Phytoplankton and environmental variables as a water quality indicator for the beaches at Matrouh, south-eastern Mediterranean Sea, Egypt: an assessment

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Abstract

This study was carried out to determine the water quality of the beaches at Matrouh, south-eastern Mediterranean Sea, Egypt, by studying environmental variables as well as phytoplankton abundance and community structure. Surface water samples were monitored from a series of beach sites over a period of five seasons during 2009–2010. A total of 203 phytoplankton species were identified from seven algal divisions. Seasonal differences in the quantitative and qualitative composition of the phytoplankton communities in the different sites were marked. Nutrient concentrations and phytoplankton abundances were found to be poorer than those of many other areas along Egyptian coast. The Shannon-Wiener Diversity Index classified Matrouh water as being between clean and moderately polluted, whereas the WQI demonstrated that it was between good and excellent. It can be concluded that the index based on WQI is currently more suitable than the phytoplankton species index for assessing the quality of the water of the Matrouh beaches.

The complete text of the paper is available at http://www.iopan.gda.pl/oceanologia/

1. Introduction

In marine environments, biotic and abiotic environmental factors have important effects on phytoplankton succession and abundance. The eastern Mediterranean Sea is one of the most oligotrophic marine areas in the world (Azov 1991). This pattern may have altered in the last few years, however, because of unfavourable hydrographic and hydrochemical changes, perhaps in response to human activities. In contrast to other areas in the Mediterranean, there has been little published data on the environmental variables and phytoplankton along the Egyptian Mediterranean coast. Moreover, such data as there are have been reported mainly from hot spots, which usually show higher concentrations of nutrient salts reaching more than 50 μM dissolved inorganic nitrogen, 15 μM dissolved phosphate and 70 μM silicate, as well as the presence of harmful blooms of algae like *Alexandrium minutum* Halim, *Prorocentrum triestinum* J. Schiller and *Skeletonema costatum* (Grev.) Cleve as the predominant species (Dorgham 1997, Mikhail 2001, El-Sherif & Mikhail 2003, Ismael & Dorgham 2003, Dorgham et al. 2004, Gharib & Dorgham 2006, Shams El Din & Abdel Halim 2008).

Tourism has become one of the most important factors in the economies of many areas along the Egyptian coast; most of the associated amenities are located there. The success of the tourist industry in those areas is often associated with an intact natural environment, and so water quality is an important factor for tourists in their choice of destination and should not be underestimated. The coastal zone of Egypt, including several beaches, has been exposed to various environmental problems. Matrouh is one of the most beautiful cities in Egypt, with many beaches where people can relax and enjoy themselves. Estimates of water quality based on physicochemical properties give us a clear picture. Reflecting the composite influence of different water quality parameters, the water quality index (WQI), is also useful for the classification of waters, and can give us an indication of the health of the water. Finally, the species composition of the phytoplankton community is an efficient bioindicator of water quality (Shashi Shekhar et al. 2008).

The aim of the present study was to evaluate the quality of water off the beaches of Matrouh by assessing its physicochemical status as well as the phytoplankton community structure, diversity and distribution.

2. Material and methods

2.1. Study area

Matrouh is located on the north-western Mediterranean coast of Egypt, 290 km west of Alexandria. The beaches at Matrouh extend for a distance of seven km and, as all visitors have testified, are some of the most beautiful in the world. The sea water is a blue-green colour, with no visible algae formation, and very transparent. It is protected from the open sea by a series of rocks forming a natural breakwater with a small opening to allow some wave penetration and ensure good water quality. The beaches selected for analysis were chosen to reflect differences in the physicochemical and biological characteristics existing in the same body of water (Figure 1). Beaches 4, 5, 6, 7 and 8 are situated in the lagoon, while beaches 9 and 10 lie some 20 and 28 km west of the lagoon respectively. Beaches 1, 2 and 3 lie to the east of the lagoon.

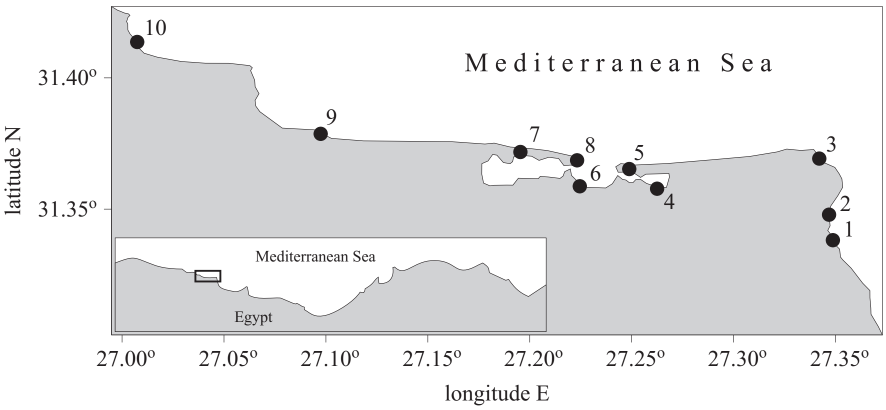

Figure 1. Area of study and sampling beaches; names of beaches: 1 – El-Remalah, 2 – Alam El-Room, 3 – Mena Hashesh, 4 – El-Fayroz, 5 – Romel, 6 – El-Boseet, 7 – Cliobatra, 8 – El-Gharam, 9 – El-Obayed, 10 – A'gebah

