BioRisk 3: 83–96 (2009)
doi: 10.3897/biorisk.3.8
www.pensoftonline.net/biorisk

RESEARCH ARTICLE

A peer-reviewed open-access journal
BioRisk
Biodiversity & Ecosystem Risk Assessment

Space-time variability of phytoplankton structure and diversity in the north-western part of the Arabian Gulf (Kuwait's waters)

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Academic editors: *L.J. Musselman, F. Krupp* | Received 14 March 2009 | Accepted 14 December 2009 | Published 28 December 2009

Citation: Polikarpov I, Al-Yamani F, Saburova M (2009) Space-time variability of phytoplankton structure and diversity in the north-western part of the Arabian Gulf (Kuwait's waters). In: Krupp F, Musselman LJ, Kotb MMA, Weidig I (Eds) Environment, Biodiversity and Conservation in the Middle East. Proceedings of the First Middle Eastern Biodiversity Congress, Aqaba, Jordan, 20–23 October 2008. BioRisk 3: 83–96. doi: 10.3897/biorisk.3.8

Abstract

Studies of the phytoplankton community were conducted in the north-western Arabian Gulf in 2005 and 2006. Seven stations throughout Kuwait's waters were sampled. The influence of nutrient-rich freshwaters from the Shatt al-Arab resulted in high phytoplankton productivity characterized by high species diversity with a strong dominance of diatoms, especially in northern Kuwait. Phytoplankton species richness gradually increased from north to south. Spatial distribution of both total abundance and biomass of phytoplankton indicated significant differences in species structure and size spectrum of the microalgae. The analysis of the temporal and spatial phytoplankton variability (distribution of total abundance and biomass, similarity of species compositions and local community structure) indicated that Kuwait's northern waters differed from areas further south in terms of phytoplankton structure and temporal and spatial variability. Environmental heterogeneity is mainly attributed to the influence of the Shatt al-Arab system, which affects the temporal and spatial variability of the phytoplankton community.

Keywords

Phytoplankton, diversity, Arabian (Persian) Gulf, Kuwait

Introduction

The ecology of phytoplankton in the Arabian Gulf has been studied during the last few decades and is relatively well known (e.g. Al-Kaisi 1976, Jacob et al. 1979, Subba Rao et al. 1999, Al-Yamani et al. 2004). Long-term studies of temporal and spatial distributions and the effects of physical effects on the phytoplankton community in Kuwait's waters have not been reported.

The main freshwater inflow into the northern Arabian Gulf is from the Shatt al-Arab River. Seasonal freshwater supply from the Shatt al-Arab has local effects on the Gulf's marine environment, especially on Kuwait's waters. The phytoplankton community in the Arabian Gulf is heterogeneous, with species compositions differing among localities (Al-Yamani et al. 2004). The main objective of this study was to describe the spatial and temporal variability of phytoplankton diversity, species composition and abundance in Kuwaiti territorial waters.

Methods

Daytime phytoplankton surveys in Kuwaiti waters were conducted twice a month from October 2005 through September 2006 at seven stations (Fig. 1).

One-liter samples from the surface layer (1 m depth) were collected by 5–liter Niskin bottles and preserved with acidified Lugol solution. After full sedimentation during at least four weeks, the top water volume was carefully siphoned off without disturbing the precipitated algae (using rubber a hose with curved end). The Utermöhl sedimentation method was used for quantitative analysis of the Niskin bottle samples (Utermöhl 1958). The concentrated sample was well shaken and an aliquot of 25 ml from each sample was placed in the standard Utermöhl settling counting chamber. After sedimentation during a 24 h period in a well-covered dark desiccator, the area of the settling chamber was examined with a Leica DMIL inverted microscope at ×200 to ×400 magnifications. For phytoplankton enumeration, the appropriate area of the chamber was scanned, depending on the abundance of each species. Randomly-selected viewing fields were examined for very abundant phytoplankton species, whereas the complete chamber area was scanned for less abundant species. The abundance for each phytoplankton taxon was calculated as the number of cells per liter. In total, 76 Niskin bottle samples were examined.

The SeaBird SBE-19 CTD profiler equipped with a Seapoint turbidity meter was deployed at each station to obtain *in-situ* data for salinity (psu), temperature (°C) and turbidity (NTU) distribution. Water samples for measuring inorganic nutrients concentrations were collected by a 5-liter Niskin bottle from one meter depth and filtered using Whatman GF/C filters. The automated determination for nitrate and silicate was based on Strickland and Parsons (1972), using a Skalar SUN Flow Analyser. For ammonia concentrations, we employed the phenol-hypochlorite method and added the required reagents immediately after obtaining the water sample. Ammonia concentra-

