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ENVIRONMENTAL CONDITIONS AND PHYTOPLANKTON DISTRIBUTION IN THE ARABIAN GULF AND GULF OF OMAN, SEPTEMBER 1986*

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Abstract

The present study is concerned with the environmental conditions and the characteristics of the phytoplankton population during September 1986 in the Arabian Gulf and the Gulf of Oman.

Marked regional variations were observed in the physical and nutritional conditions of the surface waters. Due to the impact of the surface current from the Gulf of Oman the surface salinity decreased markedly in a significant part of the Arabian Gulf. The concentrations of nutrients were higher in the Gulf of Oman than in the Arabian Gulf. Water circulation in the latter region is complicated and effects the distribution of the nutrients and phytoplankton.

During September 1986 the Arabian Gulf was characterised by a higher phytoplankton standing crop than the Gulf of Oman with an average cell count of about 9 folds greater. Chlorophyll showed clear zonation in the whole area, but it was higher in the Arabian Gulf.

The possibility of phytoplankton penetration from the Gulf of Oman into the Arabian Gulf is recognised. Toxic dinoflagellates were recorded sometimes in large numbers at several stations in the Arabian Gulf.

Introduction

The Arabian Gulf (AG) and the Gulf of Oman (GO) are two different habitats from several ecological points, particularly depth, temperature, salinity and nutrients. However, water exchange between them takes place through the Straits of Hormuz. The high saline, water of the AG flows out to the GO at depth, whilst the low saline water of the GO flows into the AG in the surface layers. Both types of water extend a significant distance from the Straits of Hormuz (Brewer and Dyrssen, 1985 ; El-Samra and El-Deeb, 1987). The water of the AG is completely exchanged every 3 years (Koske, 1972). These conditions lead to the formation of a transition area through the Straits of Hormuz with gradual change in the surface salinity. Such changes increase the possibilities of the immigration of the planktonic organisms, mostly epipelagic forms into the AG and consequently increase the number of its indigenous species.

Although phytoplankton of the northwest AG has been studied by several authors (Al-Matter and Al-Khars, 1978 ; Huq *et al.*, 1978 ; Jacob, 1979 ; Jacob and Zarba, 1979, 1980 ; Jacob *et al.*, 1979a, b, 1980 ; Jamal and Pavlov, 1979 ; Dorgham *et al.*, 1987), little is known about the southwestern part of the AG and the GO. Several cruises have been carried out either to the AG or/and GO ; International Indian Ocean Expedition (1959-1965). USS *Requisite* (1960, 1961), *Meteor* (1965) and *Umitaka Maru* R/V of Tokyo University (Dec. 1968). However, they provided little infor-

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mation on the plankton within the current study area. A few scattered works have been published (Bohm, 1931 ; Al-Kaisi, 1976 ; Grasshoff, 1976) which include information on the phytoplankton in this area.

The present study is an attempt to increase knowledge of the phytoplankton in the AG and GO, using R/V '*Mukhtabar Al-Bihar*' of Qatar University. The cruise commencing on the 3-9-1986 from Doha port Qatar, worked 44 hydrographic stations arranged in 14 sections between latitude 23° 43' & 26° 26' and longitude 51° 10' & 58° 36' (Fig. 1).

the uppermost 50 cm of the surface water. Qualitative hauls were made by towing a fine net (55 μm mesh size and 50 cm diameter) for 5 minutes behind the R/V at a speed of 2 nautical miles/h. Water samples of one litre for the cell count and chlorophyll measurements were collected by two litre Niskin bottle. For preservation of the net and cell count samples 4% neutralised formalin was used. The samples for chlorophyll extraction were filtered on millipore filter (0.45 μm) immediately after the collection and 0.2 ml of 1% suspension of $Mg\ CO_3$ added and kept in the freezer at —20°C.

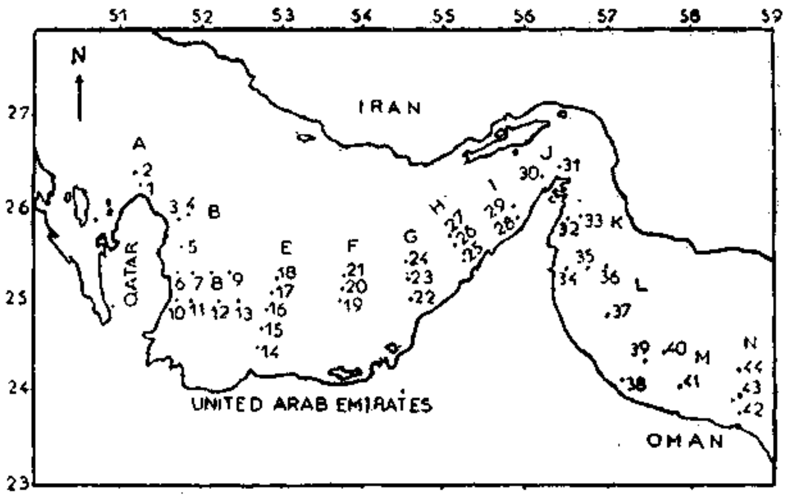

Fig. 1. The arrangement of the sampling stations in sections (A, B, C....) along the study area in September 1986.

