Revue d'Ecologie (Terre et Vie), Vol. 70 (1), 2015 : 44-57

STUDY OF THE DIATOMS OF REGHAIA LAKE, NORTHERN ALGERIA

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RÉSUMÉ.— *Étude des diatomées du lac de Reghaia, Nord de l'Algérie*.— En raison de leur importante capacité de réponse aux changements environnementaux, les diatomées sont depuis longtemps utilisées comme indicateurs biologiques de la qualité des milieux aquatiques. Cette flore a été très peu étudiée en Algérie et en Afrique du Nord ; pour cela l'objectif de cette étude est de décrire les variabilités spatio-temporelles des diatomées à l'échelle du lac de Reghaia, qui se déverse dans la Méditerranée, et les principaux facteurs abiotiques responsables de ces variabilités. D'octobre 2007 à septembre 2008, des études hydrobiologiques ont été entreprises dans ce lac. L'évolution mensuelle des paramètres physico-chimiques permet de classer cette eau dans la qualité médiocre. Les éléments nutritifs (PO_4 et NH_4), la température et l'oxygène marquent des fluctuations importantes et influent directement sur la répartition des diatomées. Nos résultats ont montré que les communautés diatomiques planctoniques récoltées se composent de 24 espèces, dont 10 ont été signalées pour la première fois en Algérie. L'espèce *Cyclotella ocellata* est la plus abondante avec des fréquences mensuelles qui varient de 4,7 % de la communauté diatomique totale (au mois de mars) à 97 % (au mois d'août). Quant à la variabilité spatiale, les stations de l'amont sont caractérisées par la dominance des espèces polluo-résistantes, ce qui est le témoin de la forte charge polluante affectant ces zones. Ces résultats montrent que les assemblages de diatomées sont influencés par les perturbations anthropiques et suggèrent qu'ils peuvent être utilisés comme indicateurs de la qualité de l'environnement.

SUMMARY.— Owing to their important capacity to answer environmental changes, diatoms have been used as biological indicators of the water quality for a very long time. Studies of the North African and, in particular, the Algerian diatom flora are few. The objective of the present study is to describe spatial and temporal changes of the diatom communities and the abiotic parameters in the Reghaia Lake, which flows in the Mediterranean Sea. From October 2007 to September 2008, monthly physico-chemical and algological samplings were undertaken in the pelagic zone of the Reghaia Lake. The physico-chemical data made it possible to classify this water as of poor quality. The nutritive elements (PO_4 and NH_4), the temperature and oxygen displayed important fluctuations both in space and time and influenced directly the distribution of the diatoms. Our results showed that the collected planktonic diatom communities are composed of 24 species, with ten taxa reported for the first time for Algeria. The species *Cyclotella ocellata* is the most abundant with monthly frequencies that vary from 4.7 % of the total diatom community (in March) to 97 % (in August). The spatial distribution is characterized by the presence of pollution tolerant species in upstream sites. These results show that the assemblages of diatoms are influenced by the anthropogenic pressure and suggest that the diatom communities can be used as sensors for the biomonitoring of the Algerian aquatic environment.

Limnological studies highlighting the role of abiotic factors in the distribution of aquatic organisms are legion (Ahriz *et al*., 2010). Despite their interest, the diatom flora has been rarely studied in Algeria and North Africa. Only the work of Baudrimont on the continental diatoms of Algeria in 1973 (Baudrimont, 1973), and more recently those concerning the assemblages of the benthic diatoms in Algerian wadi (Chaïb *et al*., 2011; Chaïb & Tison-Rosebery, 2012) have been recorded. Furthermore, in neighbouring Morocco, we can add the work of Fawzi *et al.* (2002).

The Reghaia Lake is situated in northern Algeria; its localization in a zone with large industrial activity has caused an increasing eutrophication of the ecosystem during these last years. In spite of the ecological importance of the site, Reghaia Lake, which was classified in 2003 as a Ramsar site (Samraoui & Samraoui, 2008), had never been the focus of a study dealing with algal community. Our study relates to diatoms and their spatial and temporal distribution during a period spanning October 2007 to September 2008. We identified the diatoms communities and investigated the abiotic factors driving their distribution. We also aimed to identify a set of diatom species, some pollution tolerant that could serve as bioindicators of anthropogenic impact.

METHODOLOGY

STUDY SITE

The Lake of Reghaia is located at latitudes 36° 45' to 36° 48' North and longitude 03°19' to 03°21' East, at an altitude of less than 10 m. It is part of the plain of the Mitidja, 30 km East of Algiers, in the South of the Mediterranean. It is located between a maquis in the East, agricultural lands in the West and a dune formation in the North. It is a permanent fresh water body with a maximum depth of 7 m and a total surface area of more than 75 hectares, fed mainly by two wadis: Reghaïa Wadi and El Biar Wadi (Fig. 1). The climate is typically Mediterranean with a dry and hot period of 5 months stretching from mid-May to mid-October.

