EVALUATION OF THE PHYSICO-CHEMICAL AND BIOLOGICAL QUALITY OF THE EASTERN ALGERIAN COASTAL WATERS (SOUTHWESTERN MEDITERRANEAN)

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Abstract. This study aimed to investigate the water quality of the eastern Algerian coastal area as well as the responses of the major phytoplankton groups to the variability of the physico-chemical parameters. The analysed parameters (dissolved oxygen, pH, sea surface temperature, and salinity) are found to be within the tolerated ranges. Whereas the nutrients surpassed the standards, especially on the western and central sides of Annaba Gulf, where anthropic pressures are constantly increasing. Those concentrations were less important on El Kala's coast, which is considered a reference zone, with the exception of certain elevated levels of silicate, nitrate, and ammonium detected in August, but which do not exceed the tolerated standards. Nevertheless, adjacent to El Mellah Lagoon, double the phosphate permissible level was recorded. When it comes to the phytoplankton, the highest densities were detected on the onshore of Annaba, associated with the strong concentrations of nutrients coming from the terrigenous supply of Seybouse and Boudjemma wadis, as well as from Mafragh Estuary.

Referring to previous studies conducted at the level of Annaba Gulf, we noticed that the enrichment of the coast in nutrients of various origins is intensifying, which disrupts the aquatic balance, starting with its basis, which is the phytoplankton.

Key words: nutrients, ponitoring, phytoplankton, water quality, Annaba Bay, El Kala's coast

1. INTRODUCTION

Coastal regions provide numerous benefits, such as opportunities for the economy, leisure and fishing (Aguilera *et al.*, 2001; Harvey *et al.*, 2015; Nazeer and Nichol, 2016). Those activities, combined with the increasing population and expanded industry, have significantly altered the coastal habitat, causing a variety of environmental problems and health risks for inhabitants (LeTixerant, 2004; Liu *et al.*, 2011).

Hypoxic zones have rapidly expanded in coastal areas due to deterioration of water quality, severely impairing ecosystem function (Diaz and Rosenberg, 2008), which is the main result of eutrophication and is frequently associated with harmful bloom episodes, decreased water clarity, rising pH, and reduced dissolved oxygen in the water column (Nezan *et al.*, 1997; Webster *et al.*, 2005).

In order to assess coastal water quality and analyse the effects of anthropogenic stressors, active surveillance of the physical, chemical, and biological components should be mainstreamed (Zulfa *et al.*, 2016; Glibert *et al.*, 2018).

Phytoplankton diversity and abundance are mainly dependent on the accessibility of nutrients, temperature, and light intensity (Goldman and Horne, 1983; Ghosh *et al.*, 2012). Changes in physico-chemical environmental factors can affect seriously the balance of the phytoplankton community (Vidal and Duarte, 2000), which will alter on a variety of levels (Goldman and Horne, 1983; Cloern, 2001).

Due to its susceptibility to environmental changes, phytoplankton is the biological component most commonly used to evaluate the water status (Reynolds, 2006; Lovett *et al.*, 2007; Rimet and Bouchez, 2012), particularly in coastal areas, which receive a significant amount of nutrients from a variety of sources, including urban and agricultural activities (Nixon, 1995).

Indeed, the good health of the ecosystem influences the sustainable progress of various activities (Puente-Rodríguez *et al.*, 2015). For those reasons, the investigation of the coastal water quality has become a necessity in order to maintain an equilibrium with both economic progress and ecological preservation as well as to provide remedies for the issues faced (Puente-Rodríguez *et al.*, 2015; Yuan *et al.*, 2016).

The purposes of this study are to assess the biological and physico-chemical quality of the eastern Algerian shore and to investigate the variability of the major phytoplankton groups in relation to the physicochemical parameters. This region has benefited from a few surveys with the same objective. The two main investigations, which focused on toxic or bloom-inducing dinoflagellates, were conducted at the level of the western side of Annaba Gulf (Frehi *et al.*, 2007; Hadjadji *et al.*, 2014). The remainder of the research region, notably El Kala's shoreline, has not yet been the subject of any investigations.

2. MATERIALS AND METHODS

2.1. STUDY AREA AND SAMPLE ACQUISITION

The research was conducted on the eastern Algerian continental shelf (7.8 to 8.9º E, 36.57 to 37.35º N). The investigated area extends from Cap de Garde to near the Algerian-Tunisian border and includes Annaba Gulf and El Kala's coast. As part of this study, 74 stations from the surface layer (-1m) were investigated over the 2021 year: April (10 stations), August (16 stations), November (28 stations), and December (20 stations) (Figure 1).

