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Influence of phosphorus-contaminated sediments in the abundance of potentially toxic phytoplankton along the Sfax coasts (Gulf of Gabes, Tunisia)

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Abstract

This is the first work performed in the shellfish production area located along the Sfax coasts (southern Tunisia) on the spatial and temporal patterns of toxic phytoplankton. It relates the excessive introduction of phosphorus in coastal waters from sediments contaminated with that nutrient. A multivariate approach was applyed using data derived from the National Phytoplankton Monitoring Program (REPHY) (2006-2009). We also examine if there is a direct relationship between the abundance of toxic phytoplankton and physical and chemical parameters. This study is based on phytoplankton composition and abundance, as well as physical and chemical data to evaluate the ecological status of the Sfax coasts, at shellfish farms. A total of 13 taxa included in the Intergovernmental Oceanographic Commission (IOC) toxic algae checklist and well-known bloom formers were identified in REPHY. Higher nutrient spring samples were distinguished from those of lower nutrient summer waters. The Redundancy Analysis (RDA) separated the toxic species into two groups related to nutrients availability. The large amounts of phosphorus and organic matter affected the toxic phytoplankton structure, due to the pollution of chemical origin underlining an organic load hardly biodegradable in Sfax coasts. Many of these species recorded in the water column were benthic dinoflagellates, a fact that could be explained by the resuspension of these organisms by hydrodynamics. The knowledge obtained in this study can be used to develop best management practices of the sediment compartment as well as the water column, which is crucial in the framework of any phytoplankton monitoring program.

Keywords: Southern coasts of Sfax. Harmful microalgae. Multivariate analysis. Physical and chemical parameters.

1. Introduction

All phytoplanktonic species, principally dinoflagellates, may respond to increased nutrient availability by proliferating in number. These microorganisms could be good indicatosr for eutrophication in estuarine and coastal zones (Chiaudani et al., 1980; Gillbricht, 1988; Hodgkin and Hamilton, 1993; Joint et al., 1997; Okaichi, 1997). Nutrient input is assumed to result in the rapid growth of opportunistic, fast-growing primary producers and the accumulation of extra biomass, which may have a negative impact on the ecosystems. Other features considered to be symptoms of negative impacts of nutrient enrichment include blooms of algae or the presence of toxic phytoplankton species (Smayda and Reynolds, 2001; Bricker et al. 2003). Coastal systems around the world have suffered from a variety of environmental problems, including these harmful algae blooms (HABs). There is an international growing recognition that HABs are affected by human activities, but the exact causes are still under debate. In terms

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of harmful effects, we can consider two types of causative organisms: the toxin producers and the high-biomass producers. Some HAB species are related to both characteristics; of the 4,000 marine planktonic microalgae, some 200 can be harmful, and only around 80 have the potential to produce toxins (Zingone and Enevoldsen, 2000). Moreover, toxic events can result from very low cellular concentrations of toxicity-causing organisms (Reguera et al., 1993). It has been generally recognized that data collection based on the characteristics, causes and dynamics of HABs especially toxic species, contributes to the development of appropriate monitoring programs and preventative measures against the occurrence of such harmful events in coastal ecosystems (Cembella et al., 2005, Ranston et al., 2006, Béjaoui et al., 2019). In fact, the National Phytoplankton Monitoring Program (REPHY) have been initiated in Gulf of Gabes especially in the coast of Sfax since 1996 to ensure public safety by establishing tools for early warning of HAB events.

The present study is the first attempt to investigate the composition of harmful microalgae species and their seasonal and spatial distribution coupled with environmental parameters from the shallow coastal waters of Sfax that had been heavily affected by stockpiled phosphogypsum, industrial waste and urban development. The possible effects of physical, chemical conditions and anthropogenic pressure on the phytoplankton community are also discussed.

2. Study area

Sfax is situated at the north shore of the bay of Gabes, with Kerkennah islands located in the east. The prevailing current returns the pollutants back to the coast, and that is why this area is extremely vulnerable to pollution. The coasts of Sfax stretch for 200 km, contained 8 different types of harbor, from the fish harbor of Ellouza (S1) to the industrial phosphate harbor of Skhira (S6) (Fig. 1).

This area is marked by the presence of the SIAPE industry (Industrial Society of Phosphoric Acid and Fertilizers), which has released large amounts of phosphogypsum wastes for 40 years. These phosphogypsum wastes are a significant source of phosphates, chloride and sulphates for seawater and may explain the high chemical oxygen demand in the surface waters of Sfax (Bahloul et al., 2015; Drira et al., 2016).

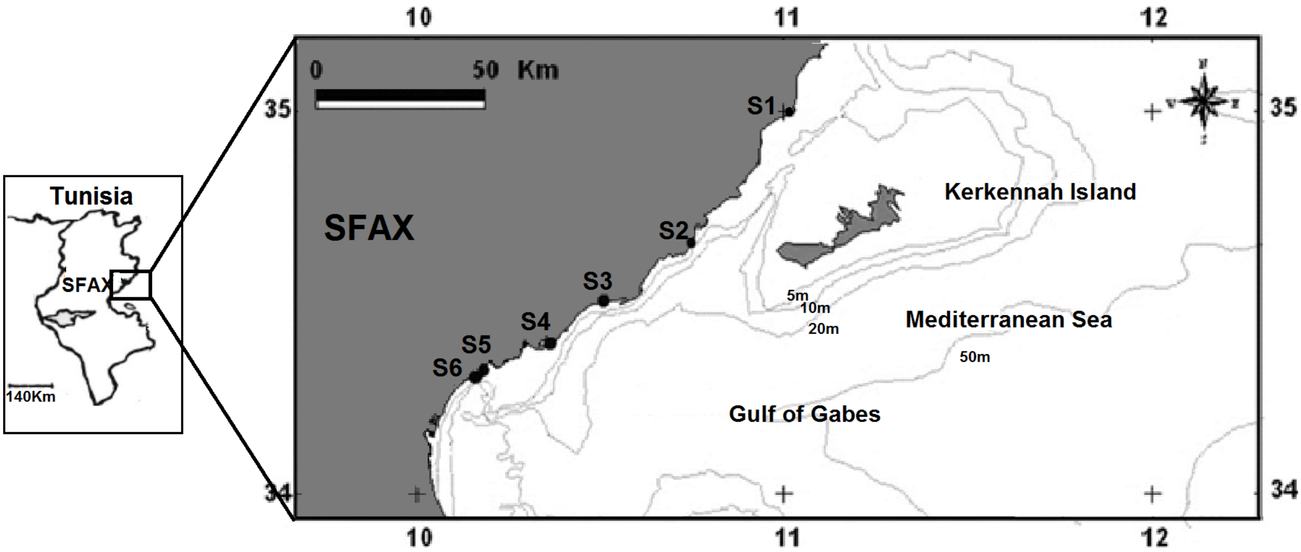

Fig. 1. Study area location and geographical localization of the six sampling stations within the Sfax coasts

Besides the SIAPE industry and its phosphogypsum wastes, the Sfax coasts comprises several industrial areas related to textiles, tanneries, salt, olive oil, food processing, construction materials, ceramics and glass. Hence, several industrial effluents are released to the sea in this area. All these anthropogenic inputs have been shown to alter the marine environment and biodiversity (Zaghden et al., 2005; Gargouri, 2006; Aloulou et al., 2012; Rekik et al., 2013; Bahloul et al., 2015). This area also suffers from the pressure of human activities (Hamza-Chaffai et al., 1997; Tayibi et al., 2009) and is subjected to increasing eutrophication with both red (Louati et al., 2001) and green tides caused by coastal *Ulva rigida* (Ben Brahim et al., 2010). The Sfax area is characterized by a benthic community, with an exceptional bionomy, made up of extensive magnoliophytes *Posidonia oceanica* and *Cymodocea nodosa* meadows (Ben Mustapha and Hattour, 2013). Their leaves provide suitable substrate for the establishment and growth of a number of epiphytic microalgae. Previous studies have focused on the sources and distribution of hydrocarbons in sediments (Louati et al., 2001; Zaghden et al., 2005) and marine bivalves (Hamza-Chaffai et al., 2003).

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The climate is arid and semiarid Mediterranean largely influenced by its mild topography and its maritime exposure (Chamtouri et al., 2008). The tide is semidiurnal, with a high tide of +1.60 m and a low tide of +0.30 m in spring tide (Zaghden et al., 2014).

