



## Ecological correlates of odonate assemblages of a Mediterranean stream, Wadi Cherf, northeastern Algeria: implications for conservation

Zineb Bouhala<sup>a,b</sup>, Chakri Khemissa<sup>a,b</sup>, Joaquín Márquez-Rodríguez<sup>c</sup>, Manuel Ferreras-Romero<sup>c</sup>, Farrah Samraoui <sup>a,d</sup> and Boudjéma Samraoui <sup>a,b\*</sup>

<sup>a</sup>Laboratoire de Conservation des Zones Humides, Université 8 Mai 1945 Guelma, Guelma, Algeria; <sup>b</sup>Département de Biologie, University of Annaba, Annaba, Algeria; <sup>c</sup>Department of Physical, Chemical and Natural Systems, University Pablo de Olavide, Seville, Spain; <sup>d</sup>Department of Ecology, Université 8 Mai 1945 Guelma, Guelma, Algeria

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We investigated the odonates of Wadi Cherf, a tributary of Wadi Seybouse, and explored the main environmental factors that may be important drivers of the abundance and diversity of Odonata assemblages. PCA analyses demonstrated a significant altitudinal gradient associated with water flow, temperature, vegetation cover, substrate and adjacent land use. Notably, pollution was a dominant structuring factor and the most widespread species, *Ischnura graellsii* and the North African endemic *Platycnemis subdilata*, were the most pollution-tolerant species. Similarly, co-inertia analysis indicated that environmental factors could account for 70% of the co-variation in shaping odonate assemblages. Equally important, threatened species were associated with less degraded but vulnerable habitats, most susceptible to anthropogenic impacts. There is thus a need to develop monitoring tools to assess the ecological integrity of North African rivers and implement a management plan that considers both connectivity and heterogeneity to ensure that Wadi Cherf, a sanctuary to three threatened species *Calopteryx exul* (EN), *Coenagrion mercuriale* (EN) and *Gomphus lucasii* (VU), continues to provide critical ecosystem functions.

**Keywords:** anthropogenic stressors; conservation; distribution; freshwater biodiversity; global change; river; Odonata; dragonfly

### Introduction

The complex life cycles of Odonata link aquatic and terrestrial communities (Corbet, 1999; Rensburg & Turner, 2009) and their ecological requirements have made them key indicator species of the quality of freshwater ecosystems and the management of aquatic biodiversity (Bried & Samways 2015; Samways, McGeoch & New, 2010). Knowledge of these ecological requirements has been turned into a useful tool for the evaluation of the overall conservation status of aquatic environments and wetland bio-monitoring (Steward & Downing, 2008).

In the last two decades, considerable attention has been devoted to increasing our knowledge of the distribution of Algerian odonates (Boudot et al., 2009; Samraoui & Corbet, 2000a; Samraoui & Menai, 1999). Yet, despite numerous studies, the size of the Algerian territory has made

\*Corresponding author. Email: [bsamraoui@gmail.com](mailto:bsamraoui@gmail.com)

it difficult to access many localities, so previous surveys have generally been confined to accessible sites. Such investigations, though useful, are biased and incomplete as relatively pristine habitats may have been left out of such surveys.

This is the case for the River Seybouse where previous studies of the main affluent, Wadi Cherf, have only been carried out in a small number of sites (Khelifa et al., 2011; Yalles-Satha & Samraoui, 2017). Thus, little is known about the odonates of the upper reaches of the River Seybouse. In addition, these past studies now date back about one decade.

Such a gap in our knowledge has implications for conservation, as the Upper Seybouse is the only known sanctuary for the Endangered *Calopteryx exul*, a Maghrebian endemic (Yalles-Satha & Samraoui, 2017). Indeed, following the first global assessment of Odonata (Clausnitzer et al., 2009), great efforts have been devoted to assessing the status of North African (Samraoui et al., 2010) and Mediterranean odonates (Riservato et al., 2009) but, as multiple anthropogenic stressors like land conversion, pollution and climate change are fast affecting the North African riverine landscape (Hafiane et al., 2016; Morghad, Samraoui, Touati, & Samraoui, 2019), there is an urgency to continually update our knowledge.

Understanding how ecological processes shape odonate assemblages by disentangling the relative influence of biotic and abiotic factors may provide insights into how freshwater communities will respond to ongoing and future disturbances like pollution, climate change and invasive species (Hofmann & Mason, 2005; Rahel & Olden, 2008; Weiher & Keddy, 1999). This paper aims to provide a comprehensive account of the composition and distribution of odonate assemblages of Wadi Cherf and explore how environmental (essentially abiotic) factors drive their diversity and abundance. Another objective of the study is to evaluate how threatened species respond to environmental factors and identify potential threats to their habitats.

## Materials and methods

### *Study area*

Intermittent rivers and streams are known, throughout North Africa and the Middle East, as wadis. Wadi Cherf, located in the northeastern part of Algeria, occupies a surface of 2905 km<sup>2</sup>. It borders three districts (wilayas): Souk Ahras, Guelma and Oum El Bouaghi (Figure 1) and constitutes the upper course of the River Seybouse. Wadi Cherf originates in the eastern Hauts Plateaux at an altitude that varies from 800 m to 1000 m. The climate is typically Mediterranean, divided into a rainy season from October to May and a dry season from June to September. Rainfall ranges from 350 mm/year upstream to 610 mm/year downstream. Contrary to the downstream part of the River Seybouse, there are no industrial plants in the watershed of Wadi Cherf. However, points of discharge of untreated sewage are often present near agglomerations, and wadis are commonly used as drinking water sources for grazing livestock.

