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Nutrient loading and occurrence of potentially harmful phytoplankton species in the North Lake of Tunis (Tunisia)

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Abstract: In the frame of a monitoring program, a systematic water sampling was carried out in different sites in the North Lake of Tunis. Sampling was performed twice a month from September 2005 to September 2006. The phytoplankton community was generally dominated by dinoflagellates or diatoms. During this annual cycle, the main results were: the detection of many potentially harmful species such as *Pseudo-nitzschia* spp., *Dinophysis* spp., *Alexandrium* spp., *Prorocentrum* spp., *Gyrodinium* spp. and *Coolia monotis*. The presence of some of them, like *Dinophysis sacculus* and *Gyrodinium spirale*, was observed all around the year, and bloom recurrence of these taxa in several sampling stations was registered. The potentially harmful phytoplankton group abundance accounted for 42% of all the phytoplankton species detected. The composition of potentially harmful phytoplankton genera and their succession were related to the available nutrients and other environmental factors. Furthermore, there was a highly positive correlation between the occurrence of potentially harmful species and the two following factors: water salinity and temperature.

Résumé : *Rejet de sels nutritifs et présence d'espèces phytoplanctoniques potentiellement toxiques dans le lac nord de Tunis (Tunisie)*. Dans le cadre du programme de biosurveillance des écosystèmes aquatiques, une étude du phytoplancton a été effectuée dans le Lac Nord de Tunis de septembre 2005 à septembre 2006. La communauté phytoplanctonique a été dominée essentiellement par les dinoflagellés suivis par les diatomées. Durant cette étude, nous avons détecté plusieurs espèces potentiellement toxiques, qui ont représenté 42% des espèces du phytoplancton récolté, tel que *Pseudo-nitzschia* spp., *Dinophysis* spp., *Alexandrium* spp., *Prorocentrum* spp., *Gyrodinium* spp. et *Coolia monotis*, dont certaines étaient présentes durant toute l'année, comme *Dinophysis sacculus* et *Gyrodinium spirale*. L'étude de la corrélation entre la composition des espèces phytoplanctoniques potentiellement toxiques et les facteurs abiotiques du milieu a montré essentiellement une relation positive entre la prolifération de ces espèces et les deux paramètres: salinité et température de l'eau.

Keywords: Potentially Harmful Phytoplankton • Nutrients • North Lake of Tunis

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Introduction

Among the different species of existing marine phytoplankton, about 80 taxa have the capacity to produce powerful toxins that can find their way through fish and shellfish to humans (Hallegraeff, 2003). Noxious or Harmful Algal Blooms (HABs) can be extensive, almost mono-specific events of marine phytoplankton bloom occurring along coastal areas (Smayda, 1997). High rates of nutrient loadings in coastal environments frequently enhance phytoplankton growth and density, and increase the rate of organic matter loading, ultimately resulting in eutrophication (Nixon, 1995; Smith et al., 1999).

The nutrient stimulus is often associated with increased availability of nitrogen sources (Capone, 2000). However, local and seasonal phosphate induction of phytoplankton growth is frequently observed (Fisher et al., 1992; Holmboe et al., 1999). In addition, the potential for nutrient limitation in both marine and freshwater aquatic ecosystems is usually governed by the concentration of nitrogen and phosphorus (combined dissolved organic and inorganic forms) and by the relative ratio of these two major nutrients (Guildford & Hecky, 2000). Furthermore, nutrient inputs into coastal waters can support phytoplankton growth and biomass to a level where other nutrients, such as silica, become growth limiting (Dortch & Whitledge, 1992; Justić et al., 1995). Knowledge of the spatio-temporal growth-rate responses of aquatic phytoplankton communities to increased nutrient loading offers insights into the potential effects of eutrophication on energy transfer within the ecosystem and provides a tool for establishing ecologically relevant management strategies (Conley, 2000). Assessing the phytoplankton biomass response to controlled experimental treatments is a valuable first-step approach for determining the positive or negative impacts of the nutrient manipulations on phytoplankton productivity (Ornolfsdottir et al., 2004).

In recent years there has been an increase in toxic and noxious phytoplankton blooms associated with fish mortalities, mainly in southern Tunisian coasts and in lakes. Romdhane et al. (1998) and Turki et al. (2006) showed that the frequent outbreaks of toxic blooms in these areas can probably be explained by the enclosed nature of these lakes, which allows them to trap cysts, nutrients and toxins.

The North Lake of Tunis is one of the most productive aquatic Tunisian areas for recreational fisheries and shellfishes collection. Even though this site has already been interested by several works, other than this is the first study aimed at analysing the relationships between the abiotic environmental parameters and the density of potentially harmful phytoplankton.

Material and methods

Study site

The northern part of the Tunis Lake is a coastal marine area which is located in the south-western region of the gulf of Tunis, North of Tunisia (along the southern coast of the central Mediterranean Sea) (Fig. 1). It's a 2400 ha area, located between 36°45' and 36°52' North latitude and between 10°10' and 10°20' East longitude.

In the past this lake was known to be one of the most eutrophic ecosystems of the world receiving most of the sewage effluents and rain water run-off from Tunis. The average of total nitrogen was about 315 μM.L^{-1}, the phosphorus one about 20 μM.L^{-1} and the Chl. *a* higher than 60 μg.L^{-1} (Ben Charrada, 1992).

This problem was mainly solved by the construction of a separation dam within the lake and a system of inlet/outlet gates in the channel which connects this lake with the sea. This system has considerably increased in the lake the water circulation driven by natural tidal forces. Consequently, the residence water time is shorter than before; varying between 17 to 24 days, and the increased water flows caused a reduction of the eutrophication of the lake itself. The average of total nitrogen becomes about 33 μM.L^{-1}, the phosphorus one about 0.7 μM.L^{-1} and the Chl. *a* fewer than 4 μg.L^{-1} (Osment et al., 1991; Ben Charrada, 1992).

The coarse sediments of the Lake are predominately colonized by green algal meadows (*Ulva lactuca* Linné 1753, *U. rigida* (C. Agarth) Le Jolis 1863 and *Enteromorpha* spp.) coupled with the phanerogam (*Ruppia cirrhosa* (Petagna) Grande) and the red algae (*Gracillaria* sp.) (Trabelsi et al., 2001).

Sampling

Water samples were collected bi-weekly between September 2005 and September 2006. The sampling stations (Fig. 1) were located using the GPS (Global Position System) Garmin GPS45. Each station was located in one of the five compartments in which the lake itself was virtually divided. They are: Station A (mean depth: 2.2 m), which represents the part of the lake which is closer to the bay of Tunis; Stations B (2 m), C (2.3 m) and D (1 m) which represent respectively the northern, western and southern parts of the lake; Station E (2.5 m) which is opposed to the station A and represents the last compartment in the Lake. Station F (3 m) is located at the end of the channel; representing the south-western part of the bay of Tunis and is considered as a control station.

