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Interrelations of phytoplankton, chlorophyll and physico-chemical factors in Arabian Gulf and Gulf of Oman during summer

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Samples for phytoplankton counts and chlorophyll data were collected from two areas, east of the strait of Hormuz (in Gulf of Oman) and west of this strait (in Arabian Gulf), during September 1986. Phytoplankton counts were higher in the west of Hormuz strait than in the Gulf of Oman. Horizontal distributions of some biological and hydro-chemical factors reflected the influence of known current system near southern side of Arabian Gulf. Generally, the most important nutrient salts affecting the phytoplankton growth, deduced from stepwise regression analysis, were nitrogen and silicon compounds.

Quantitative and qualitative studies on phytoplankton and physico-chemical characteristics of Arabian Gulf and Gulf of Oman waters have been reported[1-6]. However, no quantitative or qualitative correlations of various available data sets with biological data and environmental parameters have been made. The objective of the present study is to correlate diatoms, dinoflagellate, and blue green algae counts, along with chl *a* content with seawater density, temperature, salinity, *p*H, nitrate, phosphate, silicate, ammonia and nitrite, for 2 water layers, lying in the upper 40 m, during summer (September 1986) in an area around Hormuz strait, which separates the Gulf of Oman from Arabian Gulf (Fig. 1).

Materials and Methods

The data used were collected on board *R V L Mokhtabar Al-Behar*, in September 1986. During this cruise 17 stations were occupied in the Arabian Gulf, and 11 stations were occupied in the Gulf of Oman. All these stations were taken in the southern parts of the two gulfs. Seawater samples were collected by Nansen bottles and oxygen and nutrients in seawater were determined using standard methods[7]. Salinity was measured with a temperature compensated salinometer (Autolab 601 MK 111) while water temperature was measured using classical reversing thermometers. The *p*H was determined by a portable *p*H meter. Phytoplankton and blue green algae counts were made by an ordinary microscope and chlorophyll was estimated[7]. The hydro-biological conditions were studied in 2 layers-upper mixed layer (depth 0-10 m) and the lower layer (depth 10-40 m) which was lying in the pycnocline zone.

Application of multiple regression analysis was made to identify the environmental factors which are most closely related to phytoplankton cell counts and chl *a* concentration. These statistical analyses were carried out separately for Arabian Gulf and Gulf of Oman, and for each of the 2 considered layers.

The linear regression model[8] can be expressed by:

$$Y = C_0 + \sum_{j=1}^{n} X_j C_i$$

where Y is cell count of diatom, dinoflagellate, total phytoplankton or chlorophyll amount; C_0, constant

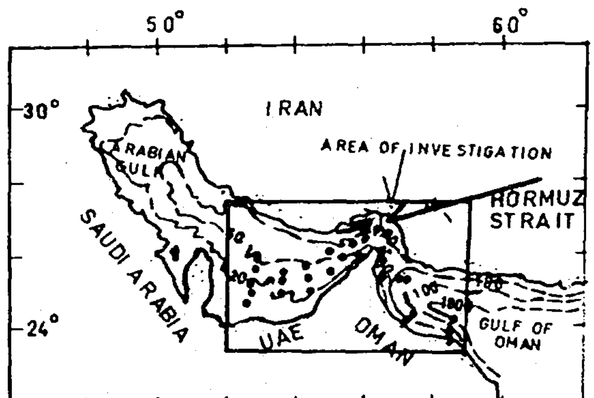

Fig. 1—Bathymetry and locations of hydrographic stations occupied during September 1986, in the Arabian Gulf and Gulf of Oman

coefficient; n, number of independent variables (i.e. environmental factors included); X_j, the value of the j's environmental factor; and C_j, the coefficient of the j's variable. Values of C_0 and C_j were determined by the least squares method, where the number of dependent variables was 5 and that of the independent variables was 7. Two different approaches were applied in the multiple regression analyses; all regression and step wise regression methods. In all regression methods, all available environmental factors are included in the fitted equation, and in the stepwise regression only the most important environmental factors are entered in the equation. For each equation total correlation coefficient, which is the correlation between observed and estimated values, was calculated. Statistical analyses were done using the Microstat software package.

