DIVERSITY AND ECOLOGY OF DIATOMS IN NORTHWEST OF ALGERIA: CASE OF EL-HAMMAM STREAM AND ESTUARY OF CHELIFF RIVER

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Abstract. Ecological research on algae from Algeria and in particular on freshwater and estuarine diatoms remains insufficient. The aim of our work is to contribute to the taxonomy and ecology of benthic diatoms from freshwaters and estuaries in Algeria. For this purpose, we studied two sites of water courses in north-western Algeria: El-Hammam stream at Mascara and the estuary of Cheliff river at Mostaganem. Our inventory of benthic diatoms during dry season at the middle of El-Hammam stream during April, June and August 2010 led to the identification of 44 cosmopolitan species, while 30 species occurred at the mouth of Cheliff river. 10 taxa were recorded for the first time in Algeria. Diversity values (Species richness, Shannon's index and Equitability index) for the two study sites are generally medium to low. The results of the 17 diatom-based metrics tested show that ROTT trophic index (TID) and the Trophic Diatom Index (TDI) best mirrored water quality, but a revision of taxa autecological values is required.

Introduction

The earliest studies on the algal flora of Algeria date back to 1799 with the work of Desfontaines (Baudrimont, 1971a), after that, first researches on Algerian diatom flora were performed by Montagne (1846), Ehrenberg (1854). The works of Baudrimont (1974) are remarkable contributions to the ecology of diatoms in Algeria. He has recorded 356 species, varieties and forms during his research on diatoms of inland waters in Algeria, estimating that this inventory represents only 17.5% of the world's known flora in 1968. Since then, the global number of described taxa has increased exponentially while the flora of Algerian diatoms has not changed apart from recent studies including the work of Al-Asadi et al. (2006), the monograph by Lange-Bertalot et al. (2009) identifying four new *Navigiolum* from samples collected in Algerian ephemeral rock pools ("Gueltas") and the papers of Chaïb et al. (2011) and Chaïb and Tison-Rosebery (2012) on samples collected from wadi (stream) Kebir-East, North-East Algeria.

Besides their floristic interest, several authors have studied diatoms as biological proxies for water quality, discussing their performance as surrogates for saprobity, trophic status, acidity, etc. Benthic diatoms are now considered key organisms for

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monitoring river ecological quality in several European countries (European Union, 2000). In Algeria apart from the study of Chaïb and Tison-Rosebery (2012), to our knowledge no attempt of diatom-based environmental monitoring has been performed to date in Algerian aquatic ecosystems, evidencing the lack of accurate ecological information linked to available diatom data.

This work presents two inventories of benthic diatoms in two different hydrosystems in northwestern Algeria: the estuary of Cheliff river (Brackish water) at Mostaganem and in the middle of El-Hammam stream (freshwater) at Mascara. The results of this study will contribute to the database of Algerian benthic diatoms. We also test the performance of 17 diatom indices in order to provide a scientific basis for the implementation of diatom-based monitoring programs in this region.

Material et methods

Study sites

Algeria includes many arid and semi-arid areas which suffer from long periods of drought and severe water shortages. Four stations at two sites have been chosen:

a) The site S1 in the middle of El-Hammam stream *(Fig. 1)*, located northwest of Algeria, municipality of Bouhanifia, region of Mascara. El-Hammam stream is subject to a semi-arid climate with an annual average temperature of 16.6 °C and a precipitation for the whole basin estimated at 385.3 mm. Its watershed is part of the great Makta's watershed; it is limited by the mountains of Beni-Chougrane north and massive of Siada south. Two stations were chosen at this site: H1 (35° 17' 58.70" N, 0° 2' 48.26" W, 231 m a.s.l.) and H2 (35° 18' 52.06" N, 0° 3' 4.45" W, 226 m a.s.l.) at a distance of about 2.26 km and 4.24 km respectively downstream of the dam of Bouhanifia.

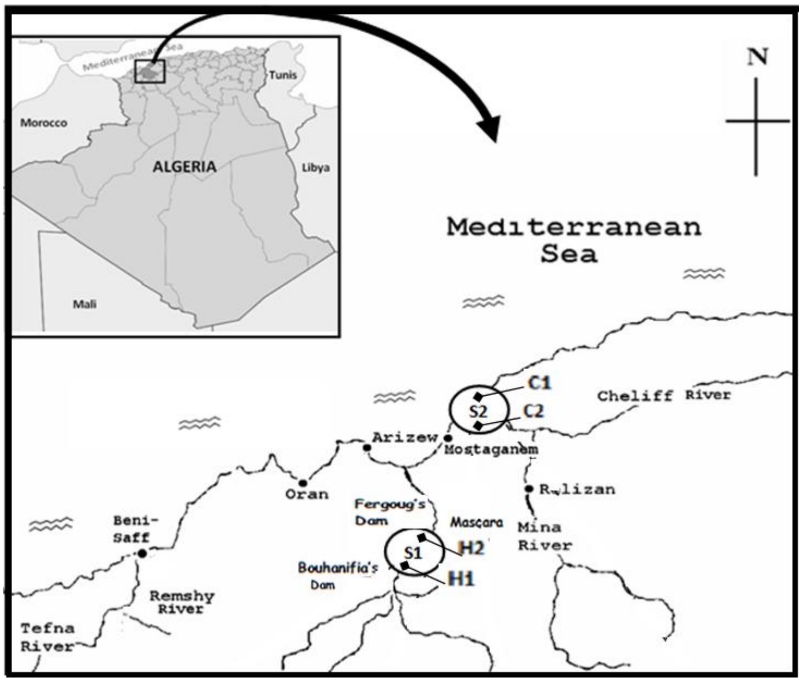

Figure 1. *Location of the four study sites H1, H2 at the site S1 at El-Hammam stream and C1, C2 at the site S2 at the mouth of Cheliff river.*

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b) Site S2 belongs to the estuary of Cheliff river *(Fig. 1)*, the largest watercourse in Algeria, located northwest of the country, 700 km long, it passes through several wilayas including Mostaganem, Relizan, Ain-Aldeffla and Cheliff (Al-Asadi et al., 2006), it rises in the Tell atlas and flows 13 km east of the city of Mostaganem (Cheliff-beach). The zone is characterized by hot summers and cool winters, with temperatures ranging from 10.41 °C in January to 24.06 °C in August, while rainfall varies from 1.37 to 74.59 mm from July to December (Al-Asadi et al., 2006). Two stations were chosen near the mouth: C1 (36° 2' 14.47" N, 0° 8' 10.00", sea level) and C2 (36° 2' 0.17" N, 0° 8' 39.50", sea level) at a distance of about 360 m and 1.21 km respectively from the Mediterranean Sea.