2.2. Methods

A total of 50 water samples were collected seasonally with a Ruttner sampler at ten coastal beaches from summer 2009 to summer 2010. Two samples were taken from each beach: one for the phytoplankton count and the other for chemical analysis. The phytoplankton samples were immediately fixed with 4% formaldehyde for laboratory analysis. Phytoplankton were counted and identified using 2-mL settling chambers with a Nikon TS 100 inverted microscope at 400x magnification using Utermöhl's (1958) method. Water temperature was measured with a thermometer sensitive to 0.1°C, transparency with a Secchi disc (diameter 30 cm), the pH using a pocket pH meter (model 201/digital pH meter), and the water salinity using a Beckman salinometer (Model NO.R.S.10); dissolved oxygen, dissolved inorganic nitrogen (DIN: nitrate, nitrite, ammonia), soluble reactive phosphorus (SRP) and reactive silicate were determined according to standard methods described in APHA (1989).

The Water Quality Index (WQI) is a mathematical tool used to transform some quantities of water characterization data into a single number that represents the water quality level (Sanchez et al. 2007). The seven parameters selected were pH, dissolved oxygen, nitrate, nitrite, ammonia, phosphate and silicate. Then, a quality value (Q value) from 0 to 100, based on the normal data range, was assigned to each parameter. Each Q value was multiplied by a weighting factor based on the importance of the parameter, and summation of the weighted Q values yielded the WQI, which defines the water as very bad, bad, medium, good or excellent.

2.3. Statistical analysis

Three indices were used to estimate the community structure: diversity (H′) (Shannon & Wiener 1963), dominance (D) (Simpson 1949) and evenness or equitability (J) (Pielou 1975). The Spearman rank correlation (r) was used to evaluate the relations between environmental variables and phytoplankton abundances at each sampling station (N=50) with the SPSS 8.0 Statistical Package Program.

3. Results

3.1. Hydrographic conditions

The seasonal average physicochemical parameters of the different beaches at Matrouh from summer 2009 to summer 2010 are shown in Table 1.

Water temperature did not deviate from the normal seasonal fluctuations on the south-eastern coast of the Mediterranean Sea (17.45–32.00°C). The lowest values were recorded during winter (17.45–18.40°C) and the highest in summer (27.25–32.00°C). Salinities were uniform on all beaches and exhibited only a narrow variation with a maximum difference of 2.65 PSU during the sampling period (37.35 to 40.00 PSU; av. 38.46 PSU). The pH varied over a very narrow range (0.27 units) on all beaches during the sampling period. Secchi depths usually reached the bottom at nearly all the beaches. The dissolved oxygen concentration fluctuated from 6.08 mg l^{-1} (summer 2009, 2010) to 10.88 mg l^{-1} (autumn).

As far as nutrients are concerned, values were generally significantly higher on beach 4. Dissolved inorganic nitrogen concentrations (DIN) were generally low, except during summer 2010, when ammonia was the main source of inorganic nitrogen, but were much higher on beach 4 (15.30 μM).

Table 1. The average seasonal physicochemical parameters from summer 2009 to summer 2010 at the beaches in Matrouh

Seasons	Parameters				
	Transparency [m]	Dissolved oxygen [mg l^{-1}]	Salinity [PSU]	Water temperature [°C]	pH
summer 2009	2.2±0.75	7.09±0.71	38.56±0.60	27.65±1.26	8.21±0.05
autumn 2009	2.65±0.41	8.13±1.18	38.34±0.36	21.09±0.21	8.24±0.06
winter 2010	2.45±0.50	7.68±0.52	38.02±0.16	17.87±0.41	8.13±0.02
spring 2010	2.40±0.52	8.37±1.25	38.58±0.37	23.0±2.30	8.19±0.08
summer 2010	2.40±0.52	7.07±0.62	38.81±0.59	28.7±0.86	8.12±0.03
Seasons	Parameters					
	NO_3 [μM]	NO_2 [μM]	NH_4 [μM]	PO_4 [μM]	SiO_2 [μM]	WQI
summer 2009	0.92±0.36	0.12±0.07	1.46±0.60	0.89±1.39	1.76±0.91	88.07±5.68
autumn 2009	1.62±0.52	0.09±0.03	1.61±1.12	1.37±2.17	1.13±1.04	84.32±6.11
winter 2010	0.63±0.65	0.02±0.03	1.85±0.57	2.00±1.38	1.84±0.61	81.10±3.94
spring 2010	2.02±1.76	0.07±0.03	2.63±5.02	0.07±0.05	2.21±0.98	90.91±2.97
summer 2010	1.32±1.07	0.01±0.01	3.67±4.18	0.06±0.04	1.39±1.28	91.64±2.69