### *Sampling*

Monthly sampling was carried out at 22 localities (S1–S22) over a three-year period from 30 July 2014 to 27 June 2017 and totaling 580 samples. At each locality, adult Odonata were sampled by walking slowly and repeatedly along a 50 m transect. Flying adults, often identified to species on sight, were collected using an insect net. These voucher specimens were identified and kept in the laboratory. Odonata have complex life histories that link aquatic and terrestrial communities (Rensburg & Turner, 2009). Adults and larvae display congruent distributional patterns and



Figure 1. Localization of sampled stations in the catchment area of Wadi Charef.

either stage may provide valuable ecological information (Hawking & New, 1999). However, larval sampling and identification is more challenging.

In addition, the main environmental variables were measured *in situ* using multi-probes at mid-water depth (water temperatures, conductivity, current speed, water depth, bed width, “hydroperiod”, riparian vegetation cover (%), and pollution) (Tables 1 and 2). Both substrate and “hydroperiod” were classified in a dichotomic way: hard/soft and permanent/intermittent (having a dry period), respectively. As a proxy to adjacent land use, pollution was measured on a scale from 1 (no obvious pollution) to 3 (severe pollution), based on the presence of algae, plastic debris, building material waste, and/or sewage. Intermediary stage 2 indicates the presence of waste products but to a much lesser extent than in stage 3. At each locality, macroinvertebrates and fish were also monthly collected using a dipnet. The status of recorded species originates from the Mediterranean and the North African IUCN Red Lists (Riservato et al., 2009; Samraoui

Table 1. List of sampled localities with GPS coordinates. T, temporary habitat; P, permanent habitats.

Code	Name	Hydroperiod	Altitude (m)	Latitude (N)	Longitude (E)
S1	Beldjoudi	T	822	36.2231	7.2144
S2	Ben Mheni	T	667	36.1506	7.2806
S3	O. El Maleh	T	748	36.1481	7.1439
S4	Aïn Arko	T	750	36.1264	7.1547
S5	Oued Dahmane	P	752	36.0531	7.3278
S6	Sedrata dam	P	746	36.0594	7.4553
S7	Sedrata bridge II	T	760	36.0522	7.4661
S8	Sedrata bridge I	P	765	36.0744	7.4942
S9	Oued Krab	P	784	36.1200	7.5461
S10	Krab bridge	T	800	36.1319	7.5711
S11	Tiffech bridge	T	860	36.1411	7.7544
S12	Oued Nil	T	864	36.1397	7.4458
S13	Dbabcha	P	610	36.2167	7.3181
S14	Oued Aar	T	617	36.2261	7.3197
S15	Oued Cheniour	P	602	36.2478	7.3433
S16	Aïn Makhlof bridge	P	590	36.2397	7.3114
S17	Aazlat Hlima	T	770	36.2697	7.2836
S18	Chaabet Bounab	T	805	36.2847	7.2844
S19	Oued Boufrais	T	612	36.3158	7.2722
S20	Selaoua	T	589	36.3483	7.2672
S21	Medjez Amar	P	249	36.4431	7.3108
S22	Aïn Makhlof dam	P	643	36.2261	7.2967

et al., 2010). Sampling details and data analyses of macroinvertebrates and fish will be reported elsewhere.

### Statistical analysis

Two-way ANOVA tests were used to compare mean differences of species richness and overall species abundance (response variables) in samples from localities with different pollution levels and “hydroperiod” (independent variables). Following the two-way ANOVA tests, we conducted Tukey multiple pairwise comparisons to distinguish between the means differences which were significantly different. Prior to the two-way ANOVA tests, both species richness and abundance were square root transformed and, because of the limited data set, pollution levels 3 and 4 were lumped together. To obtain a typology of odonate assemblages and rank environmental variables according to their importance in driving these assemblages, two principal component analyses (PCAs) were performed based on species abundance and environmental variables, respectively, using the package FactoMineR (Lê, Josse, & Husson, 2008). PCA is an exploratory multivariate analysis and a dimension-reduction technique, most valuable in the presence of highly correlated variables.

In addition, co-inertia analysis (CIA), a two-table ordination method, has been used to ordinate samples by looking for a co-structure between environmental variables and odonates (Dolédéc & Chessel, 1994). The significance of the correlation (RV) between the two sets of coordinates resulting from the CIA was tested by performing 10,000 CIAs of the abiotic variables and the odonate datasets after random permutations of their rows (Dolédéc & Chessel, 1994). The RV coefficient, which has a range of 0 to 1, provides the overall measure of similarity of two data tables using a multivariate extension of the Pearson correlation coefficient. A high RV suggests a high degree of co-structure. All means are shown  $\pm$  standard deviation, unless stated otherwise and all statistical tests were performed using R software (R Development Core Team, 2018).

Table 2. Physical and chemical data of sampled localities.