At each station, a sample was collected, for phytoplankton study, from the whole water column using a

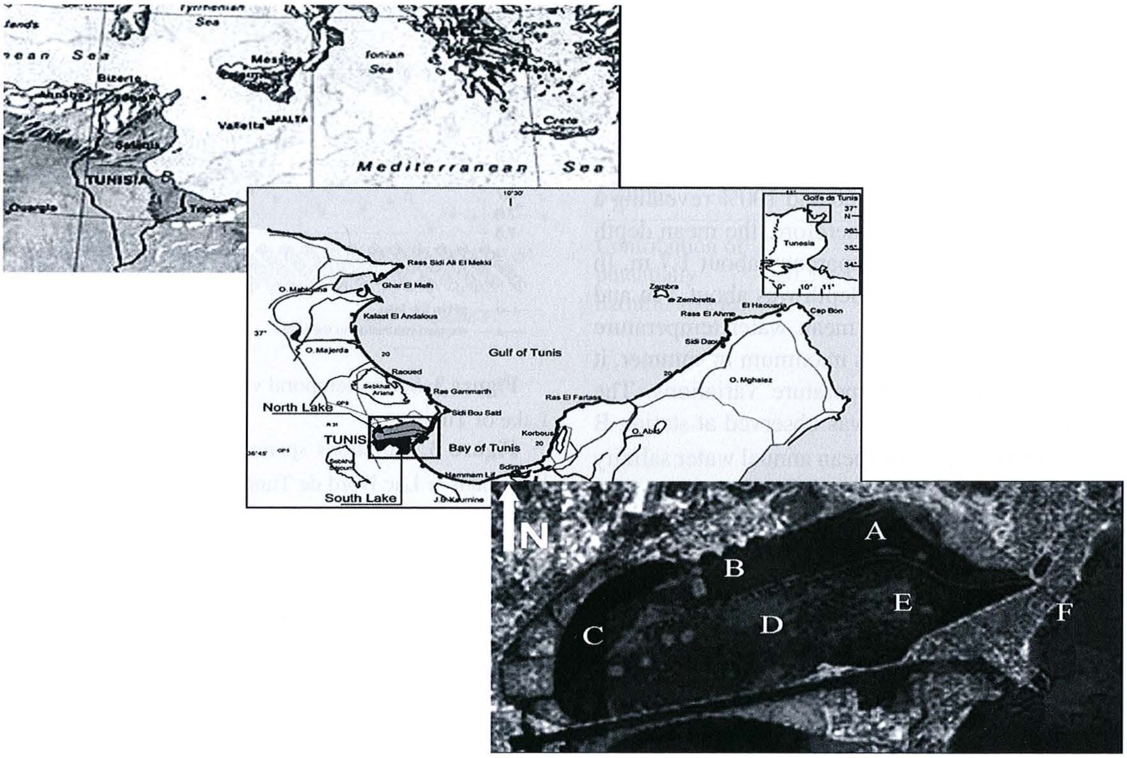

Figure 1. Sampling stations in the North Lake of Tunis.
Figure 1. Stations d'échantillonnage dans le Lac Nord de Tunis.

hose with a variable length. This sampling technique allows to overcome the difficulty of the hetero-geneous vertical phytoplankton distribution (Lindahl, 1986). Water samples were collected at 0.5 m of depth from the surface to analyse nutrient and chlorophyll a (chl. *a*) contents.

Dissolved oxygen (% saturation), temperature (°C), salinity and pH were measured *in situ* using a multi-parameter probe (Multi 340i / SET).

The transparency of the water column was estimated using a Secchi disc. Analyses of dissolved inorganic nutrients (N-NO_3^-, N-NO_2^-, N-NH_4^+, P-PO_4^-, Si-SiO_2) were performed following the method of Strickland & Parsons (1972) Potential nutrient limitation was rated using the method developed by Justić et al. (1995)

For Chl. *a* quantification, 1 litre of water was filtered on a 25 mm Millipore nitrocellulose filters with 0.45 μm pore size. The Chl. *a* was extracted in 10 mL of 90% acetone for 24 h, in the dark at - 4°C, and the extract concentration was analysed spectrophotometrically (UV-Visible Spectrophotometer PU-8800).

Microscopy analysis

Phytoplankton samples (1 L) were concentrated to 100 mL and preserved with neutralized formalin (4%). 10 mL of fixed water samples were settled in a counting chamber for 24 h. The entire chamber was scanned at magnifications of 200 - 400 x for quantitative determinations using an IMT2 inverted Olympus microscope; dinoflagellate species were identified with a BH2 Olympus microscope with a magnification of 1000 x. Phytoplankton cells were expressed as Cells L^{-1} (Throndsen, 1995).

The identification of phytoplankton species was performed according to the descriptions established by Hasle & Syversten (1997) for diatoms and Balech (1988), Sournia (1995) and Steidinger & Tangen (1997) for dinoflagellates. *Alexandrium* species were identified according the work of Balech (1995).

Statistical analysis

In order to estimate the impact of the environmental factors on the occurrence of the potentially harmful phytoplankton populations, a matrix of previously normalized physical, chemical and biological data was produced and analysed by means of a principal components analysis (PCA). This type of statistical analysis between the biological, physical and chemical descriptors is suitable when a uniform linear relationship is likely to exist between variables (Dolédec & Chessel, 1989).

Results

Physical and Chemical factors

In the North Lake of Tunis, typical trends of water secchi disc transparency ranged between 60 and 100% revealing a good transparency of the water. Therefore, the mean depth was about 2 m and the mean transparency about 1.7 m. In the reference station F, the mean depth was about 3 m and the transparency about 2 m. The mean water temperature increased in spring and reached its maximum in summer, it depends strongly of the air temperature variations. The peak water temperature of 30°C was observed at station B on August, 1st 2006 (Fig. 2). The mean annual water salinity ranged between 33.8 and 44.3 at the different stations. The maximum of 46.5 was registered on August, 1st 2006 and August, 15th 2006 at station E (Fig. 2). The maximum of dissolved oxygen reached 11.5 mg L^{-1} with 110% saturation at station A on February, 15th 2006, the average values ranged between 5.1 and 10.9 mg L^{-1}. The average values of pH ranged between 7.71 and 8.44, the maximum registered value was about 8.48 at station B on January, 17th 2006 (Fig. 3).

Nutrient ratios in the North Lake of Tunis (Fig. 4)

Potential nutrient limitation has been calculated as in Justić et al. (1995): the criteria of probable limitation are as follows:

- P limitation ($P < 0.1\ \mu M$; DIN: $PO_4 > 22$; Si: $PO_4 > 22$)
- N limitation ($DIN < 1\ \mu M$; DIN: $PO_4 < 10$; Si: $DIN > 1$)
- Si limitation ($Si < 2\ \mu M$; Si: $PO_4 < 10$; Si: $DIN < 1$)

During our study, registered Redfield ratios were DIN: PO_4 = 111 and Si: PO_4 = 74. It was DIN: PO_4 = 12 and Si: PO_4 = 8 at station F.