Ammonia fluctuated significantly throughout the sampling period (0.18–16.83 μM). The nitrate content ranged between 0.13 μM and 5.10 μM with higher values on beach 8, and the nitrite concentration was usually less than 0.30 μM. Phosphate concentrations were below detection levels during spring and summer 2010, reaching the highest value of 7.30 μM during autumn in beach 4. DIN:SRP ratios were lower than the Redfield ratio (N:P=16) in summer, autumn and winter 2009 at all beaches, but were higher than the Redfield ratio in spring and summer 2010. Silicate concentrations were generally low throughout the sampling period, except for a strong increase in the spring when levels reached 4.79 μM on beach 4. Silicate concentrations were the highest on beach 4, like the levels of the other nutrients. The WQI ranged from 80 (beach 4) to 91 (beach 3); hence, the water can be classified as between 'good' and 'excellent'.

3.2. Phytoplankton community structure and composition

From the analysed data, a visible change in phytoplankton community with regard to numerical abundance and species composition was evident among beaches and in the seasonal cycle. A total of 203 phytoplankton species were quantified through the analysis of the 50 samples collected from ten beaches in 5 seasons. Bacillariophyta made up the highest number (61 genera, 120 species), but there was a remarkably low number of Pyrrophyta (22 genera, 52 species). Freshwater Cyanophyta, Chlorophyta and Euglenophyta were represented by 14, 11 and 4 species respectively. Raphydophyta and Silicoflagellates were represented by one species each. The most diverse genus was *Nitzschia* (9 species). Many species (73) of this community were rare, having a frequency of occurrence of 2.00% in all samples, but they were very important because they controlled the levels of species diversity. Bacillariophyta and Pyrrophyta were more abundant both qualitatively (84.73%) and quantitatively (95.41%) than the other taxonomic groups. They were conspicuous as the two most diverse groups with 59.11 and 25.62% of the total species number respectively (Table 2).

Table 2. Taxonomic composition and proportional representation of the phytoplankton groups at the beaches in Matrouh between summer 2009 and summer 2010

Group	Genus	Species	%	cells l^{-1}	%
Bacillariophyta	61	120	59.11	12116	83.75
Pyrrophyta	22	52	25.62	1686	11.66
Chlorophyta	9	11	5.42	457	3.16
Cyanophyta	10	14	6.90	159	1.10
Euglenophyta	3	4	1.97	25	0.17
Raphydophyta	1	1	0.49	18	0.12
Silicoflagellates	1	1	0.49	5	0.04
Total	107	203	100	14466	100

While Bacillariophyta was quantitatively the predominant division (83.75), the total number of species on the sampled beaches demonstrated more pronounced variations at the spatial scale than the temporal one. A high diversity (86 species) was recorded at beach 1, and approximately similar numbers of species (80–82 species) were recorded at beaches 4 and 5, while a conspicuously smaller number (58 species) was found at beach 9. The numbers of phytoplankton species recorded in summer, autumn 2009, winter, spring and summer 2010 were 91, 83, 77, 82 and 89 respectively, and the maximum number of species number in a single sample was 31, at beach 5 during spring.

The following species were frequently found during the study period, even if in very low numbers: *Asterionellopsis glacialis* (Castracane) Round, 1990, *Aulacoseira granulata* (Ehrenberg) Simonsen, 1979, *Cocconeis placentula* Ehrenberg, 1838, *Cylindrotheca closterium* (Ehrenberg) Reiman & Lewin, 1964, *Licmophora flabellata* C. Agardh, 1830, *Licmophora lyngbyei* (Kützing) Grunow ex Van Heurck, 1867, *Nitzschia microcephala* Grunow in Cleve & Möller, 1878, Nitzschia sigma (Kützing) W. Smith, 1853, Pseudo-nitzschia delicatissima (P.T. Cleve, 1897) Heiden, 1928, *Alexandrium minutum* Halim, 1960, *Gonyaulax apiculata* (Pénard, 1891) Entz, 1904, *Protoperidinium minutum* (Kofoid, 1907) Loeblich III, 1970, *Scrippsiella trochoidea* (Stein) Balech ex Loeblich III, 1965 and *Chlorella marina* Butcher R. W., 1952.