Code	Locality	Temperature (°C)	Conductivity ( $\mu\text{s cm}^{-1}$ )	Water depth (cm)	Bedwidth (m)	Current speed ( $\text{m s}^{-1}$ )	Pollution	Veg. Cover (%)
S1	Beldjoudi	14.9 ± 5.2	1016.2 ± 430.4	15.2 ± 5.1	2.1 ± 1.0	0.1 ± 0.1	3	40
S2	Ben Mheni	11.8 ± 7.2	884.8 ± 620.0	13.7 ± 3.8	7.0 ± 4.6	0.2 ± 0.1	1	10
S3	O. El Maleh	10.8 ± 4.1	1332.1 ± 354.8	14.7 ± 4.9	5.6 ± 1.8	0.2 ± 0.1	2	90
S4	Ain Arko	14.8 ± 6.2	1085.4 ± 292.6	12.1 ± 4.3	0.9 ± 0.5	0.2 ± 0.1	1	80
S5	O. Dehmane	18.1 ± 5.8	474.7 ± 511.3	18.8 ± 6.2	29.8 ± 56.9	0.1 ± 0.1	3	70
S6	Sedrata dam	17.3 ± 6.5	705.0 ± 692.6	18.2 ± 7.3	107.0 ± 45.2	0.1 ± 0.1	2	70
S7	Sedrata bridge 1	16.9 ± 5.9	929.6 ± 770.6	43.1 ± 28.1	6.1 ± 1.3	0.1 ± 0.1	2	20
S8	Sedrata bridge 2	13.9 ± 5.7	486.3 ± 628.4	16.9 ± 6.5	6.8 ± 3.6	0.2 ± 0.1	1	80
S9	O. Krab	18.4 ± 6.1	1125.1 ± 505.4	32.1 ± 16.6	10.8 ± 4.1	0.2 ± 0.1	2	20
S10	Krab bridge	17.9 ± 6.6	967.6 ± 423.7	19.9 ± 11.8	2.7 ± 1.7	0.1 ± 0.1	3	70
S11	Tiffech bridge	15.2 ± 6.1	612.2 ± 201.3	25.7 ± 11.9	5.0 ± 1.5	0.2 ± 0.3	1	70
S12	O. Nil	16.6 ± 5.0	1094.2 ± 642.7	17.6 ± 6.4	2.6 ± 1.0	0.3 ± 0.2	1	10
S13	Dbebcha	19.1 ± 7.0	688.2 ± 684.7	20.5 ± 7.0	14.7 ± 7.7	0.3 ± 0.1	2	10
S14	O. El Aar	18.6 ± 8.1	626.3 ± 266.2	14.2 ± 5.0	2.9 ± 1.6	0.4 ± 0.3	1	10
S15	O. Cheniour	18.1 ± 4.7	512.7 ± 152.7	18.2 ± 6.7	2.0 ± 1.2	0.3 ± 0.2	1	20
S16	Ain Makhlouf bridge	18.8 ± 6.6	756.5 ± 618.3	30.0 ± 16.6	9.3 ± 5.6	0.3 ± 0.2	3	20
S17	Azlet Hlima	11.4 ± 4.4	580.7 ± 137.1	15.0 ± 5.1	1.1 ± 0.4	0.3 ± 0.3	1	20
S18	Chabet Bounab	15.1 ± 7.2	474.5 ± 289.6	12.2 ± 8.6	7.6 ± 4.5	0.3 ± 0.2	1	70
S19	O. Boufrais	13.9 ± 4.6	1000.9 ± 332.5	13.8 ± 4.8	3.0 ± 1.4	0.2 ± 0.1	1	60
S20	Selaoua	17.3 ± 4.8	664.2 ± 143.5	20.0 ± 6.5	3.5 ± 1.3	0.1 ± 0.1	1	10
S21	Medjez Amar	20.3 ± 6.9	925.5 ± 645.3	27.6 ± 12.4	19.1 ± 12.1	0.4 ± 0.3	3	10
S22	Ain Makhlouf dam	16.6 ± 5.1	786.0 ± 249.2	17.5 ± 5.9	1.9 ± 0.7	0.2 ± 0.2	2	70

Table 3. Checklist of recorded odonates at Wadi Cherf with list of localities.

Num	Family	Species	Localities
1	Calopterygidae	<i>Calopteryx exul</i> Selys, 1853	S10, S13, S15
2		<i>Calopteryx haemorrhoidalis</i> (Vander Linden, 1825)	S1, S9, S10, S13, S15, S21, S22
3	Lestidae	<i>Chalcolestes viridis</i> (Vander Linden, 1825)	S13, S22
4	Coenagrionidae	<i>Ischnura graellsii</i> (Rambur, 1842)	S1, S3-10, S13, S14, S16, S17, S19, S21, S22
5		<i>Ischnura pumilio</i> (Charpentier, 1825)	S3, S4, S8, S22
6		<i>Coenagrion caerulescens</i> (Fonscolombe, 1838)	S4-6, S8-11, S16, S19, S21
7		<i>Coenagrion mercuriale</i> (Charpentier, 1840)	S1, S4, S5, S7-10, S22
8		<i>Erythromma lindenii</i> (Selys, 1840)	S1, S4, S8, S9, S16, S21, S22
9		<i>Ceriagrion tenellum</i> (de Villers, 1789)	S1, S10
10	Platycnemididae	<i>Platycnemis subdilatata</i> Selys in Lucas, 1849	S1, S4-12, S14, S16-18, S22, S23
11	Aeshnidae	<i>Anax imperator</i> Leach in Brewster, 1815	S7, S11, S20
12		<i>Anax parthenope</i> (Selys, 1839)	S6
13	Gomphidae	<i>Gomphus lucasii</i> Selys in Lucas, 1849	S13, S16, S22
14		<i>Onychogomphus costae</i> Selys, 1885	S14, S16
15		<i>Onychogomphus forcipatus unguiculatus</i> (Vander Linden, 1820)	S14
16	Libellulidae	<i>Orthetrum coerulescens anceps</i> (Schneider, 1845)	S10, S11
17		<i>Orthetrum nitidinerve</i> (Selys, 1841)	S5, S9, S10, S17
18		<i>Crocothemis erythraea</i> (Brullé, 1832)	S8, S22
19		<i>Sympetrum fonscolombii</i> (Selys, 1840)	S1, S10, S11, S16, S22
20		<i>Sympetrum meridionale</i> (Selys, 1841)	S10
21		<i>Sympetrum striolatum</i> (Charpentier, 1840)	S1, S4, S11, S21

## Results

We collected 537 adults with a biased sex-ratio of 326 males to 211 females. A total of 21 species belonging to 13 genera and seven families were identified (Table 3). Two zygopterans, *Ischnura graellsii* and the Maghrebic endemic *Platycnemis subdilatata*, were the most abundant and most widespread, being found at 16 of the 22 sampled stations (Figure 2). Two more species, *C. exul* (EN) and *Gomphus lucasii* (EN), are considered threatened on both the Mediterranean and the North African IUCN Red Lists. In addition, *Coenagrion mercuriale* (EN) is considered threatened on the North African Red List while being assessed as NT on the Mediterranean Red List. Another species, *Onychogomphus costae*, figures as NT on both IUCN Red Lists.

