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Phytoplankton–zooplankton relations in three inland seas along the Qatari coast (Arabian Gulf)

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Phytoplankton and zooplankton community structures and abundance were studied in three inland seas around Qatar, two along the eastern coast and one along the northwestern coast. Despite some irregularities, the direct relationship between phytoplankton and zooplankton in both seasons indicates that despite of the oligotrophic nature of the inland seas and consequently the low diversity of species, the zooplankton community density is dependent, with different magnitudes, on the density of the phytoplankton community. Multiple regression analysis indicated that at the time where permissible pollution limits were not exceeded, salinity is the main factor controlling zooplankton distribution in the inland seas, followed by phytoplankton.

Keywords: Phytoplankton; Zooplankton; Inland seas; Qatar; Arabian Gulf

1. Introduction

The inland seas along the coastal waters of Qatar are unique shallow environments which developed as a result of ancient geological activities. Their geomorphology renders them as excellent nursery and feeding grounds for invertebrates and fish. One major importance of inland seas is their tourist attraction value; sites being visited by thousands of tourists and residents annually. They are surrounded by sand dunes, mangrove swamps or sabkhas. The inland seas around Qatar are subjected to pollutants that expose these areas to environmental stress.

Zooplankton not only acts as a secondary producer within the food chain but also as prey for larger marine organisms of economic value such as fish and shrimps. Meanwhile, their abundance and occurrence is not only associated with changes in the food supply (phytoplankton) but also with a combined effect exerted by hydrographic conditions and pollution stress.

In view of the efforts exerted by the Qatari government to protect and conserve the inland seas around Qatar and the future plans to declare them as protected areas, the present study

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aims to investigate the pelagic system of these sites including the composition of phytoplankton and zooplankton communities, their interrelation and the impact of environmental factors on their distribution and diversity.

2. Study area

Three inland seas, namely Khor Al-Odiad (site A) located at the southeastern coast, Khor Al-Dakhirah (site B) located at the northeastern coast and Khor Zikreet (site C) located at the northwestern coast of Qatar (figure 1), were chosen for this study. All the sites are relatively shallow semi-enclosed coastal water bodies with depths ranging 4.5–19 m for site A, 1–2.5 m for site B and 1.2–3.5 m for site C, during low tide. The environmental stress is more pronounced at site B mainly arising from over-fishing, pollution from small boat activities and jetty construction including associated dredging and filling. Conversely, site C is a medium-stressed environment suffering mainly from motor boat activity and tourism. Site A is subjected to increasing tourism activities (bathing, diving, sea-based watersports, etc.) and to a less extent to erosion of the banks due to high-speed currents.

3. Material and methods

During winter and summer seasons, five locations at site A, four at site B and four at site C were selected for sampling. Phytoplankton samples were collected using a 0.5 m diameter 67 μm mesh phytoplankton net. Zooplankton samples were collected using a 0.5 m diameter 120 μm zooplankton net. Plankton nets were fitted with digital flow meters as prescribed in MOOPAM [1].

Samples were collected during daytime and preserved in 4% buffered formalin in filtered seawater for quantitative and taxonomic studies. Three replicates of 1.0 ml sub-samples were defined and counted to observe taxa composition and organism abundance.

Water temperature, salinity, dissolved oxygen and pH levels were recorded during sampling using a YSI Model 6890 water quality logger. Samples for chlorophyll-*a* biomass determination (1 l) were collected, filtered using 0.45 μm membrane (47 mm diameter) filters precovered with 2 ml of 1% $MgCO_3$ and chlorophyll-*a* was determined using the 90% acetone extraction method [2]. Oil and grease in water was simultaneously collected during the sampling period and determined gravimetrically [3].

One way ANOVA was applied to test the difference in spatial patterns between means while correlations and cluster analysis were used to determine the affinities and main factors affecting the distribution of pelagic plankton. A diversity index (Shannon–Wiever) was calculated using individual counts.

4. Results and discussion

4.1. Water quality of inland seas

The water of the inland seas around Qatar is affected by and affects the coastal-water regime. Along the eastern coast, the northeastern area (site B) is subjected to current of relatively low salinity invading the Arabian Gulf from the Strait of Hormuz at the surface layer. The salinity