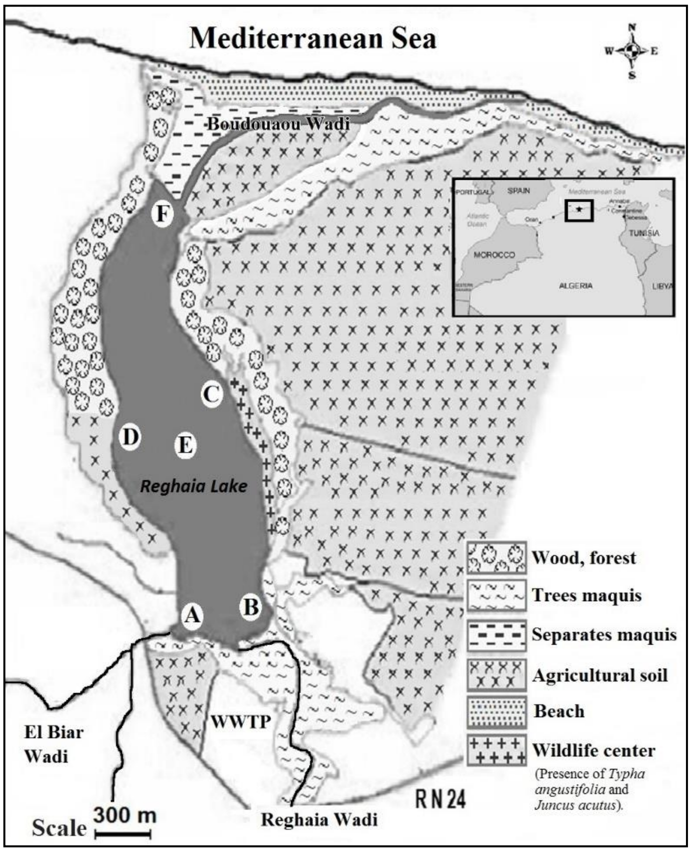

Figure 1.— Distribution of sampling stations on Reghaia Lake. Code used: RN= National road; WWTP= the wastewater treatment plant; A, B,…F are sampling sites.

The studied wetland is a vestigial part of a much more extensive wetland, the Mitidja that progressively gave way to human encroachment over the past century. The area was noted for its famed agriculture productivity owing to fertile soil and abundant water. Water is still extracted from the lake to supply 1,500 ha of farmland. An extensive industrial zone called Rouïba-Reghaïa, made up of 421 industrial units, is located nearby. The untreated waste water of these industrial plants is dumped into the lake through the Reghaïa Wadi. Part of the water of this stream passes through the treatment plant located upstream but, because of the limited capacity of the treatment plant, the rest of the untreated water is discharged directly into the lake.

PROCEDURES OF SAMPLING AND TREATMENT

For a better appreciation of the spatial variations of physico-chemical parameters and diatom flora, six sampling points were selected with four in the littoral zone (stations A, B, C and D) and two in the pelagic zone (stations E and F) that are accessible by boat (Tab. I and Fig. 1).

TABLE I

Characteristics of the study sites in Reghaia Lake

Stations	Localization	Characteristic	Maximum depth
A	At the southwestern part of the lake at the El Biar wadi entrance.	Presence of an important ripisylve and macrophytes. Dense mixed formation of *Typha latifolia* and *Tamarix africana* and very dense stand of *Olea europaea* and *Phragmites australis.*	1.5 m
B	At the southeastern part of the lake, downstream of the treated water of the Reghaia wadi.	Presence of herbaceous vegetation and dense growth of *Juncus acutus.*	2 m
C	At the centre of the lake, close to the eastern shore.	Presence of abundant and varied vegetation (essentially *Typha angustifolia* and *Juncus acutus*).	3 m
D	At the centre of the lake, close to the western bank.	Bare shore, characterized by vast agricultural land. The water of this station is used for their irrigation.	5 m
E	At the centre of the lake.	Characterized by the greatest depth;	7 m
F	On the northern, downstream part of the lake, near the dam.	Dense growth of *Typha angustifolia* and *Juncus acutus.* Station much attended by water birds.	4.5 m

Monthly water samples were collected from October 2007 to September 2008 in the six stations at different levels from the surface down to a depth of 1 m. We used a bottle with inversion of the type NISKIN with a capacity of 1 litre. By applying the standardized methods (Rodier *et al*., 2005; Aminot & Chaussepied, 1983) seventeen physico-chemical variables were measured, including six *in situ* (temperature, pH, conductivity, salinity and dissolved oxygen by a multi-parameters analyser of the type WTW 340i and transparency by a Secchi disk). Other measures of nutrients and minerals salts were performed in the laboratory.

Parallel to abiotic data, samples of microalgae were collected the same day at similar sites and depth. One litre of water was collected and filtered on the plankton net (20 µm mesh). The samples were fixed using a lugol's solution in order to obtain a final concentration of 1 % in the sample. For a long-term storage, we added 4 % of formaldehyde (additional fixation) (Laplace-Treyture *et al*., 2007). Sub-samples were placed for sedimentation in the plankton chambers of 10 ml (for quantitative analysis). Furthermore, another fraction of the sample was cleaned in boiling hydrogen peroxide and hydrochloric acid. After removing all traces of hydrochloric acid, the diatoms were dried onto cover slips and fixed on microscope slides using a high-refractive index resin (Naphrax®, R.I. = 1.7) to obtain permanent slides (AFNOR, 2007).

TAXONOMICAL AND ECOLOGICAL DATA

The analysis of the diatom flora was carried out in accordance with the recommendations of guidance standard on the enumeration of phytoplankton using inverted microscopy (standard number: BS EN 15204) (Laplace-Treyture *et al*., 2007; AFNOR, 2007). After sedimentation of the samples, we carried out two phases:

- A quantitative study: counting was carried out according to the Utermöhl technique using inverted microscopy (Utermöhl, 1958; CEN, 2006). The results were expressed by numbers of algae and cells by litre of raw water.

- A qualitative study was carried out using an Olympus BX51 differential interference contrast microscope (DIC) with 1000×magnification under oil immersion. The identification of the diatom flora was done to the genus level according to Round *et al.* (1990), Krammer & Lange-Bertalot (1991–1997), Hofmann *et al.* (2011) and work of Hankansson (2002) to identify the species belonging to the family of Stephanodiscaceae.