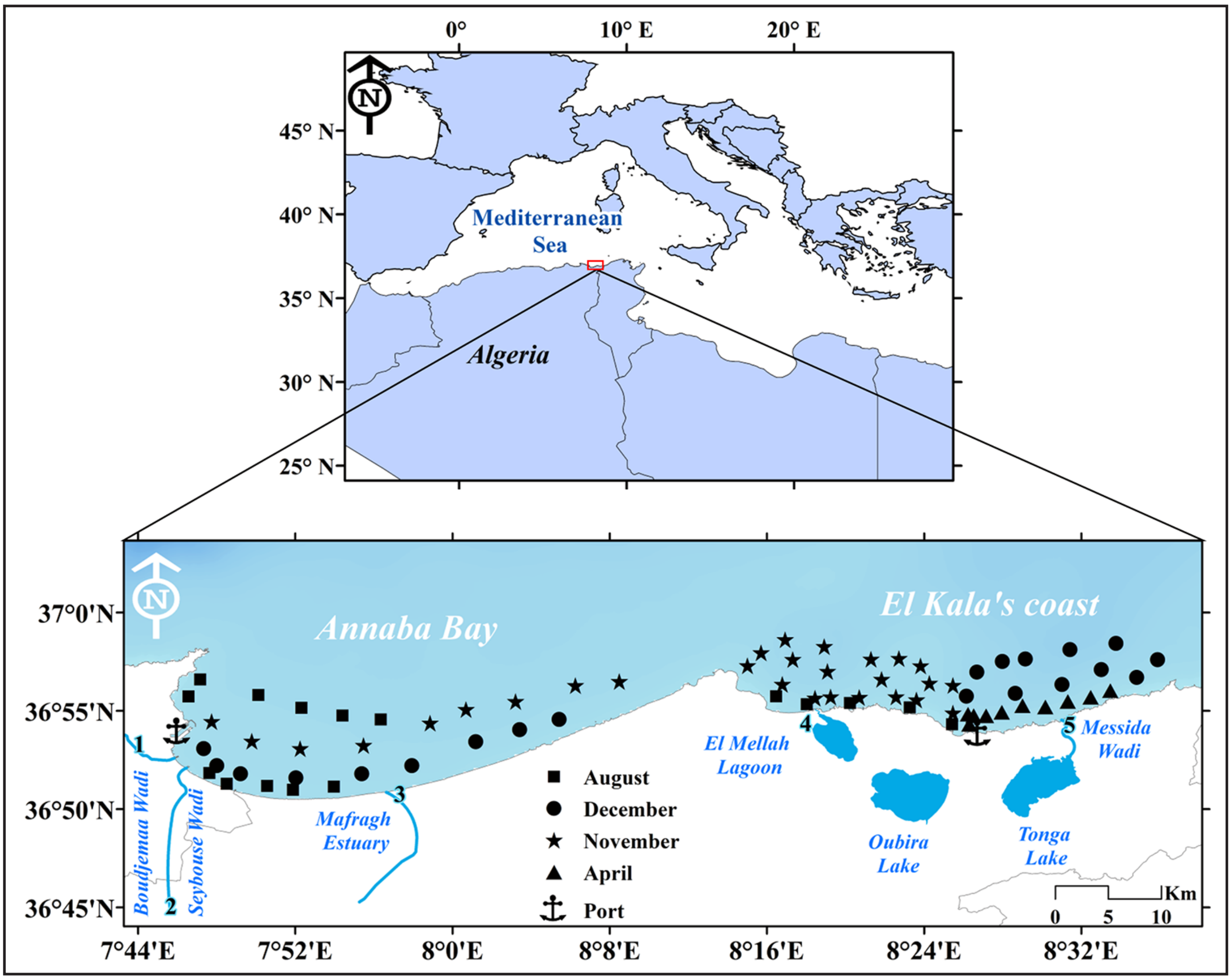

Fig. 1. The investigated area and the localization of the sampling points.

For the study of phytoplankton, 74 samples were acquired, and 34 for the analysis of nutrients, while the *in-situ* measurements (sea surface temperature, pH, salinity, and dissolved oxygen) were recorded for all stations. A Niskin bottle of 5L was used to collect the water samples.