Material and Methods

The present study deals with the environmental conditions and phytoplankton in the surface waters of the area investigated. The samples for study of the physical and chemical parameters and phytoplankton were collected concurrently. The collection and analyses of the pH, salinity, dissolved oxygen and nutrient salts were carried out by Dr. El-Samra and El-Deeb, marine chemists in the Marine Sciences Department, Qatar University. The phytoplankton samples were collected from

Identification of the different phytoplankton species was done using an inverted microscope (Van Heurck, 1896 ; Lebour, 1925 ; Hustedt, 1930-1966 ; Cupp, 1943 ; Kisselev, 1950 ; Hendey, 1964 ; Shirota, 1966 ; Sournia, 1967, 1968 ; Taylor, 1976 ; Dodge, 1982 ; Dowidar, 1983).

Phytoplankton counts are expressed as cell l^{-1}, whilst Cyanobacterians, *Trichodesmium* and *Anabaena* spp. are expressed as filaments l^{-1}. The extraction and measurements of chlorophyll were made following Strickland

and Parsons (1972) using the SCORE/UNESCO equation.

Results

Environmental characteristics

Physical conditions : The temperature, pH and dissolved oxygen data are presented in Table 1, whilst salinity is shown in Fig. 2 (El-Samra and El-Deeb, 1987). The surface water in the AG was slightly warmer than in the GO. It ranged from 30.4° C to 34.6° C in the AG and from 29.8° C to 31.9° C in the GO.

The pH values indicated higher alkalinity in the AG regardless of the wider range of its variations in the GO. This may be attributed to the high photosynthetic activity of the phytoplankton in the former region. In the Straits of Hormuz pH was lower than in either Gulfs.

The average concentration of the dissolved oxygen was lower in the AG than in the GO and highest average oxygen concentrations were found in the Straits of Hormuz.

The distribution of the surface salinity in the study area demonstrates the penetration

Table 1. *Temperature, pH and oxygen ranges in the different regions of the study area, September 1986*

		Temp. (°C)	pH	Dissolved O_2 (ml/l)
Qatari water	..	31.5—34.6	7.74—8.59	2.99—3.76
UAE Water	..	30.4—34.2	7.78—8.06	3.19—4.37
Straits of Hormuz	..	—	7.67—7.97	3.94—4.29
Gulf of Oman	..	29.8—31.9	7.57—8.57	2.98—4.06

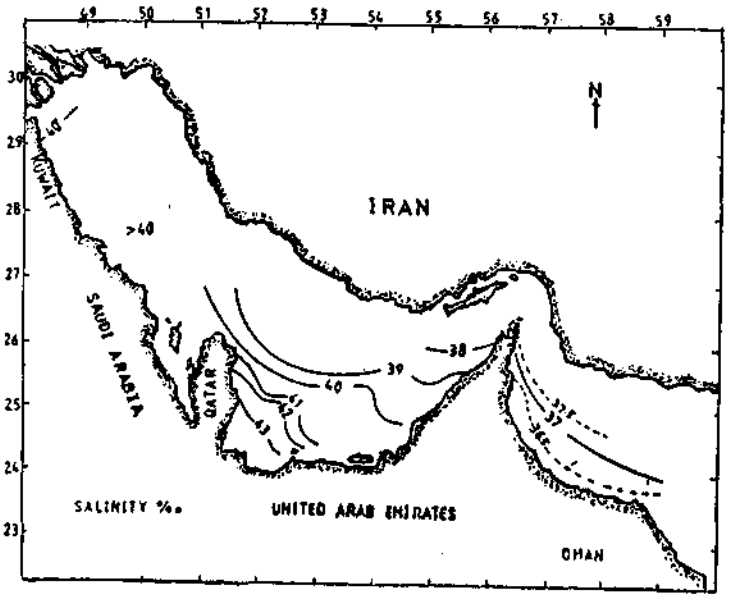

Fig. 2. Surface distribution of the salinity in the study area in September 1986 (Source : El-Samra and El-Deeb, 1987).

of GO water during September to a marked distance in the AG, particularly along its longitudinal axis. This water may sometimes reach the southern part of the United Arab Emirates Coast. However, the salinity of Qatari water and northern part of UAE Coast ranged from 41 to 43‰ especially inshore. The surface salinity of the proper Indian Ocean water in the GO region was 36.5 ‰, while in the Straits of Hormuz it showed an intermediate values varying from 37.5 ‰ to 38.0 ‰.

The water circulation in the study area was not studied during the present study. However, the available published works included some data about the current regime in the AG. Two types of water motions, according to Hunter (1986), occurred in the AG; the tidal and residual. The AG exhibits both diurnal and semi-diurnal oscillations driven primarily by tidal energy propagating through the Straits of Hormuz from the GO. The residual motion of the water is driven either by wind or density, both of which are often variable. The same author proposed that water circulation in the AG is dominated by density driven currents, and it is probable that the surface inflow from the GO is concentrated on the Iranian side of the AG, while bottom outflow is concentrated on the other side of Qatar, Saudi Arabia and UAE. However, the wind driven currents may be varied in direction and velocity in relation to the prevailing wind system. All types of water motions occurring in the AG are exposed to diurnal as well as seasonal variations. Such variations may create a complicated system of water circulations in the AG, which inturn affect the distribution and transportation of the plankton in the gulf. Grasshoff (1976) assumed that a complex system of eddies of different scales with a high degree of variability exists in the AG, especially in the part between Qatar and the Straits of Hormuz.