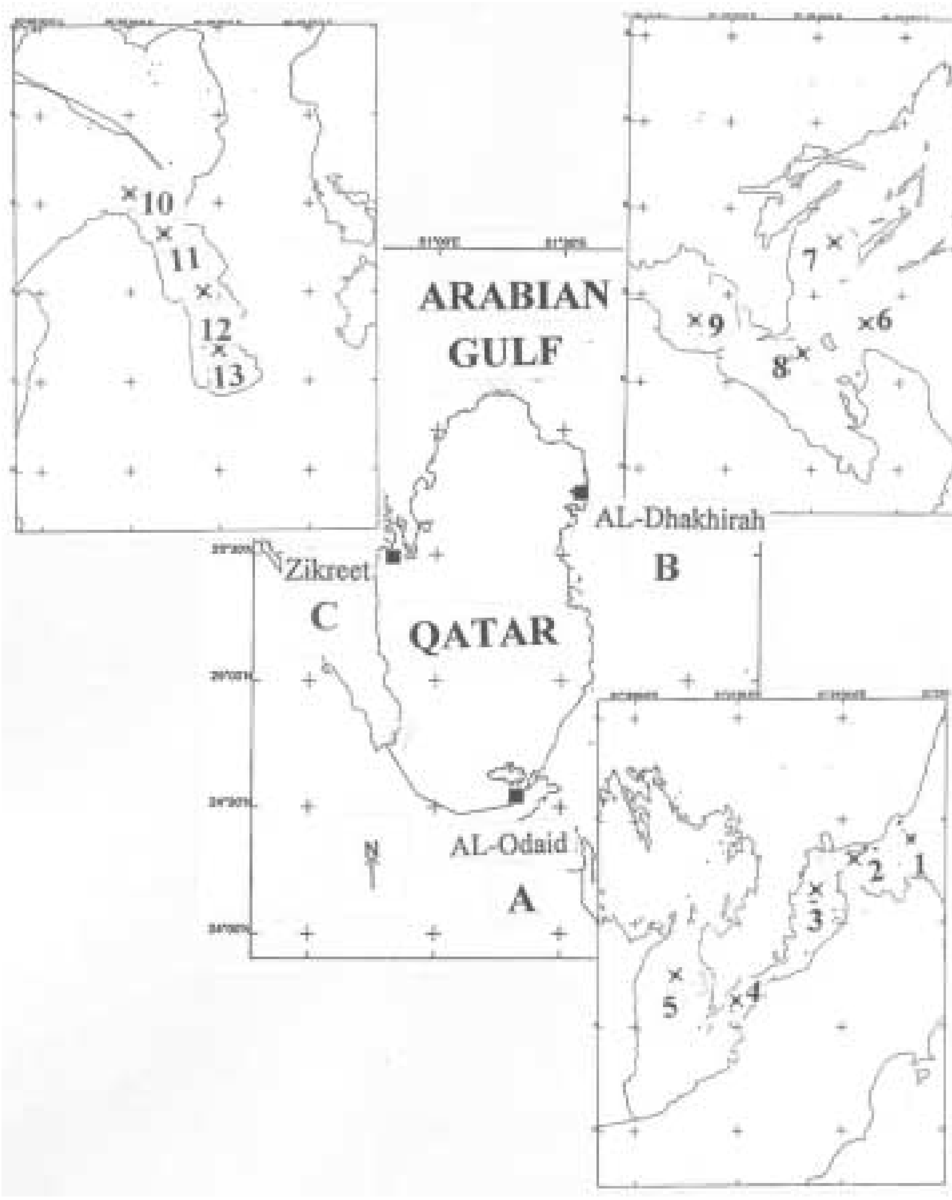

Figure 1. The State of Qatar showing inland seas and sampling sites.

of the coastal water of Qatar normally lies between 39 and 41 psu, increasing to 41.1–41.6 psu during winter and 43–44.8 psu during summer at site B. Flowing southward, the water current runs almost parallel to the coast line. Salinity increases south of Doha city lying between 44 and 45 psu. Approaching site C salinity gradually increases from the opening towards more shallower inner areas of the inland sea varying between 44.2 and 53.0 psu during winter and 45.4–55.4 psu during summer (table 1). Conversely, the western coast is affected by the current flowing along the western Gulf coast passing along the Saudi Arabian and Bahrain coasts, with an average salinity of 50 psu. Invading site C, salinity increases to 50.9–51.8 psu during the winter and 57–60 psu during summer (table 1).

The water temperature along the Qatari coast normally lies between 18 and 22°C during winter and 32 and 34°C during summer with some exceptions [4]. Similar ranges of temperatures were observed during the present study for all sites (table 1). During the period 1996–1998, water temperatures approached 38°C leading to massive fish mortalities and coral beaching. The shallowness of the sampled sites does not permit thermal stratification during summer.

Variations in pH level were not significant between different sites and even within the same site lying always between 8.1 and 8.4. pH [5].

Despite the high salinity, water at all sites is well oxygenated due to their shallowness and windy weather. Levels along the western coast were lower due to higher salinity, while within the eastern sites dissolved oxygen approached 7.2 and 7.5 mg/l for sites A and B, respectively.

All sites were considered to be nutrient poor where PO_4 and NO_3 levels were undetected at some sampling sites. This is caused by the lack of exposure to fresh water in addition to high salinity. Consequently, chlorophyll-*a* levels were low and undetected in most locations reaching a maximum of 2.5 μg/l at site B. This generally reflects the oligotrophic nature of the inland seas water. A chlorophyll-*a* gradient of decreasing levels was observed from the mouth of the inland seas inwards. This decrease in chlorophyll-*a* value is negatively correlated with the increase in salinity ($R^2 = 0.642$, $p < 0.005$ for site A; $R^2 = 0.841$, $p < 0.001$ for site B; $R^2 = 0.573$, $p < 0.010$ for site C). With respect to chlorophyll-*a* concentrations, site B is considered to be the most productive followed by A and C (table 1). The average chlorophyll-*a* for the EEZ of Qatar is 0.21 μg/l [5]. Chlorophyll-*a* values > 1 μg/l were intermittently recorded at the near shore area of the eastern coast. The near-shore northern and northeastern areas sustained low chlorophyll levels fluctuating between 0.7 and 0.48 μg/l [6]. Low salinity offshore waters invading the NE coast are relatively nutrient rich sustaining high chlorophyll-*a* concentrations (ranging 0.41–0.76 μg/l) [7]. Along the western coast of the Arabian Gulf, for a salinity ranging 38.01–42.32 psu, chlorophyll-*a* concentrations average was 1.02 ± 1.85 μg/l (ranging 0.014–9.57 μg/l) with higher levels near Shatt Al- Arab. Along the NE coast of Qatar, levels lay between 0.292 and 0.451 μg/l [8]. For 76 stations collected from the Gulf during August 2001, the surface chlorophyll-*a* concentrations ranged from 0.11 μg/l (offshore) to 1.46 μg/l (Kuwait inshore waters) with the mean of 0.38 μg/l [9].

Table 1. Range of hydrochemical parameters, chlorophyll-*a* and oil and grease measured for the inland seas around Qatar.