Water samples for the microscopic study of phytoplankton were collected and stored in 250 ml polyethylene terephthalate bottles. Fixation of the samples with Lugol in acid solution was carried out immediately after their collection. The samples were kept in the dark in a cooler at -4°C and then transported to the laboratory for examination. Phytoplankton samples were counted using an inverted microscope according to Utermöhl's method (Utermöhl, 1958), after a setting period of 24 h, and identified following the work of Tomas (1997). The counting was done on the whole surface of the bottom of the chamber. The results of the cell enumeration were expressed as the number of cells per volume (Cell/l) based on the work of Andersen and Throndsen (2003).

On the other hand, the sea surface temperature (SST), pH, and salinity were measured using a multiparameter (HI9829), while the dissolved oxygen (DO) was assessed using a field oximeter.

For the nutrient investigation, we analysed the concentration of nitrate, ammonium, phosphate, and silicate based on the spectrophotometric method, according to the protocols described in the Manual of Aminot and Chaussepied (1983).

2.2. STATISTICAL ANALYSIS

The correlation analysis based on Pearson Correlation coefficient (r) and p-value, as well as the statistical descriptive (Min, Max, and mean), were derived from all the data and were performed in the R software (version 4.0.2).

3. RESULTS AND DISCUSSION

3.1. THE ASSESSMENT OF THE PHYSICO-CHEMICAL PARAMETERS

Table 1 depicts the statistical summary of the temporal variation of each studied parameter, while Figure 2 illustrates their spatial variabilities. On the other hand, the reported results of the current study were compared to those of Frehi *et al.*, (2007), Redouane and Mourad (2017), as well as to the Algerian standards (OJ, 2002), and are depicted in Table 2.

3.1.1. PHYSICAL PARAMETERS

The investigation of the physical parameters in Annaba Gulf and El Kala's coast revealed that the lowest coastal water SST was recorded in El Kala's offshore in December (13.938 °C), while the highest value was recorded in August nearby to El Mellah Lagoon at 25.984 °C (Figure 2a). In the summer, the sea water temperature surpassed 24 °C, while in the winter it dropped to 13 °C. When comparing the recorded values of the SST with the Algerian standards, we note that the variation range of the SST at the level of the two investigated areas does not exceed the upper limit, which is 30 °C. The observed range of this variable is in agreement with the results reported by Frehi *et al.*, (2007) in Annaba Gulf, while less important values were recorded on the western Algerian coast by Redouane and Mourad (2017).

The measured salinity at all sites exceeded the average of the seawater salinity in the world's oceans (35 PSU) (Bouchet, 2006). Similar observations were reported in 2007 by Frehi *et al.*, (2007). Nevertheless, the observed range remains less important than that usually detected in the Mediterranean area (38-39 PSU) (Crise *et al.*, 1999; Aminot and Kérouel, 2004). The lowest salinity was measured in December near Mafragh Estuary (35.125 PSU), which was to be expected as this latter provides fresh water with low levels of salinity in winter (Haridi *et al.*, 2008). During the summer, the highest salinity of 37.977 PSU was recorded in the area where Seybouse Wadi discharges its water (Figure 2b). This result can only be justified by the influence of coastal areas' higher evaporation and reduced precipitation rates compared to the open sea locations (Purser and Seibold, 1973), recognizing that there is no desalination plant that could promote substantial salinity. Additionally, the semi-enclosed character of Annaba Gulf and the input of water from Seybouse and Boudjemaa wadis, which are charged by industrial and urban effluents (Khammar, 2007; Ounissi *et al.*, 2014), could be the major causes of these high sea surface salinity values. Inversely, El Kala's region, with its open coastline, presents less salinity, especially near Messida Wadi, which is linked to Tonga Lake (fresh water).

The pH ranges from 7 to 8.36 and is within the tolerated range (6.5 to 8.5). The minimum pH recorded at the water's surface was 7.010 near El Mellah Lagoon's opening in August, while the maximum was 8.36, measured in November, off the eastern edge of Annaba Gulf (Figure 2c). This parameter displayed ranges that were similar to those that Redouane and Mourad (2017) reported. The majority of the examined stations had alkalinity with pH values of over 8, which is comparable to the pH of the global ocean (Raven *et al.*, 2005). Nonetheless, as was already indicated, our studied area's salinity is greater than the global average. This occurrence may be explained by the acidifying waters using the increased salinity to maintain a pH equilibrium (Uddin *et al.*, 2014). Furthermore, the fluctuation of pH is affected by many factors, including algal blooms, aerosols and dust deposition, minerals dissolved in the water, urban and industrial waste, and the photosynthesis process (Omer, 2010). For example, the increase in pH can be due to the uptake of CO_2 by photosynthesis (Akinde and Obire, 2011), and the decrease in pH can be attributed to the mixing processes of seawater, such as upwelling (Raven *et al.*, 2005).