Results

Horizontal distributions of biological and physico-chemical variables—Horizontal distributions of different parameters are given in Figs 2 and 3 in upper and the lower layers respectively. In the upper layer, distributions of temperature, salinity, phosphate, nitrate and total phytoplankton, exhibit tongue like isoline's shape indicating the water flow towards the Gulf of Oman; this agrees with known current pattern[9] in the area and manifests the influence of current on hydro-biological distributions. In the Arabian Gulf, high diatom population prevailed with low concentrations of silicate and nitrate.

Phytoplankton counts and chl *a* concentration are shown in Table 1. In the upper layer, the means of different biological variables were much higher in the area west of the strait of Hormuz than in the area east of that strait. The *t* test (confidence limit 1%) confirmed the above conclusion. Diatom counts were higher in the upper layer. In the lower layer, the highest chl *a* concentrations were limited in the zones near to the coastline in both the gulf areas. High dinoflagellate counts were associated with high nitrate and silicate concentrations, and higher counts of blue green algae existed with lower nitrites, nitrates and silicates. The *t* test, at 1% level, on the data of the lower layer (Table 1), proved that the means of diatom, total phytoplankton and blue green algae

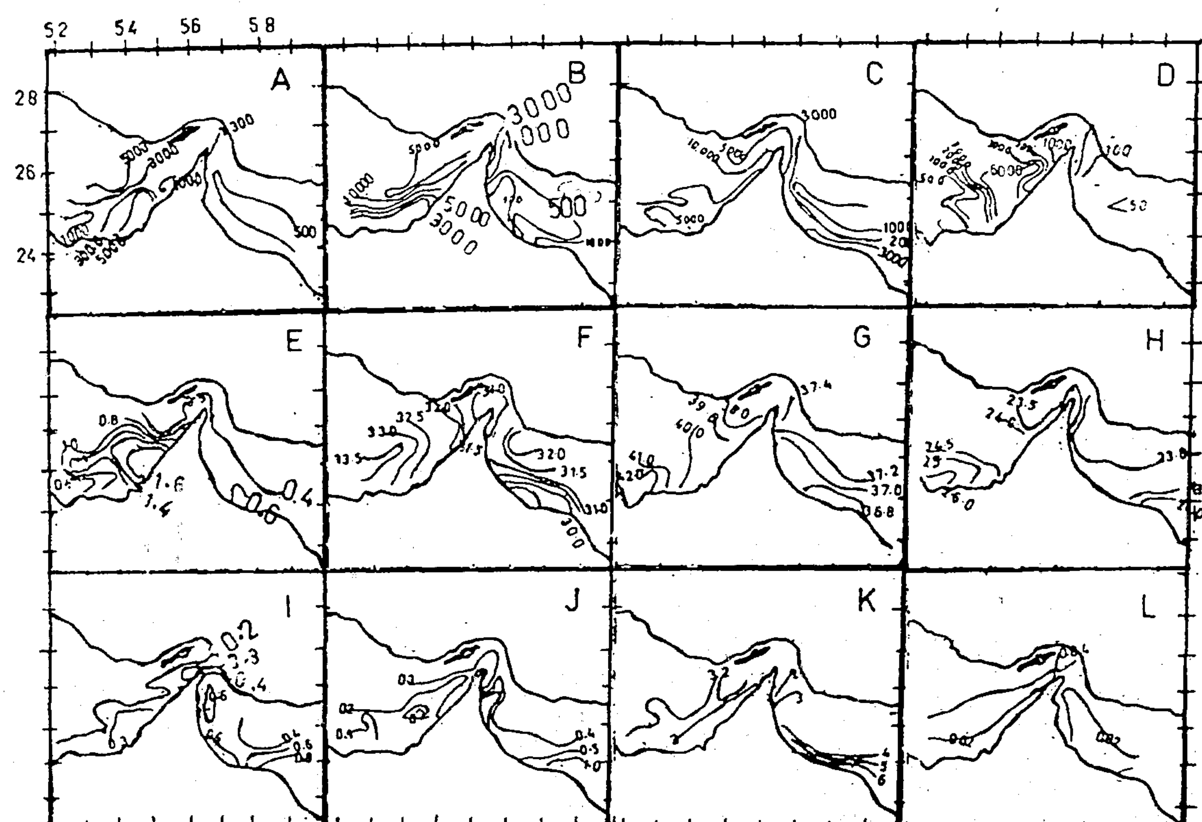

Fig. 2—Horizontal distributions of environmental parameters in the 0-10 m depth layer, during September 1986 (A = dinoflagellate no, B = diatom no, C = total count of phytoplankton, D = blue green algae no, E = chlorophyll *a* conc, F = water temperature, G = salinity, H = water density, I = nitrate conc, J = phosphate conc, K = silicate conc and L = nitrite conc)