The lowest and highest species diversities (H′) were 1.07 (beach 10) and 3.20 (beach 1) in spring. The correlations of phytoplankton abundance with species diversity indices were not significant ($r=0.125$, $p=0.386$). Species evenness (J) varied between 0.41 in summer 2010 (beach 7) and 0.97 in autumn (beach 10), with relatively higher values generally recorded during autumn, indicating a reduction in the degree of dominance at this period.

Testing the diversity-equitability, diversity-species number and diversity-dominance relationship showed that diversity was considerably influenced by species number ($r=0.926$, $p<0.001$) and exhibited no significant relation with equitability. As expected, diversity had a negative relationship with Simpson's index ($r=-0.401$, $p<0.05$).

3.3. Seasonal variation of phytoplankton

In particular, phytoplankton abundances were generally moderate at the beaches sampled, except in spring, when the highest counts were recorded at beaches 1, 3, 4, 5, 6 and 8. On the other hand, beaches 2, 7 and 9 yielded high values in summer 2009, while beach 10 recorded a high value in summer 2010. With respect to mean values, the phytoplankton abundance was the lowest in winter, and the highest in spring. Significantly higher phytoplankton abundances were recorded at beach 4. The phytoplankton communities consisted mainly of Bacillariophyta and Pyrrophyta (Figure 2), even if their contribution to the composition of the community in terms of abundances was different at the different beaches. In particular, Bacillariophyta reached their highest average abundance percentages at beach 5 (93.50%) and beach 6 (92.30%), and Pyrrophyta at beach 9 (40.40%). The contribution of Chlorophyta to the total abundances was 25.20% at beach 10. In contrast, Cyanophyta and Euglenophyta never dominated in the algal community, accounting for an average abundance percentage of only

2.00% (beach 1), 2.10% (beach 5) and 3.70% (beach 10) for Cyanophyta, and 4.80% (beach 9) for Euglenophyta.

During summer 2009 the seasonal mean total phytoplankton cell abundance was $1.11 \times 10^4 \pm 1.74 \times 10^4$ cells l^{-1}. Spatial fluctuation in summer 2009 varied widely with regard to abundance and dominant species.

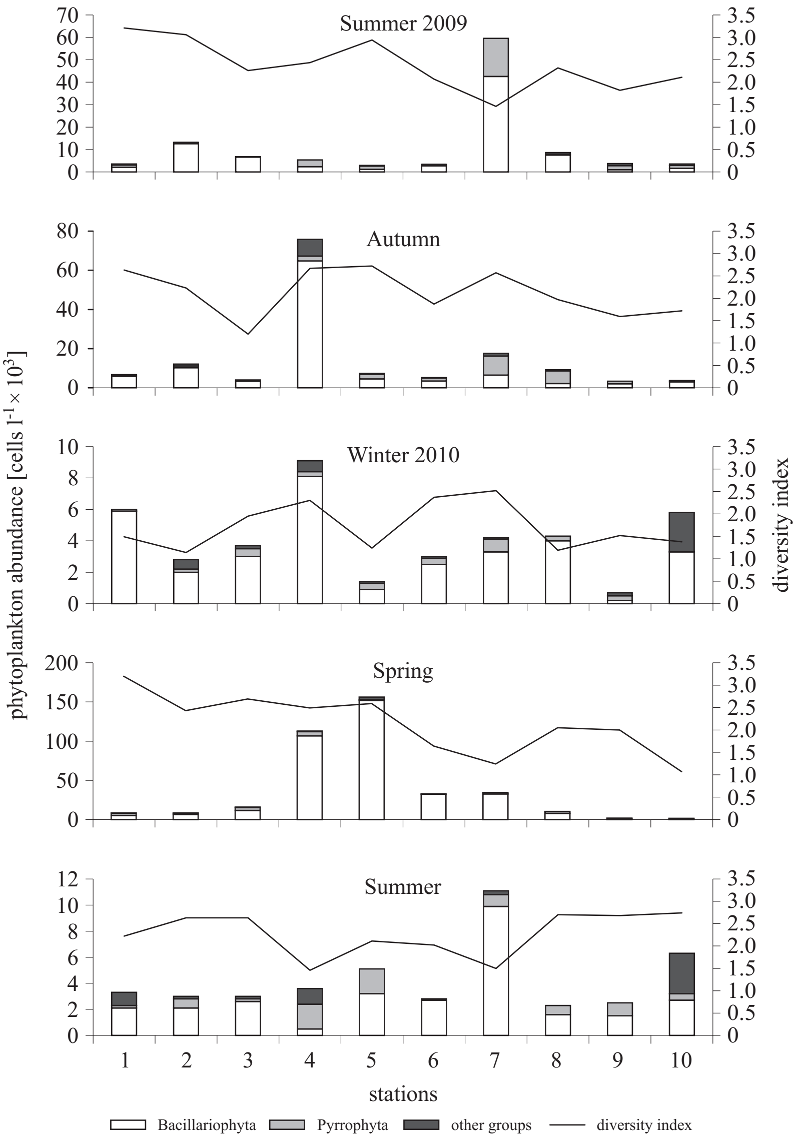

Figure 2. Seasonal variations of phytoplankton abundance subdivided by algal groups and species diversity index of the Matrouh beaches from summer 2009 to summer 2010

