



Spatio-temporal patterns of the Microphytoplankton community structure and distribution in a North African lagoon

L. Natij^{*1}, Z. Damsiri¹, A. Chaouti², M. Loudiki³, K. Khalil¹, K. Elkalay¹

¹Laboratory of Applied Sciences for the Environment and Sustainable Development, School of Technology, Essaouira, Cadi Ayyad University, Essaouira Al Jadida, Route d'Agadir, BP 383, Essaouira, Morocco.

²Laboratoire de Biochimie, Nutrition et Valorisation des Ressources Naturelles, Chouaib Doukkali University, Faculty of Sciences, Route Ben Mâachou, BP 20, 24000 El Jadida, Morocco.

³Laboratory of Algology and hydrophytes, Faculty of Sciences Semlalia of Marrakech, Cadi Ayyad University, Bd Prince Mlly Abdellah, BP 511 Marrakech, Morocco.

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*Corresponding author. E-mail: natij.laila@gmail.com; Phone: +212 615 924 491

Abstract

The spatio-temporal variability of the microphytoplankton community was investigated in the Oualidia lagoon (Atlantic-Morocco). Microphytoplankton structure, composition and distribution were analyzed at six sampling stations during an annual cycle (from June 2011 to May 2012), based on phytoplankton net and bottle samples. A total of 126 taxa belonging to 2 divisions were identified, including Bacillariophyceae (80 taxa) and Dinophyceae (46 taxa). The highest species richness (57 taxa) was found in the central zone of the lagoon (whereas the lowest one (41 taxa) was recorded in the most distal to the sea inlet station). The highest microphytoplankton abundance (2.82×10^5 cells L⁻¹) and the lowest (1.53×10^5 cells L⁻¹) were measured respectively at the most distal and proximal to the sea inlet stations. The values of H' and J' index showed that the microphytoplankton community never reached a situation of monospecificity and was in equilibrium at the entire lagoon. A diversity model (DIMO) distinctly separated the winter microphytoplankton populations from spring, summer and autumn microphytoplankton populations. The transition from the first to the second group was accompanied by an increase in species richness, diversity and evenness. The rank-frequency diagram revealed the mature character of microphytoplankton populations and thus characterized a stable environment in Oualidia lagoon.

Keywords: Morocco, Atlantic coast, Oualidia lagoon, Marine microphytoplankton, Taxonomic and functional diversities.

1. Introduction

Transitional coastal waters are characterized by specific ecological features (shallowness and relative isolation from the open sea, usually as a result of coastal barriers that maintain some communication channels or inlets [1] [2] and an intrinsic heterogeneity, mainly due to their specific geomorphology, catchment area geology, and geographic location, as well as to differences in freshwater runoff and tidal salt water exchanges [3]. They exhibit high primary and secondary productions that promote the development of extensive fisheries and aquaculture [4] [5]. These transitional coastal waters are considered as vulnerable ecosystems that need particular conservation and management measures, specifically based on the knowledge of their biological and taxonomic diversity [6]. Phytoplankton represents the base of the marine food web. These microorganisms act as primary producers and are the direct food source for other aquatic animals [7] [8]. Several factors such as residence time, depth, salinity and nutrient concentrations control phytoplankton biodiversity and dynamics in transitional coastal waters [9] [10]. Hence, phytoplankton community may serve as a water quality indicator because of its high species richness

and sensitivity to environmental stress [11]. Phytoplankton composition and distribution in Oualidia lagoon on the Atlantic Moroccan coasts have been scarcely investigated and no recent information is available, with the exception of the work of Bennouna [12] [13] on the potentially harmful dinoflagellates in this lagoon. Thus, the present study offers a good contribution to the growing body of knowledge on this lagoonal ecosystem. This work aims at investigating the spatiotemporal variability of phytoplankton community of the Oualidia lagoon. The taxonomic composition and abundances of microphytoplankton cells were studied in order to provide a taxonomic list of species that could be useful to improve our knowledge of this lagoon. This work aims also at establishing a reference situation for this Moroccan Atlantic lagoon ecosystem.

2. Materials and methods

2.1. Study area and sampling stations

The Oualidia Lagoon is located on the Atlantic coast of Morocco, between the El Jadida and Safi cities, at 32°40'42"N–32°47'07"N of latitude and 8°52'30"W–9°02'50"W of longitude. This lagoon has a stretched shape with approximately 7 km length and 0.5 km mean width [14]. It exchanges water with the ocean with a major inlet (lagoon entrance) (Fig. 1). The maximum depth ranges from 6 m, close to the lagoon entrance, to 0.5 m, at the lagoon inner part. The tide currents can reach 77 cm/s during spring tides [15]. The tidal range varies between 2 m, during spring high tides, and 0.6 m, during neap tides. Intertidal areas on both sides of the channels cover about 53% (1.6 km²) of the 3 km² surface area of the lagoon at low tide [16]. Flood tides cover more than 75% (2.25 km²) of the lagoon surface, bringing salt water up to the inner reaches of the lagoon and into a saline marsh beyond the second dam [17]. The biological and ecological importance of this system was demonstrated by its recognition as an international Ramsar site. Oualidia lagoon supports many aspects of the lives of local people, such as economic, cultural, and community relationships [18]. In the past forty years, Oualidia lagoon is subject to different land uses (rapid urbanization, boating, bathing, camping, agriculture, shell-fishing, cattle rearing) [16] [19] [20] producing various kinds of pollution. At present, most wastes discharged to Oualidia lagoon are not treated [18]. Six stations (S1, S2, S3, S4, S5 and S6) were sampled (Fig. 1). Station 1 and Station 2 were located in the downstream zone of the lagoon, Station 3 and Station 4 in the central zone, and Station 5, Station 6 in upstream zone. Distances of stations compared to the reference station (S1) is given in Table 1.

