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Diversity and distribution patterns of benthic insects in streams of the Aurès arid region (NE Algeria)

by

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Abstract

The objective of the present study was to document the knowledge about the biodiversity of benthic insect communities and their distribution patterns in the semi-arid bioclimatic stage in the streams of the Aurès Region (NE Algeria). The distribution patterns of communities were analyzed in relation to some environmental factors: physicochemical water parameters and global habitat characteristics, including human impact. The taxonomic biodiversity of six sampled streams (wadis) comprises 42 insect taxa, belonging to seven orders and 30 families, of which Coleoptera is the most diverse order (15 taxa), whereas Diptera, Trichoptera and Ephemeroptera dominate in terms of abundance. The human impact, flow velocity and some quality parameters of water (potential of hydrogen, nitrite, concentration of orthophosphates and conductivity) were identified as the most influential environmental variables, which allows the prediction of taxonomic diversity indicators. The classification and regression tree analysis (CART) for benthic insects shows the effect of environmental variables (habitat parameters and human impact in the arid region) on the diversity and distribution of insect orders. The RDA analysis showed that altitude, substrate type, human impact and physicochemical parameters of water (pH, flow velocity, conductivity and total dissolved solids) are the most important predictor variables that play an important role in the distribution patterns of benthic insects.

Key words: aquatic insects, intermittent streams, taxonomic diversity, community structure, disturbance, arid area, NE Algeria

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Introduction

Aquatic ecosystems are dynamic, complex and very important elements of the landscape, because they are characterized by high biological productivity, rich biodiversity, and a multitude of ecological processes and functions (Higler 2009). Dryland regions represent over one third of the world's land area, characterized by a low and variable rainfall pattern, yet sometimes containing a surprising array of aquatic habitats (Jenkins et al. 2005). The presence or absence of water defines much of the ecology of semi-arid and arid landscapes (Stafford Smith, Morton 1990), while rivers and their flows mediate much of the ecological variability (Walker et al. 1995).

Intermittent streams are among the main features of arid and semi-arid regions (Comin, Williams 1994). They are ubiquitous in areas with Mediterranean climate (Gasith, Resh 1999). Physicochemical and biological factors are among the most constraining environmental factors for insect fauna in the majority of these streams (Williams 1996). The patterns of water disappearance are of major importance, regardless of whether they are predictable (i.e. part of a stable cycle) or unpredictable (i.e. associated with vagaries of local climate; Wiggins et al. 1980; Delucchi 1988). Thus, the dry period duration reduces the habitat size. Temperature changes result in subtle changes in water density, which may affect smaller instars of insects, while ionic concentration tends to rise significantly as temporary water dries up, which may affect pH and perhaps have direct osmotic consequences for insects (Williams 1996). Oxygen will be further affected by changes in water temperature, which will increase with disappearance of water in summer-dry water bodies (e.g. autumnal ponds; Wiggins 1973) and decrease in winter-dry water bodies (e.g. summer ponds; Daborn, Clifford 1974).

Thermal fluctuations in the Mediterranean area are sometimes brutal and irregular heavy rainfall is concentrated in short periods of time. The streams in the region are characterized by an irregular hydrological flow (Arab et al. 2004). The hydrological pattern is characterized by a peak of water discharge in spring and autumn and severely low water levels in summer (Giudicelli et al. 1985). In arid regions with low and irregular rainfall, rivers remain dry for long periods of time due to high evaporation during periods of low water flow. The first flood following the period of low water is generally in the form of violent storms that cause heavy runoff. The latter corresponds to flood flow, brings new alluvium and causes a lot of damage that can disturb the living environment of aquatic organisms (Joly 2006).

Studies of benthic invertebrate communities, their structure and spatial distribution are of paramount importance for understanding the functioning and management of natural hydrosystems and for assessing their ecosystem health state (Dakki 1992). Macroinvertebrates, such as insects, are good bioindicators due to their sedentary status, great diversity and variable tolerance to pollution and habitat degradation (Moisan, Pelletier 2008). Perennial and intermittent flow regimes are often perceived as categorically different, flow intermittence varies continuously, and biotic communities vary along gradients of intermittence. For example, taxonomic richness in different aquatic groups continues to decrease as the severity of intermittence increases, which suggests a lack of clear thresholds in the response of communities to flow intermittence (Darty et al. 2014).

In North Africa, streams (wadis) are characterized by an extensive range of physical conditions, including severe flooding and droughts (Pires et al. 1999), irregularity of flows and strong hydrological fluctuations (Giudicelli et al. 1985). The Aurès area in Algeria, corresponding to the eastern part of the Atlas Basin, is characterized by a semi-arid Mediterranean climate. Anthropogenic activities in the region, such as agriculture and sewage discharge, contribute to the degradation of water quality. Low water levels, especially in summer, reduce the self-purification capacity of streams, making them vulnerable to pollution, while aquatic macroinvertebrates are severely affected, especially by summer drought. Some sections of streams may become partially or completely dry and lotic macroinvertebrates can survive by aestivating in cool moist microhabitats (Samraoui 2009), while lentic species prevail during high flow periods, and rheophilic species complete their life cycle and become dominant.