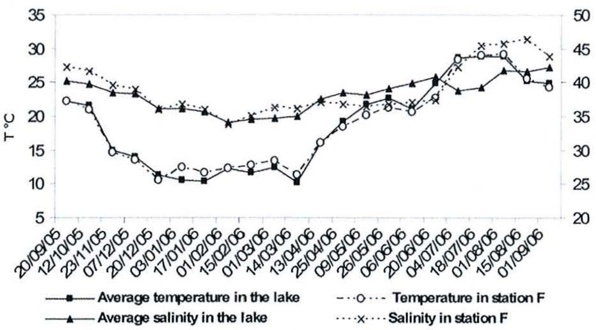

Figure 2. Spatio-temporal variations of the water temperature and salinity in the North Lake of Tunis.

Figure 2. Variations spatio-temporelles de la température et de la salinité de l'eau dans le Lac Nord de Tunis.

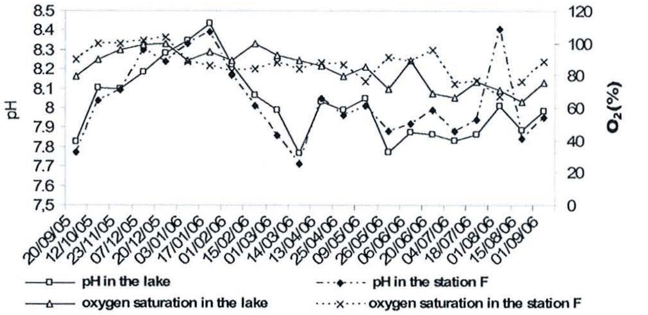

Figure 3. Spatio-temporal variations of pH and O_2 in the North Lake of Tunis.

Figure 3. Variations spatio-temporelles du pH et de l'O_2 de l'eau dans le Lac Nord de Tunis.

These results showed that phosphates can be considered as the limiting growth factors of phytoplankton in the lake. However, at station F, the two factors phosphates and silicates were limiting.

Phytoplankton

During the study period, diatoms and dinoflagellates were the dominant phytoplanktonic elements representing respectively 36.45% and 61.95% of total phytoplankton Cell number. *Chaetoceros* spp., *Navicula* spp. and *Nitzschia* spp. were the most abundant diatoms while *Gyrodinium* spp., *Peridinium* spp., *Dinophysis sacculus* Stein 1883, *Prorocentrum minimum* (Pavillard) Schiller 1933, *Prorocentrum micans* Ehrenberg 1833 and *Coolia monotis* Meunier 1919 were the commonest dinoflagellates in this community (Fig. 5).

Station A presented the highest Shannon diversity of phytoplanktonic populations (3.75). The lowest diversity was measured at station D (1.61) (Table. 1).

The contribution of the potentially harmful phytoplankton was the lowest at station A (20.5%) and the highest at station D (71%) (Table. 2).

The potentially harmful phytoplankton taxa recorded (Fig. 8, Table 3) can be grouped into four categories: potential Diarrheic Shellfish Poisoning (DSP) producers such as *Dinophysis* spp. and *Prorocentrum* spp., potential Paralytic Shellfish Poisoning (PSP) producers such as

Table 1. Shannon diversity index of phytoplanktonic populations at the different stations of the North Lake of Tunis.

Tableau 1. Indice de Shannon des populations phytoplanctoniques des différentes stations du Lac Nord de Tunis.

Stations	A	B	C	D	E	F
Shannon index	3.75	2.65	3.50	1.61	3.65	2.40

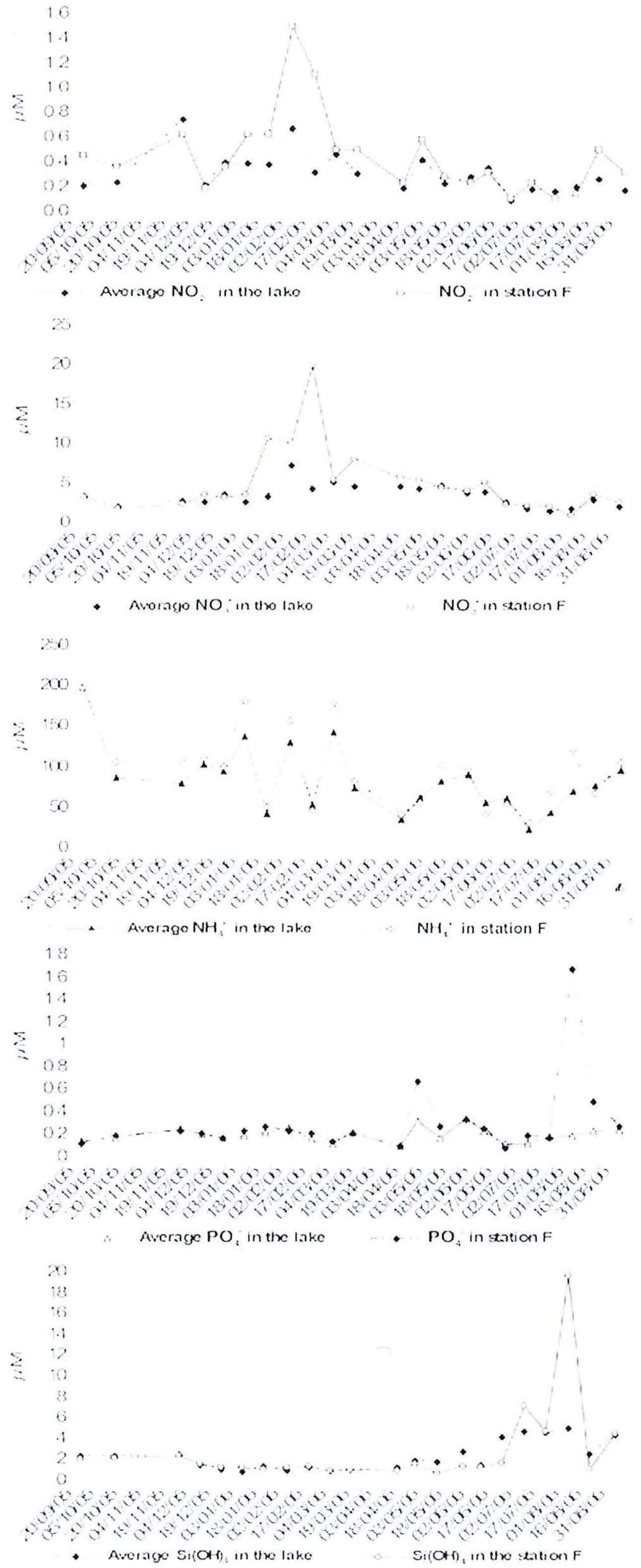

Figure 4. Spatio-temporal variations of inorganic nutrients in the North Lake of Tunis.