2.2 Sampling and identification of microphytoplankton

Temperature and salinity were measured *in-situ* with a multiparametric sensor (Multi340i WTW82362 Weilheim). Microphytoplankton populations of the Oualidia lagoon were studied bimonthly at the six sampling stations during high tide events from June 2011 to May 2012. 1 L water samples were collected from the surface (~50 cm depth) for quantitative enumeration of microphytoplankton (Abundance, diversity: Shannon-Wiener's index H' ; as \log_2 , evenness (Pielou's index J')). Additionally, microphytoplankton samples were collected by towing a 20 μm mesh size net against the current at subsurface level (~50 cm depth) for ten minutes, in order to perform taxonomic study - Species identification in the live samples, collected with net, was performed by light microscopy (Olympus BX40). The species classification was done according to literature [21] [22] [23] [24] [25] [26] [27] [28]. Microphytoplankton abundance was determined via subsamples (25 ml) fixed in Lugol's solution and settled at least 6 hours according to Utermöhl method [29]. These samples were examined in the laboratory using a Nikon Diaphot 300 inverted phase contrast microscope.

2.3 Microphytoplankton community structure analysis

Data were analysed using a combination of univariate methods. Microphytoplankton community structure was analysed regarding abundance, diversity (Shannon-Wiener's index H' ; as \log_2), evenness (Pielou's index J'), total number of species and frequency coefficient. These variables were estimated for each station and each month. Several indices were used to define the complexity of the phytoplankton community in the Oualidia lagoon.

(1) Frequency coefficient: Frequency was calculated with the following equality:

$F = \frac{F_i}{F_t} \times 100$, where F_i : presence number of i species in total sampling; F_t : total number of sampling of whole species.

(2) The Shannon–Weaver diversity index H' [30]:

$$H' = -\sum_{i=1}^S f_i \times \log_2 f_i$$

where S is the species richness and f_i is frequency of species i .

(3) The Pielou's evenness J' [31] of the distribution of individuals between the taxonomic groups:

$$R = \frac{H'}{H \text{ maximum}} \Leftrightarrow R = \frac{H'}{\log_2 S}$$

where S is the species richness of the community.

(4) The indices (S) as \log_2 , (H') and (J') of each sampling station and season were plotted together on a two-dimensional graphic representation in a diversity model called DIMO model [32] and regarded as a synthetic tool.
 (5) The Rank-frequency diagrams (RFD) were established to describe phytoplankton samples [33]. The species were ranked by decreasing abundance along the x-axis and by relative frequency along the y-axis. To improve the discrimination of the RFD, both axes were represented on a \log_{10} scale.

Significance of the differences between the biotic variables (H' and J') and abiotic variables (salinity, temperature, and turbidity) was determined using the Mann-Whitney U-test.

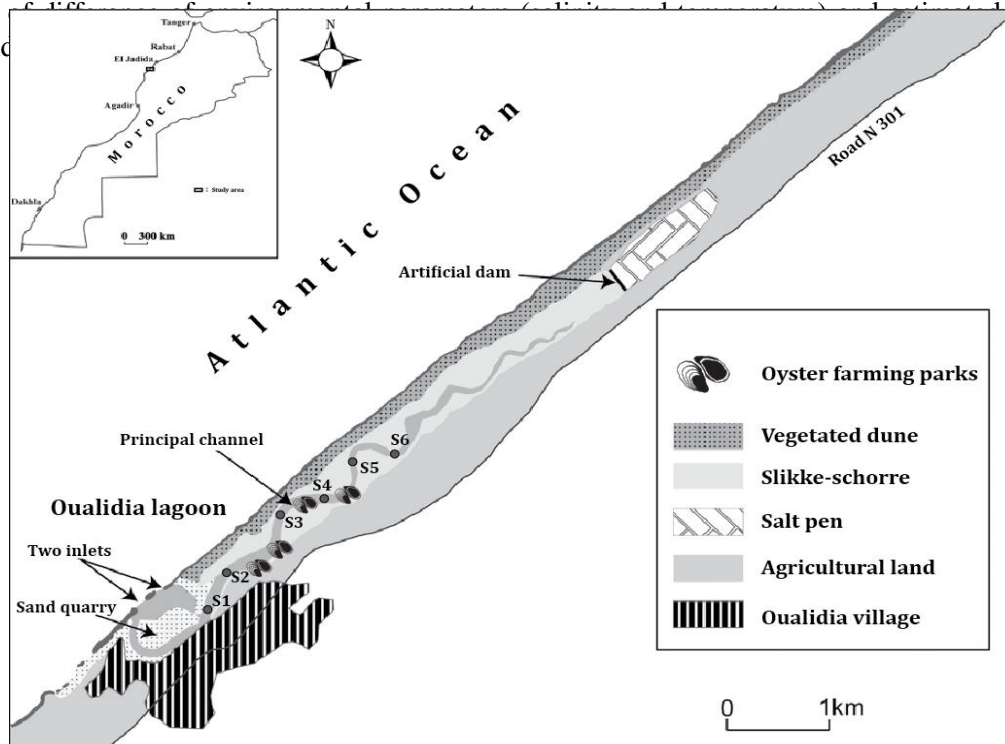


Figure 1: Location of Oualidia lagoon, position of sampling stations and oyster farming parks.

Table 1: Distances from the reference station (S1) and average depth of sampling stations.

Stations	Distance from S1 (Km)	Average depth at high tide (m)
S1	-	3.5
S2	0.5	5
S3	1	5
S4	3	3
S5	3.5	2
S6	4	2

