Diversity of Phytoplanktonic populations along the Algerian coastline

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ABSTRACT   Phytoplankton biodiversity is the basis of the functioning of the aquatic ecosystems. Also, understanding and evaluating the effects of the change in our environment and their impact on planktonic populations is an important element. In fact, this paper was to appreciate the diversity and composition of phytoplankton in relation to some physicochemical parameters. Water samples were collected along the Algerian coastline (Alboran Sea, the Algerian basin and the Middle area), during the period May–June 2013. The study area contained a diversified phytoplankton community (296 species), belonging to 138 genera. The algal groups were represented and classified as dinoflagellates (180 species), diatoms (103 species), cyanophyceae, coccolithophorids, euglenids, and chrysophytes (13 species). The spatial distribution of cell densities revealed a heterogeneous phytoplankton composition dominated by dinoflagellates, which represent 63% of the total abundance, followed by diatoms (35%). Quantitatively, we observed a highest cell density and diatoms abundance in most stations of the Alboran Sea decreasing towards the east (Algerian basin). The peak of dinoflagellates in June was represented by *Prorocentrum* and *Gymnodinium* genera.

INTRODUCTION

Phytoplankton is an important element in the marine ecosystem; this community is the basis of marine and freshwater food webs. Any change leads to variation of the trophic systems (Somoue et al., 2013), their composition fluctuations depending on hydrological conditions, such as light, temperature, salinity, pH, nutrients, and turbulence. Phytoplankton is known to exhibit rapid responses to changes in environmental conditions and is therefore commonly acknowledged as an excellent bioindicator of the impact of natural and seasonal changes in coastal ecosystems (Rimet & Bouchez, 2011). Changes in dominant base groups/species often propagate up the food chain, impacting on fish, marine mammals, and birds (Donnelly et al., 2007). Their susceptibility to environmental change is usually expressed by morphological and/or behavioral changes as well as by persistent or seasonal differences in abundance and distribution (Leterme et al., 2013). Qualitative and quantitative studies of phytoplankton allow us to recognize and describe the morphology of species,

and to analyse the dynamics of populations in time and space.

In recent years, "massive" growth of some phytoplanktonic species has been recorded along the Algerian coastline. These blooms are often linked to the eutrophication and anthropization of aquatic environments, and the nuisance that can be caused by hundreds of species may potentially present a risk to public health (David et al., 2012).

The information, concerning the composition of the phytoplankton community of the Algerian coast comes mainly from specific studies, referred to certain zones. While global data from across the Algerian coast are missing from the literature, nevertheless protection of marine ecosystems is a priority in the national development program of aquaculture and fishing activities in Algeria (Plan Aquapeche 2020, 2014).

The present study aims to explore the diversification and structure of phytoplankton populations observed on the Algerian coast during the period from May to June 2013 observed as a result of the analysis of the data collected during the prospecting Oceanographic campaign. It will reveal phytoplankton composition in three different zones of the Algerian coast, namely: the Alboran Sea, the Algerian basin and the Middle area.

The main hypothesis of this work is the influence of Atlantic waters on the structure of phytoplankton assemblages essentially, the diatom to dinoflagellate ratio.

This study will provide important information for future research, in relation to observed changes in the structure of the phytoplankton community due to the combined pressure of climate change and human impact in the Mediterranean.

MATERIAL AND METHODS

Study area

To gather information on different (qualitative and quantitative) aspects of the phytoplankton population along the Algerian coastline, the study was based on data collected during the assessment of demersal resources "ALDEM 2013" by CNRDPA (National Center for Research and Development Fisheries and Aquaculture).

The assessment of demersal resources "ALDEM 2013", which took place from May to June (2013) aboard the research vessel "Grine Belkacem", concerned the trawl bottoms of the Algerian coast at a depth from 20 to 800 m (Plateau and continental slope), Cape Segleb (36°56'45"N - 8°36'57"E), Algerian-Tunisian borders to Wadi Kiss (35°3'49"N - 2°12'50"W), Algerian-Moroccan borders. The Algerian coastline (Fig. 1) has been divided into three sectors: 1) the Alboran Sea: located in the western region of the Mediterranean Sea; its maximum width is 180 km at its eastern part, and a minimum of 14 km at the Strait of Gibraltar. The distance from the Strait of Gibraltar to the line between Cap de Gata (Almeria, Spain) and Cape Fegalo (Oran, Algeria) is 350 km. This imaginary line does not define a strict physical boundary, but an approximate delimitation of ecological processes and fluctuations in physical characteristics; 2) the Middle area: between the eastern limit of the Alboran Sea and the western boundary of the Algerian basin, goes from the wilaya of Tipasa to Tizi-Ouzou; 3) the Algerian basin: in the center of the western Mediterranean Sea, between the Algerian coasts and the Balearic Islands on the western side and the island of Sardinia on the east coast. Its width can reach about 280 km and extends over a length of about 500 km (Riandey et al., 2005).

In the present work, we named by "wilaya" a sampling site related to an administrative division (In English, Prefecture).

Sampling strategy and methods of phytoplankton analysis

The radials were selected in a grid pattern across the study region. During this campaign, in-situ hydrological measurements (temperature and salinity records) were carried out vertically by a CTD probe (Sea-Bird SBE 19 plus) and horizontally by a thermo-salinograph (Sea- Bird SBE 21) installed on board of the Research vessel. About 11 stations were chosen for the treatment and study of phytoplankton in this work, the position of these deferent study areas (Wilaya) is noted in Table I.