Sites/season		Parameters					
		Temperature (°C)	Salinity (psu)	pH	Dissolved oxygen (mg/l)	Chl.-*a* (μg/l)	Oil and grease (mg/l)
A	Winter	21.0–23.0	44.5–53.0	8.1–8.2	6.2–6.9	0.4–0.9	0.08–0.40
Al-Odaid	Summer	33.0–34.0	45.1–55.4	8.1–8.3	5.9–7.2	nd–0.7	0.04–1.17
B	Winter	21.8–22.5	41.4–41.6	8.2–8.3	6.1–6.4	0.7–2.5	nd–0.69
Dakhirah	Summer	33.0–34.7	43.0–44.8	8.1–8.3	5.2–7.5	1.0–1.6	0.04–0.37
C	Winter	18.9–19.7	50.9–51.8	8.0–8.2	5.3–5.4	0.2–0.3	0.04–0.38
Zikreet	Summer	33.2–34.7	57.0–60.0	8.1–8.4	5.7–6.8	nd–0.70	0.08–0.31

Negative correlation between chlorophyll-*a* and both NO_3 and PO_4 concentrations, though insignificant, indicate that phytoplankton in inland seas consume nutrients even in very low concentrations. Due to the evident recreation boats activities in the selected sites, oil and grease levels were chosen as an indicator of pollution. High levels were recorded near jetties, marinas or anchorage areas where considerable motor boat traffic was recorded. Intermittent spills were observed at the mouth of site A.

4.2. Phytoplankton community

Diatoms and dinoflagellates were the main phytoplankton groups recorded in all sites. Table 2 illustrates the numerical abundance (number of cells/l) recorded at each site. The main features of phytoplankton distribution are: (1) the decrease as one moves inland from sea mouths due to increasing salinity; (2) the significant decrease along the western coast (range 28 to 40×10^3 cells/l during winter and 8 to 11×10^3 cells/l during summer); and (3) a clear winter peak where temperatures are suitable (18 to 22 °C) for growth and production rather than summer conditions where cell density dropped to nearly one-third.

Different stations were compared using the one way analysis of variance (ANOVA) test to define regional differences in density distribution of phytoplankton between different sites. No significant difference appeared between the different stations of site B (probability at 0.05 level). Conversely, significant differences appeared between stations 4 and 5 and stations 1–3, all located at site A; the former being more close to stations 10–13 sampled at site C. The total phytoplankton cell numbers show a noticeable relationship with chlorophyll-*a* values ($R^2 = 0.6211$, $p < 0.01$ for site A; $R^2 = 0.8563$, $p < 0.002$ for site B; $R^2 = 0.4647$, $p < 0.02$ at site C).

The main phytoplankton community composition recorded during the present survey is displayed in table 3. A total number of 92 taxa of phytoplankton belonging to 68 diatoms, 22 dinoflagellates and 2 blue-green algae were recorded and identified during this study. Diatoms were the most frequently occurring taxa and were recorded in all samples. In terms of the relative distribution of phytoplankton groups, diatoms dominate (59–86%) followed by dinoflagellates (13–38%) whereas blue-green algae represents (0.9–2%). The majority of samples were dominated by diatoms notably by *Thalassionema nitchioides*, *Thalassiothrix frauenfeldii*, *Bacteriastrum hyalinum*, *Amphiprora eggregia*, *Amphora gigantea*, *Climacosphenia moniligera*, *Chaetoceros coarctatus*, *Licmophora longipes*, *Pleurosigma formosum*, *Rhizosolina imbricata*, *R. calcaravis*, *Ceratium furca*, *Melosira* sp. and *Nitzchia sigma* and the remaining samples were dominated by the common dinoflagellates *Ceratium breve*, *C. furca*,

Table 2. Numerical abundance of phytoplankton (X 10^3 cells/l) for inland seas around Qatar.

Sites	Season		Phytoplankton (no. cells/l)				
		Stations	1	2	3	4	5
A	Winter		283	229	181	93	25
Al-Odaid	Summer		87	83	56	40	11
		Stations	6	7	8	9	
B	Winter		412	370	182	178	
Dakhirah	Summer		193	216	109	133	
		Stations	10	11	12	13	
C	Winter		32	38	40	28	
Zikreet	Summer		11	10	9	8	

Table 3. Phytoplankton taxa in three inland seas around Qatar.

	Al-Odaid					**AL-Dakhirah**				**Zikreet**			
Phytoplankton	1	2	3	4	5	6	7	8	9	10	11	12	13
Diatoms													
Amphiprora eggregia	+	+	+			+	+	+	+				
Amphora gigantea				+	+	+	+	+	+		+	+	+
Amphora laevis	+					+	+	+					
A. cingulata						+	+	+	+		+		
Amphora lineolata	+	+	+			+	+			+			
Amphora sp						+	+	+					
Bacteriastrum delicatulum	+					+	+						
Bacteriastrum hyalinum				+	+	+		+	+	+	+	+	+
B. varians	+	+	+			+	+						
Biddulphia sp	+	+	+			+	+	+					
Camphylodiscus innominatus					+	+			+		+		
Camphylodiscus undulatus						+	+		+		+	+	+
Camphylodiscus sp						+		+					
Chaetoceros coarctatus	+	+	+			+	+	+	+	+	+		
Climacosphenia moniligera	+	+		+		+	+	+	+	+	+	+	+
Cocconeis placentula	+	+		+	+	+	+		+		+	+	
Coscinodiscus asleromphalus						+	+	+					
Coscinodiscus jonesianus	+	+	+		+	+		+					
Cyclotella sp													
Diploneis bombus						+	+	+	+	+			+
Diploneis crabro	+	+				+							
Diploneis splendia				+	+		+	+	+				
Entomoneis sp				+		+							
Guinardia flaccida						+			+				
Gymnodinium sp	+	+		+			+	+	+				
Gyrosigma hassal						+	+						
Gyrosigma spencerii	+	+				+	+	+		+			+
Hemialus sp													
Licmophora longipes						+		+		+			+
Lyrella clavata					+	+	+	+		+	+	+	+
Lyrella sp						+	+		+				
Leptocy lindrus	+	+				+	+						
Mastogloia quinquesostate				+	+	+		+	+		+		+
Mastogloia smithii							+	+		+	+		
Mastogloia sp						+	+		+		+	+	
Melosira sp		+	+	+				+	+				
Navicula elegams	+	+				+	+	+	+				
Navicula plagiotropis							+						
Navicula praetexta						+			+			+	
Navicula sp	+	+				+	+	+	+				
Nitzchia bilobata				+		+	+		+				
Nitzchia closterium						+	+	+	+				
Nitzchia insrgnis	+	+	+	+		+	+				+		
Nitzchia linearis							+	+	+				
N. longissima					+	+							+
N. Sigma							+				+	+	
N. ventricosa								+	+				

