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Annual cycle of water quality and macroinvertebrate composition in Algerian wetlands: a case study of lake Réghaïa (Algeria)

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ABSTRACT

Annual cycle of water quality and macroinvertebrate composition in Algerian wetlands: A case study of Lake Réghaïa (Algeria)

The Réghaïa wetland is a site of great ecological relevance and is included in the list of Ramsar wetlands of international importance. However, this wetland has always been subject to several risks, such as pollution, that threaten its terrestrial and aquatic biota. The water quality of the lake is classified as class 4 (highly polluted) according to Algerian standards. However, until now, there has been no study analysing the macroinvertebrate fauna of this important site. Therefore, in order to characterize the state of this wetland of international importance, which is highly affected by intense physical and chemical pollution of agricultural and anthropogenic origin, we studied its water quality (physical and chemical parameters) and its biological communities for one year to consider possible seasonal trends. According to our results, seasonal changes in the concentrations of physical and chemical elements were found, summer being the season with the highest level of nutrients and other pollutants concentration in the water. Although we observed these different environmental conditions throughout the year, we did not find evident differences in the communities of macroinvertebrates that showed small changes in composition and structure throughout the year.

Key words: water quality, macroinvertebrate communities, seasonal succession, pollution, Mediterranean wetlands

RESUMEN

Ciclo anual de la calidad del agua y la composición de los macroinvertebrados en los humedales de Argelia: Un estudio de caso del Lago Réghaïa (Argelia)

El humedal de Réghaïa es un sitio de gran relevancia ecológica, por lo que está incluido en la lista de humedales de importancia internacional de Ramsar. Sin embargo, este sitio está sometido a varios riesgos como la contaminación que amenaza su biota terrestre y acuática. La calidad del agua del lago está clasificada como clase 4 (altamente contaminada) según los criterios argelinos. Para caracterizar el estado de este medio acuático afectado por una intensa contaminación física y química de origen agrícola y antropogénico, se estudió la calidad del agua (parámetros físicos y químicos) y las características de las comunidades biológicas que viven en él. Para ello, nuestro trabajo analizó durante un año la calidad del agua y la composición y estructura de las comunidades de macroinvertebrados de este humedal. Según nuestros resultados, las características físicas del agua y las concentraciones de elementos químicos fueron distintos, acorde con las estaciones. El verano tuvo el nivel más alto de concentración de nutrientes y otros contaminantes en el agua. Aunque observamos estas distintas condiciones a lo largo de las estaciones del año, las comunidades de macroinvertebrados mostraron una baja respuesta a las distintas condiciones físicas y químicas, mostrando muy pocos cambios en la composición y estructura a lo largo del año.

Palabras clave: *calidad del agua, comunidades de macroinvertebrados, sucesión estacional, contaminación, humedales mediterráneos*

INTRODUCTION

Wetlands are important sites for the balance of ecosystems, because they serve as biotopes for many faunal and floral communities. Their roles are important with respect to the landscape in terms of flood control, renewal of groundwater, retention of toxic products, and the recycling of nutrients (Keddy, 2000; Verhoeven *et al.*, 2006). They also provide various resources and ecosystem services to the human population, including water availability and storage for grazing and agriculture, as well as tourism (Anthony *et al.*, 2009; Soy-Massoni *et al.*, 2016). Last but not least, they host many rare and endangered taxa, even supporting species and communities that are not found in other water bodies (Gopal & Junk, 2000). However, wetlands are fragile ecosystems, so they must be conserved, protected and maintained (Pérez-Ruzafa *et al.*, 2011).

The Réghaïa wetland is classified as a RAMSAR site of international importance, because it is the last remnant of the wetlands of the ancient alluvial plain of Mitidja. All this region has been transformed to a large agricultural and urban area, and the wetland, currently used for water retention, constitutes the last major water body that exists near the capital Algiers. Nevertheless, the Réghaïa wetland is not only a water reservoir but also a reservoir of remarkable biodiversity; it holds valuable heritage of fauna and flora including 233 species of plants, more than 230 species of sedentary birds, more than 170 species of invertebrates (20 of them protected by Algerian regulations) (C.C.R., 2010). However, in recent years, this RAMSAR site has faced a major threat due to the increase in pollution that may affect its genetic potential and its ecological importance. Previous studies have reported that the concentrations of pollutants that were discharged in the wetland (of industrial, urban and agricultural origin) have exceeded internationally accepted standards. According to Aydi & Benamara (2004) and Sayoud (2017), the surface waters of the lake are of very poor quality, due to discharge of domestic water from the surrounding urbanisation areas, and can only be used after specific treatment. Therefore, water

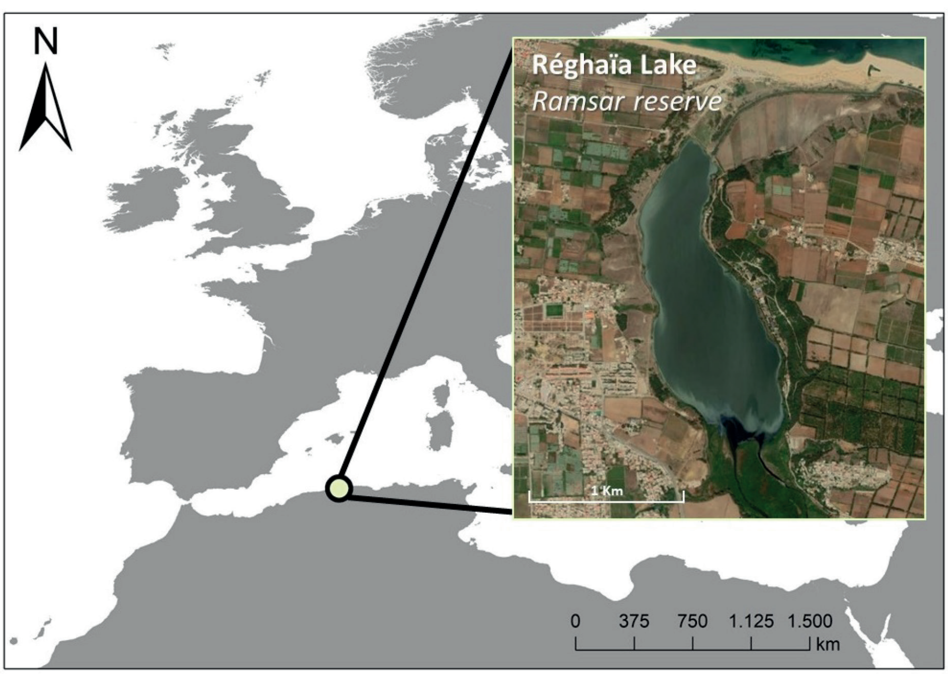

Figure 1. Geographical location and «Google Earth» satellite image of the Reghaia Lake (36° 46.363' N; 3° 20.129' E). *Ubicación geográfica e imagen de satélite de «Google Earth» del Lago Reghaia (36° 46.363' N; 3° 20.129' E).*