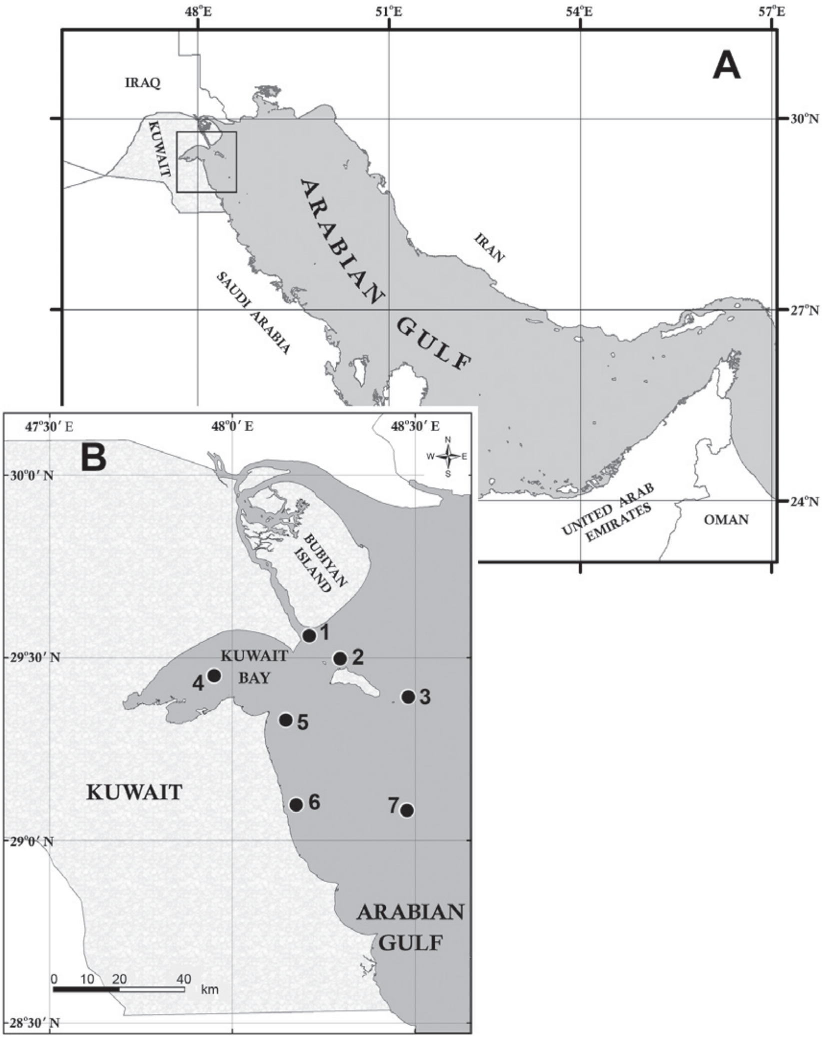

Figure 1. Area of investigation. **A** Arabian Gulf, with inset showing the greater region in which the sampling area was located **B** Map of Kuwait showing locations of the stations sampled for phytoplankton in 2005 and 2006 (black dots).

tions were measured in the laboratory using a Beckman DU-650 spectrophotometer after 24 hours of incubation in the dark (Grasshoff et al. 1983).

In order to estimate phytoplankton biomass, the individual volumes of cells (μm3) and biomass as wet weight (mg/L) for each species were calculated according to approximate geometrical fi gures (Hillebrandt et al. 1999). To describe phytoplankton diversity, the Margalef's richness index, Shannon's heterogeneity index and Pielou's evenness index were used. Similarity between species compositions was calculated by Jaccard and Czekanowski-Sørenesen indices of association. Cluster analysis was applied to generate dendrograms (group average method), based on the Jaccard and

Bray-Curtis distance matrixes among samples. Pearson correlation coefficients were calculated for estimations of the relationships between environmental variables and the phytoplankton community. Calculation of indices and cluster analysis were performed using Primer 6.1.9 software (Primer-E Ltd.).

Results

Phytoplankton diversity

The phytoplankton community in Kuwaiti waters in 2005 and 2006 was very diverse with 200 taxa identified, representing nine classes (Table 1). Diatoms (Bacillariophyceae) exhibited the greatest diversity with 134 taxa identified, followed by dinoflagellates (Dinophyceae, 56 taxa); Cyanophyceae, Prymnesiophyceae and Dictyochophyceae, each with two taxa, and Cryptophyceae, Prasinophyceae, Euglenophyceae and Ebriidae represented by a single taxon.

Diatoms and dinoflagellates were the most diverse groups. Centric and pennate diatoms accounted for the highest diversity with 84 and 50 taxa, respectively. Among the centric diatoms, the most diverse genera were *Chaetoceros* (22 taxa), *Rhizosolenia* (12 taxa) and *Coscinodiscus* (nine taxa). For pennate diatoms, the *Nitzschia* group was represented by 17 taxa (14 species of the genus *Nitzschia* and three species of the morphologically close genera *Pseudo-nitzschia* and *Cylindrotheca*). The genus *Pleurosigma* was represented by seven species. Of the 56 species of dinoflagellates, over one-half were represented by three genera: *Protoperidinium* (16 taxa), *Ceratium* (eight taxa) and *Prorocentrum* (five taxa).