Nutritional characteristics : As shown in Table 2 the nutrient contents subjected to significant variations in the study area. In general, the nutritional conditions in the GO were much better than in the AG. The average concentrations of phosphate as well as ammonia and nitrate in the GO were mostly twice those in the AG, while nitrite content was lower in the GO. The dissolved Si in the latter region was slightly greater than in the AG. Exceptionally high concentrations of the different nutrients were detected at St. 34 in the GO, where phosphate concentration was 1.94 μg at/l^{-1}, nitrate 11.60 μg at/l^{-1} and dissolved Si 18.63 μg at/l^{-1}. These values were excluded from the computation of average concentrations. On the other hand, the variations in the nutrient contents showed

TABLE 2. *The ranges and averages of the nutrients in different regions of the study area* (μg at/l^{-1}) *September* 1986

	Phosphate	Ammonia	Nitrite	Nitrate	Dissolved Si
Qatari water ..	0.03—1.23	0.00—0.23	0.00—0.16	0.12—0.90	0.66—5.12
Average ..	0.25	0.044	0.035	0.27	2.327
UAE water ..	0.00—0.56	0.00—0.34	0.00—0.05	0.13—0.40	0.57—4.85
Average ..	0.17	0.052	0.02	0.213	2.992
Straits of Hormuz ..	0.23—0.49	0.03—0.10	0.01—0.05	0.15—0.23	0.39—0.99
Average ..	0.36	0.065	0.03	0.19	0.69
Gulf of Oman ..	0.19—0.79	0.00—0.35	0.00—0.05	0.12—0.59	1.62—5.48
Average ..	0.394	0.096	0.012	0.386	3.071

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Pattern ii														
Ch. compressum	+	+	+	+	+	+	+	+	+	+	+			
Thalassionema nitzschioides	+	+	+	+	+	+	+	+	+	+	+			
Ch. decipiens	+	+	+	+	+	+	+	+		+				
Streptotheca tamesis	+	+	+	+	+	+	+	+		+	+			
R. fragilissima	+	+	+		+	+	+	+	+	+	+			
N. lorenziana	+	+	+	+				+	+	+	+			
R. pungens	+	+	+	+					+	+	+			
C. laeve	+	+	+		+			+	+	+				
Ethmodiscus gazellae						+		+	+	+	+			
Ch. distans								+	+		+			
Pattern iii														
Diploneis crabro	+	+	+	+	+	+	+	+						
Pl. angulatum	+	+	+	+	+	+	+	+						
B. thuomeyi	+	+	+	+	+	+	+	+						
Ch. teres		+	+	+	+	+	+	+	+					
Navicula wawrikae		+	+	+	+	+	+	+						
Ch. affine		+	+	+	+	+	+	+						
N. sigmoidea	+	+	+	+	+		+	+						
N. sigma v. *intercedens*	+	+	+	+	+		+	+						
Paralia sulcata	+	+	+	+	+		+	+						
Amphora ovalis	+	+	+	+	+		+	+						
A. ostrearia	+	+	+	+	+		+	+						
Diploneis bombus	+	+	+	+	+		+	+						
T. curvata	+	+		+	+	+	+							
Leptocylindrus minimus	+	+	+		+	+	+							
Surirella fastuosa	+	+	+	+	+		+							
Ch. breve	+	+	+	+	+		+							
Ch. convolutum		+	+		+	+	+	+						
Ch. laciniosum		+	+	+		+	+	+						
Amphiprora alata		+	+	+	+			+						
Ch. danicum		+			+		+		+					
Hydrosilicon mitra	+	+	+	+	+									
Pl. acutum	+	+	+	+	+									
B. aurita	+	+	+	+	+		+							
B. mobiliensis	+	+	+		+			+						
Bacillaria paxillifer	+	+	+	+	+			+						
Rh. styliformis	+	+	+	+				+						
Ch. pseudocurvisetum		+	+		+		+	+						
Ch. atlanticum					+	+		+	+					
Amphora ostrearia	+		+	+	+									
Campylodiscus decorus	+	+	+		+									
Climacosphenia moniligera	+	+			+									
Ch. lauderi	+	+		+					+					
Ch. diversum		+	+		+									
Campylodiscus fastuosus	+		+				+							
Achnanthes longipes			+		+			+						
Cos. perforatus	+	+	+											
Cos. wailesii	+		+		+									
Cos. excentricus	+	+	+	+										
Diploneis notabilis	+		+				+							
Corethron criophyllum		+	+						+					