The lowest value of DO (6.350 mg/l) was recorded in August near Seybouse Wadi, and the highest level of 8.760 mg/l was found in November on the open shore of El Kala (Figure 2d).

Table 1. The statistical summary of the studied parameters.

	Month	Diatoms density	Dinoflagellates density	Sal (PSU)	SST (°C)	pH	Dissolved oxygen (mg/l)	Nitrate (µmol/l)	Ammonium (µmol/l)	Phosphate (µmol/l)	Silicate (µmol/l)
Min	Apr	1080	640	35.960	16.038	8.020	7.580	0.120	1.120	0.080	0.210
	Aug	200	1880	37.230	25.059	7.010	6.350	0.070	0.020	0.860	0.930
	Nov	560	880	35.837	14.958	7.590	7.320	0.110	0.280	0.010	0.100
	Dec	1040	2920	35.125	13.938	7.650	6.910	0.490	0.370	0.020	0.090
Max	Apr	2680	1120	36.850	16.975	8.200	8.010	0.150	1.180	0.110	0.320
	Aug	4800	81200	37.977	25.984	8.220	8.230	6.410	32.090	7.630	9.320
	Nov	30800	58800	37.390	16.859	8.360	8.760	15.820	43.600	0.130	1.600
	Dec	44800	33600	36.926	14.676	8.220	8.620	62.980	221.320	0.690	4.350
Mean	Apr	1676	792	36.476	16.370	8.121	7.757	0.133	1.153	0.097	0.263
	Aug	1032	27021	37.699	25.600	7.555	7.402	1.799	7.831	2.854	3.066
	Nov	5051	10005	36.771	15.790	8.183	8.468	2.216	5.287	0.061	0.419
	Dec	20186	18944	36.190	14.211	8.054	7.799	8.231	32.523	0.167	0.853

Table 2. The comparison between the measured variables, previous studies, and the Algerian norms.

Parameter	The present study				Frehi *et al*. (2007)		Redaoune and Mourad (2017)		Algerian Norms (OJ, 2002)
	El Kala coast		Annaba Gulf		Annaba Gulf		Arzew Gulf		
	Min	Max	Min	Max	Min	Max	Min	Max	
SST (°C)	13.938	25.979	14.295	26.002	14.1	25.8	12	21	30
Salinity (PSU)	35.837	37.794	35.125	37.977	35.1	37.9	-	-	
pH	7.01	8.25	7	8.36	-	-	6.8	8.29	6.5-8.5
DO (mg/l)	7.12	8.76	6.35	8.75	-	-	4.3	10.5	-
Ammonium (µmol/l)	0.28	9.03	0.02	221.32	0	272.8	0.21	4.54	-
Nitrate (µmol/l)	0.11	5.69	0.07	62.98	0.01	58.36	1.66	2.66	50
Phosphate (µmol/l)	0.01	4.25	0.02	13.89	0	5.96	0.15	3.46	2
Silicate (µmol/l)	0.09	3.65	0.27	11.96	-	-	-	-	-