quality must be studied in order to conserve and protect this ecosystem, but not considering only the physical and chemical changes in water characteristics. To achieve this, ecosystem community structure and its temporal patterns can also provide information about its water quality, as community parameters such as diversity or species richness are sensitive to certain environmental alterations. These community parameters can be used as preliminary biological indicators for water quality (Jeppesen *et al.*, 2000; Declerck *et al.*, 2005), since appropriate biological indicators have not yet been developed for this region. In Algeria, although aquatic macroinvertebrates are seriously affected by different forms of disturbance, they have been poorly studied. In fact, Algerian wetlands have been poorly studied even though they constitute true sanctuaries for faunal and floral species (Samraoui & De Belair, 1998). Many studies have focused on temporary ponds but very few on lakes (Khedimallah & Tadjine, 2016). The first works on hydrosystems in northern Algeria were mainly devoted to species descriptions, but only a few of them have focused on their ecology or biogeography (Arab *et al.*, 2004).

The maintenance of areas of international importance requires scientific monitoring to determine the evolution and ecology of animal and plant species and the possible impact of pollution of lakes on their aquatic invertebrates. This way, the aim of this study was to analyse seasonal trends in the physical and chemical conditions of Lake Réghaïa and its effect on benthic fauna. To do so, we studied the relationships between water physical and chemical characteristics and macroinvertebrate community parameters (i.e., spatial and temporal distribution, abundance, diversity and taxonomic relatedness). Such perspective is of high importance because until now, no benthic macrofauna study has been carried out on Réghaïa wetland (Thibault, 2006). Considering the scarcity of studies on aquatic macroinvertebrate communities living in permanent lentic systems in Algeria, this study provides a case study in a scenario of a polluted wetland. Nevertheless, there is still a need to further study unpolluted wetlands in order to construct reliable biological indices for Algeria.

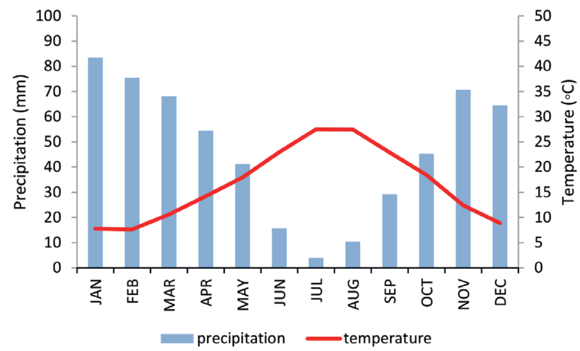

Figure 2. Ombrothermic diagram from Réghaïa station using data from a 10-year period (2009-2018). Input data: NASA Langley Research Center (LaRC) POWER Project funded through the NASA Earth Science/Applied Science Program. *Diagrama ombrotérmico de la estación de Réghaïa usando datos de un período de 10 años (2009-2018). Fuente de los datos: el proyecto POWER del Centro de Investigación Langley de la NASA (LaRC), financiado por el Programa de Ciencias de la Tierra y Ciencias Aplicadas de la NASA.*

MATERIALS AND METHODS

Study site

Réghaïa wetland is currently the only wetland that remains in the Algiers biogeographical region. It is located at 36° 46' N, 3° 20' E (Fig. 1), and it is a lacustrine and marshy environment, surrounded by a wooded belt and set back from a sandy coastal shelf that opens onto small sea beds (Larid, 2008). The water body surface area is 75 ha, located at 4 m a.s.l, and its depth varies from a few cm to 6 m. The immediate riverbanks have slopes between 0-3 %. The annual precipitation ranges from 2 to 714 mm, with an average value of 560 mm. The rains are concentrated (82 %) from October to April (Fig. 2). The average annual temperature is approximately 16.6 °C, the minimum average temperature varying from 4 °C to 12 °C during the winter period and from 21 °C to 30 °C during the summer period (Fig. 2). The conductivity of the lagoon is on average 2.40 mS/cm. The water inputs are three wadis (or ephemeral riverbeds): wadi Réghaïa, wadi El Biar and wadi Boureah. The water input includes runoff and domestic, agricultural and industrial discharges.

Sampling procedure and sample processing

Sampling points were selected in riverbanks based on accessibility (accessible all year round), depth (less than one meter), and stream flow (relatively low) with a frequency of only one sample per month. Water and macroinvertebrates were sampled in these points monthly from April 2017 to April 2018. Macroinvertebrates were captured using a dip-net with a diameter of 22 cm and a mesh size of 250 µm, creating an artificial counter flow, and fixed in 70 % ethanol. Collected material was transported to the laboratory, sorted and identified to family level using a binocular magnifying glass, a stereomicroscope and reference books (Durand & Lévêque, 1981; Tachet *et al.*, 2000; Moisan, 2010). Water samples were transported to the laboratory to analyse pollutant concentrations on the same day. We measured concentration of seven parameters (biological oxygen demand (BOD), ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^{3-}), iron (Fe^+), and organochlorine pesticides) in a quality control laboratory with the appropriate instruments for each parameter. Water temperature (T) and pH were measured *in situ* using a pH-meter that contains a built-in thermometer, simultaneously and at the same point as macroinvertebrate sampling.