As a whole, a pronounced prevalence of diatoms was typical for the phytoplankton community in Kuwaiti waters throughout the year. On the average, diatoms contributed 70% to the total species diversity. Their prevalence was at a maximum (80% to

Table 1. Diversity of the main phytoplankton groups recorded from Kuwaiti waters in 2005 and 2006; phytoplankton groups presented here follow the classification scheme of Throndsen (1997), which was partially modified by Christensen (1962, 1966).

Class	Diversity (number of taxa)
Cyanophyceae	2
Cryptophyceae	1
Dinophyceae	56
Prymnesiophyceae	2
Dictyochophyceae	2
Bacillariophyceae	134
Prasinophyceae	1
Euglenophyceae	1
Ebriidea	1
Total phytoplankton diversity	200

100%) during the autumn-winter period, especially in November and December, and reduced during the spring and summer (April to July), especially at stations 5, 6 and 7. Dinoflagellates contributed only 22% to the total species diversity, with a maximum of 40% to 70% during the spring-summer period, and <10% (often <1%) at stations 1 and 2 throughout the study period, probably a result of reduced salinities in the Shatt al-Arab discharge.

Variability of phytoplankton concentrations

Microalgae abundance ranged from 3.06×10^3 to 1.24×10^7 cells/L (1.88 ± 2.59×10^5 cells/L on average) and biomass from 0.03 to 161 mg/L (9.96 ± 24.10 mg/L on average). Diatoms dominated phytoplankton abundance numerically as well as in biomass, accounting for 99% of the latter depending on season. Phytoplankton concentrations, which were obtained in this study, are within the range of those reported previously (Al-Yamani at al. 2004, 2006).

Space-time variability of the phytoplankton structure

Assessments of the spatial and temporal variability of the structure of the phytoplankton community studied are presented in Table 2. High levels of average paired similarity between both the species compositions within stations (0.703) and within year (0.710) as well as small dispersion of these parameters testify a rather high taxonomic homogeneity of the phytoplankton community in Kuwaiti waters and similar trends in seasonal development of phytoplankton at different locations.

For the community as a whole, the high β-diversity value (21.5) indicates heterogeneity in species compositions among the replicates. Average similarity of species structure within samples (average paired samples similarity using the Czekanowski-Sørensen Index) was 0.390 ± 0.141.

Temporal variability of phytoplankton

Analysis of seasonal variability within the phytoplankton community was performed using the hierarchical clustering using the Jaccard Index of similarity. For the samples collected throughout the year, we identified four different periods based on sample similarities (Fig. 2A). The community structure of samples within each period showed a higher degree of similarity than that of samples between periods. Cluster analysis found seasonal differences as follows: Cluster-1, late winter-spring (January, February and March); Cluster-2, spring (April and May); Cluster-3, summer-early autumn (July and September) and Cluster-4, late autumn-winter (October, November, and December). Each cluster was identified by distinct phytoplankton associations (Fig. 2B, Table 3).

Table 2. Space-time variability of the phytoplankton community structure.

Attributes of community structure	**Spatial variability (7 stations)**	**Temporal variability (10 months)**
Mean number of species per sample	126	104
Number of species with absolute occurrence	40	36
Number of samples containing all species	0	0
Occurrence Index (β-diversity)	63.32	52.26
Czekanowski-Sørensen Index	0.703 ± 0.149	0.710 ± 0.058

