thus, with the exception of some well-known rheophilous, as *Velia ioannis*, or halophilous species, as *Sigara selecta* (Carbonell et al. 2011a), and, mainly, the rare Moroccan endemism *Aphelocheirus pemae* (Millán et al. 2016), not other of the water bug species studied can adequately be considered as good indicator.

Within the Moroccan aquatic Hemiptera, species of the genus *Aphelocheirus* are surely distinguished, and there is a consensus considering them as exceptional indicators of water quality, to which are assigned the highest values when applying biotic indices due to their ecophysiological characteristics (Alba-Tercedor et al. 2002). The flattened shape of their bodies improves the plastron's performance and increases their surface area, thus favoring the accumulation of oxygen, consequently allowing them to spend almost all of their life underwater between the gravel (Papácek and Soldán, 2008). In the Palearctic region, *Aphelocheirus* species can live in the benthos of little streams and lakes at a depth less than 10 m (Aukema and Rieger, 1995). In the Iberian Peninsula, the main

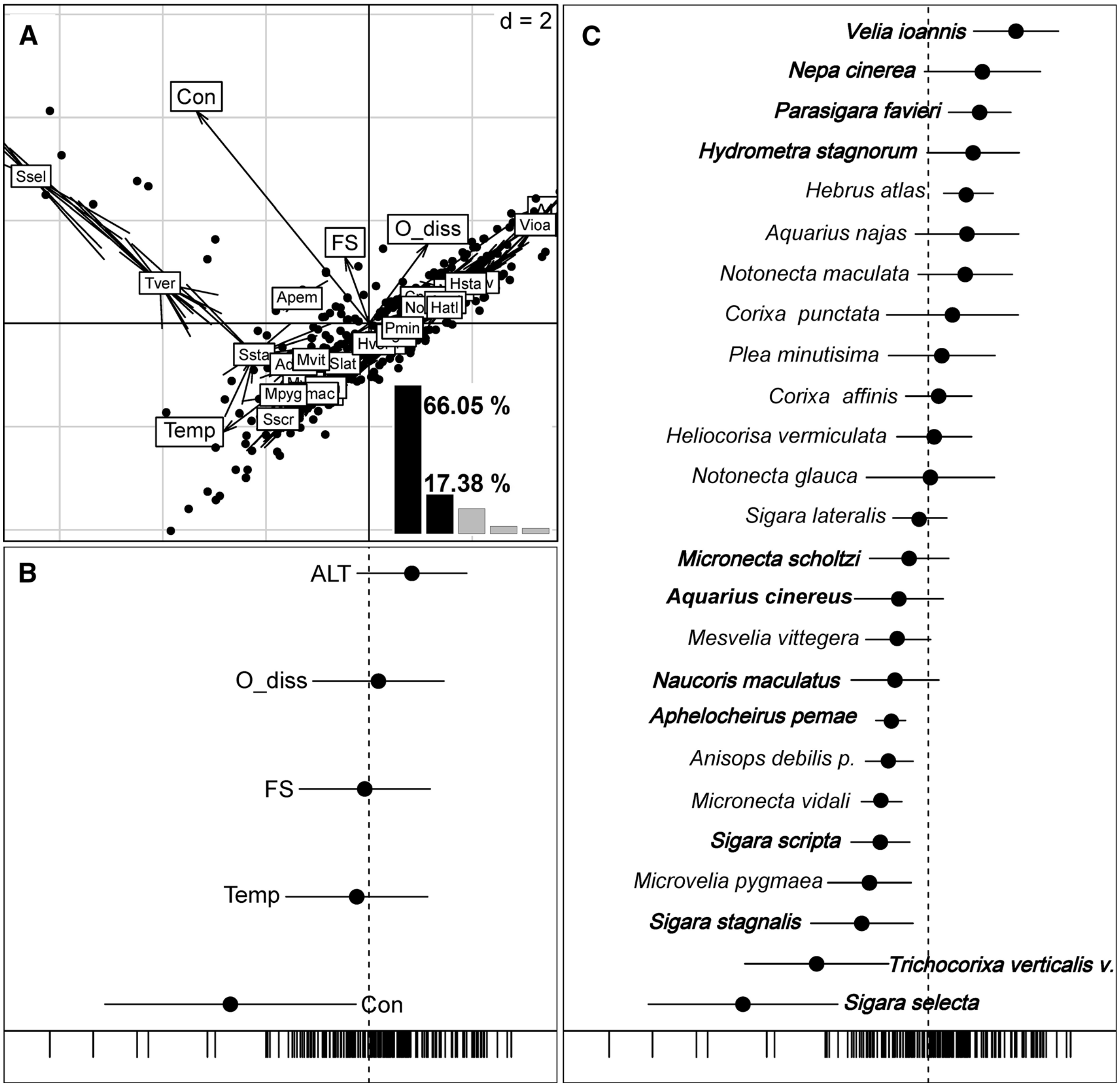

Fig. 6 Outputs of the outlying mean index (OMI) analysis. **a** Factorial design (F1 and F2 axes). **b** Contribution of the environmental parameters to the first axis of the OMI (black dot) and their dispersion in the ecological space (horizontal bars). (C) Species' niche position (black dot) and niche breadth (horizontal bars) along the first axis of the OMI. Species whose marginality is significant are identified by their names

habitats of the genus *Aphelocheirus* are middle and upper reaches of streams and rivers (Carbonell et al. 2011b). However, its infrequent occurrence in lowland rivers is also probable, as is the case for *A. pemae* in Morocco, when such river sections are ample, running and well oxygenated. Indeed, because of its habitat specificity for large rivers, the survival of *A. pemae* could be a real danger given the increase of anthropogenic activities in its very restricted range, in addition to the global changes. These characteristics confer this species the highest value as indicator and key for manage and conservation plans.

Concluding, our results underlie that aquatic Hemiptera as most macroinvertebrates are influenced by the main environmental factor of the basin, in our case degree of mineralization and current velocity.

They are also capable of organizing assemblages related to such factors, but with an important number of species overlapping between assemblages and few value as true assemblage indicators. Indeed, the analysis of the species niche breadth supported the low ecological requirements that aquatic Hemiptera need to colonize different bodies. Only *Aphelocheirus pemae* could be considered as a strong indicators of clean and current waters in more or less ample reaches of rivers, supporting this species as the most important as key species for biodiversity management and conservation.

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Declarations

Conflict of interest The authors that they have no conflict of interest.

Ethics approval *Aphelocheirus pemae* is proposed to be included as threatened species but currently it has no any kind of protection.

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