Regional Studies in Marine Science
November 2020, Volume 40, Pages 101512 (14p.)
https://doi.org/10.1016/j.rsma.2020.101512
https://archimer.ifremer.fr/doc/00655/76736/

Influence of ocean - lagoon exchanges on spatio-temporal variations of phytoplankton assemblage in an Atlantic Lagoon ecosystem (Oualidia, Morocco)

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Abstract :

The Oualidia Lagoon is a semi enclosed marine ecosystem connected to the Atlantic Ocean of Morocco and exposed to human activities, mainly agriculture and oyster farming. The present study aims to characterize the spatio-temporal variation of the phytoplankton assemblage and to highlight the effect of the main environmental parameters on this important planktonic component evolving in a vulnerable anthropized ecosystem. For this purpose, a field survey was carried out during four seasons in 2011 to determine the biotic (phytoplankton, chlorophyll a) and abiotic (temperature, salinity and nutrients) variables during low and high tide periods. Results highlight an established spatial variation of physico-chemical parameters especially at low tide, with contrasted environmental conditions between the upstream and downstream zones. The phytoplankton diversity and abundance were characterized by a pronounced seasonal pattern. The Oualidia Lagoon is a nutrient rich ecosystem, especially in its upstream part. We also showed that both planktonic diversity and abundance were maximum in autumn and summer. The phytoplankton richness is governed by two main factors: the seasonality of nutrient enrichment and the regular supply of Atlantic seawater. Nitrate and ammonium were the main environmental abiotic factors determining the development of phytoplankton populations. The dynamic of phytoplankton in the Oualidia Lagoon is highly influenced by marine waters incoming from the Atlantic Ocean especially during the upwelling season. Finally, potential harmful algal species belonging to different genera such as Pseudo-nitzschia, Alexandrium, Prorocentrum, Dinophysis, Ostreopsis, Karenia, Coolia, Gonyaulax, Gymnodinium, Dictyocha and Chattonella were encountered showing a potential in this ecosystem to develop noxious blooms.

Highlights

► The spatio-temporal variation of phytoplankton assemblage (biodiversity and abundance) was driven by environmental constraints from both land and sea. ► The taxonomic richness was dominated by typical marine species. ► The inventoried taxa were dominated by diatoms and dinoflagellates when considering both species number and density. ► Potential Harmful Algal Blooms species, belonging to different genera such as *Pseudo-nitzschia*, *Alexandrium*, *Prorocentrum, Dinophysis, Ostreopsis*, *Karenia*, *Coolia*, *Gonyaulax*, *Gymnodinium*, *Dictyocha* and *Chattonella* were encountered. ► The warm season (August and October) showed the highest values of phytoplankton species diversity and densities particularly upstream.

Keywords : Oualidia Lagoon, Phytoplankton, Environmental factors, African Atlantic coast, Ocean - Lagoon exchange

1. Introduction

Coastal Lagoons are among the most productive marine ecosystems, however they remain fragile and are often exposed to multiple natural and anthropogenic constraints (Kjerfve, 1994). Lagoons are highly productive areas that are located in the transitional areas at the land-ocean boundary (Perez-Ruzafa et al., 2012). These areas have become important because they provide the key to understanding the general dynamics of the seas they are connected with. Their existence and their influence on the coastal zones have become a fundamental study topic in many disciplines (Basset et al., 2012). A better knowledge of the functioning of these ecosystems is required to ensure their sustainable management (Rharbi et al., 2001; Rosa et al., 2019). The Oualidia Lagoon, located on the Atlantic coast of Morocco (Africa), was registered as a RAMSAR site (International convention of wetlands conservation) since 2005 (Maanan et al., 2014) because of its great ecological and socio-economic importance. It holds an increasing touristic activity and it is one of the most important Moroccan zones for oyster farming since 1950 (Rharbi et al., 2001). Other socio-economic activities in this area includes intensive agriculture, livestock, fishing, and salt mining. Local residents exploit mussels (*Perna perna* and *Mytilus galloprovincialis*) fixed on the rocks and reef flats and collect clams (*Ruditapes decussatus*) (Maanan et al., 2014; Jayed et al., 2015). Phytoplankton community in coastal Lagoons are a major component of the food web structure and functioning and supply the major source of organic carbon (Gaikwad et al., 2004). Phytoplankton sensitivity to environmental changes and the fluctuation of its specific composition are precious indicators of alterations of the whole ecosystem (Devassy and Goss, 1988). Phytoplankton species diversity is sensitive to environmental parameters, a slight modification in the state of the environment could modify this diversity (Ghsoh et al., 2012). As an example, nutrients supply, driven either from land or from the ocean through tidal influence have been shown to influence the phytoplankton activity, and consequently the functioning of communities in Lagoons (Sylaios and Theocharis, 2002).

To our knowledge, studies on phytoplankton in African Atlantic coastal ecosystems are rare. The only study on qualitative and quantitative distribution of phytoplankton in Oualidia Lagoon was carried out from January to December 1997 by Bennouna et al. (2000). They showed that diatoms were the dominant organisms at most times (70 to 98% of the phytoplankton population). However, the performed studies in Oualidia focused mainly on Harmful Algal Blooms (HABs) species (Bennouna, 1999; 2000, 2002) and were carried out in a limited number of stations. Taleb et al. (2002) showed that maximum Paralytic Shellfish Poisoning (PSP) toxin level recorded in mussel from Oualidia Lagoon during the November 1994 was up to 2500 µg Eq STX.100 g^{-1} of shellfish meat which is much higher than the regulatory international threshold of 80 µg Eq STX 100 g^{-1} of shellfish meat. Both the dinoflagellates *Alexandrium minutum and Gymnodinium catenatum* were suspected to be the causative species but without formal identification. Bennouna et al. (2002) reported the occurrence of the dinoflagellate *Lingulodinium polyedrum* causing red tides along the

Moroccan Atlantic coast including Oualidia Lagoon in July 1999. More recently, Daghor et al. (2018) reported an intense bloom of the dinoflagellate *Karenia sp*. the Oualidia Lagoon with concentrations up to 1.04 × 10^7 cells L^{-1}. Here we conducted a field study covering for the first time the entire Lagoon from downstream to upstream during four seasons in 2011 with three main objectives : 1) to highlight the diversity of microphytoplankton species of the Oualidia Lagoon on a seasonal basis, 2) to investigate the effect of environmental factors on the spatio-temporal variation of phytoplankton communities and 3) to highlight the influence of ocean - Lagoon exchange on spatio-temporal variations of phytoplankton assemblage in this African Atlantic Lagoon ecosystem.

2. Material and Methods

2.1 Study area

The Oualidia Lagoon located 76 km south of El Jadida and 67 km north of Safi (Fig. 1) is one of the most important coastal ecosystems on the Moroccan Atlantic coast. This Lagoon is 7 km long and 0.5 km wide, with a total area of 3.5 km^2 (Hilmi et al., 2005; 2009 ; Maanan et al., 2014) and widely connected with the Ocean through a major inlet (150 m wide and 2 m deep) and a secondary pass active in open sea during the highest tides (Mejjad et al., 2016; Maanan et al., 2014). The Lagoon is composed of a network of very narrow dendritic channels, connected to a main channel of 6.5 km long and 2 m depth in average with a maximum of 5 m during high tides (Bidet and Carruesco, 1982). The intertidal zone (75% of the Lagoon surface) is predominantly sandy with rare slicks. The upper part of the Lagoon (0.6 km^2) is composed of salt marshes. The Oualidia climate is arid to semi-arid, maximum temperatures of up to 40°C in summer were recorded when an Eastern warm wind (Chergui) blows. However, generally, the mean daily atmospheric temperature varies between 21°C and 22°C in summer and between 14°C and 15°C in winter (Bennouna et al., 2002). The low and seasonal rainfalls account for 1% of the fresh water entering the Lagoon and the rest is coming from groundwater. The annual cumulative rainfall in 2011 are 442.3 mm (maximum of 331.9 mm during January-June 2011 and 110.4mm during July-December; data from National Meteorological Services). The annual hygrometric deficit was 650 mm. The predominant wind directions are WSW to NW during the wet season and NNE to NE during the dry season (Zourarah, 2002; Zourarah et al, 2007; Mejjad et al., 2016). The hydrological regime of the Lagoon is tightly associated with the tidal rhythm (Orbi et al., 2008; Hilmi et al., 2005, 2009). A high nutrient input is favored by rising tides in the Lagoon, which increases organic production and improves aquaculture yields (Maanan et al., 2014). Makaoui et al. (2005) reported that he Lagoon is more influenced by the oceanic input of nutrients particularly the case of PO_4 in reason of upwelling events. Mejjad et al. (2016) suggested that seasonal and diurnal nutrient variability in the Oualidia Lagoon results from the influence of the water continental inputs, precipitation and evaporation regimes as well as oceanic-Lagoon exchanges. There are no river discharging into the Lagoon, but several authors have mentioned the existence of underground freshwater seepage probably in the first part of the Lagoon and upstream (Carruesco, 1989; Hilmi et al., 2005, 2009; Rharbi et al., 2001). Several authors (Hilmi et al., 2005; 2009, Koutitonsky et al., 2006; 2012) have studied the tidal regime and the water circulation in the Oualidia Lagoon. They concluded that this marine system is governed by the semi-diurnal tide (M2 tide) which dominates in the Atlantic Ocean. The tide's amplitude reaches around 3 m at the entrance of the Lagoon during the spring tides, and around 0.8 m during the neap tides. Due to the complex topography and the small depths observed upstream of the Lagoon, tides are asymmetric in nature and the amplitude of M2 tide is decreasing due to the friction on the bottom. On average, the maximum and minimum depths in the Lagoon are 5 m and 1.5 m, respectively (Bennouna et al., 2002). A maximum of 77% or 52% of the channel volume is flushed during one spring or neap tide, respectively (Hilmi *et al.*, 2005). Carruesco (1989) estimated a renewal of 89% or 72% of the Lagoon waters during one spring or neap tidal cycle, respectively. Using 2D hydrodynamic model, Hilmi *et al.* (2005) found that tidally averaged renewal time for the whole Lagoon was 7 days, while the local renewal time at the upstream end of the Lagoon is 25 days. Oyster farming is the most widespread aquaculture activity in the Oualidia Lagoon. The average annual production of oysters is estimated to be 250 tons (Rharbi, 2000).

