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Seasonal and daily fluctuation of diatoms during spring tide periods in Kerkennah Islands

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ABSTRACT

Objective: To study seasonal and the daily distribution of diatoms in the three tidal periods (flood, slack and ebb period) during the spring tide.
Methods: Water samples were taken and environmental variables were measured three times in each tidal period during 10 days of spring tide. Sampling was done in 2007 in Cercina station located in the western coast of Kerkennah (34°41'27" N; 11°07'45" E) (Southern Tunisia).
Results: Nutrients showed significant variation between seasons, increasing in spring and decreasing noticeably in autumn and winter. About 36 diatom species were found. Results revealed a remarkable abundance increase in spring and summer. Irregular differences in diatom abundances were revealed over the tidal periods, with the highest rates being detected during the flood and the ebb period, while the abundance rate was lowest during the slack period. This could presumably be attributed to the increase of nutrient supply of suspended particulate matter during water motion. The results revealed a correlation between diatom abundance and temperature, NO_2^-, NO_3^-, $Si(OH)_4$ and PO_4^{3}. Temperature seemed to be the most important factors which may influence the distribution and diatom abundance.
Conclusions: Tide has various effects on the nutrients status and diatoms community (in terms of species composition, succession and abundance) between different tidal periods. Fluctuation of diatoms was correlated with changes in the circulation of water bodies and changes in nutrient regime.

1. Introduction

Diatoms are considered as a euryhaline and eurythermal phytoplankton group, which inhabit and dominate the phytoplankton community in shallow, turbulent and upwelling region as coastal area. They are generally adapted to low light levels and are, therefore, able to survive in the turbid conditions[1]. Phytoplankton distribution patterns reflect the interplay between phytoplankton growth rates, commonly regulated by light, inorganic nutrients, temperature, light availability, nutrient inputs, residence times and turbulence[2,3]. These controlling factors depend on the spatial and temporal variability of physical parameters such as depth, flow velocity, and turbidity[4,5]. Diatoms tend to have significantly higher maximum uptake rates of nutrients than any other group[6]. Indeed, diatoms are the preferred food of many grazers and organisms in the upper trophic levels and thus form the basis for many of the productive fisheries. Changes in the diatom community can be related to corresponding fluctuations in water chemistry. Factors known to affect diatom distribution include salinity and trace metal levels, pH, total nitrogen and total phosphorus[7,8]. Hydrodynamism in coastal waters induces major changes in physic (depth, turbulence *etc.*) and chemical (pH, salinity, nutrients *etc.*) characteristics and in turn influence the community structure of biota in general and especially phytoplankton, as these conditions profoundly influence production of phytoplankton.

The purpose of this study was to investigate the seasonal and the daily distribution of diatoms in the three tidal periods (flood, slack and ebb period) during the spring tide in Kerkennah Islands in Southern Tunisia. In fact, on a time scale of hours, advection of water during ebb and flood determine strong changes of several fundamental parameters of the water column, such as salinity, nutrients and suspended particulate matter[9] and phytoplankton distribution[10]. The extent of such variations will vary significantly

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depending on spring-neap tidal state or amplitude[11-13]. Moreover, matters may be greatly complicated by other environmental variables, such as precipitation rate, affecting fresh water discharge, winds[11] and current velocity[12].

2. Materials and methods

2.1. Study area

This study was carried out in Kerkennah Islands during 2007 from Cercina station located in the western coast of Kerkennah (34°41'27" N; 11°07'45" E) (Southern Tunisia) with depths ranging from 3 to 5 m (Figure 1). This station is influenced by regional water circulation and directly exposed to the arrival of prevailing cold water from the channels of Louza (North of Sfax) and warmer water from the channel between Sfax and Kerkennah[13,14].

2.2. Sampling and analysis

Samples were seasonally collected in the station Cercina successively during the 10 days corresponding to spring tide. Sampling water was collected through 3 h intervals of the tidal cycle: flood (T1), slack (T2) and ebb (T3) period. Environmental variables such as salinity and temperature were measured in the field concomitantly as phytoplankton sampling. Additionally, nutrients (ammonium, nitrite, nitrate, phosphate and silicate) were analysed in a laboratory with Auto-analyser Luebbe type. Three water samples replicate of one-litter were collected by Kuttner bottle and fixed with formaldehyde (5%). Microalgae enumeration was performed with an inverted microscope after fixation with Lugol solution (final concentration 1% v / v) and settling for 48 h using Uthermöhl (1 958) method[15]. Abundances were expressed in number of organisms per liter of sample.

