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Composition and distribution of stygobionts in the Tafna alluvial aquifer (north-western Algeria)

Nouria BELAIDI [(1)], Amina TALEB [(1)], Abdelhakim MAHI [(1)] and Giuseppe MESSANA [(2)]

[(1)] Biology Dept, University of Tlemcen, B.P. 119, DZA-13000 Tlemcen, Algeria; e-mail: belaidi_nr@yahoo.fr
[(2)] Institute for the Study of Ecosystems, Florence Unit, V. Madonna del Piano, 10, 50019 Sesto F.no, Firenze, Italy.

ABSTRACT

Little is known about the hypogean fauna of Algeria, with studies mostly dating to the beginning of the twentieth century (Gurney 1908; Racovitza 1912; Monod 1924; Pesce and Tetè 1978); moreover, the knowledge varies markedly among regions. In this study, we examined the composition and distribution of the invertebrate communities in the phreatic zone of the Tafna aquifer (N-W Algeria). Twelve wells close to the Tafna wadi, ranging between 120 and 1100 m a.s.l., were studied from May 2005 to March 2006. Many specimens belonging to 37 taxa were collected, the most frequent taxa being *Typhlocirolana* sp., a stygobitic Gammaridae species, Cyclopidae and Ostracoda. Other crustacean species were relatively scarce, with discontinuous distribution, being present only in a few wells. The taxonomic richness and abundance of stygobitic crustacean communities were relatively constant over time. The spatial distribution of stygobionts was mainly related to the exchanges with surface water.

Key words: Tafna, Algeria, Stygobionts, Wells, Invertebrates

INTRODUCTION

Interest in groundwater habitats increased in the last century, particularly due to the attention given by biospeleologists and hydrobiologists. The overall image obtained is that of an unseen "ocean" beneath our feet with spatial continuity (Danielopol et al 2000). Due to the size and diversity of habitats, groundwater hosts a very diverse assemblage of adapted taxa (stygobites *sensu* Botosaneanu 1986; Rouch and Danielopol 1987), with high rates of endemism and reduced dispersal capabilities (Gibert et al 1994). Studies and assessments show that, in spite of the severity of the underground environment (Danielopol 1997), stygobitic communities present an unexpected richness.

Stygobitic communities normally consist of a majority of crustacean taxa with a very restricted distribution (high endemicity). The species diversity is locally low but can be very high at the regional scale (Ferreira et al 2003; Dole-Olivier et al 2005). In North Africa, research has been progressing in the last century (Monod 1924; Henry and Magniez 1972; Pesce et al 1981), with recent studies in Tunisia (Ghlala et al 2009) and Morocco (Boutin and Boulanouar 1983; Mathieu et al 1999; Berrady et al 2000; Boutin et al 2002). However, the groundwater domain in Algeria and its organisms are still largely unknown (Gurney 1908; Nourisson 1956; Pesce and Tete 1978; Henry and Magniez 1981; Gagneur and Chaoui-Boudghane 1991; Belaidi et al 2004). The Algerian stygofauna includes a small number of stygobitic species, which are only known through the description of a few specimens. A recent synopsis revealed the presence of nearly 34 stygobitic species, six of which are listed for the north-western part of Algeria (Decu et al 2001), reflecting a low sampling effort in the groundwater area.

This study makes up for this insufficiency by providing a first database on the Algerian stygofauna collected in the wells drilled in the alluvial aquifer of the Tafna wadi. Indeed, wells are the simplest way to access groundwater in the porous aquifer (Boutin 1984). The Tafna alluvial aquifer is a phreatic zone within a Plio-Quaternary alluvial aquifer, characterized by a deposit of stone cemented by silt and clay. Therefore, this study, aims to (1) assess the diversity of the stygobitic fauna and (2) verify the spatial distribution of the populations that have colonized the Tafna aquifer.

METHODS

Study sites

The study area is the alluvial aquifer of the western and northern watershed of the Tafna wadi. The Tafna wadi (Fig. 1) is a stream approximately 170 km long, draining an area of 7425 km^2 in north-western Algeria. The difference in altitude between the source in the Tlemcen Mountains and the Mediterranean Sea is 1100 m. The geology of the drainage basin includes dolomites and limestone upstream and a Tertiary basin downstream. The terraces and the valley floor are occupied by cultivated land, while the slopes are covered with scrubland and shrub vegetation. The water regime is influenced by the Mediterranean climate (with sub-humid to semi-arid tendencies), characterized by a cold rainy season from

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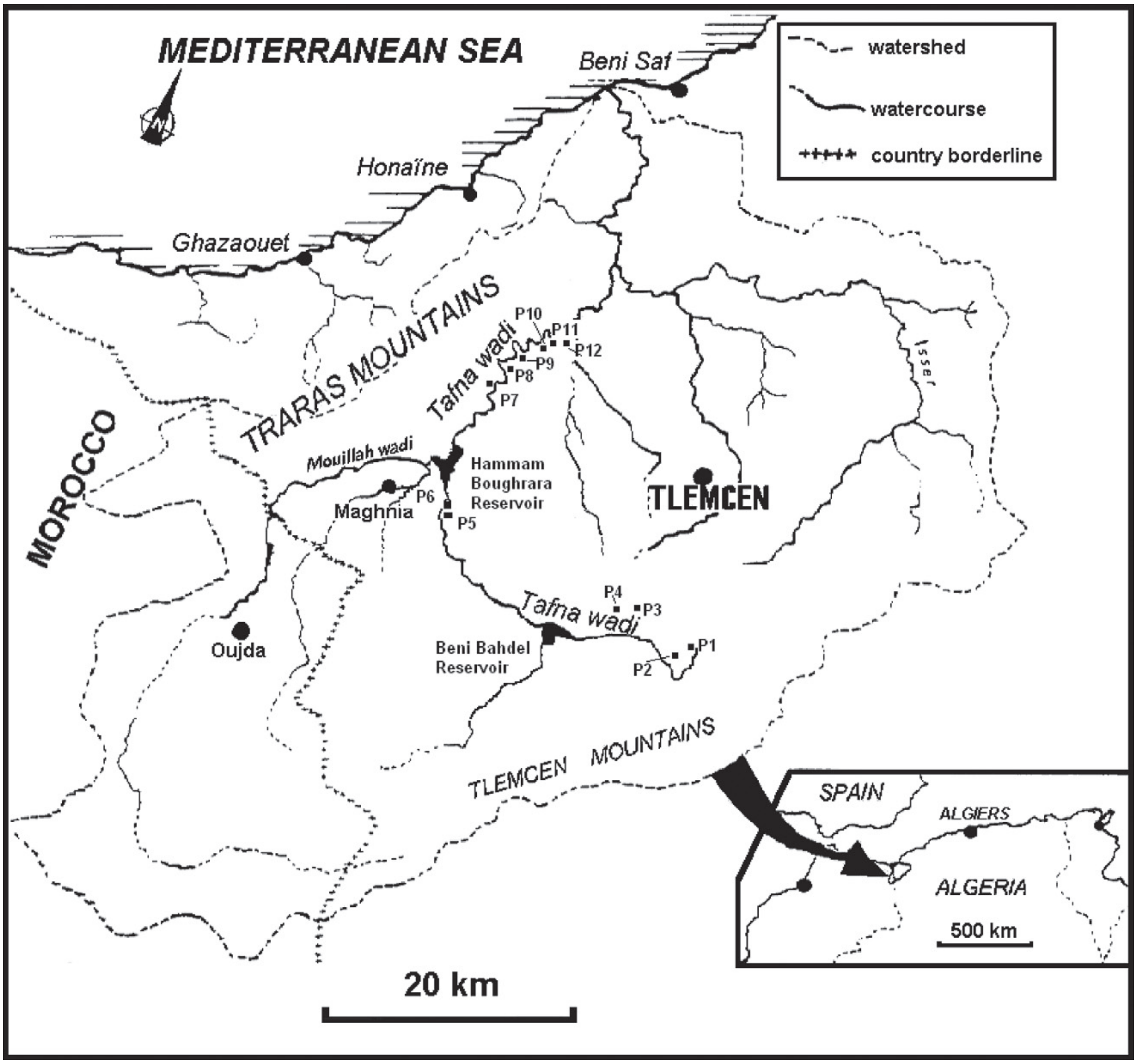

Fig. 1 - Hydrographic map of the Tafna wadi and location of the study wells.