Table 1—Means of phytoplankton counts and chlorophyll *a* amount (mg.l^{-1}) in Arabian Gulf and Gulf of Oman during September 1986

	Depth layer	
	0-10 m	10-40 m
Aribian Gulf		
No. of Samples	17	13
Dinoflagellates	3942±3478**	1213±1051
Diatoms	10761±14747	6664±4983
Blue green algae	3935±5382	798±680
Chl *a*	1.18±0.7	0.96±0.25
Total*	18696±15958	9497±6755
Gulf of Oman		
No of samples	12	11
Dinoflagellates	825±609	1092±1325
Diatoms	1535±2285	1872±3271
Blue green algae	276±458	33±61
Chl *a*	0.55±0.12	0.87±0.39
Total	3695±3452	3788±3746

*Total = sum of no. of all phytoplankton components
**standard deviation

counts were significantly higher in Arabian Gulf area than in the Gulf of Oman region. On the other hand, means of dinoflagellate counts and chl *a* concentration were not significantly different in both regions. The diatoms were also predominating in the phytoplankton community in lower layer. It can be concluded that the average values of different biological parameters (Table 1) in the Arabian Gulf side were decreasing with depth while in Gulf of Oman, dinoflagellate and diatom counts and chl *a* concentration were higher in the lower layer, with a reverse trend for the blue green algae. Vertical changes of productivity in the Gulf of Oman could be due to the outflow of relatively more productive deep Arabian Gulf waters towards the Gulf of Oman.

Multiple regression analyses: West of the strait of Hormuz—Coefficients and constants of multiple regression equations which are significant at 0.05 confidence limit in this area are computed. In the upper layer, significant best fit equations obtained by all regression methods had high total correlation coefficients (0.87-0.94) in the cases of the dependent variables; dinoflagellate and blue green algae counts and chl *a* concentration (Table 2). However, the