Community parameters

The following parameters were calculated to analyse community structure: total abundance,

Table 1. The average, maximum and minimum values of water physico-chemical and macroinvertebrate community parametres from the lake. *Los valores medios, máximos y mínimos de los parámetros físico-químicos del agua y los parámetros de la comunidad de macroinvertebrados del lago.*

		Average	*Min.*	*Max.*
Water parameters	***pH***	7.11	6.9	7.5
	T (°C)	19.214	10	33.9
	BOD (mg/L)	50.650	49.1	52
	NH4+ (mg/L)	0.432	0	0.8
	NO3-(mg/L)	3.933	2.9	5.01
	NO2-(mg/L)	0.958	0.098	1.24
	PO4 3-(mg/L)	0.231	0.01	0.41
	Fe+ (mg/L)	0.403	0.29	0.5
	O.P. (mg/L)	10.905	8	14.2
Community parameters	***Abundance (ind/month)***	239.54	124	387
	Taxonomic richness (number of families)	19.31	16	22
	Shannon-Wiener diversity index	2.72	2.20	3.26
	Evenness	0.64	0.53	0.74
	ATD	56.61	54.28	58.01
	TD	1080.84	890	1260
	VTD	485.35	408.5	542.5
	Armstrong SR	0.0016498	9.6303E-06	1.90E-03
	Jassby-Goldman SR	0.03109508	0.00672733	3.33E-02

taxonomic richness (S), evenness (J) and Shannon-Wiener diversity index (H') (Pielou, 1969). Additionally, three taxonomic distinctness indices were calculated: taxonomic distinctness (TD), average taxonomic distinctness (ATD), and variation in taxonomic distinctness (VTD) (Clarke & Gorley, 2006). The first index, TD, is the average path length between any two randomly chosen individuals, conditional on them being from different species (in our case, families) (Clarke & Warwick, 1998). The second index, ATD is the mean path length through the taxonomic tree connecting every pair of families (Clarke & Warwick, 2001). Finally, the VTD is simply the variance of these pairwise path lengths and reflects the unevenness of the taxonomic tree. It can be used to compare samples with similar ATD but different taxonomic tree structure. We also calculated Armstrong (1969) and Jassby-Goldman (1974) succession rates (SR) to analyse changes in community composition between 2 successive months. To carry out all these analyses we used PRIMER- E v.6. (Clarke & Gorley, 2006).

Data analyses

A principal component analysis (PCA) was conducted to determine which water physical and chemical characteristics best explained the variability among seasons. The variables were normalized prior to performing the PCA. The PCA was carried out with R ver. 3.1.2 using the 'prcomp' function from the package "stats". We analyzed the temporal patterns of the community by means of multivariate (permutational multivariate analysis of variance; PERMANOVA) and univariate (analysis of variance; ANOVA) procedures. PERMANOVA was used to test for significant differences in taxonomic composition among seasons. A resemblance matrix was built using the Bray–Curtis coefficient on taxa log-transformed abundances. A one-way layout was selected, with season as fixed factors. PERMANOVA uses permutations (in our case 999 per test) to obtain *P*-values (Anderson, 2001; McArdle & Anderson, 2001). Moreover, the community structure analyses were performed by means of one-way ANOVA to check the effect of season on each community parameter. Each community parameter (total abundance, taxonomic richness, Shannon-Wiener diversity index and evenness) was grouped by season in order to have a clear idea about seasonal change affecting macroinvertebrate communities. PERMANOVAs were performed using the PRIMER v6 statistical package (Clarke & Gorley, 2006), whereas ANOVAs were performed in R program ver. 3.2.1 (R Development Core Team, 2018). Finally, a NMDS analysis was used to visualize the similarity between the monthly distributions of the families of macroinvertebrates in the presence of the physicochemical elements during the study period. This analysis was performed with monthly abundances (total individuals per sample) and using the Bray-Curtis similarity index. The abundance data were square-root transformed beforehand. Then, vectors of environmental variables (T, pH, BOD, NH_4^+, NO_3^-, NO_2^-, PO_4^{3-}, Fe^+, organochlorine pesticides) were fitted into the ordination space (NMDS) to detect the possible association between the patterns of community composition and environmental variables using the 'envfit' function of the 'vegan' package in R (Oksanen *et al.*, 2014).

RESULTS

Environmental description

Our results showed a remarkable variability of the majority of the water variables during the year (Table 1) and an increase in temperature in contrast to the decrease in pH values during the dry period of the year (from June to October 2017, Fig. 3). The pattern observed for biological oxygen demand (BOD) was similar to the one obtained for water temperature, with the exception of a second peak between February and April that coincided with a pH increase. The rainy period (from December to April 2018) was characterized by a drop in temperature contemporaneous with an increase in pH. Regarding nutrient and pesticide concentrations, with the exception of the ammonium concentration (NH_4^+), that exhibited low and constant values throughout the year (less than 1 mg/l), the other analysed elements (NO_3^-, NO_2^-, PO_4^{3-}, Fe^+, organochlo-