3. Results and discussion

3.1. Temperature and salinity

Temperature varied significantly among stations (ANOVA, $F=4.143$, $p<0.01$) and months (ANOVA, $F=13.472$, $p<0.001$; Fig. 2). Temperature values ranged from 15.53 ± 0.05 °C (in January) to 23.02 ± 1.26 °C (in September). A decreasing trend was recorded from November (autumn) to March (spring). Salinity showed significant differences among stations (ANOVA, $F=4.585$, $p<0.001$) and months (ANOVA, $F=7.600$, $p<0.001$; Fig. 2). Salinity showed the lowest value (24.85 ± 0.83 psu) in August and the highest value (39.37 ± 2.92 psu) in October. A downstream-upstream increasing gradient was reported for temperature (S1: 17.1 ± 1 °C; S6: 19.8 ± 3.2 °C) reflecting the influence of the cold ocean waters at the entrance of the lagoon and the decreased depth upstream, which promotes the rapid warming of the waters. Salinity followed a decreasing downstream-upstream gradient (S1: 35.3 ± 1.3 PSU; S6: 31.1 ± 3.7 PSU) which is explained by freshwater masses upstream of the lagoon, reducing the salinity in this part. The range of temperature variation recorded in this study illustrates a pattern classically observed in the arid to semi-arid zone of the northern hemisphere, with warming starting in spring and reaching its maximum in July to August, followed by cooling in January. Temperature and salinity showed stronger temporal variations than spatial ones. The recorded temperature range of surface water was relatively narrow (16–28 °C) for a shallow lagoon (maximum 5 m deep at high tide flowing water) [34]. The temperature values, recorded in this study are consistent with those reported by several authors [35] [36] [12] in the same area. Salinity values obtained in our study can be explained by the homogeneity of the salinity in the rising tides where the values are similar to those of the ocean. The presence of a continuous freshwater input at the upstream zone clearly influences the general development of salinity. Our salinity results are lower than those recorded in the lagoon of Nador in the Moroccan Mediterranean Sea where the normal value of salinity is around 36.7 psu, due of substantially closing the inlet, and secondly the high water deficit in summer [37].

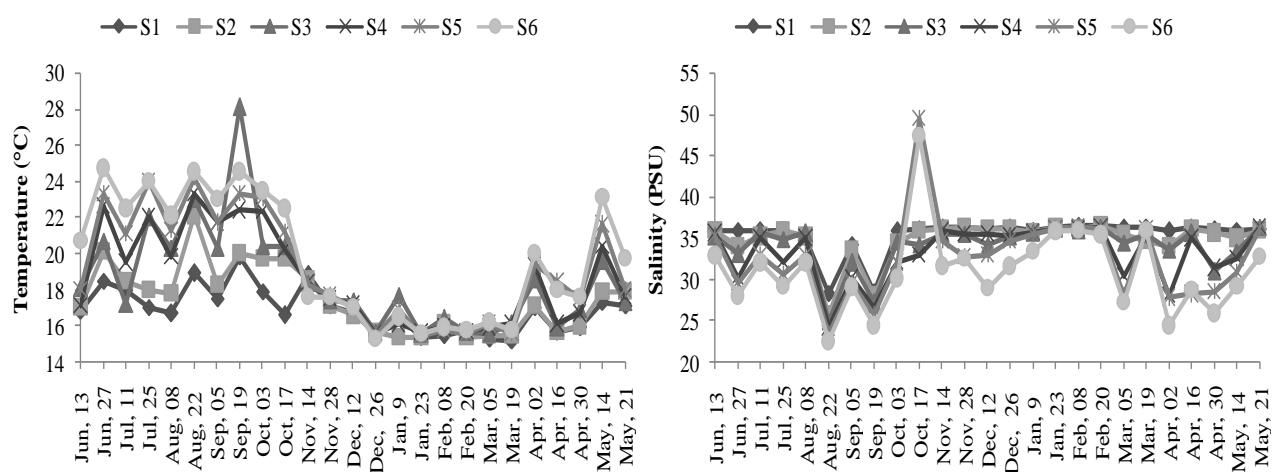


Figure 2: Temporal variability of temperature and salinity for each sampling site in the Oualidia lagoon.

3.2. Microphytoplankton community structure

The microphytoplankton community of the Oualidia lagoon consisted of two dominant groups: Bacillariophyceae and Dinophyceae. The first one dominated both qualitatively (63.5%) and quantitatively (80.3%) (Tab. 3). According to Margalef [38], the marine influence permitted the dominance of Bacillariophyceae class which was reported to be favoured by vertical mixing of water column. Our results are consistent to those of Bennouna [12] which showed that phytoplankton community in both the Qualidia and the Sidi Moussa (Moroccan Atlantic) lagoon were dominated by Bacillariophyceae and Dinophyceae. Similar results have been reported in other studies carried out in transitional water ecosystems in the Mediterranean basin [39], in the Moroccan Mediterranean Sea [40] and in the Moroccan Atlantic coast [41], [42].

Despite its small size and average depth, Oualidia lagoon supports a rather rich microphytoplakton community, in terms of the number of species, when compared with other lagoons: Moulay Bousselham lagoon (35 species) [43]; Massa estuary (105 species) [44]; Ghar El Melh Lagoon (61 species) [45]. A total of 126 microphytoplankton species were found. Bacillariophyceae made up the highest number of species (22 orders, 31 families, 46 genera, 80 species) followed by Dinophyceae (5 orders, 10 families, 14 genera, 46 species) (Tab. 2). Among the species collected in the present work, 46 were newly reported for Oualidia lagoon. Among the microphytoplankton contingent, 10 species previously reported [46] were not encountered during this study; 7 species of Bacillariophyceae and 3 species of Dinophyceae (Tab. 2). This can be explained by the number of stations sampled (6 vs. 4 in 2010) or sampling time (annual cycle vs. 4 months (February to May 2010)). Only nine species (5 Bacillariophyceae and 4 Dinophyceae) made a global contribution exceeding 1% to microphytoplankton community. The dominant Bacillariophyceae species were: (1) *Pseudo-nitzschia sp* with 15% at S4, (2) *Chaetoceros sp* with 10.6% at S6, (3) *Nitzschia sp* with 4.7% at S1, (4) *Asterionellopsis sp* with 3.5% at S3 and (5) *Coscinodiscus centralis* with 3.6% at S4. The dominant Dinophyceae species were: (1) *Prorocentrum sp* with 4.1 % at S1, (2) *Gymnodinium sp* with 4.8% at S3, (3) *Gyrodinium spirale* with 2.7% at S5 and (4) *Lingulodinium polyedrum* with 4.3% at S6. The richness in algal flora in the Oualidia lagoon can be related to the proximity of the coast and the influence of continental inputs. According to Hennani [20], winds blowing from the northern sector will produce southerly geotropic currents along the coasts, offshore transport and coastal upwelling of nutrient-rich deep waters close to the coasts. It also can be explained by the effect of the tide that remains among the factors influencing phytoplankton abundance lagoon [47] [48]: microphytoplankton assemblage at high tide is richer than at low tide. According to Hennani [20], upwelled waters with high nutrient content can be advected by flood tides into the lagoon, supporting biological production. This was also observed in previous studies at the Oualidia lagoon and the Nador lagoon [49].

