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RESEARCH ARTICLE

Dynamics of phytoplankton groups in estuarine area of Oued River (Mazafran, Algeria)

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Estuaries, being the contact areas between fresh and sea waters are very unstable ecosystems, and their hydrological and physicochemical parameters are extremely variable. Phytoplankton is a very important part of ecosystem and is extremely susceptible to the environmental variations. In our research we assessed a distribution of phytoplankton groups in estuarine zone (the mouth of Oued Mazafran) and along the adjacent coast as a function of time and space. Hydrological and phytoplankton samples were taken in four stations, which were located in Oued Mazafran, during 17.01-18.04.2018. The results of salinity, temperature, abundance, diatoms, diatom index and specific richness allow us to suggest that at Stations 1 and 2 (Colonel Abbas beach and river mouth) we dealt with the river transition ecosystems with a high salinity variations, which were from 16.32 to 30.33 at Station 2 and from 30.08 to 36.86 at Station 1. We noted here the presence of euryhaline species. At Station 3 (a freshwater environment, Mazafran Oued) the salinity was 0.8 with a temperature range in 12-18 °C and low oxygen concentration of 1.33 mg/dm^3. Here we registered phytoplankton freshwater species. At Stations 4 (seawater ecosystem with little variation, shellfish center) the species diversitsy was 343 species, while 68.8 percent were the diatoms. At Station 3 (Oued Mazafran) we registered the highest cell density of 11370 cell/dm^3.
Keywords: estuarine area; salinity; temperature; euryhaline species

Introduction

We have important interactions of ecological elements in estuaries; these are very fragile areas where we can see major variations in biodiversity that represent the environmental instability (Costanza et al., 1997). Phytoplankton successions and assemblages rely on the river or marine contributions that constitute an enrichment of that specific area (estuary). We have quantities of materials in this region that can be mobilized in a very short time span (Delphine et al., 2010).
Strong variations in salinity, shallow depths high turbidity, diversity habitat richness and food availability are factors which make estuaries important for many species of fish (Blaber and Blaber 1980; Elliott & Dewailly 1995; Beck et al., 2001; Peterson, 2003). Phytoplankton is the primary producer's foundation for aquatic ecosystems; it is highly susceptible to environmental disturbances such as nutrient inputs changes in temperature, salinity and turbidity (Smayda, 1998). These variations can be seen in the quantitative and qualitative changes in phytoplankton communities which disturb the entire food chain (Stockner, 1986). In fact, the phytoplankton distribution is heterogeneous. its dynamics are very strong reacting to variations in the biotic (predation) and abiotic (hydrology, water and salinity).
We are particularly interested in characterizing the estuarine zones according to the phytoplankton population assemblages.
Our goal was to explore the diversity and structure of phytoplankton populations observed in estuarine region of Mazafran Oued in winter and early spring of 2018 for phytoplanktonic assemblages and estimation of the ecological conditions and their evolution over time in estuarine zones.

Materials and Methods

The study area is located between the town of Bou-Ismail and Mazafran Oued in the center of the Algerian coast 50 km west of Algiers in the Tipasa region in the Bay of Bou-Ismail. The four sampled stations were located as following: stations 1 and 2 at Colonel Abbas beach station 3 in Mazafran Oued and station 4 at the shellfish experimental Around 10 km away (this is the furthest point from Mazafran Oued (Fig. 1).
Sampling strategy and Frequency of sampling
Sampling was performed during 17.01-18.04.2018 (Table 1). We did not sample in February because we were having difficulty in accessing the stations.

- Station 1: Seawater at the beach colonel Abbes.
- Station 2: Brackish water (point between fresh water (Oued) and seawater).
- Station 3: Fresh water (Oued Mazafran).
- Station 4: Seawater at the Experimental Shellfish Research center (Bou-Ismail).

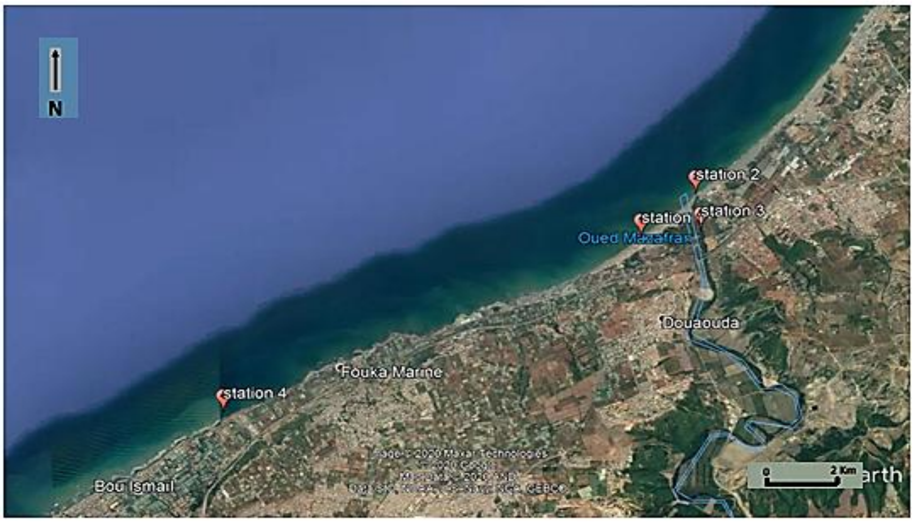

Fig. 1. Sampling stations location (from Google Earth).