The distribution of taxa and their different morphs is based on classifications found in various works: Germain (1981), Krammer & Lange-Bertalot (1986, 1988, 1991a & b) and more specific studies: Allanson (1973), Hoagland *et al.* (1982),

TABLE II

Mean monthly values of the physico-chemical parameters of water at Reghaia Lake across all depths. (∂ = Standard deviation)

Parameters	Unit/∂	O	N	D	J	F	Mc	A	M	Ju	Jl	A	S	St A	St B	St C	St D	St E	St F
Temperature	°C	22.5	15.7	14.2	15.2	16.6	14.9	20.2	22.7	26.7	27.6	28.7	25.4	21,9	21,6	20,9	20,6	21,6	20,8
	∂	2.78	0.79	1.08	1.19	1.33	2.57	0.78	1.62	0.63	0.84	1.34	0.21	4.96	5.28	5.44	5.19	5.33	5.73
pH		8.14	8.45	7.89	7.98	8.14	7.93	7.93	8.51	8.69	8.48	8.83	8.76	8,35	8,34	8,31	8,34	8,31	8,33
	∂	0.15	0.3	0.12	0.09	0.16	0.1	0.21	0.2	0.16	0.28	0.11	0.05	0.46	0.53	0.32	0.38	0.38	0.37
Conductivity	mS.cm^{-1}	1.84	1.45	1.11	1.55	1.99	2.05	2.07	2.09	2.06	2.19	2.18	2.19	1.97	1.88	1.90	1.91	1.89	1.93
	∂	0.17	0.16	0.16	0.16	0.05	0.02	0.01	0.03	0.04	0.01	0.02	0.03	0.18	0.31	0.35	0.35	0.36	0.34
Salinity	mg.l^{-1}	0.82	0.63	0.39	0.63	0.82	0.89	0.90	0.90	0.91	0.99	1.00	0.99	0.86	0.83	0.82	0.81	0.82	0.85
	∂	0.19	0.11	0.12	0.07	0.04	0.03	0.29	0	0.03	0.02	0	0.03	0.08	0.18	0.19	0.19	0.19	0.19
Transparency	m	0.37	0.94	0.57	0.63	0.48	0.46	0.50	0.27	0.51	0.43	0.71	0.49	0,24	0,28	0,54	0,61	0,59	0,65
	∂	0.46	0.21	0.18	0.21	0.11	0.15	0.11	0.08	0.11	0.08	0.21	0.1	0.15	0.13	0.14	0.2	0.24	0.26
Dissolved Oxygen	mg.l^{-1}	5.29	8.40	4.57	5.22	5.67	3.76	4.35	0.84	4.77	0.28	0.78	2.65	2,55	2,61	4,03	3,65	4,26	3,79
	∂	3.04	1.47	0.69	2.65	2.7	2.64	1.76	1.47	1.89	0.16	0.9	0.6	2.8	2.69	2.78	2.57	3.12	2.97
Saturation	%	63.18	84.65	44.05	51.70	58.78	37.69	47.21	9.99	48.71	2.91	9.53	31.96	27,56	28,10	40,95	38,37	42,8	39,05
	∂	38.25	14.52	7.13	26.49	26.51	26.27	19.18	17.62	22.81	1.98	10.66	7.47	35.7	28.6	30.9	26.3	33.07	29.8
M.E.S	mg.l^{-1}	35.00	25.77	24.28	20.52	21.56	23.10	39.35	32.65	51.93	68.78	50.33	50.27	46,2	30,3	25,4	34,5	41,1	38,7
	∂	13.4	12.2	14.02	8.02	12.36	5.58	14.5	12.1	26.9	21.2	33.8	50.6	6.9	13.4	13.3	17.4	28.5	17.2
Chloride	mg.l^{-1}	-	220.4	111.5	-	316.5	331.2	330.6	217.0	474.9	511.2	522.7	050.8	389,2	340,8	347,9	313,2	343,2	366,1
	∂		49.7	22.5		10.7	11.9	5.63	35.9	71.4	39.9	43.9	7.74	128.7	135.6	165.1	133.9	159.5	139.6
Bicarbonate	mg.l^{-1}	-	084.5	050.7	-	098.7	102.4	109.6	098.6	112.2	132.7	125.7	120.6	109,5	104,0	96,6	99,1	103,8	108,9
	∂		5.45	2.67		4.59	3.02	6.44	3.82	9.65	8.48	13.5	9.75	14.9	24.6	22.2	23.9	28.1	23.3
Calcium	mg.l^{-1}	119.7	099.2	073.7	096.5	115.9	067.6	096.1	098.4	055.5	065.8	049.2	054.0	87,3	89,5	81,6	82,7	76,1	81,4
	∂	32.5	15.3	4.26	8.08	7.76	6.09	14.6	8.4	14.7	14.53	8.34	8.29	23.6	25.9	16.1	18.7	26.1	33.5
Magnesium	mg.l^{-1}	124.1	097.5	070.5	092.1	120.3	106.3	101.9	101.5	075.8	106.9	076.2	096.6	104.82	99.6	97.6	94.2	94.3	92.5
	∂	13.4	5.9	6.15	4.81	3.06	17.68	15.33	5.89	4.28	14.7	3.31	15.44	0.6	19.4	19.5	18.9	16.6	18.7
Sulfates	mg.l^{-1}	-	713.9	460.4	487.2	357.6	659.2	615.9	469.4	616.3	523.5	376.5	572.4	597,9	496,5	519,5	556,1	523,6	487,8
	∂		114.3	55.62	71.84	141.5	102.5	120.8	76.8	99.2	61.5	61.3	37.3	190.8	203.9	145.6	142.6	121.8	121.4
Phosphates	mg.l^{-1}	-	3.35	2.39	2.57	3.69	3.81	4.11	4.97	6.09	5.87	6.96	4.45	4,98	4,26	4,24	4,27	4,54	4,69
	∂		0.21	0.08	0.25	0.47	0.33	0.19	0.59	0.48	1.1	0.64	0.23	1.07	1.54	1.65	1.53	1.76	1.62
Total nitrogen	mg.l^{-1}	-	-	-	21.38	24.62	30.52	29.46	29.53	-	-	-	-	29,750	25,955	27,156	26,253.97	26,923	28,822
	∂				4.25	2.09	3.51	0.65	0.69					.88	.02	.53		.86	.40
Ammonium	mg.l^{-1}	-	-	-	16.99	21.52	26.76	27.64	25.87	-	-	-	-	25,60	22,265	24,555	23,245.57	23,695	24,963
	∂				4.14	1.55	2.87	0.75	3.08					3.33	.27	.52			.05
Nitrite	mg.l^{-1}	0.21	0.25	1.06	0.80	0.23	0.27	0.16	0.13	0.11	0.17	0.15	0.14	0,28	0,36	0,32	0,35	0,34	0,30
	∂	0.05	0.16	0.29	0.23	0.04	0.09	0.03	0.06	0.02	0.10	0.07	0.01	0.18	0.39	0.43	0.36	0.34	0.28
Nitrate	mg.l^{-1}	-	1.18	1.46	1.33	0.22	0.51	0.59	0.27	0.09	0.14	0.18	0.14	0.28	0.55	0.43	0.65	0.56	0.46
	∂		1.35	1.01	0.34	0.05	0.1	0.59	0.14	0.04	0.07	0.26	0.19	0.17	0.65	0.49	0.93	0.7	0.54