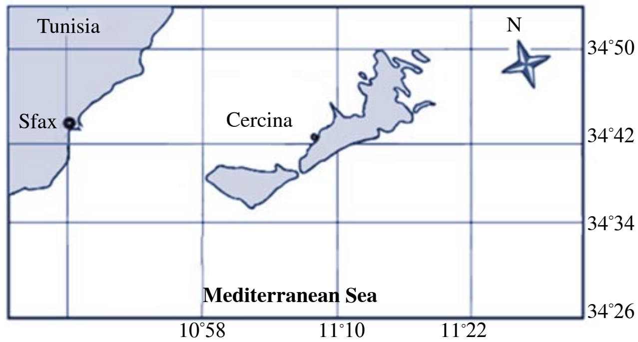

Figure 1. Map of the study area showing the sampling station of Cercina.

2.3. Statistical analyses

Permutational multivariate analysis of variance was used to analyze differences in abundance of diatoms between seasons, days and hours[16]. Permutational multivariate analysis of variance gives the permutation *P*-value for each test it performs. Data were transformed where necessary to meet the assumption of homogeneity of variances (homogeneity confirmed by non-significant Cochran's C test). Student-Newman-Keuls (SNK) test was employed for a posteriori multiple comparisons of means. Similarity percentage analysis was used seasonally to identify the contribution of individual species with the pattern of similarity and dissimilarity between the different tidal periods. To link species variability to environmental parameters, Pearson's correlation was applied to physical (temperature and salinity) and chemical parameters [NO_2^-, NO_3^-, NH_4^+, PO_4^{3-}, total nitrogen, total phosphate and $Si(OH)_4$].

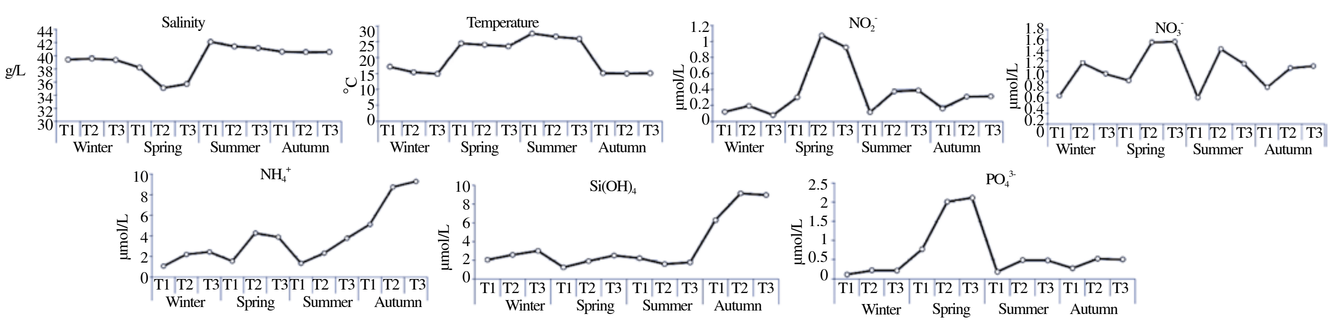

Figure 2. Variations in salinity, temperature, nitrite, nitrate, ammonia, silicate and phosphate in the surface waters in Cercina during four seasons with the three tidal periods of spring tide.

Table 1

ANOVA results for physic-chemical variables on the three tidal periods.