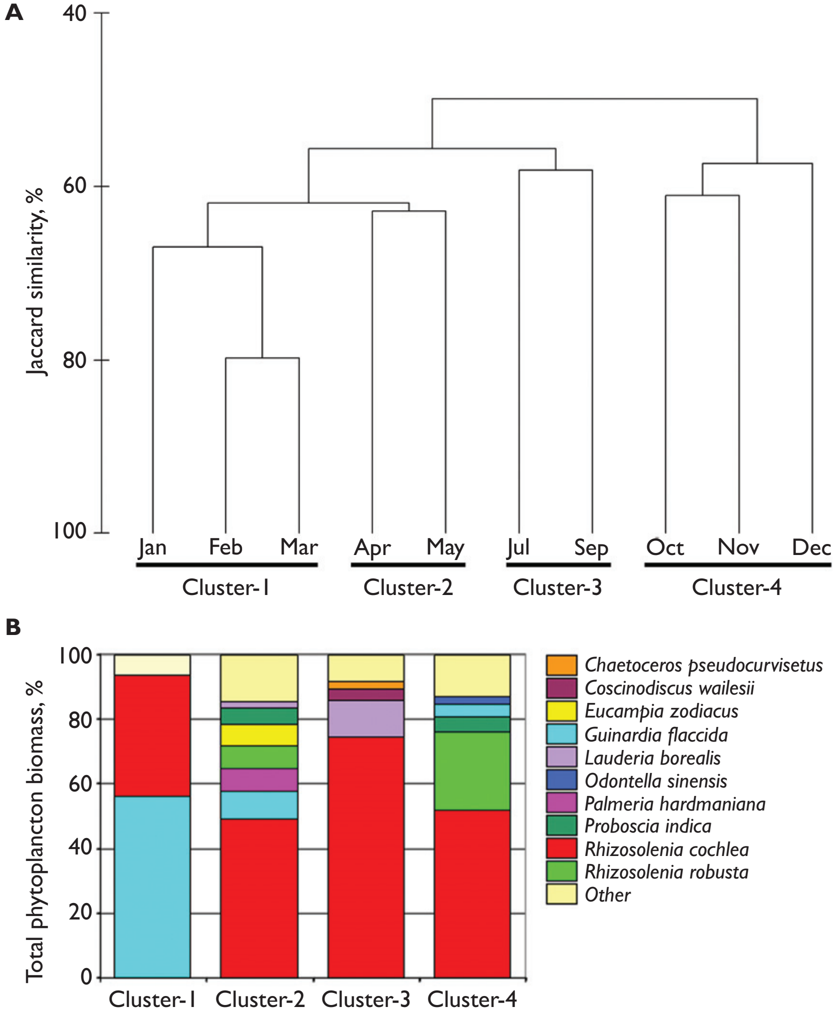

Figure 2. Temporal variability of the phytoplankton community. **A** the dendrogram of cluster analysis (group average method), based on Jaccard's distance matrix among samples (10 months × 200 species; monthly average biomass values) **B** compositions of dominant species for different phytoplankton associations within each period isolated by cluster analysis.

Table 3. Phytoplankton concentrations and community structure within different periods of the year, which were isolated by cluster analysis. Cluster numbers correspond to those in Fig. 2A.

Cluster	Total phytoplankton biomass, mg/L (mean ± SD)	Species richness		Species diversity	Community evenness
		Species number	Margalef's index	Shannon's index	Pielou's index
Cluster-1	18.5 ± 16.9	118	11.91	1.05	0.22
Cluster-2	2.2 ± 0.8	105	13.53	2.09	0.45
Cluster-3	17.0 ± 12.1	129	13.14	1.11	0.23
Cluster-4	7.5 ± 9.0	179	19.95	1.75	0.34

Composition of the top-dominant species and their percentage contributions to the total phytoplankton biomass from each isolated period of the year are shown in Fig. 2B. The beginning of the year (Cluster-1) was characterized by dominance of large-sized diatoms *Guinardia flaccida* (53% of the total phytoplankton biomass) and *Rhizosolenia cochlea* (39%). Late winter phytoplankton development was characterized by minimal values of species diversity and community evenness and maximum concentrations of phytoplankton. Diversity among dominant species during the spring (Cluster-2) was higher due to the appearance of large- and medium-sized diatoms: *Palmeria hardmaniana*, *Rhizosolenia robusta*, *Eucampia zodiacus*, *Proboscia indica* and *Lauderia borealis*. In the spring season, the decline of *G. flaccida* resulted in *R. cochlea* becoming the dominant species. This period was characterized by minimum phytoplankton concentrations; but species diversity and community evenness increased to their highest levels. In summer-early autumn (Cluster-3), the phytoplankton community consisted mainly of *R. cochlea* complemented by significant concentrations of *L. borealis*. The rather high levels of phytoplankton biomass during the late autumn-winter period (Cluster-4) were supported mainly by *R. cochlea* and *R. robusta* populations. The maximum values of phytoplankton species richness were found in October to December. Generally, winter months of 2005/2006 were characterized by the main bloom of phytoplankton biomass in the surface waters (up to 60–80 mg/L in some locations), which started in the northern part of Kuwait in December, moving southward through Kuwait Bay during January and February.

Spatial variability of phytoplankton

To estimate the spatial variability within the phytoplankton community, we applied the Bray-Curtis Similarity Index among stations. Cluster analysis identified three different phytoplankton associations in Kuwaiti waters (Fig. 3).