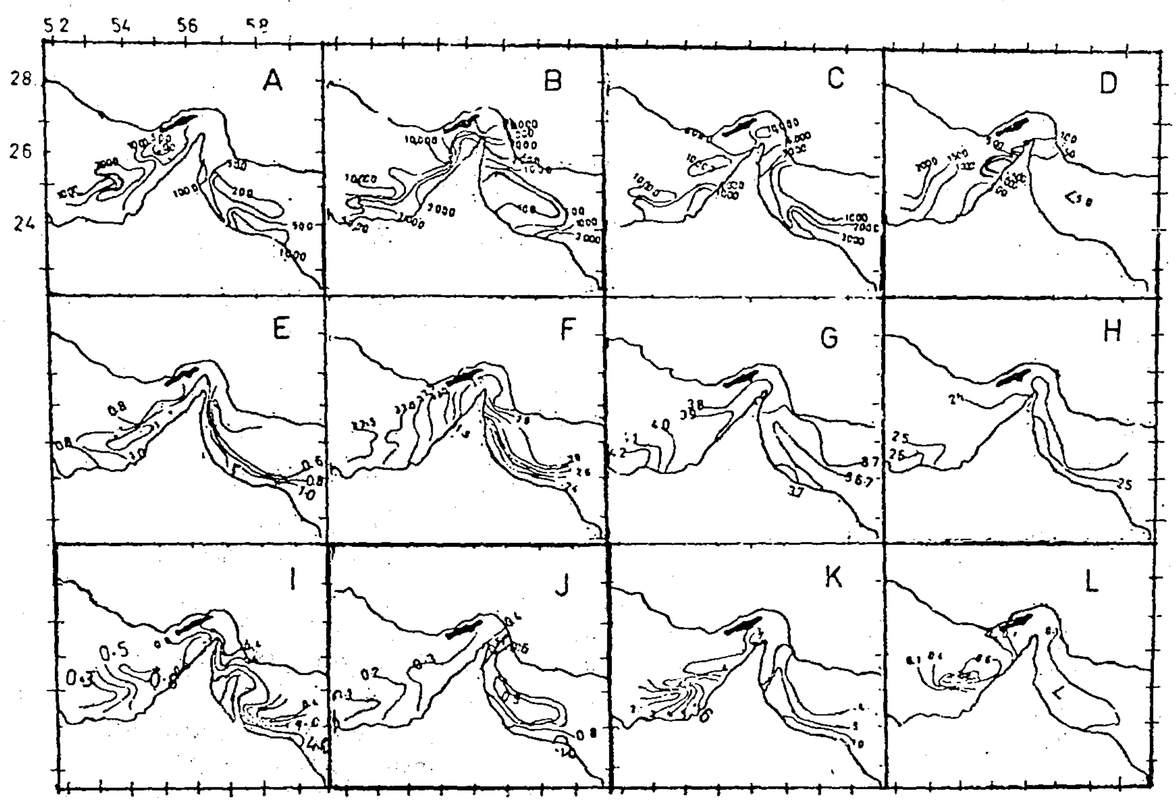

Fig. 3—Horizontal distributions of environmental parameters in the 10-40 m depth layer, during September 1986 (A = dinoflagellate no, B = diatom no, C = total count of phytoplankton, D = blue green algae no, E = chlorophyll *a* conc, F = water temperature, G = salinity, H = water density, I = nitrate conc, J = phosphate conc, K = silicate conc and L = nitrite conc)

stepwise regression method gave significant relations ($r = 0.70$-0.79) for dinoflagellate counts and chl *a*. In these 2 equations the independent variables are nitrate and silicate concentrations. Regression analysis of lower layer data of the Arabian Gulf shows that in all regression analyses, the equations of different biological variables had significant total correlation coefficients, while in the case of stepwise regression analysis, only dinoflagellate counts and chl *a* concentration had significant total correlation coefficient. In the latter case, the nutrient salts included were phosphate in the dinoflagellate equation, and phosphate, silicate, and ammonia in the chlorophyll equation. Therefore, the important factors affecting productivity are different in the upper and lower layers. The concentrations of nitrate and silicate in upper layer of Arabian Gulf water (Figs 2 and 3), were 0.1-0.3 and 1-4 μg-at.l^{-1} respectively, while in the lower layer, these concentrations were 0.1-0.8 and 1-7 μg-at.l^{-1} respectively. Here, the regression results might be related to the availability of different food components for the phytoplankton in the layer.

East of the strait of Hormuz — In the upper layer of this area, all biological dependent variables had significant all regression best fit equations with considered environmental factors (Table 2), and the stepwise regression analysis gave 4 significant equations for diatom, total phytoplankton and blue green algae counts and chl *a* concentration. In stepwise equations, the nutrient salts entered were silicate, ammonia and nitrite. This indicates that nitrogen and silicon were the most important factors affecting the phytoplankton growth. In the lower layer, the best fit equations were significant for dinoflagellate counts and chl *a* in all and stepwise regression analyses. The nutrient salts entered in the stepwise regression equation of dinoflagellate counts were ammonia, nitrate, phosphate and silicate while chl *a* concentration was dependent on silicate, ammonia and nitrite. Therefore, it seems that the nutrient salts controlling the phytoplankton growth are different in upper and lower layers in the Gulf of Oman. This may be related either to dominant phytoplankton species or other evironmental conditions such as light intensity.