Source of variation		*df*	Salinity		Temperature		NO_2		NO_3		PO_4		$Si(OH)_2$		NH_4^+	
			MS	*F*	MS	*F*	MS	*F*	MS	*F*	MS	*F*	MS	*F*	MS	*F*
Winter	Tidal period	2	0.072	0.097	13.50	12.56*	0.034	5.92*	1.03	6.33*	0.04	1.96	2.21	1.25	5.86	5.37*
	Residual	27	0.75		1.05		0.01		0.16		0.02		1.77		1.04	
	SNK test		-	T1 > T2 = T3	T2 > T1 = T3	T1 < T2 = T3	-	-	T1 < T2 = T3							
Spring	Tidal period	2	15.64	0.16	44.27	0.67	1.68	4.61*	1.79	4.29*	5.55	1.59	4.01	2.39	21.88	11.13*
	Residual	27	95.87		66.33		0.36		0.42		3.48		1.67		1.96	
	SNK test		-	-	T1 < T2 = T3	T1 < T2 = T3	-	-	T1 < T2 = T3							
Summer	Tidal period	2	2.93	1.73	6.55	1.69	0.23	5.37*	2.25	8.71*	0.31	6.96*	1.03	1.83	14.85	1.52
	Residual	27	1.69		3.86		0.04		0.26		0.04		0.56		0.26	
	SNK test		-	-	T1 < T2 = T3	T1 < T2 = T3	T1 < T2 = T3	-	-							
Autumn	Tidal period	2	0.02	0.17	0.07	0.15	0.07	3.82*	0.49	2.61	0.19	7.99*	25.11	5.97*	51.41	17.04*
	Residual	27	0.11		0.50		0.02		0.19		0.02		4.2		3.02	
	SNK test		-	-	T1 < T2 = T3	-	T1 < T2 = T3	T1 < T2 = T3	T1 < T2 = T3							

*: Significant at level 0.05. MS: Mean square.

Table 2

ANOVA results of seasonal variation of diatom on the three tidal periods.

Source of variation	*df*	Winter			Spring			Summer			Autumn		
		MS	*F*	*P* (perm)	MS	*F*	*P* (perm)	MS	*F*	*P* (perm)	MS	*F*	*P* (perm)
Tidal period	2	0.09	1.83	0.169	0.79	9.23	0.000	0.59	6.15	0.004	0.457	5.621	0.006
Residual	57	0.05			0.086			0.096			0.08		
Cochran's C-test	C = 0.461 ns	C = 0.856 ns	C = 0.558 ns	C = 0.669 ns									
Transformation			Ln(x + 1)			Ln(x + 1)			Ln(x + 1)			Ln(x + 1)	
SNK test			-			T2 < T1 < T3			T2 < T1 = T3			T2 < T1 = T3	

MS: Mean square; *P* (perm): *P*-value based on Permanova test.

3. Results

Temperature varied significantly between seasons (ANOVA, $F = 157.33$, $n = 36$, $P < 0.05$) and the highest values of temperature (27.59 °C) were recorded in summer on the T1 period, while the lowest value (15.1 °C) were detected in winter on T3 period (Figure 2). Salinity varied significantly (ANOVA, $F = 8.75$, $n = 36$, $P < 0.05$) according to seasons. Water salinity varied from 38.20 g/L in spring to 42.13 g/L in summer during the T1 period (Figure 2). Salinity increased mainly in spring and decreased in autumn and winter. No significant difference was detected for salinity for all seasons while for temperature significant difference between the three tidal periods was detected only in winter (Table 1). The nitrite NO_2^- fluctuated between seasons (ANOVA, $F = 13.48$, $n = 36$, $P < 0.05$) and the concentration values ranged between 0.08 µmol/L in winter to 1.08 µmol/l in spring. Significant difference was detected between the three tidal periods and SNK *post-hoc* test revealed that those concentration values were high during the T2 and T3 periods for all seasons (Table 1). Nitrate NO_3^- also varied significantly between seasons (ANOVA, $F = 10.73$, $n = 36$, $P < 0.05$) and the highest concentration (1.55 µmol/L) was recorded in spring, while the lowest concentration was detected in summer and winter (0.50 and 0.53 µmol/L respectively). Significant difference was detected between the three tidal periods in winter, spring and summer. The highest concentration was revealed in the T2 and T3 periods. Orthophosphate PO_4 differed between seasons (ANOVA, $F = 33.17$, $n = 36$, $P < 0.05$) and the highest concentration values were recorded in spring (2.11 µmol/L). Significant difference for orthophosphate concentration was recorded between the three tidal periods only in summer and autumn where the high concentration values were recorded in the T2 and T3 periods. Ammonium NH_4^+ concentration varied between seasons (ANOVA, $F = 3.85$, $n = 36$, $P < 0.05$) and the high concentration was recorded in autumn (9.29 µmol/L). Significant difference was recorded between the tidal periods on the winter, spring and autumn periods and the highest concentration values were observed on the slack and ebb period. Silicate $Si(OH)_2$ concentrations fluctuated between seasons (ANOVA, $F = 4.43$, $n = 36$, $P < 0.05$). The silicate concentrations were high in spring and autumn and low in winter and summer. Significant difference was recorded between the tidal periods only in autumn and the high concentration was recorded on the T2 and T3 periods.