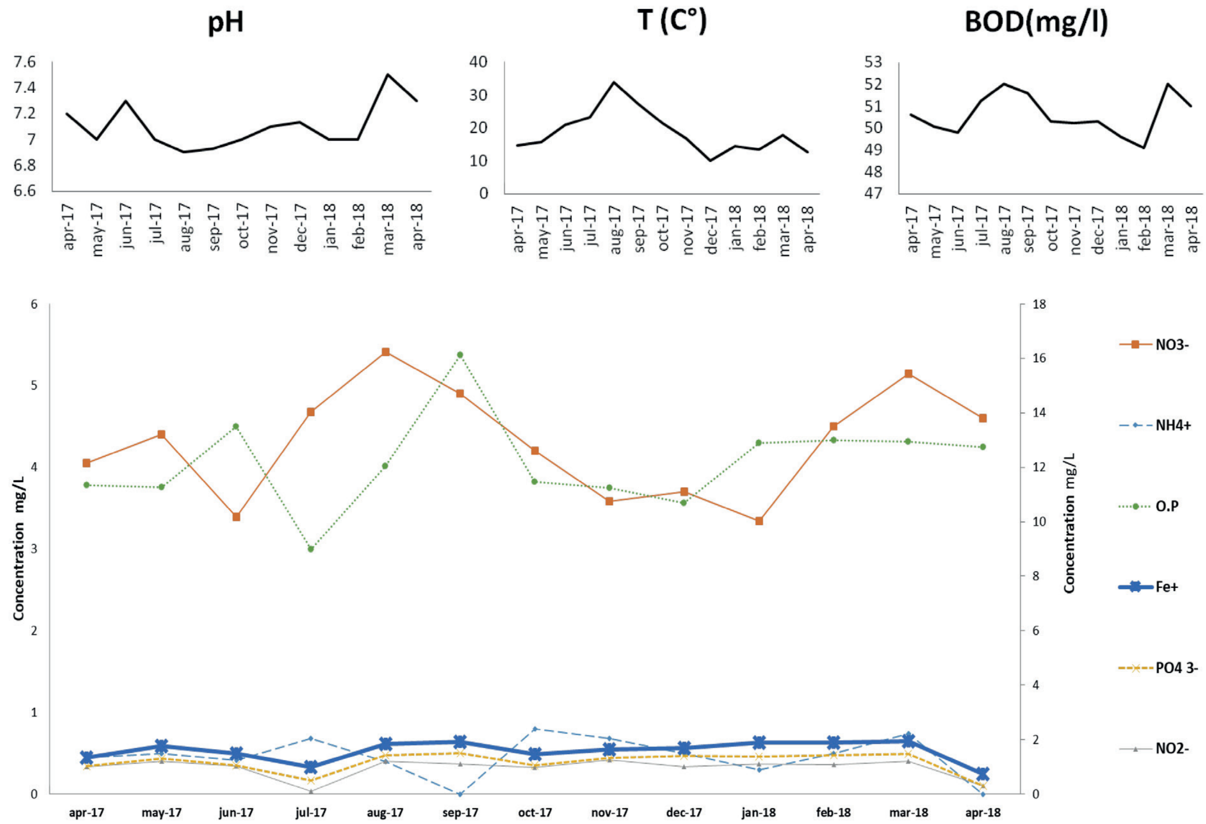

Figure 3. Temporal pattern variation of the physical and chemical parameters of water during the studied period. Upper plots (from left to right) correspond to: pH; variation in average monthly temperatures of water; BOD, variation in the concentration of biological oxygen demand. Bottom plot: variation in the water concentration of chemical elements: Fe^{+}; PO_4^{3-}; NO_3^{-}; NH_4^{+} (right Y-axis) and Organochlorine pesticides (O. P.) residues (left Y- axis). *Variación del patrón temporal de los parámetros físicos y químicos del agua durante el período estudiado. Los gráficos superiores (de izquierda a derecha) corresponden a: variación de los valores de pH; variación de las temperaturas medias mensuales del agua; DBO, variación de la concentración de la demanda biológica de oxígeno. Gráfica inferior: variación de la concentración en el agua de elementos químicos* Fe^{+}; PO_4^{3-}; NO_3^{-}; NH_4^{+} *(eje Y derecho) y residuos de Pesticidas organoclorados (O. P.) (eje Y izquierdo).*

rine pesticides) experienced two distinct periods of increase: one coinciding with the dry period, with high temperatures, and a second one in spring (Fig. 3).

The first two axes of PCA were used to evaluate eventual changes in environmental parameters during the study period, explaining 48.1 % of the variance (Fig. 4). The first axis (PC1) explained 30 % of the variance, and the second axis (PC2) explained 18.1 % of the variance. The variables with the highest contribution to PC1 were nitrate (NO_3^{-}), biological oxygen demand (BOD), temperature (T) and phosphate (PO_4^{3-}), while pH, nitrite (NO_2^{-}) and organochlorine pesticides were the main variables contributing to PC2. The dry period (i.e., summer) was characterized by having greater values in relation to all physical and chemical characteristics of nitrate, BOD, temperature and phosphate. On the other hand, greater pH and nitrite were associated with the spring period. In summary, we can distinguish four periods according to the four seasons, but the main differences were observed between summer and the rest of the year (Fig. 4).

Community composition and structure

During the study, over 3144 individuals, belonging to 22 families of macroinvertebrates, were collected, varying between 16 to 22 taxa per month (Fig. 5), mostly insects (18 taxa). Diptera was the faunal group with the highest taxa richness, with 10 families (45 %); followed by Coleoptera with 4 families (18 %); Ephemeroptera, Odonata and Gastropoda, each with 2 families (9 % each); and Oligochaeta and Crustacea with 1 family (5 % each). When analysing the changes in community abundance we noted that the maximum value was reached in September and December, being Diptera always the best-represented faunal group in every month (Fig. 5A), with a maximum of 363 individuals recorded in September. Within Diptera, Chironomidae was the best-represented family with 52 % of the total abundance; Culicidae and Psychodidae accounted for 15 % and 14 %, respectively, whereas the rest of the families were represented by lower abundances (between 1 and 5 %) (Fig. 5C). None of the six community parameters (S, H', J, TD, ATD, and VTD), nor either succession rates (Armstrong and Jassby-Goldman SR) showed significant differences linked to season, being more or less constant over the year (Table 1 and Fig. 6). However, some of them (i.e., H' and J) had marginal significance, with values from the hot period (summer and autumn) slightly lower than the values from the rest of the year (Table 2). In the case of the community composition analysed by PERMANOVA, only marginal significance was also obtained (Pseudo-F_3 = 1.606; p = 0.098).

