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Environmental properties of the southern Gulf of Aqaba, Red Sea, Egypt

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Abstract

Environmental properties (temperature, dissolved oxygen, nutrients and chlorophyll *a*) of the epipelagic zone off Sharm El-Sheikh, Red Sea, Egypt were studied seasonally throughout a year from March 1995 to March 1996. Water samples were collected from five water depths (0, 25, 50, 75 & 100 m). The studied parameters exhibited clear seasonal variability along the water column. The vertical distribution of water temperature showed thermal homogeneity during most seasons, and thermal stratification in summer. Dissolved oxygen attained slightly high concentrations (5.3-7.8 mg l^{-1}) in the whole water column, with slight seasonal variation. The concentrations of nutrients reflected dominant oligotrophic conditions in the epipelagic zone and occasional mesotrophic status at some depths. Phosphate fluctuated between 0-0.7 μM, ammonium (0-2.27 μM), nitrite (0-0.72 μM), nitrate (0-1.49 μM) and silicate (0-6.48 M). Phytoplankton biomass was generally low in the epipelagic zone throughout the study, whereas chlorophyll *a* was less than 0.5 μg l^{-1}, except relatively high concentration (0.7-1.12 μg l^{-1}) in deep layers in spring. In comparison with previous studies on the Gulf of Aqaba all environmental parameters during present study showed pronouncedly different values.

Keywords: Water properties, nutrients, chlorophyll *a*, Sharm El-Sheikh, Gulf of Aqaba.

Introduction

The morphology and biogeography of the Gulf of Aqaba have been studied by a number of authors (e.g. Al-Qutob *et al*., 2002; Abdel-Halim *et al*., 2007). The Gulf is a moderately oligotrophic basin (Reiss & Hottinger, 1984) with clear seasonal variations of hydrographical and biological characteristics (Wolf-Vecht *et al*., 1992; Badran, 2001; Manasrah *et al*., 2006).

The environmental characteristics of the northern part of the Gulf have received considerable attention. The convective/advective balance indicated vertical homogeneity of the water column in February, beginning of new thermocline in March and an upper 200m (surface temperatures reaching 26°C) overlies a thermally homogeneous layer of 21°C in summer (Wolf-Vecht *et al*., 1992). Highly positive west-to-east gradient in chlorophyll *a* was recorded in spring throughout the Gulf relative to negative gradient in sea surface temperature (Labiosa *et al*., 2003). The summer temperature revealed a clear thermocline in the upper 200m at the northern Gulf, and this was reflected on oxygen and nutrient concentrations (Manasrah *et al*., 2006). The temperature and salinity in the upper 300m in the Gulf were high in summer (~ 26°C, ~ 41‰), and low in winter (~ 21°C, ~ <41‰) at the surface, with stratified water column throughout (Paldor & Anati, 1979).

By contrary, little attention has been given to the hydrography of the southern part of the Gulf (El-Rashedi, 1992; El-Sherbiny, 1997; Aamer *et al*., 2006) as well as to the whole Gulf (Okbah *et al*., 1999; EEAA 1998-2006; Abdel-Halim *et al*., 2007).

The present study was carried out to investigate the seasonal variations in some environmental properties of the epipelagic zone of 100 m depth in the southern part of the Gulf of Aqaba off Sharm El-Sheikh City, Egypt, including water temperature, dissolved oxygen, nutrients (phosphate, ammonium, nitrite, nitrate, and silicate) and chlorophyll *a*.

Materials and Methods

The study area

Sharm El-Sheikh is situated in Sinai Peninsula at the southern end of the Gulf of Aqaba near its connection with the Red Sea proper at 27° 51’ 49” N, 34° 17’ 17” E

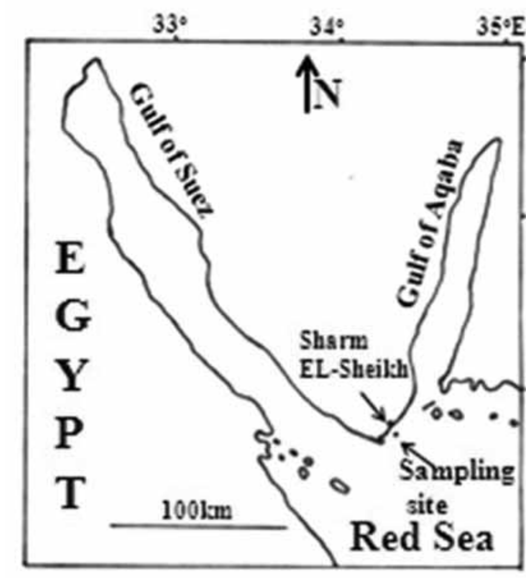

Fig. 1: Sharm El-Sheikh Area and sampling site.

