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Plankton and Some Environmental Variables as a Water Quality Indicator for Saline Pools at the Western Red Sea (Saudi Arabia)

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Abstract

This study was carried out to determine the water quality of a series of micro-pools water, north Jeddah Corniche, by studying the environmental variables as well as phytoplankton abundance and community structure. Surface water samples were monitored from a series of pools over two seasons; spring (May) and autumn (November), 2013. The pools are shallow; saline to hypersaline showed salinity gradients from 40.0 to 63.0 PSU, pH values from 7.50 to 8.18; temperatures from 21.0 to 43.0°C; dissolved oxygen concentrations from 2.1-6.4 mgl^{-1}. Nutrient concentrations were very high in spring. Nitrate ranged between 0.3 and 6.3 µM, nitrite between 0.1 and 1.2 µM, ammonia upto 16.7 µM, phosphate concentrations from 0.35 to 4.60 µM and silicate reached 20.86 µM.Species diversity (Shannon-Weaver, H) and evenness (J) were high and showed small-scale temporal and spatial variations. A total of 99 species of phytoplankton were recorded, showing a well-diversified taxonomy, belonging to 5 different classes. *Cyanophyta* dominating during spring while *Bacillariophyta* during autumn. The most representative class in terms of species richness was *Bacillariophyta* (46 species) while *Cyanophyta* and *Pyrrophyta* had 29 and 22 species, respectively. No significant differences were observed in phytoplankton population among pools. Positive correlation of *Cyanophyta* with NO_2, NO_3 and PO_4. The Shannon-Wiener Diversity Index classified the pools water as being clean, whereas the WQI demonstrated that it was between 'medium' and 'good', which means beginning deterioration of the water quality. 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 pools water. We recommended to drilling several culverts for each pool to allow good water masses exchange between pools water and the Red Sea water.

Keywords: Diversity index; Environmental variables; Phytoplankton; Red Sea pools; Water quality

Introduction

Saudi Arabia has an arid desert climate with average summer temperature of 45°C, but readings of up to 54°C are common from mid April till October, and between October to May is generally pleasant. Jeddah is the second –largest city in Saudi Arabia, it lies on the coast of the Red Sea between latitude 21°31`0" N and longitude 39°13`9" E. Jeddah Corniche, is located on the western part of the city and it stretches for almost 100 kilometers along the Red Sea coastline, and it is a major tourist attraction place where tourists and visitors enjoy and spend their holidays, hence its nickname is "the Bridge of the Red Sea". Jeddah Cornicheis characterized in the north, by numerous shallow micro-tidal saline pools, where people can relax and enjoy themselves.

In contrast to other areas in the Red Sea, there are few reports has been published on the environmental variables and phytoplankton along the coast of the Jeddah Corniche. Moreover, such data as there have been reported mainly from hot spots, which usually show higher concentrations of nutrient reaching more than 60 µM dissolved inorganic nitrogen and 4 µM dissolved phosphate [1], as well as the presence of harmful blooms forming phytoplankton like *Noctiluca scintillans* and *Platymonas intermedia* which were recorded for the first time along the coast of Saudi Arabia [2,3]. On the other hand, Aleem et al. [4] recorded numerous taxa from the freshwater Chlorophyta and Cyanophyta at the area of Obhour near Jeddah. Recently, Touliabah et al. [5] studied the phytoplankton composition at Jeddah Coast in relation to some ecological factors a bit results of this study.

Physico-chemical parameters, species composition and seasonal variation in phytoplankton abundance have been studied in other regions of Saudi Arabian coastal waters [6-12].

The success of the tourism industry in such areas is often associated with an intact natural environment, and so water quality is an important factor for tourists water quality estimation based on physicochemical properties gives us a clear picture of respective water body. The picture reflects the composite influence of different water quality parameters and the Water Quality Index (WQI). Therefore, those water quality parameters will be useful for the classification of waters and WQI will indicate water health status. Thereafter, environmental and water quality parameter determine the abundance and species composition of phytoplankton. Thus, the species composition of the phytoplankton community is an efficient bioindicator of water quality [13].

Therefore, this study was carried out to evaluate the impact of

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human activities on the water quality status of the saline pools state using physico-chemical characteristics and phytoplankton as indicators.