The flight period stretched between April and November with adults' abundance and species richness peaking in June. Species richness varied markedly along the watercourse stations from 0 (S2, S12 and S18) to 11 (S10) (Figure 3). Once our null hypothesis of an absence of interaction between pollution and hydroperiod was corroborated for species richness (two-way ANOVA:  $F_{2,16} = 3.57$ ,  $p = 0.052$ ) and abundance (two-way ANOVA:  $F_{2,16} = 2.52$ ,  $p = 0.112$ ), we fitted an additive model which indicated that both pollution (two-way ANOVA:  $F_{2,18} = 3.94$ ,  $p = 0.038$ ) and hydroperiod (two-way ANOVA:  $F_{1,18} = 5.42$ ,  $p = 0.032$ ) had a marginal influence on species richness. Tukey multiple pairwise-comparisons indicated a marginal difference in mean species richness between unpolluted sites (1) and polluted sites (3) ( $p = 0.055$ ) (Figure 4a). In addition, Odonates' abundance was also significantly influenced by pollution (two-way ANOVA:  $F_{2,18} = 7.44$ ,  $p = 0.004$ ) while hydroperiod had no effect ( $F_{1,18} = 3.40$ ,  $p = 0.082$ ). Tukey multiple pairwise-comparisons indicated a highly significant difference between unpolluted sites (1) and polluted sites (3) ( $p = 0.007$ ) (Figure 4b).

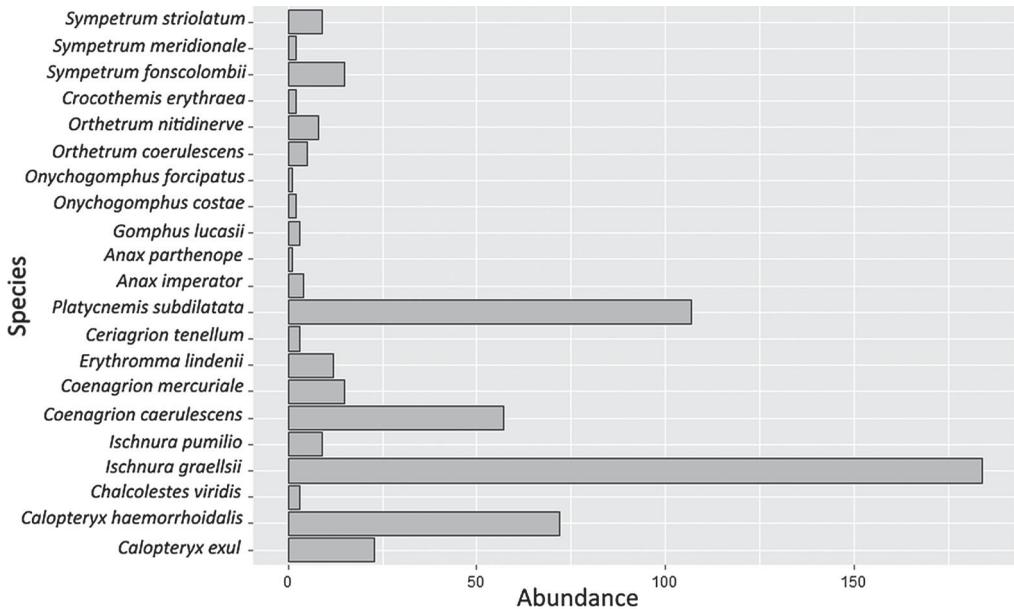


Figure 2. Barplot of species' abundance at Wadi Cherf.

PCA of the measured descriptors indicated a substantial variation of the physico-chemical properties among the sampling sites (Figure 5). The first four components represented 77.3% of the total variance. The first component (30.3% of the inertia) was associated with the altitudinal gradient and the vegetation cover that opposed lower temperature, upstream habitats with a dense vegetation (S1, S3, S4) to warmer, sparsely vegetated downstream sites (S13, S15, S16, S21). The second component (23.6% of the total inertia) separated fast-flowing, intermittent, narrow streams with relatively clean waters and hard substrates (S2, S17) to slow-flowing, permanent wider stretches of the watercourse with polluted waters and clay and sand-dominated substrates (S5, S6). The third component (14.4% of the total inertia) isolated sites with high conductivity and water depth (S7) from sites with comparatively low conductivity and water level (S6, S8). Similarly, the fourth and most minor component (8.8% of the inertia) opposed downstream sites with relatively high conductivity (S3, S21) to upstream sites with low conductivity (S7, S11). The results indicated some degree of collinearity between a number of environmental factors (e.g. vegetation cover and altitude).

The first three components of the PCA based on the odonate matrix totaled 48.8% of the total variance (Figure 6). The first component (18.5%) separated species-rich sites such as S9 and S10 inhabited by *Calopteryx haemorrhoidalis*, *Ceriagrion tenellum*, and *Orthetrum chrysostigma* from species-poor sites (S2, S12, S18). The second component (17.0% of the inertia) set apart a site (S22) adjacent to a reservoir and characterized by lentic species (*Sympetrum fonscolombii*, *Crocothemis erythraea*) found along lotic species (*Coenagrion mercuriale* and *Erythromma lindenii*). The third component (13.3% of the inertia) segregated nutrient-rich sites dominated by helophytes inhabited by *Ischnura pumilio* and *Coenagrion caerulescens* from less-polluted sites with riparian vegetation dominated by *C. exul*, *G. lucasii* and *Chalcolestes viridis*.