Table 3. *Continued.*

	Al-Odaid					AL-Dakhirah				Zikreet			
Phytoplankton	1	2	3	4	5	6	7	8	9	10	11	12	13
Plagiotropis lepidoptera						+	+			+			+
Planktoniella spp										+		+	
Pleurosigma formosum		+	+		+	+	+	+	+			+	+
P. itium						+	+	+	+			+	
Pleurosigma spencerii	+	+					+	+	+				
Pleurosigma sp		+		+		+			+	+	+		
Stephanopyxis palmeriana						+	+	+	+				
Striatella sp						+	+	+	+			+	
Surirella fatuosa						+				+	+		
Surirella sp	+	+	+				+	+					
Rhabdonema arcualum					+	+	+		+	+			+
Rhizosolina imbricata	+	+	+			+	+	+		+	+	+	
R. calcaravis	+	+	+			+	+	+	+				
R. cochlea	+	+				+		+					
R. bergonii					+		+						
R. Robusta						+		+	+				
R. seriata										+		+	
Tabellari afenestrata						+	+	+					
Thalassionema nitzchioides				+	+	+	+	+	+	+	+	+	+
Thalassiothirx frauerfeldii	+	+	+	+		+	+	+	+	+		+	
Triceratium fuvus										+		+	
Dinoflagellate													
Ceratium extensum				+	+					+	+		
C. breve	+	+	+			+	+	+	+	+		+	
C. furca	+	+				+	+	+	+	+	+		
C. fusus	+	+	+			+	+	+	+			+	+
C. lineatum	+	+	+										
C. trichoceros							+	+	+				
C. massiliense						+	+		+	+	+	+	
C. kofoidi	+	+	+										
C. pennatum				+									
C. trichoceros				+				+					
C. tripos							+		+				
Dinophysis miles						+	+	+	+				
D. caudata	+	+	+			+	+	+	+				+
Peridinium depressum	+	+				+							
P. mediterraneum							+	+	+				
P. pentagonum			+			+							
Phalacroma rapa				+	+					+			
Prorocentrum gracile							+	+					
P. triestinum				+		+	+	+	+	+	+		+
P. micans	+	+	+				+						
P. sigmoides							+	+	+		+	+	+
Pyrophacus horologicum									+				
Blue green algae													
Oscillatotia thiebauti						+	+	+	+				
Trichodesmium sp						+		+					

C. fusus and *Prorocentrum triestinum*. The blue-green algae were represented only by *Oscillatoria thiebauta* and *Trichodesmium* sp. which appeared only in Dakhirah inland sea.

In site A, *Thalassiothirx frauerfeldii* was the most dominant diatom species forming 33.1% followed by *Thalassionema nitzchioides* and *Bacteriastrum delicatulum* with 11.5% and 10%, respectively. However, for site B, the dominant diatom was *Chaetoceros coarctatus* forming about 20% of the community followed by *Melosira* sp. yielding (12.5%), *Amphora gigantea* (8.1%) and *Nitzchia insrgnis* (6.6%); whereas *Climacoshenia moniligera*, *Thalassionema nitzchioides* and *Lyrella calavata* in site C, represents 52%, 33% and 21%, respectively. Other important constituents of the genera such as *Cocconeis placentula, Amphora lineolata, Bacteriastrum hyalinum, Cocconeis placentula, Gyrosigma spengerii, Mastogloia quinquesostate, Pleurosigma formosum, Rhabdonema arcualum* appeared in the three sites (table 3). However, many species ex: *Amphiprora eggregia, Bacteriastrum varians, Biddulphia* sp., *Leptocylindrus, Melosira spp., Pleurosigma spencerii, Surirella* sp., *Rhizosolina calcaravis* and *R. cochlea* appearing in sites A and B disappeared completely from site C and inner parts of site A, indicating their inability to withstand elevated levels of salinity exceeding 45 psu.

During summer 2000, a total of 17 phytoplankton taxa belonging to four dinoflagellates, 11 diatoms and two blue-green algae were recorded for the inner Arabian Gulf samples [9]. The dinoflagellates, *Ceratium* and *Pyrodinium* were the most frequently occurring taxa and were recorded in 91 and 98% of samples, respectively; both species are considered toxic or nuisance algae. Other important phytoplankton belongs to the diatom taxa, *Synedra* and *Coscinodiscus*. During 1992, samples from the NE coast of Qatar showed a bloom of *Chaetoceros coarctatus* representing 34.4% of the diatoms community; the same species was also blooming near Bahrain constituting 55.2% [8]. The same species is significantly represented at site B constituting between 18 and 21% of the community.

The maximum number of phytoplankton species observed during the present study was recorded at site B (48–62 species) compared with site A (15–31 species) and site C (18–24 species) (table 3). The variation within each inland sea was governed by the varying salinity levels and exposure to by-products of man-made activities. Station to station variations were limited at site B but more pronounced at site A where salinity varied between 44.2 and 45.1 psu at the inland sea–coastal waters interface and 53–55.4 psu at the inner inland sea region. Meanwhile, comparison of Shannon–Weaver diversity indices (H') showed that the diversity of species decreased from site B (2.8) to site A (1.8), which insignificantly ($p < 0.003$) vary from site C (1.6).