Material and Methods

Study area

Numerous pools are located on the north of Jeddah Corniche (eastern side of the Red Sea), with average depths of about 100 cm. The pools are located at about 2 km south of Abhur Al Janubiyah. Six pools were selected for this study (Figure 1). Pools I, III, IV and VI are rectangular shape that measure 316 m by 60 m, 378 m by 90 m, 423 m by 53 m and 536 m by 97 m, respectively. The first two pools connected to the Red Sea by two culverts, while the two other are connected with the Red Sea by 3 tubes. Pool V looks like knife in its shape, and connected with the sea through 2 tubes, while pool II has a spinal shape, with 4 culverts.

Methods

The sampling was carried out twice; in May and November, 2013 to cover two seasons: spring and autumn. Composite sample was collected from each pool: one for the phytoplankton count and the other chemical analysis of water. The phytoplankton samples were immediately fixed with 4% formaldehyde for laboratory analysis and phytoplankton were counted and identified using 2-mL settling chambers with a Nikon TS 100 inverted microscope at 400x magnification using Utermöhl's method [14]. On the spot, the water temperature was measured with a thermometer sensitive to 0.1°C, the pH using a pocket pH meter (model pH 330/set1 wtw Germany), and the water salinity using a Refractometer Model (ATAGO S/MILL-E/ JAPAN); 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 [15].

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 [16]. The seven parameters were selected for WQI which were pH and 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 weighing factor based on the importance of the parameter, and summation of the weighed Q values yielded the WQI, which defines the water as very bad, bad, medium, good or excellent.

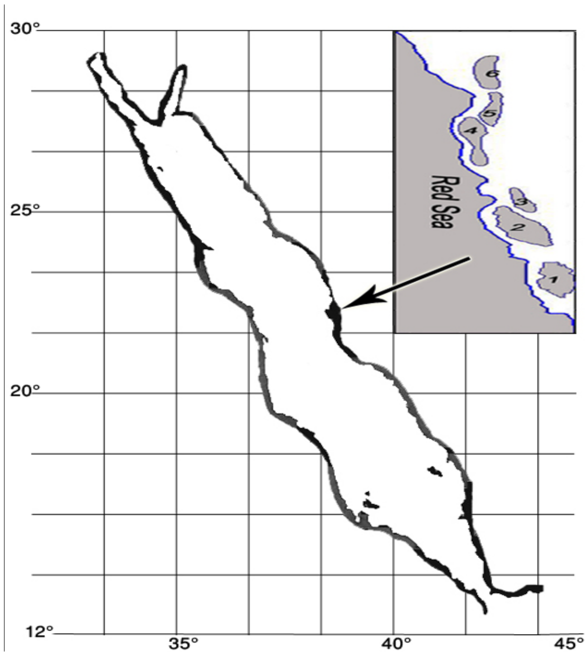

Figure 1: Area of study and sampling pools; names of pools: I Moon, II-Sun, III Train Park, IV- Abd Allah Salah, V- Sanabel, VI- Fatimah.

Statistical analysis

Three indices were used to estimate the community structure: diversity (H') Shannon et al. [17] and evenness or equitability (J) [17]. The Spearman rank correlation (r) was used to evaluate the relations between environmental variables and phytoplankton abundances at each sampling station (N=12) with the SPSS 8.0 Statistical Package Program. The canonical correspondence analyses were performed with Multivariate Statistical Package (MVSP 3.12b) software [18]. Canonical Corresponding Analysis (CCA) of the different phytoplanktonic groups with the available physico-chemical parameters was carried out according to Ter Braak et al. [19,20].

Results

Hydrographic conditions

The mean values ± SD and ranges of the physico-chemical parameters studied are shown in Table 1. Some marked variations in the physical and chemical parameters were observed between sampling stations and seasons.

The water temperatures (°C) during study period, varied from 22.5 ± 1.05°C to 41.5 ± 1.52°C.Change in pH values were always in the alkaline side. It varied over a narrow range (0.68 units) during the sampling period. It varied from 7.88 ± 0.21 to 8.02 ± 0.18. The DO values ranged between 3.75 ± 0.50 mgl^{-1} and 5.57 ± 0.73 mgl^{-1}. PH and DO values were found to be lower during spring. Salinity values ranged between 47.67 ± 4.29 PSU and 51.33 ± 3.09 PSU. However, the distribution of salinity during spring was similar to those of autumn 2013. This underlines the dominant role of the evaporation process in the distribution of salinity as temperatures increase.