3. Materials and methods

Data of Sfax governorate were collected in the framework of the National Phytoplankton Monitoring Program in the shellfish harvest areas. The program has been operating since 1995 with weekly sampling (Fig. 1). The monitoring was performed on a regular schedule all year round. Sampling stations were selected among the Tunisian National Monitoring Stations Network of Phytoplankton and Phycotoxins (REPHY) with consideration of existing station locations for seashell collection, followed by field reconnaissance. We therefore selected six sampling stations in Sfax governorate: Sfax (S1), Tabia (S2), Mahres (S3), Ras Younga (S4), Jaboussa (S5) and Skhira (S6) (Fig. 1) (Table 1). Stations S1, S2, S3 and S4 were exposed to industrial effluents as heavy metal and organic compounds (Zaghden et al., 2014) whereas S5 and S6 were affected by the petroleum pollution from the transport harbor (Kobbi-Rebai et al., 2013). The time period of the dataset used for the analysis was from 2006 to 2009.

Water for phytoplankton identification (1l) was collected with a Van Dorn bottle at 1-m depth. Temperature and salinity were measured for each water sample using a Handheld Multiparameter Instrument: WTW Multi 340i/SET. Samples were fixed with lugol (4%) solution and phytoplankton was counted using an inverted microscope using the Utermöhl's method (Utermöhl, 1958). Cell counts were carried out under an inverted microscope (Olympus CK40). Identification of algal taxa was achieved according to Tregouboff and Rose (1957), Huber-Pestalozzi (1968), Dodge (1985), Balech (1988) and Tomas et al. (1996).

Environmental variables in the water column were measured. Temperature, salinity and pH were measured at both surface and near the bottom using a multiparameter kit (Multi 340 i/SET; sensitivity (±1 digit) especially important for pH (±0.01 pH). For nutrient concentrations, samples of 125 mL were kept immediately upon collection at −20 °C, in the dark. The inorganic nutrients (nitrite: NO_2^-, nitrate: NO_3^-, ammonium: NH_4^+, orthophosphate: PO_4^{3-} and silicate: $Si(OH)_4$) were analyzed with a BRAN and LUEBBE type 3 autoanalyzer (APHA, 1992).

The statistical analysis was based on multivariate methods aiming to test the relationship between the seasonal harmful phytoplankton composition, in terms of species abundance, and the environmental variables.

Up to 13 species or genera of harmful phytoplankton were identified (Table 2). In order to improve the multivariate approach, species with low relative abundance (<2%) in all analyzed water samples were not considered in the statistical analysis (Table 2). So, the analysis included the following taxa of 12 dinoflagellate: *Akashiwo sanguinea*, *Alexandrium* spp., *Alexandrium minutum*, *Amphidinium carterae*, *Coolia monotis*, *Karenia selliformis*, *Karlodinium veneficum*, *Prorocentrum concavum*, *Prorocentrum lima*, *Prorocentrum micans*, *Prororcentrum minimum*, *Prororcentrum rathymum* and the diatom *Pseudo-nitzschia* spp. The response matrix was log-transformed. Then, inferential analyses were completed using Redundancy Analyses (RDA, Ter Braak and Smilauer, 2002) to estimate how much variation in the response matrix was attributed to the environmental variables. This analysis was performed using R software (R Development Core Team, 2017).

3. Results

3.1. Environmental factors and phytoplankton

The seasonal distributions in the surface layer of temperature, salinity, pH and suspended matter are displayed in Figure 2. Temperature tended to increase from winter to summer and showed a small decline in autumn compared to summer. The temperature was in the range of 12.3–30.08 °C, with the lowest value observed in winter and the highest in summer (Figure 2). Salinity varied from 37.8 in winter to 59.8 in summer (Figure 2). The transition from autumn to spring exhibited a net decrease in salinity, whereas in summer the salinity increase was more pronounced. The value of pH was higher in summer (8.69) than that in autumn (5.6) (Figure 2).

Nitrite and ammonium concentrations showed a considerable increase during spring and autumn. The highest nitrate concentrations were observed in summer and autumn. Overall, total nitrogen concentrations increased significantly from 10.55 µmol/L in spring to 51.85 µmol/L in summer. Total phosphate (T-P), orthophosphate and silica concentrations were higher during spring and reached respectively 29.88 µmol/L, 11.59 µmol/L and 36.73 µmol/L (Figure 2).

Table 2 shows the potentially harmful phytoplankters that were identified. Most of them are included in the Intergovernmental Oceanographic Commission (IOC) toxic algae checklist (Moestrup et al., 2008). Another was well-known bloom formers (Fukuyo et al., 1990). The list includes 12 dinoflagellates and one diatom.

The spatial seasonal cell abundances of selected harmful phytoplankton are shown in Figs. 3 and 4. Higher cell abundances of dinoflagellates (*Akashiwo sanguinea*, *Alexandrium minutum*, *Amphidinium carterae*, *Coolia monotis*, *Karenia selliformis*, *Karlodinium veneficum*, *Prororcentrum minimum*, *Prorocentrum micans* and *Pseudo-nitzschia* spp.) were measured in winter and autumn. On the other hand, the spatial cell abundances of selected harmful phytoplankters show that abundances of *Akashiwo sanguinea*, *Alexandrium minutum,*

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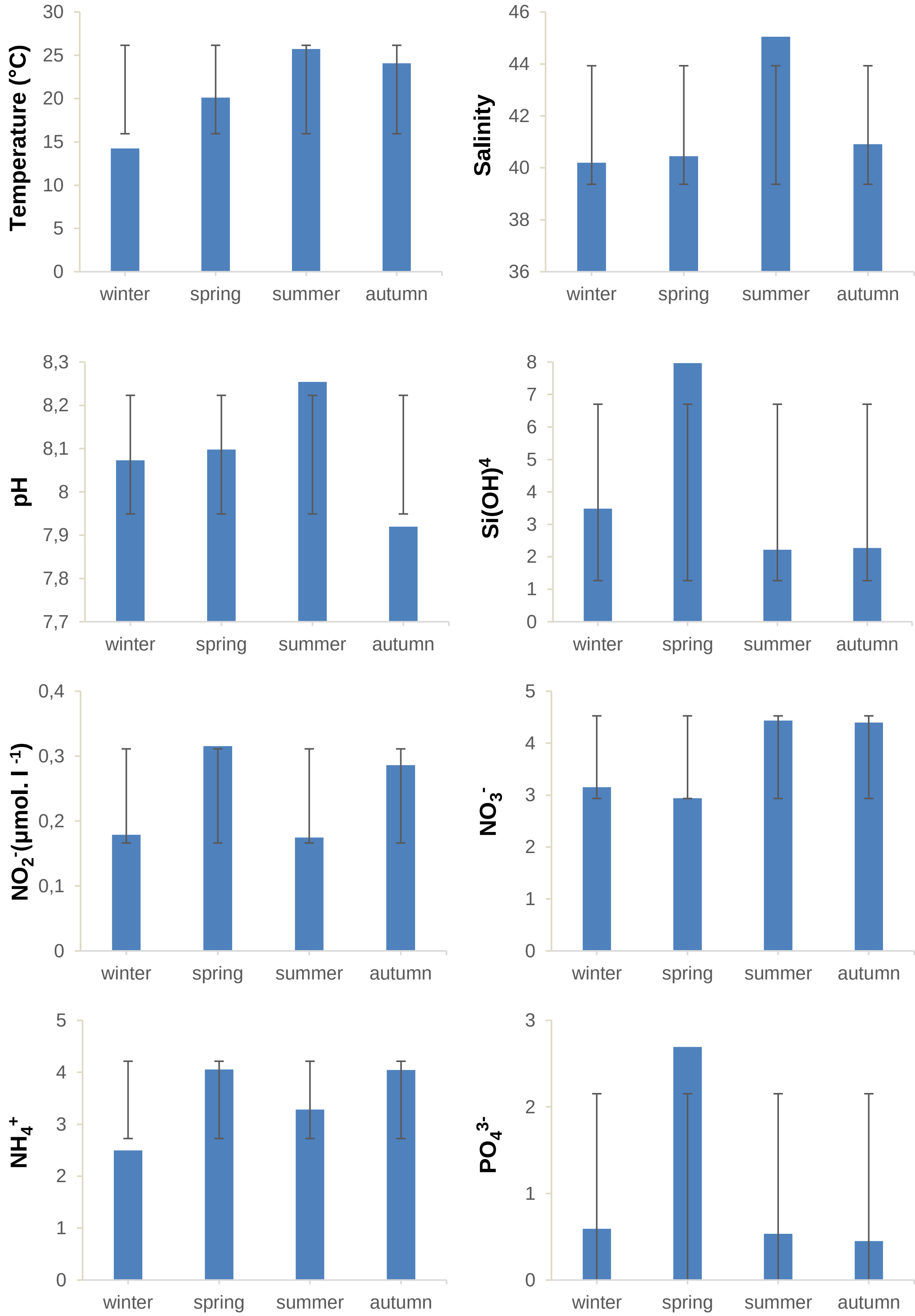

Fig. 2. Seasonal variation of physical (temperature, salinity and pH) and chemical (silicate, nitrite, nitrate, ammonia, orthophosphate) parameters at Sfax coasts.