Table 1. Samplimng schedule.

Dates	17/01/18	24/01/18	25/02/18	11/03/18	01/04/18	18/04/18
Station 1	X	x	x	x	x	x
Station 2	X	x	x	x	x	x
Station 3	X			x	x	x
Station 4	x	x	X	x	x	x

Sampling method

We used a bottle (VAN DORN type) with capacity of 2.5 liters for the phytoplankton sampling. Environmental parameters water temperature (°C); salinity; dissolved oxygen (mg.dm^{-3} and percent); pH. calculated using a form 556MPS (YSI model) multiparameter. Before each field trip the measuring device is calibrated in the laboratory with calibration solutions. Phytoplankton samples (250 mL) were fixed with lugol solution, concentrated to 100 mL by sedimentation and examined under an inverted (OPTIKA) micro-scope according to Utermohl (1958) for quantitative and qualitative analysis.

The phytoplankton analysis was performed by inverted microscopy-standard according to the guidelines of the guidance manual for enumerating phytoplankton (NF EN 12204. 2006). We have made the specific identification of phytoplankton with the appropriate books and manuals.

Diversity indices and statistical analysis

To get an overall idea of the spatio-temporal organization of the phytoplankton population in the region we determined the species richness (S), the Shannon index (H', the index of regularity or equitability (j) is calculated using the following formula:

$$j=H'/\log_2(S);$$

Where H' - Shannon index, S - specific richness of the sample.

Diatoms/Dinoflagellates index: "Diat/Dino" index which reflects the dominance models in the composition of phytoplankton (Abondance or Biomass) (Helcom, 2014, 2016). The Dia/Dino index is defined by the following formula (Wasmund, 2017).

$$\text{Dia/Dino index}=\text{Ab Dia}/(\text{Ab Dia Ab Dino})$$

Where Ab Dia=Abundance of diatoms; Ab Dino=Density of dinoflagellates

Seasonal averages of planktonic diatom biomass (BMDia) should be divided by the biomass or combined abundance (AbDia or BMDia) of planktonic diatoms and mixotrophic autotrophic dinoflagellates (AbDino or BMDino). This leads to a simple absolute measure with values ranging from 0 to 1. If the diatoms dominate, the value of the Dia/Dino index is > 0.5; if the autotrophic dinoflagellates mixotrophe dominate, the value of the index is <0.5.

Results

General condition of the environment

In order to be able to classify the various ecosystems in the study area, we chose to compare the essential environmental parameters: temperature, salinity, dissolved oxygen and pH.

Analysis of temperature fluctuations shows a gradual increase from 14 to 16 °C over the entire study region, which can be viewed as a natural seasonal change. We recorded the lowest temperature 12 °C at station 4 during January , while in April and March we recorded the most significant temperature at the same station: 17.44 and 18 °C. The temperature in the other stations stays uniform. This observation already enables us to classify station 3 (Mazafran Oued) by temperature compared to the other stations. In fact, the variations were higher, with an average of 16.08±2.76 °C and range from 12 to 18 °C. This can be explainaed by the shallow water depth of the River Oued that does not exceed 2 meters and thus becoming more prone to the impact of weather. While the range for the other stations wa 15.7 to 15.9 °C with a standard deviation of 0.5 to 0.39 (Table 2).

Table 2. Temperature variation (°C) in function of time per station.

Date	17.01	11.03	01.04	18.04	Average	SD
Station 1	15.2	16.08	15.58	16	15.72	0.41
Station 2	14.9	16.07	16.08	16.08	15.78	0.59
Station 3	12	17.44	16.88	18	16.08	2.76
Station 4	15.55	16	16.25	16.07	15.96	0.36

The salinity values increased from station 2 (Oued mouth), where we recorded an average value of 26.38 to station 4 (experimental shellfish center), the furthest from the estuarine zone, where we recorded an average value of 36.22.
We registered that at station 2 the salinity fluctuation ranged from 16.32 to 35.33 with a standard deviation of 9.89. We recorded an average of salinity of 34.39 at station 1 with a standard deviation of 2.97. Station 4 had the average salinity of 36.22 with a standard deviation of 1.38 (Table 3).

Table 3. Salinity temporal variations at the stations.