Table 2: Comparative analysis of list of microphytoplankton (A: Bacillariophyceae, B: Dinophyceae) established by this study with the previous study of Naala [46] in Oualidia lagoon.

-A-				
Taxonomic groups	Family	Species	This study	Naala (2010)
Bacillariophyceae	Achnantheaceae	<i>Achnantes longipes</i> C.Agardh	*	*
		<i>Achnantes sp.</i>	*	*
	Cocconeidaceae	<i>Cocconeis pellucida</i> Hantzsch	*	*
		<i>Cocconeis sp.</i>	*	*
	Bacillariaceae	<i>Bacillaria paxillifera</i> (O.F.Müller) T.Marsson	*	*
		<i>Cylindrotheca fusiformis</i> Reimann&J.C.Lewin	*	*
		<i>Cymatonitzschia marina</i> (F.W.Lewis) R.Simonsen	*	*
		<i>Nitzschia sp.</i>	*	*
		<i>Psammodictyon panduriforme</i> (W.Gregory) D.G.Mann	*	*
		<i>Pseudo-nitzschia sp.</i>	*	*
		<i>Cymbella sp.</i>	*	
	Lyrellaceae	<i>Lyrella praetexta</i> (Ehrenberg) D.G.Mann	*	*
		<i>Amphipleura pellucida</i> (Kützing)	*	*

	Kützing		
	<i>Frustulia sp.</i>	*	*
Diploneidaceae	<i>Diploneis bombus</i> (Ehrenberg) Ehrenberg	*	*
	<i>Diploneis sp.</i>	*	*
Naviculaceae	<i>Navicula sp.</i>	*	*
Plagiotropidaceae	<i>Plagiotropis sp.</i>	*	*
Scoliotropidaceae	<i>Scoliotropis latestriata</i> (Brébisson ex Kützing) Cleve		*
Pleurosigmataceae	<i>Gyrosigma sp.</i>	*	*
	<i>Pleurosigma sp.</i>	*	*
Rhopalodiaceae	<i>Epithemia turgida</i> (Ehrenberg) Kützing	*	*
Catenulaceae	<i>Amphora egregia</i> Ehrenberg <i>Amphora sp.</i>	*	*
Anaulaceae	<i>Anaulus creticus</i> Drebes & Schulz	*	
Biddulphiaceae	<i>Biddulphia biddulphiana</i> (J.E.Smith) Boyer	*	
	<i>Biddulphia sp.</i>	*	*
	<i>Biddulphia tuomeyi</i> (Bailey) Roper	*	
	<i>Trigonium alternans</i> (J.W.Bailey) A.Mann	*	*
	<i>Trigonium sp.</i>	*	
Hemiaulaceae	<i>Cerataulina pelagica</i> (Cleve) Hendey	*	*
	<i>Cerataulina sp.</i>	*	*
	<i>Eucampia sp.</i>	*	*
	<i>Eucampia zodiacus</i> Ehrenberg	*	
	<i>Hemiaulus sp.</i>	*	
Triceratiaceae	<i>Triceratium dubium</i> Brightwell		*
	<i>Odontella aurita</i> (Lyngbye) C.Agardh	*	*
	<i>Odontella regia</i> (Schultze) Simonsen	*	
	<i>Odontella sp.</i>	*	*
Chaetocerotaceae	<i>Chaetoceros affinis</i> Lauder	*	
	<i>Chaetoceros curvisetus</i> Cleve	*	
	<i>Chaetoceros danicus</i> Cleve	*	
	<i>Chaetoceros decipiens</i> Cleve	*	
	<i>Chaetoceros mitra</i> Cleve		*
	<i>Chaetoceros radicans</i> Schutt	*	
	<i>Chaetoceros sp.</i>	*	*
Leptocylindraceae	<i>Leptocylindrus danicus</i> Cleve	*	*
Paraliaceae	<i>Paralia sulcata</i> (Ehrenberg) Cleve		*
Coscinodiscaceae	<i>Coscinodiscus centralis</i> Ehrenberg	*	
	<i>Coscinodiscus granii</i> Gough	*	

	<i>Coscinodiscus jonesianus</i> (Grunow) Hustedt	*	
	<i>Coscinodiscus radiatus</i> Ehrenberg	*	
	<i>Coscinodiscus sp.</i>	*	*
Heliopeltaceae	<i>Actinoptychus sp.</i>	*	
Hemidiscaceae	<i>Hemidiscus sp.</i>	*	
Melosiraceae	<i>Melosira nummuloides</i> C.Agardh	*	*
	<i>Melosira sp.</i>	*	*
Lithodesmiaceae	<i>Ditylum sp.</i>	*	*
	<i>Helicotheca sp.</i>	*	
Rhizosoleniaceae	<i>Guinardia delicatula</i> (Cleve) Hasle	*	
	<i>Guinardia flaccida</i> (Castracane) H.Peragallo	*	
	<i>Guinardia sp.</i>	*	*
	<i>Guinardia striata</i> (Stolterfoth) Hasle	*	*
	<i>Rhizosolenia crassispina</i> J.L.B.Schröder	*	*
	<i>Rhizosolenia hebetata</i> J.W.Bailey	*	*
	<i>Rhizosolenia setigera</i> Brightwell	*	*
	<i>Rhizosolenia sp.</i>	*	*
Lauderiaceae	<i>Lauderia annulata</i> Cleve	*	*
	<i>Lauderia sp.</i>	*	*
Skeletonemaceae	<i>Detonula sp.</i>	*	
Thalassiosiraceae	<i>Thalassiosira anguste-lineata</i> (A.Schmidt) G.Fryxell&Hasle	*	*
	<i>Thalassiosira mendiolana</i> Hasle&Heimdal	*	*
	<i>Thalassiosira rotula</i> Meunier	*	*
	<i>Thalassiosira sp.</i>	*	*
Fragilariaceae	<i>Asterionellopsis glacialis</i> (Castracane) Round	*	*
	<i>Asterionellopsis sp.</i>	*	*
	<i>Ceratoneis closterium</i> Ehrenberg	*	*
	<i>Fragilaria sp.</i>	*	*
Licmophoraceae	<i>Licmophora sp.</i>	*	
Striatellaceae	<i>Grammatophora marina</i> (Lyngbye) Kützing	*	*
	<i>Grammatophora undulata</i> Ehrenberg	*	*
	<i>Grammatophora sp.</i>		*
Surirellaceae	<i>Surirella fastuosa</i> Ehrenberg		*
	<i>Surirella sp.</i>		*
Thalassionemataceae	<i>Lioloma sp.</i>	*	
	<i>Thalassionema nitzschioides</i> (Grunow)	*	*