Collection of benthic diatoms

Benthic diatoms were sampled during low flow periods during the months of April, June and August in the year 2010. Different natural substrates immersed in water were used for the collection of periphyton depending on sampling conditions, access and availability of substrates (Kelly et al., 1998; Prygiel and Coste, 2000; Taylor et al., 2007b). In total, 24 samples were collected. The surfaces of the natural substrates (pebbles, cobbles and stems) collected from watercourses were brushed using a toothbrush to remove periphyton containing diatoms, in the case of the filamentous algae; diatoms were collected after shaking algae in sachets containing clean medium water.

Identification of benthic diatoms

Benthic diatoms were collected in separate bottles and stored in the field with 10% of formalin neutralized the sample as treated with boiling hydrogen peroxide (H_2O_2 at 30%) for 10 minutes to degrade organic matter and for 5 minutes with boiling hydrochloric acid HCl 35%. Samples were then subjected to a series of centrifugations for 5 min at 2500 rpm and a succession of cleanings with distilled water. An aliquot of the cleaned sample was deposited on a coverslip, dehydrated by drying and mounted in the resin refractive Naphrax (Northern Biological Supplies Ltd., England, refractive index = 1.74), (Hasle and Fryxell, 1970; Prygiel and Coste, 2000). Microscopic examination of permanent slides were made using an optical microscope LEICA DM 5000 type B in differential interference contrast (DIC), diatom species were identified at a magnification X1000 with immersion oil, a minimum of 400 diatom valves were identified in each slide following usual references (Krammer and Lange-Bertalot, 1988, 1986, 1991a, 1991b, 2000 ; Prygiel and Coste, 2000; Bate et al., 2004; Taylor et al., 2007a; Lavoie et al., 2008; Blanco et al., 2010; etc.).

Physicochemical parameters

Main limnological parameters were provided by the National Agency of Water Resources (ANRH, 2010) at two stations: the dam of Bouhanifia (upstream of El-hammam) and station Hacine (downstream of El-hammam at around 8 km upstream of Fergoug’s dam). Additionally, temperature, pH and conductivity were measured at the other locations. These three parameters were measured *in situ* by a thermometer (liquid in glass), digital pH-meter type PHT-01 ATC Voltcraft and conductimeter type LWT-01 Voltcraftwe.

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Statistical analysis

Data were analysed for correlation and correspondence analyses (CA). A Correspondence Analysis (CA) was used to explore the distribution of diatom taxa in the different stations studied. The relationships between the different metrics calculated were assessed by means of Pearson's correlation coefficients. Both were calculated using XLStat software v. 2013 (Addinosoft, 2013). Diatom indices were calculated using Omnidia software (Lecointe and Coste, 1993).

Results and Discussion

The inventory of benthic diatoms at both sites consisted of a total of 56 taxa 44 of them found the middle of El-Hammam stream and 30 taxa at the mouth of Cheliff river, including 18 taxa in common to both sites. Ten taxa were recorded for the first time in Algeria *(Table 1)*.

During the low-flow periods in the months of April, June and August, the fresh water of station H1 at El-Hammam stream was characterized by the dominance (> 20%) of *Achnanthidium minutissimum*, *Cyclotella ocellata*, *C. meneghiniana*, *Nitzschia frustulum* and *N. palea*, while the station H2 was characterized by the dominance of *Achnanthidium saprophilum*, *Navicula cryptotenelloides*, *N. erifuga* and *Nitzschia palea*. Other frequent taxa (5-20%) at site H1 were *Achnanthidium saprophilum* and *Surirella brebissonii*, while at the site H2 *Achnanthidium exiguum*, *Cyclotella meneghiniana*, *Fragilaria nana*, *Gomophonema parvulum*, *Navicula frustulum*, *N. recens and*, *N. veneta* appeared as subdominant species.

Most species recorded at El-Hammam stream are known to be cosmopolitan, being common in European freshwaters with a slight salinity and alkaline content, as remarked by Baudrimont (1974) in his study of taxa from arid and semi-arid areas of Algeria inculding the region of Mascara. Most of these taxa were already recorded by some authors in north Algeria (Petit, 1895; Baudrimont, 1974; Al-Asadi et al., 2006; Chaïb et al., 2011; Chaïb and Tison-Rosebery, 2012). Baudrimont (1974) took samples at Hammam Bouhanifia from the thermal spring of El-Hammam stream with water above 50 °C, recording *Cocconeis pediculus* and *Cyclotella meneghiniana*, but no samples had been takes to date from El-Hammam stream where we record for the first time the presence of *Craticula buderi*, *Conticribra weissflogii*, *Cymbopleura incerta*, *Denticula kuetzingii*, *Fragilaria nana*, *Navicula phyllepta*, *Navicula simulata* and *Nitzschia perminuta.*