Dissolved inorganic nitrogen (DIN = NO_3 + NO_2 + NH_4) concentrations ranged between 7.56 ± 5.11 µM and 13.71 ± 5.71 µM. Higher DIN concentrations were recorded during spring. Ammonia was the major constituent during the two seasons. It fluctuated significantly throughout the sampling period (1.20-16.70 µM). Meanwhile the distribution pattern of ammonium in May was consistent with the distribution pattern in November, and the distribution of nitrite exhibited more or less similar distribution pattern as ammonia. The nitrite concentration was usually less than 1.20 µM. A peak of both nitrite and ammonium were encountered at pool VI indicating nutrients addition and magnification of pollution. Phosphate concentrations were above detection levels, it varied from 0.67 ± 0.07 µM to 3.00 ± 0.34 µM. and its concentration was generally higher in spring. DIN:SRP ratios were lower than the Redfield ratio (N:P=16) in spring at all pools, but were higher than the Redfield ratio in autumn at pools II, III and IV. Reactive Silicate concentrations were generally high throughout the sampling period, with a strong increase in pool III when levels reached > 20.0 µM. It showed similar mean values during spring and autumn (15.67 ± 3.65 µM and 15.76 ± 3.58 µM, respectively).

The WQI ranged from 59.9 (pool I) to 73.9 (pool V) during spring and between 69.4 (pool VI) and 79.8 (pool V) during autumn; hence,

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Seasons / Parameter	Spring (May) 2013		Autumn (November) 2013	
	Mean	Range	Mean	Range
Water temperature (°C)	41.5 ± 1.52	39.0-43.0	22.5 ± 1.05	21.0-24.0
pH	7.88 ± 0.21	7.5-8.1	8.02 ± 0.18	7.78-8.18
Dissolved Oxygen (mgl^{-1})	3.75 ± 0.50	2.1-4.8	5.57 ± 0.73	4.3-6.4
Salinity (PSU)	51.33 ± 3.09	44.0-63.0	47.67 ± 4.29	40.0-57.0
NO_3(μM)	3.83 ± 0.28	2.6-6.3	1.34 ± 0.12	0.30-3.44
NO_2 (μM)	0.81 ± 0.10	0.5-1.2	0.28 ± 0.05	0.10-0.47
NH_4 (μM)	9.07 ± 0.84	3.2-16.7	5.94 ± 1.06	1.20-14.35
PO_4 (μM)	3.00 ± 0.34	2.2-4.6	0.67 ± 0.07	0.35-1.55
SiO_3 (μM)	15.67 ± 1.65	10.4-20.7	15.76 ± 1.58	10.80-20.86
WQI	63.83 ± 5.97	56.64-73.94	74.90 ± 4.39	69.37-79.75

Table 1: Mean ± SD and range of physic-chemical parameters in Jeddah pools during spring and autumn, 2013.

the water can be classified as between 'medium' and 'good'.

Phytoplankton community structure and composition

From the spatial analysed data, a slight change in phytoplankton community with regard to numerical abundance and species composition was evident among pools, but with a visible change in the seasonal cycle. The temporal pattern showed no difference in the number of species, with 99 taxons recorded in the two study periods. Bacillariophyta made up the highest number (23 genera, 46 species), but there was a remarkably low number of Pyrrophyta (5 genera, 22 species). Silico-flagellates were represented by only one species, but Cyanophyta and Chlorophyta were represented by 29 and one species, respectively. The most diverse genus was *Ceratium* sp,. The total number of species on the sampled pools demonstrated pronounced variations at the spatial scale. During spring, a high diversity (79 species) was recorded at pool VI, and approximately similar numbers of species (75-77 species) were recorded at pools V and I, while a notable smaller numbers (68, 69 and 70 species) were found at pools III, IV and II, respectively. Then, During autumn, a high diversity (79-80 species) was recorded at pools IV and I, while anobvious smaller numbers (70 and 73 species) were found at pools III and V, respectively. Similar and lowest numbers of species (69 species) were recorded at pools II and IV.