		Mereschkowsky			
		<i>Thalassionema sp.</i>	*	*	
-B-					
Taxonomic groups	Family	Species	This study	Naala (2008)	
Dinophyceae	Amphisoleniaceae	<i>Amphisolenia sp.</i>	*		
	Dinophysiaceae	<i>Dinophysis acuminata</i> Claparède&Lachmann	*	*	
		<i>Dinophysis acuta</i> Ehrenberg	*		
		<i>Dinophysis caudata</i> Saville-Kent	*		
		<i>Dinophysis fortii</i> Pavillard	*		
		<i>Dinophysis hastata</i> Stein	*		
		<i>Dinophysis sacculus</i> Stein	*		
		<i>Phalacroma rapa</i> Jorgensen	*		
		<i>Phalacroma rotundatum</i> (Claparède&Lachmann) Kofoid& Michener	*		
		Ceratiaceae	<i>Neoceratium arietinum</i> (Cleve) F. Gómez, D. Moreira & P. López-García	*	
			<i>Neoceratium belone</i> (Cleve) F. Gómez, D. Moreira & P. López-García	*	
	<i>Neoceratium breve</i> (Ostenfeld& Schmidt) F.Gómez, D.Moreira&P.López-García		*		
	<i>Neoceratium candelabrum</i> (Ehrenb.) F. Gómez, D. Moreira& P. López-García		*		
	<i>Neoceratium furca</i> (Ehrenberg) F. Gómez, D. Moreira& P. López-García		*	*	
	<i>Neoceratium fusus</i> (Ehrenberg) F. Gómez, D. Moreira& P. López-García		*	*	
	<i>Neoceratium horridum</i> (Gran) F. Gómez, D. Moreira& P. López-García		*		
	<i>Neoceratium karstenii</i> (Pavillard) F.Gomez, D.Moreira&P.Lopez-García		*		
	<i>Neoceratium macroceros</i> (Ehrenb.) F. Gómez, D. Moreira& P. López-García		*		
	<i>Neoceratium massiliens</i> (Gouret)	*			

	F. Gómez, D. Moreira & P. López-García		
	<i>Neoceratium minutum</i> (Jørgensen)		
	F. Gómez, D. Moreira & P. López-García	*	
	<i>Neoceratium sp.</i>	*	
	<i>Neoceratium symmetricum</i> (Pavill.)		
	F. Gómez, D. Moreira & P. López-García	*	
	<i>Neoceratium trichoceros</i> (Ehrenb.)		
	F. Gómez, D. Moreira & P. López-García	*	
	<i>Neoceratium tripos</i> (O.F.Müller) F. Gómez, D. Moreira & P. López-García	*	
Gonyaulacaceae	<i>Alexandrium affine</i> (H.Inoue & Y.Fukuyo) Balech		*
	<i>Gonyaulax verior</i> Sournia	*	
	<i>Gonyaulax polygramma</i> Stein	*	
	<i>Gonyaulax sp.</i>		*
	<i>Lingulodinium polyedrum</i> (F.Stein) Dodge	*	*
Ostreopsidaceae	<i>Ostreopsis sp.</i>	*	*
Gymnodiniaceae	<i>Gymnodinium sp.</i>	*	*
	<i>Gyrodinium spirale</i> (Bergh) Kofoid & Swezy	*	*
Peridiniaceae	<i>Peridinium quinquecorne</i> Abé	*	*
Calciodinelloideae	<i>Scrippsiella sp.</i>	*	*
Peridiniida incertae sedis	<i>Heterocapsa sp.</i>	*	*
Polykrikaceae	<i>Polykrikos sp.</i>		*
Proto-peridiniaceae	<i>Diplopsalis sp.</i>	*	*
	<i>Proto-peridinium bipes</i> (Paulsen) Balech	*	*
	<i>Proto-peridinium cerasus</i> (Paulsen) Balech	*	*
	<i>Proto-peridinium depressum</i> (Bailey) Balech	*	*
	<i>Proto-peridinium diabolus</i> (Cleve) Balech	*	*
	<i>Proto-peridinium sp.</i>	*	*
	<i>Proto-peridinium steinii</i> (Jørgensen)	*	*
Prorocentraceae	<i>Prorocentrum cordatum</i> (Ostenfeld) Dodge	*	*
	<i>Prorocentrum gracile</i> Schütt	*	*
	<i>Prorocentrum micans</i> Ehrenberg	*	*

<i>Prorocentrum scutellum</i> Schröder	*	*
<i>Prorocentrum</i> sp.	*	*
<i>Prorocentrum triestinum</i> Schiller	*	*

Bacillariophyceae abundance was higher than Dinophyceae abundance at all sampling stations and months, with the exception of S1 in summer (June) where Dinophyceae abundance reached a value of 0.73×10^5 cells L^{-1} while Bacillariophyceae were 0.64×10^5 cells L^{-1} in the same station (Tab. 4).

Table 3: Taxonomic composition and proportional representation of microphytoplankton groups at the Oualidia lagoon.