TABLE III

Relative abundances (%) of each monthly diatom species in the water of Lake Reghaia and life forms. Site code examples: A-F = correspond to stations. 0 = surface = 1-4 levels (each 1m from the surface to the bottom). O = October. N = November. + : New species in Algeria

Diatoms	Code	New species in Algeria	Form of life	Localization	Localization essentielly in	O	N	D	J	F	Mc	A	M	Ju	Jl	A	S
Cocconeis placentula	*CPLA*		Benthic-Mobile	All stations	A_0	0	0	0	0	0	3.53	5.45	33	5.79	44.2	0	0.22
Craticula ambigua	*CAMB*	+	Benthic-Mobile	$+C_0+D_3+F_0$	F_0	0	0	0.14	0	0	0	0	0	0	0.8	0	0
Craticula cf *cuspidata*	*CRCU*.cf	+	Benthic-Mobile	all but C_1-D_2-E_4-F_2	D_4	0	0	0	0	3.11	1.18	32.7	15.6	0.2	0.4	0.34	0
Cyclotella cf *atomus*	*CATO*.cf	+	Planktonic	$+D_1+D_2$ only	D_1	0	0.26	1.63	0	0	0	0	0	0	0	0	0
Cyclotella meneghiniana	*CMEN*		Planktonic	A_0 only		0	0.52	0	0	0	0	0	0	0	0	0	0
Cyclotella ocellata	*COCE*		Planktonic	All stations		29.4	90.8	89.1	83.4	91.5	4.7	47.5	34.9	91.6	51.4	97	76.6
Cymatopleura solea	*CSOL*		-	D_0 only		0	0	0	0	0	1.18	0	0	0	0	0	0
Diatoma cf *vulgaris*	*DVUL*.cf		Benthic-colonial	$+C_1+D_0+D_2+D_3+E_1+E_3$	D_2	0	1.31	0	0	0.14	2.35	0	0	0	0	0	0.44
Diploneis puella	*DPUE*		Benthic	$+D_0+D_2+F_0$	D_2	0	0	0	2.23	0.57	0	0	0	0	0	0	0
Frustulia cf *rhomboides*	*FRHO*.cf	+	Benthic	A_0 only		0	0	0	0	0	0	0	0	0	0	0	0.22
Gomphonema parvulum	*GPAR*		Benthic-Mobile	$+C_1+D_0+D_2+D_3+F_0$	C_1	0	0.53	0	0.86	0	0	0	0	0	0	0	0.22
Gyrosigma cf *acuminatum*	*GACU*. cf		Benthic-Mobile	$+D_3+E_1$	D_3	0	0	0	0	0	0	0	0	0	0	0.34	0
Hantzschia amphioxys	*HAMP*		-	$+A_0+B_0+C_1+D_1+D_2+D_3+E_3+F_0$	A_0	0	0.26	0	0.17	0	0	0.99	0	0	1.61	0.5	2.18
Navicula cf *gregaria*	*NGRE*.cf		Benthic-Mobile	all but D_3-D_4-E_4	D_0	0	0	0	1.71	1.41	7.06	1.49	14.7	0.28	1.2	0	16.6
Navicula cf *cryptotenella*	*NCRY*.cf		Benthic-Mobile	D_0 only		0	0	0	0.34	0	0	0	0	0	0	0	0
Navicula minima	*NMIN*	+	Benthic-Mobile	D_0 only		0	0	0	0.17	0	0	0	0	0	0	0	0
Navicula sp1	*NSP1*	+	-	$+A_0+C_0+D_2+D_3+E_1$	C_0	0	0	0	0	0.28	4.71	0.5	0	0	0	1.34	1.97
Nitzschia capitellata	*NCPL*		Benthic-Mobile	$+A_0+B_0$ only	A_0	0	0	0	0	0.71	0	0	0	0	0	0	0
Nitzschia cf *palea*	*NPAL*.cf	+	Benthic-Mobile	all but A_0-B_0-C_0-F_0	E_4	0	0	0.27	0	0	0	0	0	2.06	0	0	0
Nitzschia dissipata	*NDIS*		Benthic-Mobile	$+C_0+E_1$ only	C_0	0	0	0	0	0	0	0	0	0.08	0.4	0	0
Nitzschia hungarica	*NIHU*	+	Benthic-Mobile	$+B_0+D_4+F_1$ only		0	0	0	0	0.28	0	0	1.83	0	0	0	0
Nitzschia palea	*NPAL*		Benthic-Mobile	C_0 only		11.7	0	0	0	0	0	0	0	0	0	0	0
Nitzschia sp1	*NTSP1*	+	Benthic-Mobile	all but B_0-D_4-E_0-E_1-E_2	F_0	0	0	6.93	6.68	0	20	0	0	0.04	0	0	0
Stephanodiscus cf *neoastraea*	*SNEO*.cf	+	Planktonic	all but D_2-D_4-E_1	D_0	58.9	6.3	1.9	4.45	1.98	55.3	11.4	0	0	0	0.5	1.53
Total number of genera	13					3	5	4	7	7	8	6	5	5	6	6	8
Total number of species	24					3	7	6	9	9	9	7	5	7	7	6	9