Bacillariophyta and Cyanophyta were more abundant both qualitatively (75.8%) and quantitatively (76.6%) than the other taxonomic groups. They were dominant as the two most diverse groups with 46.5 and 29.3% of the total species number, respectively (Table 2). While Cyanophyta was quantitatively the predominant division (42.5%). The total number of species on the sampled pools showed higher variations at the spatial scale than the temporal one. Pyrrophyta was subdominant (17.3-26.9%). Chlorophyta and Silicoflagellates were the less abundant groups.

Shannon Weiner Diversity index (H') and Pielou's evenness (J) have shown no significant difference among seasons, and amongst the pools. It was observed that the diversity index was slightly lower during spring (4.0785 ± o.o668) than that of in autumn (4.145 ± 0.0575). Species evenness index varied from 0.950 ± 0.005 (spring) and 0.965 ± 0.006 (autumn).

Testing the diversity-equitability and species-diversity number relationship showed that diversity was considerably influenced by species number ($r = 0.795$, $p<0.05$) and exhibited no significant relation with equitability.

Seasonal variation of phytoplankton

In particular, phytoplankton abundances were generally moderate at the pools sampled, and differences on all the pools varied over narrow range (Figures 2 and 3). With respect to mean values, the phytoplankton abundance was slightly lower in spring than autumn.

During spring 2013, phytoplankton cell abundance was 21.00 x 10_4 ± 2.25 x 10^4 cells l^{-1}. Spatial phytoplankton abundance varied between 18.73 10^4 cells l^{-1} (pool II) and 24.09 10^4 cells l^{-1} (pool VI). Cyanophyta was the dominant division at all pools (51.47-58.40%). *Merismopedia convoluta Brébisson ex Kützing* (4.69%), *Lyngbya birgei*

Group	Genus	Species	%	cellsl-1	%
Bacillariophyta	23	46	46.5	73658	34.1
Cyanophyta	15	29	29.3	91816	42.5
Pyrrophyta	5	22	22.2	48009	22.2
Chlorophyta	1	1	1	1667	0.8
Silicoflagellates	1	1	1	958	0.4
Total	45	99	100	216108	100

Table 2: Taxonomic composition and proportional representation of the phytoplankton groups at the pools during spring and autumn, 2013.

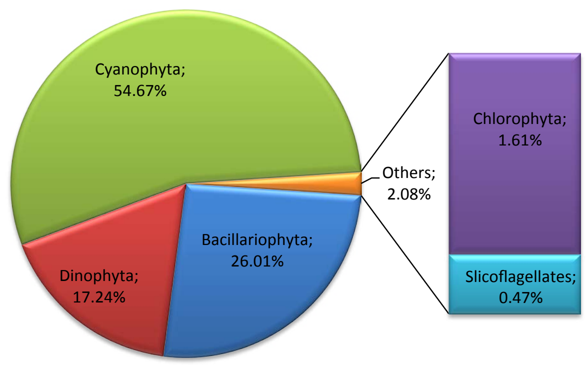

Figure 2: Percentage abundance of the phytoplanktonic groups during spring, 2013.

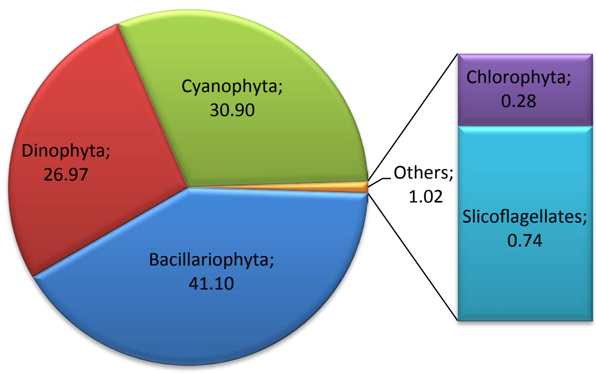

Figure 3: Percentage abundance of the phytoplanktonic groups during autumn, 2013.

G.M.Smith (2.98%) and *Microcystis aeruginosa (Kützing) Kützing*, 1846 (2.86%), *Lyngbya limnetica Lemmermann* (2.75%), *Phormidium fragile (Meneghini) Gomont* (2.40%), *M.punctata Meyen* (2.29%), *Calothrix confervicola (Roth.) Ag.* (2.29%), *Phormodium molle (Kutz) Gomont* (2.29%), *Spirulina princeps W. er G.S. West* (2.29%), *Rivularia olyotis (Agardh.) Born et Flah.* (2.18%) and *Pleurocapsa sp.* 2.06% were the most dominant species of Cyanophyta and each of the mentioned species constituted >2% of the total phytoplankton abundance.