November through April and a hot dry period from May through October. The Tafna wadi is ephemeral; it flows permanently only in winter from January to March, with discharge decreasing in the spring, and it is interrupted in the summer starting in May.

Most of the 12 study wells are used for agricultural or domestic purposes, and are located on the right (P1, P2, P3, P4, P5, P6) and left (P7, P8, P9, P10, P11, P12) banks of a 100-Km stretch of the stream starting from the Ghar Boumaza Cave. Four wells are located in the headwaters (P1, P2, P3, P4) and eight of them in the lowland (P5, P6, P7, P8, P9, P10, P11, P12). The characteristics of the wells are summarized in Table 2.

The water table flows in Jurassic limestone in the upper course of the stream and in Quaternary calcareous marl in the lower course, and it is subject to marked oscillations. The piezometric level in the study area was around 4.20 m below the ground, and it was deeper in the low plain wells with a maximum of 16.5 m.

Sampling methods

Temperature, pH, conductivity and dissolved oxygen were measured *in situ* with a WTW multi-parameter probe. The piezometric level (water level below the soil) was measured at each sampling date to monitor the quantity of groundwater resources. We used a sound sensor to measure the water depth in the wells. Fauna was collected in each well six times from May 2005 to March 2006 with two types of sampling equipment: a phreatobiological net sampler (Cvetkov 1968; Bou 1974) 20 cm in diameter at the opening, composed of a cone filter with a 150 µm mesh, drawn up 10 times in each well through the entire

Table 1 - Characteristics of the twelve wells.

Wells	Mean water level below the soil (m)	Distance/ wadi (m)	Mean water column (m)	Diameter (m)	Protection wells	Altitude (m a.s.l.)
P1	-4.64	100	2	1.25	Partial	1010
P2	-7.33	250	2	1.5	-	920
P3	-7.31	1000	2.5	1.2	Partial	922
P4	-9.68	1500	2.5	1.25	Partial	940
P5	-3.77	50	3	1.60	-	308
P6	-3.87	50	3	1.40	+	305
P7	-8.74	150	2.5	1.25	+	194
P8	-6.24	100	1.5	1.25	+	189
P9	-16.25	800	2.5	1.25	+	192
P10	-12.58	500	9	1.20	+	180
P11	-8.50	150	2	1.30	-	179
P12	-15	1000	3	1.25	Partial	180

water column, which was of different depths in the various wells; a nasse-type baited trap developed by Boutin and Boulanouar (1983). The traps were set in contact with the bottom for 24 hours. The same number of traps was placed in each well throughout the sampling period, with the same time of immersion. The samples were fixed in 5% formalin in the field. After the sorting, individuals were preserved in the field in 70% ethanol before being identified.

All animals were identified to the lowest taxonomical level possible using published and informal keys, and the numbers of individuals of each taxon were recorded. Identification sometimes required dissection and examination under a compound microscope. All Ostracoda were identified by P. Marmonier, Isopoda by C. Boutin and Amphipoda Salentinellidae by M. Messouli. The Copepoda were not identified beyond the listed taxonomic level because of the unavailability of a specialist.

Statistical methods

Abundances were calculated for each type of sampler at each well and are expressed in number of individuals per volume (ind/m^3) and number of individuals per trap (ind/trap). One-way analysis of variance (ANOVA 1) was used to compare spatial and temporal variations of the piezometric level, i.e. between the two hydrological periods of winter (high water period) and summer (low water period) (factor: season) in each well, and between the twelve wells (factor: well). ANOVA 1 was also used to compare spatial and temporal variations of the different physico-chemical variables. The abundance and richness of taxa were compared between wells and between periods (ANOVA 1). To obtain a normal data distribution, the abundance of each taxon was expressed logarithmically (Logx+1). The ADE 4 program of Thioulouse et al (1997) was used for the statistical analysis. The distribution of all crustaceans in the wells was assessed by Correspondence Analysis (CA) of the log-transformed data. Two separate analyses were performed from a table (two matrixes) with 72 rows (each representing one well on one sampling date) and 8 columns (i.e. variables) representing the density of the taxa chosen for analysis (ind/m^3 and ind/traps). The spatial community distribution was determined with a Between Analysis. An inter-class discriminant analysis, with the variable well, was used to compare the density ranking among the twelve wells. All crustacean species, including the rare ones, were taken into account in the analysis.

RESULTS

Physico-chemical variables

The temporal variation of the physico-chemical data was low (Fig. 2). The temperature followed a normal seasonal cycle with the minimum in winter (15 °C recorded in P4) and maximum in summer (26 °C in P7). The mean temperatures recorded in the wells varied from 16 °C to 22 °C, with a gradual and significant increase from upstream to downstream ($p<0.05$). Mean conductivity values were high (3900 µS/cm) and increased significantly from P1 to P12 ($p<0.05$). Conductivity varied from 540 to 1143 µS/cm in the upper part of the reach and from 2610 to 7810 µS/cm in the lower part. The pH ranged from 7.3 to 11.27, with the lowest mean value (7.3) measured in well P5.

Groundwater was generally under-saturated with dissolved oxygen, the DO concentrations ranging from 2 mg/l at P9 to 9 mg/l at P2; the highest values occurred in the upstream wells (more than 70% saturation) (Fig. 2).

Piezometric level

The depth of groundwater in the wells generally ranged from a mean of -3.77 m in P5 to -16.25 m in P9.