2.2. Sampling and measurements

Six stations along Oualidia Lagoon were sampled monthly from downstream to upstream during representative months of the four seasons of 2011: winter (February), spring (May), summer (August) and fall (October) (Fig. 1). Water sampling was performed using an hydrobiological bottle at subsurface (-0.5 m depth). The maximum depths of the stations ranged between 0.5 to 3.5m at low tide and 2 to 6.5m at high tide.

2.2.1 Abiotic factors

Temperature, salinity and nutrients (nitrate, ammonium and phosphates) were measured in all stations during low and high tides. Temperature and salinity were determined using a probe WTW LF195. 500 ml of seawater was filtered (0.45 µm) and conserved at -20 °C until the analyses of nutrients performed spectrophotometrically according to the method of Aminot and Kerouel (2004).

2.2.2. Biotic factors

Chlorophyll *a* (Chl-*a*) measurements were performed from 500 ml seawater samples filtered throughout 47 µm Whatman GF/F filter during low and high tides. Chl-*a* was extracted from filters immerged in 10 ml 90 % acetone for 24 h in the dark at -4 °C (Strickland and Parsons, 1972, Linder,1974), and analyzed using a fluorometer 10-AU (Turner Design).

Determinations of phytoplankton species and abundances were made from 100 ml of sea water fixed using Lugol's iodine. Phytoplankton counts were done for samples of only high tides. Phytoplankton counts were carried out according to the Utermöhl (1958) method and the determination of the different taxa was made by inverted light microscopy (Nikon) with appropriate identification keys (Trégouboff and Rose, 1957; Nezan and Piclet, 1996; Tomas, 1997; Botes, 2003). Phytoplankton abundance was expressed in cells L^{-1}. The frequency of taxa, expressed in%, was calculated using formula :

F = (µi / µT) *100 (µi = number of samples in which species is present and µT = total number of samples).

2.3 Data analyses

Each station was characterized by a specific assemblage of microphytoplankton described by its species richness (RS) index (number of species recorded), total density (D), Shannon diversity H index (Shannon and Weaver, 1949).

Species diversity (H) was calculated using Shannon's formula:

$$H=\sum_{i=1}^{S} ni/N * \log_2 ni/N$$

Where, S = specific richness (number of species); n_i = abundance of species i and N = total abundance of all species.

PCA and Co-inertia analysis were performed with the ADE4 package in the R software (Dray and Dufour, 2007) to evaluate the associations between species composition and environmental variables. A redundancy analysis (RDA) as developed by Van Den Wollenberg (1977) was carried out in place of the co-intertia analysis and have given very similar results. The considered taxa were diatoms and dinoflagellates with percentage of occurrence ≥ 40%. The abbreviated names of species are given in table 2. Only data related to high tide sampling were considered for the environmental parameters, since phytoplankton was only taken at high tide period. The abundances were transformed into log (X + 1) to minimize differences in numbers.

3. Results

3.1. Abiotic factors and chlorophyll a

3.1.1. Temperature and salinity

In May (spring) and October (autumn), the temperature did not undergo diurnal variations both upstream and downstream and temperature ranged between 20 and 22.5 °C at low tides (LT) and high tides (HT). In August (summer season) at HT, upwelling marine waters cool the Lagoon waters with the lowest registered temperature (15.5 °C), while at LT the temperature ranged between 20 °C and 24 °C, at downstream and upstream, respectively. In February (winter), marine inputs tend to warm the Lagoon waters and temperature increased from 15 °C to 18 °C (Fig. 2a, b and Appendix 1). The Lagoon is highly influenced by marine waters (salinity of 35) at HT, with salinity exceeding 35 at all stations (a maximum of 36.5) except at station 6 (located upstream) where an average salinity of 30 was recorded. In contrast, at LT, the Lagoon waters were characterized by a salinity increasing from 23 at upstream to 36 at downstream of the Lagoon (Fig. 2).

3.1.2. Nutrients

The Oualidia Lagoon was characterized by relatively high nutrient concentrations, generally at LT, with values increasing upstream (Fig. 3). Nitrate (NO_3) showed the highest concentration in August and October (up to 30 µM and 20 µM, respectively) at HT (Fig. 3b). At LT, February and May were characterized by the highest concentrations with values of up to 30 and 40 µM respectively at station 6 upstream (Fig.3a). Phosphates (PO_4) ranged between 1.3 and 4 µM at

HT (in February, May and August) and between 0.8 and 2.5 µM at LT (in August and May, Fig. 3c and d). October was globally the least rich month in PO_4, especially at HT (< 1µM) and February at LT (Fig. 3d). Temporal variation in ammonia (NH_4) concentration was observed with high levels (up to 30 µM) in August and October at HT (Fig. 3f). NH_4 concentrations remain low in February and May (< 3 µM) during HT (Fig. 3f). At LT, the highest levels of NH_4 (17-24 µM, maximum in May) were recorded (Fig. 3e), whereas all other concentrations were lower than 6 µM during all other seasons.

3.1.3. Chlorophyll a

The highest chlorophyll a (Chl-a) concentrations during the survey were observed in August with maximal values of 6 µg L^{-1} at LT and 3.89 µg L^{-1} at HT. During this period, Ch-a at all stations, was > 4 µg L^{-1} at LT and < 4 µg L^{-1} at HT. For the other seasons, Chl-a concentrations were < 2.1 µg L^{-1} (Fig. 4). The maximum Ch-a for each period was observed in LT when compared to HT.

3.2 Microphytoplankton

3.2.1. Taxonomic composition

The phytoplankton of the Oualidia Lagoon covers six groups and 114 taxa. Diatoms and Dinoflagellates were the most represented in term of species, with 68 and 40 taxa, respectively. In contrast, Silicoflagellates, Euglenophytes and Raphidophytes were poorly represented (Table 1). Diatom species dominated the microphytoplankton in all stations and seasons (Fig. 5), with a relative abundance exceeding 80 %. However, Dinoflagellates accounted for 50 % of microphytoplankton in St2 in May and St6 in August and were represented mainly by *Scrippsiella sp.* and *Peridinium quadridentatum.*

3.2.2. Specific richness and specific diversity

The number of taxa recorded per station varied between 13 and 42. October and particularly August showed the highest numbers of taxa (generally ≥ 32) in contrast with February and May (13-33 taxa) situations (Fig. 6a). The highest specific richness was observed upstream, at station 5 (27-40 taxa). The Shannon (H) index values of phytoplankton were generally > 3 during all periods. In summer, microphytoplankton was more diversified (H > 4), mainly downstream (maximum of 4.7) compared to upstream (3.3). The lowest diversity (2.5) was observed at Station 5 in May, due to the important proliferation of the diatom *Nitzschia spp* (Fig. 6b).

3.2.3. Distribution of microphytoplankton densities

The distribution of phytoplankton abundance was very heterogeneous along the Lagoon. The highest densities (Fig. 7) were observed in October (2.20×10^4 cells L^{-1} and 4.46×10^4 cells L^{-1}) and August (1.42×10^4 to 3.09×10^4 cells L^{-1}), with a peak in St6 (6.92×10^4 cells L^{-1}) due to the proliferation of several diatom species (*Thalassiosira* spp., *Surirella sp*., *Chaetoceros* spp…) and the dinoflagellate *Peridinium quadridentatum*. Low densities were recorded in February and May (0.4×10^4 cells L^{-1} and 1.95×10^4 cells L^{-1}).

3.3. Effects of the environmental factors

The links between species composition and environmental variables was established using a co-inertia analysis. The necessary preliminary step was to perform a centered PCA (Principal Component Analysis) in order to evaluate the spatiotemporal distribution of taxa independently of the environmental variables (Fig. 8). The analyzed matrix includes observations from all stations as summarized in Table 2. The abundances were transformed into log (X + 1) to account for the data distribution skewness and make them closer to a normal distribution. The first two axes of the factorial plane F1 X F2 represented 41% of the total inertia for the PCA. The PCA revealed important differences in species associations (Fig. 8a) between seasons and few differences between stations (Fig. 8b). The species are well scattered in the F1 x F2 factorial plane. Two main groups of taxa have emerged: Group I mostly associated to August and October periods and was represented mainly by marine species frequently encountered in Atlantic coastal waters. Some of them are considered to be upwelling indicators (*Chaetoceros*, *Pseudo-nitzschia*, *Thalassiosira*, *Leptocylindrus danicus* and *Gymnodinium* : Elghrib et al., 2012). Group II was mainly associated with February and May periods (Fig. 8a), and was mainly represented by brackish or freshwater species belonging to *Surirella*, *Paralia* and *Navicula genera*, frequently observed in this Lagoon. The equivalent PCA was performed on the environmental variables only (plot not shown) and indicated that the environmental parameters (72% of the variability accounted for the first two axis) were contrasted between seasons, driven by an axis of variable salinity (46%) and Temperature axis (26%) with nutrients evenly balanced between both.