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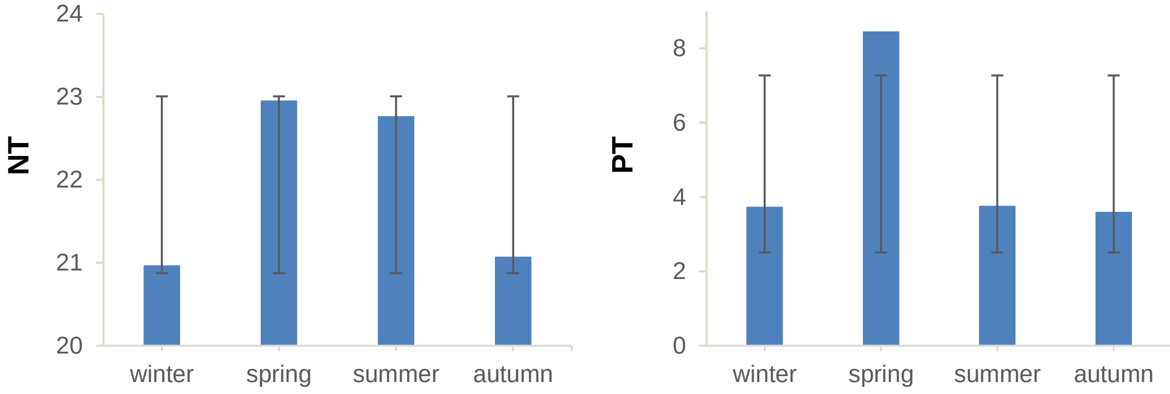

Fig. 2. (cont.) Seasonal variation of chemical (total nitrogen and total phosphorus) parameters at Sfax coasts.

Tab. 1. Mean ± SD of physical and chemical parameters in 6 sampling stations along the Sfax coasts

Stations	Longitude Latitude	Temperature (°C)	Salinity	NH_4^+ (µmol l-1)	NO_2^- (µmol l-1)	NO_3^- (µmol l-1)	PO_4^{3-} (µmol l-1)	TN (µmol l-1)	T-P (µmol l-1)	Si $(OH)_4$ (µmol l-1)
S1	34°47'35'' 10°51'36''	22.3±2.27	42.10±1.65	1.56±0.72	0.97±0.95	3.58±3.13	1.36±0.99	20.99±3.98	4.62±0.87	2.43±1.80
S2	34°40'12'' 10°44'28''	22.5±2.14	38.82±1.29	2.13±0.54	0.43±0.18	2.13±0.56	0.60±0.18	19.57±1.06	5.21±0.61	6.15±4.12
S3	34°31'16'' 10°30'00''	22.5±2.73	38.07±1.11	1.76±1.09	0.54±0.48	3.02±2.11	1.30±1.14	20.02±3.23	4.70±0.81	1.65±1.41
S4	34°24'58'' 10°21'40''	22.4±2.04	39.64±0.93	3.65±0.70	0.35±0.11	1.86±0.33	0.71±0.02	20.16±1.52	4.91±0.18	18.22±17.44
S5	34°20'49'' 10°10'58''	22.4±2.13	38.67±1.22	3.25±1.28	0.19±0.02	1.48±0.05	1.23±0.37	21.49±0.51	4.83±0.61	19.68±18.88
S6	34°19'34'' 10°09'25''	22.9±2.11	38.65±1.07	2.60±1.45	0.47±0.18	2.43±2.41	1.01±0.24	21.02±1.11	4.71±0.56	22.14±22.17

and Amphidinium carterae and *Coolia monotis* had higher concentrations at station S5. *Alexandrium* spp., *Prororcentrum minimum* and *Prororcentrum lima* peaked at station S2 and; *Karenia selliformis* proliferate at stationS1. *Karlodinium veneficum, Prorocentrum concave* and *Prorocentrum rathymum* showed a remarkable increase at station S4. *Pseudo-nitzschia* spp. and *P. micans* were present essentially in station S6.

3.2. Multivariate analysis

The bi-plot of the Redundancy Analyses results (RDA) is shown in Fig. 5 for the four seasons. The variables included in the autumn RDA analysis explained 52.8% of the sample variability. F1 component axis, which extracted 40.07% of the variability, selected positively the first group; *Karlodinium veneficum, Prorocentrum rathymum*, *Alexandrium* spp. and *Pseudo-nitzschia* spp. are related to pH, NH_4^+, NO_3^-, NO_2^- and T-N. F1 component axis selected negatively the second group, with *Coolia monotis*, *Karenia selliformis*, *Prorocentrum lima*, *Akashiwo sanguinea, P. micans* and *Amphidinium carterae* influenced by temperature, salinity, PO_4^{3-}, $Si(OH)_4$) and T-P.

The spring RDA analysis allowed the discrimination of two groups around the components of the F1 and F2 axes explaining 69.33% of the variance in the Sfax governorate. The F1 axis (51.1%) positively selected group formed by Karesel, Pseusp, Prorlim, Prormin, Coolmon, Prorcon and Alexmin correlated to T-P, PO_4^{3-}, pH, temperature and $Si(OH)_4$) in stations S2, S3, S5 and S6. This axis negatively selected the group formed by Karlven, Akassan and Prormic correlated to NH_4^+, NO_2^-, NO_3^-, T-N and salinity in stations S1 and S4.

The F1 component axis of the summer RDA analysis explained 62.8% of the sample variability, selected positively the first group of the one species Karesel correlated with $Si(OH)_4$), $PO_4^{3-}$and pH in stations S2, S3 and S6. The F1 axis (41.2%) selected negatively the second group of Prormic, Alexmin, Karlven and Amphcar correlated with T-N, pH, temperature, salinity, NH_4^+, NO_3^- and NO_2^- in stations S1 and S6.

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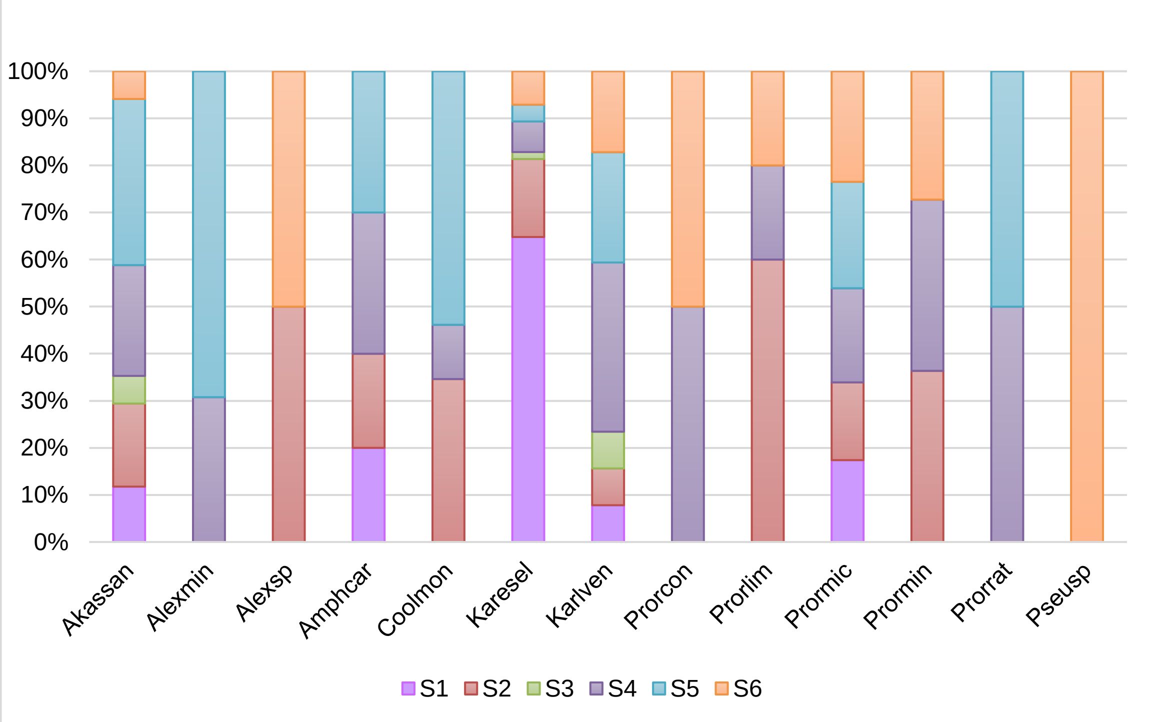

Fig. 3. Spatial variation of potentially toxic phytoplankton at sampled stations along the Sfax coasts