A total of 36 diatom species were identified in the study area inluding *Achnanthes brevipes* (Bory), *Amphiprora paludosa* W.Smith, 1853, *Amphora angusta* Gregory, *Amphora proteus* (Ehrenberg), *Asterionella glacialis* Castracane 1 886, *Asterionellopsis glacialis* Castracane, *Bacillaria paxillifera* (Gmelin), *Bellerochea malleus* (Heurck), *Biddulphia alternans* (Bailey) Van Heurck 1 885, *Chaetoceros didymus* Ehrenberg 1845, *Coscinodiscus* sp. (Ehrenberg), *Climacosphenia moniligera* (Ehrenberg), *Dactyliosolen fragilissimus* (Castracane), *Grammatophora oceanica* Ehrenberg 1840, *Gyrosigma* sp., *Guinardia delicatula* (Cleve) Hasle in Hasle & Syvertsen 1997, *Hemiaulus hauckii* (Ehrenberg), *Leptocylindrus danicus* Cleve 1889, *Licmophora gracilis* (Ehrenberg) Grunow, *Melosira moniliformis* (Agardh), *Navicula* sp. (Bory), *Nitzschia fontifuga* Cholnoky 1962, *Nitzschia pellucida* Grunow 1880, *Nitzschia acutissima* (Hassall), *Nitzschia longissima* (Brébisson in Kützing) Ralfs, *Pinnularia viridis* (Nitzsch) Ehrenberg 1843, *Plagiotropis lepidoptera* (Pfitzer), *Pleurosigma simonsenii* (Smith), *Pseudo-nitzschia* sp. (Peragallo), *Skeletonema costatum* (Greville) Cleve 1873, *Striatella unipunctata* (Lyngbye) C. A. Agardh, 1832, *Thalassiosira decipiens* (Jørgensen), *Toxarium undulatum Bailey* 1 854, *Triceratium shadboltianum* (Ehrenberg), *Rhizosolenia alata* (Brightwell) and *Rhabdonema adriaticum* Kützing 1844. The mean abundance of diatoms fluctuated between seasons and showed a significant seasonal variability (ANOVA: $F = 8.93$, $n = 239$, $P < 0.001$). The highest diatom abundance [(7 397.75 ± 1 048.53) cell/L] was detected in spring whereas the lowest abundance [(976.00 ± 97.83) cell/L] was detected in winter (Figure 3). For autumn, spring and summer, significant difference was detected between the three tidal periods (Table 2). SNK test revealed that the highest abundances were detected specially in the T1 and T3 periods whereas the lowest abundances were detected in the T2 periods. Similarity percentage analysis revealed that in winter, the most abundant diatom species contributing to dissimilarity between the different tidal periods were *Nitzchia longissima*, *Navicula* sp. and *Guinardia delicatula*, whereas in spring the main species contributing to dissimilarity between the three tidal periods were *Navicula* sp., *Skelletonema costatum*, *Cocinodiscus* sp., *Nitzchia fontifuga* and *Plagiotropis Lepidoptera* (Table 3). In summer, *Navicula* sp., *Nitzschia longissima*, *Pleurosigma simonsenii*, *Climacosphenia moniligera*, *Amphora angusta* and *Amphiprora paludosa* were the main diatom species contributing to dissimilarity, while in autumn *Navicula* sp., *Nitzchia fontifuga*, *Guinardia delicatula*, *Pleurosigma simonsenii*, *Climacosphena moniligera*, *Striatella unipunctata*, *Thalassiosira decipiens* and *Rhabdonema adriaticum* were the main species contributing to dissimilarity. Significant positive correlations were found between diatom species and physico-chemical parameters such as temperature, NO_2^-, $Si(OH)_4$, NO_3^- and PO_4^{3-} while no

Table 4

Spearman correlation coefficients between the studied physico-chemical variables and diatom abundance.

Pearson correlation	Salinity	Temperature	NO_2^-	$Si(OH)_4$	NO_3^-	NH_4^+	PO_4^{3-}
Diatom	0.120	0.273*	0.256**	0.129*	0.211*	0.028	0.385**

*: Significant at level 0.05, **: Significant at level 0.01.

significant correlation was found with salinity and ammonium (NH_4^+) (Table 4).