The phytoplankton dynamics study was divided into three distinct stages, i) sampling; ii) fixation, observation of the samples; and, finally, iii) the graphic and statistical processing of the data.

Sampling. Seawater for qualitative and quantitative study was carried out using 5 liter capacity

Niskin PVC bottles. The treatment protocol of this stand adopted in this study was based on the standards related to the Utermöhl method (Utermöhl, 1958). Phytoplankton were field-fixed immediately with Lugol's solution, conserved at low temperature (4° C) and in the dark to avoid photosynthesis. Finally, to achieve sedimentation of samples, each bottle was gently agitated for at least one minute, to homogenize its content. Utermöhl tanks were placed in sedimentation chambers (100 ml and 50 ml). The sedimentation time varied according to volume, from 24 to 72 hours (Ignatiades et al., 2009).

Observation and identification of species. Phytoplankton analysis was carried out in accordance with the recommendations of the Guide Standard for the Counting of Phytoplankton by Reverse Microscopy - Standard (Norme européenne NF EN 15204, 2006) of December 2006 - corresponding to Utermöhl method. A camera was very useful for validations of identifications and measurements.

Determination of phytoplankton species was carried out at the specific level or, in case of difficulty or uncertainty, at higher taxonomic level (genus, family or class) using several keys and/or catalogues (Meunier, 1915; Schiller, 1933-1937; Taylor, 1976; Meave-del Castillo, 2009; Meave-del Castillo et al., 2012). Then, phytoplankton species were updated according to main taxonomic database sites, like algaebase.com, and World Register of Marine Species (WoRMS, 2019).

Data analysis. In this section, we were also interested in the variations of cell density of different species and genera in each station.

Diversity and structure of phytoplanktonic populations

Three main indices have been used, namely Shannon-Wiener, Equitability and Simpson.
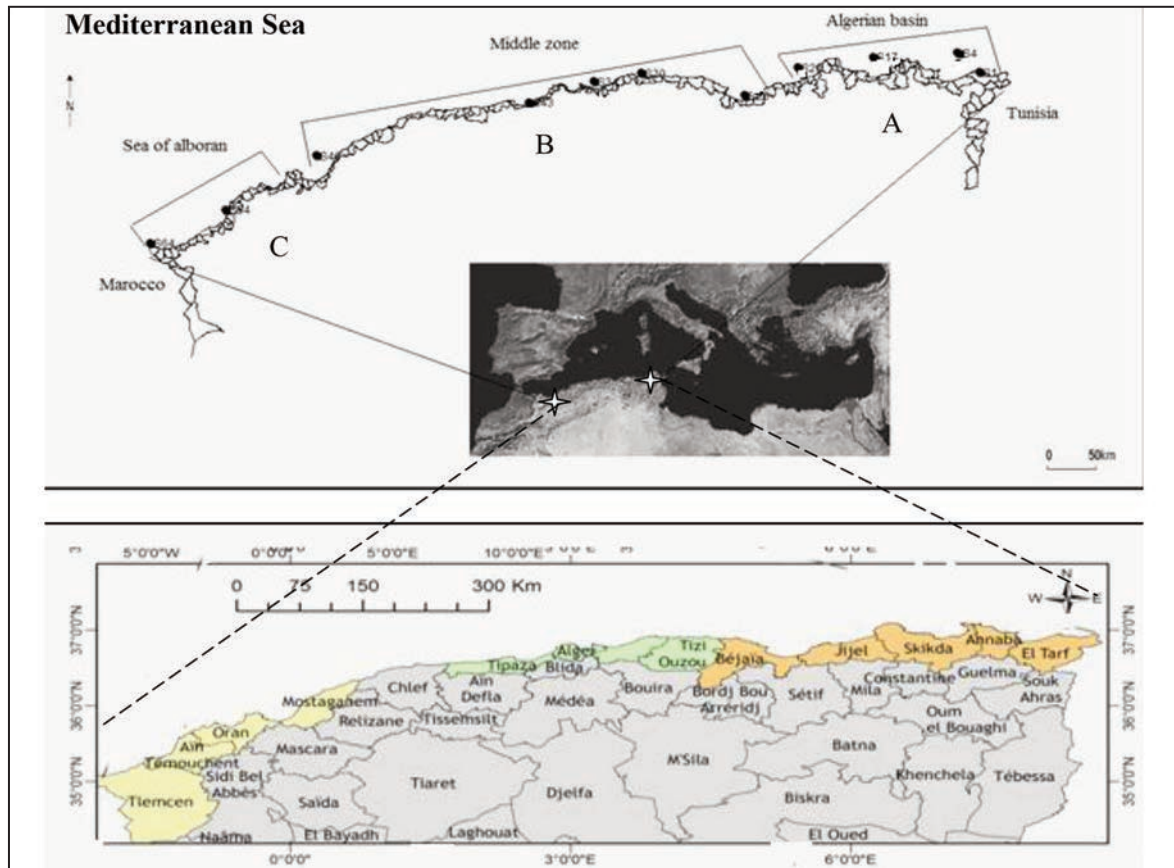

Figure 1. Localization of the study areas (site/wilaya) and subdivision of the Algerian coast.
A: Algerian basin; B: Middle area; C: Alboran Sea.