Tab. 2. List of harmful phytoplankters included in the IOC toxic algae checklist and defined in the Sfax coasts with their relative abundances

Taxa	Code	Relative abundances (%)
Dinophyceae		
Akashiwo sanguine **(Hirasaka, 1924) Hansen et Moestrup, 2000**	Akassan	4
Alexandrium **spp. Halim emend. Balech, 1989**	Alexmin	3
Alexandrium minutum **Halim, 1960**	Alexsp	2
Amphidinium carterae **Hulburt, 1957**	Amphcar	3
Coolia monotis **Meunier, 1919**	Coolmon	5
Gymnodinium catenatum **Graham, 1943**		0
Karenia selliformis **Haywood, Steidinger & MacKenzie in Haywood et al., 2004**	Karesel	46
Karlodinium veneficum **(Ballantine) Larsen in Daugbjerg et al., 2000**	Karlven	10
Ostreopsis **cf.** ***ovata*** **Fukuyo, 1981**		0
Prorocentrum concavum **Fukuyo, 1981**	Prorcon	2
Prorocentrum lima **(Ehrenberg, 1860) Stein, 1975**	Prorlim	2
Prorocentrum micans **Ehrenberg, 1834**	Prormic	17
Prororcentrum minimum **(Pavillard, 1916) Schiller, 1931**	Prormin	3
Prororcentrum rathymum **Loeblich III, Sherley et Schmidt, 1979**	Prorrat	2
Diatoms		
Pseudo-nitzschia **spp. (H. Peragallo, 1900)**	Pseusp	3

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Regarding RDA winter, axis 2 (40.3%) positively selected the group of Prormic, Akassan, Alexsp and Coolmon which is correlated with T-N, NO_3^- and $Si(OH)_4$ in stations S2, S4 and S5. Axis 2 negatively selected the group of Prormin, Karlven, Prorcon and Karesel correlated with pH, salinity, T-P, NO_2^- NH_4^+ NO_3^- in stations S1, S3 and S6.

4. Discussion

The harmful phytoplankters observed in this study are representative of both toxin producers and high biomass bloom-forming species (Masóand Garcés, 2006). Among them, some dinoflagellates are PSP, DSP or Ciguatera fish poisoning producers; the *Pseudo-nitzschia* diatoms are DA producers; and *Karenia selliformis* has been noted as a Gymnodimine producer in New Zealand (Haywood et al., 2004) and the Gulf of Gabès (Ben Naila et al., 2012). The armored dinoflagellate genus *Alexandrium* Halim, 1960, known to produce paralytic shellfish poisoning (PSP) saxitoxins and a number of related derivatives, comprises more than 30 species (Balech, 1995; Moestrup et al., 2002) distributed worldwide (Anderson et al., 1994, 2012) and defined also in the Gulf of Gabes (Abdennadher et al., 2012). Some of them have caused fish kills or produced diverse nuisance effects on the whole ecosystem. Blooms of some of these species have been previously noticed in the Gulf of Gabès (Feki et al., 2008). These blooms always took place in heavily modified and shallow environments close to the shoreline (Abdennadher et al., 2012). The results of this study revealed a large distribution of these harmful species along the whole littoral, although no high-biomass blooms were observed over this time. The location and nature of sampling sites at a certain distance to the shoreline as very shallow (<1 m in depth) near shore transect could explain the absence of these blooms. It seems to be a general trend that high-biomass blooms observed up until now in coastal Sfax waters were restricted to confined and shallow waters closer to the shoreline.

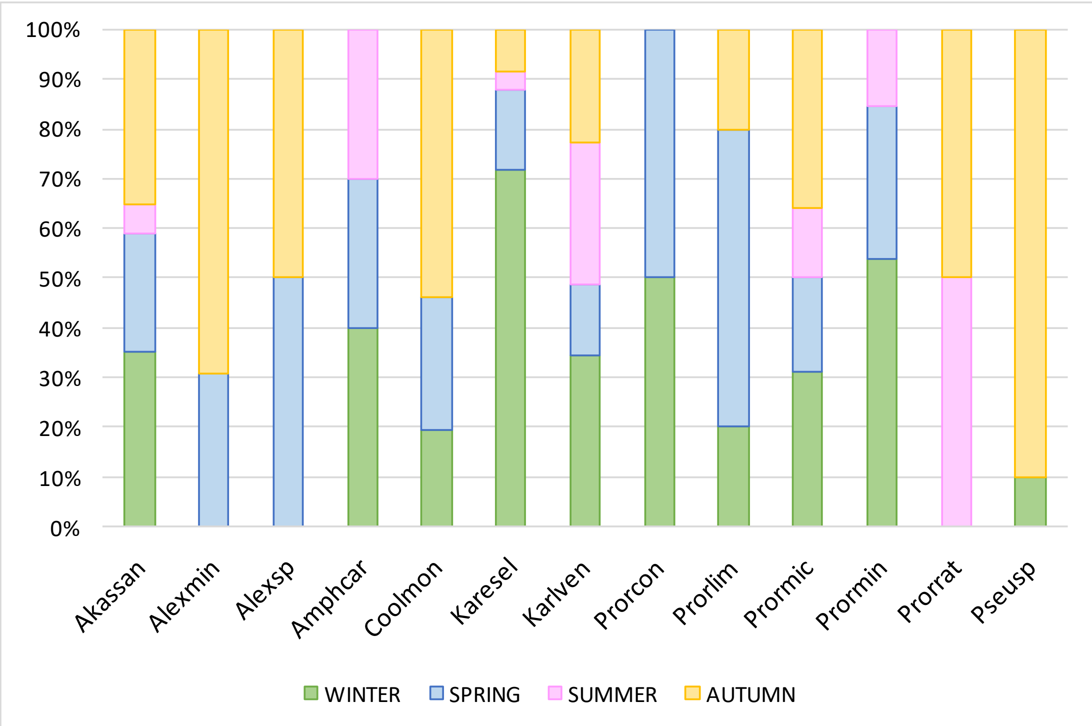

Fig. 4. Seasonal variation of potentially toxic phytoplankton within the Sfax coasts

Our results demonstrated distinct spatial and seasonal contrasts. The seasonal cycle in temperature in the six sampled stations is typical of the arid to semi-arid zone of the northern hemisphere (Bel Hassen et al., 2009), with a warming starting in spring and a maximum summer, followed by a cooling trend reaching its minimum in winter. The water salinity increased concomitantly with the increase in temperature. pH decreased along with the diminution in temperature and salinity in autumn, winter and spring. The low pH values can reasonably be attributed to the industrial activity and seems to be influenced by seasonal conditions. We found high nutrient concentrations essentially in spring and autumn.

The results showed that water temperature seems to be the main physicochemical factor affecting the proliferation of most harmful microalgae (Fig. 5). This result was also determined by Loukil-Baklouti et al. (2018) in the South of Sfax coasts. Most potentially toxic dinoflagellates recorded in Sfax coasts were correlated with several abiotic parameters, in particular with water temperature.