Concerning the saline waters, during the sampling period at the estuary of Cheliff river the dominant taxa (> 20%) in both stations C1 and C2 were *Amphora* sp. and *Berkeleya* sp.2. The most abundant taxa (5-20%) in both stations were *Achnanthes minutissimum* var. *gracillima*, *Berkeleya* sp.1 and *Navicula phyllepta*. *Cyclotella meneghiniana* was found abundant at station C1 and *Achnanthes minutissimum var gracillima*, *Cylindrotheca closterium, Halamphora coffeaeformis* and *Nitzschia incerta* at station C2. All the taxa recorded at the estuary of Cheliff river are known to be cosmopolitan. Except for a few refrences on marine diatoms from saline waters from Algeria like Chott and Sebkha (Petit, 1895; Amosse, 1941; Baudrimont, 1970, 1971a, 1974) to our knowledge no further papers study Algerian estuarine diatoms, thus we cite for the first time the following taxa: *Achnanthes minutissima var gracillima, Craticula buderi, Gyrosigma scalproides, Navicula phyllepta.*

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Table 1. *Average frequency of diatoms recorded in different stations at two sites in the middle of El- Hammam stream and at the mouth of Cheliff river. **: Taxa preceded by asterisk were recorded for the first time in Algeria.*

Absent; Rare (0.2-1 %); Common (1-5 %); Frequent (5-20 %); Dominant (>20 %)

Sites	S1 El-Hammam stream						S2 Estuary of Cheliff river					
Dates	April		June		August		April		June		August	
Taxa / Stations	*H1*	*H2*	*H1*	*H2*	*H1*	*H2*	*C1*	*C2*	*C1*	*C2*	*C1*	*C2*
Achnanthes exigua Grunow in Cleve et Grunow	0.2		0.5		0.3							
***Achnanthes minutissimum var. gracillima* (Meister) Lange-Bertalot							5.2	0.3	9	5.8		
Achnanthidium minutissimum (Kützing) Czarnecki	54.5	0.5	9.2	3	8	5.4		5.3	1.7	4.8	4.8	1.6
Achnanthidium saprophilum (Kobayasi & Mayama) Round & Bukhtiyarova	10				2.3	61.6						
Aulacoseira ambigua (Grunow) Simonsen					0.3							
Halamphora coffeaeformis (Agardh) Z. Levkov							4.8		0.3	1	4.8	9.1
Amphora sp.							0.7	1.3	38	31.8	54.	78.9
Amphora pediculus (Kützing) Grunow			1.2									
Berkeleya sp. 1 *(rutilans ?)*							5.2		2.0	11.9	9.1	0.9
Berkeleya sp. 2 *(scopulorum ?)*							58.8	55	24	22.8	2.7	0.3
Cocconeis euglypta Ehrenberg	0.5		0.7	0.4	4.4	0.4						
Cocconeis pediculus Ehrenberg			0.2		1.3							
***Conticribra weissflogii* (Grunow) K.Stachura-Suchoples & D.M.Williams					0.5			0.3	0.3		3.2	
***Craticula buderi* (Hustedt) Lange-Bertalot			0.2			0.4	0.7	1.1		0.3		
Cyclotella meneghiniana Kützing	1.2	0.2	9	1.1	23.3	6.1		1.3	0.3	1.0	9.1	2.5
Cyclotella ocellata Pantocsek	3.2	1	23.9	1.3	1.3	1.3	3.8	3.2	2	1		0.3
Cylindrothica closterium (Ehrenberg) Reimann & J.C.Lewin							0.7	5.3		0.3	0.5	
** *Cymbopleura incerta* (Grunow) Krammer				0.6								
***Denticula kuetzingii* Grunow		0.2										

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Sites	S1 El-Hammam stream						S2 Estuary of Cheliff river					
Dates	April		June		August		April		June		August	
Taxa / Stations	***H1***	***H2***	***H1***	***H2***	***H1***	***H2***	***C1***	***C2***	***C1***	***C2***	***C1***	***C2***
Encyonema minutum (Hilse) D.G.Mann	0.2		0.2		0.5							
Entomoneis sp.								2.1	0.7			
Eolimna subminuscula (Manguin) G. Moser *et* al.		0.2							0.3	0.3		0.3
** *Fragilaria nana* F.Meister(Meister) Lange-Bertalot					4.4	10.6						
Gomphonema parvulum (Kützing) Kützing	0.2	13.4	0.5	1.1	0.3							
***Gyrosigma scalproides* (Rabenhorst) Cleve										0.3		0.3
Hippodonta hungarica (Grunow) Lange-Bertalot *et* al.					0.5							
Luticola mutica (Kützing) D.G.Mann			0.5									
Navicula cryptotenelloides Lange-Bertalot		34.2	0.2	3								
Navicula erifuga Lange-Bertalot *et* Krammer			0.2	28.4	0.3	0.2						0.6
Navicula gregaria Donkin	0.2	3.2	1	0.2	1.3	0.7						0.3
Navicula lanceolata Ehrenberg	0.5		1.2	2.0	4.9	0.5		0.3			3.7	0.9
***Navicula phyllepta* Kützing	0.2						12.7	11.3	9	5.8	4.8	0.3
Navicula reichardtiana Lange-Bertalot	1.2	3	0.5	1.9	0.5	1.4		0.3				0.3
Navicula recens Lange-Bertalot in Krammer *et* Lange-Bertalot	1	8.7	4.2					0.3		0.3		
***Navicula simulata* Manguin		0.7										
Navicula sp.			0.7									
Navicula viridula var. *rostellata* (Kützing) Cleve	0.5		1		0.3							
Navicula veneta Kützing	0.2	7.4		2.8	1.8							
Nitzschia acicularis (Kützing) W.Smith					0.3							