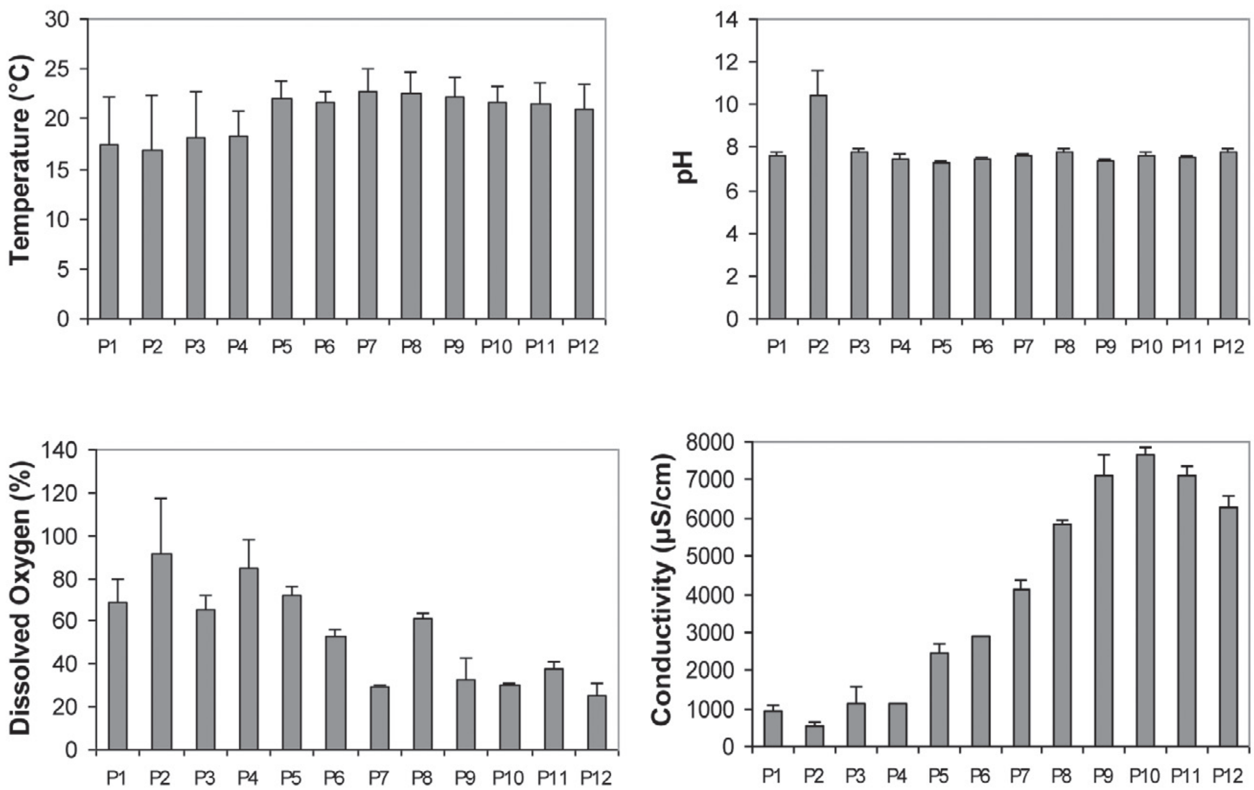

Fig. 2 - Mean value of the main groundwater physico-chemical variables in the Tafna aquifer. (Bars represent standard deviations).

It was scarcely influenced by climatic variations due to low rainfall during the study period. Overall, water levels were highest in March in relation to the high aquifer recharge during the rainy period (January-March) and lowest in August. Seasonal water variations in the wells had an amplitude of 3 to 4.5 m in the upper reach ($p < 0.05$) and became progressively less pronounced in the lower course of the river, where they did not exceed 2-3 m, in particular at wells P8, P11 and P12. Significant variations ($p < 0.05$) recorded in other wells in the lower course were mainly related to their use for irrigation (Fig. 3).

The piezometric levels generally differed most between two types of wells: wells located near the riverbank (P1, P5, P6, P8), where the water levels reached their maximum, and wells far from the riverbank (P4, P9, P10, P12) (Fig. 3).

In the upper reach, the mean water level in the wells increased from P1 (-4.65 m below the ground surface) to P4 (-9.70 m). Downstream, it increased from P6 (-1.36 m) to P9 (-16.25 m) ($p < 0.05$).

Faunal data

We collected 8309 individuals belonging to 37 taxa and 31 families (Table 2). Eight taxa were frequent (present in more than 50% of the samples) and 21 were rare (present in less than 20% of the samples); the remaining taxa were moderately frequent.

Crustaceans represented 93% of the total fauna, 72% of which were Isopoda Cirolanidae. Insects represented only 5% of the total fauna and were dominated by larvae of Diptera Culicidae. Other taxa (Mollusca, Oligochaeta, Nematoda and Hydracarina) made up 2% of the total (Fig. 4).

The invertebrate fauna collected in the wells consisted of a combination of epigean and hypogean taxa, the latter represented mainly by crustaceans. Among the nine

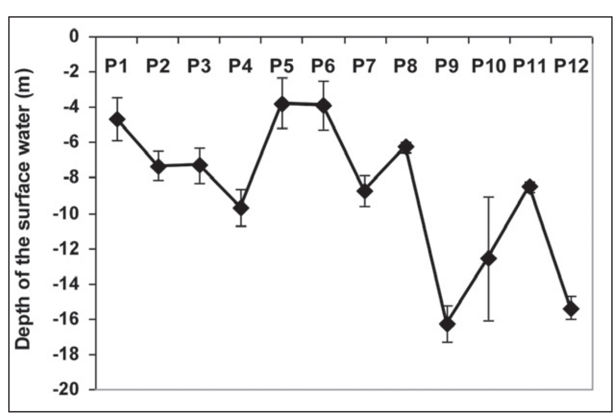

Fig. 3 - The piezometric level in the study area: main depth of the water surface of the aquifer. (Means and standard deviations).

Table 2 - Faunal list of the taxa in the twelve wells in the Tafna alluvial aquifer (**: Stygobiont)

	P1			P2			P3			P4			P5			P6		
Taxa	**ind. tot**	**ind /m³**	**ind/ trap**	**ind. tot**	**ind/ m³**	**ind/ trap**	**ind. tot**	**ind/ m³**	**ind/ trap**	**ind. tot**	**ind/ m³**	**ind/ trap**	**ind. Tot**	**ind/ m³**	**ind/ trap**	**ind. tot**	**ind/ m³**	**ind/ trap**
Nematoda							18	0.92		1	0.16							
Oligochaeta																		
Tubificidae																		
Limnodrilus sp.													23	0.6				
Lumbriculidae																		
Trichodrilus sp.							11	0.53		1	0.08							
Gastropoda																		
Bythinellidae																1	0.03	
Physidae							9	1.43		1	0.16		53	2.71	1	3	0.08	0.33
Planorbidae										1	0.16					7	0.32	
Hydrobiidae																		
Copepoda																		
Cyclopidae	55	0.984	6.86	2		0.29	4	0.21		158	2.65	15.14	414	6	52.83	115	3.7	9.83
Isopoda																		
Cirolanidae																		
***Typhlocirolana* sp.**										6		0.86	6	1		2592	0.08	432
Asellidae																		
***Proasellus* sp.**							47	2.47		1	0.08					*1*		0.17
Microparasellidae										2	0.16							
***Microcharon* sp.**																		
Amphipoda																		
Gammaridae																		
Gammarus sp.	*274*	3.012	35.86	1	0.08		2	0.16					17	0.89		72	4	4.17
***g.* sp.**													2	0.16		12	1.9	
Salentinellidae																		
Salentinella* cf. *angelieri													6	0.47				
Ostracoda																		
Cyprididae																		
Heterocypris sp.	*3*	0.221					239	13.28		19	1.15							
Herpetocypris sp.													282	11.05	1.67			
Hydracarina				2	0.24		2	0.32		2	0.156		1	0.17				
Collembola				2	0.13					1	0.08							
Heteroptera																		
Mesovellidae				2		0.28	1	0.08		1	0.08							
Corixidae													3		0.5	4		0.66
Naucoridae													6	0.08	0.83			
Pleidae										1	0.16		2		0.33			
Diptera																		
Culicidae				60	4.7		1	0.06		18	1.42		20	1.1		25	2.58	
Ptychopteridae													1	0.08				
Ceratopogonidae	5	0.793		1	0.13													
Chironomidae				**3**	0.24		2	0.29		14	1.1		2	1.08				
Dixidae																		
Coleoptera																		
Limnebiidae				8	0.42													
Elmidae	1	0.158		1	0.08		1	0.05										
Dytiscidae													7		1.17	36		6
Hydraenidae																1	0.03	
Haliplidae																7	0.08	1
Curculionidae																1	0.03	
Hydrophilidae																		
Trichoptera																		
Ecnomidae				1	0.05													
Glossosomatidae				1	0.05													
Total Taxonomic Richness		**5**			**12**			**12**			**12**			**16**			**14**	