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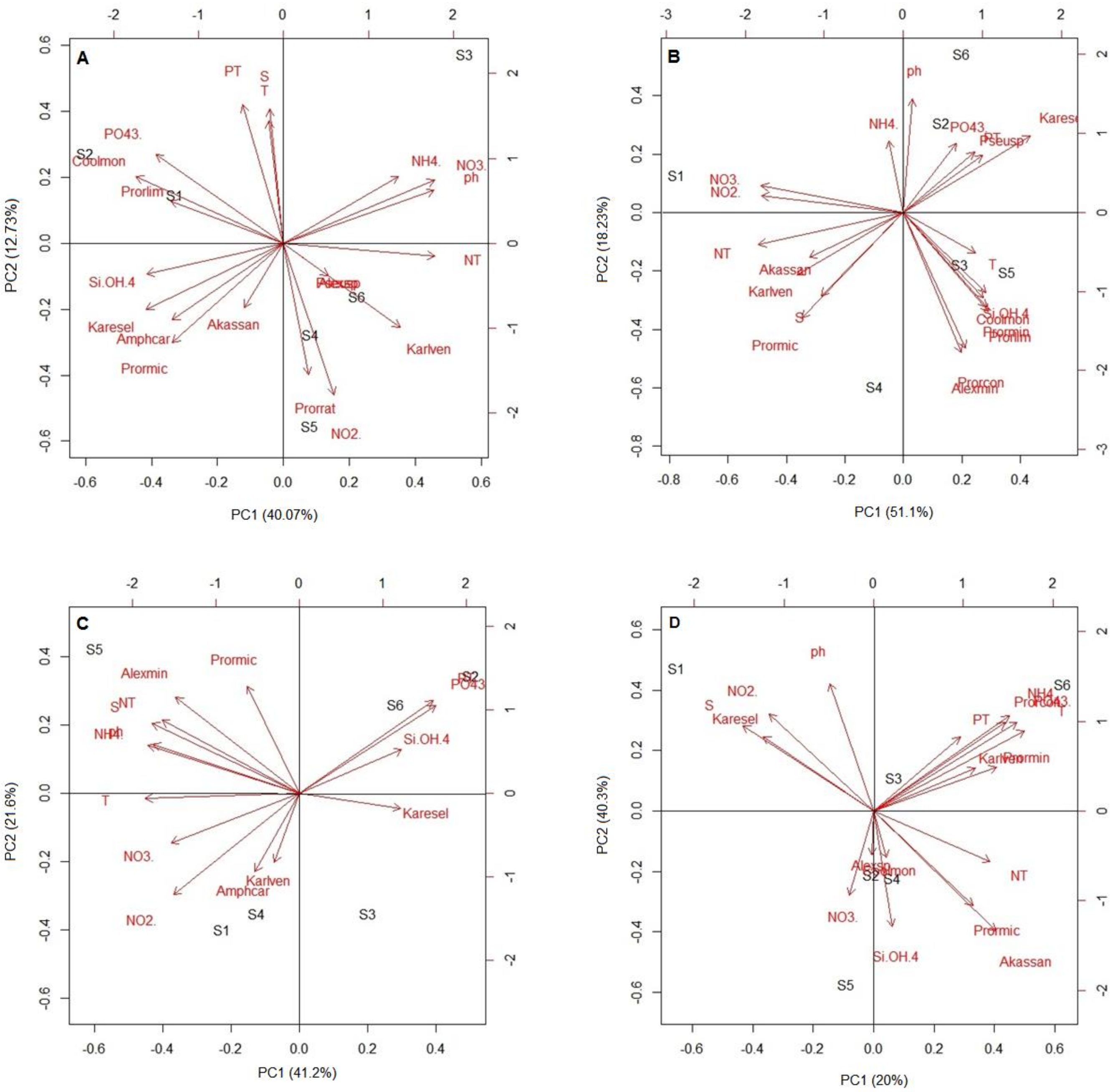

Fig. 5. Redundancy Analyses results (RDA) that combined potentially toxic phytoplankton, sampled stations, physical and chemical parameters in A) autumn, B) spring, C) summer and D) winter.

Besides, *A. minutum* outbreaks were correlated with sea surface temperature at Jaboussa "S5" (Abdennadher et al., 2012; Loukil Baklouti et al., 2018). Furthermore, several studies have reported that the temperature was the main environmental factor controlling harmful microalgae bloom occurrence and physiological processes (Laabir et al., 2013). The studies undertaken by Dammak-Zouari et al. (2009) and Feki et al. (2013) have also highlighted the effect of temperature on harmful microalgae proliferations, in summer, in the Gulf of Gabes. Another relevant factor influencing the autumn distribution of studied species especially *P. lima*, *P. micans* and *A. minutum* was salinity. These species seem to tolerate salinity (Steidinger and Tangen, 1996; Loukil Baklouti et al., 2018). In fact, *Prorocentrum* species have been reported in hypersaline lagoons (> 90) in the Caribbean islands and it was described as preferring high salinity coastal areas (Johnson and Allen, 2005). The main inference we can draw from these results is that the atmosphere temperature might enhance evaporation leading to a salinity increase because of the shallowness of the Gulf

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of Gabes. Thus, the effect of salinity on toxic species might not be a direct cause-and-effect relationship but might involve temperature as the main driving parameter. Similar results were also found in Tunisian waters (Aissaoui et al., 2014; Armi et al., 2012) and in other Mediterranean and northeast Atlantic ecosystems, for instance, along the Greek coast (Aligizaki et al., 2009) and the French Atlantic and English Channel coasts (Husson et al., 2016).

As regards to the analyses of nutrient concentrations, our results were quite similar to those reported in previous studies in the Gulf of Gabes (Kobbi- Rebai et al., 2013; Ben Salem et al., 2015). The terrestrial inputs of phosphate originating from chronic uncontrolled discharges generated by the chemical industry implemented in the Gulf of Gabes, seem to be involved in the increased phosphate concentrations (Ben Salem et al., 2015). Moreover, the studied area is urbanized and the coastline is industrialized and characterized by eutrophic systems attributed to anthropogenic inputs (Zaghden et al., 2014). The presence of anthropogenic nutrients can also control the phytoplankton community structure and have an important role in promoting harmful algae blooms (Wells et al., 2015).

Our findings showed the presence of potentially toxic epibenthic dinoflagellate (Benthic HABs) in the water column. These microphytobenthic organisms can be transferred into the water column, mainly through advection and bio-perturbation, particularly in shallow waters (Allison, 2000). The Modified Atlantic Water (MAW) flows within the continental shelf area between 50 and 100 m isobaths during winter (Bel Hassen et al., 2009) but exhibits a weak advection as summer stratification is established (Bel Hassen et al., 2008). This MAW induced water mixing, accentuated by shallow sampling depth, might result in sediment resuspension and, therefore, could increase the reproduction of epiphytic organisms during winter and spring (Feki-Sahnoun et al., 2014).

The analysis in Sfax coasts revealed that some potentially toxic dinoflagellate species were dominated by epiphytic microalgae communities such as *Amphidinium carterae*, *P. rathymum*, *P. concavum*, *P. lima* and *Coolia monotis*as highlighted in previous investigations in Gulf of Gabes (Ben Brahim et al., 2013). These epiphytic microalgae were present in the water column (Abdennadher et al., 2017; Ben Brahim et al., 2013) and attached to phanerogamic plants represented by *Posidonia oceanica* and *Cymodocea nodosa* (Ben Brahim et al., 2013; Mabrouk et al., 2014). These species are significantly affected by resuspension and deposition events which determine the vertical distribution of the organisms through the interface and the adjacent water column (Queiroz et al., 2004; Leles et al., 2014). Therefore, the succession of high and low tides gives rise to a series of oscillations characterizing the short-term dynamics of intertidal benthic microalgae biomass (Blanchard et al., 2001).

Silicate also influenced the abundance of *P. lima* in the autumn at S1 and S2 and in spring at S2 to S6. A study revealed that *P. lima* was plentiful in places loaded with silicates (Parsons and Preskitt, 2007). This species has been reported as a widespread dinoflagellate in many coastal waters and estuaries around the world, generally in spring and summer (Levasseur et al., 2003), in the northern coasts of Tunisia (Aissaoui et al., 2014), in the Fleet lagoon in the UK (Foden et al., 2005), in Greek coastal waters (Aligizaki et al., 2009) and in the Adriatic Sea (Ingarao et al., 2009). *Prorocentrum lima* correlated also with orthophosphate concentration and temperature as demonstrated by Loukil-Baklouti et al. (2018). Similar findings on the correlation with the temperature were found in Bizerte lagoon (Sahraoui et al., 2013), in the Gulf of Tunis (Aissaouiet al., 2014) and in the western Adriatic (Ingarao et al., 2009). Furthermore, *P. lima* was reported in several Mediterranean ecosystems during August in the Gulf of Tunis (Turki, 2005) and in the Tunis northern lagoon during spring and summer seasons (Armi et al., 2012).

The correlation founded between *A. minutum* and phosphate in spring can be attributed to the increase of phosphorus released by industrial and anthropogenic sewage. Previous works have shown that *A. minutum* blooms occur primarily in coastal waters and nutrient discharge areas (Abdennadher et al., 2012; Loukil-Baklouti et al., 2018), while other authors found that phosphorus deficiency in coastal areas can favor the development of species of the genus *Alexandrium* (Imai et al., 2006).

The abundance of *Coolia monotis* was correlated with phosphate in autumn and spring as well as with nitrate and total nitrogen during winter. The same results were provided along the Gulf of Gabès (Feki-Sahnoun et al., 2019) and North Lake of Tunis (Armi et al., 2010). During the study period and in all studied areas, the highest *C. monotis* abundance was recorded in winter, spring and extended until June (Feki-Sahnoun et al., 2014, 2019; Loukil-Baklouti et al., 2018). According to Aligizaki and Nikolaidis (2006), the high concentrations of *C. monotis* was detected during the winter months with the presence of a summer peak on August in the North Aegean Sea (Greece), while, Armi et al. (2010) showed significant blooms of *C. monotis* occurring in late spring and early summer in the Lake of Tunis (Northern Tunisia). This correlation goes along with the statement that *C. monotis* species can use a range of organic and inorganic nitrogenous substrates (Armi et al., 2010).