The dendogram (figure 2) shows that according to the phytoplankton appearance in the different inland seas around Qatar, stations are clustered into two main groups. Group A constituting of stations 1, 2 and 3 with stations 1 and 2 forming a subgroup of high similarity. Group B contains the rest of the stations and is subdivided into three subgroups; the first including stations 6–9 all sampled at Site B showing the highest similarities compared to the other two subgroups. The second including stations 10–12 (outer stations of site C). The third subgroup constitutes stations 4 and 5 (located in the inner part of site A) and station 13 (located at the inner region of site B). The dendogram shows that the clustering and similarity between phytoplankton communities between the inland seas depends mainly on salinity distribution with species showing high salinity tolerance clustered together.

4.3. Zooplankton community

The variability observed in terms of the relative distribution or in the total count of phytoplankton groups appears to follow changes in zooplankton populations. The zooplankton

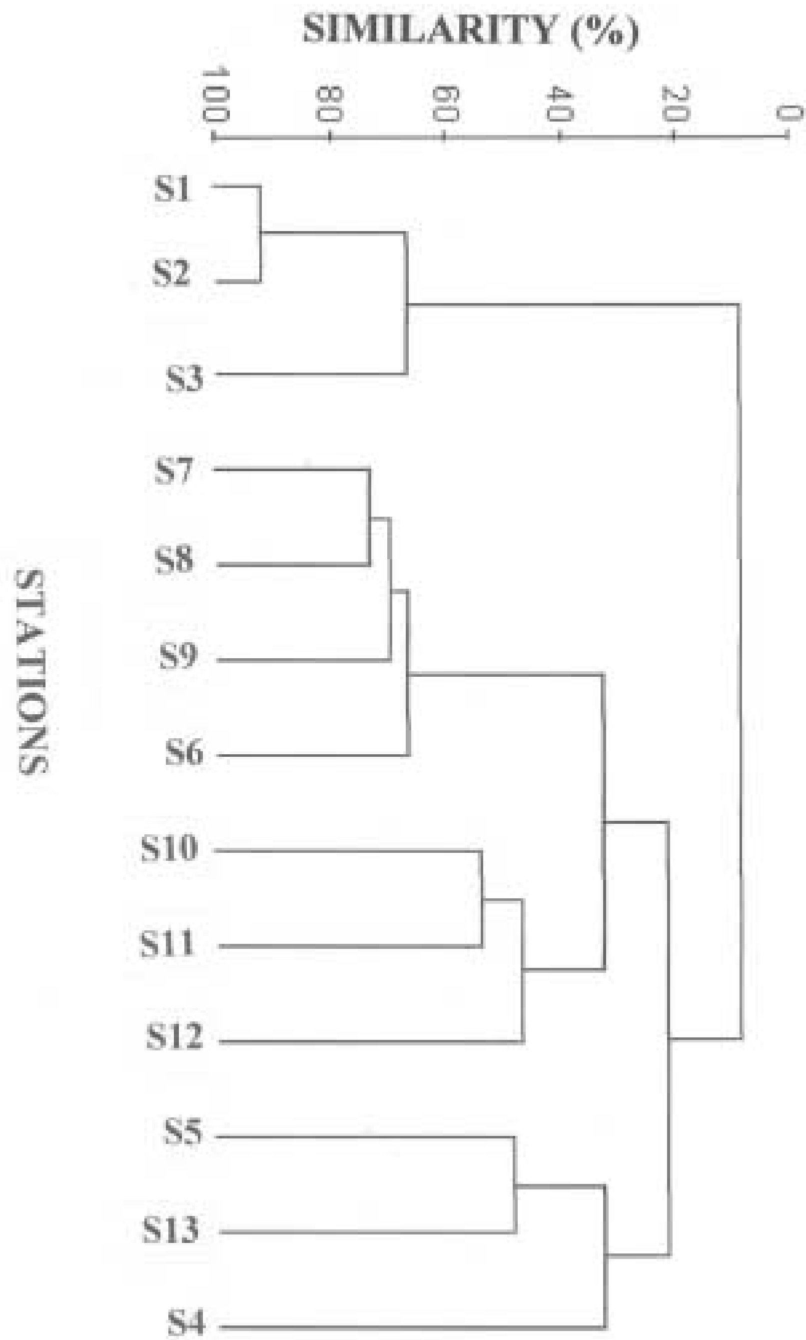

Figure 2. Cluster dendogram showing similarities between sampling stations according to phytoplankton species composition.

community in the inland seas around Qatar is dominated by copepods constituting on average about 70% of the total population. The highest density of zooplankton was observed at site B reaching 6500 organisms/m^3 at the entrance of the sea (table 4). Site C is characterized by noticeably low densities of zooplankton (ranging 79–98 organisms/m^3 in summer and 187–270 organisms/m^3 during winter) probably affected by the high salinity values. The inner stations of site A were also affected by high salinity lowering the zooplankton population density to 110 and 36 organisms/m^3 during winter and summer, respectively, corresponding to 53 and 55.4 psu, respectively (table 4). The average zooplankton standing stock along the coastal waters of Qatar was 1896 organisms/m^3 [6] for samples collected 1994. The Gulf, including Qatari waters, apparently follows the Indian Ocean's seasonal frequency of zooplankton population where significant enlargement of the community occurs during the winter Mansoon [10]. Dorgham and Hussien [11] reported that higher densities of zooplankton community are associated with low salinity values (38.4 psu) recorded off the Capital Doha and the offshore waters of the Gulf coming from Hormuz, characterized by better levels of available nutrients and chlorophyll-*a*. During Ghods Cruise organized by the Regional Organization for the Protection of the Marine Environment (ROPME) during the summer of 2002 covering the entire Gulf, 66 genera of zooplankton were recorded among which the dominant group was the copepods (particularly cyclopoids and calanoids) and Chaetognatha [9]. Copepods form 74% of the zooplankton community followed by bivalves (7.6%) and gastropod veligers (5.5%), ostracods (4.7%) and cladocera (3.4%) opposite to Mesaieed Industrial City located 15 km north of site A [12].