The co-inertia analysis revealed the seasonal effect of environmental factors of the species associations (Fig. 9). The first axis F1 was described by NO_3 and mainly NH_4. There was a clear separation between the salinity and nutrients particularly NO_3 and NH_4. Temperature contributed significantly to the formation of the F2 axis. It was opposite to the nutrient especially to the PO_4 (Fig. 9a). A separation between the different periods was also clearly visible. The stations of each period, with few exceptions, formed a single group (Fig. 9c). August and October periods are highly diversified and correspond to an important development of many phytoplankton taxa resulting from a NO_3 and NH_4 supply from the sea. In these two periods, the close relationship between environmental factors and taxa is generally well marked (Fig. 9c). August was characterized by low temperatures ranging between 15 °C and 17 °C and high levels of nutrients mainly NO_3 (from 9 to 11 µM with a maximum of 33.3 µM at station 6). This upstream station was characterized by highly contrasted environmental and biological parameters including low salinities (29.5), high temperature (22.8 °C) and high levels of nitrogen nutrients (32-33.3 µM). In August (Fig. 9b) several taxa (Group II) such as *Navicula*, *Diploneis*, *Pleurosigma* and *Surirella* were dominant whereas their abundance in the other periods were generally low; which suggest their preference for cold waters and the availability of nitrogen nutrients mainly NO_3. October was characterized by high temperatures (20 °C to 21.2°C), very low levels of PO_4 (<1 µM) and high levels of nitrogen mainly in NH_4 (31 µM). This month was marked by the proliferation of dinoflagellates taxa (Fig. 9b) such as *Scrippsiella* (700 cell L^{-1}), *Protoperidinium* (800 cells L^{-1}), and harmful or potentially toxic taxa such as *Pseudo-nitzschia* (9700 cells L^{-1}), *Prorocentrum* (900 cells L^{-1}), and *Dinophysis* species (400 cells L^{-1}) including *Dinophysis caudata; Dinophysis acuminata* and *Dinophysis fortii*. February and May were characterized by low levels of NH_4 (0.4-8 µM) but an important level in phosphates (1.4- 3.7 µM), compared to August and October (PO_4 : 0.4- 2 µM). At February and May, phytoplankton richness was low (Fig. 9b) where a few taxa (Group III) such as *Diplopsalis*, *Thalassionema nitzschoides* and *Alexandrium* showed relative high abundance.

4. Discussion

Data showed that Oualidia Lagoon is characterized by important tidal variations of the environmental parameters in all sampled stations and across seasons, with consequences on the dynamic of phytoplankton assemblages. Tidal differences in temperature were highly marked in February and August. In the summer months, the seasonal upwelling of the Atlantic coast cools the Lagoon waters and water fill the entire Lagoon at high tides. The salinity at HT was similar to that prevailing in the open Atlantic Ocean, with decreasing values from downstream to upstream (St1 to St6). At LT, the decreasing gradient of the salinity from St1 to St6 was more pronounced. The permanent occurrence of freshwater resurgences (Rharbi et al., 2003; Hilmi et al., 2009) in the Lagoon influences the distribution of salinity, mainly upstream where desalination reached its maximum (22.9). Nutrient concentrations, particularly nitrates, increased from downstream to upstream. At LT, the present study confirmed the results of several authors (Mejjad et al., 2016; Rharbi et al., 2003) who indicated the presence of an increasing gradient downstream-upstream in nutrients and a decreasing gradient for salinity. This is due to the hydrodynamic characteristics of the Lagoon (Mejjad et al., 2016; Hilmi *et al*., 2005, 2009) as the marine influence is marked downstream because of the change to Lagoon-oceanic connection (Fig. 1). The stations located upstream were more influenced by the continental enrichment together with freshwater resurgences likely rich in nutrients in this part of the Lagoon. This enhances the development and the richness of phytoplankton upstream. The upstream zone is enriched in nitrogen due to agricultural activities and even downstream area is enriched through tidal currents (Rharbi et al., 2003; Bennouna, 1999). These authors suggested that Chl-a concentration increased upstream and this is confirmed by our observation mainly at LT for chlorophyll recorded values. Tidal currents were shown to be higher downstream of the Oualidia Lagoon (Hilmi et al., 2005, 2009; Koutitonsky et al., 2006). Thus, the considerable reduction in the hydrodynamic intensity in the upstream area could favor not only the phytoplankton development as shown in our study but also the benthic fauna as suggested by other authors (Bidet and Carruesco, 1982; Elasri et al., 2015, 2017). Kamara et al. (2008) pointed out that the upstream part of the Lagoon was a stable area and was therefore suitable for Clams growth.

In terms of seasonal variability, the waters of the Lagoon were rich in nitrates and ammonium during all seasons of 2011. The higher concentrations occurred generally at LT, especially in spring (May), where NO_3 and NH_4 were at LT > 35µM and 20µM, respectively. They did not exceed 9 µM at HT. The registered high concentrations of NO_3 at LT are in favor of anthropogenic origin due mainly to agriculture, freshwater resurgence and urban discharges. High levels of PO_4 are observed at HT, particularly in February, with a maximum of 3µM, reflecting the significant oceanic input of PO_4 during this season, and probably NH_4 during August and October. These conclusions are corroborated with the study of Makaoui et al., (2005) who reported that the Lagoon is more influenced by the oceanic input of nutrients particularly PO_4 in reason of upwelling events. Mejjad et al. (2016) suggested that seasonal and diurnal nutrient variability in the Oualidia Lagoon results from the influence of the water continental inputs, precipitation and evaporation regimes as well as oceanic-lagoon exchanges.

The observed variability in nutrients concentrations have direct effect on the development of phytoplankton with high Chl-a concentrations observed in August (values of 3.89 $\mu g.l^{-1}$at HT and 6.52 $\mu g.l^{-1}$ at LT). Interestingly the values of Chl-a are high despite moderate microphytoplancton concentrations in Oualidia. This could be explained by the potential contribution of other groups as pico and nano-phytoplankton. Further studies have to focus on the distribution and abundance of these groups, their contribution to the total chlorophyll biomass and to quantify potential relationships linking their temporal changes to environmental factors. Our results corroborated those of Garcia Olivia et al. (2018) who suggested that the functioning of the coastal lagoons and their biological assemblages are strongly determined by the environmental conditions of each Lagoon and by the connectivity that these environments maintain with the adjacent sea. At the same time, the hydrodynamic behavior of coastal lagoons plays a crucial role in their functioning, not only in terms of water quality conditions, but also in terms of environmental range for species inhabiting the Lagoons, species connectivity, and fishing capacities (Pérez-Ruzafa et al., 2012; 2018, Gamito et al., 2005). Our results show that most of the environmental variables including nutrients are influenced by hydrodynamic and tidal rhythm in the Oualidia Lagoon.

Studies on phytoplankton diversity and dynamic in Oualidia are rare; the obtained data characterizing the spatio-temporal variations of abundance and diversity of microphytoplankton would help us to better understand the functioning of this human impacted ecosystem but also may contribute to sustainable management of the aquacultural resources as the reared mollusk *Crassostrea gigas*. Our results suggest that in terms of phytoplankton, the Lagoon of Oualidia is a highly diversified ecosystem, well structured and balanced in phytoplankton populations during all the periods and particularly in August. The Shannon index values ranged between 3 and 4.69 bits suggesting the influence of oceanic waters on the phytoplankton populations of the Lagoon. Ghosh et al. (2012) suggested that high diversity indices reflect a healthy ecosystem when the opposite is a sign of degraded environment. Our data corroborated those of Bennouna (1999; 2000) who showed that the diversity indices of phytoplankton in Oualidia were high (3 to 4.5 bits) and approached those observed in oceanic environment. The phytoplankton of Oualidia Lagoon was represented by five groups, with diatoms and dinoflagellates being the most dominant taxa when considering both species number and density. During our survey, diatoms dominated upstream and downstream during the different seasons, with the exception of St2 in May and St6 in August which showed an important development of two dinoflagellate species *Scrippsiella sp*. and *P. quadridentatum*. These results corroborated those of Elghrib et al. (2012) and Demarcq and Somoue (2015) who showed that diatoms are dominating in Moroccan Atlantic coastal waters. Bennouna, (1999; 2000) reported that the Oualidia Lagoon was characterized by the dominance of diatoms almost 10 years ago. Other studies showed that diatoms and dinoflagellates dominate the phytoplankton in Moroccan Atlantic coastal ecosystems such as Dakhla Bay (Saad et al. 2013), Moulay Bousselham Lagoon (Loumrhari et al., 2009) and Cintra Bay (unpublished data) but also in Moroccan Mediterranean marine ecosystems (the coastal waters M'diq Bay or Oued Laou : Rijal leblad et al., 2013 and the Nador Lagoon : El Madani et al., 2011) but also in the Tunisian Mediterranean lagoons of Bizerte (Armi et al., 2010) and the Cullera Estany spanish Lagoon (Pachès et al., 2014). Badylakande and Philips, (2004) reported that the relatively high level of diatoms dominance in lagoons may in part be attributable to tidal mixing energy and tidal water in flux. Diatoms are often more dependent on and tolerant of environments characterized by strong vertical mixing energy, while the turbulence of the water column at these sites may have a negative impact on the relative success of dinoflagellates (Margalef et al. 1979; Smayda and Reynolds 2001). At the species level, another feature of tidally mixed regions of the Lagoon is the presence of phytoplankton taxa considered oceanic or neritic such us *Thalassionema nitzschioides* and *Skeletonema costatum*. Overall, there was a general tendency for dinoflagellates to bloom during the warm season, while the dominant diatoms bloomed over a broader temperature range (Badylakande and Philips, 2004).

Phytoplankton in the Oualidia Lagoon was represented by 114 taxa, mainly dominated by marine species, such as *Leptocylindrus danicus*, *Leptocylindrus minimus*, *Pseuonitzschia delicatissima*, *Pseudo-nitzschia seriata*, *Thalassiosira*, *Chaetoceros*, *Dinophysis*, *Protoperidinium*. Brackish or freshwater taxa were faintly encountered such as *Bacillaria paxillifera*, *Epithemia*, *Euglena*. We also noted the presence of benthic species such as *Amphora, Cocconeis, Licmophora, Nitzschia* indicated a mixing of the water column with a sediment resuspension from the bottom favored by the hydrodynamic regime and the shallow depth of the lagoon (Bennouna et al., 2000; Rharbi, 2000). Our results suggest that the oceanic waters substantially influence the Oualidia lagoon. The present study highlights the influence of the tidal currents in the Oualidia Lagoon on phytoplankton composition with marine species entering at HT periods from the Atlantic Ocean.