CIA coupled the fauna and descriptors matrices and organized the odonate assemblages of Wadi Cherf along the first axis (70.4% of the total inertia) that segregated polluted sites with high water temperatures and soft substrates occupied by *I. graellsii* and *P. subdilatata* from cleaner sites with fast-flowing current and hard substrate (Figure 7a). The second axis (17.6% of the total inertia) expressed an altitudinal gradient which opposed high altitude intermittent

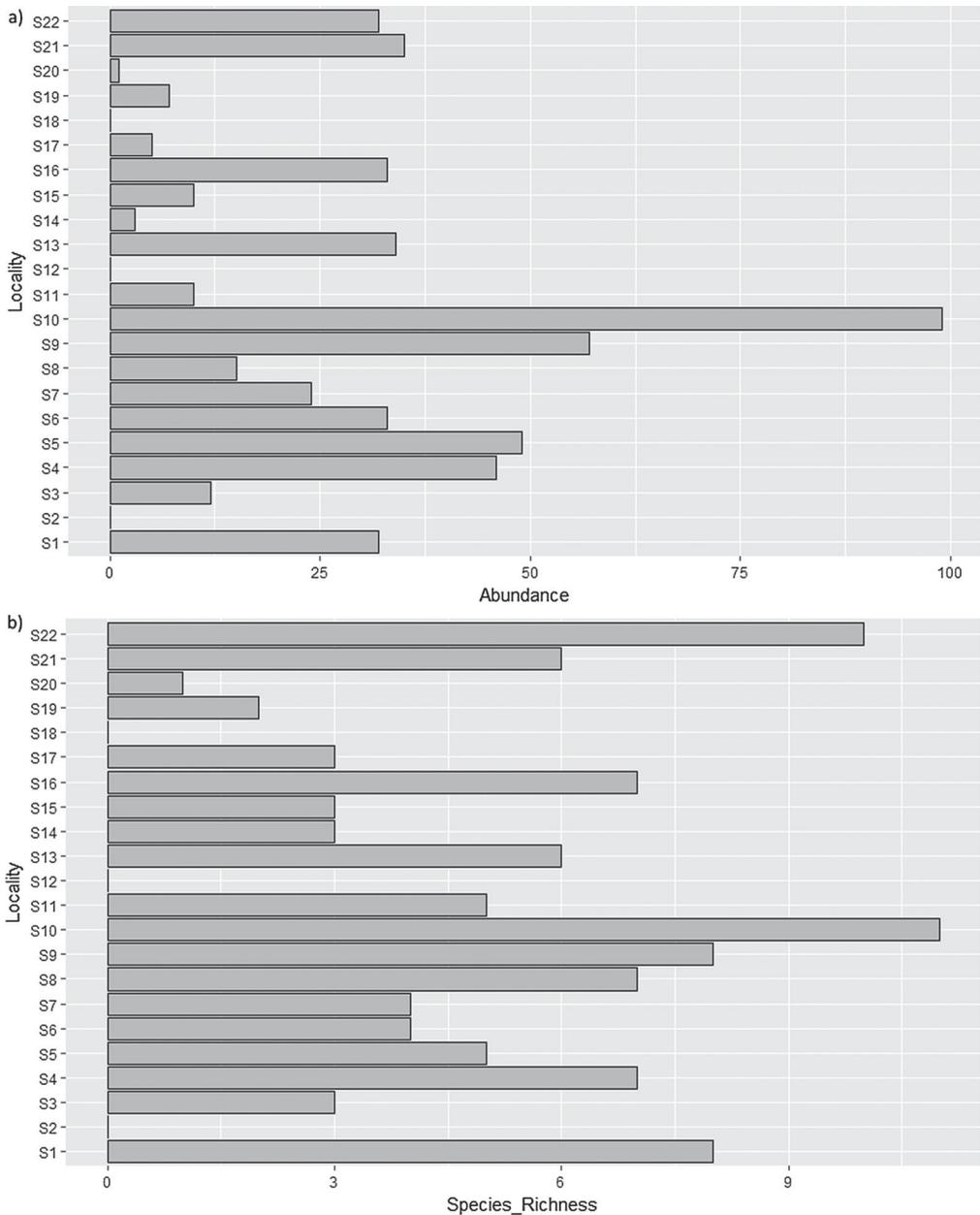


Figure 3. (a) Total abundance and (b) species richness of odonates at sampled localities of Wadi Cherf.

sites with dense vegetation, dominated by *C. haemorrhoidalis* and *C. caerulea*, to downstream fast-flowing permanent sites with high water depth dominated by *P. subdilatata*. The RV-coefficient, an index of the strength of the relationship between the two tables, was 0.26. A potential co-structure was tested using a permutation test which, however, indicated an only marginally significant relationship ( $p = 0.12$ ) (Figure 7b).