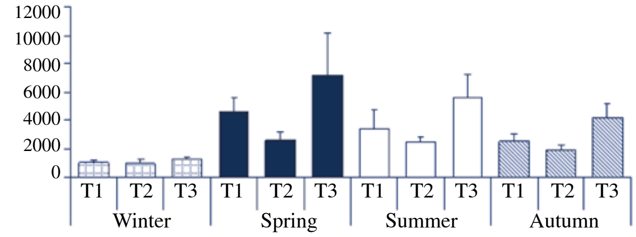

Figure 3. Mean abundance of diatoms (cells/L ± SD) at the three time interval of spring tide and for each season in the station of Cercina.

Table 3

The main diatom species contributing to the dissimilarity between the three tidal periods for each season.

Season	Period	Average dissimilarity	Average dissimilarity of the main species
Winter	Flood *vs* slack period	68.93	*Nitzchia longissima* (18.90)
			Navicula sp. (14.67)
			Guinardia delicatula (12.67)
	Ebb *vs* Slack period	59.49	*Navicula* sp. (18.89)
			Nitzchia longissima (14.06)
			Guinardia delicatula (10.89)
	Flood *vs* ebb period	62.02	*Navicula* sp. (19.27)
			Nitzchia longissima (18.98)
			Guinardia delicatula (13.91)
Spring	Flood *vs* slack period	83.70	*Navicula* sp. (13.41)
			Skelletonema costatum (10.79)
			Cocinodiscus (7.66)
	Ebb *vs* Slack period	84.55	*Navicula* sp. (10.35)
			Cocinodiscus (10.32)
			Skelletonema costatum (9.20)
	Flood *vs* ebb period	81.12	*Cocinodiscus* (11.03)
			Navicula sp. (9.76)
			Nitzchia fontifuga (7.32)
			Plagiotropis sp. (5.70)
Summer	Flood *vs* slack period	73.67	*Navicula* sp. (16.09)
			Nitzchia longissima (12.97)
			Pleurosigma simonsenii (9.48)
			Climacosphena moniligera (6.76)
			Amphora angusta (6.22)
	Ebb *vs* Slack period	73.30	*Navicula* sp. (16.04)
			Nitzchia longissima (9.39)
			Pleurosigma simonsenii (8.48)
			Cocinodiscus sp. (7.74)
			Climacosphena moniligera (6.93)
			Amphiprora paludosa (5.27)
	Flood *vs* ebb period	75.16	*Navicula* sp. (15.98)
			Pleurosigma simonsenii (8.92)
			Nitzchia longissima (8.31)
			Cocinodiscus sp. (7.58)
			Climacosphena moniligera (5.86)
Autumn	Flood *vs* slack period	61.96	*Navicula* sp. (15.56)
			Nitzchia fontifuga (13.54)
			Guinardia delicatula (11.36)
			Pleurosigma simonsenii (9.99)
			Climacosphena moniligera (6.37)
	Ebb *vs* Slack period	61.88	*Navicula* sp. (13.49)
			Nitzchia fontifuga (13.58)
			Guinardia delicatula (7.75)
			Striatella unipunctata (7.11)
			Thalassiosira decipiens (6.27)
			Pleurosigma simonsenii (5.03)
	Flood *vs* ebb period	68.21	*Navicula* sp. (13.58)
			Nitzchia fontifuga (12.16)
			Guinardia delicatula (7.76)
			Striatella unipunctata (6.51)
			Pleurosigma simonsenii (5.88)
			Thalassiosira decipiens (5.62)
			Rhabdonema adriaticum (5.05)

4. Discussion

Seasonal distribution of diatom species was detected with a tidal distribution according to tide regime and therefore to the physico-chemical parameters in Kerkennah Islands. The data-base was performed in order to collect enough information related to the diatom dynamics for the two scales: seasonal and tidal period. Our study shows two key results: a high abundance of diatoms recorded in spring and summer with maximum abundance occurring in the spring and a high abundance of diatom recorded in the T1 and T3 periods.