Some potentially toxic diatoms, such as *Pseudo-nitzschia* spp. was occurred in autumn and spring seasons and correlated with nitrogenous nutrients in S3 to S6 as highlighted by Loukil-Baklouti et al. (2018). Nitrogen were the main nutrients associated with proliferations of *Pseudo-nitzschia* spp. in northwestern US (Trainer et al., 2012). Various studies on *Pseudo-nitzschia* species in the Bizerte Lagoon (northern Tunisia) revealed a positive correlation between their abundance and nitrate concentration during late spring (Sahraoui et al., 2012).

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The toxic dinoflagellates *Karenia selliformis* correlated with phosphate and silicate in autumn, summer and spring. Many studies show that *K. selliformis* occur in these seasons along the Gulf of Gabes (Feki et al., 2008; Feki-Sahnoun et al., 2017, 2018). Water temperature was correlated with species in autumn, spring and winter. A negative relationship between *K. selliformis* and temperature was highlighted in summer. This corroborates the results showed in Feki-Sahnoun et al. 2017. The correlation defined between the species and the phosphorus form through the year is due to discharge from large-scale phosphate production plants in Sfax and Gabes (Béjaouiet al., 2004; Ghannem et al., 2010), which can reach 12,000 ton per day.

Conclusion

Our study provides the monthly spatial distribution of harmful microalgae in the water column revealing high density of harmful microalgae on the coasts of Sfax. This increase was justified by the nutrient availability especially in spring. Our results clearly confirmed that the physical parameters influenced the distribution of most potentially toxic dinoflagellate species. The benthic dinoflagellates presence was justified by the continual mixing of the water column generating a sediment resuspension process that is favorable to the resuspension of benthic dinoflagellate from sediment and its presence in the water column. This study highlights anthropogenic inputs in the surface waters of the coastal area of Sfax. These anthropogenic inputs undoubtedly have substantial impacts on structure and functioning of marine ecosystems in the Sfax coastal area. For this reason, this study emphasizes the need for an effective treatment and management measures for industrial effluents and other anthropogenic discharges into the coastal waters so as to reduce the impact of pollution.

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References

Abdennadher, M., Hamza, A., Fekih, W., Hannachi, I., Zouari-Belaaj, A., Bradai, M.N., Aleya, L., 2012. Factors determining the dynamics of toxic blooms of *Alexandrium minutum* during a 10-year study along the shallow southwestern Mediterranean coasts. Estuarine, Coastal and Shelf Science 106, 102–111. http://dx.doi.org/10.1016/j.ecss.2012.04.029

Aissaoui, A., Armi, Z., Akrout, F., Ben Hassine, O.K., 2014. Environmental factors and seasonal dynamics of *Prorocentrum lima* population in coastal waters of the Gulf of Tunis, South Mediterranean. Water Environment Research 86, 2256–2270. http://dx.doi.org/10.1016/j.hal.2014.07.017

Aligizaki, K., Nikolaidis, G., 2006. The presence of the potentially toxic genera *Ostreopsis* and *Coolia* (Dinophyceae) in the north Aegean Sea, Greece. Harmful Algae 5, 717–730. https://doi.org/10.1016/j.hal.2006.02.005

Aligizaki, K., Nikolaidis, G., Katikou, P., Baxevanis, A.D., Abatzopoulos, T.J., 2009. Potentially toxic epiphytic *Prorocentrum* (Dinophyceae) species in Greek coastal waters. Harmful Algae 8, 299–31. https://doi.org/10.1016/j.hal.2008.07.002

Allison, J.G., 2000. Dynamics of Estuarine Microphytobenthos in a Shallow Water Sand Bottom Habitat (Thèse de doctorat). The University of West Florida, 99pp.

Aloulou, F., Elleuch, B., Kallel, M., 2012. Benthic foraminiferal assemblages as pollution proxies in the northern coast of Gabes Gulf, Tunisia. Environmental Monitoring and Assessment 184, 777–795. https://doi.org/10.1007/s10661-011-2001-2

Anderson, D.M., Kulis, D.M., Doucette, G.J., Gallagher, J.C., Balech, E., 1994. Biogeography of toxic dinoflagellates in the genus *Alexandrium* from the northeastern United States and Canada. Marine Biology 120, 467–78. https://doi.org/10.1007/BF00680222

Anderson, D.M., Alpermann, T.J., Cembella, A.D., Collos, Y., Masseret, E., Montresor, M., 2012. The globally distributed genus *Alexandrium*: Multifaceted roles in marine ecosystems and impacts on human health. Harmful Algae 14, 10–35. https://doi.org/10.1016/j.hal.2011.10.012

APHA (American Public Health Association)., 1992. Standard methods for the examination of water and waste water. Washington. DC: American Public Health Association.

Armi, Z., Trabelsi, E., Turki, S., Ben Maiz, N., Mahmoudi, E., 2012. Composition and dynamics of potentially toxic dinoflagellates in a shallow Mediterranean lagoon. Oceanological and Hydrobiological Studies 41, 25–35. https://doi.org/10.2478/s13545-012-0036-9

Bahloul, M., Chabbi, I., Dammak, R., Amdouni, R., Medhioub, K., Azri, C., 2015. Geochemical behaviour of PM10 aerosol constituents under the influence of succeeding anticyclonic/cyclonic situations: case of Sfax City, southern Tunisia. Environmental Monitoring and Assessment 187, 757. doi: 10.1007/s10661-015-4980-x

Balech, E., 1988. Los dinoflagelados del Atlantico sud occidental. Madrid: Instituto Espanõl de Oceanografia, Publicaciones Especiales, 309 pp.

Balech, E., 1995. The Genus *Alexandrium halim* (Dinoflagellata). Sherkin Island Marine Station, Sherkin Island, Co. Cork, Ireland, 151 pp.

Béjaoui, B., Ben Ismail, S., Othmani, A., Ben Abdallah-Ben Hadj Hamida, O., Chevalierd, C., Feki-Sahnoun, W., Harzallah, A., Ben Hadj Hamida, N., Bouaziz, R., et al. 2019. Synthesis review of the Gulf of Gabes (eastern Mediterranean Sea, Tunisia): Morphological, climatic, physical oceanographic, biogeochemical and fisheries features. Estuarine, Coastal and Shelf Science 219, 395–408. https://doi.org/10.1016/j.ecss.2019.01.006

Béjaoui, B., Rais, S., Koutitonsky, V., 2004. Modélisation de la dispersion du phosphogypse dans le golfe de Gabès. Bulletin de l'Institut national scientifique et technique d'océanographie et de pêche 31, 103–109.

Journal of Sedimentary Environments
Published by Universidade do Estado do Rio de Janeiro
4 (4): 458-470. October-December, 2019
doi: 10.12957/jse.2019.47324

Bel Hassen, M., Drira, Z., Hamza, A., Ayadi, H., Akrout, F., Issaoui, H., 2008. Summer phytoplankton pigments and community composition related to water mass properties in the Gulf of Gabes. Estuarine, Coastal and Shelf Science 77, 645–656. https://doi:10.1016/j.ecss.2007.10.027

Bel Hassen, M., Drira, Z., Hamza, A., Ayadi, H., Akrout, F., Messaoudi, S., Issaoui, H., Aleya, L., Bouain, A., 2009. Phytoplankton dynamics related to water mass properties in the Gulf of Gabes: ecological implications. Journal of Marine Systems 75, 216–226. https://doi:10.1016/j.jmarsys.2008.09.004

Ben Brahim, M., Hamza, A., Ben Ismail, S., Mabrouk, L., Bouain, A., Aleya, L., 2013. What factors drive seasonal variation of phytoplankton, protozoans and metazoans on leaves of *Posidonia oceanica* and in the water column along the coast of the Kerkennah Islands, Tunisia? Marine Pollution Bulletin 71, 286–298. http://dx.doi.org/10.1016/j.marpolbul.2013.01.024

Ben Brahim, M., Hamza, A., Hannachi, I., Rebai, A., Jarboui, O., Bouain, A., Aleya, L., 2010. Variability in the structure of epiphytic assemblages of *Posidonia oceanica* in relation to human interferences in the Gulf of Gabes, Tunisia. Marine Environmental Research 70, 411–421. https://doi.org/10.1016/j.marenvres.2010.08.005

Ben Mustapha, K., Hattour, A., 2013. Le couvert végétal marin du golfe de Gabès: cartographie et réseau de surveillance de l'herbier de Posidonie. Institut National des Sciences et Technologies de la Mer.