Taxa	P7			P8			P9			P10			P11			P12		
	ind. tot	ind/ m³	ind/ trap	ind. tot	ind/m³	ind/ trap	ind. tot	ind/ m³	ind/ trap	ind. tot	ind/m³	ind/ trap	ind. tot	ind/m³	ind/ trap	ind. tot	ind/m³	ind/ trap
Nematoda																		
Oligochaeta																		
Tubificidae																		
Limnodrilus sp.																		
Lumbriculidae																		
Trichodrilus sp.																		
Gastropoda																		
Bythinellidae		0.4																
Physidae	3	7		2	0.21		9	0.63	0.17	2	0.064					17	0.84	0.17
Planorbidae																1	0.052	
Hydrobiidae				1	0.11													
Copepoda																		
Cyclopidae	4	0.05	0.5							8	0.022	1.17	4	0.47		9	0.212	0.67
Isopoda																		
Cirolanidae																		
***Typhlocirolana* sp.	468		78	2598		433							332		55.33			
Asellidae																		
***Proasellus* sp.																		
Microparasellidae																		
***Microcharon* sp.																		
Amphipoda																		
Gammaridae																		
Gammarus sp.				3	0.29													
***g.* sp.	3	0.16		4	0.08	0.5	1	0.05					4	0.42				
Salentinellidae																		
***Salentinella* cf. *angelieri*				1	0.08													
Ostracoda																		
Cyprididae																		
Heterocypris sp.	5	0.55	0.17				4	0.31		2	0.064							
Herpetocypris sp.																3	0.105	0.17
Hydracarina																		
Collembola																		
Heteroptera																		
Mesovellidae																		
Corixidae																		
Naucoridae																		
Pleidae																		
Diptera																		
Culicidae	1	0.16		17	1.79		7	0.47		10	0.25		41	4.24		15	0.86	0.17
Ptychopteridae																		
Ceratopogonidae							1	0.04					1	0.105		1	0.04	
Chironomidae							**2**	0.08	0.17	2	0.05		5	0.42		8	0.38	0.17
Dixidae										1	0.012							
Coleoptera																		
Limnebiidae																		
Elmidae																		
Dytiscidae																		
Hydraenidae																		
Haliplidae																		
Curculionidae																		
Hydrophilidae										1	0.012							
Trichoptera																		
Ecnomidae																		
Glossosomatidae																		
Total Taxonomic Richness		**6**			**7**			**6**			**7**			**6**			**7**	

crustacean taxa, five were stygobiont. The most diverse groups were Isopoda (3 taxa) and Amphipoda (3 taxa), followed by Ostracoda (2 taxa) and Copepoda Cyclopidae. The last taxon might be a stygobitic species.

Larval stages of winged insects belonged to 18 families; the most diverse order was Coleoptera (7 families) followed by Diptera (5 families), Heteroptera (4 families) and Trichoptera (2 families).

The mean taxonomic richness recorded in all the wells was 10 taxa. Stygobionts were represented by 5 taxa: Isopoda Cirolanidae (*Typhlocirolana* sp.), Microparasellidae (*Microcharon* sp.) and Asellidae (*Proasellus* sp.), Amphipoda Salentinellidae (*Salentinella* cf. *angelieri)* and Gammaridae (stygobitic Gammaridae sp.). Specimens of all these Amphipoda were without eyes and pigment.

The mean density of invertebrates varied significantly among wells ($p<0.05$), being lowest in P9 (0.26± 0.56 ind/m^3; 0.4 ± 0.51 ind/trap) and highest in the P6 (2.14±1.71 ind/m^3; 452±247 ind/trap). These differences among wells were primarily due to crustaceans, among which only the Isopoda Cirolanidae showed strong variations in abundance. The difference in Cirolanidae abundance among wells was significant (ANOVA 1, $p<0.05$). Isopods were most abundant in P6 and P8, with a mean density of 452±232 ind/trap and 433±247 ind/trap respectively (Fig. 5). In contrast, the mean density of insects was low and varied among wells, albeit without significant differences.

The structure of the invertebrate fauna varied among wells. Although the mean taxonomic richness was similar among wells (Table 1), the total number of taxa showed significant differences ($p<0.05$) (Fig. 6). Well P5 was most taxa-rich (16 taxa) and P1 least taxa-rich (only 5 taxa). This difference in richness is explained mainly by the presence of insect families: 6 and 8 families were present in P4 and P5 respectively. The richness of wells P4 and P5 can also be explained by the presence of 3 and 5 stygobiont species respectively.

A strong dominance of a few taxa was generally observed, with one dominant taxon per well, often representing over 70% of the total fauna. This was particularly true for Cyclopidae in P4 (70%), for the Ostracoda *Heterocypris* sp. in P3 (71%), for the Gammaridae *Gammarus* sp. in P1 (81%) and for Diptera Culicidae in P2 (70%). In well P5, Cyclopidae represented 49% of the total fauna and the Ostracoda *Herpetocypris* sp. 33.37%. Similarly, stygobitic crustaceans were dominated by the single species *Typhlocirolana* sp. which represented 86-98% of the total abundance in wells P6, P7, P8 and P11. In P9 and P12, the invertebrate community was dominated by two epigean taxa: Physidae (Mollusca, Gastropoda) and Culicidae (Arthropoda, Insecta). The remaining taxa were only present in 1 to 3 wells with very low abundance (<3%), except for Chironomidae (Arthropoda, Insecta) which were present in most wells with low abundance.

In general, the taxonomic richness and total abundance did not vary significantly over time ($p>0.05$). For