Figure 4. Variations spatio-temporelles des nutriments inorganiques dans le Lac Nord de Tunis.

Table 2. Contribution of potentially harmful species in the different stations of the North Lake of Tunis.

Tableau 2. Contribution des espèces phytoplanctoniques potentiellement toxiques dans les différentes stations du Lac Nord de Tunis.

Stations	A	B	C	D	E	F
Contribution of potentially harmful species	20.5%	59.6%	34.1%	71%	69%	42%

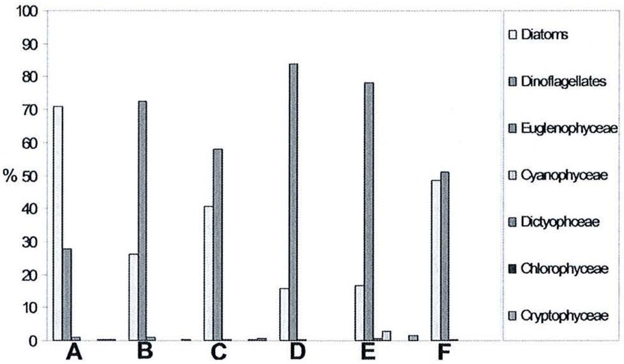

Figure 5. Distribution of phytoplankton groups in the different stations in the North Lake of Tunis.

Figure 5. Distribution des groupes phytoplanctoniques dans les différentes stations du Lac Nord de Tunis.

Alexandrium spp., potential Amnesic Shellfish Poisoning (ASP) producers such as *Pseudo-nitzschia* spp. and Ciguatera toxin producers such as *Coolia monotis*.

Dinophysis sacculus, *Gyrodinium impudicum* Fraga & Bravo (Bergh 1881), *Gyrodinium spirale* (Bergh) Kofoid & Swezy 1921, *Scripsiella* spp. and *Chaetoceros* spp. were distributed largely in the North Lake of Tunis. They were wide spread along the study area and their presence was registered throughout the year.

Dinophysis sacculus occurred with the highest density of 7.10^3 Cells L^{-1} on December 2005 at station E (Index of Presence IP = 93.4%), co-occuring with the dinoflagellate species *Scripsiella* spp., *Prorocentrum micans* and *Gyrodinium* spp.

Gyrodinium spirale was recorded almost all over the annual cycle with an IP of about 81.2%, reaching the highest density on August, 1st 2006 (6.10^3 Cells L^{-1} at station F). *Gyrodinium aureolum* proliferated also in the same station and at the same period with 38.10^3 Cells L^{-1}.

Prorocentrum minimum was recorded mainly in the northern part of the lake (stations A, B and C), reaching its maximum on December, 7th 2005 (87.10^3 Cells L^{-1} at station B).

Table 3. Distribution of potentially harmful species in the North Lake of Tunis.

Tableau. 3. Distribution des espèces phytoplanctoniques potentiellement toxiques dans le Lac Nord de Tunis.

	A	B	C	D	E	F
Pseudo-nitzschia spp	+	+	+	+	10^4 (22/09/05)	+
Alexandrium catenella	-	+	+	+	+	+
A. foedum	+	-	-	-	-	+
A. insuetum	+	-	-	-	-	+
A. minutum	-	+	-	+	-	-
A. tamerense	-	+	+	+	+	-
Coolia monotis	+	+	+	5.10^5 (09/05/06)	+	+
Dichtyocha fibula	+	+	-	-	-	-
Dinophysis acuminata	+	+	+	+	+	+
D. caudata	-	+	-	-	-	-
D. fortii	+	+	-	+	+	-
D. sacculus	+	+	+	+	7.10^3(07/12/05)	+
Gonyaulax polyedra	+	+	+	+	+	+
Gymnodinium sanguineum	+	+	+	+	+	+
Gyrodinium aureolum	+	+	+	+	+	38.10^3 (01/08/06)
G. impudicum	+	+	+	+	+	+
G. spirale	+	+	+	+	+	6.10^3 (01/08/06)
Ostreopsis siamensis	+	+	-	-	-	+
Prorocentrum lima	+	+	-	+	-	+
P. minimum	17.10^3(07/12/05)	87.10^3 (07/12/05)	23.10^3 (07/12/05)	+	+	+
Protoperidium depressum	+	+	+	+	+	+

(+ : present / - : absent)

Alexandrium spp. was present in lower amounts compared to the other toxic species. *Alexandrium catenella* (Whedon & Kofoid) Balech 1985 maximum concentration (1400 Cells L^{-1}) was recorded during the summer period (July, 18th 2006) at station E.

Coolia monotis proliferated in spring at station D (The peak was recorded on May, 9th 2006 with a maximum of 5.10^5 Cells L^{-1}) and *Pseudo-nitzschia* spp. proliferated on September, 22nd 2005 at station E with a density of 10^4 Cells L^{-1}.

Phytoplankton and chlorophyll a data

Chl. *a* distribution in the Lake was heterogeneous (Fig. 6). The highest concentration was about 1.8 $\mu g\ L^{-1}$ at station A on November, 23rd 2005 corresponding to a windy weather and agitated water. Spatio-temporal variations of the mean chl. *a* and the phytoplankton density are illustrated in Figure 6. The mean concentrations of chl. *a* were respectively about 0.5 $\mu g\ L^{-1}$ and 0.4 $\mu g\ L^{-1}$ in the lake and at station F.

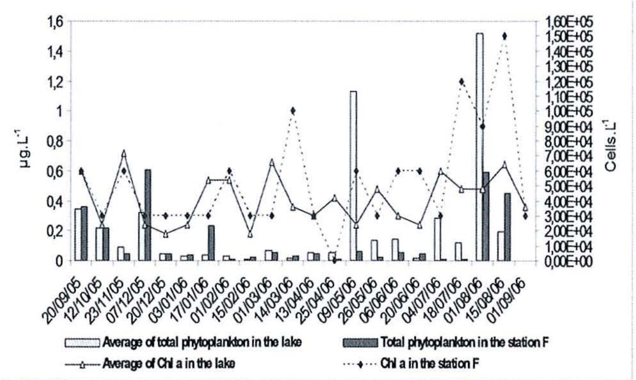

Figure 6. Total phytoplankton distribution and variation of the Chl a.

Figure 6. Distribution du phytoplancton total et variation de la Chl a.

Statistical analyses

The PCA used to estimate the interactions between potentially harmful phytoplanktonic groups observed in the North Lake of Tunis and the registered physico-chemical parameters, is illustrated in Figure 7. We have calculated these correlations using all the data compiled from all the stations during all the period of study (n = 132).