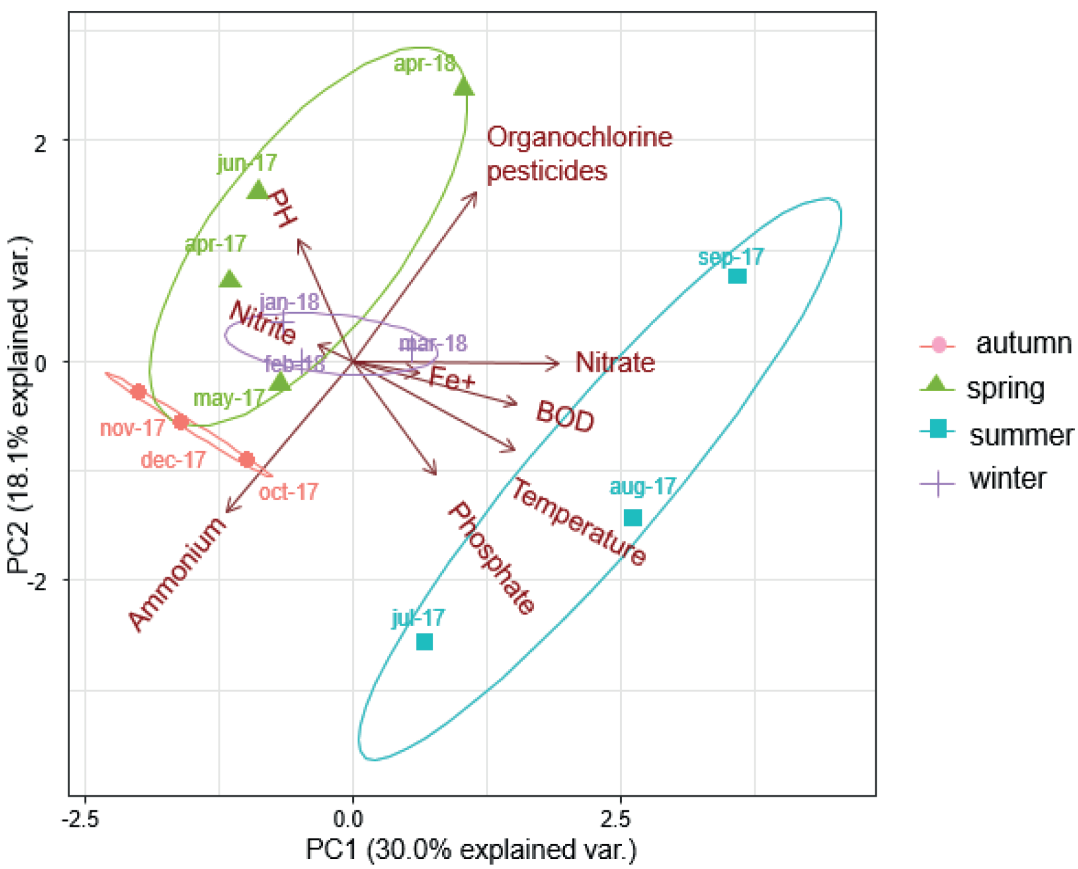

Figure 4. PCA plot showing the position of samplings in relation to the physical and chemical characteristics of water. The ellipses correspond to seasons. *Resultado del PCA que muestra la posición de los muestreos en relación con las características físicas y químicas del agua. Las elipses corresponden a las estaciones.*

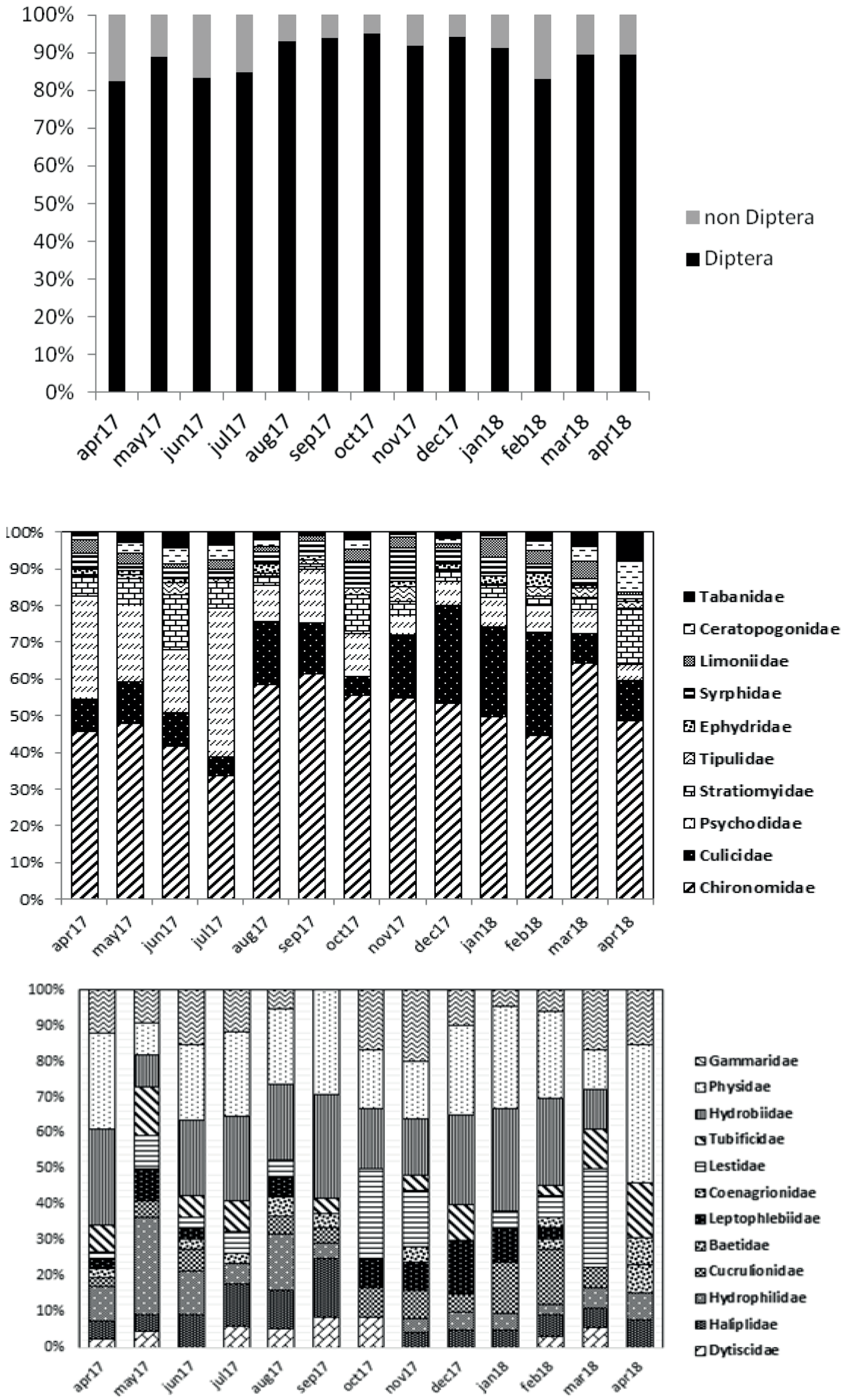

Figure 5. Macroinvertebrate composition in each sampled month. A) Proportion of Diptera abundance in relation to the total macroinvertebrate abundance. B) Abundance proportion of Diptera families. C) Abundances proportion of non-Diptera families. *Composición de macroinvertebrados en los meses muestreados. A) Proporción de la abundancia de Diptera en relación con la abundancia total de macroinvertebrados. B) Proporción de la abundancia de las familias de dípteros. C) Proporción de abundancia de las familias que no son dípteros.*