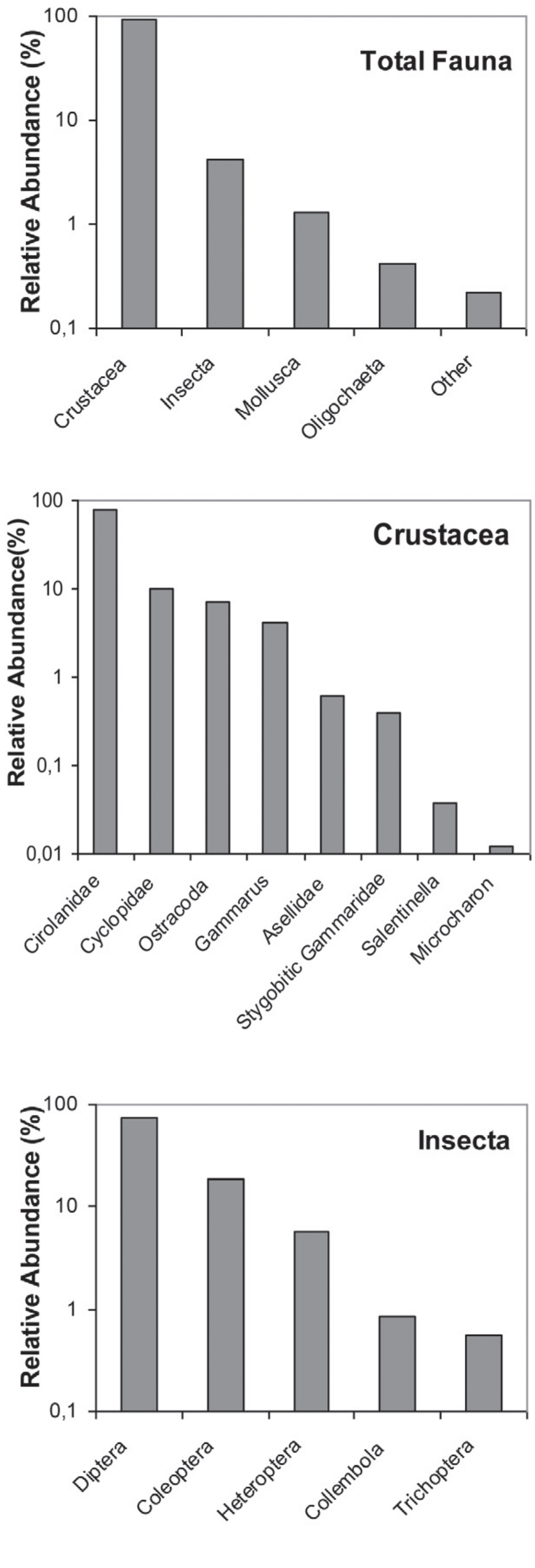

Fig. 4 - Relative abundance of invertebrates: total (epigean + stygobitic), epigean (insects) and stygobionts (crustaceans).

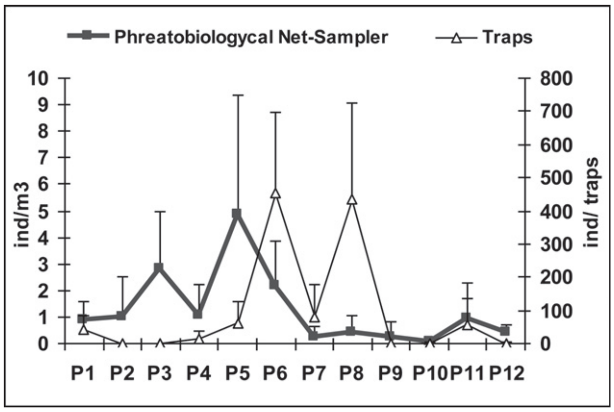

Fig. 5 - Mean density of total taxa (epigean + stygobitic) collected in the wells with the two sampling techniques.

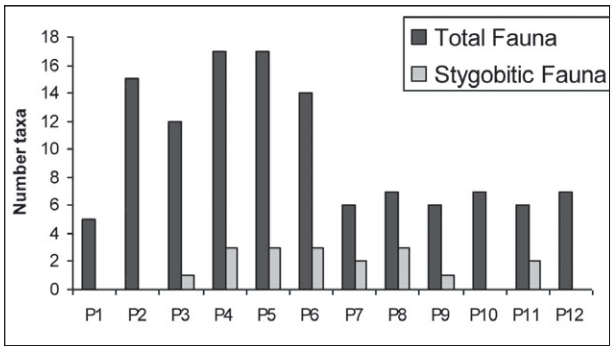

Fig. 6 - Total number of taxa (epigean + stygobitic) and of stygobitic taxa collected in the wells.

most wells, there was only a temporal change in composition. For example, among the stygobiont crustaceans, *Typhlocirolana* and the stygobitic undetermined Gammaridae species were present throughout the entire sampling period, while *Microcharon* sp., *Proasellus* sp. and *Salentinella* cf. *angelieri* were present only from March, in relation to the aquifer recharge.

Comparative use of two sampling methods

The phreatobiological net sampler allowed us to collect 35 taxa and 1393 individuals belonging to 4 higher stygofaunal taxonomic groups, primarily Crustacea Salentinellidae (*S.* cf. *angelieri*), Isopoda (*Microcharon*), Asellidae (*Proasellus)* and Ostracoda (Fig. 6). The nasse trap yielded only 17 taxa and 6916 individuals, consisting mainly of Cirolanidae (*Typhlocirolana*), Gammaridae (*Gammarus*) and Cyclopidae (Fig. 7). All taxa of other groups were collected with the net sampler, especially Culicidae, Ceratopogonidae, Trichoptera, Oligochaeta and nematodes which were absent in the trap (Fig. 7)

Comparison of the two techniques by ANOVA1 revealed a significant difference in taxonomic richness and abundance ($p<0.05$).The phreatobiological net had higher total richness but lower total abundance, whereas the trap had lower total richness but higher total abundance (Table 2).

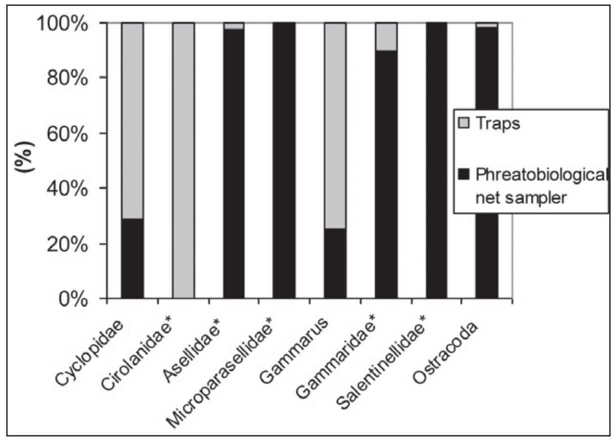

Fig. 7 - Relative abundance of crustaceans (epigean + stygobitic) collected with the two sampling techniques.

Spatial distribution of crustaceans

Copepoda, Ostracoda and the isopod *Typhlocirolana* sp. were widely distributed along the longitudinal transect, with a maximum number of 2500 individuals per well. The total abundance was significantly different among wells ($p<0.01$), being much higher in the wells near the riverbank (P1, P5, P6, P8). However, the correlation (Pearson) of crustacean total abundance and the distance to the river was not significant ($P=0.11$). Stygobitic Gammaridae coexisted with Cyclopidae, Ostracoda and *Typhlocirolana* sp., but Gammaridae were less abundant and frequent. Collections of *Microcharon*, S*alentinella* and *Proasellus* were rare (Fig. 8).

The results of the Correspondence Analysis (Fig. 9) show the spatial distribution of various crustacean species on the longitudinal transect of the Tafna alluvial aquifer for both sampling techniques:

Phreatobiological net sampling

The byplot explains 55% of the variability of the data matrix, with 30% of the variance explained by the first axis. The F1 axis is mainly related to four crustacean taxa (Proasellus, Cyclopidae, Salentinella and Ostracoda) located near the ends of the axis (Fig. 9 A). An inter-well discriminant analysis was performed to understand the contribution of the wells to the variability. Four wells were discriminated mainly by the F1 axis and are divided into two groups according to the distance that separates them from the bed of the wadi. The first group is negatively correlated to the axis and is associated with Proasellus and Microcharon. It is formed by wells P3 and P4, farthest from the stream. In contrast, the second group (wells P1, P6 and P8, all located near the stream bed) is associated mainly with Cyclopidae, S. cf. angelieri and stygobitic Gammaridae. The F2 axis isolates P5 and P12, characterized by the ostracod Herpetocypris.