The first area outlined (Cluster-1, station 1) was located in Kuwait's extreme northern waters closed to the Shatt al-Arab. The second area outlined (Cluster-2) consisted mainly of stations along Kuwait's coast (stations 4, 5 and 6) and included station 2. The remaining area (Cluster-3) was restricted to open waters (stations 3 and 7;

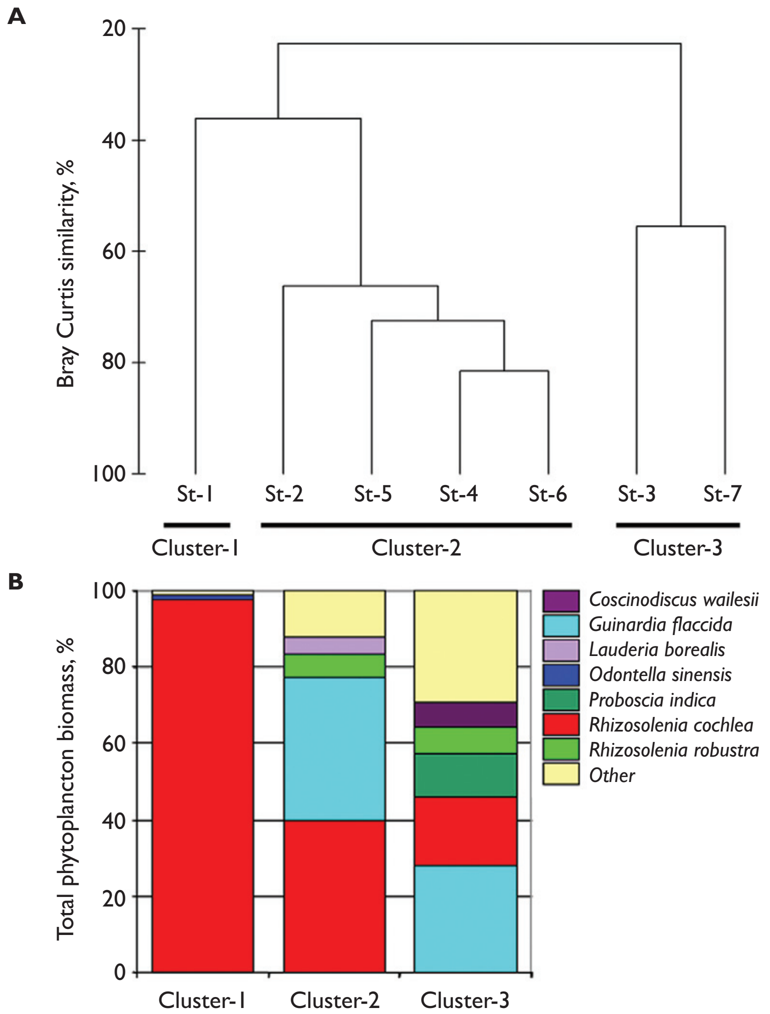

Figure 3. Spatial variability of phytoplankton community. **A** Dendrogram of the cluster analysis (group average method), based on the Bray-Curtis distance matrix among samples (seven stations × 200 species; annual average biomass values) **B** Compositions of dominant species in different phytoplankton associations within each area outlined by the cluster analysis.

Fig. 3A). Within each area outlined, distinct phytoplankton associations were found with regard to composition, concentration, species richness and diversity as well as community evenness. Dissimilarity of community structure between phytoplankton from different associations is illustrated in Fig. 3B and Table 4.

The first association (Cluster-1) greatly differed from other locations by the highest phytoplankton concentrations, the minimum values of species richness, diversity and community evenness. The high levels of phytoplankton biomass were supported

Table 4. Phytoplankton concentrations and community structure within different areas of Kuwait's waters, which were isolated by cluster analysis. The cluster numbers correspond to those in Fig. 3A.

Cluster	Total phytoplankton biomass, mg/L (mean ± SD)	Species richness		Species diversity	Community evenness
		Species number	Margalef's index	Shannon's index	Pielou's index
Cluster-1	15.0	65	6.66	0.16	0.04
Cluster-2	12.1 ± 4.1	176	16.22	1.70	0.33
Cluster-3	2.3 ± 0.8	175	20.66	2.72	0.53

by almost total prevalence of the large-sized diatom *R. cochlea*. Coastal waters were characterized by the dominance of *R. cochlea* and *G. flaccida* (the second association, Cluster-2). Phytoplankton composition in open waters (the third association, Cluster-3) differed clearly from those of northern Kuwait and the coastal waters due to low densities, despite maximum species richness, diversity and community evenness. In decreasing order of abundance for the offshore stations, the most important species included: *G. flaccida*, *R. cochlea*, *Proboscia indica*, *R. robusta* and *Coscinodiscus wailesii*.

Variability of phytoplankton structure along latitudinal gradient

In order to assess macro-scale spatial variability of the phytoplankton community within Kuwaiti waters, we analyzed distributions of species richness and diversity of large taxonomic groups as well as phytoplankton composition along a latitudinal gradient. Figure 4 shows the phytoplankton species richness plotted against latitude. Margalef's index gradually increased from north to south. This trend conformed to a linear regression model, which described 91% of the spatial variability for mean species richness (r^2=0.91). Phytoplankton composition from northern waters near the Shatt al-Arab estuary was less diverse than that of southern waters. The observed increasing trend was supported mainly by an increase of dinoflagellate diversity.