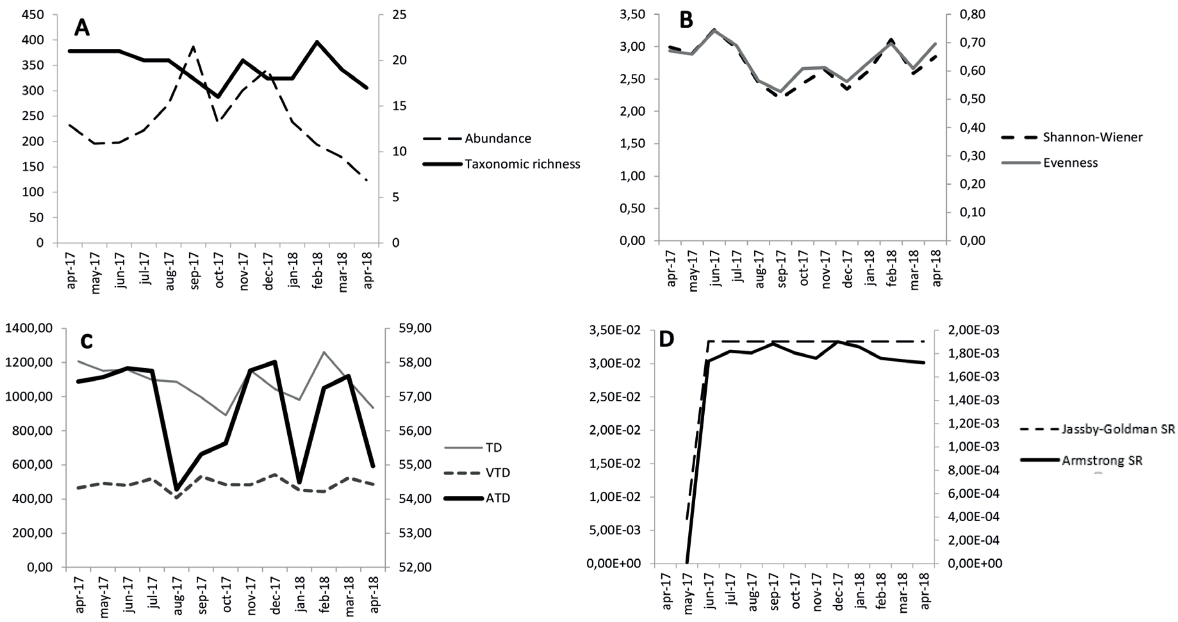

Figure 6. Temporal pattern of community variables during the studied months: A) total abundance (left Y-axis) and taxonomic richness (right Y-axis). B) Shannon-Wiener diversity (left Y-axis) and evenness (right Y-axis). C) taxonomic distinctness (TD) and variation in taxonomic distincness (VTD) (left Y- axis), and average taxonomic distinctness (ATD) (right Y-axis). D) Jassby-Goldman SR (left Y-axis) and Armstrong SR (right Y-axis). *Patrón temporal de las variables de la comunidad durante los meses de estudio: A) abundancia total (eje Y izquierdo) y riqueza taxonómica (eje Y derecho). B) diversidad de Shannon-Wiener (eje Y izquierdo) y equitabilidad (eje Y derecho). C) diferencia taxonómica (TD) y variación de la diferencia taxonómica (VTD) (eje Y izquierdo), y diferencia taxonómica media (ATD) (eje Y derecho). D) Jassby-Goldman SR (eje Y izquierdo) y Armstrong SR (eje Y derecho).*

Community composition and environmental parameters

When examining the relationships between community composition and water characteristics, the NMDS showed that only nitrite (p = 0.028) and ammonium (p = 0.029) were significantly related. Lestidae and Tipulidae seemed to be strongly related to ammonium, while Curculionidae and Leptophlebiidae were highly associated with nitrite. Baetidae and Coenagrionidae were placed very distant to the other taxa, and in an opposite relationship with the vector of the significant water characteristics, which indicated that their abundances increased when low concentrations of both ammonium and nitrite were present (Fig. 7).

DISCUSSION

The water quality of the lake Réghaïa is considered as 'very poor' (class 4) according to Algerian standards. Already in the 1980s, there were concerns about the water quality of the lake, as it was noted that eutrophication was accelerated by organic pollution (Akli, 1988). Since then, several studies have recorded the low quality of the water of the lake (El Haouati *et al.*, 2009; Zouatine, 2019). This state is due to exogenous contribution from the industrial zone, agricultural land leaching and discharges of untreated urban water from the surrounding area. These contributions provide high nitrogen concentrations (Zouatine, 2019), a fact that is consistent with our results, which showed nitrogen to be highly represented in its different forms. The combination of several human pressures and pollutant discharges as a consequence of land transformations in the catchment basins is common in other coastal lagoons (e.g., Vicente & Miracle, 1992; Viaroli & Christian, 2003; Pérez-Ruzafa *et al.*, 2011), since most coastal lagoons are surrounded by densely populated areas, and this makes them among the most

Table 2. Results of the statistical comparison between seasons for the different parameters of the community. All parameters were analysed by means of an ANOVA, except the one marked by an asterisk, that was analysed by means of Welch one-way F-test due to its lack of variance homogeneity. *Resultados de los análisis estadísticos entre estaciones para los diferentes parámetros de la comunidad. Todos los parámetros fueron analizados mediante una ANOVA, excepto el marcado con un asterisco, que fue analizado con la prueba F univariante de Welch debido a su falta de homogeneidad de varianza.*

	Df	F	*P- value*
Abundance	3; 9	2.21	2.2103
Taxonomic richness	3; 9	0.63	0.6165
Evenness*	3; 4.7	4.66	0.0704
Shannon-Wiener diversity index	3; 4.39	5.08	0.0667

heavily impacted ecosystems on Earth (Kjerfve, 1994; Arévalo *et al.*, 2013). Among human impacts, agriculture has been described to be one of the most relevant (e.g., Aydi & Benamara, 2004), causing changes in water turnover and nutrient dynamics (Badosa *et al.*, 2008), as well as in pesticide loadings (López-Flores *et al.*, 2014). In fact, according to Zouatine (2019), 68 % of inhabitants of areas close to Réghaïa wetland are farmers and use fertilizers and other products for favourable yield, ignoring the severity of sanitary discharges to the water table and the lake ecosystem. The observed high values of organic pollution (high values of BOD), iron and pesticides found in the present study are consistent with these observations.