The diatom *Pseudo-nitzschia* spp accounted for 5% of the total diatoms population in this area during the study period. This potentially harmful diatom was positively

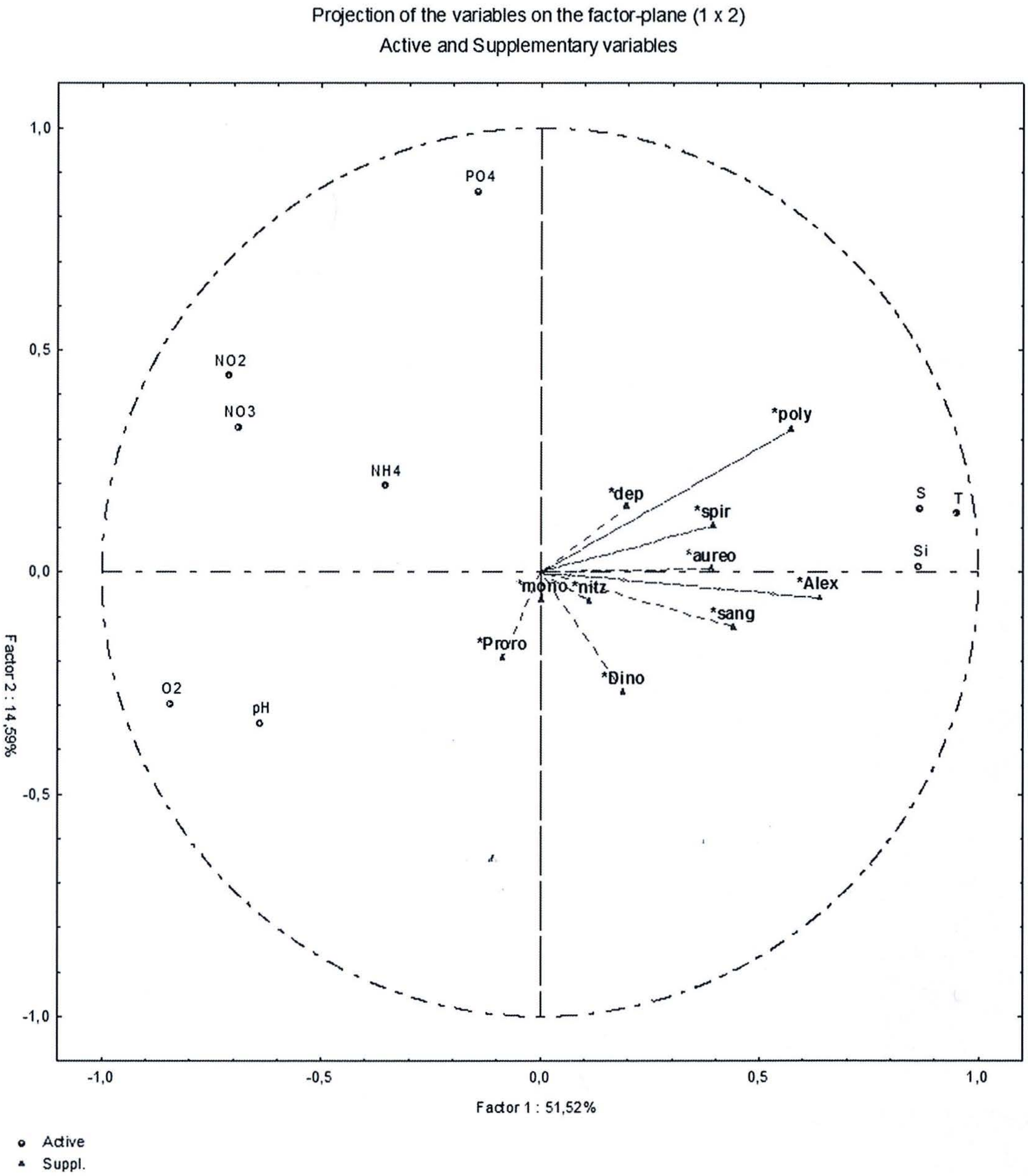

Figure 7. Principal Components Analysis (PCA) of abiotic parameters and Harmful phytoplankton species in the North Lake of Tunis.

Figure 7. Analyse en Composantes Principales (ACP) pour les paramètres abiotiques et le phytoplancton potentiellement toxique dans le Lac Nord de Tunis.

correlated to the salinity which was about 42.5 ($r = 0.29$, $p < 0.05$) and to NH_4^+ ($r = 0.48$, $p < 0.05$), it presented a low positive correlation with SiO_2 ($r = 0.14$, $p > 0.05$).

P. minimum presented its highest concentration (87.10^3 Cells L^{-1}) on December 2005 at station B, corresponding to 14°C ($r = - 0.15$, $p > 0.05$) and 38 ($r = 0.05$, $p > 0.05$). In contrast a significant positive correlation was found between the abundance of *P. minimum* and the values of pH (> 8.2) ($r = 0.19$, $p < 0.05$) and the dissolved oxygen ($O_2 \geq 100\%$) ($r = 0.29$, $p < 0.05$).

The correlation test showed a weak negative relationship between *Dinophysis* spp. cell numbers and nutrient loading in most of the sampling stations. No significant relationships between its abundance and dissolved inorganic nutrients or climatic conditions were found during this study. However, *Dinophysis sacculus* presented a high