Date	17.01	11.03	01.04	18.04	Average	SD
Station 1	35.1	36.86	35.51	30.08	34.39	2.97
Station 2	34.4	35.33	19.45	16.32	26.38	9.89
Station 3	1.10	0.72	0.75	0.70	0.82	0.19
Station 4	35.3	36.8	37.88	34.9	36.22	1.38

The average concentrations of dissolved oxygen were very low, it was 1.33 ± 0.54 mg dm^{-3} at Station 3 (Mazafran Oued). If the concentration of dissolved oxygen fall below 2 mg dm^{-3}, the waters are considered to be hypoxic and most living species could be threatened with this (Rabalais et al., 2010). We had an average of 3.93±0.29 and 4.05±1.32 mg dm^{-3} for stations 2 and 1 (Oued mouth and Colonel Abbas beach), these were low values compared to the standard seawater values. The minimum oxygen content for coastal and estuarine waters is about of 5.0 mg dm^{-3} (Beaupoil, 1997) (Fig. 2).
We got an average of 7.8 ± 0.29 mg dm^{-3} at station 4 (shellfish centre) Values for seawater which can be considered natural.
Even during this time in the Mzafran Oued we have persistent hypoxia the concentrations that did not exceed 2 mg dm^{-3}.
At stations 1 and 2 we consider the effect of hypoxia, where the concentrations were very low compared to normal values between 2 and 5 mg dm^{-3}.
- Station 1: Lower salinity fluctuation and seasonal variation in temperature, very low dissolved oxygen concentrations.
- Station 2: Heavy salinity instability, the level of oxygen dissolved is very small.
- Station 3 (Mazafran Oued): It is normal freshwater environment with an average salinity of 0.82 with very small temperature variations.

On other hand, we had here a heavy temperature fluctuation together with hypoxia. We defined four types of ecosystem: a shallow freshwater ecosystem with a high temperature variation (Mazafran Oued); a typical estuarine environment, which is very unstable from a salinity point of view (Oued mouth); a coastal environment with a more stable salinity, but which remains under the influence of runoff (Colonel Abbas beach); and finally a typical marine coastal environment shellfish experimental station.

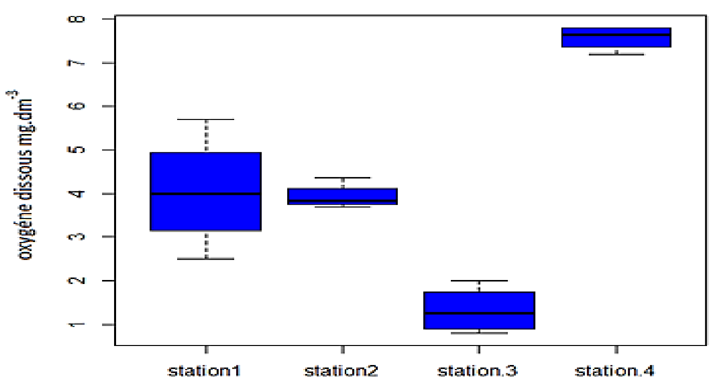

Fig. 2. Oxygen concentrations at the stations.

PH

We observed a slightly basic pH in the Mazafran estuary region, which ranged between 7.7 and 8.2 ± 0.2 (Fig. 3).

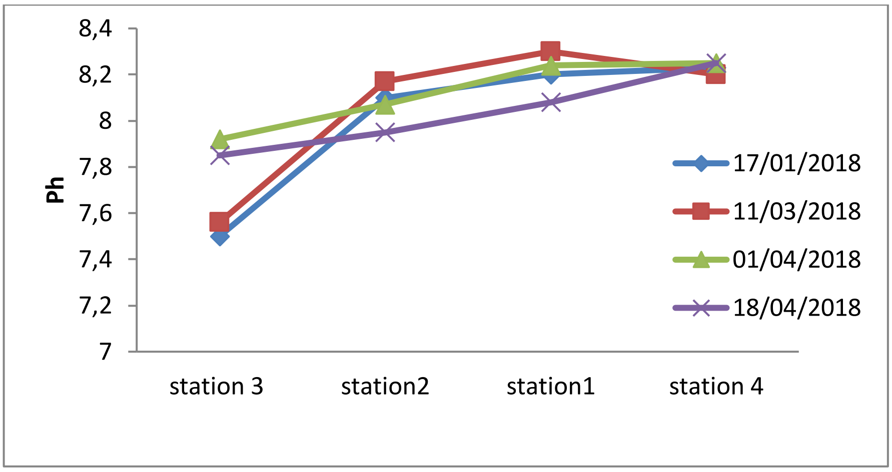

Fig. 3. Changes in pH values, Mazafran Estuary.

Qualitative analysis

The Qualitative analysis of the samples indicates a diverse population of phytoplankton. During this time, the specific richness reported at the level of the different stations is 343 species with 68.8 per cent of diatoms. Depending on the stations the number of species identified is homogeneous this ranges from a maximum of 54 species in the shellfish farming center to a minimum wealth of 17 species in the Oued Mazafran station (Fig. 4). We also found that the different richness of the three stations: station 2, station 1and the station 4 shows a similar variability between 105 and 98 taxa. with a diatom rate ranging from 70 to 77 per cent of the total phytoplankton species.