(Fig. 1). It is one of the most accessible and developed tourist resorts in Egypt, for diving and snorkeling, windsurfing and other water sports. Sharm El-Sheikh area is also one of the most important coastal areas from ecological and economic points of view, not only for Egypt but also for the whole world natural heritage due to its rich and highly diversified coral communities. The sampling location was selected in an open water area, at about 2 km off Sharm El-Sheikh City.

Sampling

The collection was carried out seasonally for one year from March 1995 to March 1996 in spring (April), summer (July), autumn (October) and winter (January). Water samples were collected at 0, 25, 50, 75 & 100 m depths for the determination of water temperature, dissolved oxygen, phosphate, ammonium, nitrite, nitrate, silicate and chlorophyll *a,* using a Nansen water sampler of 5 liters capacity. The water samples for chlorophyll *a* and nutrients measurements were kept in cold condition until reaching the laboratory. For nutrient determination, 500 ml of each water sample were filtered using membrane filter of 47 mm diameter and 0.45 μm pore size, and the filtered water samples were kept frozen at -20 °C for later analysis.

Water temperature was measured by an ordinary mercury thermometer graduated to 0.1 ºC fitted to the water sampler. Nansen bottle was withdrawn up quickly in order to avoid change in the recorded temperature at the required depth. Dissolved oxygen was determined according to Winkler's method (APHA, 1985), whereas the water sample was poured carefully from the water sampler to a BOD-bottle (250 ml) and fixed immediately, using manganus sulfate and alkaline-iodide solutions, and after stopper the bottle was turned upside down several times to ensure complete mixing. In the laboratory, concentrated sulfuric acid was added and a known volume of the sample was titrated against 0.025 N sodium thiosulphate solution, using starch indicator. Chlorophyll *a* was measured by filtering two liters of seawater from each depth through 47 mm diameter Sartorius membrane filters (pore size 0.45 μm). The filter was dissolved in 90% acetone and kept at -20 °C in complete darkness for 24 hours, after then chlorophyll *a* was determined according to Parsons *et al.* (1984).

Dissolved inorganic nutrients (ammonium, nitrite, nitrate, phosphate and silicate) were determined colourimetrically in the filtered water samples according to the methods described by Strickland & Parsons (1975). Ammonium (NH_4^+—N) was measured using the indophenols blue technique, in which ammonium was allowed to react with hypochlorite in slightly alkaline medium to form mono-chloramine, which in presence of phenol, nitroprusside ion and an excess hypo-chlorite gave indophenol blue. After 24 hours, the developed blue color was measured at 640 nm wave length.

Nitrite (NO_2^-—N) was determined based on Griess reaction, whereas 50 ml of the filtered water sample react with sulfanilamide for 2-8 minutes to produce diazonium salt coupled with N-(1-naphthyl)-ethylenediamine di-hydrochloride solution. After 10 minutes the pink azo dye color extinction was measured at 543 nm.

Nitrate (NO_3^-—N) was determined by the cadmium reduction method, 100 ml of slightly acidified filtered water sample was run through a glass column containing cadmium fillings loosely coated with metallic copper, where all the nitrate content was reduced into nitrite, which was determined as described above and correction was made for any nitrite initially present in the water sample.

Dissolved inorganic Phosphorus (Reactive phosphorus) was determined by forming phosphor-molybdate complex through the reaction of 50 ml filtered water sample with 5 ml composite reagent (a mixture of molybdic acid, ascorbic acid, and trivalent antimony). After five minutes and within two hours the extinction of the reduced blue color was measured spectrophotometrically at 885 nm. All spectrophotometric readings of both chlorophyll *a* and nutrients were carried out by Milton Roy 601 spectrophotometer. The correlation coefficients between the measured parameters were calculated in order to assess the relationship between these parameters.