Bacillariophyta was the second most important division during spring (26.27%) at all pools, with a mean of 5.52 x 10^4 ± 1.13 x 10^4 cells l^{-1}. Spatial fluctuation varied widely with regarded to abundance, but dominant species were nearly similar. It ranged between 4.44 x 10^4 cells l^{-1} (pool V) and 7.42 x 10^4 cells l^{-1}(pool I).The main components were *Pseudo-nitzschia delicatissima (Cleve) Heiden, Nitzschia sigma (Kützing) W.Smith, Nitzschia longissima (Brebission), Rhizosolenia setigera Berightwell., Rh. alata f. gracillima (Cleve) Gran., Chaetoceros affine Lauder, Ch. breve Schutt, Gyrosigma strigile (W. Smith), Pleurosigma salinatum Grunow, P. affine Grunow and Navicula salinarum Grunow*. Each of the lasted species formed >1% of the total phytoplankton abundance.

Pyrrophyta constituted 17.27%, with an average of 3.63 x 10^4 ± 0.67 x 10^4 cells l^{-1}. The abundance fluctuated between 3.01 x 10^4 cells l^{-1} (pool IV) and 4.92 x 10^4 cells l^{-1} (pool VI). The main components were *Ceratium fusus (Ehrenberg) Dujardin, Prorocentrum micans Ehrenberg and Protoperidinium pyriforme (Paulsen) Balech., Protoperidinium rotundata Abe, Ceratium furca Cleve, Ceratium fusus (Ehrenberg) and Ceratium longinum Karsten*. Each of the lasted species formed >1% of the total phytoplankton abundance.

During autumn 2013, the phytoplankton cell abundance was 22.22 x 10^4 ± 2.73 x 10^4 cells l^{-1}. Spatial phytoplankton abundance varied between 19.91 10^4 cells l^{-1} (pool V) and 25.75 10^4 cells l^{-1} (pool I). Bacillariophyta was the dominant division at all the pools (36.61- 48.39%). *Pseudo-nitzschia delicatissima (Cleve) Heiden* (2.49%), *Nitzschia sigma (Kützing) W.Smith* (2.17%), *Chaetoceros affine Lauder* (1.93%) and *Chaetoceros breve Schutt* (1.85), were the most dominant species.

Cyanophyta was sub- dominant division at all the pools (28.48- 35.35%). *Merismopedia convoluta Brébisson ex Kützing, Merismopedia elegans A. Br, M.punctata Meyen, Merismopedia tenuissina Lemmermann, Microcystis aeruginosa (Kützing) Kützing, Chroococcus giganteus W. West, Lyngbya birgei G.M. Smith, Lyngbya limnetica Lemmermann, Phormidium fragile (Meneghini) Gomont, Phormodium molle (Kutz) Gomont Rivularia olyotis (Agardh.) Born et Flah. andSpirulina princeps W. er G.S. West*, were the most dominant species of Cyanophyta.

Pyrrophyta fluctuated between 21.75% and 31.13%. The abundance ranged between 5.04 x 10^4 cells l^{-1} (pool IV) and 7.61 x 10^4 cells l^{-1} (pool VI). The main components were *Prorocentrum micans Ehrenberg, Protoperidinium rotundata Abe, Protoperidinium pyriforme Paulsen, Ceratium furca Cleve, Ceratium fusus (Ehrenberg) and Ceratium longinum Karsten*. Each of the lasted species formed >1% of the total phytoplankton abundance.

Zooplankton community structure

The results showed heterogeneity in the zooplankton community, most probably due to the differences in some limnologic variables (mainly salinity and depth).The dominant group, in terms of density, were the copepods in four ponds, mainly because the high densities of nauplii and copepodites and the rotifers in two ponds (pool III & IV). The density of the different zooplankton groups was higher in the arid season than the moderate season all over the study period with domination of copepods in the arid season in pool I (Figure 4). Rotifers were more frequent in pool III in the arid season, while cladocera was rarely recorded during the period of investigation.