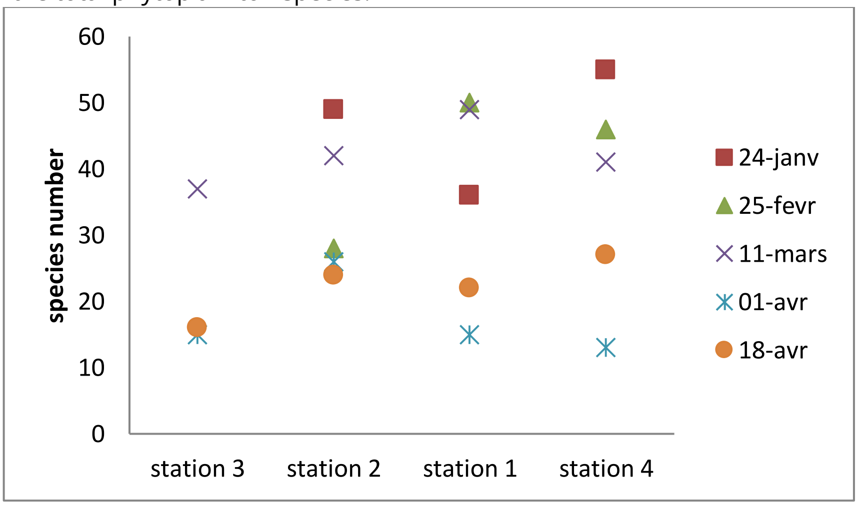

Fig. 4. Time dynamics of species richness at the stations.

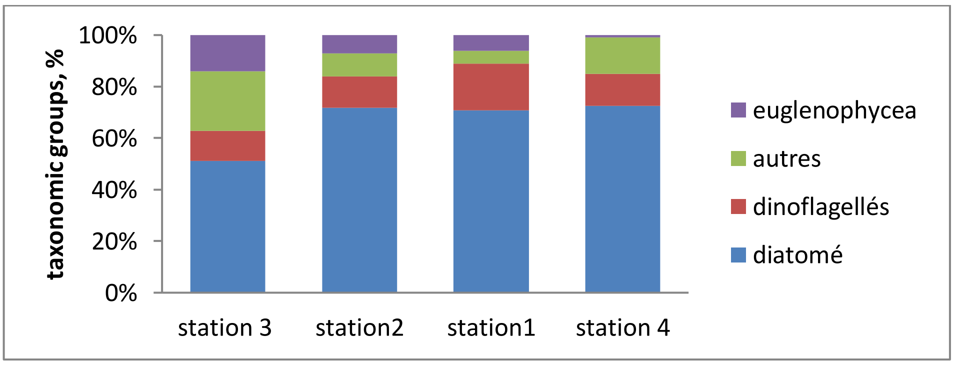

Fig. 5. Relative contribution of each taxonomic group in species diversity.

At Station 3 (Oued Mazafran) the phytoplankton population included 43 species, 51 per cent of which were the diatoms (Fig. 5). In March we registered the maximum speces richness (38 species) in January – the minimum, 17 species (Table 4 and Fig. 5). At Station 2 (mouth of Oued) we detected that from 99 species, the diatoms were 72 percents. Maximum species diversity – 51 species was recorded in February and minimum diversity – 16 species was reported in early April.

Station 1 (Colonel Abbas) reported a species diversity of 98 species, including 71 percent of diatoms. The maximum diversity – 48 species was in January and minimum – 25 species was reported in April. The species diversity reported in the 'shellfish rising center' reference station was 105 species, of which 72 percent were the diatoms with a maximum of 54 species registered for sampling in January and a minimum of 14 species registered on 01.04.

Table 4. Temporal variation in species diversity by stations.

Date	24.01	25.02	11.03	01.04	18.04	Average	SD
Station 3	-	-	38	17	17	24.00	12.12
Station 2	37	51	50	16	23	29.67	17.95
Station 1	48	29	43	27	25	31.67	9.87
Station 4	54	47	42	14	28	28.00	14.00

Shannon index (H ') and Pilou index

Table 5. Time dynamics in Shannon index, H' and Pielou index, J.

Date	24.01		25.02		11.03		01.04		18.04	
	H'	J	H'	J	H'	J	H'	J	H'	J
Station 3	-	-	-	-	2.29	0.63	1.34	0.47	2.00	0.71
Station 2	2.04	0.56	1.24	0.34	2.79	0.71	2.61	0.94	2.72	0.98
Station 1	2.57	0.66	1.26	0.37	3.11	0.83	1.01	0.30	3.08	0.93
Station 4	3.01	0.75	0.83	0.02	1.78	0.48	2.09	0.79	2.03	0.77

Station 3 (Mazafran Oued)

Diversity index of Shannon ranged from 1.34 to 2.29 bit/ind. Low values relative to Hmax for the March 11 and April 1 samples suggesting a dominance of one or a limited number of species in the population. On the other hand, for the last sampling (April 18) we had an H' value that was similar to the Hmax value and implied a healthy diversity of the different organisms in the population.