	Genus	Species	%	10^5 cells L^{-1}	%
Bacillariophyceae	46	80	63.5	28.85	80.3
Dinophyceae	14	46	36.5	7.07	19.7
Total	60	126	100	35.92	100

The distribution of microphytoplankton revealed significant amplitudes of temporal variations (Bacillariophyceae, ANOVA, $F=26.66$, $p<0.001$; Dinophyceae, ANOVA, $F=10.78$, $p<0.001$) and a relatively high similarity between stations (Bacillariophyceae, ANOVA, $F=0.30$, $p=0.90$; Dinophyceae, ANOVA, $F=0.90$, $p=0.50$). The rainy period (December, January, and February) is characterized by low algal productivity. All species included, total cell abundance reached its minimum value in winter 4.03×10^5 cells L^{-1} , while the maxima of total cell abundance were recorded in spring with 9.22×10^5 cells L^{-1} (Tab. 4). This finding was also reported by Bennouna [13], where low phytoplankton cell concentrations coincided with the rainy period (0.12×10^5 cells L^{-1} in February), while high concentrations were recorded in dry season (1.19×10^5 cells L^{-1} in June). Comparing our results to those of Benouna [13] total microphytoplankton abundance values in this study is high.

Table 4: Cell number abundance of microphytoplankton in the Oualidia lagoon ($\times 10^5$ cells L^{-1})

Stations	10^5 cells L^{-1}							
	Bacillariophyceae				Dinophyceae			
	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring
S1	0.64	0.96	0.55	1.40	0.73	0.49	0.06	0.46
S2	0.55	0.88	0.52	1.22	0.51	0.39	0.07	0.36
S3	0.61	0.70	0.70	1.30	0.37	0.37	0.08	0.35
S4	0.53	1.13	0.80	1.04	0.29	0.30	0.07	0.39
S5	0.45	0.99	0.54	1.09	0.36	0.20	0.05	0.34
S6	0.31	0.84	0.49	0.94	0.20	0.18	0.10	0.33
Mean \pm SD	0.52 ± 0.12	0.92 ± 0.15	0.60 ± 0.12	1.17 ± 0.17	0.41 ± 0.19	0.32 ± 0.12	0.07 ± 0.02	0.37 ± 0.05
Total	3.09	5.5	3.6	6.99	2.46	1.93	0.43	2.23

The microphytoplankton species richness varied from 11 species (S3 in November and S1 in December) to 103 species (S1 in May; Fig. 3). This change in species richness may be limited by environmental factors such as nutrients [50]. As reported by Natij [51], species richness showed a negative correlation with nitrite. In Oualidia lagoon, the maximum value of nitrite was measured in fall ($5,717 \pm 0,751 \mu\text{mol. } L^{-1}$) and winter ($11,580 \pm 0,841 \mu\text{mol. } L^{-1}$) [52], whereas during the same period, low species richness was reported. Species richness showed significant differences among sampling months (ANOVA, $F=271.29$, $p<0.001$) but no significant differences were detected for this variable between sampling stations (ANOVA, $F= 0.10$, $p= 0.99$). Species richness decreased from November to February and increased during March at all sampling sites (Fig. 3).

Microphytoplankton diversity estimated by the Shannon-Wiener's index exhibited a pattern similar to species richness. No significant differences were detected between sampling sites (ANOVA, $F=0.05$, $p=0.99$), but microphytoplankton diversity differed significantly between months (ANOVA, $F=69.39$, $p<0.001$). Similar to temporal trends of species richness and the Shannon-Wiener's, Pielou's evenness indices reached its minimum value in December and increased in March (Fig. 4). In Oualidia lagoon, all the values of H' shown in Figure 4 are comprised between 1.09 and 4.33. The lowest value recorded in December at station S4 is caused by the strong proliferation of the genera *Chaetoceros sp* and *Pseudo-nitzschia sp*. The highest value estimated in May at station S1 indicated that the community was very complex this month at all the stations. Furthermore, H' index calculated in the lagoon, never dropped below 1 which was the lower threshold of the range provided by Sournia [17]. This finding enables us to assume that the community never approached a situation of monospecificity during the study period, most probably due to strong hydrodynamics that gives to the system a very high dilution power and wide distribution of nutrients in its entirety. Therefore, several genera, and not only the most opportunist ones, would proliferate and dominate. As a consequence the index of Shannon would never approach 0. In terms of evenness (E), the threshold used by Daget [53] as an index of a stable population ($E=0.80$) has been reached at all sites during various periods of the year except at station S4 in December where the evenness reached its minimum value (0.37, Fig. 4). According to this result it may be assumed that microphytoplankton assemblage was in equilibrium at the entire lagoon during the largest part of the year.

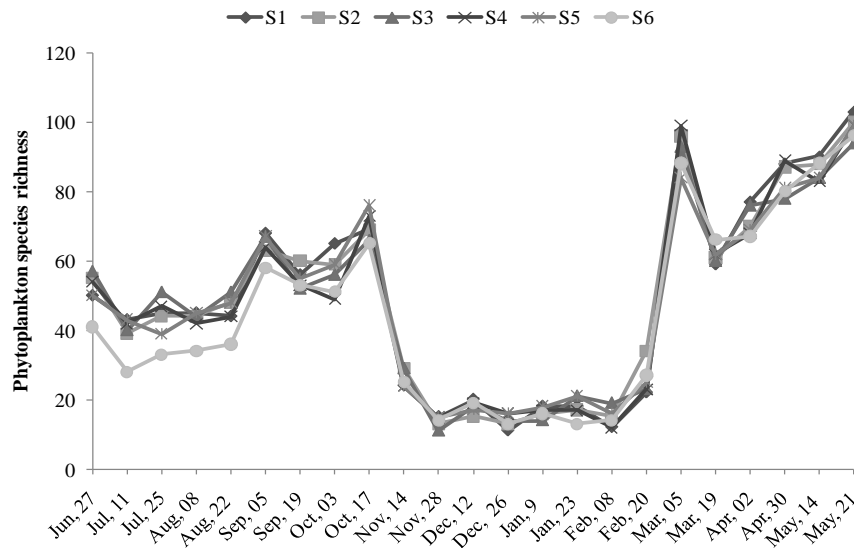


Figure 3: Temporal variability of the microphytoplankton species richness at sampling sites from June to May in the Oualidia lagoon.