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Sites	S1 El-Hammam stream						S2 Estuary of Cheliff river					
Dates	April		June		August		April		June		August	
Taxa / Stations	*H1*	*H2*	*H1*	*H2*	*H1*	*H2*	*C1*	*C2*	*C1*	*C2*	*C1*	*C2*
Nitzschia dissipata (Kutzing) Grunow. var. *dissipata*					0.8	0.4				0.3		
Nitzschia capitellata Hustedt				0.4	0.5	0.4		4.2				
Nitzschia clausii Hantzsch									0.3		1.1	
Nitzschia clausii Hantzsch									0.3		1.1	
Nitzschia frustulum (Kützing) Grunow	24.2	18.6	15.2	17.5	6.5	1.1	0.3	0.3	1.3	0.3		0.9
Nitzschia filiformis (W.Smith) Hustedt			0.5				0.3		0.7			
Nitzschia linearis (C.Agardh) W.Smith			2.2	0.4	0.3							
Nitzschia palea (Kützing) W.Smith	1.2	6.5	17.5	35.3	22.5	7.6	1.4	1.8	2	1	0.5	0.3
***Nitzschia perminuta* (Grunow) M.Peragallo				0.2								
Nitzschia incerta (Grunow) M.Peragallo							4.8	6.3	4.0	8.7		
Nitzschia fonticola (Grunow) Grunow in Van Heurck				0.4	2.8	0.9						
Pleurosira laevis Ehrenberg *f. laevis*					0.3	0.5						
Rhoicosphenia abbreviata (C.Agardh) Lange-Bertalot	0.2		4.2	0.2	1.8	0.2						
Stauroneis sp.							0.7		1.7	0.6	0.5	
Surirella brebissonii Krammer et Lange-Bertalot	0.2	1.7	2.5		6.5							
Tabularia fasciculata (C.Agardh) D.M.Williams et Round			1			0.2						
Tryblionella apiculata Gregory		0.2	1.2		1.3	0.2			0.3	0.6	1.1	0.3
Ulnaria ulna (Nitzsch) P.Compère								0.3	2.0	1.0		1.6

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Concerning diversity indices, the values of stand structure metrics (species richness S, Shannon's diversity H_α and evenness E) at both sites are generally low, with an average Shannon's diversity not exceeding 2.5 bits *(Table 2)*. At El-Hammam stream, the diatom communities at stations H1 April and H2 August are less balanced and diversified compared to others stations. Station H1 April was dominated by *Achnanthidium minutissimum* (55%) and *Nitzschia frustulum* (24%) wich influenced negatively Shannon's diversity "Hα" and evenness "E". Chaïb and Tison-Rosebery (2012) noted that *Achnanthidium minutissimum* represented up to 75% of the community abundance during the summer at a station of Kebir-East stream (North-est of Algeria). Mean calculated values of diversity index at Kebir-East stream in summer were around E= 0.7 and Hα= 3.7, being E= 0.6 and Hα= 1.9 at El-Hammam stream.

Table 2*. Shannon-weaver diversity index and equitability of El-Hammam stream and Cheliff's estuary.*

El-Hammam Stations	April		June		August	
	H1	***H2***	***H1***	***H2***	***H1***	***H2***
Shannon -weaver diversity index (H_α)	1.41	1.95	2.39	1.80	2.51	1.48
Equitability (E)	0.48	0.72	0.73	0.61	0.73	0.49
Species richness (S)	19	16	27	19	30	20
Estuary of Cheliff Stations	***C1***	***C2***	***C1***	***C2***	***C1***	***C2***
Shannon -weaver diversity index (H_α)	1.53	1.72	1.96	1.85	1.71	0.95
Equitability (E)	0.58	0.59	0.65	0.60	0.65	0.33
Species richness (S)	14	19	20	21	14	18

At Cheliff river, station August C2 shows clearly the most unbalanced and less diversified assemblage, with E= 0.33 and Hα= 0.95. This was characterized by the abundance (78%) of *Amphora* sp. *(Table 1)*. In general, diatom diversity at the estaury of Cheliff river (around E= 0.5 and Hα= 1.6) was influenced by the presence of brackish taxa such *Berkeleya* sp. 2 and *Amphora* sp., ecological studies of most species of the genus *Amphora* recorded at Algeria were from saline and brackish waters such Chott (Baudrimont, 1970, 1971a, 1974). However, the ecology of the genus *Berkeleya* in Algerian saline waters is still uknown (Petit, 1895; Amosse, 1941). Rovira et al. (2009) studied the diversity of periphytic diatom community in a Mediterranean salt wedge estuary at the Ebro Estuary (Spain), noting the most abundant genera (considering all species) were *Cocconeis* (23%), followed by *Navicula* (21%), *Nitzschia* (17%) and *Tabularia* (11%), with a mean value of Hα= 3.4 and species richness S= 39, in clear contrast with our results. The diatom community at estuary of Cheliff river was less diversified, with a mean Hα= 1.6 and S= 18, these values probabli related to mineral and organic pollutants accumulated in this area (Kies, 2009). Al-Asadi et al. (2006) studied the Cheliff river, finding that diatoms showed less dominance than in the Mina river in northwestern Algeria.

Concerning organic pollution, ecoligical studies in Algerian waters have been focused only on inorganic components, with no previous mesurements of parameters such as biological or chemical oxygen demand. The saprobity status of Algerian waters has not been properly assessed either. We calculated the Organic Pollution Index or

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"Indice de Pollution Organique IPO" (Leclercq and Maquet, 1987) from physicochemical data given by National Agency of Water Ressources of Algeria *(Table 3)* in summer of 2010 at El-hammam stream upstream of fargoug's dam which value of "IPO" show that water quality was strongly polluted by organic materials (IPO: from 2.0 to 2.9). Also we calculated the same index at Kebir-East stream in summer 2007 from physicochemical data published by Chaïb and Tison-Rosebery (2012) which water was also strongly polluted by organic materials (IPO: from 2.0 to 2.9). Using this metric, Bahroun and Kherici Bousnoubra (2011) at the Kebir-East stream in 2004-2005, indicated that water was extremely polluted by organic materials.