In general, our results corroborated those obtained in macrotidal Atlantic Lagoons and differed from those of Mediterranean ecosystems. In terms of seasonality, Rosa et al. (2019) showed in their study on Ria Formosa lagoon (southwestern Iberia) that this Lagoon acted as a source of material during Spring and Summer seasons, which contributed to increase the biological productivity of the coastal ocean. Upwelling events that occurred more evidently during the Autumn survey drove an import amount of nutrients into the Lagoon, enhancing its biological productivity. Glé et al. (2008) showed that nutrient levels in Arcachon Bay (a mesotidal coastal lagoon of 174 km2 on the southwest Atlantic coast of France) seem to play an important role in the control of phytoplankton primary production rates during the productive period and explain their spatial, seasonal and inter-annual variability. Bennouna et al., (2000) revealed that phytoplankton development in the Oualidia Lagoon, begins in May and is marked by two peaks: in June (maximum 11.9×10^4 cells L^{-1}) and July (7.6×10^4 cells L^{-1}). In August, phytoplankton concentrations are again low (0.25×10^4 to 0.71×10^4 cells L^{-1}), then increase and fluctuate to give an autumnal peak in October and November. In Moulay Bousselham Lagoon (located in Northern Moroccan Atlantic Ocean), Loumrhari et al., (2009) emphasized that a maximum phytoplankton abundance was recorded from March to September with a maximum of 3.6×10^4 cells L^{-1}. The minimum phytoplankton abundance was recorded in February (9×10^3 cells L^{-1}). In the Nador Lagoon (Moroccan Mediterranean), El Madani et al, (2011) have listed 311 phytoplankton species belonging to seven groups with 133 diatoms and 169 dinoflagellates species. The maximum phytoplankton abundance was found in August due to the bloom of *Nitzschia longissima* (1.7×10^7cells L^{-1} at station located in the N-W Beninsar area). The minimum abundance was recorded in November. In the Tunisian North Lagoon of Bizerte, Armi et al., (2010) reported the importance of environmental factors and nutrient inputs in structuring the biomass of phytoplankton communities. According to Kjerve (1986; 1994) and Umgiesser et al. (2014), coastal lagoons can be subdivided into choked, restricted, and leaky systems based on the degree of water exchange between lagoon and ocean. This exchange greatly influences the variability of abiotic factors, thus controlling the abundance and composition of phytoplankton populations and consequently the upper trophic levels in the lagoons. Oualidia Lagoon is considered to be a leaky system (Hilmi et al., 2009), and is subject to a very significant oceanic influence.

In our study, the highest phytoplankton species diversity (> 4 bits) and density (> 400×10^2 cells L^{-1}) were found in summer and autumn in the entire lagoon, particularly at St5 and St6. This was due to the higher nutrient concentrations (>30 µM) measured in the stations located upstream and confirmed by the regularly high values of Chl-a recorded at all stations in summer at LT. This zone was also exceptionally exposed to the sediment suspension rich in organic matter, caused by the dredging of the sediment trap set up upstream in February 2011. This event could be responsible of the high levels of ammonium and nitrate measured during May 2011, which could stimulate the phytoplankton development observed in August and October 2011. Also, the nutrients input originating from continental shelf together with freshwater resurgences and from Atlantic waters related to upwelling characterizing this region mainly in summer and persisting in autumn (Makaoui et al., 2005) are probably responsible of the observed enrichment of the Oualidia Lagoon waters. In contrast, Winter (February) and Spring (May) periods showed the lowest values of species diversity and phytoplankton cell abundances. Our results corroborated those of Rharbi (2000; 2001) who reported that the Oualidia Lagoon is under the influence of the upwelling, causing a drop in temperature together with high nutrient concentrations enhancing phytoplankton development during spring and summer. Our results showed that nutrients seem to be the main environmental abiotic factors determining the development of several phytoplankton populations. In Oualidia, the phytoplankton diversity seems to be favored by a wide range of temperature and salinity related to intense water exchanges with the Atlantic Ocean. Phytoplankton showed a rapid response to modified nutrient levels through changes in biomass and composition (Reynolds, 2006). Our field results show that nitrogenous compounds (NO_3 and NH_4) could be responsible for the growth of many taxa such as *Thalassiosira*, *Scrippsiella*, *Chaetoceros*, *Prorocentrum*, *Protoperidinium* and *Surirella* mainly in August and October, although they are less represented in space and during all periods. Potential toxic or harmful species (Lassus et al. 2016; Moestrup et al. 2009), which appear in the 'harmful algal bloom' list of the Intergovernmental Oceanographic Commission of UNESCO, belonging to different genera such as *Pseudo-nitzschia*, *Alexandrium*, *Prorocentrum*, *Dinophysis*, *Ostreopsis*, *Karenia*, *Coolia*, *Gonyaulax*, *Gymnodinium*, *Dictyocha* and *Chattonella* were present in Oualidia, particularly in October. Even if their concentrations were relatively low (unpublished data), they are subject to regular monitoring program as Oualidia Lagoon holds important oyster farming and recreational activities. Consequently, the ecology, the biology and the toxicity of these HABs species have to be investigated.

Acknowledgements

We thank the staff of the marine environment monitoring station INRH in the Oualidia. This work is dedicated to the memory of Doctor Jaouad Lakhdar Idrissi who died while carrying out the first missions of a comprehensive integrated program of rehabilitation of the Oualidia Lagoon and whose present work is part. Thanks to IRD (Institut de Recherche pour le Développement France) for funding Dr Mohamed Laabir stay in INRH (Institut National de Recherche Halieutique, Morocco) laboratory in Casablanca during 2017.

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Figures legend

Fig. 1. Sampled stations from downstream to upstream of the Oualidia Lagoon (Atlantic coast, Morocco). Parks (1, 3, 5, 7 and 8) and Past indicate the oyster farming zones and the Ocean/lagoon connection, respectively.

Fig. 2. Spatio-temporal variations of temperature (°C) and salinity at low tide (a and c) and high tide (b and d) periods in the sampled stations of Oualidia Lagoon, upstream and downstream for station 1 and 6.

Fig. 3. Spatio-temporal variations of phosphate, nitrate and ammonium concentrations (µM) at low tide (a,c and e) and high tide (b, d and f) in the sampled stations of Oualidia Lagoon.

Fig. 4. Spatio-temporal variation of chlorophyll *a* concentrations (µg L^{-1}) measured at low (a) and high tide (b) in the sampled stations of Oualidia Lagoon.

Fig. 5. Spatio-temporal variation of percentages (%) in term of abundance of different phytoplankton groups in Oualidia lagoon.

Fig. 6. Spatio-temporal variations in species richness (a) and specific diversity (b: Shannon index)

Fig. 7. Spatio-tempral variations of total phytoplankton densities (cells L^{-1}) in Oualidia Lagoon.

Fig. 8. Spatio-temporal projection of phytoplankton communities obtained by performing a central principal component analysis (PCA). (a: Species association; b and d: Projection of stations and c: Projection of seasons)

Fig. 9. Co-inertie analysis performed with environmental factor matrix and phytoplankton matrix. (a: Relationship between environmental variables (a), Species and stations in different seasons respectively (b and c); Contribution of axes: d). (NB: ▲ indicates potentially toxic species)

Table 1. Inventory and percentage frequency of taxa encountered at the Oualidia lagoon

Table 2. The codes assigned to the hydrological and phytoplankton communities for the Co inertie and PCA analyses.

Appendix 1: Table a. Spatio-temporal variation of the temperature (a1) and salinity (a2) at high (HT) and low tides (LT). Table b. Spatio-temporal variation of the concentrations in µM of nitrate (b1), Phosphate (b2) and ammonium (b3) at high (HT) and low tides (LT)

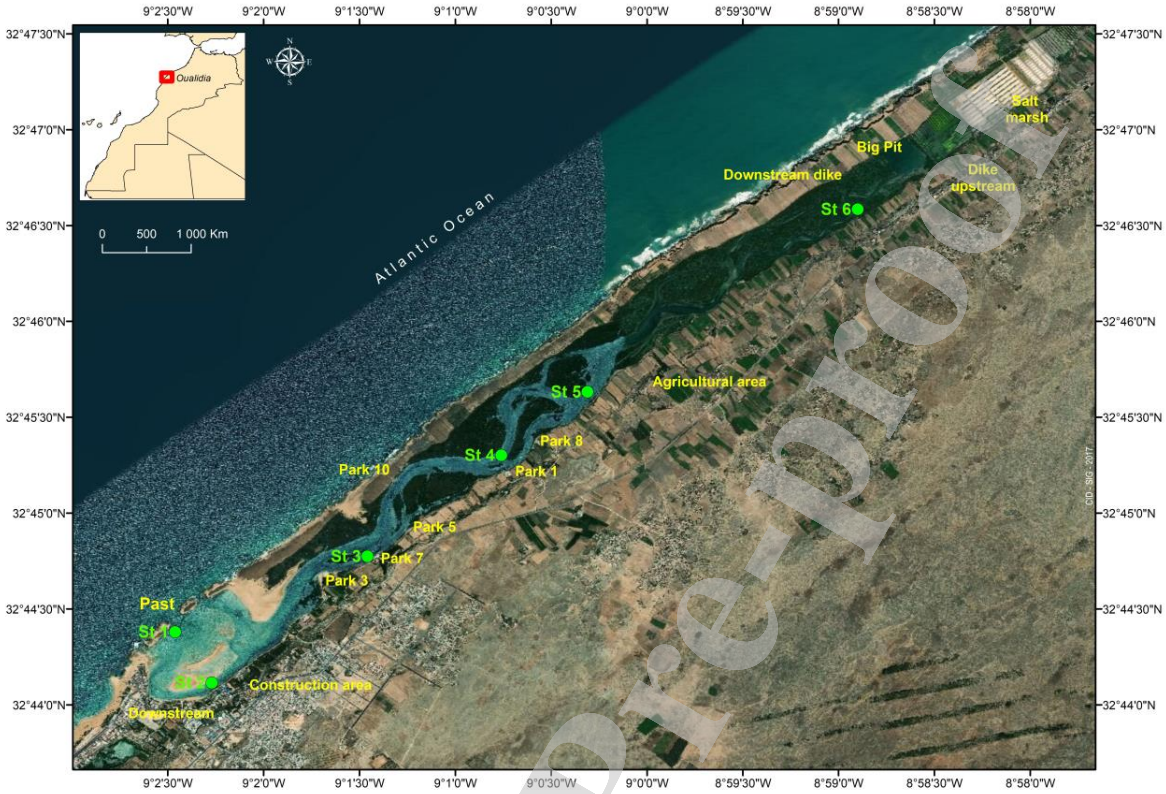
Oualidia
0
500
1 000 Km
N
S
E
W
Atlantic Ocean
Salt marsh
Big Pit
Downstream dike
Dike upstream
St 6
Agricultural area
St 5
Park 8
St 4
Park 1
Park 10
Park 5
St 3
Park 7
Park 3
Past
St 1
St 2
Construction area
Downstream
CID - SIG - 2017
9°2'30"W
9°2'0"W
9°1'30"W
9°1'0"W
9°0'30"W
9°0'0"W
8°59'30"W
8°59'0"W
8°58'30"W
8°58'0"W
32°47'30"N
32°47'0"N
32°46'30"N
32°46'0"N
32°45'30"N
32°45'0"N
32°44'30"N
32°44'0"N