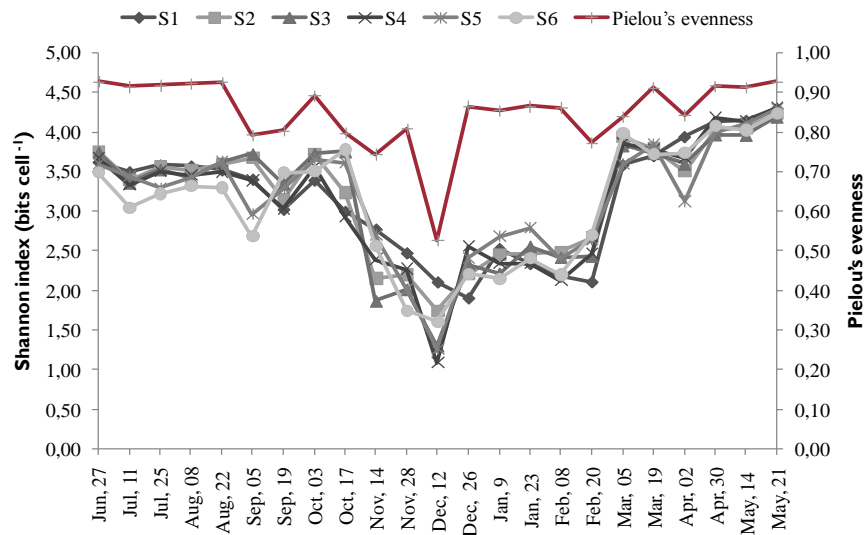


Figure 4: Temporal variability of the Shannon Diversity Index and Pielou's evenness of the microphytoplankton community at the sampling sites from June to May.

Nutrient level and availability should be one of the direct factors that could not only control phytoplankton abundance but also influence the community composition [54]. Besides the dissolved nutrients, many other factors might also influence the species composition, like currents, temperature, feeding pressure by zooplankton and benthos [55]. The results obtained by Natij [51] and the evaluation of statistical relationships between the composition of phytoplankton and the physicochemical environment variables in Oualidia lagoon, showed a positive correlation between dissolved oxygen, total microphytoplankton, Dinophyceae and Bacillariophyceae. Dinophyceae showed a significant negative correlation with salinity value ($p < 0.01$). Number of species displayed also a negative correlation with salinity ($p < 0.05$). A significant positive correlation was founded between temperature and Dinophyceae. Total microphytoplankton, Dinophyceae, Bacillariophyceae, species richness and species diversity showed a negative correlation with nitrite, whereas Bacillariophyceae indicated a negative correlation with orthophosphorus [51].

Species richness ($\log_2 S$), Shannon index (H') and evenness (J) plotted together in the DIMO diagram, showed similar positions of months at all stations (Fig. 5). The two-dimensional representation highlighted a type of evolution 2 "evenness type" reflecting richness and changing diversity from one month to another while the evenness remained constant. The months June, July and August were the closest to the evenness line.