Robinson & Rushforth (1987), Pringle (1990), Katoh (1992), Passy (2007), Rimet & Bouchez (2011) and Berthon *et al*. (2011).

DATA ANALYSIS

A principal component analysis (PCA) and canonical correspondence analysis (CCA) were used to check the correlations between the physico-chemical parameters and to determine the environmental variables that explain most of the variability of the diatom communities. The statistical processing of PCA and CCA were analysed using the R software (R Development Core Team, 2011), to determine taxonomical similarities between the samples and physico-chemical characteristics of the site. The ade4 library/package was also used for multivariate analysis (Dray & Dufour, 2007).

RESULTS

PHYSICO-CHEMICAL CHARACTERISTICS

Monthly averages of physico-chemical parameters of waters of Reghaia Lake are presented in Table II. Analyses of physico-chemical parameters of water indicated a clear seasonal trend with three distinct periods: summer, winter-spring and autumn-winter (Fig. 2a). Furthermore, the analyses indicated a clear spatial separation between upstream stations (A and B) from the rest (Fig. 2b). These two upstream polluted stations were characterized by high values of the physico-chemical variables associated with anthropogenic impact. Some of the parameters like phosphates, conductivity or chlorides, exhibited the highest variance among sites. Other stations (stations at the centre and the downstream part of the lake) formed another group and marked a clear separation compared to upstream stations, the most polluted stations.

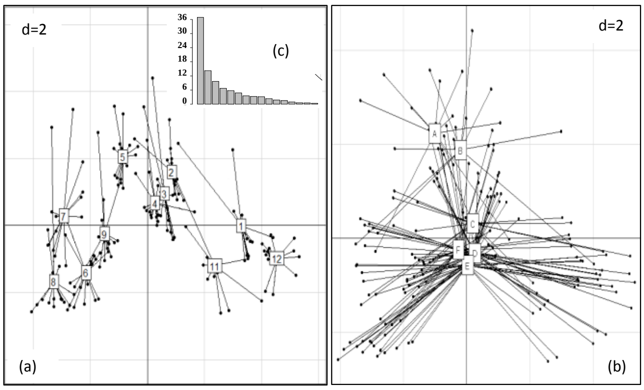

Figure 2.— Results of principal component analysis (PCA) for: (a) monthly sampling; (b) the six sampling stations; (c) the histogram of the eigenvalues which shows a total variance of 53.25 % for plane PCA1 x PCA2 (38.42 % for axis 1; 14.83 % for axis 2. Code used for PCA: the numbers indicate the months of year (1=January, 2=February...); A, B…F= stations); d= Euclidean distance.

THE DIATOM FLORA OF REGHAIA LAKE

The cell count of planktonic diatoms allowed us to identify 24 species distributed in 13 genera: *Cocconeis, Craticula, Cyclotella, Cymatopleura, Diatoma, Diploneis, Frustulia, Gomphonema*, *Gyrosigma*, *Hantzschia*, *Navicula*, *Nitzschia* and *Stephanodiscus.* The number of genera identified each month ranged from 3 to 8 (Tab. III).

The average composition of the diatom communities was of 77.71 % euplanktonic life-forms, 12.16 % epiphytic species and 5.65 % epilithic, whereas the rest is represented by the other periphytic species.