The ratio (H'/Hmax) or Pielou J index for the first two samples ranged between 0.45 and 0.63, which indicates a dominance of a few species in the population (Table 5).

In sample from April 18 we registered that two indices, H 'and Hmax were similar with J'=0.71, which indicates a tendency to match the number of individuals in the different species (Table 6).

Station 2 (the mouth of the Oued)

The Shannon Diversity Index were 2.04 and 1.24 (bit/ind) for the samples from January 24 and February 25 with a ratio (H'/Hmax) that exceeds 0.34 and indicated a dominance of one or a limited number of species in the population. On other hand, in the samples from March 11 and 01 and April 18 that H 'and Hmax indexes were similar to each other, while index of Pielou were 0.71, 0.94 and 0.98, which suggested a trend towards a balance in the population (Table 7)

Table 6. Dominant species at station 3.

Date	Dominant species and frequency
11.03	*Haematococcus pluvialis*, 31.31% *Rhoicosigma compactum,* 18.29% *Actinoptychus* sp., 11.43%.
01.04	*Euglena* sp, 67.53%.
18.04	*Navicula* sp., 41.43%, *Actinoptychus* sp., 17.14%, *Euglena* sp., 11.43%.

Table 7. Dominant species per sample at station 2.

Date	Species and frequency
24.01	*Euglena* sp., 44.93%.
25.02	*Gyrodinium Torodinium,* 60.64%.
01.04	*Gyrodinium Torodinium,* 79.85%.

At the station 1 (Beach Colonel Abbas) we had high values of Shannon Diversity Index (H) – 1.26 and 1.01 (bit/ind) in samples from February 25 and March 11. The ratio (H'/Hmax) were 0.34 and 0.30, which tends toward zero (0) and reflected a dominance of some species in the population.

Table 8. Dominant species per sample at station 3.

Date	Species and frequency
24.01	*Euglena* sp., 50.66%, *Coscinodiscus* sp., 17.18%.
25.02	*Euglena* sp., 27.74%.
11.03	*Euglena* sp: 28.52%, *Nietzsche* sp: 16.97%.

In samples of January 24 and April 18 we noted that the two indices H 'and Hmax are very similar with J'=0.66 and J'=0.83 and J=0.93, which represents a tendency to equalize the number of individuals per species in the population (Table 8).
In station 4 (conchylicol center), the Shannon diversity Index (H') was 3.01, 2.09 and 2.03 (bit/ind) for the samples collected on January 1 and 24, and on April 18 correspondingly. These values compared to the Hmax values with a ratio (H'/Hmax) of J'=0.75, J'=0.79 and J'=0.77, which tends towards one (1) and represents a propensity to equalize the number of individuals of a species in the population.
The samples from February 25 and March 11 had H' indices of 0.83 and 1.78 bit/ind., that was very low compared to Hmax, and a Pielou index values of 0.02 and 0.48 which tends towards (0), reflecting a predominance of one or two species in the population (Table 9).

Table 9. Dominant species per sample at station 4.

Date	Species and frequency
24.01	*Euglena* sp. 25.07%, *Licmophora Ehrenbergi*: 11.55%.
11.03	*Haematococcus pluvialis* 45.28%, *Fibrocapsa* sp. 31.90%.
01.04	*Polykrikos Schwartzi* 35%, *Polykrikos* sp. 15%, *Melosira moniliformis*: 12.5%.
18.04	*Euglena* sp. 33.2%, *Stephanodiscus hantzschii:* 32%.

Quantitative analysis

Abundance: During this analysis we reported significant variations in cell density in the different stations. The maximum density of 11370 cells dm^{-3} was observed in the March sample at station 3 whereas the minimum density of 230 cells dm^{-3} was reported in the April 1 sample at station 4.
We registered the largest abundances in March 11 samples (11370 cells/dm^3) at station 3, and in samples on February 25 and April 1 at station 2 (5640 cells/dm^3 and 5410 cells/dm^3). We also observed average abundances in stations 1 and station 4 between 1270 and 2910 cells/dm^3 during January, February and March. On other hand, we found a lower density in these stations in April, which was between 230 and 510 cells/dm^3 (Fig. 6). At Station 2 we had higher abundance than at other stations, which could be casued by the continuous enrichment of the area. We note the existence of species that endorse strong variations in salinity in the estuarine region and speak of euryhalin taxa, such as *Flagilaria pulchella* and *Craticula halophila*.
The low cell density in the samples from all stations in April 18 and at the station 1 on Aplril 1 could be explained by the high turbidity restricting the growth rate of phytoplankton (Desmit et al., 2005). The amount of water flowing into the estuary, should also be an important factor in controlling the seasonal production of phytoplankton (Muylaert et al., 2005).