The objective of the study was to document the poorly-known freshwater invertebrate fauna of North Africa, especially insects, and to identify relevant environmental factors (natural or anthropogenic) that shape the structure of freshwater communities in arid-land streams. We have tested two hypotheses:

(i) diversity of benthic insects is significantly lower compared to streams in humid regions due to constraining bioclimatic characteristics of streams in arid areas;

(ii) distribution patterns in streams are different in arid regions from those in humid regions, both in terms of taxonomic diversity, population size and habitat quality bioindicator taxa.

Materials and methods

Description of the study area and the surveyed streams

Our study involved six streams of the Aurès region (NE Algeria), referred to in this work as wadis (Fig. 1 and Table 1). Four of these wadis (W. Chaaba, W. Bouilef, W. El Ma and W. Hamla) are located in the National Park of Belezma (35°32′40″–35°37′46″N; 5°55′10″–6°10′45″E), which was designated a biosphere reserve in June 2015. It occupies 26 250 ha and is mainly dominated by Atlas Cedar Forests (*Cedrus atlantica*). The two others (W. Chelia and W. Yabous) are located in the Chelia mountain range (35°23′15″–35°17′24″N; 6°33′53″–6°45′49″E) that cover approximately 8831 ha and are located in the central part of the Aurasian Atlas. These mountains are mainly dominated by forests of cedar, green oak (*Quercus ilex*) and Aleppo pine (*Pinus halepensis*). The studied wadis are characteristic of the North African arid regions, with their small width and depth and intermittent water flow. The amount of water flowing through these wadis depends on the precipitation in winter, especially on slowly melting snow. The general climate of the park is a seasonal Mediterranean climate, classified globally in the arid climatic stage with cold winters (NPB 2015).

Three sites were explored for each of the six wadis, taking into consideration different levels of human pressure and habitat cover. These were: forest environment, agricultural and domestic activities and urban area. The level (or degree) of human pressure was recorded on an ordinal scale for each site as: (a) forest, (b) agriculture and domestic activities, (c) urban (Table 1).

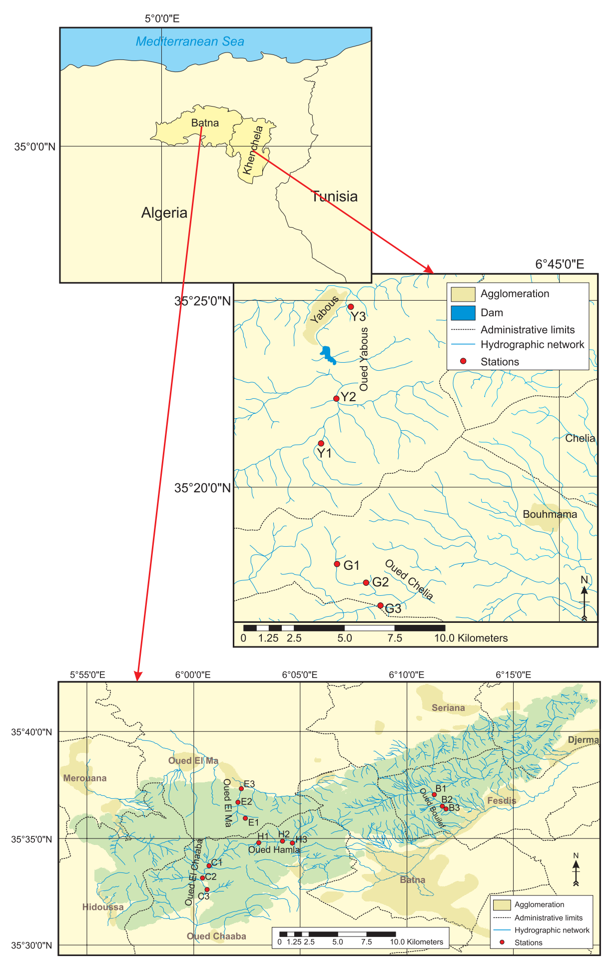

Figure 1

General hydrographic network of the surveyed area with the location of the six wadis and the study sites in the semi-arid region of NE Algeria

Environmental characteristics and water analysis

The stream substrates were classified into one of the four types: (i) fine sand (diameter < 2 mm); (ii) coarse sand (2–25 mm); (iii) stones (25–250 mm); and (iv) rocks (> 250 mm; Tachet et al. 2010), and their percentage cover was assessed visually (Touron-Poncet et al. 2014). The estimated flow velocity of water was weighted in four scales (Berg 1948): (a) very slow ($v < 10$ cm s^{-1}); (b) slow ($10 < v < 25$ cm s^{-1}); (c) moderate ($25 < v < 50$ cm s^{-1}); (d) fast ($v > 50$ cm s^{-1}). The wadis are bordered by low vegetation but no aquatic vegetation was observed.

Physicochemical analysis of water was performed on the same day as the sampling of insects (AFNOR 2005): pH (pH units), electrical conductivity (Cond µS cm^{-1}), salinity (S, PSU), nitrate (NO_3, mg l^{-1}), nitrite (NO_2^-, mg.l^{-1}), orthophosphates (PO_4^{3-}, mg l^{-1}), dissolved oxygen (O_2, mg l^{-1}), total dissolved solids (TDS, mg l^{-1}), chlorine (Cl^- mg l^{-1}), Total/Complete Alkalinity Titration (TAC, mg l^{-1}) and sulfate (SO_4^{2-}, mg l^{-1}).