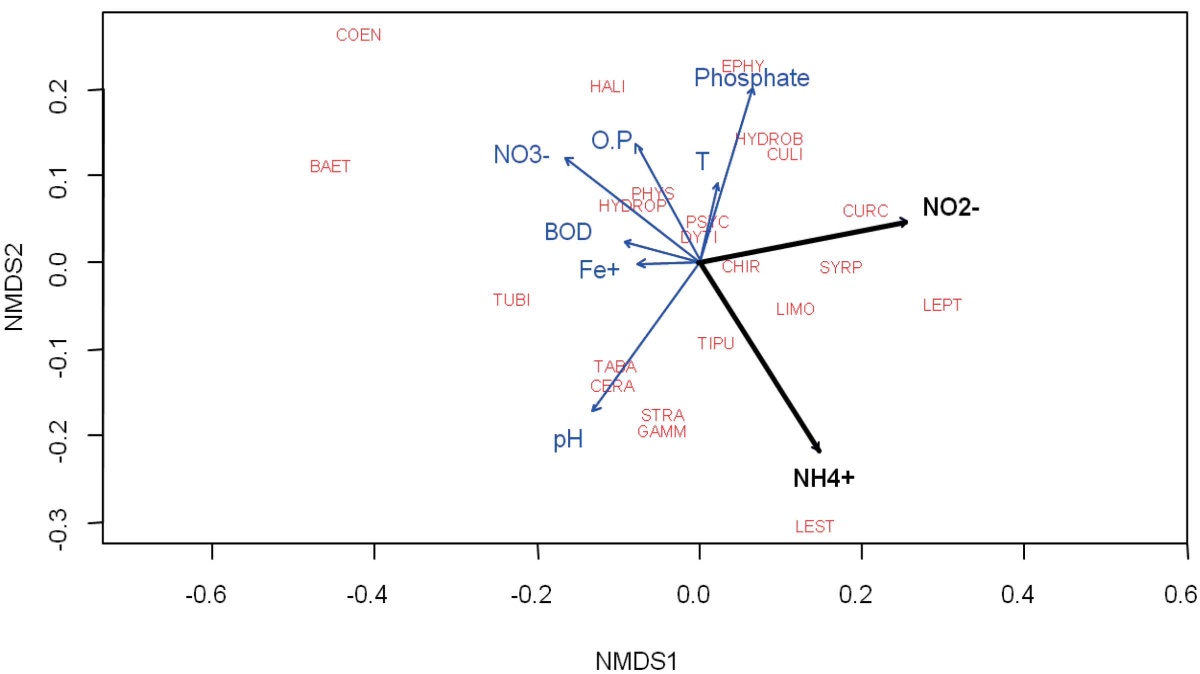

Figure 7. NMDS plot showing the similarities among taxa and their relation to environmental parameters. Environmental factors (temperature, pH, biological oxygen demand, NH_4^+, NO_3^-, NO_2^-, PO_4^{3-}, Fe^+, organochlorine pesticides) are represented by arrows. The bold arrows indicate the environmental variables with a significant effect (NH_4^+; $p = 0.029$) (NO_2^-; $p = 0.028$). *Resultado del análisis NMDS que muestra la semejanza entre taxones y su relación con los parámetros ambientales. Los factores ambientales (temperatura, pH, demanda biológica de oxígeno, NH_4^+, NO_3^-, NO_2^-, PO_4^{3-}, Fe^+, pesticidas organoclorados) están representados por flechas. Las flechas en negrita indican las variables ambientales con un efecto significativo (NH_4^+; $p = 0.029$) (NO_2^-; $p = 0.028$).* Abbreviations: BAET: Baetidae; BOD: biological oxygen demand; CERA: Ceratopogonidae; CHIR: Chironomidae; COEN: Coenagrionidae; CULI: Culicidae; CURC: Curculionidae; DYTI: Dytiscidae; EPHY: Ephydridae; GAMM: Gammaridae; HALI: Haliplidae; HYDROB: Hydrobiidae; HYDROP: Hydrophilidae; LEPT: Leptophlebiidae; LEST: Lestidae; LIMO: Limoniidae; O.P: Organochlorines pesticides; PHYS: Physidae; PSYC: Psychodidae; STRA: Stratiomyidae; SYRP: Syrphidae; T: temperature; TABA: Tabanidae; TIPU: Tipulidae; TUBI: Tubificidae.

As the Réghaïa wetland is characterized by a Mediterranean climate (Larid, 2008), the dry season from May to October has several effects on the lake ecosystem (Arab & Arab, 2017). During this time, the marshy banks dry out due to higher temperatures, indicating the beginning of the wetland confinement phase (sensu Guelorget & Perthuisot, 1983). Moreover, water level fluctuations are characteristic of wetlands in the Mediterranean region (Beklioglu *et al.*, 2007) and several Mediterranean water bodies show an increase in water level in winter, coinciding with freshwater inputs, and a gradual decrease during summer periods, coinciding with the maximum degree of confinement (Quintana *et al.*, 1998). Due to the lack of inputs and the intense evaporation, during confinement water tends to concentrate in terms of salinity, nutrients and organic matter, so that internal loading processes become more important than external inputs (Dugdale & Goering, 1967; Gamito *et al.*, 2005; Glibert *et al.*, 2010). Thus, an increase in organic matter and nutrient contents might be the consequence of a natural concentration caused by the sharp reduction in water volume during confinement, rather than by external pollution. In this sense, high concentrations of nutrients or organic matter have been found in natural and in less polluted wetlands (Quintana *et al.*, 1998; Badosa *et al.*, 2006; Serrano *et al.*, 2006). Confinement processes, however, mainly concentrate organic forms of nutrients, inorganic forms being indicative of external inputs (Àvila *et al.*, 2019). In the case of phosphorus, natural well-preserved sediments actively absorb inorganic phosphate reducing its proportion in water (Golterman, 2004), and the ratio of inorganic vs organic phosphorus has been proposed as a measure of severe anthropogenic eutrophication (Serrano *et al.*, 2017). Inorganic nitrogen forms are especially scarce during confinement due to high losses via denitrification (López-Flores *et al.*, 2014), leading to a strong nitrogen limitation of primary producers (Quintana *et al.*, 1998; López-Flores *et al.*, 2014; Àvila *et al.*, 2019). Confinement level is not easy to stablish in Réghaïa wetland, since water fluxes to the lake are poorly estimated (Thibault, 2006). However, our results show that inorganic nutrient concentrations are very high when compared with other Mediterranean coastal lagoons, indicating that they are caused by nutrient inputs from the catchment area and eliminating the possibility of accumulations due to natural confinement (Quintana *et al.*, 1998; Evagelopoulos *et al.*, 2008;).

Knowledge of macroinvertebrate fauna in Algerian coastal wetlands is very scarce. The few studies carried out have generally been fragmentary and have mostly concentrated on certain families or species. According to Haouchine (2011), after the 1980s, hydrobiological programmes were launched by the laboratories of the universities of Algiers, Tizi Ouzou, Tlemcen and Guelma, improving knowledge of aquatic macroinvertebrates. In Réghaïa wetland, faunal research has been focused on turtles, birds, mammals and terrestrial insects (e.g., Djitli, 2016; Bakhouche *et al.*, 2019), but no studies have been carried out on aquatic macroinvertebrates. Twenty-two macroinvertebrate families belonging to seven orders were sampled during the 13 months of study at Lake Réghaïa, insects being the best represented group with 18 families. Similar figures for family richness have been reported in neighbouring coastal wetlands of Lake Tonga (Djamai *et al.*, 2019), but according to other studies this richness is clearly underestimated (Khedimallah & Tadjine, 2016). Moreover, the observed richness is slightly low or lower than published levels in other oligohaline coastal wetlands in the Mediterranean basin or at other latitudes (e.g., Boix *et al.*, 2008; Pérez-Bilbao *et al.*, 2013). Therefore, we have to consider the reported richness for Réghaïa wetland in the present study as a low value.