Eight copepod species form the bulk of the copepod population: *Oithona nana*, *Acartia clausi, Paracalanus parvus, Labidocera wallastoni, Euterpina acutifrons, Temora discaudata, Acartia negligens* and *Oncea conifera*. The remaining species were comparatively less represented in the samples. Calanoids representing on average 44% of the copepod community (14 species) followed by cyclopoids (representing 31% of total copepods with 28 species) dominated during both seasons. These results are in agreement with those of Yamazi [13] and Michel *et al*. [14]. Harpacticoids (25% of total copepoda) were represented by five species namely: *Microstella norvegia, M. rosea, M. gracilis, Euterpina acutifrons* and *Tigriopus* sp. Along the Gulf, copepods normally accounted for 60–83% of the total zooplankton community [15]. Nour El-Din and Abdel-Moati [16] observed that among

Table 4. Numerical abundance of zooplankton (no. organisms/m^3) for inland seas around Qatar.

Sites	Season		Zooplankton (organims/m^3)				
		Stations	1	2	3	4	5
A	Winter		3720	2165	1385	872	110
Al-Odaid	Summer		1036	950	622	560	36
		Stations	6	7	8	9	
B	Winter		6500	5043	4180	3700	
Dakhirah	Summer		3412	3200	1950	2030	
		Stations	10	11	12	13	
C	Winter		270	187	205	120	
Zikreet	Summer		90	98	79	82	

copepods, calanoids composed 42% followed by cyclopoids 36% and harpacticoids 22% of the total copepod community. They observed that the most abundant calanoid species along the Qatari coastline during 1998 were *Paracalanus crassirostris* and *P. aculeatus* while *Oithona nana* and *Oncea conifera* were the most abundant cyclopoids and *Euterpina acutifrons* is the dominant harpacticoid. For the 1994 samples collected off Qatar, *Paracalanus* sp. was the most dominant calanoid followed by *Acartia* sp. and *Temora* sp. [6] while *Oithona* sp. and *Oncea* sp. and *Euterpina* spp. dominated cyclopoids and harpacticoids, respectively.

Copepod species such as *Temora longicornis, Centropagus typicus, Paracalanus nanus, Pleuromamma* sp. and to a lesser extent *Acartia clausi* (calanoids), *Oncea conifera* (cyclopoid) and *Tigriopus* sp. (harpacticoid) showed a tendency to withstand elevated salinity levels. Meanwhile, other zooplankton taxa such as Noctiluca, Foraminefera, Tintinnida, Polychaete and Cirripid larvae, Gastropod and bivalve veligers, Appendicularia and to a less extent Ascidiacea showed also a similar trend.

Similar to phytoplankton, the diversity of zooplankton (number of species or genera recorded in each site) were at their maximum at site B varying between 29 and 39. A clear decline in the number of genera was observed along the inner region of site A, reducing to 13 species at station 5, characterized by high salinity (table 5) compared to 25–33 species in the outer region, which is in direct connection to the coastal waters and slightly exposed to oil pollution. The minimum number of species was observed at site C (between 8 and 10). The Shannon–Weaver diversity index (H′) for zooplankton species calculated for site B (H′ = 2.6) was high when compared to sites A (H′ = 2.0) and C (H′ = 1.7).

Examining the relationships between stations with respect to their zooplankton community structure, two main groups of stations were characterized from the cluster dendogram (figure 3). Group A consisted of two subgroups of stations the first comprising highly saline stations 4 and 5 (inner region of site A) and station 12 (site C) while the second group consisted of stations 10 and 13 (both located at site C). The other group is divided according to similarity to three subgroups with different similarity levels; the first comprising stations 1 and 2 (outer region of site A, directly contacted with the coastal waters) while the second comprising stations 6–9 (all located at site B) both showing 70–80% similarity. Forming a separate second subgroup, stations 3 and 11 show similarity at the 30% level but clustered with those of low salinity stations (figure 3).

4.4. Phytoplankton–zooplankton interrelation

The relationship between phytoplankton and zooplankton communities in the three inland seas is presented in figures 4 and 5. Despite some irregularities, the direct relationship between phytoplankton and zooplankton in both seasons indicates that despite the oligotrophic nature of the inland seas, and consequently the low diversity of species, the zooplankton community density is dependent, with different magnitudes, on the density of the phytoplankton community. The relationship is more pronounced in winter ($R^2 = 0.8901$, $p < 0.002$) rather than summer ($R^2 = 0.7526$, $p < 0.013$). Individual relations within each inland sea shows that the highly significant correlation for site B in both winter ($R^2 = 0.8730$, $p < 0.004$) and summer ($R^2 = 0.7674$, $p < 0.011$) seasons, is the factor affecting the general trend. Correlations with the other sites are less significant due to variable salinity levels within the same inland sea, especially site A in winter ($R^2 = 0.4013$, $p < 0.112$) and summer ($R^2 = 0.3367$, $p < 0.157$). Regression equations for the phytoplankton–zooplankton relationship showed that in absence of phytoplankton, the zooplankton community would still exist with a higher magnitude in

Table 5. Zooplankton taxa in three inland seas around Qatar.