Results

The surface water temperature varied seasonally between a winter minimum of 22.8 °C and a summer maximum of 30.5 °C. The vertical thermal difference between the surface and 100m depth fluctuated between 1.8 °C in winter, 1.4 °C in autumn and 2.1 °C in spring, while the difference in summer was relatively high 7.7°C. These values indicate a clear stratification in summer and tran-

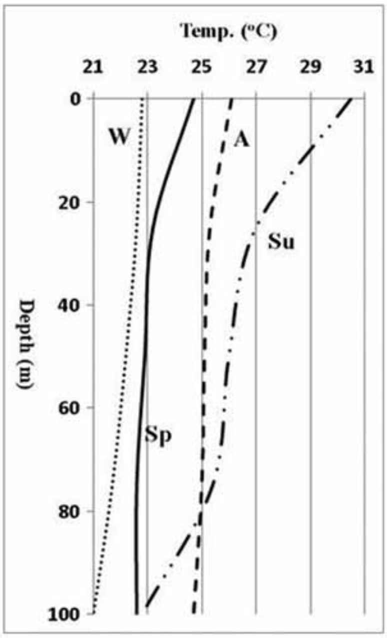

Fig. 2: Vertical distribution of water temperature along epipelagic zone off Sharm EL-Sheikh in winter (W), Spring (Sp), summer (Su) and autumn (A).

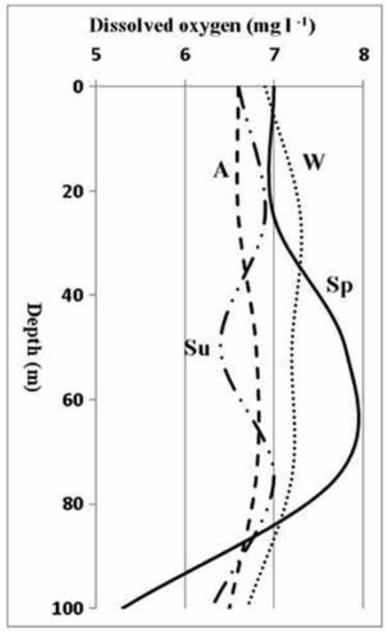

Fig. 3: Vertical distribution of dissolved oxygen along epipelagic zone off Sharm EL-Sheikh in winter (W), Spring (Sp), summer (Su) and autumn (A).

sition state during the other seasons (Fig. 2).

The dissolved oxygen demonstrated narrow seasonal variations in the surface water (6.6-7 mg/l), with a generally homogenous distribution in the epipelagic zone most of the year. The vertical difference between the surface and 100 m depth was relatively small (0.3 - 0.7 mg/l), but it was large (2.5 mg/l) during spring (Fig. 3).

The surface water phosphate sustained values within the range of 0.03 -0.41 μM, while along the epipelagic zone the highest value was reported in spring (0.382 μM) followed by summer (0.162 μM). On the other hand, pronouncedly low concentrations of phosphate were found in autumn (0.032 μM) and winter (0.024 μM). Clear stratification occurred during spring and less stratification was observed in summer, while homogeneous profiles were recorded in autumn and winter (Fig 4).

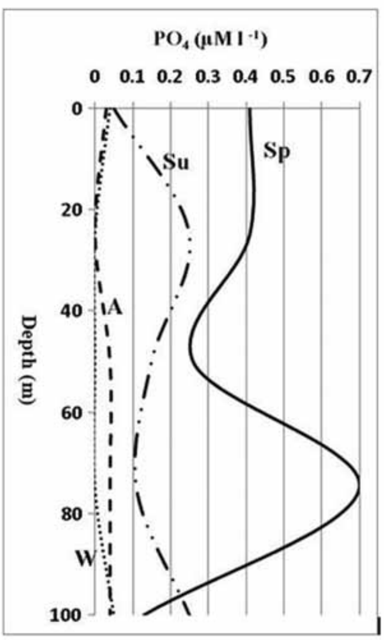

Fig. 4: Vertical distribution of phosphate along epipelagic zone off Sharm EL-Sheikh in winter (W), Spring (Sp), summer (Su) and autumn (A).