Phytoplankton composition within the northern waters was characterized by high prevalence of diatoms (from 76% to 96% of total species richness; Fig. 5A). If not totally absent, dinoflagellates contributed only 6% to 18% to the total species richness. The portion of dinoflagellates in the phytoplankton increased exponentially along the north-south gradient (Fig. 5B). The diatom/dinoflagellate ratio was equal to 11 within northern waters (station 1); whereas it was reduced to 2.6 in coastal waters, and even further to 2.3 in open waters (115 diatom species versus 50 dinoflagellates).

Relationship between phytoplankton community and environmental variables

In order to detect the differences between various areas within Kuwait's waters, we analyzed the composition of the main environmental factors (salinity, turbidity and nutri-

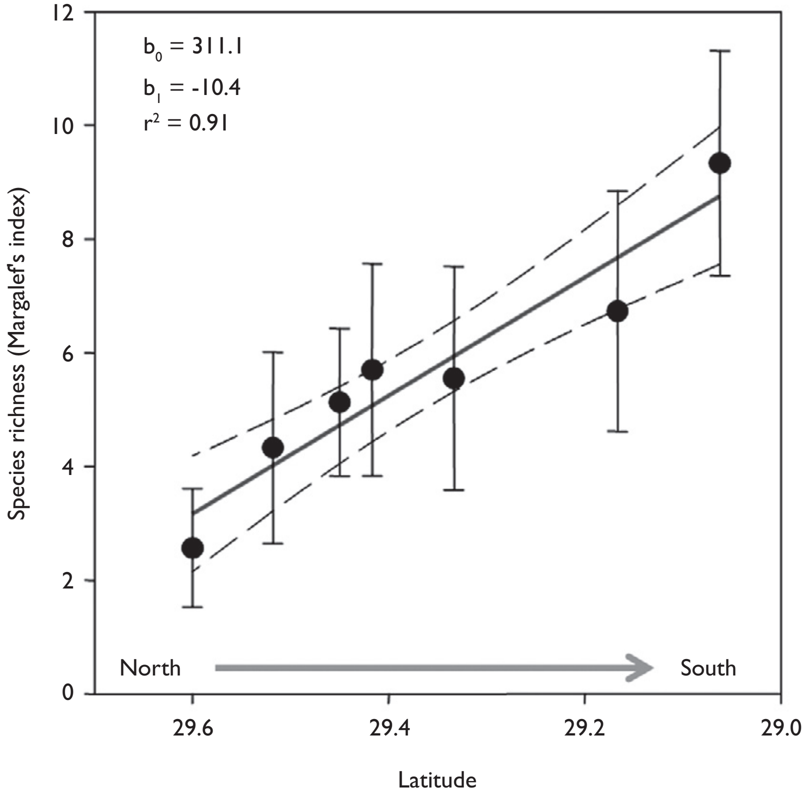

Figure 4. Change of species richness in the phytoplankton community along a north-south latitudinal gradient. The dots represent the annual average values of Margalef's Index ± SD; the solid line represents the linear regression; the dashed lines represent the 95% confidence interval.

ent concentrations). Salinity values increased from the north to the south (Fig. 6A), whereas the opposite trend was observed for turbidity and nutrient concentrations along the latitudinal gradient (Figs 6B–D).

To estimate the relationships between the phytoplankton community and the main environmental variables, we calculated the Pearson correlation coefficients. Correlation analysis was applied to the matrix of annual average values for each variable analyzed (Table 5).

The relationships between phytoplankton and environmental variables were not significant in terms of microalgae concentrations. Correlation analysis, however, revealed strong statistically significant correlations among phytoplankton structure and environmental variables. Species richness of phytoplankton community and selected taxonomical groups as well as percentage contribution of dinoflagellates to the community were strongly correlated with salinity (positive correlations with values of 0.82–0.97, $p < 0.001$), turbidity (negative correlations, r from -0.88 to -0.97) and with