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Chaetoceros boreale		+	+		+									
Ch. vixvisibilis					+	+	+							
Navicula lyra	+	+	+		+		+							
Cyrosigma balticum	+	+	+	+				+						
Nitschia plana	+		+	+	+		+							
Fragilaria linearis	+		+		+			+						
Donkinia recta	+	+	+		+									
N. sigma		+	+	+	+									
N. panduriformis	+	+	+	+										
Podosira stelliger	+	+	+			+								
Triceratium favus	+	+	+		+									
Plagiogramma vanheurckii			+		+		+							
Thalassiosira gravida	+		+				+							
Triceratium pentacrinus	+			+	+									
Grammatophora marina	+				+	+								
Ch. weissflogii					+	+	+							
Pattern v														
Ch. coarctatum						+		+	+	+	+	+	+	+
R. acuminata								+	+	+	+	+	+	+
Cos. granii										+				+
Pattern vi														
Nitzschia lorenziana v. *incurva*											+	+	+	
Cos. lineatus											+			
R. castracanei													+	
R. hebetata f. *semispina*													+	+
b. Dinoflagellates														
Pattern i														
Ceratium fusus	+	+	+	+	+	+	+	+	+	+	+	+	+	+
C. furca	+	+	+	+	+	+	+	+	+	+	+	+	+	+
C. furca f. *eugrammum*	+	+	+	+	+	+	+	+	+	+	+	+	+	+
C. massiliense	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Gonyaulax diegensis	+	+	+	+	+	+	+	+	+	+	+	+	+	+
G. polygramma	+	+	+	+	+	+	+	+	+	+	+	+	+	+
G. minuta	+		+	+	+	+	+	+	+	+	+	+	+	+
Prorocentrum micans	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Protoperidinium divergens	+	+	+	+	+	+	+	+	+	+	+	+	+	+
P. depressum	+	+	+	+	+	+	+	+	+	+	+	+	+	+
P. ovatum	+	+	+	+	+	+	+	+	+	+	+	+	+	+
P. granii	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Pyrophacus horologium	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Protoperidinium crassipes	+	+		+	+	+	+	+	+	+	+	+	+	+
P. orbiculare	+	+	+		+	+	+	+	+	+	+	+	+	+
P. abei	+	+	+	+	+	+	+	+	+	+		+	+	+
P. leonis	+	+	+	+	+	+	+	+	+	+	+		+	+
P. oceanicum	+	+	+		+	+	+	+	+	+	+	+	+	+
Pyrophacus steinii	+	+	+	+	+	+	+	+	+	+	+	+	+	
Glenodinium danicum		+	+	+	+	+	+	+	+	+	+	+	+	+
Dinophysis caudata	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Ceratium trichoceros	+	+	+		+	+	+	+	+	+	+	+	+	+
Pronoctiluca pelagica	+	+	+		+	+	+	+	+	+	+	+	+	+
Dinophysis miles	+		+		+	+	+	+	+	+	+	+	+	+

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Protoperidinium brochii	+	+	+		+	+	+	+	+	+	+	+	+	
P. grande	+	+			+	+	+	+	+	+	+	+	+	+
P. globulus	+	+	+	+	+	+		+		+		+	+	
P. pedunculatum					+	+	+	+	+	+	+	+	+	+
P. conicum		+	+	+	+	+		+	+	+	+	+	+	
P. ovum		+	+	+	+			+	+	+		+	+	+
Ceratium tripos v. *indicum*	+				+	+	+	+	+	+	+	+	+	+
C. tripos v. *atlanticum*	+		+		+	+	+	+	+	+	+	+	+	+
C. tripos	+		+				+	+	+		+	+	+	+
C. breve	+		+		+	+	+	+	+	+	+	+	+	+
C. falcatum	+	+	+		+	+	+	+	+	+	+	+	+	+
C. extensum	+	+	+		+	+		+	+	+	+	+	+	+
Exuviaella compressa	+		+	+	+		+	+	+	+	+		+	+
C. massiliense v. *armatum*	+	+	+		+	+	+	+			+	+	+	
C. breve v. *parallelum*	+		+		+	+		+	+	+	+	+	+	
C. biceps			+		+	+	+	+	+			+	+	+
C. humile	+				+	+	+	+	+	+		+	+	
C. deflexum		+			+	+	+	+				+	+	+
Protoperidinium tenuissimum	+	+	+		+	+	+	+	+			+		+
Gonyaulax polyedra	+		+	+			+	+	+	+	+		+	
Ornithocercus thurnii	+		+		+				+	+	+	+	+	+
Phalacroma rotundatum		+	+	+	+		+		+	+		+		+
Gonyaulax monocantha	+	+	+	+			+					+	+	
Cymnodinium splendens	+	+	+	+	+							+	+	
Triadinium sphaericum			+	+	+		+	+	+	+	+	+		
Ceratium macroceros	+		+				+		+				+	+
C. pulchellum					+		+		+			+	+	
Triadinium polyedricus	+		+		+	+							+	+
Protoperidinium diabolus				+	+					+		+	+	
Histioneis vouckii	+					+		+			+		+	
Protoperidinium murrayi					+					+			+	+
P. pellucidum			+	+						+			+	
Ceratocorys armata	+	+	+								+	+	+	
Ceratium declinatum	+								+				+	+
C. dens						+				+				+
C. lineatum		+	+											+
Pyrodinium schilleri								+				+		+
Pattern ii														
Ceratium bigelowii		+	+	+	+	+	+		+	+		+		
C. tripos v. *balticum*	+	+	+		+		+	+	+	+	+	+		
Protoperidinium pentagonum	+	+	+	+	+	+		+	+	+		+		
Gonyaulax digitale	+	+	+	+	+	+	+	+	+	+	+			
Protoperidinium sourniai	+	+	+	+	+	+	+	+		+	+			
P. subinerme	+	+	+	+	+	+	+	+		+	+			
P. conicum v. *asamushi*	+	+	+	+	+	+			+	+	+			
P. subpyriforme		+		+	+	+	+	+	+	+				
P. elegans					+	+		+	+	+	+			
Ceratium ehrenbergii	+				+	+	+					+		
C. horridum					+	+					+	+		