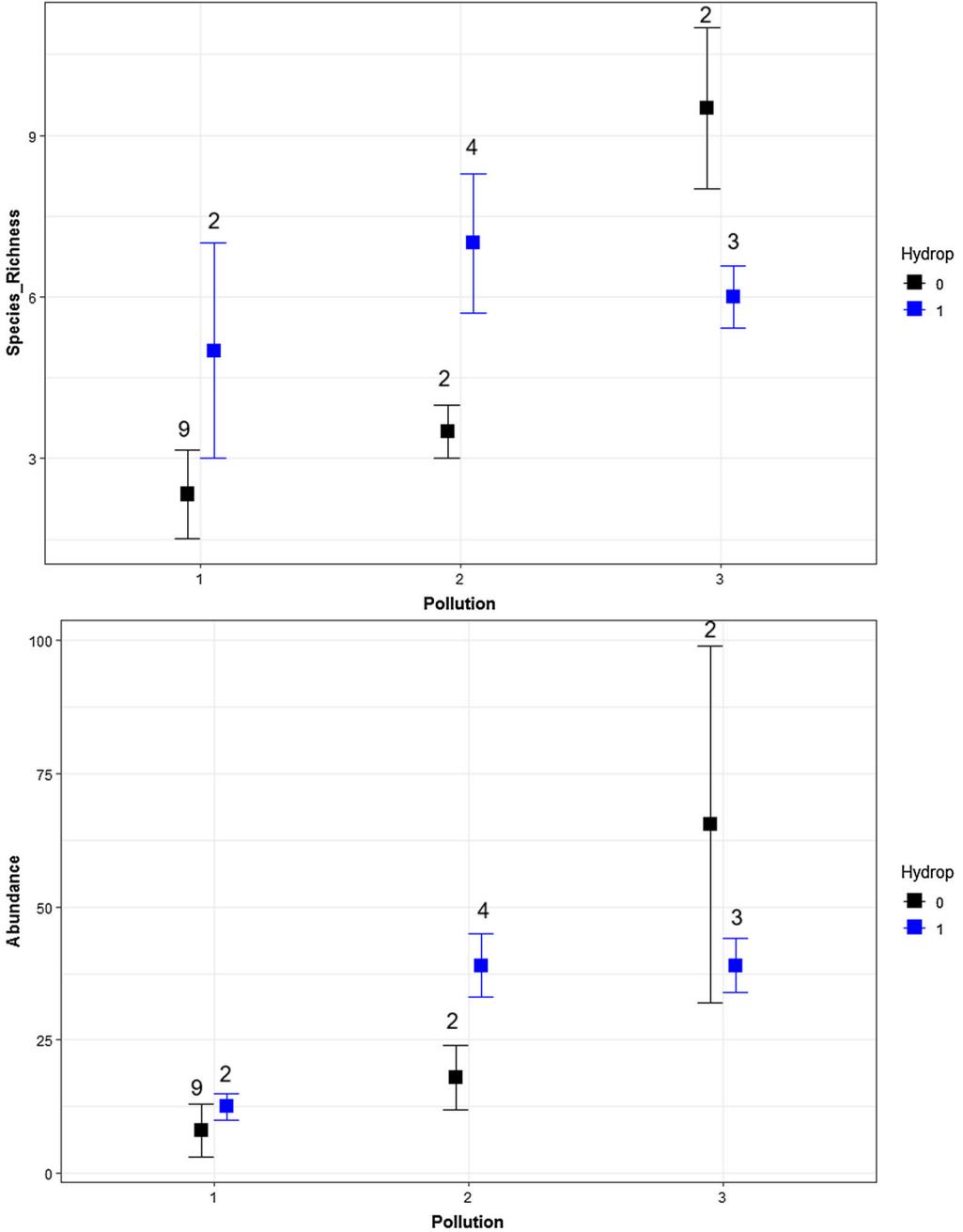


Figure 4. Interaction plot of pollution and hydroperiod for a two-way ANOVA of (a) species richness and (b) abundance. Square points represent means, and error bars indicate standard errors of the mean.

**Discussion**

Noteworthy is the finding of two new localities for the Endangered Maghrebian endemic *C. exul* (Figure 8a) which is recorded to be locally abundant in one of these two sites. Over the last three decades and despite extensive efforts across Algeria, *C. exul* has never been found outside the

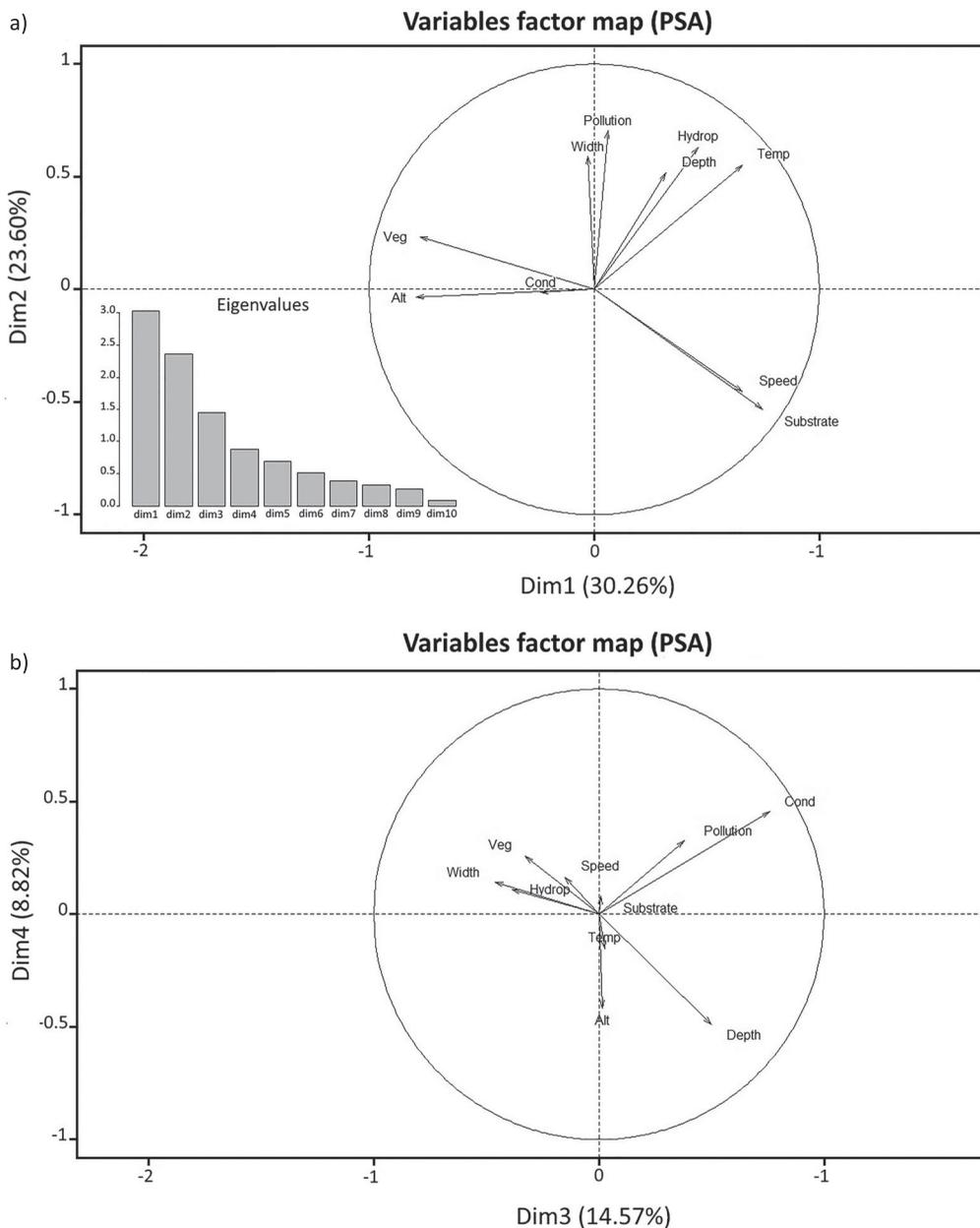


Figure 5. Descriptors factor map of principal component analysis with scree plot (inset). (a) First two components and (b) components three and four.