The surface water ammonium varied seasonally between 0.53 μM in summer and 2.27 μM in spring. The average spring concentration in the upper 100m (1.83 μM) was about 3-4 folds higher than those recorded in the other seasons. The vertical distribution of ammonium revealed seasonal stratification (Fig. 5), whereas spring sustained the highest value over the year at the surface and at 75 m, summer and autumn had relatively high values at 75-100m, and higher winter value occurred at the surface.

Nitrite in the surface water was lowest over the year, with a maximal concentration of 0.15 μM in autumn. The highest nitrite in the epipelagic zone occurred mostly at 100 m, except in spring where the value reached 0.72 μM at 75 m. The mean seasonal nitrite value was the highest in the water column in autumn and lowest in both summer and winter (Fig. 6).

In contrast to the other nutrients, nitrate attained its lowest value at 50 m depth during most seasons, demonstrating relatively clear vertical stratification over the year. The average nitrate in the water column was the highest in autumn, and decreased successively in spring, summer, and reached the lowest value in winter. The vertical profile showed the highest nitrate concentration at

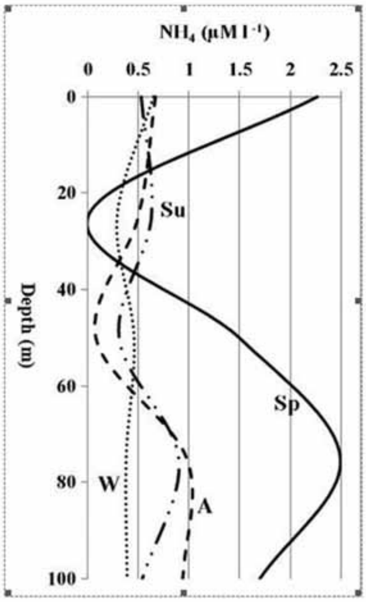

Fig. 5: Vertical distribution of ammonium along epipelagic zone off Sharm EL-Sheikh in winter (W), Spring (Sp), summer (Su) and autumn (A).

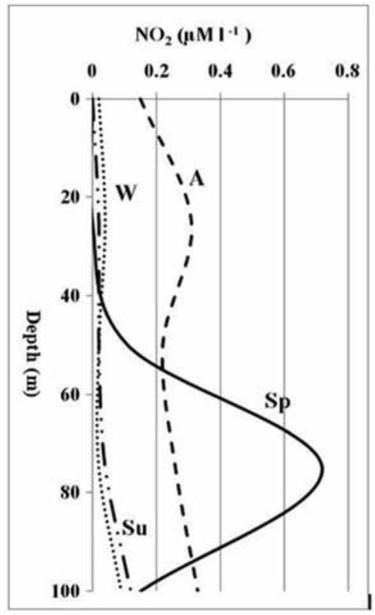

Fig. 6:Vertical distribution of nitrite along epipelagic zone off Sharm EL-Sheikh in winter (W), Spring (Sp), summer (Su) and autumn (A).

100 m in spring, summer and winter, while it occurred at 75 m in autumn (Fig. 7).

The surface silicate showed its maximum value in winter, relatively lower in summer and autumn and the minimum value in spring. The vertical distribution of silicate demonstrated different seasonal patterns, whereas in autumn it increased with depth, reaching the maximum at 100 m, but in other seasons the highest values were reported at the surface and 100 m in winter, at 25 and 75 m in spring, and at 50 and 100 m in summer (Fig. 8).

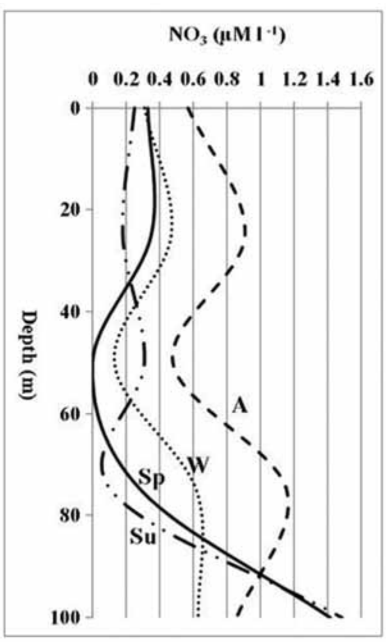

Fig. 7: Vertical distribution of nitrate along epipelagic zone off Sharm EL-Sheikh in winter (W), Spring (Sp), summer (Su) and autumn (A).