	Al-Odaid					AL-Dakhirah				Zikreet			
Zooplankton	1	2	3	4	5	6	7	8	9	10	11	12	13
Noctiluca	+	+	+	+	+	+	+	+	+			+	+
Foraminifera			+			+			+	+	+		
Tintinnida	+	+	+	+	+	+	+	+	+		+		
Radiolaria						+		+	+				
Siphonophora						+		+					
Medusae							+	+					
Ctenophora						+	+		+				
Chaetognatha	+	+						+	+				
Polychaeta larvae	+	+		+	+	+	+	+	+			+	+
Cladocera						+							
Ostracoda						+		+	+				
Cirriped larvae				+	+					+			+
Copepoda													
A-Calanoidae													
Acartia clausi	+	+	+			+	+	+	+	+	+		
A. negligens	+					+		+	+				
A. discaudata	+	+				+	+	+	+				
Temora longicornis					+					+		+	
T. stylifera	+	+				+	+	+	+				
Centropages furcatus					+							+	
C. typicus				+	+			+		+			+
Paracalanus aculeatus	+	+	+			+	+	+	+				
P. nanus					+						+		+
P. parvus	+	+				+	+	+	+				
Clausocalanus arcuicornis	+	+				+	+	+	+				
C. furcatus							+						
Labidocera wallastoni	+	+	+			+	+	+	+				
Pleuromamma spp.	+	+		+				+	+		+		
B- Cyclopoidae													
Oithona nana	+	+				+		+	+				
O. plumifera	+	+				+	+	+	+	+			+
O. setigra						+							
Corycaeus conifera						+	+		+				
C. flaccus	+		+			+	+	+	+				
C. limbatus	+					+			+				
Oncaea conifera	+	+				+	+	+	+				
O. venusta				+	+							+	
C- Harpacticoidae													
Microsetella norvegica	+	+	+			+	+	+	+				
M. rosea						+	+						
Macrosetella gracilis	+	+				+	+	+	+				
Euterpina acutifrons	+		+			+	+	+	+				
Tigriopus spp.				+	+						+		+
N. larvae of Copepoda	+	+	+	+	+	+	+	+	+			+	
Copepodite stages	+	+	+	+	+	+	+	+	+	+	+		

Table 5. (*Continued*).

	Al-Odaid					AL-Dakhirah				Zikreet			
Zooplankton	1	2	3	4	5	6	7	8	9	10	11	12	13
Mysis larvae		+						+	+				
Zoaea larvae	+						+						
Mollusca													
a- Gastropod veligers	+	+		+		+	+	+	+	+		+	
b- Bivalve veligers	+	+		+	+	+	+	+	+		+	+	+
c- Pteropoda	+		+			+		+	+				
d- Cephalopoda	+					+			+				
Echinodermata larvae	+	+				+							
Appendicularia	+		+	+		+	+	+	+	+		+	
Thaliacea						+		+					
Ascidiacea	+	+		+								+	
Fish eggs	+	+	+			+	+	+	+				
Fish larvae	+					+		+					

winter than summer, indicating that the abundance of the zooplankton community could be dependent on other food sources or could withstand environmental conditions in absence of phytoplankton.

A multiple stepwise regression model was used to show the impact of the different water quality parameters on the phytoplankton–zooplankton communities. The regression for the phytoplankton as an independent variable was:

phytoplankton (cells/l) = 128.4 − 22.4 salinity (psu) − 6.14 temperature (°C) + 0.94 oil and grease (mg/l) + 0.12 DO (mg/l) – 0.008 pH + 0.007 NO_3 (μM/l) ($R^2 = 0.6673$, $p < 0.05$)

while for zooplankton the multiple regression equation was:

zooplankton (organisms/m^3) = 43.6 + 1.55 salinity (psu) + 16.9 phytoplankton (cells/l) – 5.08 oil and grease (mg/l) + 0.29 temperature (°C) + 0.09 DO (mg/l) ($R^2 = 0.7173$, $p < 0.05$)

indicating that salinity is the main factor controlling both phytoplankton and zooplankton distribution in the inland seas surrounding Qatar. Oil pollution is also a common factor especially at the inland sea–coastal water interaction zone and sites for anchoring speed boats used for recreation purposes. Although nutrient concentrations are not highly influential in the distribution of phytoplankton, especially PO_4, which is insignificant to enter in the equations, food represented by phytoplankton density governs to a great extent the zooplankton distribution. Other factors such as dissolved oxygen appeared in both equations as they are inversely related to high salinity levels. Nour El-Din and El-Khayat [12] stated that in a stressed area, pollution levels were found to have a greater effect on the zooplankton community structure rather than to reduce food sources. This is not the case in the present study since natural factors such as salinity variations dominate more and the permissible pollution limits were not exceeded.