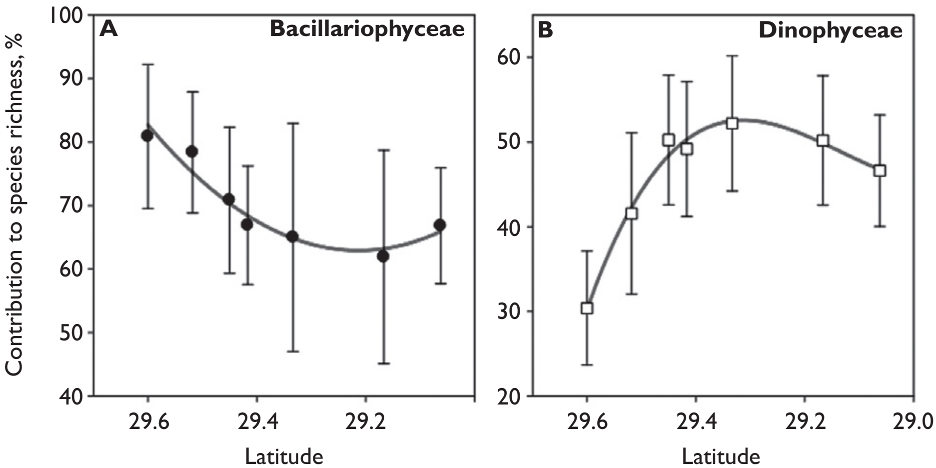

Figure 5. Percentage contribution of phytoplankton groups to the total species richness plotted against latitude. **A** Diatoms **B** dinoflagellates; annual average values of species richness (number of species) ± SD.

nutrient concentrations, especially with silicate (negative correlations, *r* from -0.91 to -0.99) (Table 5). For diatoms, we found significant positive correlations with turbidity as well as with nutrient concentrations. Additionally, the high prevalence of diatoms in phytoplankton composition was associated with low salinity (*r* = -0.98).

Discussion

The relatively small geographic area of Kuwait's waters covers a very important transitional zone at the extreme north-western corner of the Arabian Gulf. From north to south, coastal waters of Kuwait extend for 170 km. There is a range of interaction between the Shatt al-Arab River discharge and the Arabian Gulf marine environment. The shallow waters of Kuwait are characterized by high biological productivity (Al-Yamani et al. 2004), which are supported mainly by very abundant and diverse phytoplankton communities.

The high species diversity of the phytoplankton community (200 identified taxa) is mainly due to diatom algae. The assessment of phytoplankton species diversity presented here is close to the maximum number of phytoplankton taxa recorded in the Arabian Gulf area, which is 223 taxa, including 134 diatoms and 86 dinoflagellates (Jacob and Al-Muzaini 1990). The latest estimation of diversity in Kuwaiti waters was 220 taxa, including 162 diatoms and 53 dinoflagellates (Al-Yamani et al. 2004).

The phytoplankton community in Kuwaiti waters differs from the rest of the Arabian Gulf by high prevalence of diatoms and low dinoflagellate species diversity due to the abundance of silicate nutrients in these waters. The occurrence of a significant