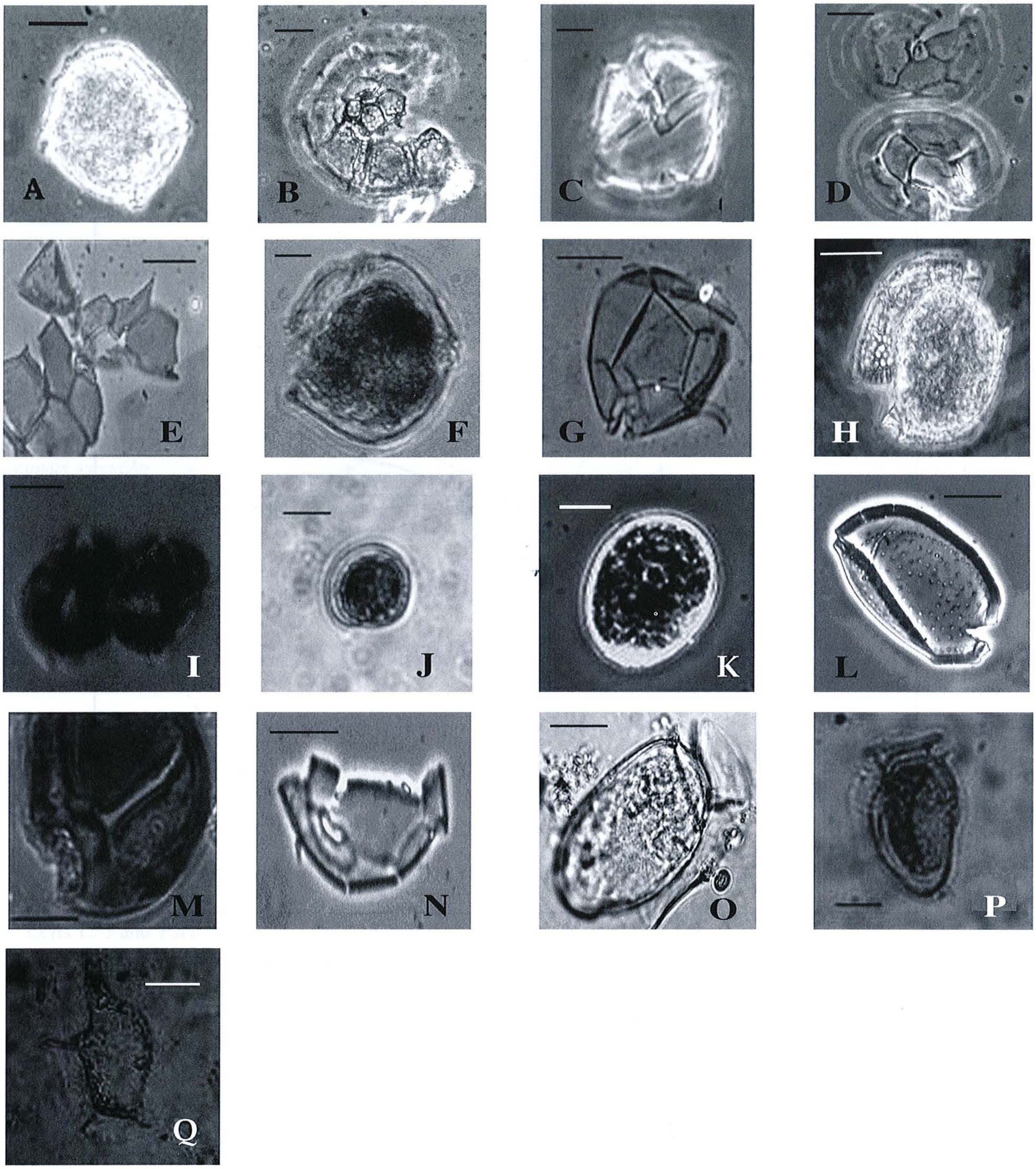

Figure 8. Some harmful phytoplankton species detected in the North Lake of Tunis. **A, B.** *Gonyaulax polyedra,* hypothecal plates. **C, D.** *Alexandrium catenella,* epithecal and hypothecal view. **E.** *Alexandrium minutum,* epithecal plates. **F.** *Alexandrium tameranse*. **G.** *Alexandrium foedum*. **H.** *Alexandrium insuetum*. **I.** *Gyrodinium aureolum*. **J.** *Prorocentrum minimum*. **K, L.** *Prorocentrum lima,* thecal view. **M, N.** *Coolia monotis,* sulcus view. **O.** *Dinophysis acuminata*. **P.** *Dinophysis sacculus*. **Q.** *Dinophysis caudata*. Scale bar = 10 μm.

Figure 8. Quelques espèces phytoplanctoniques potentiellement toxiques détectées dans le Lac Nord de Tunis. **A, B.** *Gonyaulax polyedra,* plaques de l'hypothèque. **C, D.** *Alexandrium catenella,* épithèque et hypothèque. **E.** *Alexandrium minutum,* plaques de l'épithèque. **F.** *Alexandrium tameranse*. **G.** *Alexandrium foedum*. **H.** *Alexandrium insuetum*. **I.** *Gyrodinium aureolum*. **J.** *Prorocentrum minimum*. **K, L.** *Prorocentrum lima,* valve. **M, N.** *Coolia monotis,* sulcus. **O.** *Dinophysis acuminata*. **P.** *Dinophysis sacculus*. **Q.** *Dinophysis caudata*. Echelle = 10 μm.

density (7.10^3 Cells L^{-1}) at station E at the end of the autumn (December, 7th 2005). A positive correlation was revealed between temperature and salinity and cell density of the majority of potentially toxic phytoplankton.

In our study period, *Alexandrium* spp. presented a high diversity (we found 5 species: *A. catenella, A. foedum* Balech 1990, *A. insuetum* Balech 1985, *A. minutum* Halim 1960 and *A. tamerense* (Lebour, 1925) Balech 1992)) and a low density in this ecosystem (1400 Cells L^{-1} of *A. catenella* on July 2006). Its density showed a strong correlation with water temperature (29.5°C) ($r = 0.66$, $p < 0.05$) and salinity (46) ($r = 0.36$, $p < 0.05$).

Gyrodinium aureolum, G. spirale, Gymnodinium sanguineum, Gonyaulax polyedra and *Protoperidinium depressum* (Bailey) Balech 1974 showed also a high positive correlation with temperature and salinity. However, *G. aureolum* presented its highest concentration during our period of study at station F with 38.10^3 Cells L^{-1} on August, 1st 2006, when the water temperature was about 29.2°C ($r = 0.36$, $p < 0.05$) and the salinity was about 45.7 ($r = 0.36$, $p < 0.05$).

Coolia monotis proliferation is signalled for the first time in this area of study. Its peak was detected at station D on May, 9th 2006 with 5.10^5 Cells L^{-1}.

Discussion

In the study period, the water of the North Lake of Tunis was characterized by higher DIN: PO_4 ratios and greater potential for phosphorus limitation of the phytoplankton growth. Overall, N-NH_4 was the most abundant nutrient throughout the lake. These conditions may favour the majority of dinoflagellates species (Harrison, 1976; Nedwell et al., 2002; Badylak & Philips, 2004). In addition, the amount of chl. *a* indicates an oligo-trophic state in this area during the annual cycle.

Dinoflagellates and diatoms have several significant ecophysiological differences including a different affinity for nutrients, considerable nutritional diversity involving mixotrophic nutrition, and motility (Smayda, 1997). These ecophysiological characteristics are important in bloom regulation and dynamics, and may directly influence growth rates and competitive ability (Heil et al., 2005).

In this study, there is evidence that phosphate concentration did not positively correlate with harmful phytoplankton species abundance and distribution. This is in agreement with the fact that potentially harmful dinoflagellates and the diatoms *Pseudo-nitzschia* spp. are shown to be negatively related to phosphate trend (Sournia et al., 1987; Yamamoto et al., 2004; Penna et al., 2006).