Ben Naila, I., Hamza, A., Gdoura, R., Diogene, J., Iglesia, P., 2012. Prevalence and persistence of gymnodimines in clams from the Gulf of Gabes (Tunisia) studied by mouse bioassay and LC–MS/MS. Harmful Algae 18, 56–64. http://dx.doi.org/10.1016/j.hal.2012.04.004

Ben Salem, Z., Drira, Z., Ayadi, H., 2015. What factors drive the variations of phytoplankton, ciliate and mesozooplankton communities in the polluted southern coast of Sfax, Tunisia? Environmental Science and Pollution Research 22, 11764–11780. http://doi: 10.1007/s11356-015-4416-8

Blanchard, G.F., Montagna, P.A., 1992. Photosynthetic response of natural assemblages of marine benthic microalgae to short- and long-term variations of incident irradiance in Baffin Bay, Texas. Journal of Phycology 28, 7–14. https://doi.org/10.1111/j.0022-3646.1992.00007.x

Cembella, A.D., Ibarra, I.A., Diogene, J., Dahl, E., 2005. Harmful algal blooms and their assessment in fjords and coastal embayments. Oceanography 18, 158–171. https://doi.org/10.1111/j.0022-3646.1992.00007.x

Chamtouri, I., Abida, H., Khanfir, H., Bouri, S., 2008. Impacts of at-site wastewater disposal systems on the groundwater aquifer in arid regions: case of Sfax city, Southern Tunisia. Environmental Geology 55, 1123–1133. https://doi.org/10.1007/s00254-007-1060-8

Chiaudani, G., Marchetti, R., Vighi, M., 1980. Eutrophication in Emilia-Romagna coastal waters (North Adriatic sea, Italy): a case history. Mediterranean Coastal Pollution 12, 185–192. https://doi.org/10.1016/B978-0-08-026058-7.50019-4

Dammak-Zouari, H., Hamza, A., Bouain, A., 2009. Gymnodiniales in the Gulf of Gabes (Tunisia). Cahiers de Biologie Marine 50, 153–170. https://doi.org/10.21411/CBM.A.3F122090

Dodge, J.D., 1985. Atlas of dinoflagellates. A scanning electron microscope survey. London: Ferrand Press.

Drira, Z., Kmiha-Megdiche, S., Sahnoun, H., Hammami, A., Allouche, N., Tedetti, M., Ayadi, H., 2016. Assessment of anthropogenic inputs in the surface waters of the southern coastal area of Sfax during Spring (Tunisia, Southern Mediterranean Sea). Marine Pollution Bulletin 104, 355–363. http://dx.doi.org/10.1016/j.marpolbul.2016.01.035

Feki, W., Hamza, A., Bel Hassen, M., Rebai, A., 2008. Les efflorescences phytoplanctoniques dans le golfe de Gabès (Tunisie) au cours dedix ans de surveillance (1995–2005). Institut National des Sciences et Technologies de la Mer 35, 105–116.

Feki, W., Hamza, A., Frossard, V., Abdennadher, M., Hannachi, I., Jacquot, M., Bel Hassen, M., Aleya, L., 2013. What are the potential drivers of blooms of the toxic dinoflagellate *Karenia selliformis*? A 10-year study in the Gulf of Gabès, Tunisia, southwestern Mediterranean Sea. Harmful Algae 23, 8–18. http://dx.doi.org/10.1016/j.hal.2012.12.001

Feki-Sahnoun, W., Hamza, A., Mahfoudi, M., Rebai, A., Bel Hassen, M., 2014. Long-term microphytoplankton variability patterns using multivariate analyses: ecological and management implications. Environmental Science and Pollution Research 21, 11481–11499. http://DOI 10.1007/s11356-014-3009-2

Feki-Sahnoun, W., Hamza, A., Njah, H, Barraj, N., Mahfoudi, M., Rebai, A., Bel Hassen, M., 2017. Bayesian network approach to determine environmental factors controlling *Karenia selliformis* occurrences and blooms in the Gulf of Gabès Tunisia. Harmful Algae 63, 119–132. http://dx.doi.org/10.1016/j.hal.2017.01.013

Feki-Sahnoun, W., Njah, H., Hamza, A., Barraj, N., Mahfoudi, M., Rebai,A., Bel Hassen, M., 2018. Using general linear model, Bayesian networks and Naive Bayes classifier for prediction of *Karenia selliformis* occurrences and blooms. Ecological Informatics 43, 12–23. https://doi.org/10.1016/j.ecoinf.2017.10.017

Feki-Sahnoun, W., Njah, H., Abdennadher, M., Hamza, A., Barraj, N., Mahfoudi, M., Rebai, A., Bel Hassen, M., 2019. A Naïve Bayesian network approach to determine the potential drivers of the toxic dinoflagellate *Coolia monotis* (Meunier, 1919) in the Gulfof Gabès, Tunisia, Euro-Mediterranean Journal for Environmental Integration 4, 30. https://doi.org/10.1007/s41207-019-0123-z

Foden, J., Purdie, D.A., Morris, S., Nascimento, S., 2005. Epiphytic abundance and toxicity of *Prorocentrum lima* populations in the Fleet Lagoon, UK. Harmful Algae 4, 1063–1074. https://doi.org/10.1016/j.hal.2005.03.004

Gargouri, T., 2006. Diagnostique de la zone côtière Sud de Grand Sfax, Projet SMAP III- Tunisie (2006–2008). Tunisie: Stratégie de Gestion Intégré de la zone Côtière Sud de Grand Sfax.

Ghannem, N., Azri, C., Serbaji, M.N., Yaich, C., 2010. Spatial distribution of heavy metals in the coastal zone of "Sfax-Kerkennah" plateau, Tunisia. Environmental Progress & Sustainable Energy 30, 221–233. https://DOI: 10.1002/ep.10462

Gillbricht, M., 1988. Helgolãnder Meeresuntersuchungen 42, 435–467. https://doi.org/10.1007/BF02365620

Hamza-Chaffai, A., Amiard-Triquet, C., El Abed, A., 1997. Metallothionein-like protein, is it an efficient biomarker of metal contamination? A case study based on fish from the

Journal of Sedimentary Environments
Published by Universidade do Estado do Rio de Janeiro
4 (4): 458-470. October-December, 2019
doi: 10.12957/jse.2019.47324

RESEARCH PAPER

Tunisian coast. Archives of Environmental Contamination and Toxicology 33, 53–62. DOI: 10.1007/s002449900223

Haywood, A.J., Steidinger, K.A., Truby, E.W., 2004. Comparative morphology and molecular phylogenetic analysis of three new species of the genus *Karenia* (Dinophyceae) from New Zealand. Journal of Phycology 40, 165–179. https://doi.org/10.1111/j.0022-3646.2004.02-149.x

Hodgkin, E.P., Hamilton, B.H., 1993. Fertilizers and eutrophication in southwestern Australia: setting the scene. Fertilizer Research 36, 95–103. https://doi.org/10.1007/BF00747579

Huber-Pestalozzi, G., 1968. Das phytoplankton des Susswassars, 1. Halfte, Cryptophyceae, Chloromonadophyceae, Dinophyceae. Stuttgart: E. Schweizerbart Verlag.

Husson, B., Hernández-Fariñas, T., Le Gendre, R., Schapira, M., Chapelle, A., 2016. Two decades of *Pseudo-nitzschia* spp. blooms and king scallop (*Pecten maximus*) contamination by domoic acid along the French Atlantic and English Channel coasts: seasonal dynamics, spatial heterogeneity and interannual variability. Harmful Algae 51, 26–39. https://DOI: 10.1016/j.hal.2015.10.017

Imai, I., Yamaguchi, M., Hori, Y., 2006. Eutrophication and occurrences of harmful algal blooms in the Seto Inland Sea, Japan. Plankton and Benthos Research 1, 71–84. https://doi.org/10.3800/pbr.1.71

Ingarao, C., Lanciani, G., Verri, C., Pagliani, T., 2009. First record of *Prorocentrum lima* (Dinophyceae) inside harbor areas and along the Abruzzo region coast, W Adriatic. Marine Pollution Bulletin 58, 596-600. https://doi.org/10.1016/j.marpolbul.2009.02.012

Johnson, W.S., Allen, D.M., 2005. Zooplankton of the Atlantic and Gulf Coasts: A Guide to Identification and Ecology. The Johns Hopkins University Press: Baltimore.