Our results showed that Kerkennah Island was a complex system in which the spatial distribution and seasonal variability of abundance and composition of diatom species is affected by the variations of physico-chemical parameters that in turn are governed by the seasonal dynamics[9,17,18]. Seasonal variability of diatoms was revealed in the same area by Ben Brahim *et al.* showing that phytoplankton structure was dominated by diatoms both in abundance and the species number specially in spring and summer[17]. This prevalence of diatoms in such environment can be explained by the fact that the ebb period in this region is slightly longer than the flood period, with a greater maximum ebb speed than flood and with a general current of approximately 38 cm/s[19,20]. This situation generated a higher flow of nutrients and suspended particles into this area than elsewhere[21], creating changes in both diatom abundance and the community structure between regions. Similar result on seasonal variability was observed by Arndt *et al.* in the Scheldt Estuary (Netherlands) where the highest abundances of diatoms were occurred in summer (June until August)[4]. Sushanth and Rajashekhar also revealed a noticeable seasonal variation of diatoms species in Arabian Sea of Uttara (Kannada District, Karnataka) which may be attributed to the local climatic conditions and water exchange mechanism[22].

Diatoms are valuable indicators of ecological quality as they respond directly and sensitively to many physical, chemical and biological changes in aquatic environment and may quickly respond to changing physical, chemical, and biological conditions in the environment[23,24]. The physicochemical parameters such as temperature, irradiance, salinity and nutrients were found to influence the occurrence of diatoms. Our results showed an increase of diatom in spring and summer with the maximum was reached in spring. In particular, temperature seemed to be the most important factors in the coastal ecosystem which may influence the distribution and abundance of phytoplankton. Water temperature affects the abundance of diatoms and most of them were correlated with temperature variation[25,26].

The concentration of nutrients seems also to be an important factor that explains the dominance of diatoms as it influences the other environmental factors controlling diatoms[27]. Nitrate concentration is likely the most important predictor among the macronutrients and its positive effect on diatom abundance[28]. Moreover, silicic acid is known as an important predictor for the abundance of diatoms since it is used to build their frustules[29]. Phosphate exerts a significant influence on diatoms by operating growth characteristics and cell metabolism[30]. Diatoms were sensitive to changes in phosphate concentration; they were not able to dominate when phosphate was deficient, although silicate and nitrate were in excess. Moreover, the cell number declined with decreasing phosphate concentration in the medium[31,32].

Water motion in our study area (Cercina) is a system with a semidiurnal tide and showed horizontal displacement of water masses with a periodicity of 12 h[33]. The horizontal motion generates maxima in tidal current speeds and turbulent mixing with a periodicity of 6 h. Environmental forcing by the tidal cycle is an important driver of diatom variability in Cercina. In fact, diatom biomass in our study area exhibits variability at small temporal scales over the tidal period. Our result revealed that diatom concentration fluctuations correlated with different tidal periods and thus with horizontal transport of different water masses. Diatom concentrations consistently peaked on T1 and T3 in each season. Tides cause a pattern of stabilization-destabilization in circulation resulting in a highest abundance in flood and ebb periods during each season.

Lauria *et al.* showed that diatoms responded positively to turbulence, showing enhanced growth rates with increased mixing aeration and stirring in laboratory experiment when the depth reached his maximum, certainly due to the increase of nutrient supply of suspended particulate matter during water motion[34]. Otherwise, the turbidity maximum appears as a transient phenomenon related to tidal currents, dissipating rapidly by sedimentation during current slacks. In fact, turbulence generated by tidal current was the primary control over the transport and distribution of sediments and nutrients in field environments[35]. Diatoms are considerably less sensitive to turbulence and their lower affinity towards nutrients than dinoflagellate[36,37]. They are associated with eutrophic conditions owing to their fast growth rate and as consequence[38,39], they thrive in relatively turbulent and nutrient-rich waters[40]. Moderate mixing is essential to increase the available irradiance for diatoms photosynthesis as most of this group lack for active motility[41]. Indeed, Lauria *et al.* showed that diatoms were sinking organisms which relied on physical mixing to ensure sufficient photosynthesis active radiation levels to sustain production[34]. Those authors suggest that the centric diatoms used an opposing feature of the tides by being mixed throughout the water column during periods of intense mixing, and sinking under stable conditions. Similar result was found by Domingues *et al.* in Guadiana River's estuary (Portugal) where tidally-induced resuspension is considered a primary mechanism governing the variability of suspended particulate matter and light in estuaries and so phytoplankton patchiness associated[42]. The same result was revealed also by Brunet and Lizon where significant differences were found in pennate diatoms abundance in the winter and spring, with higher values during spring tides and lower during neap tides[43]. This may probably be related to a higher vertical mixing induced by higher river flow during spring tides, leading to resuspension of microphytobenthic diatoms.