Zones	Wilaya	Stations	Longitude	Latitude	Distance to coast /m
Algerian basin	El Taref	S1	36° 55' 53.4606"	8° 18' 10.8"	1700
	Annaba	S11	37° 8' 43.0182"	8° 1' 14.4588"	28000
	Skikda	S12	37° 1' 18.12"	7° 14' 6.7806"	1900
	Jijel	S24	36° 54' 44.9388"	6° 3' 10.6806"	5100
Middle area	Bejaia	S26	36° 41' 18.3588"	5° 19' 50.6388"	4800
	Tizi-Ouzou	S30	36° 55' 21.7626"	4° 1' 25.3194"	2000
	Boumerdes	S34	36° 50' 14.5212"	3° 25' 29.8194"	7000
	Tipasa	S43	36° 36' 59.1006"	2° 35' 56.6406"	800
	Mostaganem	S46	36° 3' 7.2606"	-0° 5' 56.8788"	19000
Alboran Sea	Ain-Temouchent	S54	35° 29' 2.8782"	-1° 14' 25.9188"	1200
	Tlemcen	S64	35° 7' 44.4606"	-1° 11' 39.0114"	4000

Table 1. Geographical coordinates for each sampled site (wilaya) by region and its distance to the coast.

The Shannon Index indicates the number of species in a community in relation with stability of the environment; When the index is high, it is explained by a stable environment. This index is given by the following formula:

$$H' = ISh = -\sum P_i.\log P_i, \quad P_i = n_i/N$$

P_i: specific abundance; N: total number of phytoplankton population considered;
n_i: number of individuals of the species "i".

This index varies in a range of $-\log S$ and $+\log S$ (S specific richness); The unit of information is the Bits.ind-1.

Equitability index: since diversity depends on both relative frequencies of the species and number of species that can vary widely from one stand to another,it is defined by the formula:

$$E(R) = ISh (bits) / \log_2 S (bits)$$

Equitability Index varies between "0" and "1"; it tends towards "0" when most of the cell density is concentrated on one species; it tends to "1" when all species have nearly the same abundance.

Simpson Diversity index (L): this index meas-ures the probability that two individuals randomly selected belong to the same species for each given sample. It is given by the formula:

$$L = \sum e [n_i(n_i-1)] / [N(N-1)]$$

n_i=number of individuals in species i, N=total number of individuals. The index is inversely proportional to diversity. When diversity is maximal its value is 0; when diversity is minimal the value tends to 1.

Diatoms/Dinoflagellates index: "Dia/Dino" index reflects the dominance patterns in the phytoplankton composition (Abundance or Biomass) (Helcom, 2014, 2016). The Dia/Dino index is defined by the following formula (Wasmund et al., 2017).

$$Dia/Dino\ index = Ab_{Dia} / (Ab_{Dia} + Ab_{Dino})$$

Ab_{Dia} = Diatoms abundance; Ab_{Dino} = Dinoflagellates abundance.

Seasonal averages of the biomass of planktonic diatoms (BM_{Dia}) have to be divided by the combined biomass or abundance (Ab_{Dia} or BM_{Dia}) of planktonic diatoms and autotrophic + mixotrophic dinofla-

gellates (Ab_{Dino} or BM_{Dino}). This leads to a simple absolute measure with values ranging from 0 to 1. If diatoms dominate, the value of the Dia/Dino index is >0.5; if autotrophic + mixotrophic dinoflagellates are dominant, the value of the index is <0.5.

Principal component analysis (PCA): is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables. This analysis was based on correlation matrices applied to the parameters used in the study.