Joint, I., Lewis, J., Aiken, J., Proctor, R., Moore, G., Higman, W., Donald, M., 1997. Interannual variability of PSP (paralytic shell-fish poisoning) outbreaks on the northeast UK coast. Journal of Plankton Research 19, 937–956. https://doi.org/10.1093/plankt/19.7.937

Kobbi-Rebai, R., Annabi-Trabelsi, N., Khemakhem, H., Ayadi, H., Aleya, L., 2013. Impacts of restoration of an uncontrolled phosphogypsum dumpsite on the seasonal distribution of abiotic variables, phytoplankton, copepods, and ciliates in a man-madesolar saltern. Environmental Monitoring and Assessment. 185, 2139–2155. https://DOI:10.1007/s10661-012-2695-9

Laabir, M., Collos, Y., Masseret, E., Grzebyk, D., Abadie, E., Savart, V., Sibat, M., Amzil, Z., 2013. Influence of environmental factors on the paralytic shellfish toxin content and profile of *Alexandrium catenella* (Dinophyceae) isolated from the Mediterranean Sea. Marine Drugs 11, 1583–1601. https://doi: 10.3390/md11051583

Leles, S.G., Souza, C.A.D., Faria, C.D.O., Ramos, A.B., Fernandes, A.M., Moser, G.A.D.O., 2014. Short-term phytoplankton dynamics in response to tidal Stirring in a tropical estuary (Southeastern Brazil). Brazilian Journal of Oceanography 62, 341–349. http://dx.doi.org/10.1590/s1679-87592014070506204

Levasseur, M., Couture, J.Y., Weise, A.M., Michaud, S., Elbrächter, M., Sauve, G., Bonneau, E., 2003. Pelagic and epiphytic summer distributions of *Prorocentrum lima* and *P. mexicanum* at two mussel farms in the Gulf of St. Lawrence, Canada. Aquatic Microbial Ecology 30, 283–293. http://.doi. 10.3354/ame030283

Louati, A., Elleuch, B., Kallel, A., Saliot, A., Dagaut, J., Oudot, J., 2001. Hydrocarbon contamination of coastal sediments from the Sfax area (Tunisia), Mediterranean Sea. Marine Pollution Bulletin 42, 445–452. https://doi.org/10.1016/S0025-326X(00)00179-X

Loukil-Baklouti, A., Feki Sahnoun, W., Hamza, A., Abdennadher, M., Mahfoudhi, M., Bouain, A., Jarboui, O., 2018. Controlling factors of harmful microalgae distribution in water column, biofilm and sediment in shellfish production area (south of Sfax, Gulf of Gabès) from southern Tunisia. Continental Shelf Research 152, 61–70. https://doi.org/10.1016/j.csr.2017.11.003

Mabrouk, L., Hamza, A., Bradai, M.N., 2014. Variability in the Structure of Planktonic Microalgae Assemblages in Water Column Associated with *Posidonia oceanica* (L.) Bedin Tunisia. Journal of Marine Biology ID 241410, 1–7. http://dx.doi.org/10.1155/2014/241410

Masó, M., Garcés, E., 2006. Harmful microalgae blooms (HAB); problematic and conditions that induce them. Marine Pollution Bulletin 53, 620–630. http://doi:10.1016/j.marpolbul.2006.08.006

Moestrup, Ø., Codd, G.A., Elbrächter, M., Faust, M.A., Fraga, S., Fukuyo, Y., Cronberg, G., Halim, Y., Taylor, J.R., Zingone, A., 2002. IOC taxonomic reference list of toxic algae. Intergovernmental Oceanographic Commission of UNESCO. http://ioc.unesco.org/hab/data4taxlist.htm

Okaichi, J.M., 1997. Red tides in the Seto Inland Sea. *In*: Okaichi, T., Tanagi, T. (eds.), Sustainable Development in the Seto SeaInl and Japan: from the Viewpoint of Fisheries. Terra, Tokyo.

Parsons, M.L., Preskitt, L.B., 2007. A survey of epiphytic dinoflagellates from the coastal waters of the island of Hawaii. Harmful Algae 6, 658–669.

Queiroz, R.L., Brandini, F.P., Pellizzari, F.M., 2004. Dynamics of microalgal communities in the water-column/sediment interface of the inner shelf off Parana State, southern Brazil. Brazilian Journal of Oceanography 52, 183–194. http://dx.doi.org/10.1590/S1679-87592004000300002

R Core Team., 2017. R: A Language and Environment for Statistical Computing. https://www.R-project.org/

Ranston, E.R., Webber, D.F., Larsen, J., 2006. The first description of the potentially toxic dinoflagellate, *Alexandrium minutum* in Hunts Bay, Kingston Harbour, Jamaica. Harmful Algae 16, 29–47. https://doi.org/10.1016/j.hal.2006.05.006

Reguera, B., Bravo, I., Marinõ, J., Campos, M.J., Fraga, S., Carbonell, A., 1993. Trends in the occurrence of *Dinophysis* spp in Galician coastal waters. *In*: Samyda, T.J., Shimizu, Y. (eds.), Toxic Phyto-plankton Blooms in the Sea. Elsevier, Amsterdam.

Rekik, A., Maalej, S., Ayadi, H., Aleya, L., 2013. Restoration impact of an uncontrolled phosphogypsum dump site on the seasonal distribution of abiotic variables, phytoplankton and zooplankton along the near shore of the south-western Mediterranean coast. Environmental Science and Pollution Research 20, 3718–3734. doi: 10.1007/s11356-012-1297-y

Sahraoui, I., Bouchouicha, D., Mabrouk, H.H., Hlaili, A.S., 2013. Driving factors of the potentially toxic and harmful species of

Journal of Sedimentary Environments
Published by Universidade do Estado do Rio de Janeiro
4 (4): 458-470. October-December, 2019
doi: 10.12957/jse.2019.47324

RESEARCH PAPER

Prorocentrum Ehrenberg in a semi-enclosed Mediterranean lagoon (Tunisia, SW Mediterranean). Mediterranean Marine Science 14, 353–362. http://dx.doi.org/10.12681/mms.338

Smayda, T.J., Reynolds, C.S., 2001. Community assembly in marine phytoplankton: application of recent models to harmful dinoflagellate blooms. Journal of Plankton Research 23, 447–461. https://doi.org/10.1093/plankt/23.5.447

Steidinger, K.A., Tangen,K., 1996. Dinoflagellates. *In*: Tomas,C.R. (ed.), Identifying Marine Diatoms and Dinoflagellates, Academic Press, New York.

Tayibi, H., Choura, M., López, F.A., Alguacil, F.J., López-Delgado A., 2009. Environmental impact and management of phosphogypsum. Journal of Environmental Management 90, 2377–2386. https://doi.org/10.1016/j.jenvman.2009.03.007

Ter Braak, C.J.F., Smilauer, P., 2002. CANOCO Reference Manual and Cano Draw for Windows User's Guide: Software for Canonical Community Ordination (Version 4.5). Microcomputer Power, Ithaca, NY.

Trainer, V.L., Bates, S.S., Lundholm, N., Thessen, A.E., Cochlan, W.P., Adams, N.G., Trick, C.G., 2012. *Pseudo-nitzschia* physiological ecology, phylogeny, toxicity, monitoring and impacts on ecosystem health. Harmful Algae 14, 271–300. https://doi.org/10.1016/j.hal.2011.10.025

Tregouboff, G., Rose, M., 1957. Manuel de planctonologie méditerranéenne. Volume II. Paris: CNRS.

Tomas, C.R., Hasle, G.R., Steidinger, A.K., Syvertsen, E.E., Tangen, C., 1996. Identifying marine diatoms and dinoflagellates. London: Academic Press.

Turki, S., 2005. Distribution of toxic dinoflagellates along the leaves of seagrass *Posidonia oceanica* and *Cymodocea nodosa* from the Gulf of Tunis. Cahiers de Biologie Marine 46, 29–34. DOI: 10.21411/CBM.A.2FF8790A

Uthermöhl, H., 1958. Zur Vervollkommung der quantitativen Phytoplankton-Methodik. Mitteilungen Internationale Vereinigung Theoretische und Angewandte Limnologie 9, 1–38. https://doi.org/10.1080/03680770.1931.11898492

Wells, M.L., Trainer, V.L., Smayda, T.J., Karlson, B.S., Trick, C.G., Kudela, R.M., Ishikawa, A., Bernard, S., Anderson, D.M., Cochlan, W.P., 2015. Harmful algal blooms and climate change: learning from the past and present to forecast the future. Harmful Algae 49, 68–93. https://doi.org/10.1016/j.hal.2015.07.009

Zaghden, H., Kallel, M., Elleuch, B., Oudot, J., Saliot, A., Sayadi, S., 2014. Evaluation of hydrocarbon pollution in marine sediments of Sfax coastal areas from the Gulf of Gabes of Tunisia, Mediterranean Sea. Environmental Earth Sciences 72, 1073–1082. https://doi.org/10.1007/s12665-013-3023-6

Zaghden, H., Kallel, M., Louati, A., Elleuch, B., Oudot, J., Saliot, A., 2005. Hydrocarbons in surface sediments from the Sfax coastal zone, (Tunisia) Mediterranean Sea. Marine Pollution Bulletin 50, 287–294. https://doi.org/10.1016/j.marpolbul.2005.04.045

Zingone, A., Oksfeldt Enevoldsen, H., 2000. The diversity of harmful algal blooms: a challenge for science and management. Ocean & Coastal Management 43, 725–748. https://doi.org/10.1016/S0964-5691(00)00056-9