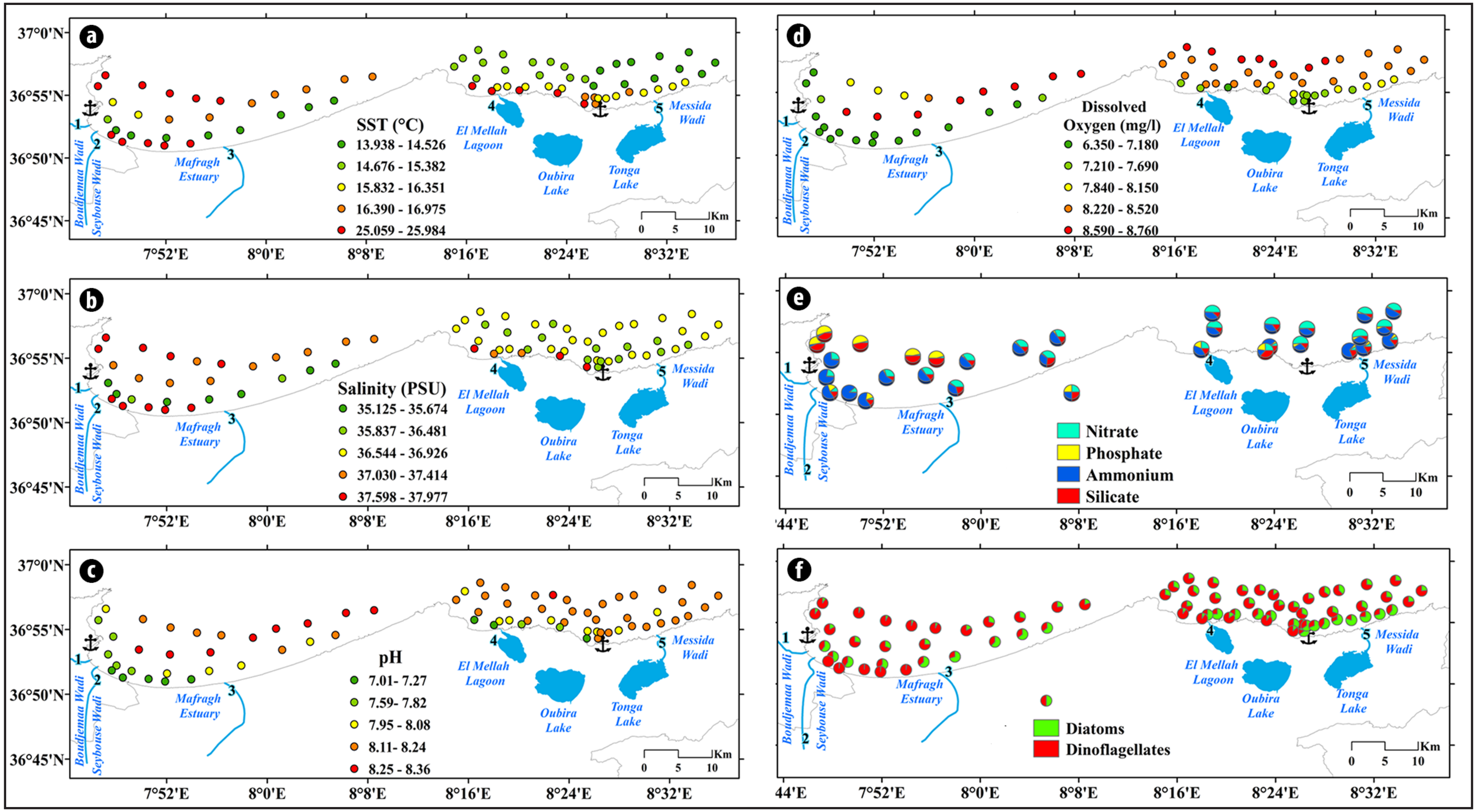

Fig. 2. The spatial variability of the analysed parameters: (**a**) SST; (**b**) Salinity; (**c**) pH; (**d**) Dissolved oxygen; (**e**) Nutrients; (**f**) Phytoplankton distribution.

All the measured values remain within the global standards in comparison with the minimum detected by Redouane and Mourad (2017) in the Gulf of Arzew, which is close to the lower limit. This parameter can be affected directly by the salinity and temperature. In the water, the solubility of oxygen is inversely correlated with temperature and salinity (Marine, 1999), which is coherent with our results (Table 4). The sharp decrease in DO levels near the coastline during August and April may be justified by the increase in temperature (Aminot and Kérouel, 2004). The situation is reversed in November with the decrease of the SST. Nevertheless, the lowest DO recorded from our field measurements (6.35 mg/l) is much higher than the limit defined as hypoxia (Al-Ansari *et al.*, 2015), which is less than 2 mg/l.

3.1.2. NUTRIENTS

Regarding the nutrient's variability, the minimum nitrate content at the water surface was 0.07 µmol/l measured in August in Annaba open water and a maximum of 62.98 µmol/l obtained in December near the junction of Boudjemaa and Seybouse wadis (Figure 2e). Nitrates surpass the tolerated standards and exceed the value detected by Frehi *et al.* (2007) at the level of Annaba Gulf. While their concentration is less important at the level of El Kala's coast, nevertheless, these values remain more important compared to the upper limit measured by Redouane and Mourad (2017) in the waters of the Gulf of Arzew. The high surface nitrate concentrations may be due either to terrigenous input from Seybouse, Boudjemaa Wadi, Mafragh Estuary and El Mellah Lagoon, or to the degradation of organic matter (Saliot *et al.*, 1991).