Sampling of benthic insects

Insects were sampled between March and April 2016. At each of the six sampled wadis, three subsamples were collected from the habitat compartments (substrate) using a Surber net (500 µm mesh size, 0.20 m^2 area; Touron-Poncet et al. 2014). Samples were stored in plastic flasks with 4% formalin (Tachet et al. 2010). The sampled insects were identified to the genus or species according to Tachet et al. (2010).

For each benthic insect family, the abundance frequency ratio (AF%) was calculated as a percentage of the individuals number of a considered family to the

Table 1

General characteristics of the studied streams and sites in NE Algeria

Wadis	Site	Altitude (m)	Longitude (N)	Latitude (E)	Dominant substrate	Human pressure
W. Chaaba	C1	1331	35°33′42″	06°00′43″	coarse sand, stone, rocks	forest
	C2	1270	35°33′07″	06°00′24″	coarse sand, stone, rocks	forest
	C3	1233	35°32′34″	06°00′37″	coarse sand, fine sand, Stone	forest/agricultural
W. Bouilef	B1	1065	35°37′02″	06°11′16″	fine sand, stone	forest/agricultural
	B2	1032	35°36′29″	06°11′39″	coarse sand, rocks	agricultural
	B3	1024	35°36′21″	06°11′50″	coarse sand, stone	agricultural
W. El Ma	E1	1431	35°35′55″	06°02′25″	coarse sand, rocks	forest
	E2	1235	35°36′40″	06°02′05″	coarse sand, stone	forest/ agricultural
	E3	1143	35°37′19″	06°02′14″	coarse sand, stone	urban
W. Hamla	H1	1406	35°34′47″	06°03′03″	fine sand, stone	forest
	H2	1289	35°34′51″	06°04′09″	stone, rocks	agricultural
	H3	1246	35°34′45″	06°04′37″	coarse sand, fine sand	urban
W. Chelia	G1	1560	35°17′30″	06°38′11″	coarse sand, stone, rocks	forest/agricultural
	G2	1415	35°17′04″	06°38′50″	coarse sand, stone	forest/urban
	G3	1320	35°16′47″	06°40′01″	coarse sand, stone, rocks	agricultural
W. Yabous	Y1	1365	35°21′10″	06°38′35″	coarse sand, stone, rocks	forest/agricultural
	Y2	1285	35°21′39″	06°38′37″	coarse sand, stone, rocks	agricultural/urban
	Y3	1097	35°24′54″	06°39′19″	coarse sand, stone, rocks	agricultural/urban

total of all individuals number. For each benthic insect community, we calculated the total taxonomic richness (S), the diversity index of Shannon-Weaver H′ ($H' = -\Sigma p_i \times \log_2 p_i$) and Pielou's evenness index ($J' = H'/H_{max}$, with $H_{max} = \log_2 S$; Magurran 2004).

Statistical analysis

Differences between different wadis in terms of Shannon's diversity index, the evenness and the physicochemical variables (conductivity, pH, temperature, TDS and TAC) were compared by performing separate one-way ANOVAs followed by the Newman-Keuls test when significant treatment effects were found ($p \leq 0.05$). The abundance and other physicochemical variables (S, NO_3, NO_2^-, PO_4^{3-}, Cl^- and SO_4^{2-}) were compared between different wadis using the Kruskal-Wallis test, when the normality of the residuals for these variables was not achieved. The effects of the environmental variables (altitude and human pressure intensity) and the physicochemical parameters of water (conductivity, pH, nitrites and orthophosphates) on the variation of taxonomic richness and abundance were tested using a generalized linear model (GLM). Calculations were made using R (R Development Core Team, 2013), a Poisson-distributed error and a log link function. Only variables with $p < 0.05$ were considered statistically significant.

The effects of the environmental variables on the structure of insect assemblages were examined using the classification and regression tree (CART) analysis. A multivariate regression tree (MRT) was generated for the abundance of six insect orders. The Hymenoptera order was not considered in this analysis, because it was represented by only one individual. The environmental variables: (i) altitude, (ii) human pressure intensity, (iii) substrate type and physicochemical parameters of water (flow velocity, pH, temperature, conductivity, turbidity, salinity, TDS, TAC, NO_3, NO_2^-, PO_4^{3-}, Cl^- and SO_4^{2-}) are the predictor variables included in the construction of the regression tree. The tree size was selected using a cross validation procedure. Thus, the tree was pruned to the smallest structure, for which the error rate was within one standard error of the minimum (De'ath 2002). CART analysis was performed using the mvpart package (Therneau, Atkinson 2013) in the open-source statistical software environment R 3.1.0 (R Development Core Team 2013).

Redundancy Analysis (RDA) was used to examine the insect relationships with 18 sampling sites and 23 environmental variables. Before the analysis, the abundance of insects was transformed using log (n + 1). Forward selection was employed to test which of the environmental variables explained a significant ($p < 0.05$) proportion of taxa variance. The significance of explanatory variables was tested against 500 Monte-Carlo permutations. The k-means algorithm was applied to the scores of the sampling sites on the most significant RDA axes in order to divide the scatterplot into clusters. Statistical tests were performed using the R (R Development Core Team, 2013).