Fig. 1

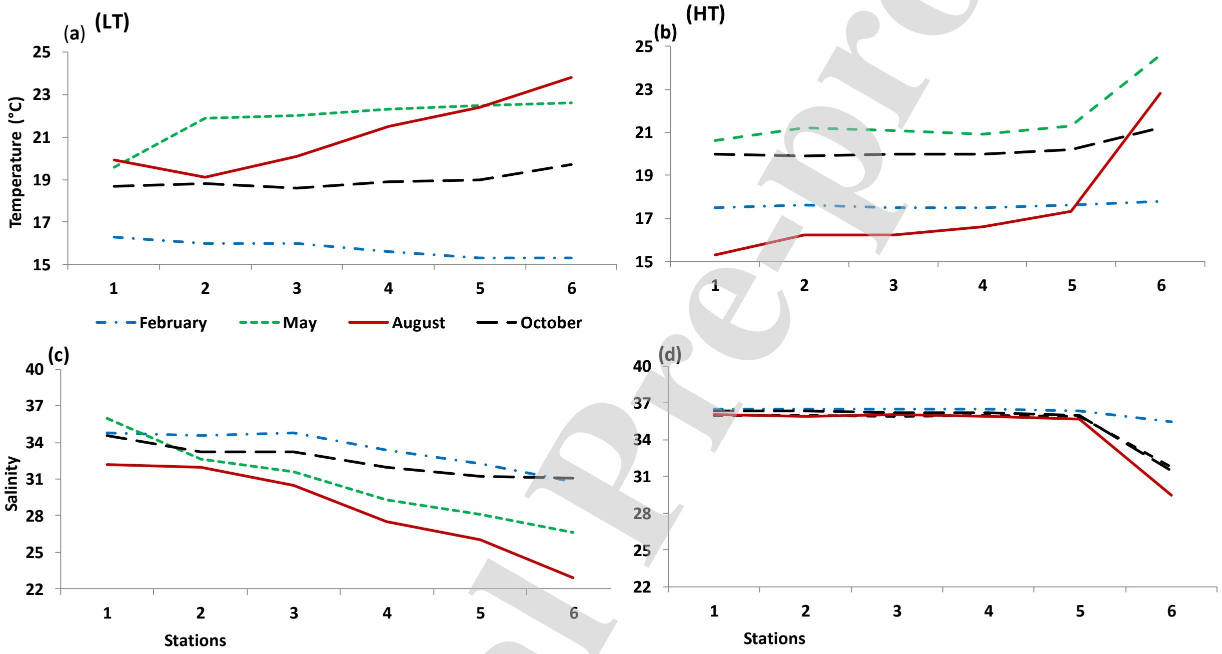
(a) (LT)
Temperature (°C)
25
23
21
19
17
15
1
2
3
4
5
6
(HT)
(b)
25
23
21
19
17
15
1
2
3
4
5
6
February
May
August
October
(c)
Salinity
40
37
34
31
28
25
22
1
2
3
4
5
6
Stations
(d)
40
37
34
31
28
25
22
1
2
3
4
5
6
Stations

Fig. 2

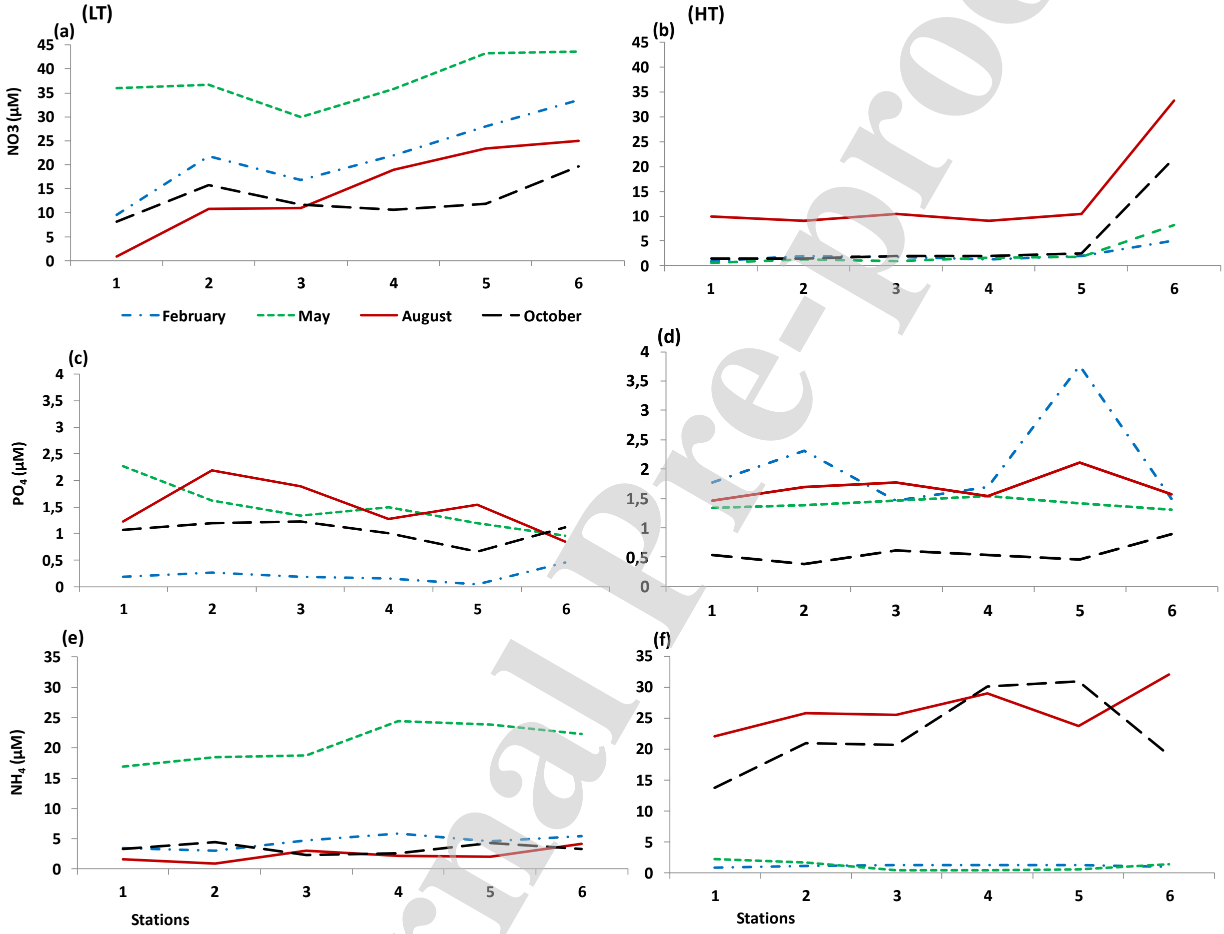
(LT)
(HT)
(a)
(b)
NO3 (µM)
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
February
May
August
October
(c)
(d)
PO₄ (µM)
4
3,5
3
2,5
2
1,5
1
0,5
0
(e)
(f)
NH₄ (µM)
35
30
25
20
15
10
5
0
Stations
Stations

Fig. 3

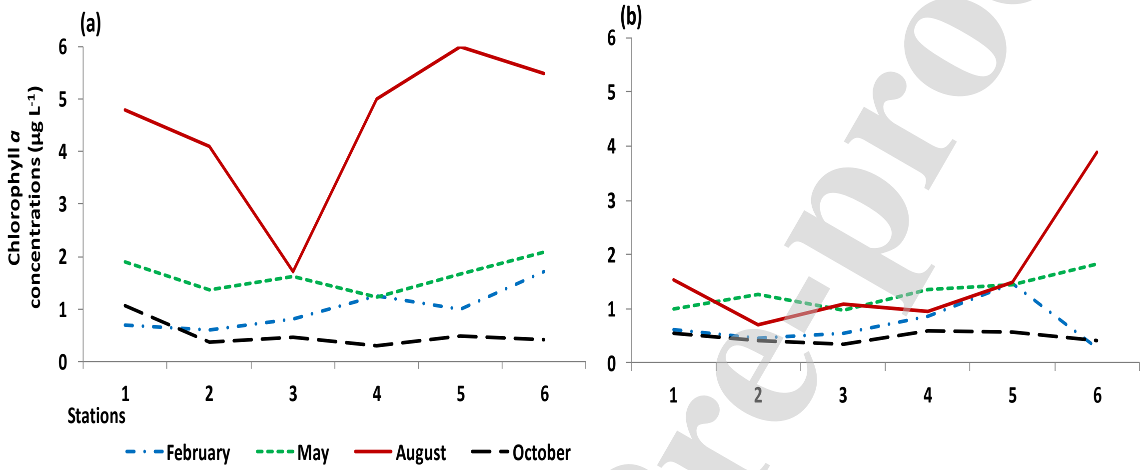
(a)
(b)
Chlorophyll a concentrations (μg L-1)
0
1
2
3
4
5
6
1
2
3
4
5
6
Stations
February
May
August
October