However, the above-mentioned studies also agree in that, in these environments, insects were the best represented group. Accordingly, insects were the most abundant group in our study, representing 94 % of the sampled specimens. The dominance of the community abundance by insects has been reported in other Algerian coastal wetlands (such as Lake Tonga, but with lower values (52.7 %); Khedimallah & Tadjine, 2016). Diptera was the most abundant insect order, accounting for 45 % of the abundance, with Chironomidae the most abundant family, similar to results reported from other coastal wetlands

(Correia *et al.*, 2012; Pérez-Bilbao *et al.*, 2013). Diptera was also the richest order, including ten families, followed by Coleoptera with four families and, finally, Ephemeroptera and Odonata with two families each, whereas non-insect macroinvertebrate groups were only represented by a few families (2 Mollusca families, 1 family of Annelida, and 1 of Crustacea). This composition, dominated by insects and mainly by Diptera and Coleoptera, is commonly observed in oligohaline coastal wetlands (e.g., Della Bella & Mancini, 2009; Pérez-Bilbao *et al.*, 2013), contrasting with lower richness of insects in more saline ones (Anton-Pardo & Armengol, 2014; Coelho *et al.*, 2015). It is known that lower richness of insects is normally found in brackish waters (Cognetti & Maltagliati, 2000; Nebra *et al.*, 2011). Throughout this study, absence of some groups (i.e., Hemiptera families) and the low number of observed families contrasted with richness values reported for other coastal wetlands (e.g., Boix et al., 2008; Pérez-Bilbao *et al.*, 2013). However, these undetected taxa, such as Notonectidae and Corixidae, have been previously reported in the gut contents of the freshwater turtle *Mauremys leprosa* from the same lake (Bakhouche *et al.*, 2019). Finally, the abundance of non-insect groups (oligochaetes, crustaceans and gastropods) only represented 6 % of the total individuals captured, although these groups are usually more relevant in terms of abundance in other coastal wetlands (e.g., Correia *et al.*, 2012; Coelho *et al.*, 2015; Khedimallah & Tadjine, 2016).

Our results showed that both the composition and structure of the community were very homogeneous throughout the study period, with a small abundance increase in summer, while the lowest abundance was recorded in April. In temporal terms, summer was the most successful season compared to the other seasons (Khedimallah & Tadjine, 2016) with the highest macroinvertebrate abundances during the period of eutrophic conditions. However, and although water variables also showed a pattern characterized by more eutrophic conditions during the warmer period (higher nutrient concentrations), we were not able to detect significant changes in community structure. Communities of coastal wetlands (such as estuaries, lagoons or salt-marshes) are characterized by a great proportion of euryhaline and tolerant species (Cognetti & Maltagliati, 2000; Gascón *et al.*, 2005). Clearly, temporal changes that are commonly described in macroinvertebrate communities of other aquatic habitats (such as inland or temporary wetlands Boix *et al.*, 2008) are not expected to be so evident in coastal wetlands. However, less significant temporal changes in the structure of the macroinvertebrate community did not imply an absence of them. In fact, it has been described that community composition of coastal oligohaline wetlands commonly differs according to hydrology, salinity and trophic state (e.g., Nebra *et al.*, 2011; Pérez-Bilbao *et al.*, 2013). However, these factors are not the only ones responsible for the changes of macroinvertebrate communities and their stability in coastal wetlands, the presence / abundance of fish and vegetation, involves both a refuge and a trophic resource (e.g., Compte *et al.*, 2012; Gascón *et al.*, 2013; Tagliapietra *et al.*, 2016). In this sense, it is important to note that the surface of the bottom of the studied lake is dominated by bare sediments (El Haouati *et al.*, 2009) and, although fish are present (i.e. *Gambusia holbrooki*, and *Anguilla anguilla*), seasonal changes in its composition or abundance are still unknown, as recent existing information is poor or has not been updated (Thibault, 2006; Bakhouche *et al.*, 2019). However, abiotic variables in seasonal patterns were found also to be crucial in determining the macrobenthic community structure in coastal waters (Evagelopoulos *et al.*, 2008; Anton-Pardo & Armengol, 2014). Our results in Réghaïa wetland contrast with the changes in community structure commonly reported from other Mediterranean wetlands, since neither abundance peaks nor significant compositional changes were observed during the studied period.

As in other regions or habitats (Verdonschot *et al.*, 2012), no biological indicators explicitly exist for Algerian wetlands. In these situations, the use of general community parameters has been proposed as adequate candidates to assess the ecological status of these habitats (Della Bella & Mancini, 2009; Pérez-Bilbao *et al.*, 2013; Piló *et al.*, 2015). However, we did not find any difference among the parameters studied that could be linked to the main seasonal differences of the physical and chemical conditions of the lake. The present work showed that ammonium and nitrite were significantly associated with differences in the macroinvertebrate assemblage, so these components affected community composition. Moreover, other studies in Lake Réghaïa have revealed that the low levels of nitrite in hot periods are mainly due to the low levels of dissolved oxygen, which causes high amounts of ammonium. These low levels of dissolved oxygen are the result of the high organic loads from wastewaters. The concentrations of nitrogen reported in this study and in others, performed in the same wetland, were very high (El Haouati *et al.*, 2009). The danger of high concentrations of chemical elements is always present, some authors (Melhaoui, 2010) have stated that nitrates are declared toxic when their level exceeds 50 mg/l, and nitrites are toxic for poikilothermic animals (fish, molluscs, crustaceans and aquatic insects). However, the effect of ammonium, nitrite or nitrate on wetland macroinvertebrates is not clearly stablished, since low effects or no effects have been reported (e.g., Cooper *et al.*, 2007; Dalu *et al.*, 2012;), and it is barely studied in Algeria and especially in Lake Réghaïa. Overall, this wetland is an area affected by intense pollution, and the waters of the lake are classified as very poor in quality due to various factors. The macroinvertebrate community was characterized by a low richness, by a composition dominated, in both richness and abundance, by dipterans (i.e., tolerant taxa), and exhibited no changes in structure during the year. These characteristics altogether could indicate that the present physical and chemical conditions in the lake imply a poor but very resilient macroinvertebrate community. In conclusion, the present study constitutes a first step for future research on the environmental and spatio-temporal impact of water quality on aquatic fauna in Réghaïa wetland, for which urgent management decisions are needed to preserve its biodiversity value.

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