Results

Environmental parameters

The substrate was mainly coarse sand, stones and rocks (Table 1). The temperature of water was significantly lower in W. Yabous, W. Bouilef and W. Chaaba compared to other sites ($p < 0.001$). The pH values were above 7 at all sites and ranged between 7.05 and 8.16; they were significantly more alkaline at W. El Ma and W. Bouilef sites ($p < 0.001$). No significant difference was observed in conductivity and concentration of NH_4^+ between sampling sites ($p > 0.05$). Significantly the highest concentration of PO_4^{3-} was recorded in W. Bouilef compared to other sites in the land-use categories. TDS values, salinity and concentration of NO_2^- showed a slight significant difference between our sampling sites ($p < 0.05$; Table 2).

Structure and diversity of insect communities

A total of 1545 individuals were collected, with 42 genera/species spread over 7 orders and 30 families. Coleoptera were the most diversified group with 14 genera/species. Diptera dominated, accounting for 55.85% of the total abundance. Coleoptera, Plecoptera, Heteroptera and Hemenoptera were less abundant with respectively 3.75, 1.35, 1.10 and 0.65% of the total abundance. Ephemeroptera and Trichoptera accounted respectively for 16.96 and 20.32% of the total abundance. The most abundant families were: Simuliidae (53.98% of the total abundance); Brachycentridae (16.76%) and Baetidae (13.33%; Table 3).

Only the taxonomic richness (S) and Shannon index (H') differed significantly between the sampling sites, with higher scores of S recorded in W. Chaaba compared to W. Hamla ($p < 0.001$; Fig. 2). The highest H' was also determined in W. Chaaba compared to W. Bouilef ($p < 0.001$; Fig. 2). No significant difference in terms of the abundance and Pielou evenness index (J') was recorded between the sampling sites ($p > 0.05$).

The GLM model indicates that abundance and taxonomic richness were determined mainly by altitude, human pressure and physicochemical parameters of water (pH, conductivity and PO_4^{3-}). The analyzed variables were statistically significant except the variation of taxonomic richness with altitude (Table 4).

Effects of the environment factors on the distribution of insect communities

The error in the multivariate regression tree was 0.58, indicating that the obtained three-leaf RT explained 42% of the total variance. The human pressure and substrate type are identified as the main factors predicting the distribution of different taxa within the insect assemblages. In urban areas (human pressure = c) and on stone substrates (S), Diptera were more abundant than other insect orders. In forest

Table 2

Physicochemical characteristics of water at the study sites

Sites	T°	Flow Velocity (cm s^{-1})	pH	Cond (µS cm^{-1})	TDS (mg l^{-1})	Sal (PSU)	NO_2^- (mg l^{-1})	NH_4^+ (mg l^{-1})	PO_4^{3-} (mg l^{-1})
C1	17	25 < v < 50	7.67	517	228	0.2	0.03	0.17	0.14
C2	22	25 < v < 50	7.43	655	289	0.2	0.02	0.06	0.1
C3	17	v < 10	7.66	608	269	0.2	0.03	0.11	0.05
B1	20	25 < v < 50	8.12	702	338	0.3	0	0	16.8
B2	18	25 < v < 50	8.14	722	348	0.3	0	0	2.4
B3	17	25 < v < 50	8.16	725	349	0.3	0	0	0.09
E1	24	25 < v < 50	8.12	615	271	0.2	0.02	0.05	0.02
E2	26	25 < v < 50	7.74	523	230	0.2	0.02	0.02	0.03
E3	24	25 < v < 50	8.04	550	242	0.2	0.02	0.02	0.04
H1	19	10 < v < 25	7.05	633	293	0.2	0.02	0.02	0.08
H2	20	25 < v < 50	7.74	669	303	0.3	0.01	0.17	0.06
H3	20	10 < v < 25	7.82	921	416	0.4	0.02	0.15	0.14
G1	19	v < 10	7.21	665	333	0.3	0	0	0.15
G2	20	25 < v < 50	7.5	741	371	0.3	0	0.18	0.15
G3	19	10 < v < 25	7.1	873	437	0.4	0	0.03	0.15
Y1	17	v > 50	7.37	421	187	0.1	0.01	0.4	0.01
Y2	16	v > 50	7.41	562	247	0.2	0.03	0.05	0.14
Y3	16	v < 10	7.35	662	293	0.2	0.02	0.21	0.04

Table 3

Systematic inventory, codes and abundance of benthic insects collected in six streams of NE Algeria. W.C – Wadi Chaaba; W.B – W. Bouilef; W.E – W. El Ma; W.H – W. Hamla; W.G – W. Chélia; W.Y – W. Yabous. AF (%) – abundance frequency; und. – unidentified taxa