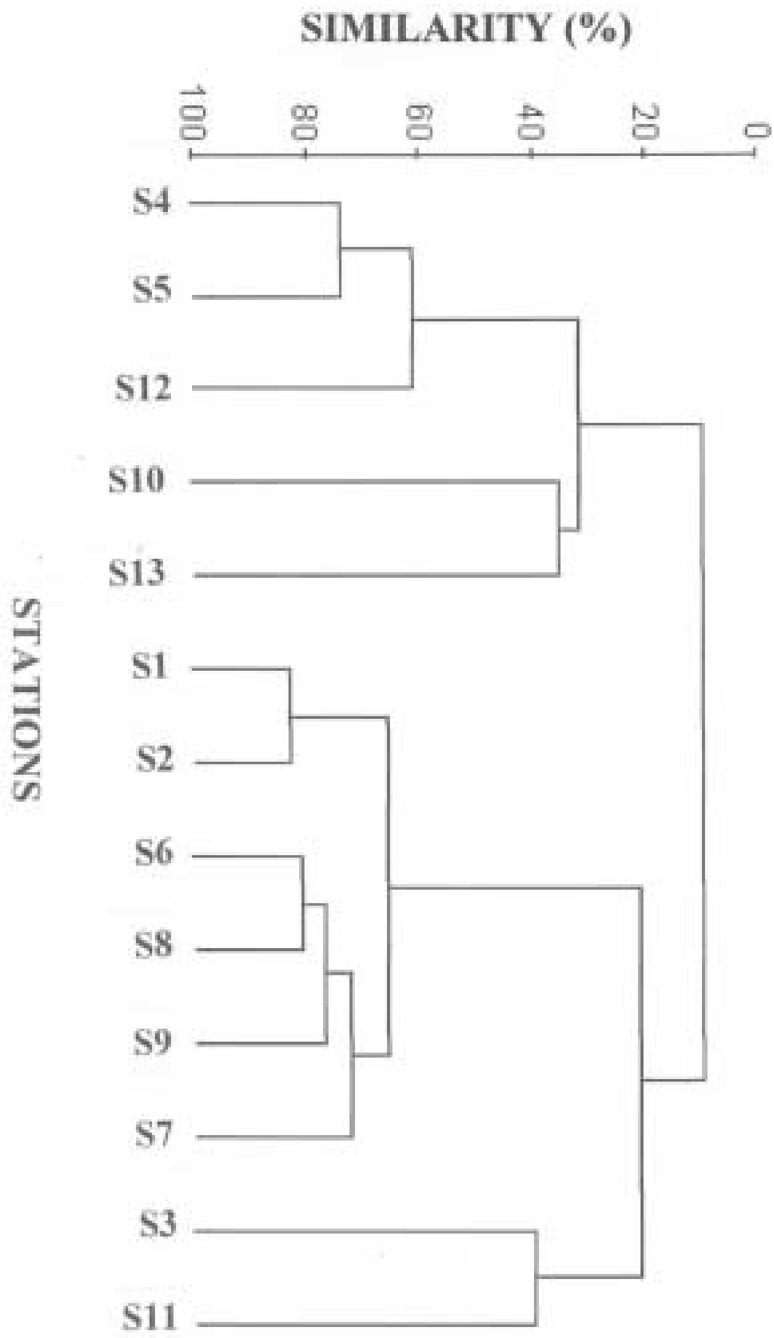

Figure 3. Cluster dendogram showing similarities between sampling stations according to zooplankton species composition.

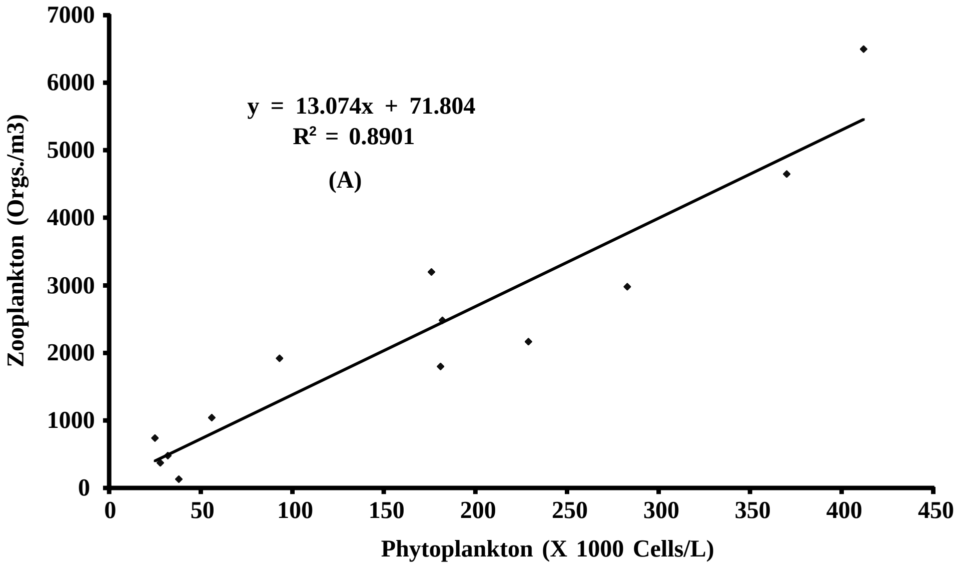

Figure 4. Phytoplankton–zooplankton relationship in inland seas during winter.

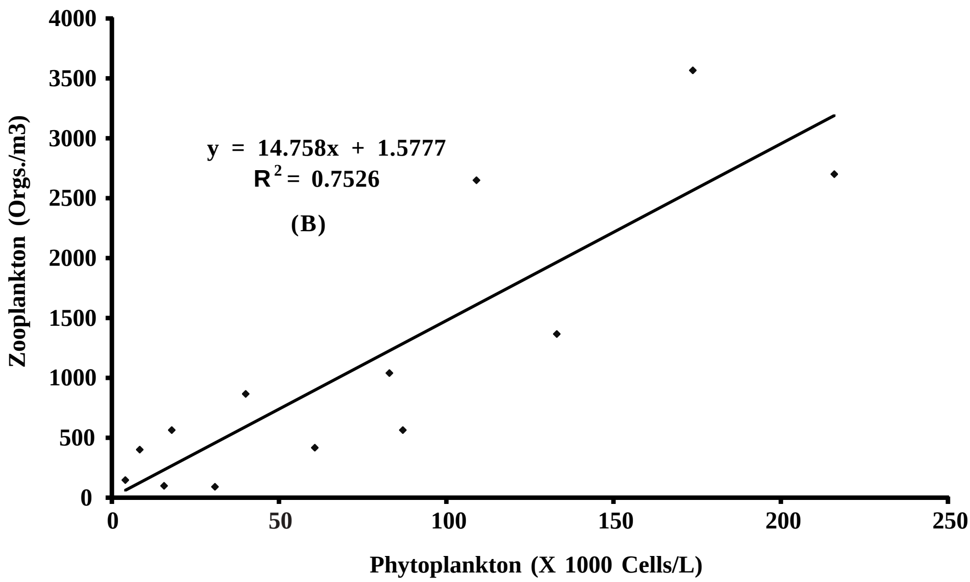

Figure 5. Phytoplankton–zooplankton relationship in inland seas during summer.

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