Diatom index

The diatom index reveals a time-variation. We note that for the sampling at the end of April. the diatom index is very high and ranged from 0.65 to 0.77 in all four stations. suggesting a predominance of diatom in the population. At the beginning of April we had a low diatom index of 0.11 to 0.30 in stations 1, 2 and 3, suggesting a population dominated by other phytoplankton classes such as dinoflagellates. In other sampling time, we registered diatom index at Station 1 ranged from 0.14 to 0.50, suggesting a homogeneous population (diatoms are not dominant). In Station 4 we had diatom indices ranging from 0.69 to 0.61, which indicates that the phytoplankton population is mainly dominated by diatomas. In conclusion, the different stations in the study area indicated that there was a clear presence of diatoms in populations with a global diatom index of 0.49 (Fig. 7).

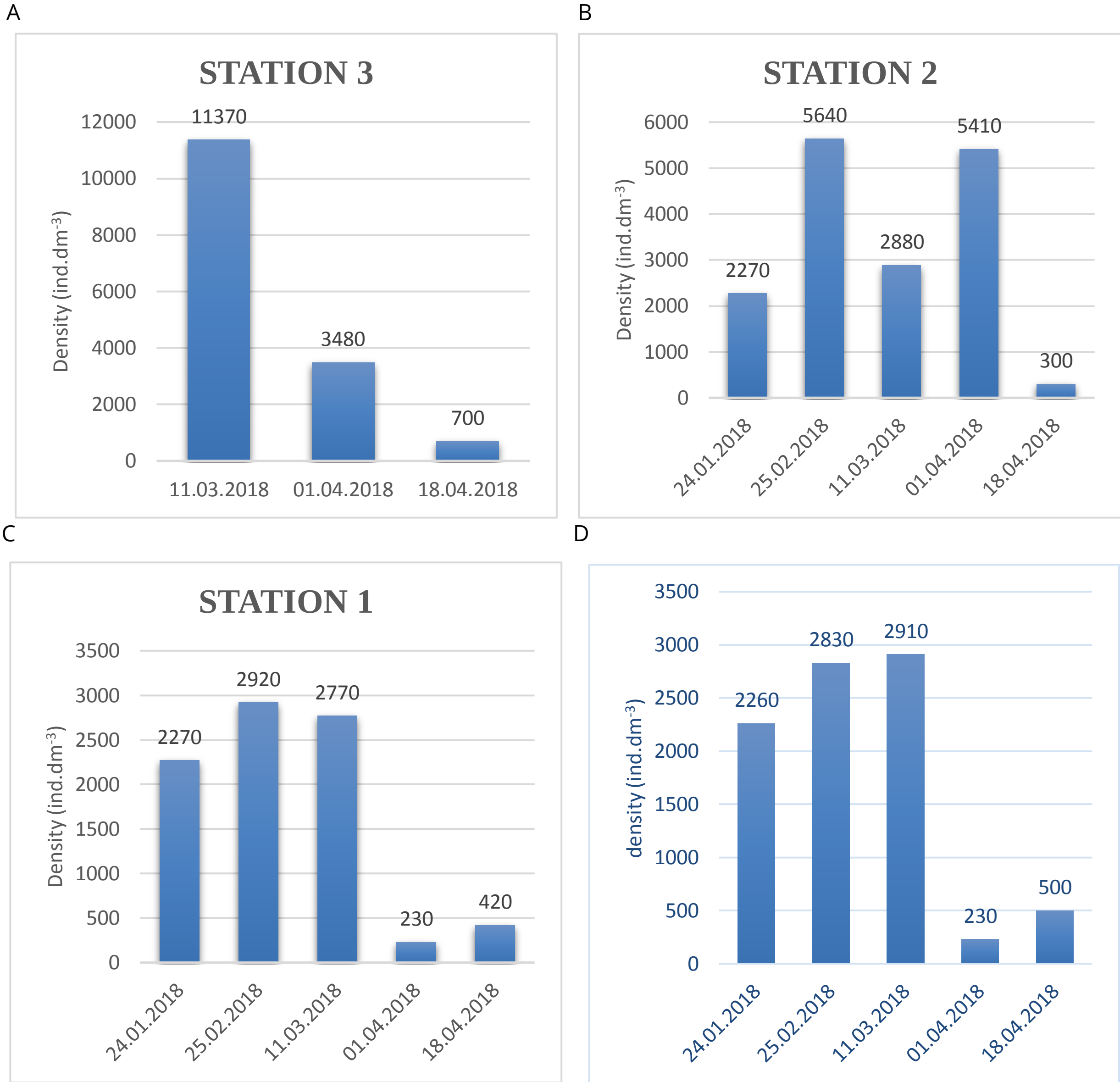

Fig. 6. Phytoplankton cell density depending on time per station.