Physico-chemical water quality parameters showed characteristic cyclic variations with the influence of tidal and so that resuspension events within field may impact nutrient cycling. Maximum concentrations occurred during slack and ebb periods. Seasonal cycling of physico-chemical water quality parameters was revealed in the same area of Gabes Gulf by Feki-Sahnoun *et al.* where the seasonal variability showed in the coastal water it was subjected to a marked seasonal cycle[44]. Cyclic pattern of physic-chemical parameters among tide periods was also observed by Montani *et al.* in Tidal Estuary in the Seto Inland Sea, Japan where low salinity water import was stronger at the lower low tide[45]. Similar result was showed also by Magni *et al.* in the Seto Inland Sea, Japan, where the major changes in nutrient concentrations depended on the tides, which nitrate and nitrite concentrations were quantified to be up to 1.8 times higher during the ebb than during the flood[46]. In our study, no significant difference of salinity was observed within the study area for all seasons. However, for nitrite and nitrate, the effect of the tide is important in determining the concentrations, which were stronger on flood and ebb periods.

Moser *et al.* stated that diatoms were sensitive to a wide range of limnological and environmental variables and quickly responded to changing physical, chemical, and biological conditions in the environment[47]. In fact, each diatom species has its own characteristic ecophysiological traits which determine how it responds to the environment. Diatoms community structure is determined by a complex interaction between the physiological characteristics of each species, environmental conditions, resource availability and species competition[29]. The distribution of *Guinardia delicatula*, *Skelletonema costatum*, *Climacosphena moniligera*, *Striatella unipunctata* and *Thalassiosira decipiens* in the water column, is closely associated with the periods of increased mixing. These passive organisms were distributed throughout the water column during the increased shear at each tide[23-34].

Navicula sp. was the main specie making difference between the three tidal periods for all seasons. Mutshinda *et al.* demonstrated that this specie had no irradiance as an important variable, whereas *Nitzchia longissima* had irradiance as an important variable and none had phosphate or silicic acid concentration as important variables, while *Guinardia delicatula* had no irradiance or nitrate as important predictors[29]. Generally, irradiance is an important variable for the major diatoms with abundance decreasing with increasing irradiance. Cell abundance of *Cocinodiscus* sp. was high in spring [(429 ± 334.61) cell/L] and summer [(152.67 ± 82.47) cell/L]. One of reasons of this increase was the warm weather, with longer hours of sunshine and the high concentration of NO_3^- [48]. Otherwise *Cocinodiscus* sp. was detected in significant number by Wasmund *et al.* in winter/spring and it was considered as cold water species[26]. The high abundance [(285 ± 152.1) cell/L] of *Thalassiosira decipiens* was recorded in autumn on the ebb period when an increase in vertical mixing (in September/October) resulting in upward transport of remineralised nutrients from the bottom water. This centric diatom forms large chains and has high aggregation and sinking rates and was therefore better adapted to buoyancy during strong vertical advection and high water column mixing[49-51]. Tilstone *et al.* revealed in the Ría de Vigo (NW Spain) an increase in the biomass of *Thalassiosira* spp[52]. During the vertical convective fluxes coupled with the horizontal convective fluxes during upwelling while, the low biomass was related to periods of upwelling relaxation. Diatoms such as *Thalassiosira* sp., *Skeletonema costatum* and *Cocinodiscus* sp. form an important link in the food chain to zooplankton and fish larvae[52,53]; those latter observations are in concordance with our results and may explain the low abundance of diatom in the T2 period and their high growth in the ebb and flood periods. In fact, tide and current tide is a defining environmental parameter that can potentially influence algal-grazer interactions and may impose strong energetic and ecological constraints on both algae and herbivores[9-55]. Other research suggest that current tide has been shown to affect herbivore movement rates[56,57], patterns of immigration and colonization[38-57], and may control herbivore distribution across the streambed[58], as well as determine the taxonomic and architectural composition of their benthic algal food[59-61].

Tide has various effects on the nutrients status and diatoms community (in terms of species composition, succession and abundance) between different tidal periods. Fluctuation in diatom composition and number has been correlated with changes in the circulation of water bodies and changes in nutrient regime. Physical and nutrient regimes are tightly coupled and it is often difficult to discern their individual effects on species successions and changes in biomass and primary production. Statistical results revealed the high abundance of diatom was detected in the flood and the ebb periods. This study therefore suggests the high-resolution monitoring programs that are essential to capture the natural variability of phytoplankton in coastal waters.

Conflict of interest statement

We declare that we have no conflict of interest.

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