Order/Family	Genus/Species	Code	W.C	W.B	W.E	W.H	W.G	W.Y	AF (%)
Ephemeroptera									
Baetidae	*Baetis* sp.	*Bae*	12.24	29.72	18.2		5.37	11.02	13.33
	Procloeon sp.	*Pro*	1.02		0.24		1.65		0.39
	Acentrella sp.	*Ace*		6.30				2.20	1.42
Heptageniidae	*Heptagenia* sp.	*Hep*	11.22						0.71
	Ecdyonurus sp.	*Ecd*	7.14						0.45
Leptophlebiidae	*Leptophlebia* sp.	*Lep*	3.06						0.19
Caenidae	*Caenis* sp.	*Cae*	1.02	5.40					0.45
		Total Ephemeroptera	35.71	41.44	18.45	0	7.02	13.22	16.96
Plecoptera									
Capiniidae	*Capnia* sp.	*Cap*	4.08						0.26
Chloroperlidae	*Siphonoperla* sp.	*Sip*	2.04			53.84			0.58
	Xanthoperla sp.	*Xan*	3.06						0.19
Nemouridae	*Protonemura* sp.	*Prot*			1.24				0.32
		Total Plecoptera	9.18	0	1.24	53.84	0	0	1.36
Heteroptera									
Notonectidae	*Notonecta* sp.	*Not*					0.41		0.06
Hydrometridae	*Hydrometra* sp.	*Hydrom*	1.02	0.90	0.49				0.26
Mesoveliidae	*Mesovelia* sp.	*Mes*						0.14	0.06
Veliidae	*Microvelia* sp.	*Mic*	6.12					0.44	0.58
Nepidae	*Nepa* sp.	*Nep*			0.24			0.14	0.13
		Total Heteroptera	7.14	0.90	0.74	0	0.41	0.72	1.10
Hymenoptera									
Agriotypidae	*Agriotypus* sp.	*Agr*					4.13		0.65
Coleoptera									
Scirtidae	*Hydrocyphon* sp.	*Hydroc*	25.51			30.76			1.88
Dytiscidae	*Bidessus* sp.	*Bid*			0.24		0.41		0.13
	Agabus sp.	*Aga*			0.24				0.06
	Hydrovatus sp.	*Hydrov*	3.06				0.41	0.44	0.45
	Ilybius fenestratus	*I.fen*			0.24				0.06
	Copelats sp.	*Cop*					0.82	0.44	0.32
	Hydroporinae und.	*Hydrop*	1.02						0.06
Elmidae	*Dupophilus* sp.	*Dup*			0.49				0.13
	Elmidae and	*Elm*			0.74				0.19
Hydrophiidae	*Laccobius* sp.	*Lac*			0.24				0.06
Hydraenidae	*Hydraena* sp.	*Hydra*			0.24				0.06
	Hydroscapha sp.	*Hydros*			0.24				0.06
Noteridae	*Noterus* sp.	*Not*	2.04			7.69			0.19
Spercheidae	*Helophorus* sp.	*Hel*	1.02						0.06
		Total Coleoptera	32.65	0	2.74	38.46	41.64	0.88	3.75
Trichoptera									
Brachycentridae	*Brachycentrus* sp.	*Bra*			2.24		70.24	11.76	16.76
Hydropsychidae	*Hydropsyche* sp.	*Hydrops*	6.12	42.43	0.24				3.5
	Cheumatopsyche sp.	*Che*	1.02						0.06
		Total Trichoptera	7.14	42.43	0.49		70.24	11.76	20.32
Diptera									
Limoniidae	*Dicranota* sp.	*Dic*	4.08			7.69		0.44	0.52
Scatophagidae	*Acanthocnema* sp.	*Aca*	3.06				0.41		0.26
Tabanidae	Tabanidae und.	*Tab*			0.74				0.19
Culicidae	*Culex* sp.	*Cul*			0.24				0.06
Chaoboridae	*Mochloyx* sp.	*Moc*						0.14	0.06
Chironomidae	*Chironomus* sp.	*Chi*			0.24				0.06
Dixidae	*Dixa* sp.	*Dix*		9				0.14	0.71
Simuliidae	Simuliidae und.	*Sim*	1.02	6.30	73.06		16.11	72.64	53.98
		Total Diptera	8.16	15.31	74.31	7.69	16.52	73.36	55.86