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Pattern iii														
Gonyaulax catenata	+	+		+	+	+	+	+	+					
Pyrodinium bahamens	+	+	+	+	+	+	+		+					
Ceratium fusus v. *seta*	+	+	+	+	+	+	+							
C. massiliense v. *protuberans*	+	+	+			+		+	+					
C. minutum		+	+				+	+	+					
Bernadinium sp.					+			+						
G. subulata		+			+		+							
Prorocentrum gracile	+		+	+										
P. lenticulatum		+		+		+								
Protoperidinium pyriforme	+	+	+	+										
P. curvipes	+	+	+	+										
G. spinifera	+	+	+	+										
Gymnodinium pygmaeum		+	+	+										
Dinophysis diegensis					+	+	+							
Gonyaulax diacantha	+	+	+											
Ceratium longirostrum	+	+	+											
Pattern iv														
Ceratium pentagonum										+				
Phalacroma irrigulare										+				
Protoperidinium acutipes										+				
P. breve										+				
P. orientale										+				
Pattern v														
Podolampas bipes									+	+	+	+	+	+
Ceratocorys horrida								+	+	+	+	+	+	+
Pyrocystis pseudonoctiluca										+	+	+	+	+
Oxytoxum scolopax										+	+	+	+	
Ceratium schrankii									+	+	+	+		
C. schmidtii									+		+	+		
Podolampas spinifera										+	+		+	
Protoperidinium cerasus										+	+		+	
Pyrocystis obtusa											+	+		+
Oxytoxum longiceps									+				+	
Protoperidinium oviforme										+	+			
Pattern vi														
Pyrocystis fusiformis													+	+
Ceratium arietinum												+		
C. azoricum														+
C. contortum														+
C. symmetricum													+	
C. vultur													+	
Dinophysis cuneus													+	
Glenodinium lenticula														+
Gonyaulax hyalina													+	
G. kofoidii												+		
Oxytoxum brunelli													+	
Phalacroma minutum														+
Ph. operculatum													+	
Ph. pulchellum											+			
Prorocentrum pyriforme														+
Protoperidinium heterocanthum												+		
P. minusculum													+	
P. spiniferum														+
P. thorianum														+
Pyrocystis robusta														+

stations. Beside *Trichodesmium* sp. the diatom species *Nitzschia seriata* (upto 50%), *Climacodium frauenfeldianum* (upto 50%), *Guinardia flaciida* (upto 30%), or *Thalassiothrix longissima* (upto 30%) dominated at the same stations. The co-dominant species were *Protoperidinium curvipes* (upto 20%), *Ceratium furca* (upto 15%), *C. breve* (upto 15%), *C. trichoceros* (upto 10%), *C. extensum* (upto 10%), *Ceratocorys horrida* (upto 10%), *Gonyaulax polygramma* upto 10%), *Ceratium tripos* (upto 8%), *Gonyaulax hyalina* (upto 7%), *Nitzschia closterium* (upto 10%) or *Hemidiscus hardmanianus* (upto 5%).

The dominant species in the Straits of Hormuz were more or less similar to those in both the AG and GO. *Trichodesmium* sp. (upto 40%) and *Nitzschia seriata* (upto 50%) dominated in the straits with the co-dominance of *Climacodium frauenfeldianum* (3%), *Lauderia annulata* (4%), *Thalassiothrix longissima* (3%), *Leptocylindrus minimus* (2%) or/and *Gonyaulax polygramma* (3%).

Biomass : The biomass of the phytoplankton, measured by both cell count and chlorophyll showed wide range of regional variations. The count of the *Trichodesmium* sp. and *Anabaena* sp. should be considered separately as filament l^{-1} ($f\ l^{-1}$). The average standing crop of the two species in the AG (400 $f\ l^{-1}$) was about 9 folds that in the GO (430 $f\ l^{-1}$). Even inside the AG the average count of those two species was variable. Off the UAE the average count (6460 $f\ l^{-1}$) was markedly greater than that off Qatar (1600 $f\ l^{-1}$). In the latter region, *Anabaena* sp. was mostly dominated the *Trichodesmium* sp., while the opposite was observed in the water of the UAE.

The cell count of the phytoplankton, without the above mentioned blue green, in the Qatari water was characterized by the greatest values (average : 106000 cell l^{-1}) with a maximum of 449000 cell l^{-1} at St. 1. The average cell count off the UAE (39000 cell l^{-1}) was markedly low, while in the GO, it was sharply

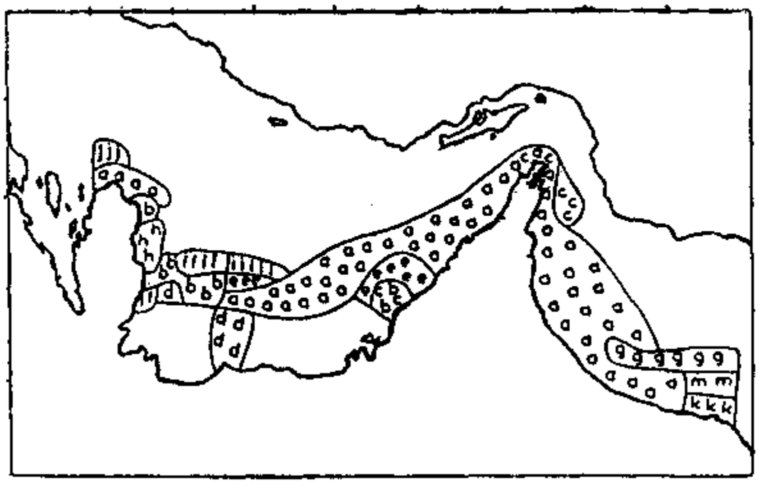

FIG. 3. Distribution of the dominant species in the study area in September 1986 (a : *Triceratium* sp., b : *Chaetoceros curvisetum*, c : *Nitzschia seriata*, d : *Rhizosolenia calcar-avis*, e : *Ceratium furca*, f : *Thalassiothrix frauenfeldii*, g : *Climacodium frauenfeldianum*, h : *Rh. shrubsolei*, i : *Coscinodiscus perforatus* j : *Rh. alata f. indica*, k : *Guinardia flaccida*, l : *Pyrodinium bahamense*, m : *Th. longissima*.

