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The Planktonic Community Structure and Fluxes Nutrients in the Sefid-Rood River Estuary (South Caspian Sea)

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Abstract: The aim of this study was to examine spatial and temporal variability in phytoplankton and zooplankton abundance and diversity in Sefid-Rood River Estuary (SRE). Variability of Chlorophyll a and inorganic nutrient concentration were determined during a year (November 2005- October 2006) in five sampling stations. Total chlorophyll a concentration during the investigation ranged between zero to 22.8 µg L^{-1} and the highest levels were consistently recorded during Summer and the lowest during winter with a annual mean concentration 4.48 µg L^{-1}. Nutrient concentration was seasonally related to river flow with annual mean concentration: NO_2 0.05±0.2, NO^{-}_3 1.13±0.57 and NH^{+}_4 0.51±0.66 mg L^{-1}, total phosphate 0.13±0.1 and SiO_2 5.68±1.91 mg L^{-1}. *Bacillariophytes*, *Cyanophytes*, *Chlorophytes*, *Pyrophytes* and *Euglenophytes* were the dominant phytoplankton groups in this shallow and turbid estuary. The diversity and abundance of phytoplankton had a seasonal pattern while *Diatomas* and *Chrysophytes* were dominant throughout the year but *Cyanophytes* observed only during the Summer. Zooplankton community structure was dominated by copepods which 68% of the total Zooplankton. In the winter and summer seasons two increased in the number of zooplankton community and usually toward the sea had occurred. Zooplankton also showed a significant spatial and temporal variation. The high turbidity and temperature prime characteristics of SRE seem to be determining factors acting directly on Phytoplankton and Zooplankton temporal variability and nutrient fluctuations. Everywhere in this estuary nutrients appeared to be in excess of algal requirement and did not influence an phytoplankton and zooplankton composition. Also there was a positive correlation between chlorophyll a and temperature and a negative one with DIN and TP.

Key words: Phytoplankton, zooplankton, nutrients, sefid-rood estuary, Caspian Sea

INTRODUCTION

The term estuary is commonly regarded as intermediate transition zone linking freshwater and marine systems (Mclusky and Elliott, 2004); or simply an area where rivers meet, or enter the sea. Estuaries are among the most productive marine ecosystems and the phytoplankton is an important component of these systems (Lali and Parsons, 1997; Karleskint, 1998). Major factors influencing phytoplankton production include light and nutrient availability (Underwood and Kromkamp, 1999).

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The limitation of light penetration by turbidity has been frequently cited as a factor controlling primary production in estuaries (Pennock, 1985; Lehman, 1992; Irigoien and Castel, 1997). Estuarine ecosystems typically express high spatial and temporal variability of chlorophyll (Cloern, 2001). Recent attention has focused on regional climate and weather patterns that produce variability of nutrients, Dissolved Organic Matter (DOM) and Suspended Particulate Matter (SPM) traceable to freshwater flow (Najjar, 1999). Plankton has been used recently as an indicator to observe and understand global change because it seems to be strongly influenced by climatic features (Li *et al*., 2000).

Physical and other chemical factors such as temperature, salinity and the concentration of mineral nutrients (PO_4^{3-} and NO_3^-) are also involved in the modulation of chlorophyll and primary production (Cunha *et al*., 2000; Almeida *et al*., 2002). Unstable periods, which are represented by a situation of mixing of the water column, cause an increase of nutrients, either by sediment resuspension or riverine water input (dependent on the seasonal cycle).

The subsequent stratification period presents the necessary conditions to induce phytoplankton growth. The important factor on fluctuation of nutrients in the estuaries are source of freshwater, dissolved inorganic nutrients (Malone *et al*., 1983; Fisher *et al*., 1988, 1992; Hardling *et al*., 1986, 2002) superimposed on the annual cycles of chlorophyll a and p.p.

Variability is associated with frontal features and tide (Cloern *et al*., 1983; Seliger *et al*., 1981; Hood *et al*., 1999); lateral gradients driven by estuarine circulation (Malone *et al*., 1986) and the outecology of individual bloom forming species (Tyler *et al*., 1982). The measurement of chlorophyll a is one of the estimation methods for determination of phytoplanktonic biomass rate.