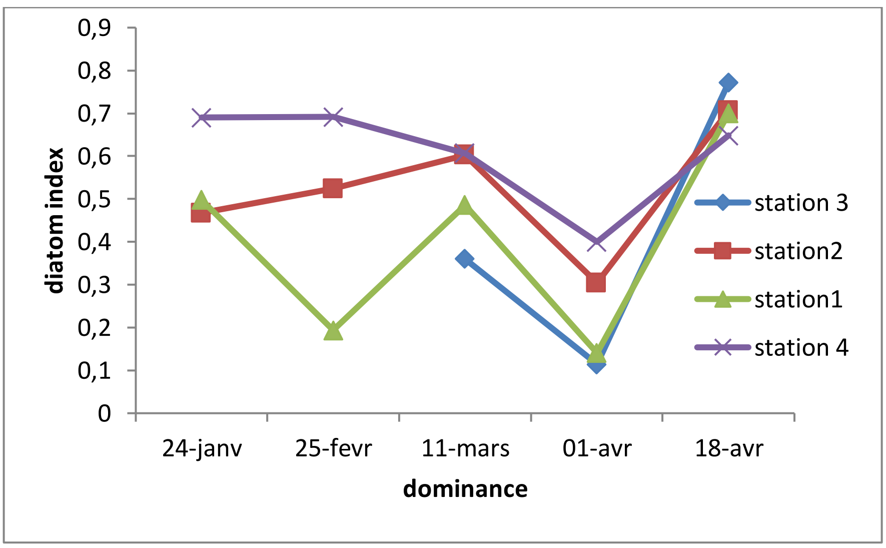

Fig. 7. Time vriation of the diatom index at different stations.

Discussion

In order to observe the dynamics of the phytoplanktonic communities in an estuarine zone Oued Mazafran, we performed the sampling during the winter and in the beginning of spring. This period of year was characterized by heavy floods (Oued), open channel with the sea and direct contact between the two ecosystems (marine and fresh water).

Qualitative and quantitative research reveals that the phytoplankton population's evolution and distribution is unpredictable and displays major variations depending on the characteristics of the ecosystems in which they live. Indeed the various groups especially dinoflagellates differ from diatoms because of their sensitivity to variations in ecological conditions: temperature, salinity, turbulence, nutrients, these environmental factors are the precursors of the phenomena that govern the dynamics of phytoplankton groups. The environmental conditions at the origin of these variations are complex and specific to the considered geographic area, as well as to the species, responsible for these variations (Gailhard, 2003). The temperatures also influence the entire ecosystem (Anderson et al., 2002).
Diatoms, chlorophytes and dinoflagellates are a characteristic association of estuarine ecosystem phytoplanktonic algae (Lemaire, 2002). We noted that diatoms dominated in this area during this period. Indeed, according to Baki (2009), the diatoms dominated at temperatures between 5 and 20 °C. Wasmund et al. (1998, 2013, 2017) and Klais et al. (2013) had shown that the proliferation of diatoms takes advantage of winter temperatures. According to Goffart et al. (2002), the diatoms in the Mediterranean develop mainly in late winter to early spring.