Lomas & Gilbert (1999) found that *Prorocentrum minimum* growth rate was similar at 20.8 °C and at 4.8 °C, that is in agreement with our results indicating that the variation of the temperature did not influence this species' abundance. In Mediterranean waters, or in areas with a Mediterranean climate, temperature does not appear to be the main factor controlling *P. minimum* blooms (Grzebyk & Berland, 1996; Hajdu et al., 2005). Blooms usually occur between April and June and between October and November (Silva, 1985) when it is often rainy. In our case, *P. minimum* presented its highest concentration (87.10^3 Cells L^{-1}) on December 2005 at station B, with a water temperature of 14°C and a salinity of 38. Conversely a significant positive correlation was observed between the abundance of *P. minimum* and the values of pH (> 8.2) and of dissolved oxygen ($O_2 \geq 100\%$).

Hansen (2002) explored the influence of pH on *P. minimum* in the Mariagerfjord, Denmark, showing that this species has one of the highest tolerances for high pH values.

Among others, a decrease of salinity generally coupled with increasing nutrient concentrations could be determining factors in the activation of *P. minimum* blooms.

The absence of correlation between nutrient loading and *Dinophysis sacculus* density fits well with other studies (Delmas et al., 1992; Blanco et al., 1998; Aubry et al., 2000; Caroppo et al., 2001; Smayda & Reynolds, 2001; Godhe et al., 2002) and this may be attributed to the potential mixotrophic character of *Dinophysis* cells and to the tendency of this species to accumulate in low depths.

In agreement with our observations, Vila et al. (2001) found that *Alexandrium catenella* was present in the plankton in Catalonia when water temperature is higher than 20ºC. Also, the positive correlation of the water temperature and salinity with the *Gyrodinium* spp., *Gonyaulax* spp. and *Protoperidinium depressum* (Bailey) Balech 1974 prove the fact that temperature and salinity influence cell density of the majority of phytoplankton species, essentially potentially toxic ones.

The climatic factors were the principal stimulants of the proliferation of *Coolia monotis*; a low tidal mixing energy with a high water temperature (22°C) and a photoperiod of more than 12 hours/day helped for the stratification phenomena conducting to the proliferation of this species. *Coolia monotis* also showed a positive correlation with the highest concentration of N-NO_3^- on May, 9th 2006 at station D ($r = 0.21$, $p < 0.05$). According to Turki (2005), this epiphytic dinoflagellate is found almost yearly in the *Cymodocea nodosa* and the *Posidonia oceanica* seagrass bed ecosystem in the Gulf of Tunis and its proliferations occurred with relative high temperature (> 27°C) and salinity (> 37).

Conclusion

In the North Lake of Tunis, a dinoflagellate dominated phytoplankton community was observed throughout the year. This contrasted with the reference station in the bay which was dominated by the diatoms species. In addition, it seems that temperature and salinity influenced the majority of potentially harmful phytoplankton genera distribution.

The analysis carried out to reveal a correlation between the potentially harmful phytoplankton groups in water samples and nutrients present in the seawater showed that there is a sufficient availability of nutrients for the growth of the phytoplankton community in the North Lake of Tunis.

It was evident that a higher abundance of potentially harmful dinoflagellate species commonly occurred during spring, summer and early autumn, periods coinciding with an increase in salinity and temperature. During this period, essentially climatic conditions favoured the formation of potentially harmful diatom and dinoflagellate assemblages.

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References

Aubry F.B., Berton A., Bastianini M., Bertaggia R., Baroni A. & Socal G. 2000. Seasonal dynamics of *Dinophysis* in coastal waters of the NW Adriatic Sea (1990-1996). *Botanica Marina*, **43**: 423-430.

Badylak S. & Philips E.J. 2004. Spatial and temporal patterns of phytoplankton composition in a subtropical coastal lagoon, the Indian River Lagoon, Florida, USA. *Journal of Plankton Research*, **26**: 1229-1247.

Balech E. 1988. Los Dinoflagelados del Atlantico sudoccidental. *Publicaciones Especiales Instituto Español de Oceanografia*, **1**: 1-31.

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

Ben Charrada R. 1992. Le lac de Tunis après les aménagements: paramètres physico-chimiques de l'eau et relation avec la croissance des algues. *Marine Life*, **1**: 29-44.

Blanco J., Moroño Á., Pazos Y., Maneiro J. & Mariño J. 1998. Trends and variations of the abundance of main PSP and DSP producing species in the Galician Rias: environmental and biological influences. In: *Harmful Algae* (B. Reguera, J. Blanco, M.L. Fernández & T. Wyatt eds), pp. 204-207. Xunta de Galicia and Intergovernmental Oceanographic Commission of UNESCO.

Capone D.G. 2000. The marine microbial nitrogen cycle. In: *Microbial Ecology of the Oceans* (D.L. Kirchman ed), pp. 455-493. Wiley-Liss Inc., New York.

Caroppo C., Congestri R. & Bruno M. 2001. Dynamics of *Dinophysis* sensu lato species (Dinophyceae) in a coastal Mediterranean environment (Adriatic Sea). *Continental Shelf Research*, **21**: 1839-1854.

Conley D.J. 2000. Biogeochemical nutrient cycles and nutrient management strategies. *Hydrobiologia*, **410**: 87-96.

Delmas D., Herbland A., Maestrini S.Y. 1992. Environmental conditions which lead to increase in cell density of the toxic dinoflagellates *Dinophysis* spp. in nutrient-rich and nutrient-poor waters of the French Atlantic coast. *Marine Ecology Progress Series*, **89**: 53-61.

Dolédec S. & Chessel D. 1989. Rythmes saisonniers et composantes stationnelles en milieu aquatique. II. Prise en compte et élimination d'effets dans un tableau faunistique. *Acta Oecologica*, **10**: 207-232.

Dortch Q. & Whitledge T.E. 1992. Does nitrogen or silicon limit phytoplankton production in the Mississippi River plume and nearby regions. *Continental Shelf Research*, **12**: 1293-1309.

Fisher T.R., Peele E.R., Ammerman J.W. & Harding L.W. 1992. Nutrient limitation of phytoplankton in Chesapeake Bay. *Marine Ecology Progress Series*, **82**: 51-63.

Godhe A., Svensson S. & Rehnstam-Holm A.S. 2002. Oceanographic settings explain fluctuations in *Dinophysis* spp. and concentrations of diarrheic shellfish toxin in the plankton community within a mussel farm area on the Swedish west coast. *Marine Ecology Progress Series*, **240**: 71-83.

Grzebyk D. & Berland B. 1996. Influences of temperature, salinity and irradiance on growth of *Prorocentrum minimum* (Dinophyceae) from the Mediterranean sea. *Journal of Plankton Research*, **10**: 1837-1849.

Guildford S.J. & Hecky R.E. 2000. Total nitrogen, total phosphorus, and nutrient limitation in lakes and oceans: is there a common relationship? *Limnology and Oceanography*, **45**: 1213-1223.

Hajdu S., Pertola S. & Kuosa H. 2005. *Prorocentrum minimum* (Dinophyceae) in the Baltic Sea: morphology, occurrence - a review. *Harmful Algae*, **4**: 471-480.