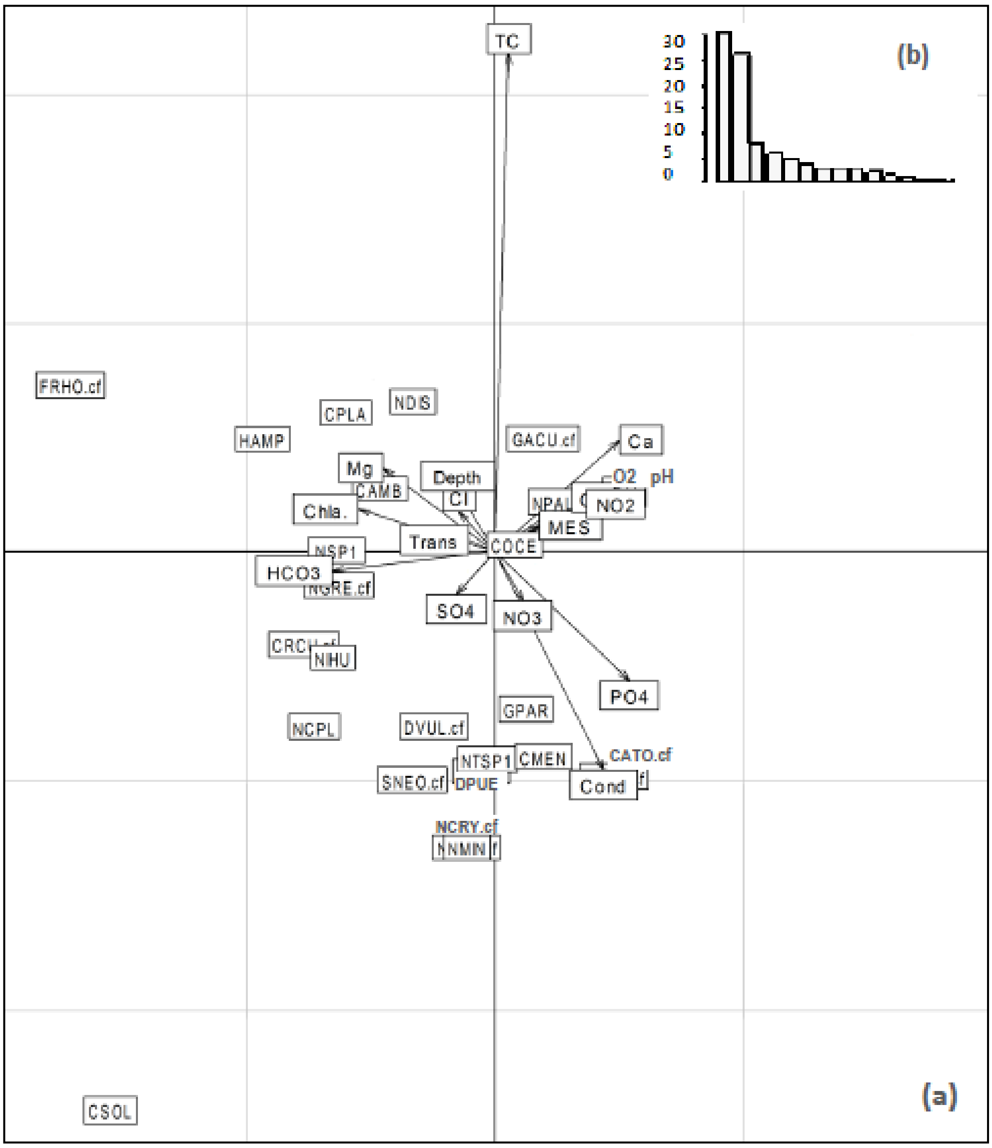

Figure 3.— (a) Canonical Correspondence Analysis (CCA) performed on the diatom taxa and environmental variables; (b) the histogram of the eigenvalues shows a total variance of 56.71 % for the plane CCA1 xCCA2 (30.14 % for axis 1; 26.57 % for axis 2. Code used for CCA: Chla = chlorophyll "a", Trans = Transparency, Cond = conductivity. The species code is provided in Table III.

The diversity of benthic forms was most important with 20 benthic species. Among these, 14 species may exhibit gliding motility. This diversity increased during the spring and autumn periods.

The study of the abundance of taxa (Tab. III) showed that the genus *Cyclotella* occupied an important place in the diatom community, with more than 50 % of the diatoms present in winter and summer. On the other hand, during the spring and autumn periods, we noted the dominance of *Stephanodiscus* and *Navicula* with the appearance of *Cymatopleura* in station D in March. The genus *Cyclotella* was represented by three species: *C. ocellata*, *C. meneghiniana* and *C.* cf. *atomus. C. ocellata* was the most abundant with monthly frequencies which varied from 4.7 % (in March in stations C and D) to 97 % (in August in station E) of the total diatom community. *C. meneghiniana* was present only in the station A0 in November with a small percentage (0.52 %). In addition, *C.* cf. *atomus* appeared during the months of November and December at depths of 1 m and 2 m in the station D.

In almost all the samples taken, the genus *Stephanodiscus* appeared with one species (*S.* cf. *neoastraea*). The genus *Cocconeis* (*Cocconeis placentula*) registered its development in all stations and only during the warmest period. The genus *Craticula* was represented by two species, *C.* cf. *cuspidata* from February to August and *C. ambigua* inventoried only in the coastal zone during the months of December and July. The genus *Navicula* was represented by four species. *N.* cf. *gregaria* and *N.* sp1 were mainly found in spring and September. On the other hand, *N. minima* and *N.* cf. *cryptotenella* appeared only in January at the station D0. The genus *Nitzschia* was the most diversified with six species but with low frequencies, its distribution in the lake was heterogeneous. The other genera (*Gyrosigma, Cymatopleura* and *Frustulia*) were rarely recorded (Tab. III).

THE STRUCTURE OF THE DIATOM FLORA IN RELATION TO WATER QUALITY

The canonical correspondence analysis (CCA), carried out with 16 environmental variables and 24 diatom species, highlighted the links between the environmental characteristics of the Raghaia Lake and the different diatom species. This analysis, based on the two-first axes of the CCA, representing 56.71 % of the variance, revealed that the phosphate, conductivity, calcium, bicarbonate and temperature significantly explained the variability of diatom communities (Fig. 3). The first axis (30.14 % of the variance) opposes temperature and water conductivity and phosphate. Various genera (*Cymatopleura*, *Navicula*, *Cyclotella*, *Stephanodiscus*, *Diatoma*, *Gomphonema* and *Nitzschia* (except *N. dissipata* and *N. palea*)) were found to be closely associated with high conductivity and phosphate levels. The second axis (26.57 % of the variance) associates high levels of calcium and two species (*Gyrosigma* cf *acuminatum* and *Nitzschia palea*). This axis is negatively correlated with bicarbonate and species of the genera *Navicula* and *Craticula.*