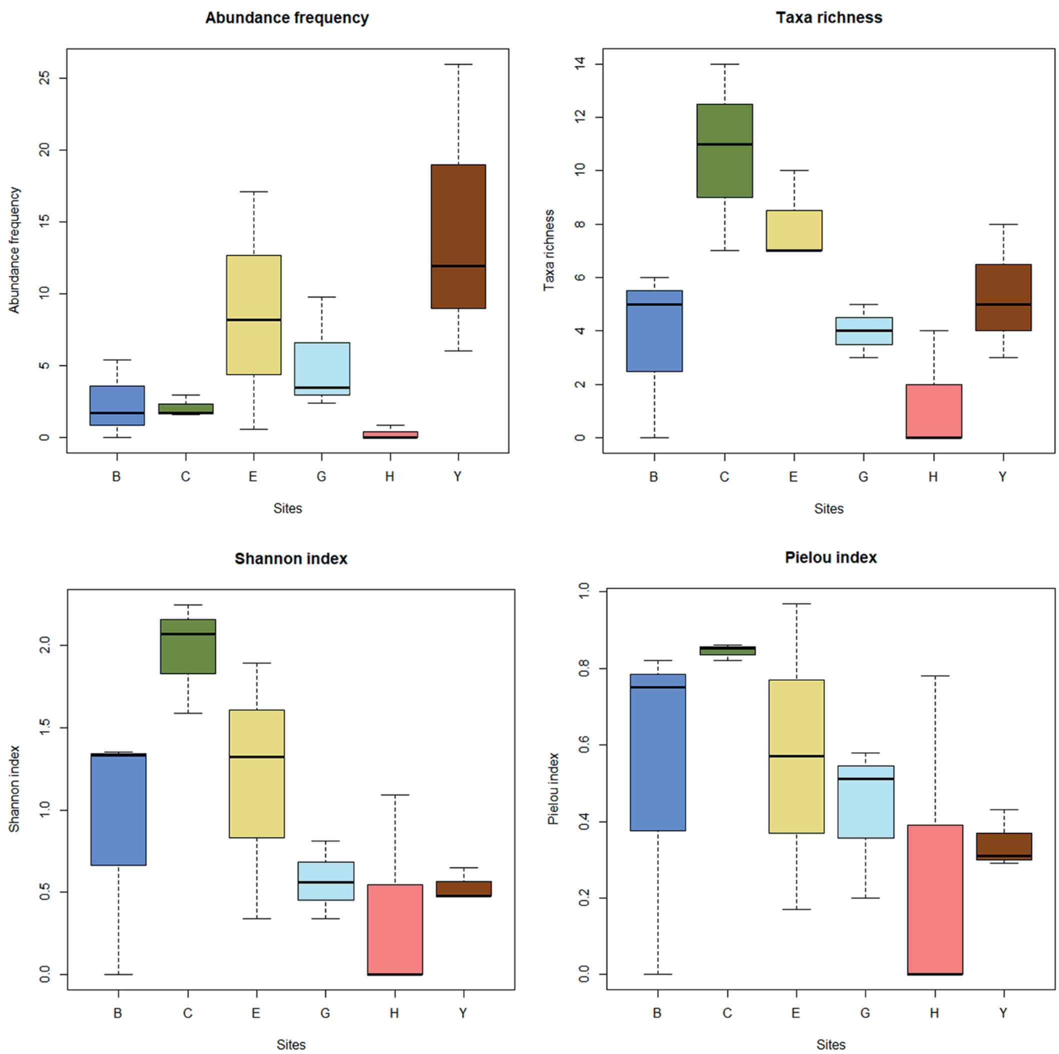

Figure 2

Box-plots showing differences between the six studied wadis in terms of the community abundance (AF), total specific richness (S), Shannon diversity index (H') and Pielou index (J') of benthic entomofauna. B – Wadi Bouilef; C – W. Chaaba; E – W. El Ma; G – W. Chélia; H – W. Hamla; Y – W. Yabous

Table 4

Generalized linear model analyzing effects of environmental variables and human pressure (H. pressure) on the taxonomic richness and abundance of benthic insects in streams of NE Algeria

	Taxonomic richness (S)					Abundance				
	Df	Deviance	Resid. Df	Resid. Dev	Pr (> Chi)	Df	Deviance	Resid. Df	Resid. Dev	Pr (> Chi)
Null			773	2824.7	0.08758			773	79260	
Altitude	1	2.92	772	2821.8	0.08758	1	2687.7	772	76572	$< 2.2 \times 10^{-16}$ ***
Conductivity	1	600.92	771	2220.8	$< 2.2 \times 10^{-16}$ ***	1	9284.5	771	67288	$< 2.2 \times 10^{-16}$ ***
NO_2^-	1	230.92	770	1989.9	$< 2.2 \times 10^{-16}$ ***	1	758.1	770	66772	$< 2.2 \times 10^{-16}$ ***
pH	1	33.17	769	1956.8	8.427×10^{-9} ***	1	4227.5	769	45952	$< 2.2 \times 10^{-16}$ ***
PO_4^{3-}	1	40.01	768	1916.7	2.522×10^{-10} ***	1	655.6	768	45108	$< 2.2 \times 10^{-16}$ ***
H. pressure	2	416.64	766	1500.1	$< 2.2 \times 10^{-16}$ ***	2	22932.3	766	14560	$< 2.2 \times 10^{-16}$ ***

*** highly significant ($p < 0.001$)

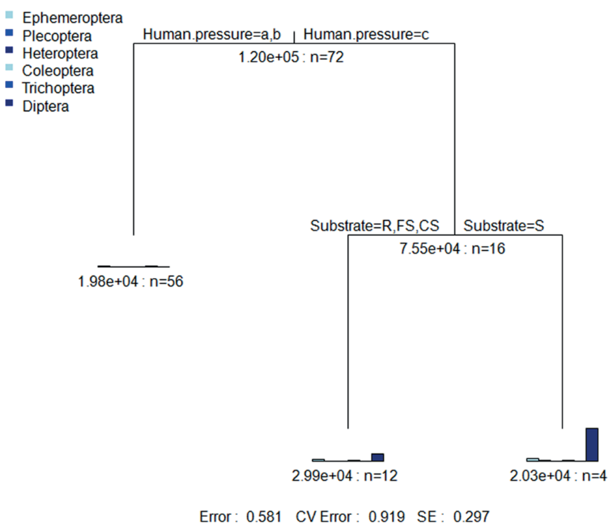

Figure 3

Multivariate regression tree for the abundance of insect orders. Each split (terminal nodes) is labeled with a variable and the value that determines the split. Substrate (FS – Fine Sand; CS – Coarse Sand; S – Stone; R – Rock); human pressure (a – forest; b – agriculture and domestic; c – urban)

and agricultural areas (human pressure = a, b), the abundance of Ephemeroptera and Trichoptera was more or less higher. Assemblages were characterized by low and uniform abundance for most orders (Fig. 3).