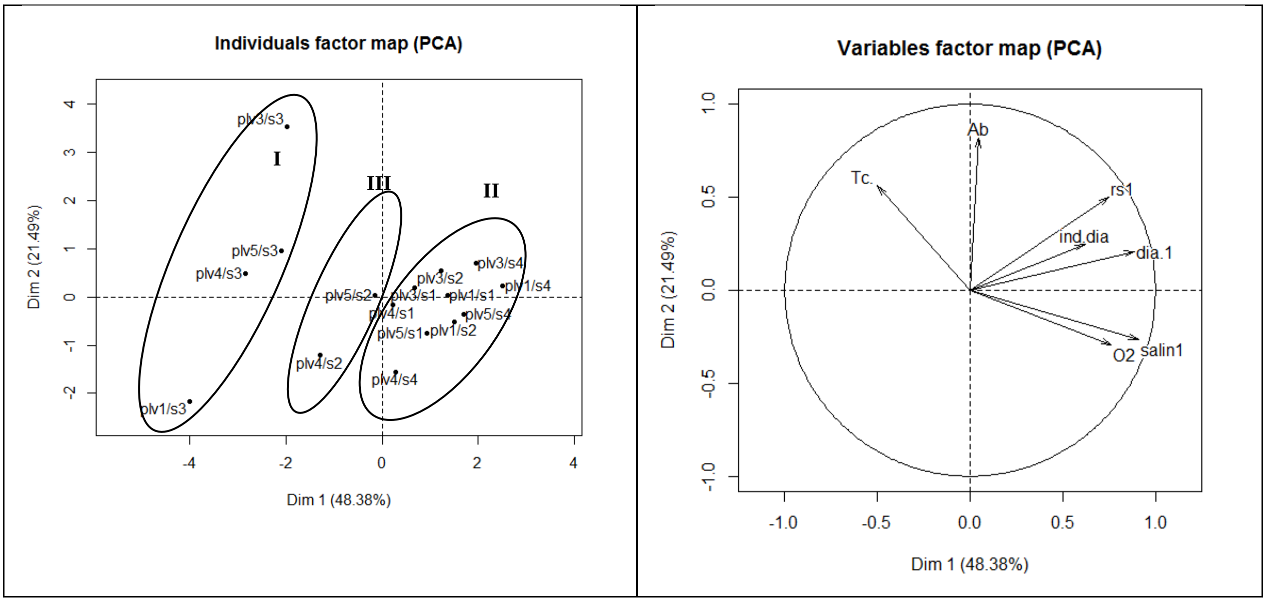

Fig. 8. Principal component analysis. RS – Species richness; dia – diatoms; salin – salinity, 02 – Dissolved oxygen; ind.dia – Diatom index. AB –= Abundance; Tc – Temperature. Avec plv – samples and numerals for the date at s –station

Table 10. Correlation Matrix of Principal Component Analysis.

	Species richness	Diatoms	Salinity	Abundance	Diatom index	Temperature	Dissolved oxygen
Species richness	1						
Diatoms	0.68675	1					
Salinity	0.57105	0.72129	1				
Abundance	0.46202	0.16092	-0.086706	1			
Diamom index	0.47749	0.60452	0.344622	-0.133680	1		
Temparature	-0.28141	-0.30144	-0.655065	0.200321	0.19473	1	
Disolved oxygene	0.2661046	0.53745	0.740879	-0.160024	0.49691	-0.33441	1

The Principal Component Analysis performed for the results obtained and taking salinity. Temperature, abundance, diatoms, diatom index and specific richness were considered and contributed to distinguish three ecosystems:
• Ecosystem (I): Freshwater station 3 (Mazafran Oued)
• Ecosystem (II): Seawater with little variation at station 4 (shellfish center)
• Ecosystem (III): Transition zone and influence of Oued station 2 and 1 (colonel Abbas beach and mouth, Fig. 8).

The comparison of the results obtained in the three estuarine zone stations with the reference station "shellfish center" indicates that the estuarine zone offers conditions that affect the growth of phytoplankton populations in a more important way than the reference area. Indeed, we note a correlation of 0.72 between salinity and diatomic cell densities (Table 10): the variability in salinity directly affects the ecology and growth of phytoplankton groups, such as diatom classes. Also, the high water turbidity limits the growth rate (Desmit et al., 2005; Muylaert et al., 2005).
Secondly, we noted a correlation of 0.74 between the dissolved oxygen and salinity which suggests that the hypoxia reported in the estuarine zone originates from the influence of Oued waters. Indeed, hypoxia can be exacerbated and prolonged if the

temperatures are high and the floods discharge significant amounts of urban effluent in a short period (Etcheber et al. 2011) and it occurs in rainy weather, during wastewater overflows (Even et al., 2007).
We also have a correlation exceeding 0.5 between specific and salinity and dissolved oxygen, which suggests that the amount of water flowing through the estuary is also an significant factor in controlling the seasonal production of phytoplankton in water- and estuarine-influenced areas (Arndt et al., 2007).

Conclusion

Monitoring the dynamics of phytoplankton populations in the Mazafran Oued estuary region has allowed us to highlight the functioning of three separate flora-related ecosystems as well as environmental conditions. Mazafran Oued has a low temperature between 18 °C and a minimum of 12 °C. with an average temperature of 16.08±2.04 °C.
The Oued's salinity is small, it ranges from 1.1 to 0.7 characterizing a freshwater environment hence the presence of freshwater species such as: *Chlorococcum* sp., *Chlorella vulgaris, Cosmarium* sp., *Closterium* sp., and *Achnanthes flexella*.
The mouth of the Oued has natural seasonal temperature regime. Temperatures are higher than in Mazafran Oued and they are between 16.8 °C maximum and 14.09 °C minimum, with an average of 15.96 ± 0.53 °C. The salinity fluctuated between a maximum of 35.33 and a minimum of 16.32, which indicates that this zone is a point of contact and mixing, between fresh water and seawater and where the species (euryhalines) tolerate highly fluctuating conditions such as: *Craticula halophila* and *Flagilaria pulchella*. These species was present everywhere particularly in environments rich in organic matter whether marine or saumatra. The *Euglene* sp. was found almost everywhere especially in environments that were rich in organic matter whether marine or brackish.
In Colonel Abbas Beach and Shellfish Farming Stations we registered temperatures between a minimum of 15.2 °C and a maximum of 16.07 °C with an average of 15.88 ± 0.32 °C. The salinity varied from 34 to 35. The evaluation of the phytoplankton population dynamics made it possible to identify the species that do not support significant salinity fluctuations, which confirms that this is rather a marine biotope. Tese sepceis were *Navicula* sp., *Nitzschia* sp., *Coscinodiscus* sp., *Licmophora ehrenbergii, Thalassiophysa hyaline,* and *Nitzschia* sp. During this period the Mazafran Oued's influence can extend over the entire area of Colonel Abbas station.

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