The concentrations of chlorophyll *a* reflected low phytoplankton biomass (Seasonal average: 0.11 – 0.33 µg l^{-1}) in the epipelagic zone in the southern Gulf of Aqaba, particularly in the surface water. However, the vertical distribution showed relatively high values (0.7 – 1.12 µg l^{-1}), especially within the depth range of 75-100 m in spring, and slight stratification during summer, autumn and winter (Fig. 9).

Discussion

The seasonal range of surface water temperature in the southern Gulf of Aqaba in the present study (22.8-30.5 °C) was wider than that in the northern and central parts of the Gulf (21.3-26.7°C) (Plähn *et al*., 2002; Cornils *et al*., 2007). The higher temperature in the southern part of the Gulf may be attributed to the warm water entering the Gulf from the Red Sea. This is supported by Genin *et al*. (1995) and Manasrah *et al*. (2004) who reported that water temperature in the Gulf is affected by the warm water inflow from the Red Sea and the air-sea heat flux. The seawater temperature plays a major role in winter convection (mixing) and summer stability (stratification), which in turn drive the biogeochemical cycle in the northern Gulf of Aqaba (Labiosa *et al.,* 2003). In the present study, temperature did not significantly affect the vertical distribution of nutrients and chlorophyll *a*, since clear differences in nutrients concentrations were observed along the water column.

The dissolved oxygen was homogeneous in the epipelagic zone off Sharm El- Sheikh, even during summer thermal stratification although chlorophyll *a* showed some vertical differences. This may reflect the limited

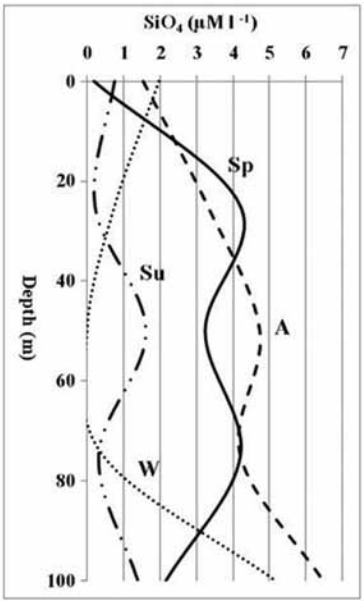

Fig. 8: Vertical distribution of silicate along epipelagic zone off Sharm EL-Sheikh in winter (W), Spring (Sp), summer (Su) and autumn (A).

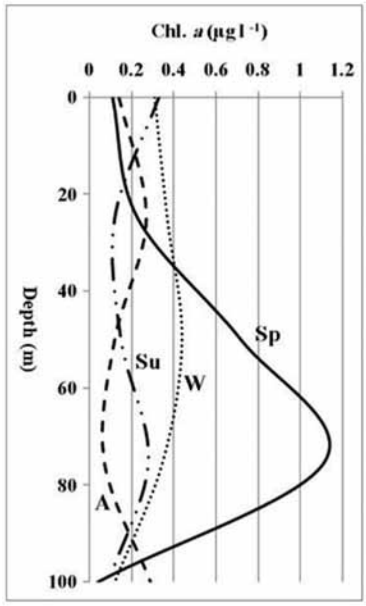

Fig. 9: Vertical distribution of chlorophyll *a* along epipelagic zone off Sharm EL-Sheikh in winter (W), Spring (Sp), summer (Su) and autumn (A).

role of photosynthesis in dissolved oxygen production in the southern Gulf of Aqaba. On the other hand, the drop of dissolved oxygen at 100 m in spring may be attributed to oxygen consumption in oxidation of organic matter produced from the death of phytoplankton cells in the upper layer (75m) which sustained the highest chlorophyll *a* in spring. The dissolved oxygen in the present study was close to those reported in other parts of the Gulf (Badran *et al*., 2005; Manasrah *et al*., 2006; El-Sherbiny *et al*., 2007).