The RDA analysis carried out with 23 environmental variables and 42 insect taxa accounted for 61% of the total variance. The contribution of canonical axes in the total model is highly significant (Monte Carlo significance test: $p < 0.0001$). The first axis accounts for 39.9% of the total variance and the second axis for 21.1%. Forward selection allowed the identification of 17 variables that explain a significant amount of the taxa variance (arrows in Fig. 4a).

The K-means algorithm enabled the identification of four clusters of sites. Sites in cluster 1 are surrounded by forest and are basically devoid of constant human pressure. On the other hand, sites in cluster 2, located in agricultural areas, were characterized by rock substrates and high altitudes. Sites of cluster 3 were typical of streams flowing through urban areas. Sites grouped in cluster 4, also located in agricultural areas, showed high orthophosphate concentrations (Fig. 4).

Parameters with the greatest impact on the distribution of taxa in cluster 1, represented mainly by *Hydrocyphon* sp., are fine sand substrate and some physicochemical parameters of water (conductivity, turbidity, salinity and TDS). The altitude, the percentage of rocks and SO_4^{2-} at sites of cluster 2 significantly explain the distribution of *Brachycentrus* sp. Sites of cluster 3 show higher diversity (taxonomic richness) and abundance of insects, especially *Simuliidae*, *Baetis* sp. and *Acentrella* sp. Their distribution is explained by the following environmental variables: human pressure, flow velocity, coarse sand and percentage of stones. Sites of cluster 4 show higher abundance of *Hydropsyche* sp. and minor presence of *Acentrella* sp., *Caenis* sp. and *Dixa* sp.

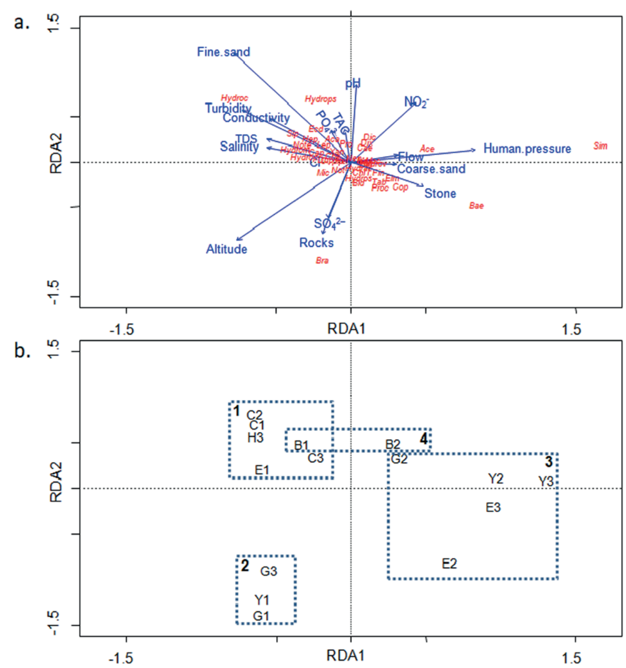

Figure 4

Redundancy analysis (RDA) ordination plots. a) taxa and environmental variables (taxa codes are explained in Table 3); b) sites (taxa codes are explained in Table 1)

Discussion

The current survey provides an initial insight into the composition of insect assemblages, representative of the Aurasian wadis, and some of the environmental determinants that appear to affect the structure of these assemblages.

A total of 42 benthic insect taxa were recorded during our inventory, confirming the low qualitative and quantitative taxa diversity revealed in previous studies on North African wadis, which, like other Mediterranean rivers, are exposed to a wide range of hydrological fluctuations and extreme physical conditions (Arab et al. 2004; Lounaci et al. 2000; Belaidi et al. 2004). As a result, intermittent streams generally harbor fewer species than permanent streams (Del Rosario, Resh 2000). Despite the difference in the sampling effort, the taxonomic richness observed in this semi-arid region was lower compared to that reported from the more humid climate of North Algeria with higher annual precipitation, e.g. from the Kabylie region inventoried by Lounaci (2005), or the Soummam streams inventoried by Zouggaghe, Moali (2009). The low taxonomic richness and abundance also found in different arid and semi-arid bioclimatic regions of Algeria (Bebba et al. 2015; Sellam et al. 2017) can be explained by unstable environmental conditions, particularly the frequent lack of flow, insufficient flowing-water levels and high summer temperatures (> 35°C), leading to prolonged periods of drought, with a negative impact on biodiversity that tends to be low (Arab et al. 2004). This phenomenon was also observed in temporary streams of all regions around the world: California, the Mediterranean Basin, Chile, South Africa and SW Australia (Williams 1996; Bonada 2003). In terms of abundance, insect assemblages were dominated by Diptera, Ephemeroptera and Trichoptera. Diptera were much more dominant taxa, as was the case in other arid Mediterranean rivers in North Africa (Sellam et al. 2017). Pires et al. (2000) reported that Diptera were also dominant in intermittent streams in Portugal, because of their ability to tolerate drought conditions and their efficient recolonization mechanisms. Simuliidae were among the most abundant family found in W. El Ma and W. Yabous with larvae adhered to stable substrates such as stones and rocks, probably due to their filtering habit (Tachet et al. 2010) and tolerance to moderate levels of pollution (Augusto, Marcos 2010).