The most dominant zooplankton species recorded during the present study are shown in table 3. Oithona sp and Oncaea sp was the most dominant followed by Brachionus plicatilis.

Correlation analysis

The relationships between phytoplankton abundance and environmental variables were not significant. Correlation analysis, however, revealed strong statistically significant correlations among phytoplankton structure and environmental variables. Most diatoms and dinoflagellates species were inversely correlated to nutrients. There was a positive correlation of Cyanophyta with temperature, NO_3, NO_2 and PO_4. This related the dependency of the blue green algae with the above nutrients. On the other hand, Cyanophyta has negative correlation with O_2 and WQI. Diatoms have a negative correlation with NO_3, NO_2, and PO_4 which means that diatoms are oligotrophic in this study area.

The best correlation was between phosphate and WQI (r = -0.856, p<0.001). Among the dominant phytoplankton species, *Nitzschia sigma* and *Ceratium furca* showed significant negative correlations with ammonia(r = -0.612, p<0.05, r = -0.717, p<0.05, respectively). Other frequent species were dependent on specific environmental variables, e.g. *Pseudo-nitzschia delicatissima* and *Prorocentrum micans*, which were found to be inversely correlated with salinity (r = -0.636, p<0.05, r = -0.708, p<0.05, respectively) whereas, *Lyngbya birgei* and *Microcystis aeruginosa* were positively correlated with phosphate (r = 0.729, p<0.05, r = 0.584, p<0.05, respectively).

The Canonical Correspondence Analysis (CCA) was used to

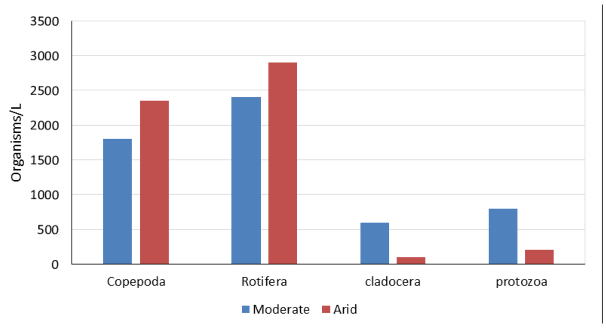

Figure 4: Density of the different zooplankton groups in Arid and Moderate seasons in Jeddah Pools during period of study.

Group	genus	Presence
Copepod:	*Oithona nana*	++++
	O. simplex	+++
	Oncaea sp.	++++
Rotifera:	*Brachionus plicatilis*	++++
	Cephalodellagibba	+++
	Euchalanusdilatata	+++
	Hexarthraoxyuris	++
	Lecaneluna	+

++++: Dominant species +++: subdominant ++: frequent +: rare

Table 3: Taxonomic composition and proportional representation of the zooplankton groups at the pools during spring and autumn, 2013.

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examine distribution pattern of the different phytoplankton groups (Figure 5). In this type of analysis, the environmental parameters are represented with arrows. The ordination of CCA for the present study revealed that Cyanophyta have a positive strong relationship with water temperature, orthophosphate, ammonia, and reactive silicate. While a negative relation is found between Cyanophyta and salinity. Bacillariophyta had a strong negative relation with silicate. On the other hand Silicoflagellates and Pyrrophyta showed a positive relation with pH. The ordination of CCA for the present study revealed that *Copepoda* affected positively by water temperature, salinity and NO_3. *Rotifera* negatively correlated to salinity and water temperature and positively with SIO_3.

Discussion

Coastal pools occur commonly along sedimentary shorelines on all continents. They hold considerable potential for fisheries, tourism, and are increasingly popular sites for housing and industrial developments. This suggests the need for the development of effective operational methods of monitoring to identify changes along pool margins and trends in water quality. Jeddah pools are a coastal area with significant recreational activities and development pressure from an ever increasing population and tourism. They are the most attractive places due to its beauty and shallowness which are safety for recreational uses. Furthermore, the pools are opened with seas by culverts which allow exchange with sea water. However, currently Jeddah coastal area is under stress resulting from diverse human activities for example, and thus pools water must be continuously monitor to maintain standard to avoid any threat for both of ecosystem and human health.

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.