dropped (2500 cell l^{-1}). The maximum biomass recorded in the latter two regions were 277000 and 7200 cell l^{-1} at Sts. 25 and 33 respectively. The most abundant species in the water samples forming the main bulk of the standing crop were *Ch. curvisetum* (upto 406000 cell l^{-1}), *Ch. tortissimum* (upto 135000 cell l^{-1}), *Ch. affine* (upto 84000 cell l^{-1}), *Leptocylindrus minimus* (64000 cell l^{-1}), *Nitzschia seriata* (53000 cell l^{-1}) and *Leptocylindrus danicus* (30000 cell l^{-1}). The dinoflagellates showed the lowest biomass during the present study. The maximum cell count recorded (35300 cell l^{-1}) was at St. 22 with the dominance of the *Pyrodinium bahamense* (32000 cell l^{-1}).

In contrast to the cell count, chlorophyll measurements included *Trichodesmium* sp. and *Anabaena* sp. The average values of chlorophyll in the AG (1.0 mg m^{-3}) was greater than those in the GO (average 0.66 mg m^{-3}). Clear zonation was observed in the distribution of chlorophyll in both regions. As shown in Fig. 4, chlorophyll in the inshore water was lower than the offshore in both the AG and GO. In the Straits of Hormuz the values of chlorophyll reflected the mixing conditions between the two regions, particularly the inshore waters.

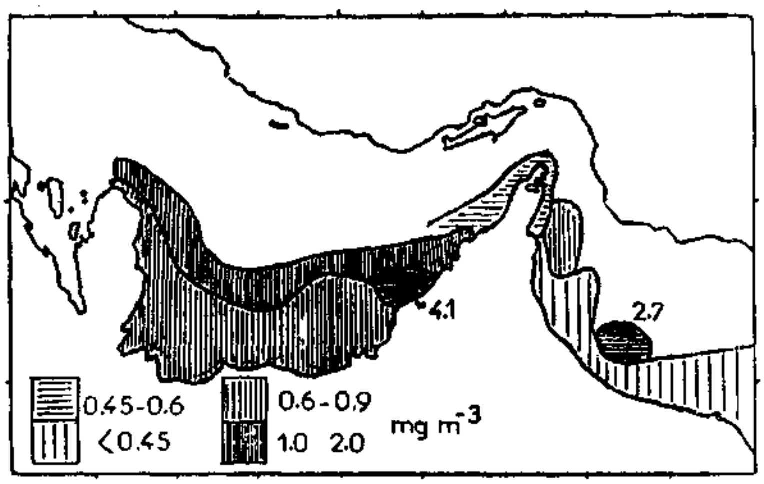

FIG. 4. Chlorophyll distribution in the surface water of the study area in September 1986.

DISCUSSION

The two regions of the study area, AG and GO are differentiated from each other by several ecological conditions. However, the water exchange between GO (salinity 36.5‰) and AG (salinity 40-43‰) leads to significant variations in their physical and chemical characteristics, especially in the neighbouring parts. Such variations are controlled by the volume of the exchanged waters. Koske (1972) estimated 3 years for total exchange of the AG water. The velocity of exchange is affected by the system of surface and bottom currents through the Straits of Hormuz, which is rather complex, because of the mainly transversal direction of the monsoon in this region giving rise to eddies with rather large fluctuation (Grasshoff, 1976). On the other hand, the low saline water of the GO penetrating to the AG causes the decrease of the surface salinity along the Iranian Coast upto 39‰ and reaches significant part of the UAE Coasts

(Brewer and Dyrssen, 1985 ; El-Samra and El-Deeb, 1987). The Southwest Arabian Gulf is more or less impacted by the low saline water of the GO. This water is rich in nutrients and they are mixed with the bottom layers. Seibold *et al.* (1969, 1970) assumed that the penetration of nutrient-rich water into the AG and its further distribution and mixing are a function of the stability of the water column, the system of currents and eddies and the bottom topography.

The effect of the high salinity water of the AG was not detected in the surface water in the GO. Grasshoff (1976) admitted that the AG water penetrates through the Straits of Hormuz in a thin layer at the bottom (100 m depth) and finally cascades down on the slope of the GO.

The ecological conditions in the investigated area pointed to the possibility of the immigration of the plankton organisms in the two opposite directions between the AG and GO. According to Leveau and Szekielda (1968), any plankton organisms carried by the low saline surface water towards the Persian Gulf (AG) and unable to withstand either its shallowness or its high temperatures and salinities, will die as soon as they reach the steep walls leading towards the narrow and shallow entrance into the Gulf. The view of these authors may be suitable for the abrupt change of any ecological factor. The available published informations (Brewer and Dyrssen, 1985 ; El-samra and El-Deeb, 1987) confirmed the existence of transition area at the surface water between the AG and GO through the Straits of Hormuz. Within the transition area the salinity of the water penetrating the AG increases gradually, that enable the transported plankton organisms to adapt themselves to these changes. Even, if some organisms will die, the continuous transference of these organisms with the inflowing water will make it possible for some of them to survive and acclimatize to the new habitat in the AG. Dorgham *et al.* (1987) pointed to the increase of the number of the phytoplankton species in the AG during the past 15 years due to their transportation from the Arabian Sea and Gulf of Oman.