W. Chaaba, which is located in the integral zone of the NPB, is characterized by high biodiversity compared to other wadis, whereas the fauna of W. Hamla, W. Chelia and W. Yabous was less diverse. This difference in the diversity between the sites is probably due to the anthropogenic disturbances of the aquatic ecosystem, as some of the sites were exposed to domestic pollution. Similarly, Azrina et al. (2006) and Cereghino et al. (2002) noted that species richness is sensitive to human impact on aquatic ecosystems, particularly aquatic insects, which are often good indicators of environmental conditions in streams and are therefore very sensitive to pollution. Species richness can be a good descriptor of the human impact on streams (Compin, Cereghino 2003).

The distribution of benthic insects is closely associated with environmental factors. Their composition and abundance are determined by physicochemical and ecological characteristics of the physical environment. The results of the research on the distribution of different insect groups are consistent with the fact that the observed response of the total insect abundance could largely reflect the abundance of the dominant order (Diptera). The abundance of Diptera, which was mainly dominated by Simuliidae, was higher in the urban area with a stone substrate. The substrate type was found to be a strong determinant of invertebrate distribution (Halwas et al. 2005). Relatively coarse-grained and highly structured stable substrates attract benthic fauna, because they represent sites of minimal disturbance during floods and provide refuges where recolonization can occur after flooding (Lancaster, Hildrew 1993; Rempel et al. 1999). Moreover, the identification of the human impact as the primary factor affecting the abundance of insect groups could also be explained by the fact that Diptera were the most abundant order, being more resistant to pollution (Augusto, Marcos 2010).

Our results indicate that *Baetis* sp. and *Acentrella* sp. occurrences in urban areas are correlated with the substrate size and flow velocity. Due to the differences in the substrate composition (characterized by relatively high cover of stones and coarse sand) and moderate flow velocity in urban areas, the distribution of the two above genuses can be explained by the habitat suitability for these groups. Baetidae are eurytopic and tolerant taxa, currently found in large numbers in lowland and piedmont streams of northern regions of Algeria. Changes in the sediment heterogeneity may be very important when explaining the variation in the taxonomic composition of macroinvertebrates along the residential gradient (De Sousa et al. 2008). The nature of the sediment substrate and the current velocity also seem to influence the structure of macroinvertebrate communities in North African humid and arid streams (Loanaci et al. 2000; Arab et al. 2004; Chaib et al. 2011; Sellam et al. 2017). The structure of benthic communities in semi-arid streams in Portugal was associated with low stability and high resilience, with species having strong capacity to recolonize streams subject to large scale floods or affected by drought (Cortes et al. 2002).

Brachycentrus sp. was found in the Chelia and Yabous mountain wadis, characterized by relatively high cover of rocks. As a consequence, fewer habitats are vacant for stenothermal taxa, causing lower taxonomic diversity due to the lack of potential habitats. In the same way, the upstream-downstream species replacement found in other streams (Dakki 1992; Arab et al. 2004; Arigue et al, 2016) did not or scarcely occurred in the Aurès arid streams. However, the particular high-altitude climatic characteristics of

North Africa induce an adaptation of some headwater taxa (Giudicelli 1984; Giudicelli et al. 1985). The most abundant taxa that do not belong to any of the four groups identified in the RDA analysis can therefore be considered: i) ubiquitous as they are located in the middle of the RDA plane, or ii) with a narrow spatial distribution, highly affected by one or several environmental factors.

Environmental factors in these streams directly or indirectly affected the macroinvertebrate assemblages, which indicate that macroinvertebrates are useful indicators of water quality. Biotic communities could suffer from irreversible changes resulting from anthropogenic shifts from perennial to intermittent flow regimes (Darty et al. 2014). Populations may become even more fragmented under dry conditions and local extinctions could be more likely for some poorly adapted taxa that may be eliminated from newly intermittent rivers (Phillipsen, Lytle 2013). The invertebrate fauna of these intermittent streams is sensitive to severe environmental conditions and can therefore be used as a valuable monitoring tool in the assessment of freshwater aquatic environments. Given the short period of our study, it would be unreasonable to consider the presented conclusions as definitive or to relate the obtained results to other periods of the year, while further studies could indicate how insects respond to seasonal and annual changes in the structural characteristics of the environment. This will allow to predict how changes in habitat conditions may affect assemblages of insects.

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