Fig.4

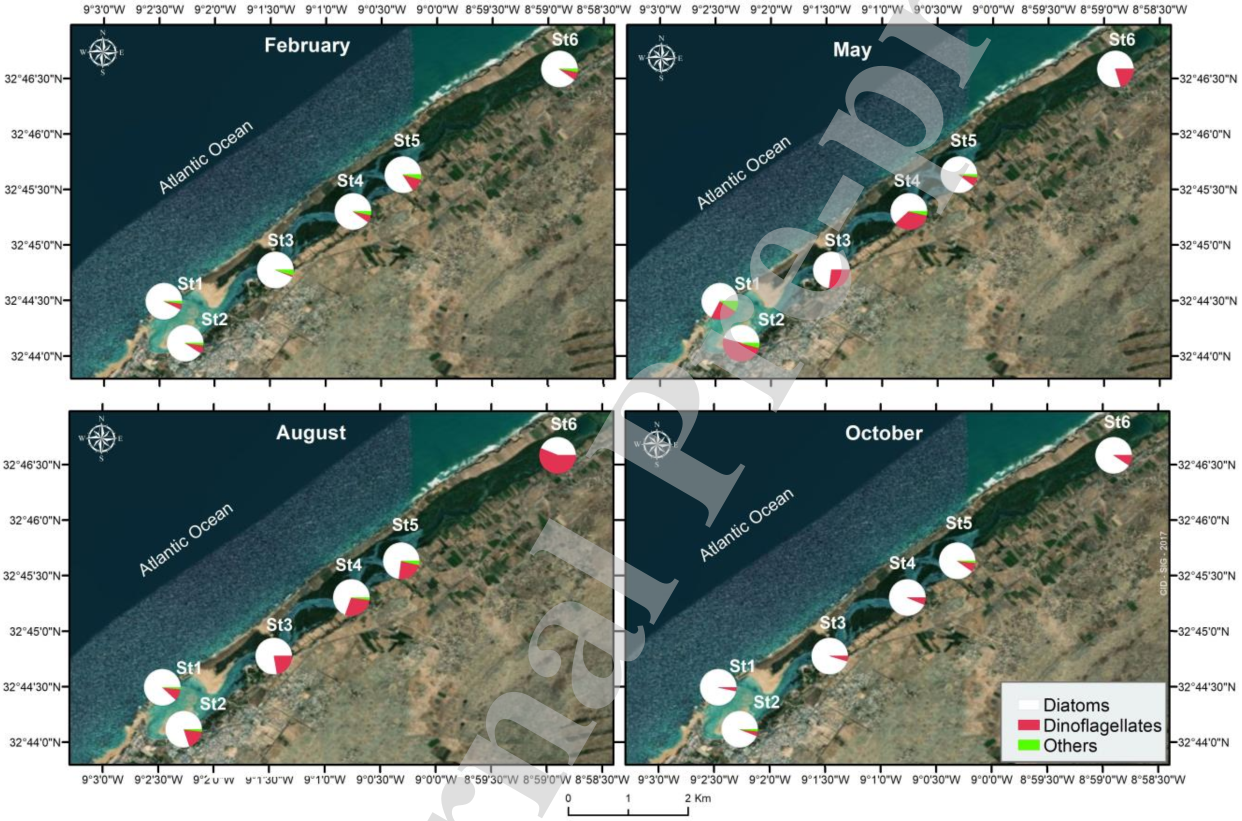
February
May
August
October
Atlantic Ocean
St1
St2
St3
St4
St5
St6
Diatoms
Dinoflagellates
Others
9°3'0"W
9°2'30"W
9°2'0"W
9°1'30"W
9°1'0"W
9°0'30"W
9°0'0"W
8°59'30"W
8°59'0"W
8°58'30"W
32°46'30"N
32°46'0"N
32°45'30"N
32°45'0"N
32°44'30"N
32°44'0"N
0
1
2 Km

Fig.5

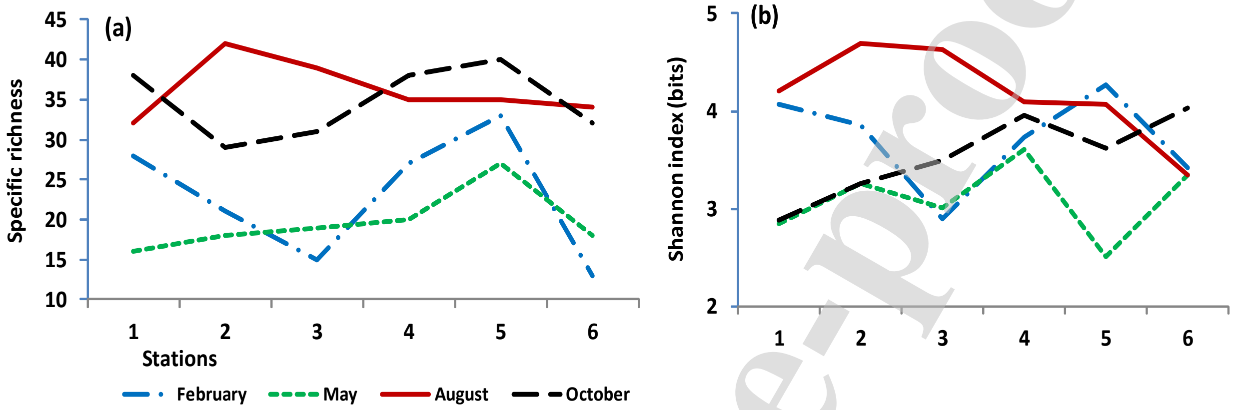
(a)
Specific richness
45
40
35
30
25
20
15
10
1
2
3
4
5
6
Stations
February
May
August
October
(b)
Shannon index (bits)
5
4
3
2
1
2
3
4
5
6

Fig.6

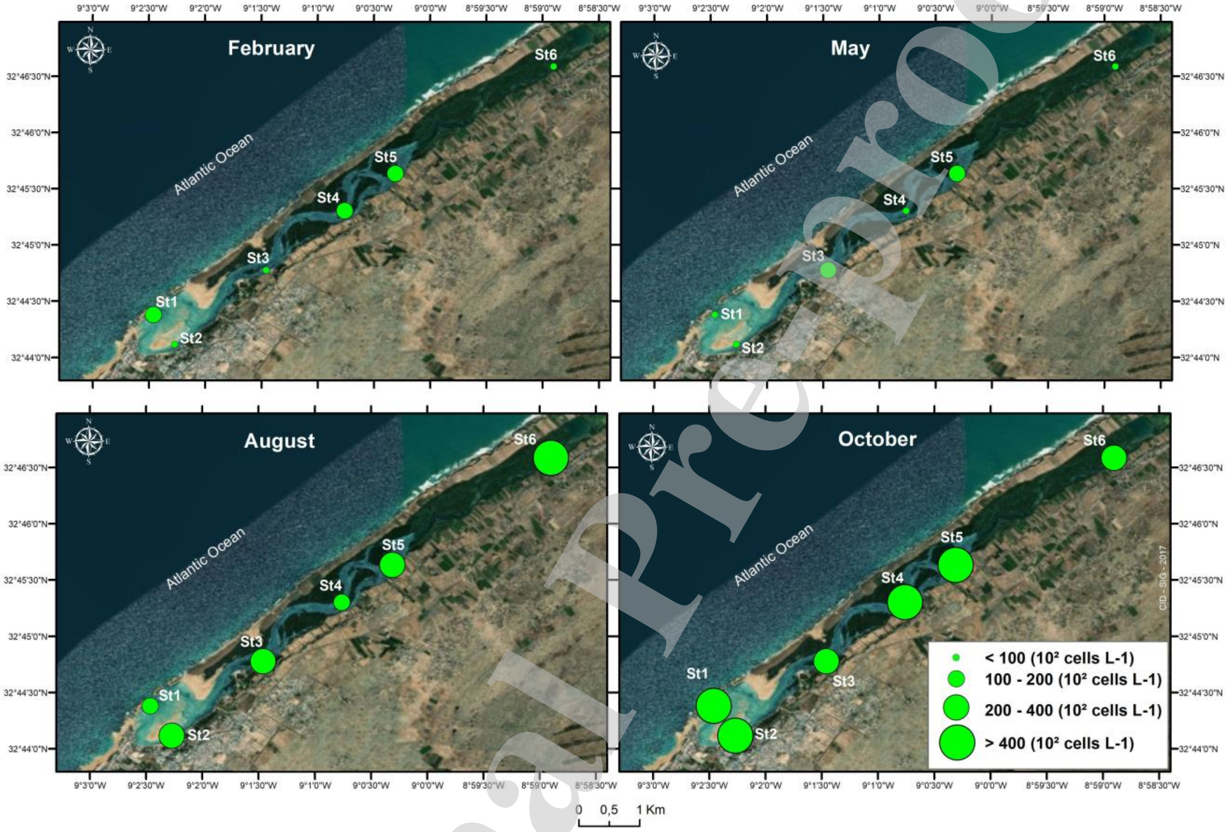
February
May
August
October
Atlantic Ocean
St1
St2
St3
St4
St5
St6
< 100 (10² cells L-1)
100 - 200 (10² cells L-1)
200 - 400 (10² cells L-1)
> 400 (10² cells L-1)
9°3'0"W
9°2'30"W
9°2'0"W
9°1'30"W
9°1'0"W
9°0'30"W
9°0'0"W
8°59'30"W
8°59'0"W
8°58'30"W
32°46'30"N
32°46'0"N
32°45'30"N
32°45'0"N
32°44'30"N
32°44'0"N
0 0,5 1 Km