Bacillariophyta was the dominant division at all the beaches (26.40–97.20%) except 4, 5 and 9, where Pyrrophyta was the dominant group (55.10%, 48.10% and 47.30% respectively). There was an increase in the cell abundance of Euglenophyta at beach 9. The total phytoplankton abundance varied between 0.28×10^4 cells l^{-1} (beach 5) and 5.96×10^4 cells l^{-1} (beach 7). *Chaetoceros* sp. and *C. closterium* were the most dominant diatom species, and *Prorocentrum lima* (Ehrenberg, 1860) Stein, 1878 and *Neoceratium fusus* (Ehrenberg) F. Gomez, D. Moreira & P. Lopez-Garcia, 2009 from the Pyrrophyta constituted the main components at beach 7. *Cyclotella comta* was predominant at beach 1, *A. granulate* at beaches 2 and 3, *C. closterium* at beaches 6 and 8, and co-dominant with *S. trochoidea* at beach 4, while this last species was dominant at beaches 5 and 10, and *P. minutum* at beach 9.

During autumn the seasonal mean total phytoplankton cell abundance was $1.45 \times 10^4 \pm 2.20 \times 10^4$ cells l^{-1}. Spatial fluctuation in autumn also varied widely in abundance and the presence of dominant species. Bacillariophyta was the dominant division at all beaches except for 7 and 8, where Pyrrophyta was predominant, whereas Chlorophyta was the second most important division at beach 4. The total abundance of phytoplankton varied between 0.35×10^4 cells l^{-1} (beach 9) and 7.58×10^4 cells l^{-1} (beach 4). The main components at beach 4 were *P. delicatissima* and *Navicula cryptocephala* Kützing, 1844, the predominant diatom species, and *C. marina* (Chlorophyta). The genus *Leptocylindrus* Cleve, 1889 was dominant at beaches 1 and 10, *P. delicatissima* at beaches 3 and 6, and co-dominant with *S. trochoidea* at beach 6, while this last species was dominant at beaches 8 and 9 and co-dominant with *G. apiculata* at beach 8. *Leptocylindrus danicus* Cleve, 1889 was predominant at beach 1, *L. lyngbyei* at beach 2, *Nitzschia palea* (Kützing) W. Smith, 1856 at beach 5, and *Nitzschia longissima* (Brébisson in Kützing) Ralfs in Pritchard, 1861, *G. apiculata* and *P. lima* at beach 7.

The lowest phytoplankton abundance was observed in winter 2010 ($0.41 \times 10^4 \pm 0.24 \times 10^4$ cells l^{-1}). The dominant group was Bacillariophyta at all beaches except for beach 9, where Pyrrophyta and Chlorophyta were predominant, sharing abundance in equal measure. The total abundance varied between 0.73×10^3 cells l^{-1} (beach 9) and 9.10×10^3 cells l^{-1} (beach 4). *Chaetoceros curvisetus* P.T. Cleve, 1889 and *Skeletonema costatum* (Greville) Cleve, 1873 formed the bulk of the phytoplankton abundance at beach 4. *Rhizosolenia stolterfothii* H. Peragallo, 1888 was the dominant species at beaches 1, 3, 5, and 10, whereas the dominant phytoplankton species were *S. costatum* at beaches 7 and 8, *Guinardia flaccida* (Castracane) Peragallo, 1892 at beach 2, *C. curvisetus* and *Rhizosolenia delicatula*

P. T. Cleve, 1900 at beach 6, and the green algae *Oocystis borgei* J. Snow 1903 at beach 9. The Chlorophyta contribution to the total phytoplankton was the highest in winter.