DISCUSSION

The stations selected in the lake did not present a thermal stratification during the study period. This was due to their low depths (Leblond, 1976). The high concentrations of PO_4 that were noted at upstream stations confirmed that the effluents brought back to the lake a considerable phosphate load which is discharged in major part (80 %) from the output of the sewage treatment plants (Rodier *et al*., 2005). In addition, at the least affected station, the decrease was due to the absorption of PO_4 by macrophytes (Jensen & Andersen, 1992) immersed in the station C. The monthly variations of bicarbonates during the summer period were due to an increase of bacterial activity but also to the presence of industrial and urban wastes. The increase in conductivity is related to the lithological nature of the surrounding field (Rimet *et al*., 2007), water temperature (Harch-Rass *et al*., 2012) and with the importance of the discharges strongly loaded with mineral elements (Gourari *et al*., 2000) in the lake. As for the vertical variations, mineralization naturally increased with depth under the action of sedimentation (Abba *et al*., 2008). On the horizontal plane, conductivity tended to decrease from upstream to downstream because of the progressive decantation of mineral elements brought by effluents. The highest values of the pH were observed for the summer period, in surface waters. These high values were due to an increase in photosynthetic activity (Parinet *et al*., 2004). The chloride load was related mainly to the nature of the watershed and with the contributions of urban and industrial wastewaters (Rodier *et al*., 2005). The reduction in the values was related to dilution (Abba *et al*., 2008) by contributions from the tributary of the reservoir and the runoff water. The fluctuations of the suspended matter indicated a certain irregularity both at vertical and temporal levels, according to the season, rainfall and the discharges (Savary, 2003).

The water of the lake was low in oxygen. These low values could be explained by the oxygen uptake by the bacteria (Dandelot *et al*., 2005), which was favoured by the increase of urban and industrial wastewaters containing a great quantity of organic matters, and by the increase of the water temperature (Arrignon, 1998). Ahriz *et al*. (2010) confirmed our results about the presence of organic pollution in the lake as well as advanced stage of eutrophication. The evolution of the nitrogen contents showed a temporal difference. The low values were dependent on an important nitrification (Abba *et al*., 2008) and on a strong absorption (Issola *et al*., 2008). The water of the lake was also rich in calcium and magnesium because of the geological nature of the watershed (Yelle, 2003) and the waste coming from industrial sources (especially the brewing industry) (Gaujous, 1995).

The annual means of physico-chemical parameters were used to classify the water of the Reghaia Lake as of poor quality, according to the classification of ANRH (2008). Both Stations A and B displayed a high level of pollution in contrast to the rest of the stations which exhibited a moderate level of pollution.

The specific composition of diatoms communities of Reghaïa Lake and their temporal and spatial distribution were influenced by the change of parameters of the medium. The determining factors of the development and the seasonal succession of these algae were a combination of physical (depth…), chemical (the presence of nutrients, phosphorus, nitrogen and silica), and biological factors (competition) (Wille, 1990). The diatom flora in the waters of Reghaia Lake was dominated by the genus *Cyclotella.* It also presents a recognizable heliophilous character and it develops in an optimal way when the temperature is around 20°C (Loudiki, 1990). The dominant species is *Cyclotella ocellata* who was present in Algeria in lakes with salinity levels > 0.7 ‰, whereas Van Dam *et al*. (1994) and Ludes and Coste (1996) have reported it in sites with lower salinity (< 0.2 ‰). The classification based on the oxygen indicated that *C. ocellata* supported variable rates of oxygen. *C. ocellata* is an important component of the diatom community of eutrophic lakes (Schelegel and Scheffler, 1999) and it was already reported in the waterways of North Africa (Fawzi *et al*., 2002; Chaïb & Tison-Rosebery, 2012). The *Cyclotella meneghiniana* species also present in the same wadi, is known for its high resistance to pollution (Germain, 1981), a result confirmed in our study.

In spring and in autumn, we observed the development of small algae well adapted to relatively low temperatures and low light intensities like *Stephanodiscus.* This genus was represented by only one species *S.* cf. *neoastraea* that in all stations, essentially in the euphotic zone. According to Van Dam *et al.* (1994) this species is found in areas with relatively high oxygen content (70 to 85 %), our results indicated that it can tolerate much lower rate, up to 10 %. The *Navicula* genus occurred in the lake with four species two of which (*N. minima* and *N.* cf. *cryptotenella*) are new in the continental waters of Algeria, and were present in January. This is due to their ecological requirements; both species proliferate in an environment with a salinity > 0.9 ‰ (Van Dam *et al.*, 1994). *N.* cf. *gregaria* was the most abundant species in the genus *Navicula*. The latter has already been reported in the running water of North Africa (Fawzi *et al*., 2002; Chaïb *et al*., 2011); it tolerates water pollution and the presence of relatively high concentrations of salts. It is clearly euryhaline and was present during the period when the salinity was greater than or equal to 0.9 ‰ (Germain, 1981). The fourth species within this genus has not been identified (*Navicula* sp1). The *Cymatopleura* genus also develops in the spring period with a single species *C. solea*. This latter generally proliferates in water rich in mineral elements (Maurice, 2004), which justifies its presence in the station (station D) close to agricultural land exposed to leaching of soil.