Distribution of the phytoplankton species recorded in the study area showed that the community of the AB in autum was markedly rich in species composition than the GO. However, the population of the two major groups were significantly different in the diversity of species in both regions. In the AG, the diatom population (175 sp.) was more diversified than the dinoflagellate (124 sp.). The opposite pattern was observed in the GO, where the dinoflagellate population (92 sp.) was greater in diversity than the diatoms (54 sp.). The abundance of the diatoms in the AG and GO did not reflect their relation to the concentration of the dissolved Si in both regions. The average content of the dissolved Si in the AG (2.66 μg at/l^{-1}) was lower than in the GO (3.07 μg at l^{-1}). Thus, it seems that the growth of diatoms in the GO was affected by factor other than dissolved Si. Vargo (1968) stated that variation in the standing crop usually is the result of several factors acting together, though one may influence or appear to influence phytoplankton numbers more than the others.

The great majority of the species recorded in the AG during the present study had been found before in the Indian Ocean by Wood (1963 a) and Taylor (1976). The occurrence of many species (108) common to the AG and GO may confirm the immigration and acclimatization of the Indian Ocean plankton to the condition of the AG. Eventhough, many other species were found restricted either to the AG or GO and some of these species extended in their distribution to the Straits of Hormuz from both sides. This pattern of species distribution may indicate to the Straits of Hormuz as passway for some epipelagic species and as barrier for others.

The distribution pattern of the dominant species in the study area showed clear patchness, which may be attributed to the variations in the nutrient contents or to the water circulation, prticularly in the AG (Grasshoff, 1976 ; Hunter, 1986). From the present study it was clear that *Trichodesmium* sp. dominated most Stations in the GO except at Sts. 33, 40, 42 & 43, where the diatoms : *Climacodium frauenfeldianum*, *Thalassiothrix longissima*, *Guinardia flaccida* or *Nitzschia seriata* were dominant. In the AG, several species of diatoms and dinoflagellates other than *Trichodesmium* dominated at different stations, particularly in the Quatri water (Fig. 3).

The phytoplankton biomass showed marked variations in the different parts of the study area. These variations were related to the similar variations in the nutrient contents. *Trichodesmium* sp. was responsible of the main bulk of the biomass in the GO and great part of the Southwest AG. However, some diatom species replaced this species at some stations in the GO and in the great part of the Qatari water (AG). This may be attributed to the high nutrient content in the Qatari water and the GO.

The existence of *Trichodesmium* sp. as main constituent in the biomass of the phytoplankton in the study area is a characteristic phenomenon for the tropical and subtropical waters. The maximum count of this species (30600 f l^{-1}) was recorded at St. 22 in the AG., where the concentration of the nitrogen salts, particularly ammonia and nitrite, were very low. Observations of Marumo and Asaoka (1974 a, b) and Dowidar *et al.* (1978) showed that when *Trichodesmium* occurred nitrite and nitrate were almost nil, but ammonia and phosphate were present. Dowidar *et al.* (1978) recorded a maximum of 22500 f l^{-1} of *Trichodesmium* sp. in July in the Red Sea water off Jeddah. In the presently investigated area, *Trichodesmium* sp. was observed in low number where the phytoplankton was dominated by diatoms. This observations are analogous to those in the North Pacific Ocean (Marumo and Asaoka, 1974 a, b) and in the Red Sea (Dowidar *et al.*, 1978).

Concerning the abundance of distom individuals at some stations in relation to the concentration of nutrients it was observed that the dissolved Si is not always the limiting factor in the growth of diatoms and other nutrients may affect their growth.

The biomass measurements exhibited the low production of the phytoplankton in the GO compared to the A.G. This phenomenon is contradicted to the good nutritional conditions in the GO, which point to the possibility of high production. The observed situation indicates that the autumn is not the suitable season for the phytoplankton bloom in the GO. The cell count of the phytoplankton was subjected to significant variations at the different stations, particularly in the AG (Table 4, 5). These variations may be attributed to the variations in the nutrient contents or to the complex system of eddies in the AG supposed by Grasshoff (1976). The present study showed that the inshore waters were less productive than the offshore due to the lower nutrient contents in the former waters. Halim (1984) pointed to the higher nutrient concentrations and standing crop of the phytoplankton in the offshore water of the AG than those inshore. Considerable productivity was admitted by Grasshoff (1976) in the transition area in the Straits of Hormuz and in eastern parts of the AG of the coast of UAE.