Fig.7

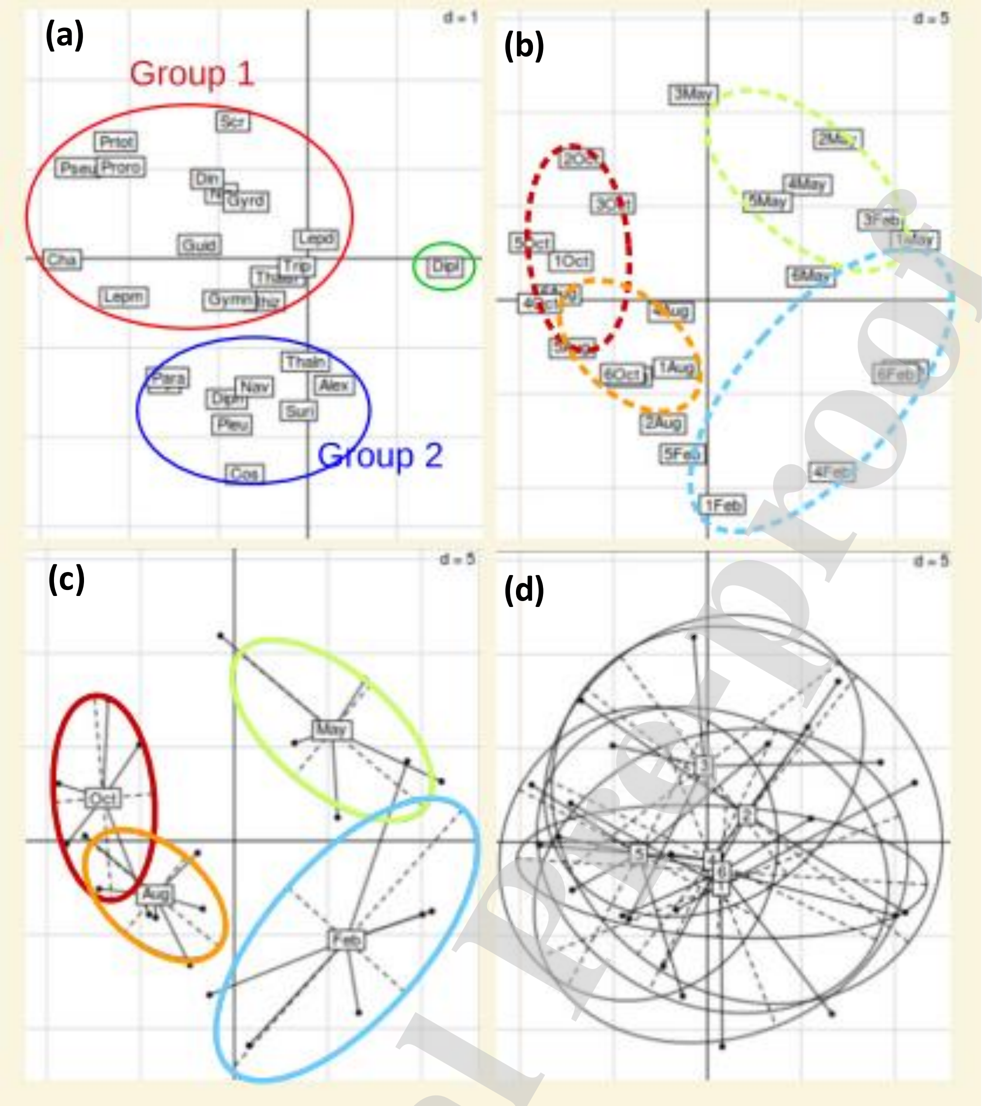
(a)
d = 1
Group 1
Scr
Prtot
Pseu
Proro
Din
Gyrd
Lepd
Guid
Cha
Trip
Dipl
Lepm
Gymn
Thaln
Para
Nav
Alex
Dipm
Sun
Pleu
Group 2
Cos
(b)
d = 5
3May
2May
2Oct
4May
3Oct
5May
3Feb
1May
5Oct
1Oct
6May
4Oct
4Aug
6Oct
1Aug
6Feb
2Aug
5Feb
4Feb
1Feb
(c)
d = 5
May
Oct
Aug
Feb
(d)
d = 5
3
2
5
1
6
4

Fig.8

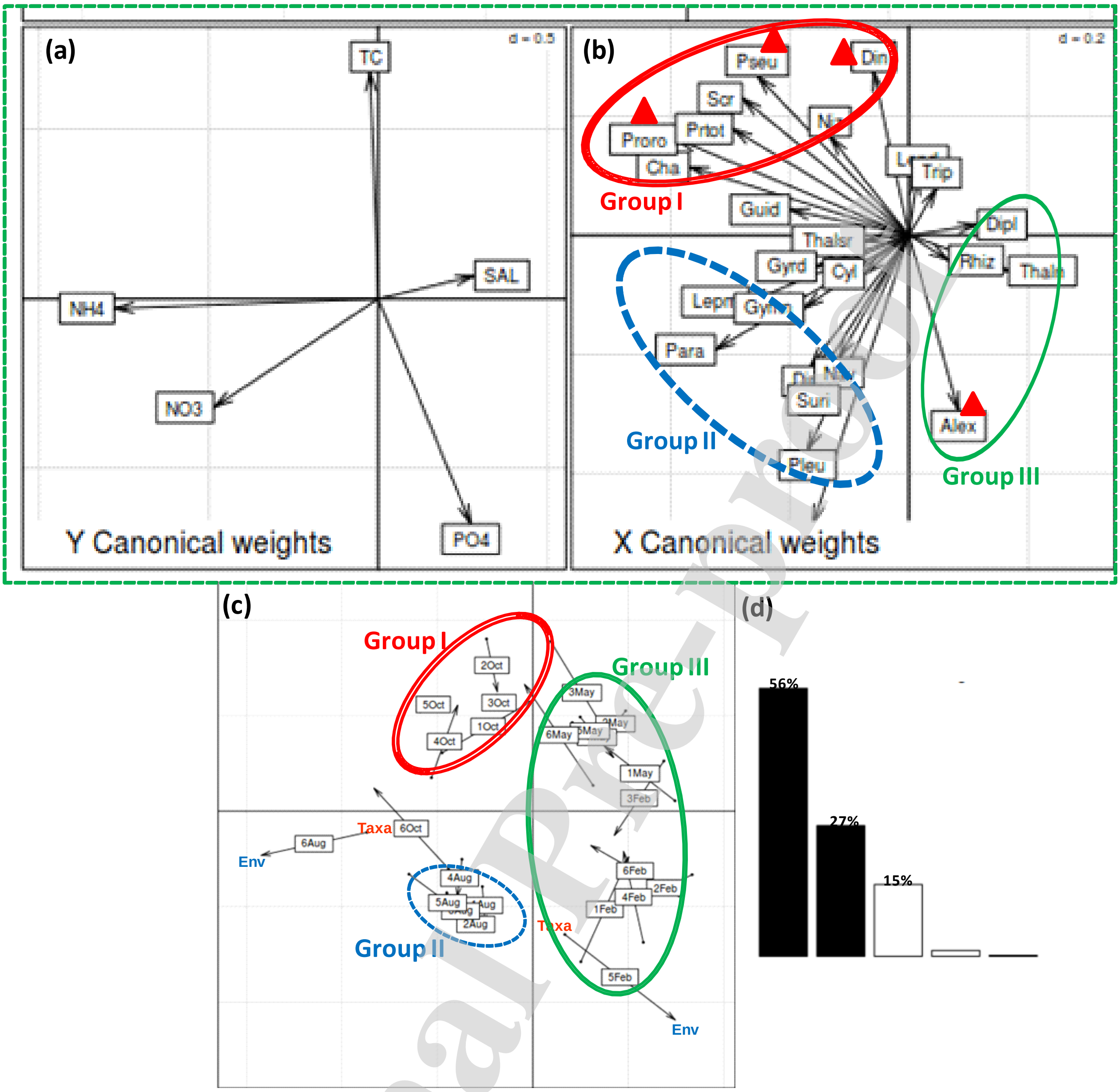
(a)
d = 0.5
TC
SAL
NH4
NO3
PO4
Y Canonical weights
(b)
d = 0.2
Pseu
Din
Scr
Prtot
Proro
Cha
Group I
Guid
Trip
Dipl
Rhiz
Thalr
Thalsr
Gyrd
Cyl
Lepn
Gymn
Para
Suri
Pleu
Alex
Group II
Group III
X Canonical weights
(c)
Group I
2Oct
3Oct
5Oct
1Oct
4Oct
Group III
3May
6May
5May
2May
1May
3Feb
Taxa
6Oct
6Aug
Env
4Aug
5Aug
2Aug
Group II
6Feb
2Feb
4Feb
1Feb
5Feb
Taxa
Env
(d)
56%
27%
15%