With the increase of temperature, these three species (*Cymatopleura solea, N. minima* and *N.* cf. *cryptotenella*) disappeared and were then successively replaced by five species of *Nitzschia*, mainly composed of benthic forms. Among these, *Nitzschia capitellata* is reported for the first time in these environments, it is a species that tolerates polluted water up to the level polysaprobe (Krammer & Lange-Bertalot, 1986). This latter observation confirmed those made by Van Dam *et al.* (1994). In addition, *Nitzschia palea,* which only appeared during the month of October, is known for its resistance to organic pollution (Lange-Bertalot, 1979) and relatively high concentrations of H_2S (Baudrimont, 1973). Our results indicated that *Nitzschia palea* was absent in the most polluted stations (A and B). This oligohalobe diatom (Foged, 1987), a common species in Algerian surface waters (Baudrimont, 1973; Chaïb *et al*., 2011), seemed to have a different behaviour with regard to water pollution. The third species of the genus, *N. hungarica*, is considered as a highly variable diatom from a morphological and ecological point of view (Germain, 1981). It was first recorded in 1973 in the Hamiz reservoir (Baudrimont, 1973) which is located in the same climatic zone as the study site. *Nitzschia dissipata* is also present at the Hamiz reservoir and other water bodies of the region (Chaïb *et al*., 2011 ; Fawzi *et al*., 2002). Its maximum growth was noted in June, the warmest month and the most oxygenated. These results were in agreement with the works of Germain (1981) and Van Dam *et al.* (1994). *Hantzschia amphioxys* is defined as a species highly resistant to eutrophication (Ludes & Coste, 1996) and to important changes in oxygen. Its maximum development appeared in the most polluted station (station A), which confirms the work of Van Dam *et al.* (1994).

Cocconeis placentula is a common epiphytic diatom (Germain, 1981), which develops on macrophytes. Its presence in the water is due to a drift from the shore which is its real habitat. It has already been observed in North African wadis (Fawzi *et al*., 2002; Chaïb *et al*., 2011). It is clearly euryhaline (Germain, 1981) which explains its growth only during the warmest period. *Gomphonema parvulum* is absent in the most polluted stations (A and B) which is due to adverse environmental conditions for its development. This species was observed previously in North African wadis (Fawzi *et al*., 2002; Chaïb *et al*., 2011). Like *Nitzschia, Gyrosigma* is a benthic form with high mobility (Round *et al*., 1990; Tudesque *et al*., 2012). The species *Gyrosigma acuminatum* is known for its tolerance to high concentrations of nutrients (Passy, 2007; Berthon *et al*., 2011), which justified its presence in August when phosphates were at their maximum rate and oxygen level at its minimum. *Diatoma* cf. *vulgaris* is also a large benthic diatom, which is absent completely in upstream stations, which confirmed the conclusions of Germain (1981). In contrast, *Frustulia* cf. *rhomboides* was observed in the most polluted station in September. *Diploneis puella* is an oligohalobe species present only during the winter season, which coincides with low salt content and high levels of oxygen.

The canonical correspondence analysis (CCA) performed on the diatom communities and all environmental variables (physico-chemical and habitat) indicated that phosphate, conductivity, calcium, bicarbonate and temperature were the physico-chemical variables which significantly influenced the diatom communities. Soininen & Kononen (2004), in the same kind of study of rivers in Finland, came to the same results. The distribution of diatom species was influenced essentially by conductivity and phosphates, confirmed by Potapova & Charles (2003) in the United States, Almeida & Gil (2001) in Portugal and Rott et *al.* (1998) in Canada. The distribution of diatoms is mainly explained by phosphorus. Nutrients, primarily nitrogen and phosphorus, constitute one of the most important factors affecting the structure of the diatoms communities (Kelly, 2003). Our results suggest that phosphate and conductivity represent variables which explain most of the difference in the community's composition between the six studied stations. But calcium, bicarbonate and temperature are also important driving factors of the spatial distribution of diatoms.

CONCLUSION

The results achieved in the present study clearly confirm the eutrophic character of the studied lake as all parameters used were generally above threshold values. The waters of Reghaia Lake were alkaline, excessively mineralized and hard. Some environmental parameters played a key role in the functioning and evolution of this lake. These parameters include nutrients (PO_4 and NH_4), temperature and oxygen which marked important fluctuations during our study and influenced directly the distribution of diatoms. At the southern stations, especially in station A located downstream from the entry of waste waters, the predominance of *Cocconeis placentula*, *Hantzschia amphioxys*, *Nitzschia capitellata* and the appearance of *Cyclotella meneghiniana* are witnesses to the strong polluting load affecting this zone. The waste waters of the wadi El Biar and Reghaia have a significant impact on the water quality and on the diatom flora of the site. This impact is naturally reduced by a self-purification of the lake, which leads to an improvement of water quality in downstream stations marked by the appearance of polluto-sensitive diatoms like *Diatoma* cf. *vulgaris* and *Craticula ambigua.*

According to the available literature, ten taxa found in this study were reported for the first time in Algeria: *Craticula ambigua, Craticula* cf *cuspidate, Cyclotella* cf *atomus, Frustulia* cf *rhomboids, Navicula minima, Navicula* sp1, *Nitzschia hungarica, Nitzschia cf palea, Nitzschia* sp1, *Stephanodiscus* cf *neoastraea.*

The diatoms display a considerable diversity in lakes and aquatic ecosystems in general (Mann & Droop, 1996). This diversity constitutes an important element in the indices of phytoplankton which are used for the evaluation of trophic lakes (Brettum, 1989; Dokulil *et al*., 2005; Buzzi *et al*., 2007; Nixdorf *et al*., 2006). This range of different applications underlines the importance of studying the ecology of diatoms, especially in an arid area like North Africa where water is scarce and wetlands under considerable anthropogenic pressure (Hollis, 1992; Samraoui *et al.*, 1992; de Bélair & Samraoui, 1994).

ACKNOWLEDGMENTS

We thank members of the laboratory "Evolution and Biodiversity" and the various anonymous referees for their contribution to the achievement of this article. B.S. is supported by the Algerian Ministère de l'Enseignement Supérieur et de la Recherche Scientifique (DGRSDT/MESRS and DSFP, King Saud University, Saudi Arabia.

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