The distribution of the biomass along the western side of the AG was significantly variable. Comparison with the previous works (Al-Kaisi, 1976 ; Huq *et al.*, 1978 ; Jacob *et al.*, 1979 a, b ; Halim, 1984) indicated the higher productive water off Kuwait than the other regions of the AG. The present

TABLE 4. *Standing crop (cell/l) of the different phytoplankton groups in the Arabian Gulf, September 1986*

St. No.	Diatoms	Dino-flagellates	Total	Blue-greens f./l
1	446834	2294	449128	992
2	11210	2945	14155	380
3	332664	8466	341130	6952
4	51049	1704	52753	2201
5	53485	1615	55100	2406
6	155592	1224	156816	1008
7	26845	1820	28665	819
8	22400	3920	26320	640
9	114480	6624	121104	576
10	4300	2700	7000	—
11	7620	3360	10980	840
12	n.r.	n.r.	n.r.	n.r.
13	6426	1350	7776	702
14	7280	1120	8400	350
15	12152	490	12642	196
16	47125	2405	49530	1430
17	12936	4312	17248	264
18	19855	6270	26125	380
19	92659	976	93635	7869
20	4599	8176	12775	2947
21	9700	8245	17945	9700
22	4288	35309	39597	30619
23	23115	13248	36363	15594
24	3808	4760	8568	11764
25	276830	570	277400	5225
26	11210	2280	13490	13870
27	—	70	70	1400
28	4224	2688	6912	1056
29	—	279	279	744

TABLE 5. *Standing crop (cell/l) of the different phytoplankton groups in the Straits of Hormuz and the Gulf of Oman*

St. No.	Diatoms	Dino-flagellates	Total	Blue-greens f./l
30	16287	6405	22692	18300
31	5580	900	6480	540
32	900	1500	2400	225
33	6695	520	7215	5330
34	51	2091	2142	—
35	—	306	306	—
36	—	936	936	—
37	—	200	200	—
38	159	4717	4876	106
39	3888	96	3984	—
40	400	350	750	—
41	—	220	220	—
42	4680	240	4920	—
43	600	2100	2700	—
44	440	495	935	—

study showed that the average values of chlorophyll in the southwest Gulf (0.7-1.06 mg m^{-3}) was markedly lower than those (1.0-4.7 mg m^{-3}) found before by Huq *et al.* (1978) in the Northwest Gulf. The possible reason for such conditions is the annual fresh water discharge of km^3 (Hartmann *et al.*, 1971 ; Grasshoff, 1976) of the Euphrates and Tigiris to the Kuwaiti water. On the other hand, the phytoplankton biomass in Qatari water was higher, according to Al-Kaisi (1976), than in the water of the UAE. The opposite was recorded during the present study. The observed contradiction may be related to changes in the environmental conditions, nutrient contents (Table 5) or the time of sampling.

TABLE 6. *Concentrations of nutrient salts in the Arabian Gulf in different times* (in μg at l^{-1})

Nutrients	Qatari water	UAE water	Reference
Phosphate ..	0.06—0.48	0.05—0.96	Al-Keisi, 1976
Nitrate ..	0.03—0.70	0.00—0.74	,, ,,
dissolved Si ..	0.30—3.40	0.00—2.00	,, ,,
Phosphate ..	0.03—1.23	0.00—0.56	Present Study
Nitrate ..	0.12—0.90	0.13—0.40	,, ,,
dissolved Si ..	0.66—5.12	0.57—4.85	,, ,,

It is worth mentioning that several species were found to be high salinity (upto 43‰) tolerant. Such species were *Hydrosilicon mitra, Nitzschia sigma, N. sigma* v. *intercedens, N. sigmoidea, Paralia sulcata, Plagiogramma vanheurckii, Pleurosigma acutum, Pl. fasciola, Triceratium favus, T. pentacrinus, Surirella fastuosa, S. javanica, Protoperidinium curvipes, P. brevipes, P. pyriforme, Prorocentrum gracile, Gonyaulax spinifera, Exuviaella marina, Diplopsalopsis orbicularis* and *Cochonina niei*.

The noticeable phenomenon in the study area was the existence of some dinoflagellates such as *Pyrodinium bahamense, Gonyaulax polyedra* and *Prorocentrum micans*, which were considered toxic by Shimizu (1984). In the Arabian Gulf, *P. bahamense* was recorded in significant frequency at several stations (Sts. 10, 21, 22, 23, 24). The highest frequency (38 %) of this species was detected at St. 10 where phosphate (1.23 μg at l^{-1}) and nitrate (0.90 μg at l^{-1}) reached their maximum in the whole AG, while ammonia was nil. The occurrence of such species in the high concentrations of phosphate and nitrate may lead to classifying it among the indicators of eutrophication. The other two species were, however, observed with less frequencies.

Conclusions

The connection between the two different habitats, AG and GO, through the Straits of Hormuz leads to significant variations in the ecological conditions and the phytoplankton population in both regions. The effect of the low salinity water from GO was more obvious in the surface water of the AG, particularly along the Iranian Coast. However, the western coast was more or less affected. The marked variation was the decrease of surface salinity from 43 ‰ to 39-38 ‰ and the increase of the nutrient contents in great part of the AG.

Phytoplankton population in the AG was more diversified than in the GO, but the diversity of the two main groups, diatoms and dinoflagellates, was contradicted each other in both regions.

Ecological distribution of the recorded species indicates the possibility of transportation of epipelagic phytoplankton into the AG through the inflowing surface current. Meanwhile, the complex system of the water circulation leads to marked variations in the distribution of the phytoplankton species.

Clear contradiction between the phytoplankton biomass and the nutrient contents was sometimes observed in the study area. The high nutrient contents in the GO, compared to the AG, was accompanied by low biomass, while the opposite was observed in the AG. The offshore waters, however, were richer in nutrients and more productive than the inshore in both the AG and GO. The most abundant species in the study area were mostly *Trichodesmium* sp. and *Anabaena* sp. However, Qatari water, some stations in the UAE and the GO were dominated by diatom species.

The distinct phenomenon was the appearance of some toxic dinoflagellates in significant numbers, particularly in the AG.

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