Fig.9

Table 1

Diatoms (% Frequency taxa)	**February**	**May**	**August**	**October**
Asteromphalus Ehrenberg. 1844	0.0	0.0	33.3	0.0
Adoneis Andrews & Rivera. 1987	16.7	0.0	0.0	0.0
Actinocyclus Ehrenberg. 1837	16.7	0.0	33.3	0.0
Amphora Ehrenberg ex Kützing. 1844	16.7	0.0	83.3	50.0
Bacillaria paxillifera (Müller) Marsson 1901	0.0	0.0	16.7	0.0
Bellerochea Van Heurck. 1885	0.0	16.7	33.3	16.7
Chaetoceros Ehrenberg. 1844	33.3	50.0	83.3	100.0
Cocconeis Ehrenberg. 1836	16.7	0.0	0.0	16.7
Coscinodiscus Ehrenberg. 1839	83.3	0.0	100.0	50.0
*Cyclotella (*Kützing) Brébisson. 1838	0.0	0.0	66.7	50.0
*Cerataulina pelagica (*Cleve) Hendey 1937	0.0	0.0	0.0	16.7
Cylindrotheca closterium (Ehrenberg) Reimann & Lewin 1964	66.7	0.0	50.0	100.0
Dactyliosolen Castracane. 1886	0.0	16.7	33.3	33.3
Detonula Schütt ex De Toni. 1894	0.0	0.0	16.7	16.7
Diploneis bombus (Ehrenberg) Ehrenberg 1853	83.3	33.3	100.0	50.0
Diploneis crabro (Ehrenberg) Ehrenberg 1854	0.0	0.0	33.3	33.3
Diploneis spp	100.0	16.7	83.3	100.0
Diatomée sp	16.7	16.7	16.7	0.0
Ditylum brightwellii (West) Grunow in Van Heurck 1885	16.7	0.0	0.0	0.0
Entomoneis Ehrenberg. 1845	0.0	33.3	33.3	33.3
Fragilaria Lyngbye. 1819	66.7	16.7	66.7	16.7
Eucampia Ehrenberg. 1839	0.0	0.0	0.0	33.3
Epithemia Kützing. 1844	0.0	0.0	50.0	33.3
Grammatophora Ehrenberg. 1840	0.0	50.0	50.0	83.3
Guinardia flaccida (Castracane) Peragallo 1892	0.0	0.0	33.3	0.0
Guinardia striata (Stolterfoth) Hasle. 1996	16.7	0.0	33.3	50.0
Guinardia sp1	16.7	0.0	33.3	16.7
Guinardia sp2	0.0	33.3	16.7	16.7
Gyrosigma Hassall. 1845	16.7	0.0	50.0	83.3
Hemiaulus proteus Heiberg. 1863	33.3	0.0	33.3	33.3
Helicotheca tamesis (Shrubsole) Ricard. 1987	16.7	0.0	50.0	16.7
Lauderia annulata Cleve. 1873	16.7	0.0	50.0	50.0
Leptocylindrus danicus Cleve. 1889	66.7	66.7	66.7	83.3
Leptocylindrus minimus Gran 1915	83.3	33.3	100.0	100.0
Leptocylindrus mediterraneus (Peragallo) Hasle 1975	16.7	0.0	0.0	16.7
Licmophora Agardh. 1827	16.7	16.7	16.7	33.3
Lyrella Karayeva. 1978	33.3	0.0	0.0	0.0
Mastogloia Thwaites in Smith. 1856	16.7	0.0	0.0	16.7
Melosira Agardh. 1824	16.7	0.0	66.7	83.3
Navicula Bory de Saint-Vincent. 1822	83.3	83.3	100.0	83.3
Nitzschia Hassall. 1845	83.3	100.0	100.0	100.0
Odontella Agardh. 1832	33.3	16.7	50.0	0.0

Paralia Heiberg. 1863	33.3	16.7	100.0	66.7
Pleurosigma Smith. 1852	50.0	16.7	100.0	33.3
Proboscia alata (Brightwell) Sundström. 1986	33.3	33.3	66.7	50.0
Pseudo-nitzschia delicatissima (Cleve) Heiden. 1928	16.7	50.0	33.3	100.0
Pseudo-nitzschia seriata (Cleve) Peragallo. 1899	0.0	16.7	16.7	83.3
Pseudonitzschia sp	16.7	0.0	16.7	0.0
Rhizosolenia styliformis Brightwell. 1858	0.0	0.0	0.0	16.7
Neocalyptrella robusta (Norman ex Ralfs) Hernández-Becerril & Meave del Castillo. 1997	16.7	0.0	0.0	0.0
Rhaphoneis Ehrenberg. 1844	0.0	16.7	16.7	16.7
Rhizosolenia imbricata Brightwell. 1858	33.3	0.0	0.0	0.0
Rhizosolenia sp	16.7	0.0	0.0	0.0
Rhizosolenia setigera f. pungens (Cleve-Euler) Brunel. 1962	0.0	0.0	0.0	16.7
Rhopalodia Müller. 1895	0.0	0.0	33.3	16.7
Rhabdonema Kützing. 1844	0.0	0.0	16.7	0.0
Synedra Ehrenberg. 1830	0.0	0.0	16.7	83.3
Scoliopleura Grunow. 1860	33.3	16.7	0.0	0.0
Skeletonema costatum (Greville) Cleve. 1873	0.0	0.0	0.0	33.3
Stephanopyxis palmeriana (Greville) Grunow. 1884	0.0	0.0	16.7	33.3
Striatella Agardh. 1832	33.3	0.0	16.7	0.0
Surirella Turpin. 1828	100.0	66.7	100.0	66.7
Thalassionema pseudonitzschioides (Schuette & Schrader) Hasle in Hasle & Syvertsen. 1996	16.7	0.0	33.3	0.0
Thalassionema nitzschioides (Grunow) Mereschkowsky. 1902	50.0	50.0	0.0	33.3
Thalassionema frauenfeldii (Grunow) Tempère & Peragallo. 1910	50.0	0.0	0.0	0.0
Thalassiosira Cleve. 1873	100.0	100.0	100.0	100.0
Trigonium Cleve. 1867	16.7	0.0	16.7	16.7
Triceratium Ehrenberg. 1839	16.7	0.0	0.0	0.0
Dinoflagellates (% Frequency taxa)	**February**	**May**	**August**	**October**
Alexandrium Halim. 1960	50.0	33.3	66.7	16.7
Tripos fusus (Ehrenberg) Gómez. 2013	0.0	0.0	0.0	33.3
Tripos furca (Ehrenberg) Gómez. 2013	33.3	16.7	16.7	16.7
Tripos macroceros (Ehrenberg) Gómez. 2013	16.7	0.0	0.0	16.7
Cochlodinium Schütt. 1896	0.0	0.0	33.3	0.0
Coolia monotis Meunier. 1919	0.0	16.7	16.7	0.0
Dinophysis acuminata Claparède & Lachmann. 1859	0.0	16.7	0.0	50.0
Dinophysis caudata Saville-Kent. 1881	0.0	0.0	0.0	16.7
Dinophysis fortii Pavillard. 1923	0.0	0.0	0.0	16.7
Dinophysis sp	0.0	0.0	0.0	16.7
Diplopsalis Bergh. 1881	50.0	83.3	33.3	16.7
Gonyaulax Diesing. 1866	50.0	0.0	33.3	0.0
Dinoflagellé sp	0.0	0.0	16.7	0.0

Gymnodinium Stein. 1878	66.7	100.0	100.0	83.3
Akashiwo sanguinea (Hirasaka) Hansen & Moestrup. 2000	16.7	0.0	16.7	0.0
Gyrodinium Kofoid & Swezy. 1921	0.0	16.7	83.3	33.3
Gyrodinium fusus (Meunier) Akselman. 1985	0.0	33.3	16.7	0.0
Gyrodinium spirale (Bergh) Kofoid & Swezy. 1921	0.0	16.7	33.3	0.0
Heterocapsa Stein. 1883	0.0	33.3	16.7	33.3
Hermesinum Zacharias. 1906	0.0	0.0	16.7	0.0
Peridiniella Kofoid & Michener. 1911	16.7	16.7	0.0	0.0
Peridinium quadridentatum (Stein) Hansen. 1995	0.0	0.0	16.7	16.7
Polykrikos Bütschli. 1873	0.0	16.7	16.7	16.7
Prorocentrum sp	0.0	16.7	16.7	0.0
Prorocentrum gracile Schütt. 1895	0.0	16.7	33.3	0.0
Prorocentrum lima (Ehrenberg) Stein. 1878	0.0	16.7	0.0	0.0
Prorocentrum micans Ehrenberg. 1834	0.0	50.0	100.0	100.0
Prorocentrum triestinum Schiller. 1918	0.0	0.0	0.0	16.7
Protoperidinium depressum (Bailey. 1854) Balech. 1974	16.7	0.0	0.0	16.7
Protoperidinium diabolum (Cleve. 1900) Balech. 1974	0.0	0.0	16.7	50.0
Protoperidinium conicum (Gran. 1900) Balech. 1974	0.0	0.0	0.0	33.3
Protoperidinium spp	16.7	66.7	50.0	66.7
Pronoctiluca Fabre-Domergue. 1889	0.0	16.7	50.0	33.3
Pyrophacus Stein. 1883	0.0	16.7	0.0	33.3
Karenia Hansen & Moestrup. 2000	0.0	0.0	16.7	0.0
Katodinium Fott. 1957	0.0	0.0	0.0	16.7
Scrippsiella Balech Loeblich III. 1965	16.7	100.0	83.3	83.3
Oxytoxum Stein. 1883	0.0	33.3	16.7	0.0
Ostreopsis Schmidt. 1901	0.0	33.3	33.3	50.0
Torodinium Kofoid & Swezy. 1921	0.0	0.0	16.7	0.0

Others groups (% Frequency taxa)	**February**	**May**	**August**	**October**
Raphidophyceae				
Chattonella Biecheler. 1936	50.0	33.3	33.3	33.3
Euglenophyceae				
Euglena Ehrenberg. 1830	83.3	50.0	33.3	16.7
Coccolithophorideae				
Coccolithus Schwarz. 1894	16.7	33.3	33.3	50.0
Silicoflagellates				
Octactis octonaria (Ehrenberg) Hovasse. 1946	16.7	0.0	33.3	33.3
Dictyocha sp	33.3	33.3	0.0	0.0
Dictyocha fibula Ehrenberg. 1839	0.0	0.0	0.0	16.7

Table 2

Hydrological variables	**Codes**
Temperature	TC
Salinity	SAL
Phosphates	PO_4
Nitrates	NO_3
Ammonium	NH_4

Taxa	**Codes**
Chaetoceros	Cha
Coscinodiscus	Cos
Cylindrotheca closterium	Cyl
Diploneis	Dipn
Guinardia	Guid
Leptocylindrus danicus	Lepd
Leptocylindrus minimus	Lepm
Navicula	Nav
Nitzschia	Niz
Paralia	Para
Pleurosigma	Pleu
Pseudonitzschia	Pseu
Rhizosolenia	Rhiz
Surirella	Suri
Thalassionema	Thaln
Thalassiosira	Thalsr
Alexandrium	Alex
Dinophysis	Din
Diplopsalis	Dipl
Gymnodinium	Gymn
Gyrodinium	Gyrd
Prorocentrum	Proro
Protoperidinium	Prtot

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Supervision : L. Somoue

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Montpellier 03 th may 2020
Dr. Mohamed Laabir and co-authors