According to the classification of Van Dam et al. (1994), the most frequent taxa at El-hammam stream were β-mesosaprobous (42.7%) and polysaprobous (30.7%), compared to Kebir-East stream were most taxa recorded as frequent by Chaïb and Tison-Rosebery (2012) were β-mesosaprobous to α-meso-/polysaprobous (*Achnanthidium minitissimum*, *Amphora pediculus*, *Gomphonema parvulum*, *Navicula gregaria*, *Nitzschia frustulum*, *Eolimna subminuscula*) except for *Cyclotella ocellata* (oligosaprobous) and *Nitzschia palea* (polysaprobous). While species abundance at El-Hammam stream was a bit different additional to *Achnanthidium minitissimum*, *Cyclotella ocellata*, *Nitzschia frustulum*, *Nitzschia palea* we recorded also *Achnanthidium saprophilum* (polysaprobous), *Cyclotella meneghiniana* and *Navicula cryptotenelloides (*β-mesosaprobous). The abundance of *Cyclotella ocellata* at El-Hammam stream reached up (23%) at H1 June and was not as stable as that of *Nitzschia frustulum* and *N. palea* during the summer at El-Hammam stream probably because high oxygen concentrations (128 % stauration) recorded near this station at dam of Bouhanifia *(Table 3)*. The abundance of *Nitzschia frustulum* and *N. palea* was also noted by Fawzi et al. (2001) at wadi Hassar from Morocco, under semi-arid climate with oceanic influence at, where these two species indicated an important degree of organic pollution.

With respect to the trophic status, the communities at stations of El-Hammam stream were generally dominated by eutrophentic (42.5%) and hypereutrophentic taxa (28 %), Dominant species (>20%) such as *Nitzschia frustulum* at H1 April, *Navicula erifuga* at H2 June and *Cyclotella meneghiniana* at H1 August were eutrophilous, but hypereutrophilous taxa such as *Achnanthidium saprophilum* at H2 August, or *Nitzschia* palea at H2 June and H1 August also occured, thereby indicating that these areas were impacted by nutrient inflows, presumably related to adjacent anthropogenic activities including agriculture. The same pattern was observed at Kebir-East stream by Chaïb and Tison-Rosebery (2012) with eutrophentic taxa representing 52.5% of the community.

Concerning conductivity and salinity levels, most dominant taxa at El-Hammam stream were fresh-brackish taxa (55.7%) with salinity optima under 0.825 PSU according to the classification of Van Dam et al. (1994) and brackish-fresh taxa (34.9%) with salinity optima of 0.825 - 1.65 PSU.

In general, the same dominant species were recorded at Kebir-East stream by Chaïb and Tison-Rosebery (2012), including *Achnanthidium minutissimum*, *Cyclotella ocellata*, *Nitzschia frustulum*, and *Navicula recens*, exept species such *Amphora pediculus*, *Navicula caterva* and *Eolimna subminuscula* that occurred at Kebir-East stream or *Achnanthidium saprophilum*, *Cyclotella meneghiniana*, *Fragilaria nana* and *Navícula cryptotenelloides* at El-Hammam stream. The high chloride concentration (325 mg l^{-1}) and conductivty levels (around 1575 µS cm^{-1}), together with wastewater discharges

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observed near station H2, favored the developement of taxa adapted to such conditions. Baudrimont (1974) concluded that 206 different species recorded in Algerian aquatic systems such as wadis, chotts and sebkha were related to salt waters, concluding that freshwater streams with oligohalobious species were absent in Algeria. In our case, we noted the ocasional abundance of freshwater taxa such *Cyclottela ocellata* in H1 June and H2 August, although oligohalobous species were indeed very rare. Chaïb and Tison-Rosebery (2012) showed comparable results at Kebir-East stream, with scarce occurrence of oligohalobous species.

Table 3. *Physicochemical parameters at dam of Bouhanifia (A: upstream of El-hammam) and at downstream of El-Hammam (B: upstream of Fergoug's dam)*. *O_2 sat = saturation of oxygen; O_2 dis = dissolved oxygen; Cond = conductivity; BOD = Biological oxygen demand after 5days. Source: Nationa Agency for Water Resources, Algeria (ANRH, 2010).*

		April		May		June		July		August	
Parameters	**Stations** / **Unit**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
T	C°	17	18	20	20	25	-	28	25	30	28
pH		8.1	7.9	7.9	7.7	8.2	-	7.9	7.8	8.1	7.8
Cond	µS cm-1	1270	3460	1330	1392	1204	-	1249	1281	1330	1363
O_2 sat.	%	82.2	111.	82.6	69	128.4	-	69.7	77.7	87.7	80
O_2 dis.	mg l-1	*7.7*	*0.2*	7.3	6.1	10.4	-	5.4	6.3	6.6	6.2
Cl	mg l-1	256	834	237	244	246	-	243	250	268	268
SO_4	mg l-1	208	798	241	245	184	-	208	203	227	227
SiO_2	mg l-1	2.3	2.5	2.2	2.1	4.5	-	3.1	3.4	3.9	4.2
BOD	mg l-1	8.7	13.5	9.7	11.9	7.1	-	8.7	13.3	10.3	13.5
NO_3	mg l-1	3	2	5	6	3	-	5	3	2	1
NO_2	mg l-1	0.32	0.05	0.45	0.32	0.24	-	0.17	0.25	0.1	0.12
PO_4	mg l-1	0.04	0.06	0.03	0.18	0.08	-	0.08	0.23	0.07	0.1

Regarding the acidity levels at El-Hammam stream, the diatom communities observed consist generally of a mixture of alkaliphilous (53.3%) and circumneutral (46.3%) taxa. Field pH measurements ranged from 7.5 to 7.9, with water temperatures betweenf 18 and 28 °C during the study period. Acidophilous species were absent. Most taxa observed by Chaïb and Tison-Rosebery (2012) at Kebir-East stream were also alkaliphilous (70 %), with pH ranging from 6.5 to 8.3 and scarce some acidophilous species. Baudrimont (1974) noted that species typical from European acid waters can adapt to alkaline waters in Algeria.