River Seybouse and its affluents which can be considered as a hotspot for Mediterranean fresh-water biodiversity (Riservato et al., 2009). Wadi Cherf is also a sanctuary for another Vulnerable Maghrebien endemic, *G. lucasii* (Figure 8b), and the Endangered *C. mercuriale*.

This study also indicated that while the flight period stretched between April and October for the majority of recorded species, some species, e.g. *C. viridis*, were observed flying up to November, as shown by previous studies (Agüero-Pelegrín, Ferreras-Romero & Corbet, 1999; Ferreras-Romero & Márquez-Rodríguez, 2014; Samraoui, 2009). Temporal abundance and



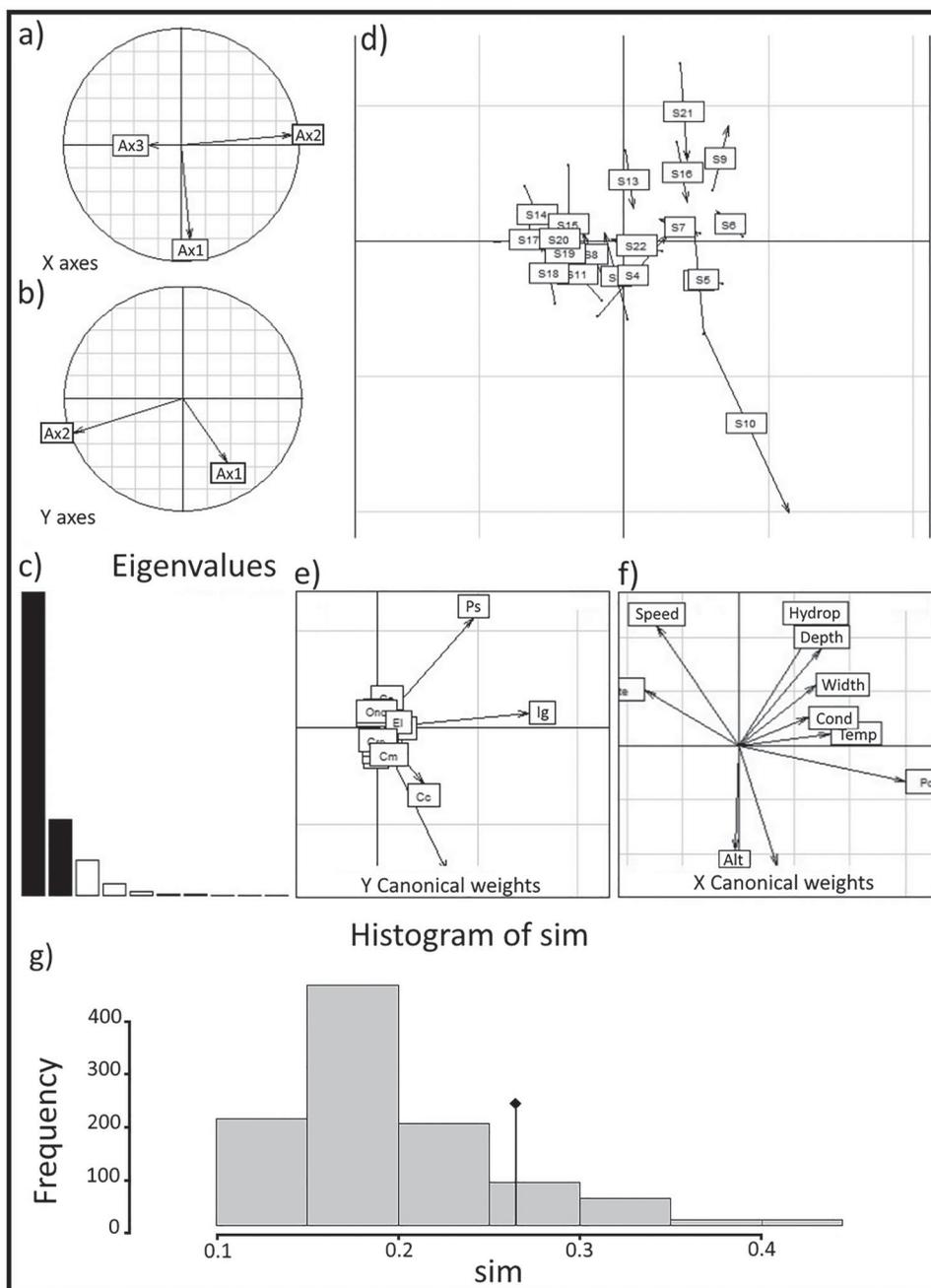


Figure 7. Results of the co-inertia analysis (CIA) using recorded Odonata abundance and measures of environmental descriptors at Wadi Cherf. (a) Components of the standardized principal component analysis of the environmental dataset projected onto the co-inertia axes; and (b) components of the centered principal component analysis of the odonatological data set projected onto the co-inertia axes. (c) Distribution of eigenvalues of CIA. (d) F1 x F2 factorial plane of CIA with arrows linking localities according to physico-chemical descriptors (base of arrows) and Odonata (end of arrows). (e) Distribution of species on the F1 x F2 factorial plane of CIA. (f) Distribution of environmental descriptors on the F1 x F2 factorial plane of CIA. (g) Results of the permutation test to measure the strength of the relationship between the two tables (species/descriptors).