Trap sampling

The byplot explains 70% of the variability of the data matrix, with 38% of the variance explained by the first

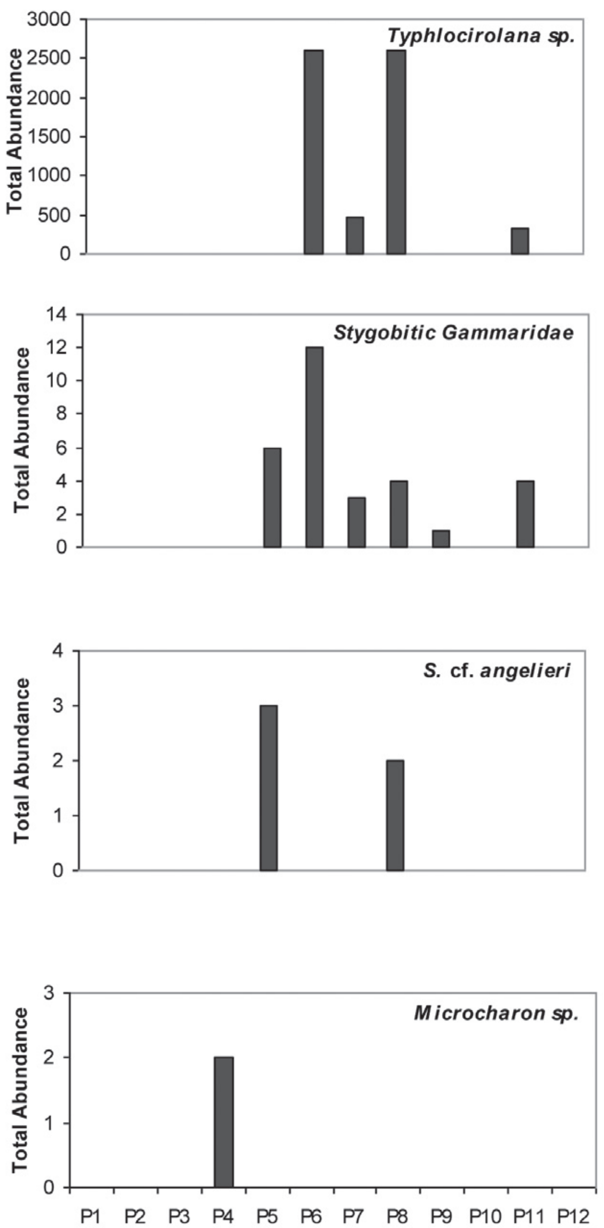

Fig. 8 - Spatial distributions of the five stygobiont taxa in the twelve wells.

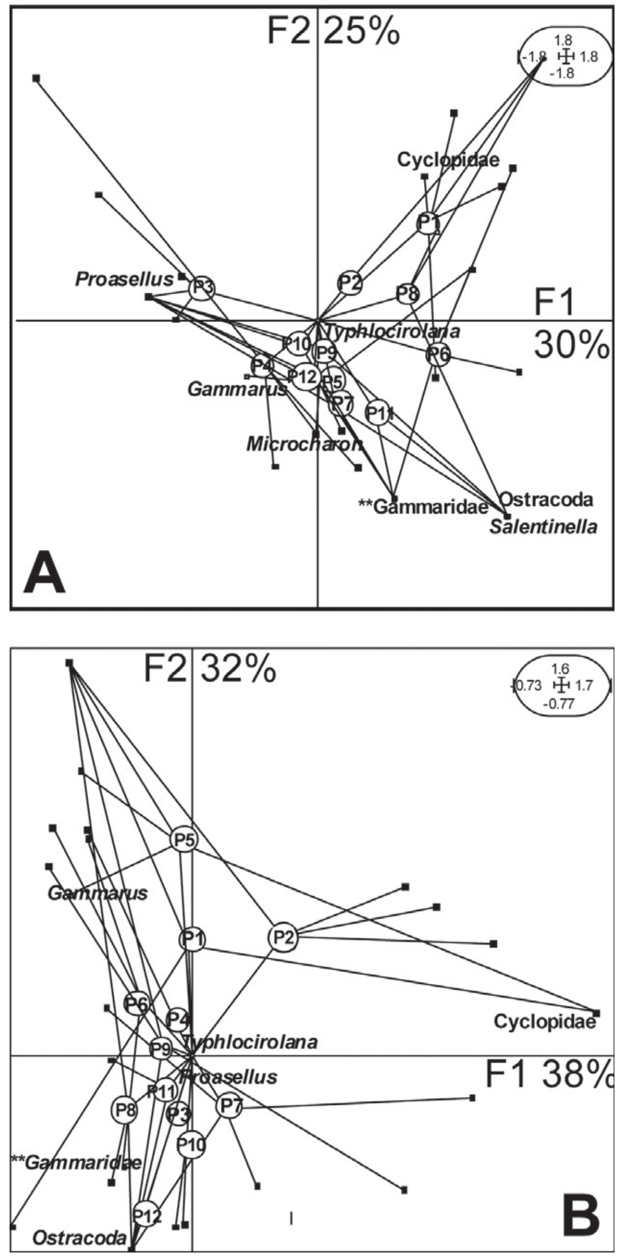

Fig. 9 - Between-group Correspondence Analysis of crustaceans sampled in the wells with the (**A**) phreatobiological net sampler and (**B**) trap sampler.
Position of the crustaceans and wells in the F1-F2 ordination graph. Position of taxa in the F1-F2 ordination graph indicated by small squares, position of wells by large circles.

axis. Three wells were discriminated mainly by the F1 axis. P7 is positively correlated to the axis and is associated with a low density of *Typhlocirolana*. In contrast, P6 and P8 are associated with a high abundance of this isopod. The F2 axis isolated P1, characterized by the dominance of *Gammarus,* and P12, associated with the ostracod *Herpetocypris* (Fig. 9 B).

DISCUSSION

The fauna of the wells in the Tafna alluvial aquifer is dominated by epigean taxa (86% of all taxa). The mean taxonomic richness in the 12 wells is lower than that observed in Morocco, e.g. by Boutin and Dias (1987) at Marrakech (a mean of 12 species in 11 wells), by Boulal (1988) in Tiznit region in the northern Anti-atlas (a mean of 14 species in 10 wells) and by Boutin and Idbennacer (1989) in the southern Anti-atlas (a mean of 10.8 species in 7 wells). Moreover, the subterranean aquatic fauna collected in this study is characterized by relatively low taxonomic richness: 11 and 18 stygobitic species were reported in previous studies of wells in Morocco (Boulal 1988; Boulanouar 1986).

Of the 34 species of stygobitic crustaceans identified in Algeria, 5 were already recorded and identified in the Tlemcen area: 4 Harpacticoida and 1 Asellidae (Decu et al 2001). Five taxa were recorded in the study wells. *Microcharon* sp. (Isopoda Microparasellidae) was recorded only in well P4. Two species of this genus have been cited for Algeria (Decu et al 2001): *Microcharon zibani* Pesce and Tetè 1978 and *M. karamani* Pesce and Tetè 1978, collected respectively in wells of Biskra and Dirah in eastern Algeria. *Proasellus* sp. (Isopoda Asellidae) was recorded in wells P3, P4 and P6. It should be noted that *Proasellus notenboomi* Henry and Magniez, 1981 was recorded in the study area in a karst spring between 900 and 1100 m altitude in Sebdou (Tlemcen) (Decu et al 2001; Henry and Magniez 2001). Eight species of this genus have been cited for Algeria, but only three of them are depigmented and anophthalmic, namely *P. notenboomi* in Tlemcen, *P. delhezi* in Kabily and *P. bragadicus* (Decu et al 2001; Henry and Magniez 2001). However, no Stenasellidae were recorded in the study wells, even though two species of this group have been cited for Algeria; *Johannella purpurea* Monod recorded in Msila and *Metastenasellus leysi* Magniez in Ain Sefra.