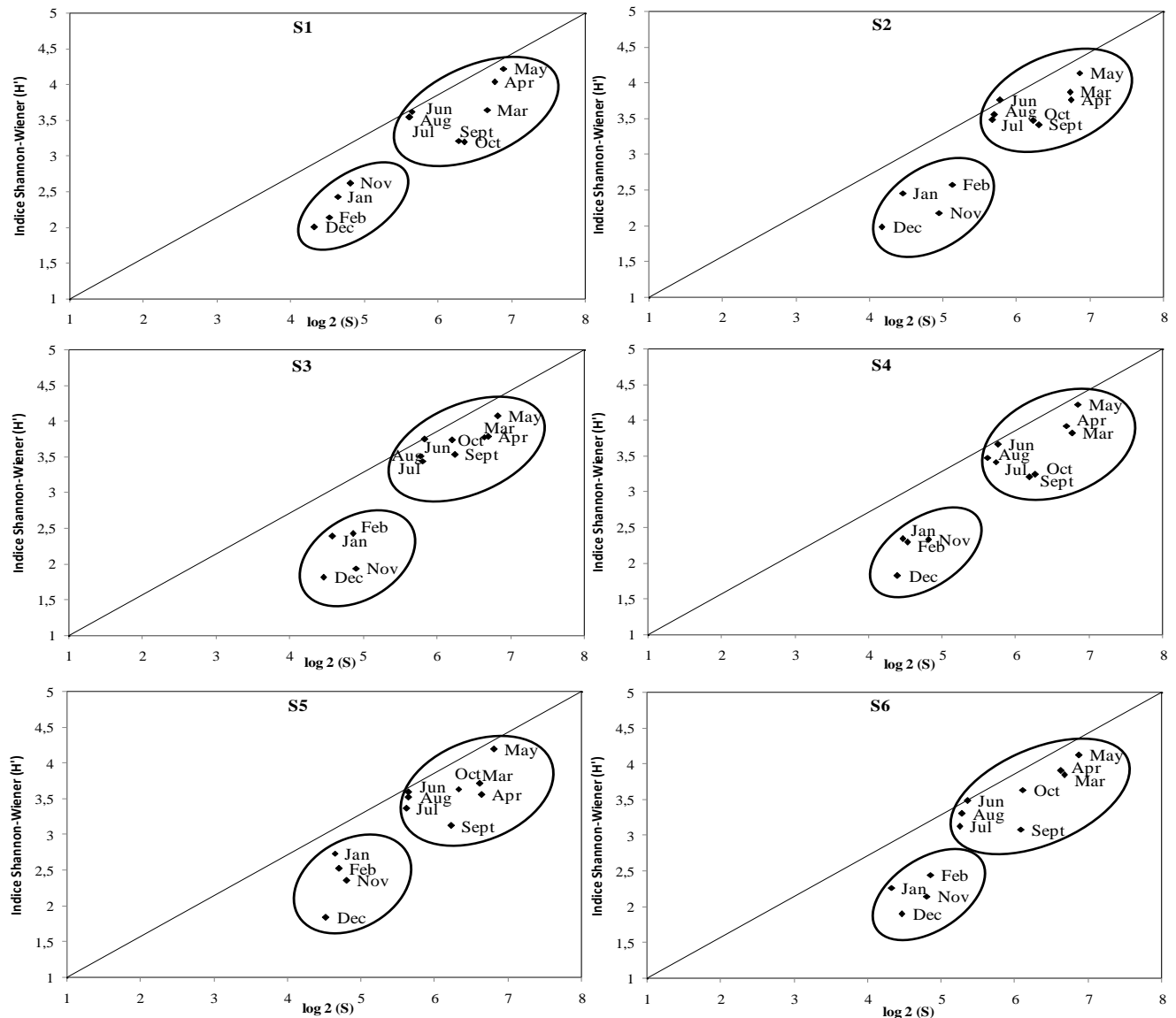


Figure 5: Simultaneous representation of species richness $\log_2(S)$, Shannon-Wiener index (H') and Pielou's evenness (J) (=diagonal line), of microphytoplankton community in the six sampled stations in the Oualidia lagoon with the DIMO model

Considering all stations, the DIMO model (Fig. 5) was used to divide the months into two groups. The first group was less diverse and poorest in terms of species and included the winter months from November to February, while the second consisted of the remaining period from March to October was characterized by the highest values of species richness and diversity.

The spatio-temporal analysis of diversity indices (Shannon-Wiener index " H " and Pielou index " J "), approached by DIMO model [32] provided a synthetic frame of the microphytoplankton community structure in the Oualidia lagoon. The microphytoplankton assemblage during June, July, August, September, October, November, March, April and May was more diverse and better structured than the entity of the December, January, February assemblage.

For a better understanding of the degree of organization of the microphytoplankton population in the Oualidia lagoon, a rank-frequency distribution model was applied. Seasonal changes in the structure of microphytoplankton community clearly appeared on RFD diagrams (Fig. 6).

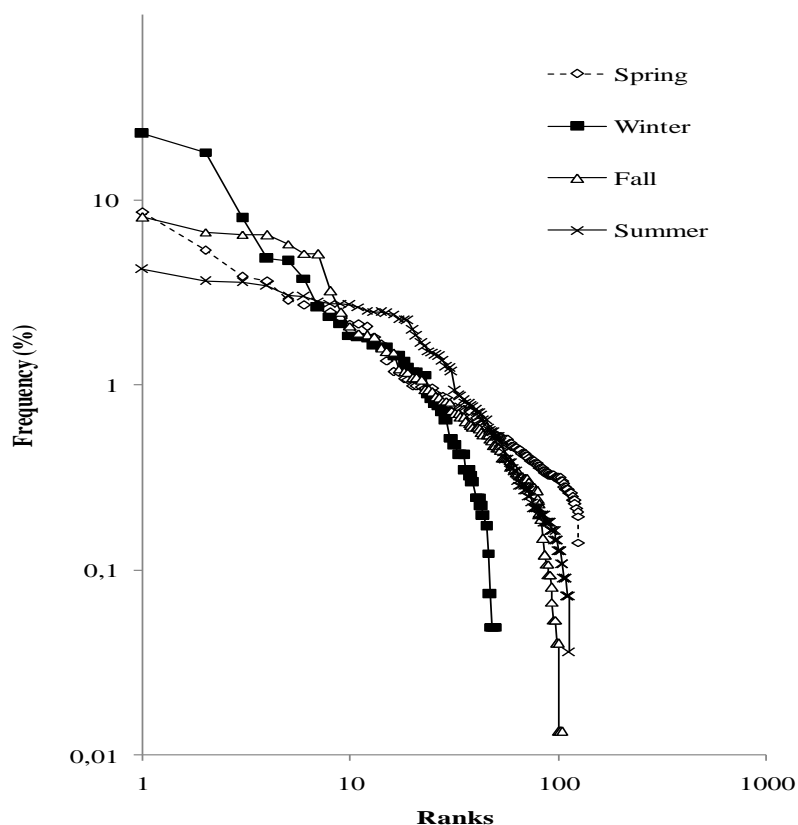


Figure 6: Rank-frequency diagram of the microphytoplankton community in the Oualidia lagoon. Both axes are on a logarithmic scale.

In winter (December, January, February), RFD exhibited the shape of stage 1 (pioneer community) with the dominance of both *Chaetoceros sp* and *Pseudo-nitzschia sp* and low diversity. In spring (March, april, May), the dominant species were more numerous (*Navicula sp*, *Gyrodinium spirale*, *Chaetoceros affinis*) and rare species (*Trigonium sp*, *Rhizosolenia sp*) were less common while diversity presented a maximum (stage 2, mature community). The shape of the summer (June, July, August) RFD indicated a stage 3 (senescent community), characterized by an increase of the most abundant species of phytoplankton population (*Neoceratium furca*, *Navicula sp*, *Asterionellopsis glacialis*, *Neoceratium trichoceros*). Diversity decreased in summer season compared to the spring season. In autumn (September, October, November), the dominant species were more numerous and more uniform in term of abundance (*Pseudo-nitzschia sp*, *Chaetoceros sp*), whereas abundance and diversity increased slightly. These findings indicate an intermediate stage between stages 1 and 2.

Conclusion

In recent years, a deterioration of water quality of Oualidia lagoon has been reported due to increasing human activities. These activities are increasing without enough consideration of the environmental impacts on biodiversity and other aspects of ecological change. The results of this study show significant amplitudes of temporal variations but no significant differences were detected for distribution of cell abundance of microphytoplankton and species richness between sampling stations. The study of microphytoplankton abundance indicated that the maximum abundance of microphytoplankton occurred in downstream area of the lagoon in summer and spring season. This part of Oualidia lagoon received the waste water (organic matters, nutrients) due to pollution (oyster farming, tourist activity especially in summer) while in rainy season, the maximum abundance in microphytoplankton is reported in upstream area which is due to agriculture pollution (leaching and infiltration of fertilizers). Obtained data from species diversity showed that Oualidia lagoon was in equilibrium at the entire lagoon but not throughout the entire year.

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