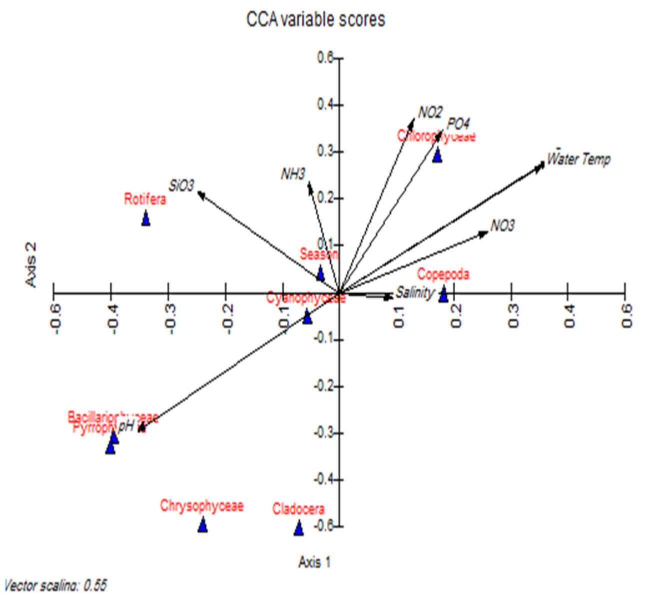

Figure 5: The Canonical Correspondence Analysis (CCA) between the different planktonic groups and some of environmental data.

The studies using phytoplankton for water quality monitoring have shown that changes in composition reflect not only variations in water quality, but also changes in physical variables and biotic interactions. Turkoglu et al. [21], Naz et al. [22], Turkoglu et al. [23], Turkoglu et al. [24] 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.

Jeddah pools area has a hot and humid climate all year-round. Its salinity is much higher than that of the Red Sea which was 42.5 PSU (average) [25]. The pools water has a mean salinity of 49.5 PSU, but it sometimes reaches upto 63.0 PSU as recorded in spring. Consequently, the high salinity of the pools may be a result of the arid local climate, high evaporation rates, low precipitation and the small size of the pools. Dissolved oxygen were usually under saturation (34-86%) and below the levels that support aquatic life which recommended by Chaturvedi et al. [26]. This could be attributed to exhaustion of dissolved oxygen during break down organic matter brought into the pools.

A steady increase of nutrient concentrations at the southern coast of Jeddah as reported by Omar et al. [1], El-Sayed et al. [27] reflected the direct effect of the ambient Jeddah coastal water up on the pools water, and means that the pools are at early stage of stagnant environment. Also, the oxidation of organic matter discharged could be responsible for the production of nitrate and ammonium and consumption of dissolved oxygen. The high phosphate concentrations recorded in the pools, reached >4 μM, may be associated with the discharge of different types of human and domestic wastes and also, sediments may be play an important role as a sink and or a source of phosphorus due to the continuous transportation of chemical species across the sediment-water interface [28]. The fluxes rate, uptake and release from the water column as well as their circulation are considered as the main factors for controlling the levels of different nutrients in the pools. The recorded value is slightly higher than the 0.46 uM reported by Turki and Mudarris et al. [29] for Al-Nawrus pool and lower that the polluted waters from Al-Arbaeen and Al-Shabab pools (North of Jeddah) which reached 44.1 and 20.2 μM, respectively [30]. There was no major variation in physicochemical parameters that were monitored among the different pools. Redfield [31] reported that the optimal N:P ratio for phytoplankton growth, known as the Redfield ratio, is 16:1 (based on molecular concentrations). The N:P ratios in the current study were lower (3.03-9.14) than the Redfield ratio during the spring in all pools, suggesting potential nitrogen limitation, but the ratio in the autumn were higher than the Redfield ratio, suggesting a higher nitrogen budget in relation to phosphorus. Silicate concentrations were generally high throughout the sampling period, with a strong increase (> 20 μM) at pool III, which was also the same case with the other nutrients.

Water quality in an aquatic ecosystem is determined by many physical and chemical factors [32]. 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 [16]. The results indicated that the water quality of the different pools ranged from 59.9 to 79.8, i.e. from medium to good. During spring, the quality of the selected pool water samples was medium except for pool V that was good, and during autumn, the water quality was good except for pool VI that was medium, which means beginning of deterioration of the water quality. From the correlation coefficients between WQI and water quality parameters, it is evident that phosphate was the factor governing the computed WQI values of the pool waters (r = -0.856, p<0.001).