The weakest ammonium concentration (0.020 µmol/l) was measured in August off Annaba Gulf, while the peak of 221.320 µmol/l was detected in December adjacent to the effluents of Boudjemaa and Seybouse wadis (Figure 2e). Although this value represents a peak in comparison with the maximum detected in the Gulf of Arzew (Redouane and Mourad, 2017), Frehi *et al.* (2007) reported a higher concentration (272.8 µmol/l) in almost the same location.

In terms of phosphate concentration, a minimum of 0.010 µmol/l was measured in November off El Kala's coast, and the highest value of 7.630 µmol/l was detected in August close to Seybouse Wadi (Figure 2e). This element behaves as a tracer of continental inputs (Aminot *et al.*, 1997), which are enriched in phosphate by the most important urban and industrial effluents, as well as the wastewater of Annaba city. It was reported that Seybouse Wadi discharges about 700 tons of phosphorus per year and a comparable amount of inorganic nitrogen (Khammar, 2007; Ounissi *et al.*, 2014). The maximum detected concentration far exceeds the tolerated concentration and is more than twice that reported by Frehi *et al.* (2007) in the Gulf of Annaba and more than twice that measured in the Gulf of Arzew (Redouane and Mourad, 2017). Moreover, phosphorus can be derived from the recycling of organic matter by mineralization or from various biological processes (Héral *et al.*, 1983). Those findings are consistent with previous research that highlighted several blooms on the western side of Annaba Gulf (Frehi *et al.*, 2007; Hadjadji *et al.*, 2014). The generation of that algal fluorescence requires a large amount of nutrients, and the most frequently responsible for eutrophication are nitrogen and phosphorus (Smith *et al.*, 1999; Howarth *et al.*, 2000; Anderson *et al.*, 2002), which, when compared to numerous wadis in the Mediterranean, are found in Seybouse water with a high proportion (Ounissi *et al.*, 2014).

At the water's surface, the lowest concentration of silicate was recorded in December off El Kala's water (0.090 µmol/l), and the highest (9.320 µmol/l) was recorded in August close to Seybouse Wadi (Figure 2e). In contrast to El Kala's water, where silicate concentrations are less significant, this element is contained at an important concentration at the level of Annaba Gulf. Silicates are not a limiting factor for most phytoplankton species (Aminot *et al.*, 1997), but they are necessary for species with siliceous skeletons, mainly diatoms. Examining the concentration of the two regions, silicate ranged from 0.09 to 3.65 µmol/l and from 0.27 to 11.96 µmol/l, for El Kala's coast and Annaba Gulf, respectively. The distribution of silicate is inhomogeneous in space, the low values detected in August at the surface can be explained by a low phytoplankton biomass (Diatoms), the enrichment of the environment with this nutrient can lead to harmful or toxic algal blooms. Conversely, a lack of silica can exacerbate the eutrophication phenomenon by reducing the role of diatoms in the coastal food web (Officer and Ryther, 1980). Therefore, this region experiences numerous dinoflagellate bloom episodes during the year (Frehi *et al.*, 2007). Those species feed on diatoms and contribute to a considerable decrease of this element in the sea water.

3.2. THE INVESTIGATION OF THE SPATIOTEMPORAL DISTRIBUTION OF DIATOMS AND DINOFLAGELLATES

When it comes to the examination of the spatiotemporal distribution of the phytoplankton, different distribution patterns of the two analysed groups are observed. Diatom densities recorded at 74 sampled locations spanned from 200 to 44800 cells/l, while for dinoflagellates, the densities ranged from 640 to 81200 cells/l (Table 1). Throughout every site that was sampled in April, the cell density of diatoms was greater than that of dinoflagellates. On the other hand, in August, all examined locations had significantly more dinoflagellates than diatoms (Figure 2f).

In November and December, diatoms predominate close to the shore and wadi outputs, as well as close to the harbour region, which agrees with the considerations of Falkowski *et al.* (1998) regarding the availability of silica, which mainly comes from rivers, being aware that this element is fundamental for diatom's proliferation. In contrast, at the other stations, the density of dinoflagellates was very high. The maximums of both groups are observed on the western side of Annaba Gulf, from 7° 46′ to 8° 0′. Our results are consistent with those of Frehi *et al.*, (2007) and Hadjadji *et al.*, (2014), who demonstrated the multi-period bloom associated with dinoflagellate species in the same location.