RESULTS

The inventory of phytoplankton species gives a total of 296 species distributed over the Algerian coast, grouped in 138 genera. In general, dinoflagellates are dominant with 180 species, followed by diatoms with 103 species. Another less frequent group was considered, it gathers the classes of Cyanobacteria, Euglenophyceae and Chlorophyceae (Figs. 2, 3). On the spatial level, the number of diatom species is higher in the Alboran Sea, inversely to the Algerian basin where dinoflagellates species are dominant. Equilibrium between diatoms and dinoflagellates was noted in the middle area. The specific richness "S" along the Algerian coastline is 296 species. It varies from one station to another and from one area (Wilaya) to another with an average value of 45 species. The lowest values were recorded in the Alboran Sea, precisely in both wilaya of Ain-Temouchent and Tlemcen with respective
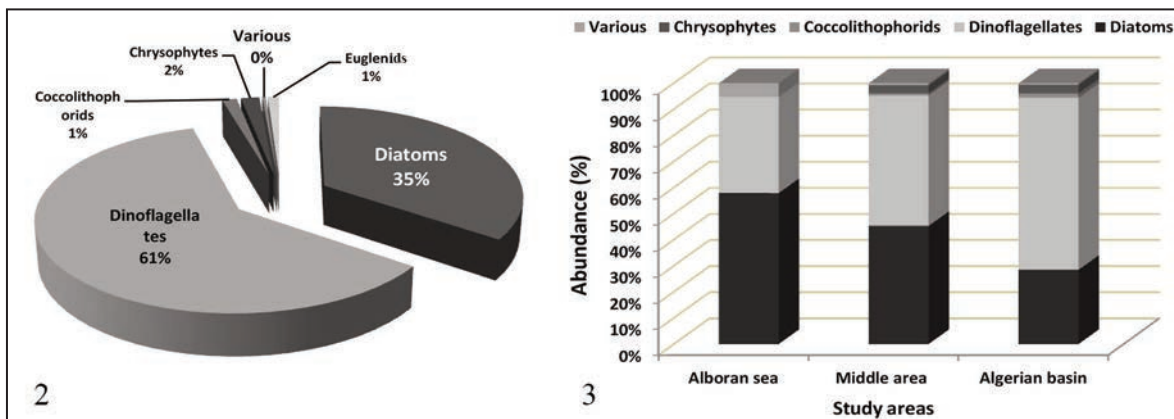
Figures 2, 3. Specific richness "S" of the phytoplankton groups recorded in the study areas of the Algerian coastline. Fig. 2: specific richness of the phytoplankton groups. Fig. 3: spatial variation of the specific richness.
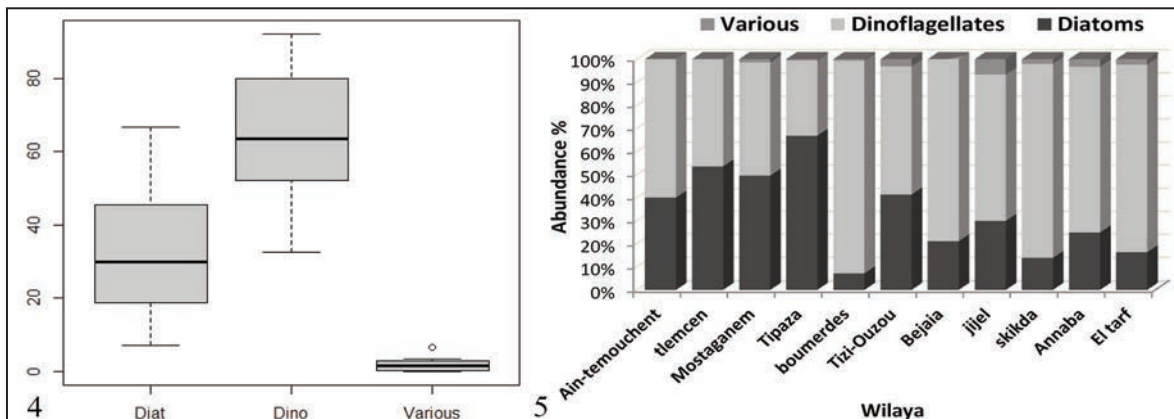
Figures 4, 5. Abundance of phytoplankton groups along the Algerian coastline. Fig. 4: abundance of phytoplanktonic groups presented in box and whiskers plot. Fig. 5: spatial variation of phytoplanktonic groups abundance.

values of 24 and 13 species. The most represented taxa in this zone are *Navicula* sp. and *Gymnodiuim* sp. Indeed, we recorded the highest specific richness values in the Algerian basin at the areas of Skikda and El-Tarf with respective values of S=108 and S=74 species. The observations recorded during our study show that the most important relative frequencies are due to the genera *Prorocentrum* and *Gymnodinium* in the Algerian basin. The Middle area specific richness varied between 28 and 47 species and the most important taxa observed were: *Prorocentrum mecans*, *Peridinium* sp., in Tizi-Ouzou and *Chaetoceros* sp., in Tipaza.

The results detailed in figures 4, 5 show the frequency and abundance variation of dominant phytoplanktonic groups at the target wilaya of three regions (Alboran Sea, Middle area and Algerian basin). For frequency (F), dinoflagellates and diatoms are the most frequent and constant phytoplankton groups (F>50%) compared to other taxonomic groups. The remainder of the phytoplankton composition indicates that the coccolithophorids are the rarest group (F<25%). This explains the fact that they are less competitive than the other microalgae. On the side of the Alboran sea we have an important presence of the diatoms with F>50% in both stations (Tlemcen, Ain-Temouchent). On the other hand, dinoflagellates constituted the constant phytoplankton groups in the different area of Algerian basin (Jijel, Skikda, Annaba, and El-Tarf). We noted, in the Middle area, a large frequency of diatoms in Tipaza wilaya, which
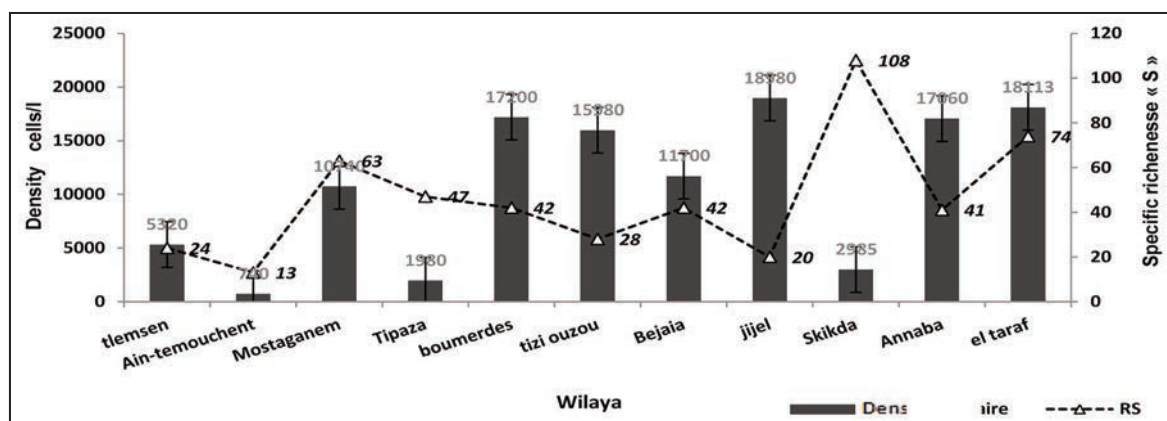
Figure 6. Spatial variation of the phytoplankton cell density in the study areas of the Algerian coastline (Average values).