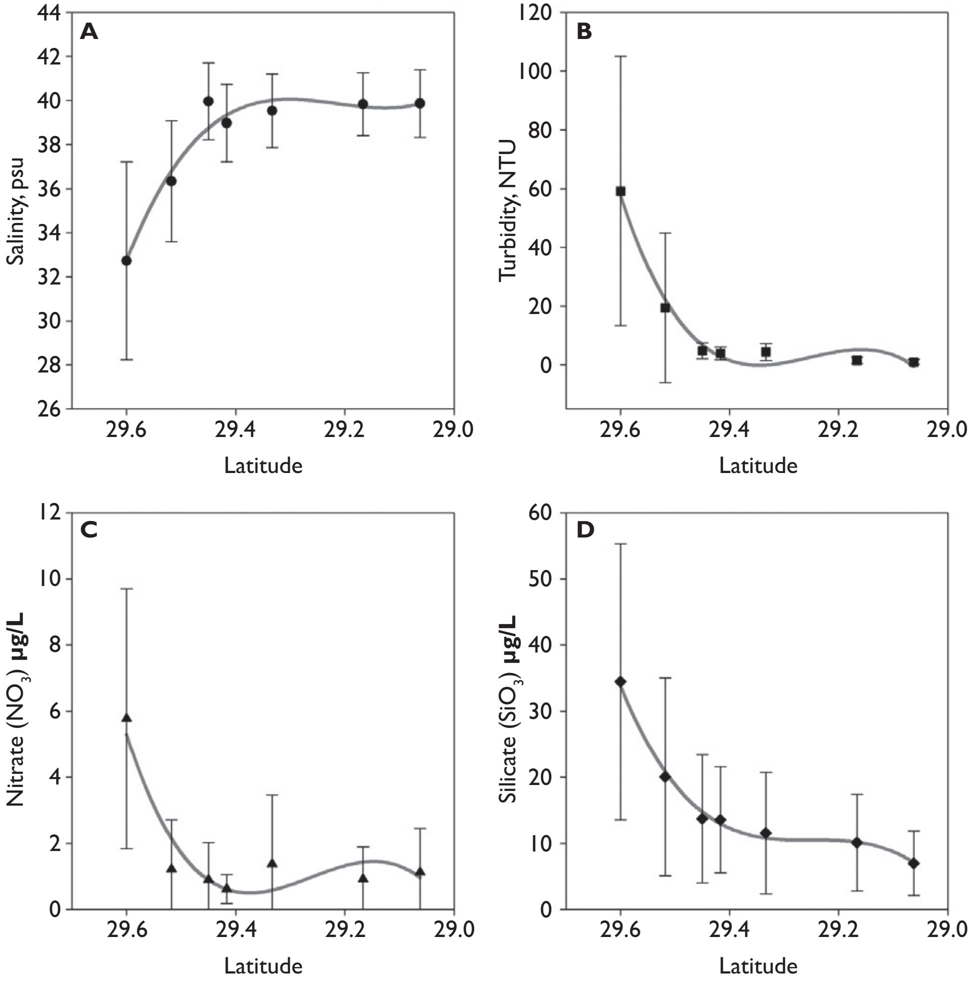

Figure 6. Distribution of environmental variables (annual average values ± SD) along the north-south latitudinal gradient. **A** Salinity **B** turbidity **C** nitrate **D** silicate.

abundance of pennate diatoms, especially benthic taxa (large- and small-sized) diatom algae from periphyton, epipelon and epipsammon associations (genera *Pleurosigma*, *Diploneis*, *Surirella*, *Trachyneis*, *Nitzschia*, *Entomoneis*, *Plagiotropis*) is also noteworthy. For some of them (such as *Pleurosigma* spp., *Surirella fastuosa*, *Trachyneis antillarum,* and *Nitzschia* spp.) significant abundances were observed in some inshore locations.

Both the spatial and temporal components contributed to the variability of the phytoplankton community in Kuwaiti waters. During the winter months, the northern area was characterized by the highest concentrations of phytoplankton, whereas the lowest phytoplankton concentrations were observed in open waters in summer. The minimum diversity level was associated with the spring months, whereas the maximum was in autumn (October). Phytoplankton species richness gradually increased

Table 5. Pearson's Correlation Coefficients (*r*) among phytoplankton community and environmental variables measured in Kuwaiti waters in 2005/2006. The values in bold represent significant correlations ($p < 0.001$).

		Species richness			Species composition	
	Total phytoplankton biomass	**Total phytoplankton**	**Diatoms**	**Dinoflagellates**	**Diatoms contribution**	**Dinoflagellates contribution**
Salinity	-0.62	**0.90**	**0.82**	**0.94**	**-0.98**	**0.97**
Turbidity	0.58	**-0.92**	**-0.88**	**-0.93**	**0.96**	**-0.97**
Ammonia	0.56	**-0.92**	**-0.89**	**-0.92**	**0.93**	**-0.94**
Nitrate	0.46	**-0.85**	**-0.86**	**-0.82**	**0.85**	**-0.88**
Silicate	0.63	**-0.97**	**-0.91**	**-0.99**	**0.98**	**-0.97**

southward, with the lowest richness recorded in the waters closest to the Shatt al-Arab and the highest towards the southern waters.

The analysis of space-time phytoplankton variability allowed the clustering of similar samples and hence the identification of the different phytoplankton associations in Kuwaiti waters. The northern zone is unique and differs from the rest of the study area, which is clearly expressed in the distinctive features of phytoplankton structure and space-time variability. Pronounced differences in the northern area are explained by the strong influence of lower-salinity waters that are discharged from Shatt al-Arab River and the Shatt al-Basrah channel.

The Shatt al-Arab system, which collects the waters of the Tigris, Euphrates and Karun rivers, is the principal fluvial input to the Arabian Gulf, especially to the northern areas including Kuwaiti waters (Al-Yamani et al. 2004). Seasonal freshwater supply from the Shatt al-Arab appears to have a local effect on the marine environment of the examined area. The influence of the Shatt al-Arab River discharge on the northern Arabian Gulf results in a gradient of environmental conditions, which change according to river flow volume. As a result of this interaction, different locations and distinct periods may be identified in Kuwaiti waters. There is a northern zone, which is constantly more dynamic, turbid and rich in nutrients and at the same time less saline. For the other areas of Kuwait's waters, two different time periods were identified: the beginning of the year to May was characterized by higher nutrient concentrations and a decrease in salinity, which corresponds to higher river discharge, while the remainder of the year is characterized by lower nutrient concentrations and higher salinities.

There is a significant correlation among phytoplankton structure and physicochemical variables of Kuwaiti waters. The results suggest that salinity, turbidity and inorganic nutrient concentrations (inorganic nitrogen and silicate) were the main factors controlling changes in the phytoplankton community within the area examined.

Acknowledgements

We are grateful to Alan Lennox (Kuwait Institute for Scientific Research, Kuwait) for his effort in collecting the samples for this study, *in-situ* measurements of environmental variables and for his tremendous technical support. We also thank Hadeel Al-Mansori and Mariam Al-Enezi (Kuwait Institute for Scientific Research, Kuwait) who conducted the chemical analyses of the nutrient concentrations. Dr James Bishop (Kuwait Institute for Scientific Research, Kuwait) is thanked for editing the manuscript. We thank the Kuwait Institute for Scientific Research for funding this research project.

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