The oxygen saturation in the study area varied between 99% and 110% over the year, indicating relatively good water quality for the living animals. However, the high salinity and water temperature in the northern Gulf cause the oxygen to be relatively low (Badran, 2001).

The concentrations of nutrients in the present study and in the earlier studies in other parts of the Gulf of Aqaba demonstrated different patterns. Phosphate concentration (annual average: 0.148 µM) was lower than that reported by El-Sherbiny *et al*. (2007) (annual average: 0.18µM) and higher than the values (annual average: 0.107- 0.117µM) found in the northern Gulf (Manasrah *et al*., 2006). Phosphate in autumn and winter was pronouncedly lower than in spring and summer during the present study, may be because of uptake by phytoplankton or due to the intrusion of nutrient-depleted surface waters from the Red Sea to the Gulf of Aqaba (Al-Qutob *et al*., 2002).

In contrast to phosphate, the present records of ammonium (0.29 - 2.5 µM) were relatively higher than those reported by Badran (2001) in the northern Gulf. But except its relatively high value in spring, ammonium level was less than 1 µM over the year. Light has inhibitory effect on ammonium oxidation by nitrifying bacteria (Guerrero & Jones, 1996). In the study area, light was not the reason of low ammonium, because it was actually low even in the presence of high light in autumn and summer.

The maximum nitrite concentration in the Gulf of Aqaba occurred when winter mixing reached its highest depth (Al-Qutob *et al*., 2002), and nitrite accumulation in the water column is due to excretion by algal cells (Collos, 1998), which was estimated by 10- 15% of the total amount of nitrogen entering the mixed-water column (Al-Qutob *et al*., 2002). By contrary, the winter nitrite in the present study was low and coincided with higher chlorophyll *a* than in other seasons which sustained high nitrite. This reflects the negligible role of phytoplankton in nitrite secretion during winter in the southern Gulf. However, this role was clear in the study area during spring at 75 m and less so in autumn at 100 m, where the highest nitrite was associated with the maximal chlorophyll *a*.

Nitrate content in the surface water in the present study was lower than that in the deeper layers. However, the average nitrate value recorded in the epipelagic zone in summer (0.47 µM) was about half those reported in the upper 400 m (0.80-0.86 µM) in the northern Gulf in five successive summers (Manasrah *et al*., 2006). Although the winter mixing deepening increased nitrate enrichment into the euphotic zone from deeper water (Al-Qutob *et al*., 2002), which resulted in more phytoplankton growth (Häse *et al*., 2002), nitrate sustained the lowest value in winter and spring in the present study, which coincided with low phytoplankton biomass.

The nitrate/phosphate ratio (N/P) exhibited irregular seasonal variations along the epipelagic zone in the study area. Spring and summer showed markedly low values (0.4-10.9), against high values (12-91) in autumn and winter. Similar wide range of N:P ratio was reported from a depth of 5 m in the northern Gulf of Aqaba (Lindell *et al.,* 2005), ranging from 0.3-4.9 in summer–autumn and 7.7-71 in winter–spring during two successive years. However, Häse *et al.* (2006) reported that the Gulf is subjected to benthic injections of nitrogen during winter that maintain the N:P ratio close to the Redfield ratio.

Despite the average silicate content in the epipelagic zone was 2.36 µM in the present study the summer average concentration (0.76 µM) was lower than those reported for 5 successive summers (1.46-1.62 µM) along the upper 400m in the northern Gulf (Manasrah *et al.,* 2006). On the other hand, Badran (2001) reported that nitrate, phosphate and silicate in the northern Gulf of Aqaba had similar seasonal patterns, with high concentrations in deeper water during summer, while in winter the three nutrients exhibited relatively high concentrations and were homogeneously distributed in the entire water column. By contrary, the present study demonstrated different seasonal vertical profiles for nitrate, phosphate and silicate in the southern Gulf presumably, due to the flux of the Red Sea, which exhibits more effect on the vertical distribution of nutrients in the southern part of the Gulf than in the northern part. On the other hand, the occasionally high nutrients recorded in the epipelagic zone in the present study assume enrichment from the coastal rich waters, particularly those adjacent to the coral reef. A rough estimation of nutrients enrichment to the Gulf of Aqaba is about 3.3×10^5, 6.4×10^4 and 6.5×10^6 kg year–1 of inorganic nitrogen, phosphate and silicate respectively (Rasheed *et al*., 2006), in addition to nutrient concentrations in reef cavities (Ayukai, 1993; Richter *et al*., 2001; Rasheed *et al.,* 2002).