We counted and studied the variability of the entire group (diatoms, dinoflagellates), and therefore the dominance of a particular species in the collected samples was not highlighted because the purpose of this study was not to examine the behaviour or ecology of each phytoplankton species in response to environmental factors. Additionally, the main dinoflagellate species that have been found are comparable to those that Frehi *et al.*, (2007) described in Annaba Gulf. Nevertheless, those findings constitute the first investigation regarding the major phytoplankton groups' density at the coast of El Kala.

3.3. VARIABILITY OF PHYTOPLANKTON DENSITY IN RESPONSE TO THE PHYSICO-CHEMICAL PARAMETERS

In order to investigate the direct or indirect effects of physical and chemical parameters on phytoplankton groups, we employed the linear regression model to assess the response of diatoms and dinoflagellates to the grouped physico-chemical parameters (Table 3), and then we studied the correlation between all the parameters based on Pearson correlation (r) and p-value (Table 4). Regarding the fit of the regression model (Table 3), each group exhibited a different response to physicochemical variations. Diatom density is influenced by the combined physical parameters (R^2 = 0.566, p-value = 0.000) as much as it is influenced by the grouped nutrients (R^2 = 0.582, p-value = 0.001). While the density of dinoflagellates was influenced by all the physical parameters (R^2 = 0.371, p-value = 0.000) more than it was impacted by the quantity of nutrients (R^2 = 0.205, p-value = 0.142). However, this group remains less impacted by the variables studied in comparison with diatoms.

The investigation of the response of phytoplankton groups to each element separately based on Pearson correlation showed the important relationship between salinity and the density of diatoms (r =-0.610, p-value = 0.000). In contrast, pH has the least important influence (r = 0.001, p-value = 0.992).

Salinity is the variable that most influences diatom abundance in the entire study area. Our findings are coherent with the considerations of Frankovich *et al.*, (2006) and Wachnicka *et al.*, (2011) that highlighted the significant relationship between the distribution of diatoms and salinity. Nevertheless, Potapova (2011) emphasized in her paper that there is currently no evidence for a disjunction in species turnover along the salinity fluctuations, given that recent phylogenetic studies have revealed that a number of diatom clusters are capable of shifting their salinity affinities. Furthermore, the degree of the correlation varies amongst the environmental factors examined. Salinity covariation with other parameters can be confusing since it makes it challenging to determine the relative weight of each factor (Thornton *et al.*, 2002).

In the second position comes the SST, which directly affects diatom physiology by impacting assemblages' structure (Anderson, 2000; Berges *et al.*, 2002). Although the physiological significance of temperature at the cellular level is evident, such results are difficult to understand (Raven and Geider, 1988), due to the insufficient knowledge of the association between physiological impacts of temperature and ecological behaviours and the fact that the influence of temperature depends on other factors (DeNicola, 1996), as demonstrated in our correlation matrix (Table 4).

Moreover, diatom distribution is influenced by a wide range of variables, many of which are closely interrelated. A substantial amount of research suggests that temperature is less essential than other parameters such as nutrients, dissolved organic carbon, and pH, that control the diatoms' community structure (Korsman and Birks, 1996), despite the publication of Patrick (1971) that implies that temperature is an important component of diatom ecology.

Concerning the nutrients, the most important correlation is observed with ammonium (r = 0.587, p-value = 0.000), followed by nitrate (r = 0.542, p-value = 0.001), then comes phosphate (r = -0.207, p-value = 0.257), and lastly, silicate, with the least important influence (r = 0.054, p-value = 0.769). The strong dependence of diatoms on ammonium and nitrate could be explained by the relevance of these nutrients for phytoplankton growth (Holm and Armstrong, 1981; Sterner *et al.*, 1995).

Table 3. The fit of the regression model between phytoplankton density and physico-chemical parameters.

	Diatoms		Dinoflagellates	
Independent variable	**R2**	**p-value**	**R2**	**p-value**
SST, Salinity, pH, DO	0.566	0.000	0.371	0.000
Nitrate, Ammonium, Phosphate, Silicate	0.582	0.001	0.205	0.142

Table 4. The correlation between physicochemical and phytoplankton in the eastern Algerian coastal water.