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 resulting in high productivity [33,34]. 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 and can be used as biological determination of the water quality [35,36]. Furthermore, they are suitable for the determination of the impact of toxic substances on the aquatic environment because any effect on the lower level of the food chain will also have consequence on the higher level and so, used for assessing the degree of pollution or as indicator of water pollution of different water bodies [37-40].

The present study showed mix populations of freshwater and marine phytoplankton in these saline pools, furthermore, many species have adapted to the seasonal fluctuating environmental conditions. The seasonal trends were relatively higher in autumn than in spring, with somewhat homogeneous communities in all pools, showing no dominance on the community during the current study; the pools were not susceptible to generating algal blooms. Cyanophyta was most conspicuous in the studied pools, but Chlorophyta was unnoticeable. Cyanophyta was persistently dominant during spring and reduced dominance during autumn. High surface temperature, low N: P and high nutrient concentrations favours growth of Cyanophyta. The average Cyanophyta abundance in the study pools during spring was 11.51 x $10^4 \pm 1.21 \times 10^4$ cells l^{-1}, this value is not high to threat the ecosystem, but any blooms will cause a strong negative effect on water quality, as certain species of Cyanophyta are capable of producing toxins, such as; *Microcystis, Oscillatoria, Nodularia* and *Lyngbya*. Carmichael et al. [41] recognized the last four mentioned genera as the most important genera as toxigenic species. On the other hand, high salinity in the pools may reduce the abundance of Cyanophyta community in the pools, the same observation was recorded by Barron et al. [42], Salomon et al. [43]. Cyanophyta has generally higher temperature optima for growth than other phytoplankton, and temperature has been considered the most important factor contributing to Cyanophyta dominance (r = 0.933, p<0.001) as recorded by Vander Westhuizen et al. [44], Rapala et al. [45].

It is well- known that diatoms are sensitive to a wide range of limnological and environmental variables, and for that their community structure may quickly respond to changing physical and chemical conditions in the environment [46]. During autumn, water quality improvement; water temperatures and nutrient concentrations decreased. Bacillariophyta formed the major phytoplankton group. Further, the abundance showed a negative correlation with nutrients (NO_2, r = - 0.821, PO4, r = - 0.699). Species such as *Pseudo-nitzschia delicatissima*, *Nitzschia sigma, N. longissima, Pleurosigma affine, Chaetoceros breve* and *Rhizosolenia setigera* were noticed during the autumn. In autumn 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 [22,23,47-50].

The high zooplankton density in the arid season can be explained by the fact that decrease in the water level in arid season causes the concentration of nutrients, which would favour phytoplankton growth and increase of zooplankton, which in turn limits phytoplankton development. Thus, both nutrient supply and zooplankton grazing may control phytoplankton growth. The presence of cyanobacteria did not affected zooplankton community greatly since there were not any high blooms of cyanobacteria during the period of study.

Sometimes, diversity indices serve as a good indicator of the overall pollution of water. Non-polluted waters are often characterized by high diversity with large number of species, each flourishing with relatively low but almost uniform number of organisms with no single species dominating in numbers over others. However, with pollution causing a stress, sensitive species are eliminated out and the tolerant species increase in numbers to make their dominance. According to Wilhm et al. [51] diversity above 3 means clean condition. It is interesting to notice that the diversity values were > 4 for all pools during the two seasons, which means that the pools have a high specific structure and a well balanced phytoplankton community. This is the fact inconsistent with the values of WQI, the high nutrient concentrations and the presence of many species typical inhabitants of heavily polluted waters.

Diversity index may, in fact, increase in moderately eutrophicated condition as reported by Joubert [37], in several water bodies. It is only under the prevalence of conditions of algal blooms that the diversity index can fall. Results show a positive correlation (p<0.05) between diversity and phytoplankton abundance(r = 0.704).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 pools water.

The increasing urbanization and industrialization along Jeddah Corniche is posing a very serious threat in that it is creating an ever increasing quantity of effluents of all types being added to pools water, and so, we recommended to drilling several culverts for each pool to allow good water masses exchange between pools water and the Red Sea water in controlling the distribution and behaviour of hydrochemical characteristics inside the pools.

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