Hallegraeff G.M. 2003. Harmful algal blooms: a global overview. In: *Manual on Harmful Marine Microalgae* (G.M. Hallegraeff, D.M. Anderson & A. Cembella eds), pp. 25-49. UNESCO Publishing, Paris.

Hansen P.J. 2002. Effect of high pH on the growth and survival of marine phytoplankton: implications for species succession. *Aquatic Microbial Ecology*, **28**: 279-288.

Harrison W.G. 1976. Nitrate metabolism of the red tide dinoflagellate *Gonyaulax polyedra* Stein. *Journal of Experimental Marine Biology and Ecology*, **21**: 9-209.

Hasle G.R. & Syversten E.E. 1997. Marine diatoms. In: *Identifying Marine Phytoplankton* (C.R. Tomas ed), pp. 5-385. Academic Press, St. Petersburg, Florida, USA.

Heil C.A., Gilbert P.M. & Fan C. 2005. *Prorocentrum minimum* (Pavillard) Schiller. A review of a harmful algal bloom species of growing worldwide importance. *Harmful Algae*, **4**: 449-470.

Holmboe N., Jensen H.S. & Andersen F.O. 1999. Nutrient addition bioassays as indicators of nutrient limitation of phytoplankton in an eutrophic estuary. *Marine Ecology Progress Series*, **186**: 95-104.

Justić D., Rabalais N.N., Turner R.E. & Dortch Q. 1995. Changes in nutrient structure of river-dominated coastal waters: stoichiometric nutrient balance and its consequences. *Estuarine, Coastal and Shelf Science*, **40**: 339-356.

Lindahl O. 1986. A divided hose for phytoplankton sampling. ICES, C. M. L: 26, Annex 3.

Lomas M.W. & Gilbert P.M. 1999. Interactions between NH_4^+ and NO_3^- uptake and assimilation: comparison of diatoms and dinoflagellates at several growth temperature. *Marine Biology*, **3**: 541-551.

Nedwell D.B., Dong L.F., Sage A. & Underwood G.J.C. 2002. Variations of the nutrients loads to the mainland U.K. estuaries: correlation with catchment areas, urbanization and coastal eutrophication. *Estuarine, Coastal and Shelf Science,* **54**: 951-970.

Nixon S.W. 1995. Coastal marine eutrophication: a definition, social causes, and future concerns. *Ophelia*, **41**: 199-219.

Nusch E.A. 1980. Comparison of different methods for chlorophyll and phaeopigment determination. *Archiv für Hydrobiologie–Beiheft Ergebnisse der Limnologie,* **14**: 14-36.

Ornolfsdottir E.B., Lumsden E.S. & Pinckney J.L. 2004. Phytoplankton community growth-rate response to nutrient pulses in a shallow turbid estuary, Galveston Bay, Texas. *Journal of Plankton Research*, **26**: 325-339.

Osment J., Reeve D.E., Ben Maïz N. & Moussa M. 1991. A.P.C. based water prediction tool for Tunis North Lake. (Technic for environmentally sound water development. *African regional symposium Egypt*. eds), Wooldridge, Hydraulics Research.

Penna A., Ingarao C., Ercolessi M., Rocchi M. & Penna N. 2006. Potentially harmful microalgal distribution in an area of the NW Adriatic coastline: Sampling procedure and correlations with environmental factors. *Estuarine, Coastal and Shelf Science,* **70**: 307-316.

Romdhane M.S., Eilertsen H.C., Daly Yahia-Kefi O. & Daly Yahia M.N. 1998. Toxic dinoflagellate blooms in Tunisian lagoons: causes and consequences for aquaculture. In: *Harmful Algae* (B. Reguera, J. Blanco, M.L. Fernández & T. Wyatt eds), pp. 80-83. Xunta de Galicia and Intergouvernmental Oceanographic Commission of UNESCO. Vigo.

Silva E.S. 1985. Ecological factors related to *Prorocentrum minimum* blooms in Obidos Lagoon (Portugal). In: *Toxic Dinoflagellates* (D.M. Anderson, A. White & D. Baden eds), pp. 251-256. Elsevier, New York.

Smayda T.J. 1997. Harmful algal blooms: their ecophysiology and general relevance to phytoplankton blooms in the sea. *Limnology and Oceanography*, **42**: 1137-1153.

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.

Smith L.D., Wonham M.J., McCann L.D., Ruiz G.M., Hines A.H. & Carlton J.T. 1999. Invasion pressure to a ballast flooded estuary and an assessment of inoculants survival. *Biological Invasions*, **1**: 67-87.

Sournia A., Birrien J.L., Douvillé J.L., Klein B. & Viollier M. 1987. A daily study of the diatom spring bloom at Roscoff (France) in 1985. The spring bloom within the annual cycle. *Estuarine, Coastal and Shelf Science,* **25**: 355-367.

Sournia A. 1995. Red tide and toxic marine phytoplankton of the world ocean: an inquiry into biodiversity. In: *Harmful marine algal blooms* (P. Lassus, G. Arzul, E. Erard, P. Gentien & C. Marcailou-Le Baut C. eds), pp. 103-112. Paris,.

Steidinger K.A. & Tangen K. 1997. Dinoflagellates. In: *Identifying Marine Phytoplankton* (C.R. Tomas ed), pp. 387-584. Academic Press, St. Petersburg, Florida, USA.

Strickland J.H.D. & Parsons T.R. 1972. A practical handbook of seawater analysis. *Fisheries Board of Canada Bulletin*, **167**: 311 p.

Throndsen J. 1995. Estimating cell numbers. In: *Manual on Harmful Marine Microalgae* (G.M. Hallegraeff, D.M. Anderson, A.D. Cembella & H.O. Enevoldsen H.O. eds), pp. 63-80. IOC Manual and Guides No. 33. UNESCO, Paris.

Trabelsi E.B., Shili A. & Ben Maïz N. 2001. Marine flora of the North Lake of Tunis 12 years after its restoration. MED-COAST, 01, **2**: 945-952.

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.

Turki S., Harzallah A. & Sammari C. 2006. Occurrence of harmful dinoflagellates in two different Tunisian ecosystems: the lake of Bizerte and the gulf of Gabès. *Cahiers de Biologie Marine*, **47**: 253-259.

Vila M., Camp J., Garces E., Maso M. & Delgado M. 2001. High resolution spatio-temporal detection of potentially harmful dinoflagellates in confined waters of the NW Mediterranean. *Journal of Plankton Research*, **23**: 497-514.

Yamamoto T., Inokuchi Y. & Sugiyama T. 2004. Biogeochemical cycles during the species succession from *Skeletonema costatum* to *Alexandrium tamarense* in northern Hiroshima Bay. *Journal of Marine Systems,* **52**: 15-32.