Zone/ Parameters	Alboran Sea	Middle area	Algerian basin
Chl *a* µg/L	0.29	0.26	0.27
T°C	15.07	15.1	15.2
Salinity PSU	36.57	36.46	36.27
NO3 µmol/L	0.29	0.28	0.19
NO2 µmol/L	0.06	0.07	0.05
PO4 µmol/L	0.03	0.2	0.02
SIO2 µmol/L	0.38	0.23	0.33

Figure 7. Nutrients of samples collected from the Algerian coastline and spatial variations of environmental parameters.

is the closest to the eastern limit of the Alboran Sea. Whereas, on the other side, Tizi-Ouzou shows a dominance of dinoflagellates.

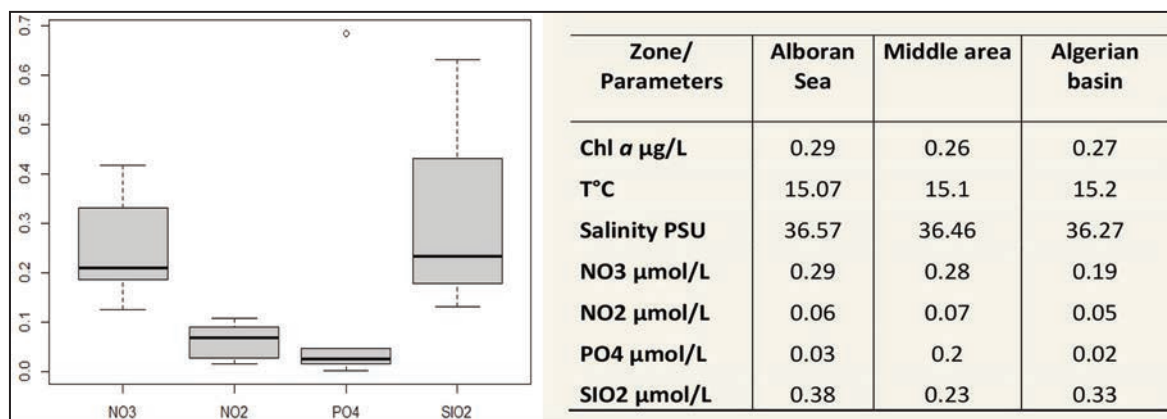The observations recorded during our study, show that the most important relative frequencies are those of the genera *Prorocentrum* and *Gymnodinium* (F=58% and F=30%, respectively). In Diatoms, we recorded a relatively high value of the genera *Coscinodiscus*, *Chaetoceros*, *Melosira* and *Thalassiosira*, while the other genera of diatoms and dinoflagellates are marked by low frequencies (Fr<25%).

The preceding statement is also confirmed by the relative abundance values (Ab %) of diatoms which largely exceed the average value of 50% in the majority of stations of the Alboran Sea and slightly exceeds 35% in the wilaya of the Middle area. We have a phytoplankton abundance that is above average value in the different stations of the Algerian basin; indeed dinoflagellates contribute significantly to quantitative richness in this region with proportions exceeding 70%.

Figure 6 illustrates the distribution of total cell densities found in each region (Alboran Sea, Middle area and Algerian basin). We noted that low cell density was recorded at the wilayas of Ain-Temouchent, Tipaza and Skikda; while in the wilayas of Jijel, Annaba, Tizi-Ouzou and Boumerdes, we have a high cell density. Analysis of the diatom and dinoflagellate densities in phytoplankton populations shows that in the:

Alboran Sea: diatoms varied from 240 to 10200 cells/L and dinoflagellates from 360 to 10100 cells/L. The recorded observations show the lowest total cell density recorded along the Algerian coastline (740 cells /L) in Ain-Temouchent.

Algerian basin: the recorded observations show a total cell density ranging from 2985 cells/L (Skikda) to 18980 cells/L (Jijel) with large dominance of dinoflagellate groups.

Middle area: Dinoflagellates contribute significantly to phytoplankton production in this region. Wilaya of Boumerdes showed the highest phytoplankton total cell density in this sector; on the other hand, wilaya of Tipaza recorded the lowest concentration.

In Some Wilaya stations we noted a high phytoplanktonic concentration, corresponding to a low specific richness, which means that the population of these areas is dominated by one or two species (*Gymnodinium* sp.; *Prorocentrum* sp. in case of dinoflagellates; and *Melosira* sp. and *Chaetoceros* sp. in case of Diatoms).