Typhlocirolana sp. (Isopoda Cirolanidae) was recorded in wells P4, P5, P6, P7, P8 and P11. Three species of *Typhlocirolana* were previously described for Algeria (Racovitza 1912), two in the north-west (*T. buxtoni* and *T. gurney*) and one in the south-east (*T. fontis*). *Salentinella* cf. *angelieri* (Amphipoda Salentinellidae) was recorded in wells P5 and P8 and stygobitic Gammaridae sp. (Amphipoda Gammaridae), depigmented and anophthalmic, was recorded in wells P5, P6, P7, P8, P9 and P11. One species of stygobitic Gammaridae had already been identified in Algeria, namely *Echinogammarus tacapensis* collected from a spring near Guelma in eastern Algeria (Stock 1986). However, no Melitidae and no Bogidiellidae were recorded in the study wells. Two stygobitic species of *Pseudoniphargus* were previously cited for Algeria, *P. africanus* Chevreux in Annaba and *P. macrotelsonis* Chevreux et Gauthier in Guelma, while two stygobitic species of *Bogidiella* were known for eastern Algeria, *B. africana* Karaman et Pesce in Biskra and *B. chapuis* Ruffo.

No specimens of the depigmented and anophthalmic Syncarida Parabathynellidae were collected in our samples, although this taxon was previously recorded in the hyporheic habitat of the Tafna wadi by Gagneur and Chaoui-Boudghane (1991) and Belaidi et al (2004); hence, it can be considered the sixth stygobitic taxon from the Tafna alluvial aquifer. It should be noted that *Cteniobathynella essameuri* Dumont Syncarida Parabathynellidae is a stygobitic species recorded in the central Sahara of Algeria (Decu et al 2001).

Copepoda Cyclopidae were collected in most of the study wells. This group is represented in Algeria by one stygobitic species, *Megacyclops donnaldsoni algericus* Kiefer recorded in Ain Sefra (Decu et al 2001). However, no Copepoda Harpacticoida were collected in the wells during the study period, despite the presence of five stygobitic species in Algeria identified by Rouch (1986). Four of them were recorded in Tlemcen: *Parapseudoleptomesochra minoricae* (Chapuis et Rouch), *Elaphoidella algeriensis*, *Parastenocaris numidiensis* Rouch and *Parapseudoleptomesochra* sp. The fifth species, *Nitocrellopsis petkovskii* Rouch, was recorded in Bechar. Moreover, Copepoda Harpacticoida were previously recorded in a hyporheic zone of the study area (Belaidi et al 2004).

The fauna collected in the study wells is mainly represented by the genus *Typhlocirolana* (Cirolanidae), which coexists in the wells with the undetermined stygobitic Gammaridae species collected with the same frequency but with lower abundance. The coexistence of these two species is related to the particle size of the sediment, which provides favourable conditions for the establishment of a large fauna; in fact, according to Boutin (1984), *Typhlocirolana* occurs where the sediment spaces are large enough to allow free space for the animal.

Among the rare taxa, *Salentinella* cf. *angelieri* (Amphipoda, Salentinellidae) was collected in only two wells, with low abundance and very low frequency. This confirms its preference for deep aquifers (Marmonier and Dole 1986). The Microparasellidae *Microcharon* sp. (Isopoda) is very abundant in the hyporheic zone of Tafna wadi (Gagneur and Chaoui-Boudghane 1991; Belaidi et al 2004) and was accidentally collected in one of the study wells. This is probably related to the sampling methods. A third taxon collected with low abundance and intermediate frequency in three of the wells is the isopod *Proasellus* sp. (Asellidae). The rarity of this taxon is related to water withdrawal from the wells for irrigation: in fact, its density increased during the entire study period when water was not pumped.

In general, the distribution of the stygofauna in the Tafna alluvial aquifer was very heterogeneous. The spatial distribution of species in the groundwater indicates that they are preferentially located in areas influenced by the river water. In fact, the species diversity and abundance were higher in wells located near the riverbed than those further away along the bank. This distribution may reflect environmental conditions in the groundwater which correspond to the species' requirements. Almost all of the oxygen and organic matter required by the stygofauna comes from surface water (Ward and Palmer 1994); hence, there is an attraction effect of surface water on stygobitic fauna (Maridet et al 1992). Indeed, mixing with the stream surface water was higher near the bed. It should be noted that during low water flow the river was fed by dam release water (Taleb et al 2004). These results confirm the crucial role of connectivity between groundwater and surface water identified by Dole-Olivier (1998), and particularly in the wadi system by Gagneur and Chaoui-Boudghane (1991), Belaidi et al (2004) and Taleb et al (2008) (the term "wadi" generally used in North Africa to name watercourses refers to the great variations in flow).

We did not detect a differential distribution of the stygobitic taxa along a longitudinal gradient, despite the north-south gradient of increasing conductivity recorded in the wells. Indeed, an extremely high gradient of water salinity is tolerated by cirolanids, which live in water with salinity ranging from perfectly fresh water to almost sea water (Botosaneanu 1986). This would explain the wide distribution of this species in the Tafna alluvial aquifer and, similarly, the wide distribution recorded for *Salentinella* sp., which belongs to a genus that may live in saline waters (Notenboom 1991).

CONCLUSION

At present, we are still far from knowing the actual groundwater biodiversity in the Tafna watershed. In Algeria, data on the stygofauna are still very fragmentary and rare due to the few sampling campaigns conducted in the past. Significant efforts are still required to increase our knowledge about the presence and distribution of stygobitic fauna, and it is likely that many taxa have yet to be discovered.

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REFERENCES

Belaidi, N., A. Taleb, J. Gagneur 2004. Composition and dynamics of hyporheic and surface fauna in a semi--arid stream in relation to the management of a polluted reservoir. Annales de Limnologie - International Journal of Limnology 40: 237-250.

Berrady, I., K. Essafi, J. Mathieu 2000. Comparative physico-chemical and faunal studies of two thermal spring brooks near Sidi Harazem (Morocco). Annales de Limnologie - International Journal of Limnology 36: 261-274.

Botosaneanu, L. 1986. Stygofauna Mundi. A Faunistic, Distributional, and Ecological Synthesis of the World Fauna inhabiting Subterranean Waters (incl. the marine interstitial). Brill E. J., Dr. W. Backhuys, Leiden, The Netherlands.

Bou, C. 1974. Les méthodes de récolte dans les eaux souterraines interstitielles. Annales de Spéléologie 29: 611-619.

Boulal, M. 1988. Recherches écologiques sur la faune aquatique des puits de la région de Tiznit (Anti-Atlas Occidental, Maroc). Unpublished Thèse 3ème cycle, Faculté des Sciences, Marrakech.