The average phytoplankton biomass (Chlorophyll *a*) in the epipelagic zone in the present study was 0.28 µg l^{-1}. In the northern Gulf of Aqaba, chlorophyll *a* showed homogeneous vertical distribution down to 400 m depth, with a concentration around 0.2 µg l^{-1}, while in southern Gulf, it was more variable and showed an intermediate value, with a subsurface maximum of 0.4 µg l^{-1} at about 50 m depth and minimum values at depths below 200 m (Stambler, 2005). In the present study, the highest values of the subsurface chlorophyll *a* (0.44 µg l^{-1}) were observed at 50 m in winter (0.72-1.12 µg l^{-1}) and between 50-75 m depth in spring. The subsurface high chlorophyll *a* is a common phenomenon in the Gulf of Aqaba, and was reported in summer at 50 – 100 m in the northern Gulf (Cornils *et al*., 2005; Al-Najjar *et al.,* 2006) and in different layers over the year in the southern Gulf of Aqaba (El-Sherbiny *et al*., 2007).

In the present study, the levels of nutrients and phytoplankton biomass in the epipelagic zone off Sharm El-Sheikh could be referred to as oligotrophic and sometimes mesotrophic. The oligotrophic conditions have been frequently reported in the Gulf of Aqaba (Cornils *et al*., 2005; Al-Najjar *et al.,* 2006; Rasheed *et al.,* 2006; El-Sherbiny *et al*., 2007.

The statistical analyses indicated significant correlations between some of the measured parameters, but with different trends over the year. Temperature showed significantly negative correlation with nitrite in summer and

Table 1: Significant correlations between environmental parameters in different seasons (** Significant at p = 0.05, * Significant at p = 0.1)

	Temp.	DO	PO_4	NO_3	NO_2	SiO_4
Spring						
NO_3		-0.9600**				
N/P		-0.9362**		0.9924**		
Chl.*a*					0.8224*	
Summer						
NO_2	-0.8693*			0.9195**		
SiO_4		-0.9427**				
Chl.*a*			-0.9439**			
Autumn						
NO_2	-0.8117*					
N/P			-0.9181**			
SiO_4	-0.9508**					
Chl.*a*		-0.8547*				
Winter						
PO_4		-0.981**				
SiO_4		-0.9264**	0.9145**		0.8975**	
Chl.*a*		0.8827**	-0.87**		-0.8784**	-0.9705

autumn and with silicate in autumn (Table 1). These correlations supposed that the effect of high temperature in summer and autumn on the concentration of nitrite may be through the effect on nitrification and denitrification processes or on the release of nitrite by phytoplankton cells. Temperature may also influence the silicate uptake by phytoplankton, which sustained low biomass during autumn, concomitant with the highest silicate concentration in the euphotic zone.

The dissolved oxygen showed significantly negative correlation with chlorophyll *a* during autumn and a positive correlation in winter, in addition to its negative correlation with silicate during summer and winter. Dissolved oxygen exhibited also a negative correlation with nitrate in spring and with phosphate in winter. These correlations reflect the strong relationship between oxygen production through photosynthesis in the euphotic zone and phytoplankton biomass, which in turn affect the uptake of different nutrients. However, the seasonal differences in such correlations may be attributed to numerous biotic and abiotic factors, such as the physiological activities of the phytoplankton cells, temperature, ratios between different nutrients salts, as indicated from the significant correlations of chlorophyll *a* with the nutrients from one side and between the different nutrients from the other (Table 1).

Conclusions

The present study demonstrated that the nutrients in the epipelagic zone off Sharm El-Sheikh, as a part of the southern Gulf of Aqaba, were usually low, but they sometimes sustained relatively high values, particularly in subsurface layers. This pattern caused clear stratification in the vertical profile of most nutrients throughout the year, particularly in spring. In the meantime, dissolved oxygen was homogeneously distributed in the epipelagic zone most of the year regardless of the different seasonal vertical patterns of chlorophyll *a*.

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