Zone	Station (Wilaya)	Diatoms	Dinoflagellates	Dominant species	Diat/Dino index
Alboran Sea	Tlemcen	2720	2360	*Gymnodinium* sp	0.54
	Ain-Temouchent	240	360	*Navicula* sp	0.40
	Mostaganem	10200	10100	*Melosira* sp/ *Gymnodinium* sp	0.51
Middle area	Tipaza	2500	1220	*Chaetoceros* sp	0.67
	Boumerdes	6980	9360	*Gymnodinium* sp	0.43
	Tizi-Ouzou	1140	14600	*Prorocentrum micans*	0.07
	Bejaia	4840	18080	*Prorocentrum* sp	0.21
Algerian basin	Jijel	5680	12040	*Gymnodinium* sp	0.32
	Skikda	2700	16320	*Gymnodinium* sp	0.14
	Annaba	7700	22180	*Gymnodinium* sp	0.26
	El Tarf	8620	42900	*Prorocentrum* sp	0.17

Table 2. Spatial variation of Dia/Dina index in the study areas.

The Dia/Dino index shows only abundance data on diatoms and dinoflagellates (Table 2). It reflects the dominance patterns in the phytoplankton, the average value being around 0.5. As reported above, diatom dominance, (Dia/Dino index>0.5), was observed in two wilayas of the Alboran Sea area (Tlemcen; Mostaganem). In the wilayas of the Middle area the values of this index varied between 0.07 (Tizi-ouzou) and 0.67 (Tipaza). The minimum average value of this index was recorded in the eastern region confirming the dominance of the dinoflagellates, especially in Skikda.

The Shannon H' Index ranges from 0.86 to 1.9 bit/ind along the Algerian coastline (Table 3). These values are very close to the values of Hmax (log S), which varied between 1.3 and 2.02 bit /ind. The lowest value of this index (H'=0.86 bit /ind) was recorded in the wilaya of Tizi-Ouzou (Middle area) which moves away from the optimal value of Hmax. The wilaya of Skikda (Alboran Sea) was the most diversified area, as it presents the values closest to the optimal value (H'=1.85 bit /ind). The values of the equitability index (E) of each wilaya oscillate between 0.56 and 0.92. The minimum (tending to 0) is related to the wilayas of El Taref and Tizi-Ouzou, which means a specific dominance of a particular species or two, thus displaying an irregular spatial distribution. Actually, *Prorocentrum* sp. and *Gymnodinium* sp. resulted to dominate with 58% and 29% of relative abundance, respectively.

In the wilaya of Tipaza the maximum value of the index tends to "1", thus giving the image of a most diversified population with an equi-distribution. The spatial variation of the Equitability index is in decreasing order among the three studied regions, from the Aboran Sea (0.84) towards the Algerian basin (0.75). Conversely, the Simpson index shows average values increasing from the Alboran Sea (0.10) towards the Algerian basin (0.13).

The results of the spatial variations of temperature (°C), Chlorophyll a (Chla, in μg/L) value, Salinity (P.S.U), and the nutrients PO_4^{3-}, NO_3^{2-}, NO_2^{2-} and SiO_2 (μmol/L) of seawater samples collected from the Algerian coastline during May-June 2013 are shown in figure 7.

The normal thermal cycle was clear in this study period, and it was typical in all sector, ranging from a minimum of 14.6 °C at Ain-Temouchent (Alboran Sea) and a maximum of 15.9 °C at Skikda (Algerian basin), with a spatial mean value of 15.13 °C in the Algerian coastline.

The highest value of Chla, was recorded during this period at the Alboran Sea region precisely at Tlemcen (0.34 μmol/L) and the lowest at Skikda (0.23 μmol/L). Whereas, seawater salinity (P.S.U.) varied with small spatial differences with an average value of 36.42.

As far as nutrients are concerned, the reactive phosphate (PO_4^{3-}) was very low during spring and summer in all stations, whereas the maximum value was recorded at the eastern region (Algerian basin, 0.02 μmol/L). The dissolved nitrate (NO_3^{2-}) in the Algerian coast ranged between a maximum value of 0.41 μmol/L at Ain-Temouchent (Alboran Sea), and a minimum of 0.12 μmol/L in Jijel (Algerian basin). This variation is very limited for nitrite (NO_2^{2-}) with a spatial mean value of 0.06 μmol/L at all stations of the Algerian coast. In this study, the most important values of Silicium (SiO_2) concentration were related to the stations of Alboran Sea.

The principal component analysis (PCA) and the projection of the stations and hydrological variables in the plane of the I-II axes are illustrated in figure 6. This analysis was based on correlation matrices applied to total phytoplankton counts, phytoplankton classes, specific richness, and the physicochemical parameters. The first two axes I and II hold more than 83% of the total inertia. On this plane (I and II), some environmental variables (T° (C); S (P.S.U.), Chla; DC and PO_4; NO_3) are more explanatory of the phytoplankton abundances.

Several groups of wilayas have been identified according to their distance from the coast, physicochemical characteristics and phytoplanktonic abundance (Fig. 8).

Group I corresponds to wilayas of Alboran Sea and Middle area (Tlemcen; Ain-Temouchent, Tizi-ouzou and Tipaza). These wilayas are associated with a dominance of diatoms and characterized by high concentration of NO_3^{2-} and PO_4^{3-}.

Group II. Most of wilayas of the Algerian basin (Bejaia; El-Tarf; Annaba). The environmental variables are related to important phytoplankton abundances and, particularly, to those of dinoflagellates. The distance to the coast (DC) was the variable which gave a large contribution to the detachment of this 2nd group.