According to the classification of Van Dam et al. (1994), the dominant taxa at stations of El-Hammam stream were generally from moderately oxygenated environments -such as *Nitzschia frustulum*- to poorly oxygenated ones like *Achnanthidium saprophilum* or *Nitzschia palea*. Poly-oxibiontic taxa represented by *Achnanthidium minutissimum* were only occasional with abundance (54%) at station H1 April and *Cyclotella ocellata* (24%) at H1 June. A similar variation was observed by Chaïb and Tison-Rosebery (2012) at Kebir-East stream, with *Achnanthidium minutissimum* reaching 75% of the whole diatom community during summer.

Biological Diatom index BDI (Lenoir and Coste, 1996) had been already tested in north-eastern Algeria at Kebir-East stream by Chaïb and Tison-Rosebery (2012). BDI scores in their study were not contrasted enough, and did not appear to be in correspondence with the water quality gradient, where high conductivities and associated species tended to confuse the biological quality status; of the highest BDI value (18/20) was obtained at Ain Assel in summer 2007 by these authors, where

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Achanthidium minutissimum was dominant, and did not reflect the actual poor water quality of that station, with $[NH_4^+]$ = 1 mg l^{-1} and $[PO_4^{3-}]$ = 0.5 mg l^{-1} (Chaïb and Tison-Rosebery, 2012).

In our case, firstly we calculated Pearson's correlations between 17 diatom indices and IPO for Kebir-East wadi by using diatom counts and physicochemical results provided by the workcounts of diatom species and physicochemical variables of Chaïb and Tison-Rosebery (2012) from seven stations at summer *(Table 4)*. The highest correlation for Kebir-East wadi at summer is for TDI: Trophic Diatom Index (Kelly and Whitton, 1995) with r= 0.62 and p=0.14. As a result we calculated the Pearson's correlations between 16 diatom indices and TDI for El-hammam stream (*Table 5)* and the results give the highest correlation are respectively for TID: ROTT trophic index (Rott et al., 1999) with r=-0.95 and p=0.004, IDAP: Artois-Picardie Diatom Index (Prygiel et al., 1996) with r=-0.92, p=0.011 and GDI: Generic Diatom Index (Rumeau and Coste, 1988) with r=-0.90 and p=0.013. Being based on a low taxonomic resolution, GDI does not give accurate results; usually GDI exhibits significant correlations against PO_4^{3}-P and Cl^- concentrations (Blanco et al., 2007). In which the mean concentration of Cl^- and PO_4^- exceed 316 and 0.1 mg l^{-1} respectively at El-Hammam stream. Fawzi et al. (2001) tested some diatoms indices at Hassar stream (Morocco), concluding that IDAP (Prygiel et al., 1996) is more suitable for the assessment of water quality in this stream. It has a fairly significant correlation with the Organic Pollution Index (IPO) and seems to incorporate saltwater taxa.

Table 4. *Pearson correlation coefficients between diatom indices and organic pollution index (IPO) applied for Kebir-Est stream [results are calculated by using Data counts of diatom species and physicochemical variables was trailed from work of Chaib & Tison-Rosebery (2012) of seven sampling stations on the Kebir-East stream in summer period].* ***SLA:*** *Sládeček's Index;* ***DESCY****:Descy's Pollution Index;* ***IDSE:*** *Leclerq;* ***SHE****: Schiefele and Schreiner's index;* ***WAT:*** *Watanabe index****; TDI:*** *Trophic Diatom Index;* ***%PT:*** *Pourcentage of Pollution Tolerant Taxa****; GDI****: Generic Diatom Index;* ***CEC****: Commission of Economic al Community Index;* ***SPI****: Specific Pollution Sensitivity Index;* ***BDI****: Biological Diatom Index;* ***IDAP****: Artois-Picardie Diatom Index;* ***EPI-D:*** *Eutrophication/Pollution Index;* ***DI_CH:*** *Hurlimann Suisse;* ***IDP:*** *Pampean Diatom Index;* ***LOBO:*** *LOBO index;* ***SID****: Saprobic Index and* ***TID:*** *Rott Trophic Index.* ***IPO:*** *Organic Pollution index "Indice de Pollution Organique".*

Indices	SLA	DESCY	IDSE/5	SHE	WAT	TDI	GDI	CEE	SPI	BDI	IDAP	EPI-D	DI_CH	IDP	LOBO	SID	TID
IPO	-0.37	0.31	-0.26	-0.21	-0.18	**0.62***	-0.12	-0.14	-0.15	-0.21	-0.14	-0.51	-0.28	-0.3	-0.54	-0.46	-0.57

Table 5. *Pearson correlation coefficients between diatom indices and Trophic Diatom Index (TID) applied for El-Hammam stream.*

Indices	SLA	DESCY	IDSE/5	SHE	WAT	GDI	CEE	SPI	BDI	IDAP	EPI-D	DI_CH	IDP	LOBO	SID	TID
Trophic Diatom Index (TDI)	-0.58	-0.44	-0.66	-0.55	-0.06	-0.9	-0.8	-0.87	-0.87	-0.92	-0.69	0.03	-0.68	-0.33	-0.24	**-0.95***

Tested indices at El-hammam stream *(Table 6)* show that water quality indicated by TDI and TID at station H1 in April reflect a water quality with a little degree of eutrophication, being eutrophic in June and August with some evidence of organic

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pollution (PT%= 21-40%). While station H2 in April and June show a high degree of eutrophication with organic pollution likely to contribute significantly to eutrophication of site (PT%=41-60), being fairly eutophic at August with free of significant organic pollution (PT%= <20). The station H2 was frequently influenced by fluctuating urban wastewater discharges from Bouhanifia while station H1 near to downstream of the dam of Bouhanifia (2.2 Km) was less influenced by urban discharges.