During spring, the seasonal cycle of phytoplankton abundance was characterized by a peak corresponding to diatom blooms dominated by *Nitzschia* spp. (46.60%) and *S. costatum* (16.70%). The total phytoplankton abundance varied between 0.17×10^4 cells l^{-1} (beach 10) and 15.61×10^4 cells l^{-1} (beach 5) with a seasonal mean value of $3.96 \times 10^4 \pm 5.29 \times 10^4$ cells l^{-1}. Diatoms dominated the phytoplankton at all the sampling beaches. The development of Chlorophyta and Cyanophyta cell abundance also reached a maximum in spring. Spatial fluctuation in spring showed wide variation in abundance and dominant species. *Nitzschia palea*, *N. sigma* (Kützing) W. Smith, 1853, and to a lesser extent *Pseudo-nitzschia seriata* (P. T. Cleve, 1883) H. Peragallo in H. & M. Peragallo, 1900, which formed the bulk of the phytoplankton abundance at beach 5. The dominant species in the phytoplankton community were *S. trochoidea* (a dinoflagellate) and *Dactyliosolen fragilissimus* (Bergon) Hasle apud G. R. Hasle & Syvertsen, 1996, *Striatella unipunctata* (Lyngbye) C. Agardh, 1830 (diatoms) at beach 1, *L. flabellata* at beach 2, *A. granulata* at beach 3, *S. costatum* at beach 4, *Chaetoceros socialis* H. S. Lauder, 1864 at beaches 6 and 8, *Pseudosolenia calcar-avis* (Schultze) Sundström, 1986 at beach 7, and *A. minutum* at beaches 9 and 10, the last-mentioned species sharing the community with several diatom species such as *N. palea*, *Pleurosigma* sp. and *Rhizosolenia delicatula* P. T. Cleve, 1900.

During summer, the seasonal mean value of total phytoplankton cell abundance was $4.32 \times 10^3 \pm 2.69 \times 10^3$ cells l^{-1}. The total abundance varied between 0.33×10^4 cells l^{-1} (beach 1) and 1.11×10^4 cells l^{-1} (beach 7). The dominant group was Bacillariophyta at all beaches except for beach 4 in which Pyrrophyta was predominant. *C. closterium* formed the main bulk of phytoplankton abundance at beach 7. *Nitzschia microcephala* Grunow in Cleve & Möller, 1878 was predominant at beach 1, *R. stolterfothii* at beach 2, *A. granulata* at beaches 3 and 10, the last-mentioned species being co-dominant with the green algae *Crucigeniella rectangularis* (Nägeli) Komárek, 1974, *C. marina* and *Pandorina* sp. at beach 10. *A. granulata* was the dominant species at beaches 4, 5, 8, and 9, and was co-dominant with *C. marina* at beach 4, *C. closterium* at beaches 5, 6 and 8; *A. granulata* and *S. trochoidea* were the dominant species at beach 9.

In general, the overall average cell abundance was 1.45×10^4 cells l^{-1}, and the highest cell abundance of phytoplankton was observed in spring due to the high Bacillariophyta abundance at beach 5.

3.4. Correlation analysis

The statistical relationships between the composition of phytoplankton and the physicochemical environment variables at the different sites were analysed. The single environmental variable that best correlated with the phytoplankton patterns was silicate ($r=0.479$, $p<0.001$), followed by nitrite ($r=0.306$, $p<0.05$). Furthermore, phytoplankton abundance displayed a positive correlation with ammonia ($r=0.361$, $p<0.05$). None of the other correlations between Bacillariophyta, Pyrrophyta and environmental variables were statistically significant ($p>0.05$).

The best correlation was between phosphate and WQI ($r= -0.816$, $p<0.001$), followed by that between silicate and ammonia ($r=0.636$, $p<0.001$). Among the dominant phytoplankton species, *C. closterium* and *P. delicatissima* showed significant positive correlations with silicate ($r=0.355$, $p<0.05$; $r=0.555$, $p<0.001$ respectively). Other frequent species were dependent on specific environmental variables, e.g. *A. granulata*, which was found to be inversely correlated with temperature ($r= -0.420$, $p<0.05$) and positively correlated with ammonia ($r=0.490$, $p<0.05$).

Some species recurrently show an association with others in different divisions. For example, *C. closterium* showed a tendency towards association with dinoflagellates such as *N. fusus* ($r=0.943$, $p<0.001$), *P. marinum* ($r=0.910$, $p<0.001$) and *Gymnodinium* spp. ($r=0.870$, $p<0.001$).

4. Discussion

Generally speaking, the water quality was detected and measured using various physical, chemical and biological methods. The biological analysis, i.e. the analysis of phytoplankton communities was carried out in support of the interpretation of the results obtained from the physicochemical analysis of the water. The monitoring of phytoplankton is of great importance because monitoring based solely physicochemical analysis is sometimes insufficient. The phytoplankton composition not only reflects the real condition of the waters but also the previous conditions of the water.

The main feature of the studied beaches is the high spatial variability of the physicochemical variables, phytoplankton abundances and diversity. Reynolds (1984), Turkoglu & Koray (2000), Turkoglu & Koray (2002), Naz & Turkmen (2005) and Turkoglu (2010a,b) acknowledge the fact that seasonal variations in phytoplankton species composition and abundance are believed to depend on interactions between physical and chemical factors, which are in turn influenced by climatic factors.