Groups III and IV are associated with a single wilaya for each group (Jijel; Skikda). Group III is linked to Jijel characterized by dominance of other

Zone	H'	J'	L	wilaya	H'	Log S	J'	L
Alboran Sea	1.18	0.84	0.10	Tlemcen	1.22	1.38	0.88	0.09
				Ain-temouchent	1.02	1.11	0.92	0.11
				Mostaganem	1.29	1.80	0.72	0.10
Middle area	1.21	0.74	0.12	Tipasa	1.53	1.67	0.92	0.05
				Boumerdes	1.40	1.62	0.86	0.06
				Tizi-Ouzou	0.86	1.45	0.60	0.23
Algerian basin	1.29	0.75	0.13	Bejaia	1.05	1.62	0.65	0.17
				Jijel	0.94	1.30	0.72	0.18
				Skikda	1.85	2.03	0.92	0.02
				Annaba	1.28	1.61	0.79	0.08
				El-Tarf	1.07	1.87	0.57	0.25

Table 3. Spatial variation of Shannon (H', H' max), Simpson (L) and Equitability "J" index per Wilaya.

phytoplanktonic taxa (Various); and group IV is linked to Skikda characterized by a high specific richness "S".

CONCLUSIONS

This study has shown remarkable phytoplankton richness with the presence of two main groups (diatoms and dinoflagellates). The qualitative study of phytoplankton based on samples collected by the CNRDPA during the period May-June 2013 by the GRINE BELKACEM vessel indicates the presence of 296 species identified in 11 stations distributed along the Algerian coast. Dinoflagellates and diatoms predominate in all stations with 103 and 180 species, respectively, along with the presence of other groups (in very low percentages) such as Coccolithophoridae and Euglenids. Our results are in line with those found in the Mediterranean by Ignatiades et al. (2009) who analyzed samples collected at nine stations (at an interval of 220 km minimum to a maximum of 558 km), and identified 216 species including 48 diatoms (22%), 112 dinoflagellates (52%) and 56 coccolithophores (25%). Besides, Moroccan Atlantic coasts presented, during the spring period 2013, a structure of the phytoplankton community composed of the same three phytoplankton groups dominated by diatoms with 47 taxa, followed by dinoflagellates with 34 taxa (Gallouli et al., 2014). The large number of phytoplankton species in common with those of the different Mediterranean ecosystems shows the wide geographical distribution of this microscopic flora and its strong relationship with the circulation of water bodies in the region.

Quantitatively, we observed a highest cell density and diatoms abundance in most stations of the Alboran Sea and decreases towards the east, where diatoms are replaced by dinoflagellates. This group of phytoplankton exhibited a remarkable quantitative richness with the dominance of main genera including *Prorocentrum*, *Gymnodinium* which were already reported by Gaumer (1981) in Algerian waters. This area identified as Alboran Sea is closer to the Strait of Gibraltar and is under the influence of Modified Atlantic Water (MAW), which arrives from the Atlantic along the Spanish coast in the Alboran Sea and then joins, via the Almeria-Oran jet, the North-African coast. It runs alongside the Straits of Sicily by the Algerian current. The dominance of diatoms on the coast of the Alboran sea shows that these regions are more prone to the influence of waters coming from the Atlantic at the surface, whose physico-chemical quality is different from that found in the Algerian basin where a dominance of dinoflagellates was observed. The disappearance of diatoms and their replacement by dinoflagellates was discussed in several studies (Wasmund et al., 1998, 2013, 2016; Alheit et al., 2005). According to some authors, this decline in the Dia/Dino index indicates a worsening of the en-

vironmental conditions. According to Lassus et al. (1982), dinoflagellates can develop with low concentrations of nutrients and salts, usually necessary for the development of phytoplankton.

The works carried out on the Algerian coasts by various authors (including Kruger, 1950; Lecal, 1952; Bernard & Bertoldo, 1958; Bucalossi, 1960; Lalami-Taleb, 1971; Illoul, 1991) have shown that, despite the large availability of nutrient reserves, Mediterranean waters in general and Algerian waters in particular remain relatively poor in phytoplankton. The concentration of chlorophyll a is directly related to the phytoplankton biomass, which depends on the supply of nutrients and, therefore, is a parameter commonly used in many works as indicator of the trophic state of the environment (Bricker et al., 1999). Ignatiades (2005) established the trophic status of the Aegean coastal waters according to chlorophyll a concentrations. When the concentration is less than 0.5 mg.m-3, the medium is oligotrophic. This allows us to consider the waters of the Algerian basin as olig-

otrophic. On the other hand, temperature and salinity are factors that influence the phytoplanktonic distribution. Wasmund et al. (1998, 2013, 2016) noted that the magnitude of the diatom bloom is controlled by the minimum winter temperature. This conclusion is supported by Klais et al. (2013) who report a large proportion of dinoflagellates in the vicinity of Algiers in Mediterranean waters (Salinity > 37 ppm), associated with strong surface illumination and the presence of small diatoms in winter and their blossoming in early spring. Bernard & Bertoldo (1958) in the same sector but in Atlantic-type waters, in the Alboran Sea area, reported, on the contrary, the preponderance of diatoms. Bucalossi (1960), in waters of the same type, found an influx of dinoflagellates when salinity increases.