Discussion

Phytoplankton population and growth depend on several environmental factors which are variable in different seasons and different regions. The major factors affecting photosynthetic rates are degree of irradiance, spectral composition of light, water temperature and concentrations of nutrient salts. The seasonal and regional variations of phytoplankton growth are complicated due to interactions between ecological factors and rates of regeneration of nutrients and their return to the water column by

Table 2— The total correlation coefficients (TCC) for the significant multiple regression equations between phytoplankton counts and chlorophyll *a* and environmental factors in the Arabian Gulf and Gulf of Oman during September 1986 (Independent variables in all regression analyses are density, seawater temperature, salinity, *p*H and concentrations of nitrite, phosphate, silicate, ammonia and nitrite)

Depth (m)	Method	No. of samples in eqn.	TCC for dependent var. a	b	c	d	e	Independent variables included	Critical TCC at 95%
						Arabian Gulf			
0-10	ALR*	17	0.90	–	0.87	0.94	-	all	0.48
	STPW**	17	0.70	- -	–	0.79	–	NO_3, SiO_4	
10-40	ALR	13	0.86	0.95	0.86	0.91	0.97	all	0.55
	STPW	13	0.76	–	··	0.88	···	(a) temp, *p*H, PO_4	
								(b) temp, sal., PO_4, SiO_4, NH_4	
						Gulf of Oman			
0-10	ALR	12	0.83	0.93	0.89	0.86	0.93	all	0.58
	STPW	12	—	0.89	0.87	0.79	0.91	density, SiO_4, NH_4, NO_2	
10-40	ALR	11	0.99	—	—	0.99	---	all	0.60
	STPW	11	0.95	–	—	0.81	—	(a) density, NO_3, PO_4, SiO_4, NH_4	
								(b) density, SiO_4, NH_4, NO_2	

* = ALR is all regression analyses, ** = STPW is stepwise regression analysis, a = dinoflagellates, b = diatoms, c = blue green algae, d = chl *a*, e = total phytoplankton count

physical and chemical processes, as well as the rates of their consumption in the primary production process. Temperature is an important factor when irradiance excess light saturation, and the phytoplankton species in warmer regions have to face high optimum temperature[10]. The rates of the enrichment of the water column by nutrient salts depend on the rates of decomposition of organic matter and the distribution of these salts by vertical turbulent motion. Rates of decomposition are expected to be enhanced by high temperature, especially in shallow water; similar case exists in the Arabian Gulf during summer, and vertical transfer of nutrient salts depends on the water stability.

Distributions of biological, chemical and physical parameters and statistical analyses in the southern parts of the Arabian Gulf and Gulf of Oman, during summer, showed the following:

(1) Phytoplankton population in the west of the strait of Hormuz was higher than that in the east of that strait. This can be explained by the higher concentrations of nutrient salts in the shallow Arabian Gulf side. Vertical distributions of density showed that the depth of the pycnocline in the whole study area was between 10 and 20 m depth, but the vertical density gradient was less acute in the Arabian Gulf side; this is due to the significantly lower surface salinity in Gulf of Oman. Consequently, high temperature of water in Arabian Gulf can be felt up to the bottom and it enhances the decomposition of the deposited organic matter. Nutrient salts produced by this process can be returned back to water column more effectively by turbulence in the Arabian Gulf.

(2) In the Arabian Gulf, the most important factors affecting phytoplankton growth, given by the stepwise regression analysis, are different in the upper and lower layer. In the upper layer nitrate and silicate entered the best fit equations, and phosphate, silicate and ammonia were included in the equations of the lower layer. This can be explained by the availability of different nutrient salts; the nutrient with low concentrations were included in the best fit stepwise regression equations. In the Gulf of Oman, both lower and upper layer equations had only nitrogen and silicon components. In general, the stewpise regression results agree with the conclusions from N/P ratio[6], according to which the nitrogen is the growth limiting factor.

The use of the best fit equations for estimation of marine productivity needs more observations in the same area for validation purpose.

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