The study area is one of the less populated areas in Egypt, but has been become an attractive place in summer and autumn for the beauty of its water. Beaches 4, 5, 6 and 7 are set in a lagoon: this is protected from the high seas by a series of rocks forming a natural breakwater with a small opening to allow some wave penetration and ensure good water quality. But owing to the large numbers of summer and autumn visitors, these beaches occasionally exhibit high nutrient concentrations and high phytoplankton densities, especially beach 4, which is a semi-enclosed, shallow basin suitable for children because it is safe.

Nutrient concentrations at the Matrouh beaches were lower than in other areas along the Egyptian coast. For instance, in the study area, nitrate, nitrite, ammonia, phosphate and silicate concentrations respectively varied in the ranges 0.13–5.10 μM, 0.01–0.30 μM, 0.18–16.83 μM, 0.01–7.30 μM and 0.20–4.79 μM, whereas in the Western Harbour, west of Alexandria, previous nitrate, nitrite, ammonia, phosphate and silicate concentrations varied in the ranges 0.21–20.46 μM, 0.29–3.30 μM, 0.56–57.46 μM, 0.12–5.70 μM and 0.30–36.30 μM respectively (Dorgham et al. 2004).

Redfield (1958) reported that the optimal N:P ratio for phytoplankton growth, known as the Redfield ratio, is 16:1 (based on molecular concentrations). In the eastern Mediterranean, in contrast to many other marine environments, phosphate rather than nitrate is the limiting nutrient (Krom et al. 1991, Bethoux & Morin 1992), although Fahmy et al. (1999) showed that N:P ratios in Egyptian Mediterranean coastal waters were nitrogen-limited because the waters in the eastern part of this sea come from different sources. The N:P ratios in the current study were lower (3.51–9.63) than the Redfield ratio during the summer, autumn and winter sampling periods in 2009 at all the sampling beaches, suggesting potential nitrogen limitation, but the ratios in the spring and summer of 2010 were higher than the Redfield ratio, suggesting a higher nitrogen budget in relation to phosphorus. Silicate concentrations were generally low throughout the sampling period, except for a strong increase in the spring (4.79 μM) at beach 4, which was also the case with the other nutrients.

Water quality in an aquatic ecosystem is determined by many physical and chemical factors (Sargaonkar & Deshpande 2003). The WQI is also suggested as being a very helpful tool enabling the public and decision makers to evaluate water quality. The index is a numerical expression used to transform a number of variable data to a single number that represents the water quality level (Sanchez et al. 2007). The results indicated that the water quality off the different beaches in Matrouh ranged from good to excellent. However, it was generally observed that 48.00% and 52.00% of all seasonally computed WQI values correspond to 'excellent' and 'good' water quality respectively. From the correlation coefficients between WQI and water quality parameters, it is evident that phosphate was the factor governing the computed WQI values of Matrouh beach waters ($r = -0.816$, $p<0.001$).

Coastal anthropogenic inputs seem to affect the distribution and composition of the phytoplankton assemblages, even though the general circulation in the Egyptian coastal waters has been taken into account.

Phytoplankton abundance was significantly correlated with the environmental variables because of the ecological peculiarity of the Matrouh beaches. In fact, shallow and semi-enclosed seas have specific functional and structural characteristics resulting from their location between land and sea. The shallowness of these systems promotes a short nutrient turnover (Nixon 1982) resulting in high productivity (Knopper 1994). Furthermore, in such ecosystems the effect of anthropogenic nutrient inputs are more evident, and phytoplankton abundance is strongly related to such nutrients, mainly nitrogen compounds.

In general, the overall average phytoplankton abundance in the study area was 1.45×10^4 cells l^{-1}, this average being 2–4 times lower than in other Egyptian coastal areas, which can have abnormal algal blooms as a consequence of freshwater discharges and other terrestrial sources of nutrients (El Sherif & Gharib 1994, Abdel-Aziz et al. 2006, Gharib & Dorgham 2006, Shams El-Din & Abdel Halim 2008). In an earlier study, Dowidar (1988) recorded that the algal bloom in the Egyptian coastal area during the winter was due mainly to the low grazing impact of both zooplankton and phytophagous fish (principally sardines), whereas the spring blooms in the present study coincided with a 6.00°C increase in water temperature from 18.00°C to 24.00°C and a decline in phosphorus concentrations (0.07 ± 0.05 μM). On the other hand, the phytoplankton abundance decreased in winter as a consequence of relatively low temperatures, even though nutrient levels, especially phosphate levels, were high during this period. However, the increase in phytoplankton abundance in spring was also typically nutrient-limited in both the eastern Mediterranean (Dorgham et al. 1987) and the whole of that sea (Kideys et al. 1989, Delgado 1990, Polat & Piner 2002).