Figure 8. Close-up views of the threatened Maghrebian endemics (a) *Calopteryx exul* and (b) *Gomphus lucasii*.

A quadratic effect of disturbance has been shown in other Algerian wadis (Bouchelouche, Kherbouche-Abrous, Mebarki, Arab & Samraoui, 2015; Hafiane et al., 2016), but the underlying processes are not clear. Whether pollution may favor species richness at intermediate levels (Connell, 1978; Wilkinson, 1999) is still a contentious issue (Fox, 2013) and nonsignificant,

unimodal and monotonic relationships between diversity and one of many characteristics of ecological communities (productivity, disturbance, spatial and temporal heterogeneities, predation, etc.) may occur with similar frequencies (Gillman & Wright, 2006).

Equally important, our results indicated congruence between both *P. subdilatata* and *I. graellsii* and polluted sites. Some odonates, like *Ischnura* spp., are well known for their capacity to withstand pollution (Campos et al., 2014; Ferreras-Romero, Márquez-Rodríguez, & Ruiz-García, 2009; Solimini, Tarallo & Carchini, 1997; Yalles-Satha & Samraoui, 2017). This finding provides support to the reliability of our pollution index at detecting water quality deterioration.

At the same time, our results indicated an association between intermittent/permanent habitat and odonate community structure. Permanent sites which were unpolluted or had low levels of pollution had a higher abundance of adults and a higher species richness than equivalent intermittent sites, suggesting that drought may affect local Odonata assemblages. Drought is recognized as an important stressor of Mediterranean hydrosystems which are exposed to a seasonal sequence of extreme flooding and drying, driven by a wide range of natural and anthropogenic disturbances (Bond, Lake & Arthington, 2008; Gasith & Resh, 1999; Hershkovitz & Gasith, 2013). Thus, it is expected that Mediterranean odonates' life history traits would be shaped by habitat and disturbances (Ferreras-Romero & García-Rojas, 1995; Samraoui, Bouzid, Boulahbal & Corbet, 1998; Schridde & Suhling, 1994; Statzner, Doledec & Hugueny, 2004) and their assemblages might reflect these selective pressures.

Because of increased demands of fresh water for human welfare, water abstraction for agriculture is widespread in North Africa and the presence of large dams and small impoundments alters flow regime, decreases ecosystem connectivity and exacerbates the impact of pollution (Karaouzias, Theodoropoulos, Vardakas, Kalogianni & Skoulikidis, 2018) with severe impact on macroinvertebrate communities (Bredenhand & Samways, 2009).

The PCA results suggested that pollution was collinear to both bed width and water conductivity. High values of electrical conductivity often indicate the presence of pollutants affecting water quality (Ding et al., 2015; Loock, Beukes & van Zyl, 2015). The results also showed that both environmental factors and odonates exhibited a significant altitudinal gradient, a result shown previously in the Middle and Lower Seybouse (Yalles-Satha & Samraoui 2017). As found in other studies (Allan, 1975; Culp & Davies, 2011; Hawking & New, 1999; Suhling, 2001; Ward & Voelz, 1998), this longitudinal zonation was associated with factors such as water flow, temperature, conductivity, substrate, pollution, bed width, vegetation cover, and biotic interactions. As a result, pollution-tolerant species like *I. graellsii* or *P. subdilatata* could be found in degraded habitats, whereas threatened and endemic species like *C. exul* and *G. lucasii* were confined to relatively well-preserved habitats with relatively clean water and well-preserved riverine vegetation. The CIA confirmed the presence of a longitudinal gradient but the co-structure between the fauna and the environmental descriptors could not be statistically demonstrated, possibly because of the limited number of sampling stations. Alternatively, other unmeasured factors could influence the distribution of odonates along Wadi Cherf.

Equally important are interspecific interactions to understand species co-occurrence (Schoener, 1982; Suhling, 1999) which may inform us on mechanisms by which species are distributed and whether they may coexist (Chesson, 2000; McPeck & Brown, 2000; Suhling, 1996). For example, the resilience of stressed macroinvertebrate communities is frequently tested by the colonization of degraded habitats by opportunistic, thermophilic, and highly dispersive species (Hafiane et al., 2016). The steady invasion of stressed North African wadis by thermophilic species (*Paragomphus genei*, *Brachythemis impartita*, *Diplacodes lefebvreii*, *Trithemis arteriosa* and *T. kirbyi*) and the concomitant extinction of threatened species has been well documented in the region (Morghad et al., 2019; Yalles-Satha & Samraoui, 2017).

## Conservation

If considerable efforts over the last decades have been directed towards the protection of freshwater habitats, these efforts have been mainly focused on lentic habitats like freshwater lakes, salt lakes and ponds, and their vertebrate (mainly birds) communities (Samraoui & Samraoui, 2008). An indication of the neglected and sorry state of North African freshwater habitats is the proportion of threatened species in the region, which is higher, at 24.4%, than the 10% assessed worldwide (Clausnitzer et al., 2009; Samraoui et al., 2010).

Our results indicate that the upstream region of Wadi Cherrif is still able to host threatened species confined to upstream habitats, relatively well preserved. Therefore, conservation efforts need to prioritize these habitats for protection. Unfortunately, neither wadis nor invertebrates figure prominently in Algeria's conservation strategy and unless urgent steps are taken to mitigate the current rate of habitat degradation and biodiversity loss of rivers and streams in North Africa, the ongoing anthropogenic pressures will disrupt the functioning of lotic ecosystems with ineluctable adverse consequences for human livelihoods in an already water-stressed region (Droogers et al., 2012; Islam & Susskind, 2015).

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## ORCID

Farrah Samraoui  <http://orcid.org/0000-0003-2407-3004>

Boudjéma Samraoui  <http://orcid.org/0000-0002-0608-9021>

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