Table 6. *Values of diatom indices applied for stations at El-Hammam stream.*

Indices \ Stations	Avril		Juin		Aout	
	H1	**H2**	**H1**	**H2**	**H1**	**H2**
SLA	14.3	9.3	10.9	9	9.2	9.4
DESCY	14.8	10.3	9.9	6.3	8.4	7.8
IDSE/5	4.24	2.83	3.16	2.72	2.88	2.96
SHE	13.4	6.7	9.2	5.4	8.5	6.6
WAT	14.7	10.2	9.5	7.6	7.8	4.2
TDI	36	85	71.8	82.5	68.8	35.4
%PT	26.4	42.2	38.9	57.4	40.4	11.4
GDI	12.7	9.3	8.5	5.9	9	14.6
CEE	13.9	4	6.7	2.7	6.3	7.1
SPI	13.9	7.5	7	4	6.8	10.5
BDI	14.2	10.1	10.3	7.6	10	12.1
IDAP	12.9	5.1	9.2	6.4	8.9	10.7
EPI-D	15.4	7.5	11.7	8	8.6	9.8
DI_CH	10.2	7.3	10	5.2	5.8	3.2
IDP	13.8	7.7	8.8	7.8	8.2	8.5
LOBO	19.7	14.5	17.2	19.3	14.7	16.5
SID	11.7	9.4	10.2	9.3	10.1	8.5
TID	7.8	4	5.9	4.8	5.2	7.1

Sites C1 and C2 at the estuary of wadi Cheliff river had in general the same taxa composition during April, June and August, including *Berkeleya* sp. 1, *Berkeleya* sp. 2, *Amphora* sp. *Navicula phyllepta*, *Achnanthidium minutissimum* var. *gracillimum* and *Nitzschia incerta*. These sites there are not affected by effluent discharges or wastewater inflows between sites C1 and C2. This zone being characterized by a high input of inorganic nitrogen and phosphorus (Kies, 2009).

Correspondence analysis (CA) applied to diatom abundance data in relation with the different sampled stations is represented on a factorial symmetrical plot of two axes *(Fig. 2 and 3)* with the maximum of inertia (57.91%) for El-Hammam stream analysis and 84.05% for estuary Cheliff river ($p < 0.001$). CA applied for species densities in El-Hammam stream (F1= 33.78%, F2 = 24.04%) show that the x-axis separated the stations H2 April and H2 August from the others *(Fig. 2)*. Conversely, the y-axis distinguishes stations H2 April, H1 June and H2 June from H1 April, H1 August and H2 August. Site H2 at El-hammam stream was characterized by taxa singular taxonomic composition in April, June and August, this maybe due to urban wastewater discharge and a unstable flow regime caused by water discharges from the dam of Bouhanifia followed by dry summer periods. All these factors were unstable during the

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study period, but site H1, near to the downstream of dam of Bouhanifia and not influenced by signficant urban waswater discharges, remained more stable, with similar diatom communities along the study period.

At the the estuary of Cheliff river, CA (F1=73.44%, F2 = 10.62%) shows that first two axes discriminate stations C1 and C2 monthly *(Fig. 3)*. The stations C1 and C2 June, and C1 and C2 August, appear very close, while C1 and C2 April are more distant, this can be related to the fact that diatom community in April C1, near to sea water, was more influenced by sea intrusions during this month.