		Diatoms	Dinoflagellates	Salinity	SST	pH	DO	Nitrate	Ammonium	Phosphate
Salinity	r	-0.610**	0.290							
	p-value	0.000	0.012							
SST	r	-0.350	0.350	0.733						
	p-value	0.002	0.002	0.000						
pH	r	0.001	-0.581**	-0.343	-0.674					
	p-value	0.992	0.000	0.003	0.000					
DO	r	-0.416	-0.480	0.073	-0.451	0.741				
	p-value	0.000	0.000	0.535	0.000	0.000				
Nitrate	r	0.542**	0.232	-0.306	-0.125	-0.330	-0.400			
	p-value	0.001	0.202	0.088	0.494	0.065	0.023			
Ammonium	r	0.587**	0.287	-0.306	-0.114	-0.372	-0.467	0.960		
	p-value	0.000	0.112	0.089	0.533	0.036	0.007	0.000		
Phosphate	r	-0.207	0.605**	0.468	0.718	-0.834	-0.634	0.050	0.103	
	p-value	0.257	0.000	0.007	0.000	0.000	0.000	0.785	0.574	
Silicate	r	0.054	0.690**	0.283	0.569	-0.868	-0.762	0.375	0.420	0.925
	p-value	0.769	0.000	0.117	0.001	0.000	0.000	0.035	0.017	0.000

* Correlation is significant (p-value<= 0.05).
** Correlation is significant (p-value<= 0.01).

Additionally, they are one of the main restricting factors for phytoplankton development, particularly in the Mediterranean and in the central basins of the large oceans (Berland *et al.*, 1978). This is consistent with the assumption of Malone *et al.* (1980) and Kokkinakis and Wheeler (1987) that large diatoms preferentially use nitrate for growth and also with other experiments that reveal that ammonium may be absorbed preferentially by small phytoplankton species (Koike *et al.*, 1986; Dortch and Postel, 1989). Moreover, this interaction with nutrients can be affected by environmental factors, as suggested by Lomas and Glibert (1999) regarding the limitation of nitrate uptake by diatoms caused by temperature.

On the other hand, those results could be justified by diatoms' ecological strategy, which is physiologically best adapted to high dynamic conditions and more effective in nutrient absorption. Furthermore, they can absorb nutrients and store them in their large vacuoles, depriving other groups while promoting their own growth (Falkowski *et al.*, 2003; Estrada and Vaqué, 2014).

Regarding dinoflagellates, their density is most impacted by pH ($r = -0.581$, p-value = 0.000), which is considered the main variable influencing their abundance according to Yoo (1991). In our case, the density of dinoflagellates is negatively correlated with pH. Similar results have been reported by Nasution *et al.*, (2021) in Jakarta Bay. In contrast, our findings are not coherent with the work of Hinga (1992), who reported a strong affinity of dinoflagellates for high pH levels. Nevertheless, those abiotic factors are complexly interconnected, and the pH requirements of phytoplankton differ from one trophic state to another (Moss, 1972).

Another strong link was observed between dinoflagellates and silicate concentration ($r = 0.690$, p-value = 0.000). This high correlation could be justified by their feeding pattern. A considerable number of the detected dinoflagellates in our samples are heterotrophs, such as *Protoperidium sp* and *Noctulica scintillians*, or mixotrophs, such as *Scrippsiella sp*, *Alexandrium sp*, some *Dinophysis sp, Gymnodinium sp*, and *Prorocentrium sp*. Those species are recognized by their grazing of diatoms that, in turn, contain silicate from the bio-silicification process (Flynn and Martin-Jézéquel, 2000; Gilpin *et al.*, 2004). Nonetheless, Zhang *et al.*, (2017) reported that some diatoms are hard for dinoflagellates to ingest.

The DO exhibited the second significant negative correlation ($r = -0.480$, p-value = 0.000). The nutritive character of this group might also be associated with this link. In fact, diatoms are responsible for the increase in the quantity of organic matter in the water that will be grazed by the dinoflagellates. The density of dinoflagellates will increase, which will subsequently lead to a reduction in the quantity of DO in the environment (Conley *et al.*, 1993; Spilling *et al.*, 2018).

4. CONCLUSION

The present investigation contributed to a better characterisation of the water quality in our study area where only a few surveys were conducted and published.

The study of the response of phytoplankton groups to the fluctuation of physico-chemical parameters highlights the important weight that water quality has on the density of diatoms and dinoflagellates

Annaba Gulf has to be actively monitored in order to prevent the potential damage to its marine ecosystem and find solutions to mitigate the anthropogenic pressures. Although no alarm can be triggered for the moment regarding El Kala's coast, this region requires regular assessment in order to maintain water quality and phytoplankton abundance in the best possible conditions as a part of sustainable aquatic resource management.

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CONFLICTS OF INTEREST

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