Boulanouar, M. 1986. Etude écologique comparée de quelques puits de la région de Marrakech. Impact des pollutions sur la zoocénose des puits. Unpublished Thèse 3ème cycle, Faculté des Sciences, Marrakech.

Boutin, C. 1984.- Sensibilité à la pollution et répartition de quelques espèces de Crustacés phréatobies à Marrakech. Mémoires de Biospéologie 11: 55-64.

Boutin, C., M. Boulanouar. 1983. Méthodes de capture de la faune stygobie: Expérimentation de différents types de pièges appâtés dans les puits de Marrakech. Bullettin de la Faculté des Sciences de Marrakech 2: 5-21.

Boutin, C., M. Boulanouar, N. Coineau, M. Messouli. 2002. Biodiversity in the stygobiontic cirolanids (Crustacea: Isopoda) from the Mediterranean Basin. I. A new species of *Typhlocirolana* in Morocco, taxonomic, ecological and biogeographic data. Journal of Natural History 36: 797-817.

Boutin, C., N. Dias. 1987. Impact de l'épandage des eaux usées de la ville de Marrakechsur la nappe phréatique. Bulletin de la Faculté des Sciences de Marrakech 3: 5-27.

Boutin, C., B. Idbennacer. 1989. Faune stygobie du Sud de l'anti- Atlas marocain: Premier résultats. Revue des sciences de l'eau 2: 891-904.

Cvetkov, L. 1968. Un filet phréatobiologique. Bulletin de l'Institut de Zoologie et Musée, Sofia 22: 215-219.

Danielopol, D.L. 1997. La colonisation d'environnements contraignants: Exemple des eaux souterraines. GeoBios, M.S. 21: 55-66.

Danielopol, D.L., P. Pospisil, R. Rouch. 2000. Biodiversity in groundwater: a large-scale view. Trends in Ecology and Evolution 15: 223-224.

Decu, V., C. Juberthie, B. Collignon, B. Lebreton 2001. Algérie. Pp. 1477- 1496 *in* C. Juberthie, V. Decu, eds. Société internationale de Biospéologie. Encyclopædia Biospeologica III. Moulis-Bucarest.

Dole-Olivier, M.J. 1998. Surface water-groundwater exchange in three dimensions on backwater of the Rhône River. Freshwater Biology 40: 93-109.

Dole-Olivier, M.J., F. Malard, D. Ferreira, J. Gibert 2005. Biodiversité dans les eaux souterraines. La Houille Blanche 3: 39-44.

Ferreira, D., M.-J. Dole-Olivier, F. Malard, L. Deharveng, J. Gibert 2003. Faune aquatique souterraine de France: base de données et éléments de biogéographie. Karstologia 42: 15-22.

Gagneur, J., C. Chaoui-Boudghane. 1991. Sur le rôle du milieu hyporhéique pendant l'assèchement des oueds de l'ouest Algérien. Stygologia 6: 77-89.

Ghlala, A., D. Della Valle, G. Messana. 2009. First record of the genus *Typhlocirolana* Racovitza, 1905 (Isopoda: Cirolanidae) from Tunisia and description of a new species from the National park of Ichkeul. Zootaxa 2176: 57-64.

Gibert, J., D.L. Danielopol, J. Stanford. 1994. Groundwater Ecology. San Diego: San Diego Academic Press.

Ginés, A., J. Ginés. 1977. Datos bioespeleológicos obtenidos en las aguas cársticas de Mallorca. Comunicacions 6è Simposium d´Espeleologia, Terrassa : 81-95.

Gurney, R. 1908. A new species of Cirolana from a freshwater spring in the Algerian Sahara. Zoologischer Anzeiger 32: 682-685.

Henry, J.P., G. Magniez 1972. Un Aselle interstitiel de Tunisie: *Proasellus bagradicus*. Annales de Spéléologie 17: 183-193.

Henry, J. P., G. Magniez. 1981. Un aselle cavernicole d'Algérie: *Proasellus notenboomi* n.sp. et nouvelles données sur les asellides d'Afrique du Nord. Crustaceana 41: 208-215.

Maridet, L., J.G. Wasson, M. Philippe. 1992. Vertical distribution of fauna in the bed sediment of three running water sites: Influence of physical and trophic factors. Regulated River: Research and Management 7: 45-55.

Marmonier, P., M.J. Dole. 1986. Les amphipodes des sédiments d'un bras court-circuité du Rhône. Logique de répartition et réaction aux crues. Revue des Sciences de l'Eau 5: 461-486.

Mathieu, J., K. Essafi, H. Chergui. 1999. Spatial and temporal variations of stygobite Amphipod populations in interstitial aquatic habitats of karst /floodplain interfaces in France and Morocco. Annales de Limnologie - International Journal of Limnology 35: 133-139.

Monod, Th. 1924. Sur quelques Asellides nouveaux des eaux douces de l'Afrique du Nord. Bulletin de la Société d'Histoire Naturelle d'Afrique Nord 15: 327-336.

Notenboom, J. 1991. Marine regressions and the evolution of groundwater dwelling amphipods (Crustacea). Journal of Biogeography 18: 437-454.

Nourisson, M. 1956. Etude morphologique comparative et critique des *Typhlocirolana* (Crustacés Isopodes Cirolanidae) du Maroc et d'Algérie. Bulletin de la Société des Sciences Naturelles et Physiques du Maroc 36: 103-124.

Pesce, G.L., P. Tete. 1978. Microparasellides d'Algérie (Crustacea: Isopoda). Revue de Zoologie Africaine 92: 992-1002.

Pesce, G.L., P. Tete, M. De Simone 1981. Ricerche faunistiche in acque sotterranee freatiche del Maghreb (Tunisia, Algeria, Morocco) e dell'Egitto. Natura Soc. Ital. Sc. Nat. Museo civ. Stor. Nat. E Acquario civ. Milano 72: 63-98.

Racovitza, E.G. 1912. Cirolanides , 1ère série. Archives de Zooologie Expérimentale et générale 10: 203-329.

Rouch, R. 1986. Sur l'écologie des eaux souterraines dans le karst. Stygologia 2(4): 352-398

Rouch, R., D.L. Danielopol. 1987. L'Origine de la faune aquatique souterraine: entre le paradigme du refuge et le modèle de la colonisation active. Stygologia 4: 345-372.

Stock, J.H. 1986. Amphipoda: Gammarid grouping (Gammaridae s. str. Sensu Bousfield). Pp. 497-503. *in* L. Botosaneanu eds., Stygofauna Mundi. J. H. Brill (Leiden).

Taleb, A., N. Belaidi, J. Gagneur. 2004. Water quality before and after dam building on a heavily polluted river in semi-arid Algeria. River Research and Applications 20: 1-14.

Taleb, A., N. Belaidi, J. M. Sanchez Perez, P. Vervier, S. Sauvage, J. Gagneur. 2008. The role of the hyporheic zone in the nitrogen dynamics within a semi-arid gravel bed stream located downstream of a heavily polluted reservoir (Tafna wadi, Algeria). River Research and Applications 24: 183-196.

Thioulouse, J., D. Chessel, S. Dolédec, J.M. Olivier. 1997. ADE-4: a multivariate analysis and graphical display software. Statistics and Computing 7: 75-83.

Ward, J.V., M.A. Palmer. 1994. Distribution patterns of interstitial freshwater meiofauna over a range of spatial scales, with emphasis on alluvial river-aquifer systems. Hydrobiologia 287: 147-156.