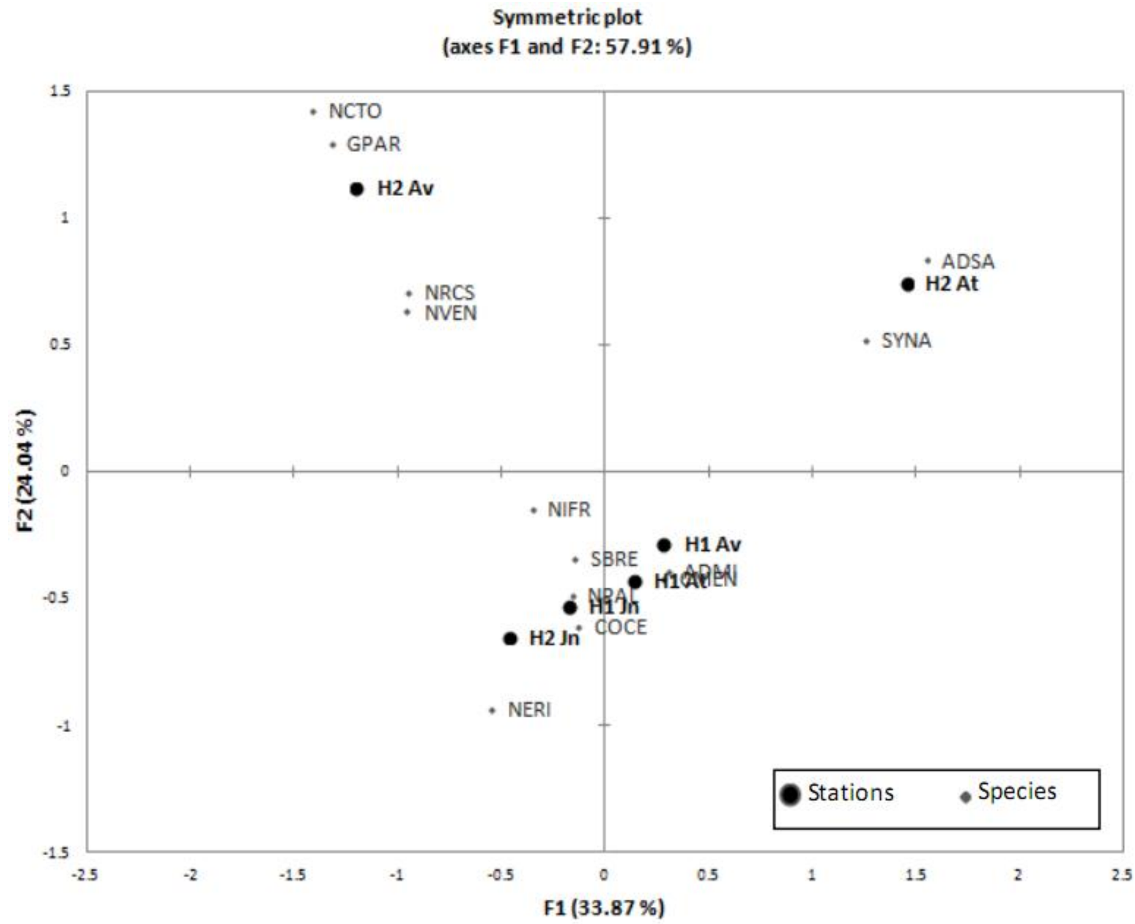

***Figure 2**. Factorial plot of the Classification Analysis (CA) applied to the distributions of 13 species densities (abundance >5%) on sampled sites of El-Hammam stream H1 and H2: April (**H1 av**; **H2 av**), June (**H1 Jn**; **H2 Jn**), and H1 August (**H1 At**; **H2 At**). Each species was coded by four letters of scientific name of the species* **ADMI:** *Achnanthidium minutissimum.* **ADSA:** *Achnanthidium saprophilum.* **CMEN:** *Cyclotella meneghiniana.* **COCE:** *Cyclotella ocellata.* **SYNA:** *Fragilaria nana.* **GPAR:** *Gomphonema parvulum.* **NCTO:** *Navicula cryptotenelloides.* **NERI:** *Navicula erifuga.* **NRCS:** *Navicula recens.* **NVEN:** *Navicula veneta.* **NIFR:** *Nitzschia frustulum.* **NPAL:** *Nitzschia palea.* **SBRE:** *Surirella brebissonii.* **AMGR:** *Achnanthes minutissima var gracillima.* **ACOF:** *Amphora coffeaeformis.* **A.sp:** *Amphora sp,* **B.sp1:** *Berkeleya sp. 1 (rutilans?).* **B.sp2:** *Berkeleya sp. 2 (scopulorum?).* **NPHY:** *Navicula phyllepta.* **NZCL:** *Cylindrotheca closterium.* **NREV:** *Nitzschia incerta.*

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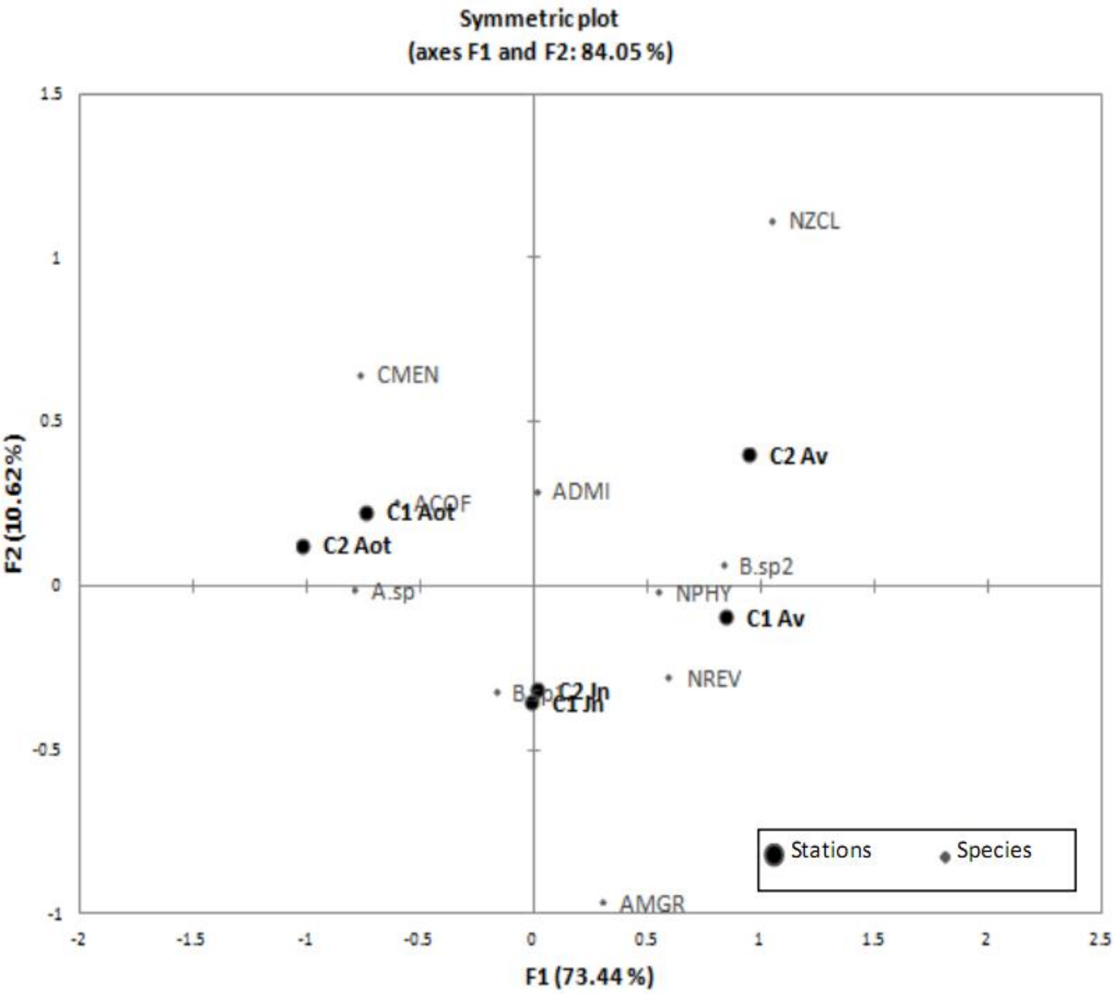

Figure 3. *Factorial plot of the Classification Analysis (CA) applied to the distributions of 10 taxa densities (abundance >5%) on sampled sites of estuary of Cheliff river C1 and C2: April* ***(C1 av; C2 av)****, June* ***(C1 Jn; C2 Jn)****, and C1 August* ***(C1 At; C2 At)****. Each species was coded by four letters of scientific name of the species (Fig. 2).*

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