Phytoplankton reflects water quality through changes in its community structure, patterns of distribution and the proportion of sensitive species. Throughout the study, the phytoplankton in the waters off the Matrouh beaches was dominated by diatoms. Similar findings were reported from most Egyptian coastal waters by Shams El-Din & Dorgham (2007) in Abu-Qir bay, Gharib & Dorgham (2006) in the Western Harbour, and Shams El-Din & Abdel Halim (2008) in the coastal waters of three tourist villages in western Alexandria.

The decline in Bacillariophyta abundance could be due to nutrient limitation resulting from the lack of phosphorus and silicates in the water (reactive P and Si concentrations were below or near the detection limit). Diatoms were more frequent (common: 84 species, rare: 36 species) than Pyrrophyta (common: 25 species, rare: 27 species). The bloom of *Pseudo-nitzschia* spp. was probably a response to higher nutrient concentrations. It is known that, in the Western Harbour and at El-Maadia on the Alexandria coast, such blooms have occurred in response to coastal eutrophication (Abdel-Aziz et al. 2006, Gharib & Dorgham 2006). This hypothesis is supported by the strong positive correlation between *Pseudo-nitzschia* spp. and the different nutrient salts.

Relatively higher phytoplankton abundances were recorded in the Matrouh lagoon (beaches 4–7), the high numbers of diatoms reflecting the general eutrophic nature of this semi-enclosed basin (Labib 1994). In spring the community was characterized by higher numbers of *Pseudo-nitzschia* spp. and *Chaetoceros* spp., which are typical of enclosed and semi-enclosed basins as well as of estuarine Mediterranean waters (Totti et al. 2000, Gharib 2006, Turkoglu 2010a,b, Turkoglu & Oner 2010, Turkoglu & Erdogan 2010).

Chlorophyta reached maximum densities in autumn (beach 4) and summer 2010 (beach 10) owing to tourist activity during the summer and autumn. The most abundant species were *C. marina* and *C. rectangularis*. The phytoplankton abundance did not differ between beaches 9 and 10 and was of the same order of magnitude. The seasonal trend was also similar on both beaches, with the annual peak occurring in summer 2010.

Species rarity is of particular importance in the overall configuration of species diversity. Rare species (a group of organisms that are very uncommon or scarce) constitute an important component of species richness and are a focus of many ecological theories and controversies (Lyons et al. 2005, Irwin et al. 2006). If rare species constitute the largest component of species richness, they may play a vital role as a 'safety net' for community conservation and diversity (Lyons et al. 2005). In the present work, though sporadic in spatial occurrence, they made an overall important contribution (36.00%) to the species richness of the oligotrophic waters of the Mediterranean. It has also been shown that the species diversity level was controlled by the number of rare species, e.g. when rare species were removed from the original data set for each beach, the species diversity was substantially lower.

The diversity index of phytoplankton fluctuated between 1.07 and 3.21 nats, but the variation range is wider than that (1.00–2.50 nats) recorded by Margalef (1978) for the growing coastal populations and other eutrophic areas on the Alexandria coast, like Dekhaila Harbour (Ismael & Dorgham 2003) and the Western Harbour (Gharib & Dorgham 2006).

Species diversity was highest in summer 2009 (2.37 nats) and lowest in winter (1.71 nats). In winter, the diversity index was low owing to the dominance of just a few species. Species diversity decreases to minimum levels when one or a few species are dominant (Ignatiades 1969). In the present study, the highest species diversity, found in summer 2009, was attributed to a more balanced distribution of abundance among species. The present study found that the diversity and abundance of phytoplankton species varied seasonally. Although this study failed to conclusively support this variation with statistical significance, it is believed that other factors were responsible for the noted seasonal variation.

Three classes of water quality were defined for the Shannon-Weaver diversity index by Wilhm (1975), who implied that a high H' value suggested a rich diversity and therefore a healthier ecosystem (less pollution), whereas a low H' value suggested poor diversity and thus a less healthy ecosystem (more pollution). In terms of H' values, the waters off beaches 3–10 in Matrouh can be placed in class II, which implies that they are moderately polluted; beaches 1 and 2 varied between clean and moderately polluted.

The differences of phytoplankton abundance among the beaches were significant, as were the temporal differences. The seasonal variations in nutrient concentrations were also significant. There was very little freshwater input to the area, and anthropogenic effects in the area were very limited, in contrast to many coastal areas along the Egyptian coast. In addition, no high nutrient concentrations were measured during the study period, nor was there any dominance of harmful phytoplankton species.

The results suggest that the most striking feature of the phytoplankton communities was the high spatial variability in terms of abundance and species diversity, which showed specific coastal Mediterranean values. It can be concluded that the index based on WQI is currently more suitable than the phytoplankton species index for assessing the quality of the water off the Matrouh beaches.

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