Diversity can influence the primary production and abundance of phytoplankton; some authors have studied the relationship between productivity and biodiversity of ecosystems, but the form of the relationship is variously reported as a negative lin-

	F1	F2	F3
Eigen values	3.37	2.33	1.42
%Variance totale	67.92	32.08	16.78
% Cumulative	48.64	83.22	100

Abbreviation of wilayas (Sampled sites): skik: Skikda; **Bejai:** Bejaia; **Tizi**; Tizi-ouzou; **Ain-tem:** Ain temouchent; **El tarf:** El taref; **Mosta:** Mostaghanem; **tlem:** Tlemcen; **Tipa:** Tipaza; **Anna:** Annaba; **Boum:** Boumerdes.

The analysis was performed using the average value of data.
S: salinity; **TC**: Temperature; **PO₄**: phosphate concentration; **NO₃**: nitrate concentration; **NO₂**: Nitrite concentration, **Chl*a***: chlorophyll a; **SIO₂**: Silicium ; **DC**: Distance to coast, **Diat**: Diatoms density; **Dino**: Dinoflagellates density; **Divers**: Various groups density; **Density**: Total phytoplanktonic density.
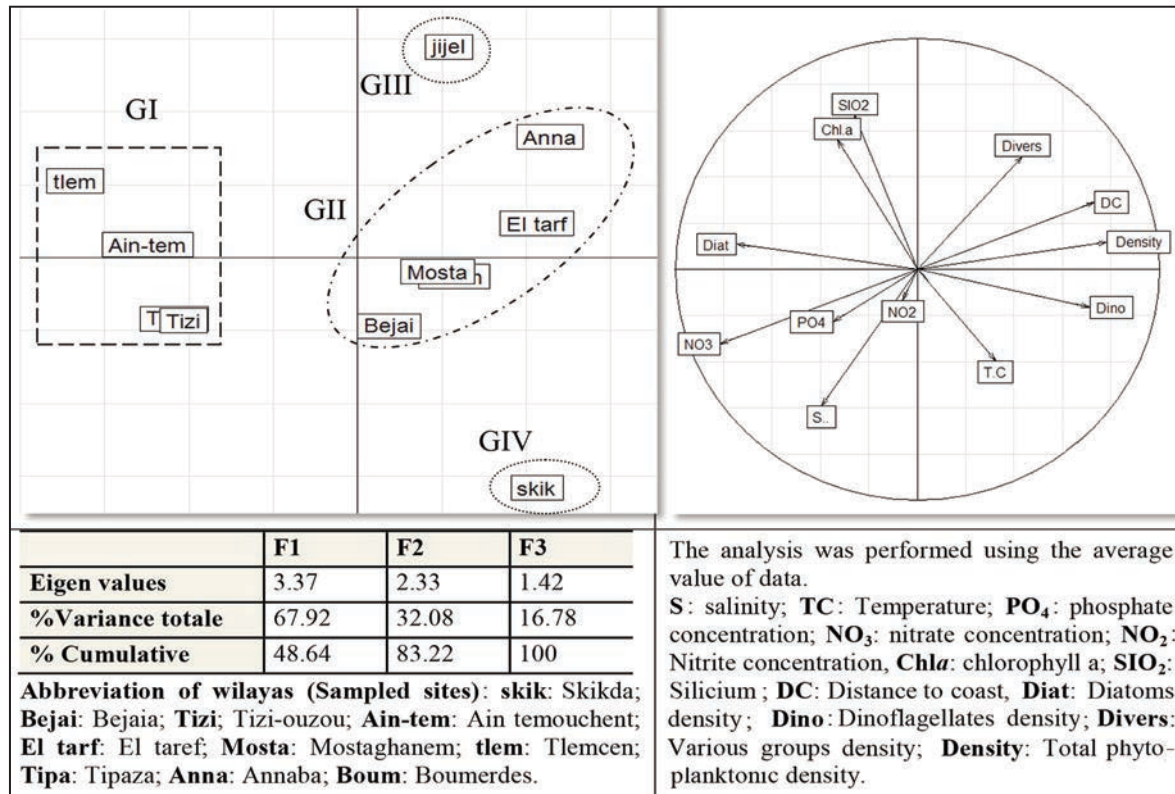
Figure 8. The principal component analysis (PCA) and the projection of the stations
and hydrological variables in the plane of the I-II axes.

ear relationship, a positive linear relationship, a unimodal relationship or, still, no relation (Chase & Leibold, 2002; Jouenne et al., 2007; Claquin et al., 2010).

There is a negative relationship between specific richness and cell density because high production is associated with low biodiversity due to the dominance of one or a few species that exclude other taxa from the ecosystem. In the wilaya of Skikda and Tipasa a very low cell density was noted, but at the same time a good specific richness. While in Jijel, Annaba, Tizi-Ouzou and Boumerdes we have a large cell density but a low specific richness, which means that the populations in these regions are dominated by one or two species. The complexity and variability of environmental factors may explain the heterogeneity of the diversity-productivity relationship, as well as the different methodologies used to describe the degree of diversity (Napoléon et al., 2014). Alternatively, sampling strategy is another factor that may cause this fluctuation and an unbalanced distribution.

The combined action of climate change and the impact of anthropogenic activities in the Mediterranean suggest changes in the perspectives for the structure and diversity of phytoplankton populations; this study provides useful background information and a framework for future research.

Finally, this work contributes to understanding the functioning of a coastal ecosystem along with the composition of phytoplankton populations, especially according to the spatial variation. Indeed, it will be more interesting, as a prospect, to continue this study according to the different seasons thus ensuring the follow-up of phytoplankton successions throughout the year.

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