Of other effective factors on rate of chlorophyll a, nutrient and especially total phosphorous are worth mentioning. Furthermore, factors such as transparency depth and water temperature are considerable. Many phytoplankton researchers think that planktonic pattern in large rivers results from interactions among river morphology, hydrology, light availability and algal growth rate (Desey and Gosselain, 1994) and the seasonal dynamics of phytoplankton is regulated by nutrient concentration.

The zooplankton community structure in estuaries is like phytoplankton composition and the variability observed in the distribution of zooplankton is due to abiotic parameters (e.g., Climatic or hydrological parameters: temperature, salinity, stratification, advection), to biotic parameters (e.g., food limitation, predation, competition …) or to a combination of both (Christou, 1998; Escribano and Hidalgo, 2000; Beyst *et al*., 2001).

However, due to multifactorial relationships. It is difficult to correlate zooplankton variability with those environmental factors intentioned (Fromentin and Ibanez, 1994).

Estuary ecosystems are of particular interest for studying zooplankton variations because they are subject to strong fluctuations of hydrological parameters that are directly influenced by climatic variation (Viitasalo *et al*., 1995).

Caspian sea is the largest lake on the face of the earth. It is home to more than 100 different species of fishes and the most valuable sturgeon fishes endemic to their habitat are dependent on discharging rivers such as Sefid-Rood for their reproduction.

Sefid-Rood is the largest and the longest river in southern Caspian Sea watershed. This river with regard to the rate of discharge, depth, different human usage, spawning ground for some of the most important migratory fish is the most important estuary along the southern coastline. It is a part of Boujagh National Park which is also an important international wetland on Ramsar site having a temperate perhumid climate. It is protected by the Department of Environment, has 3276 ha area and serves as an important habitat for aquatic birds and conservation of sturgeon fished. The region is located about 26 m below, precipitation and temperate of 1260 mm and 16°C, respectively (Darvishsefat, 2006). Despite of existence of more than 250 seasonal and permanent rivers in the southern Caspian Sea watershed, so far no estuarine studies have been conducted and thus this study is considered to be the first of its kind in north Iran.

MATERIALS AND METHODS

Description of Sampling Sites

Sefid-Rood estuary (Fig. 1) at the mouth of the Sefid-Rood river is a shallow and tideless estuary on the south west coast of Caspian sea in the north of Iran. The estuary is characterized by a salinity gradient, which is caused by the dominance of freshwater riverine run off. For sampling, five stations were selected from the offshore station about 2 km away from the shore with a depth of about 10 m and other 4 up to about 7 km upstream. Sampling was done monthly throughout the year (November 2005-October 2006) at 3 substations.

Physical and Chemical Variable

Water samples were collected to analyze different parameters including water temperature, salinity and pH and were measured *in situ* with a thermometer, an ATAGO S/Mill-E refractometer and a HI9813 pH meter (Hanna Instruments), respectively. Transparency was obtained using a 20 cm diameter secchi disk. Water sample for nutrient analysis and chlorophyll a determinations were transferred into pre-rinsed 1 L and 15 plastic bottles, the bottles were then tightly stopperred and stored under ice.

In the laboratory, 500 mL sub-samples from the 1 L bottles were filtered through 0.45 μm Whatman GF/F filters for soluble nutrient determination. In most cases, the filtered samples were analyzed on the day of sampling . Nitrate-nitrogen was determined as the nitrite ion using the sulphanilamide method after reduction through a copper-cadmium column (Mackereth *et al.*,1989). Soluble reactive phosphorus was determined as orthophosphate using the ascorbic acid method. Silica was determined on filtered samples using the molybdosilicate method on filtered. All the nutrients were determined using a Jenway 6300 Spectrophotometer (American Public Health Association, 2005).

Chlorophyll a and Planktonic Analysis

Sample for the quantification of chlorophyll a were filtered through GF/F Whatman filters then frozen for later analysis. The pigments were quantified with a Shimadzu UV-1603 spectrophotometer.

Water samples (100 mL) with three replicates for phytoplankton identification and cell counts were collected and immediately fixed with Lugol's solution. After homogenizing the samples, subsamples were allowed to settle on 5, 10 and 25 mL sedimentation chambers and counts were performed using an inverted light microscope Olympus IX70, at 400x magnification. At least 200 cells were counted, Small phytoplankton identification was mainly based on Ricard (1987) and Round *et al*. (1990).

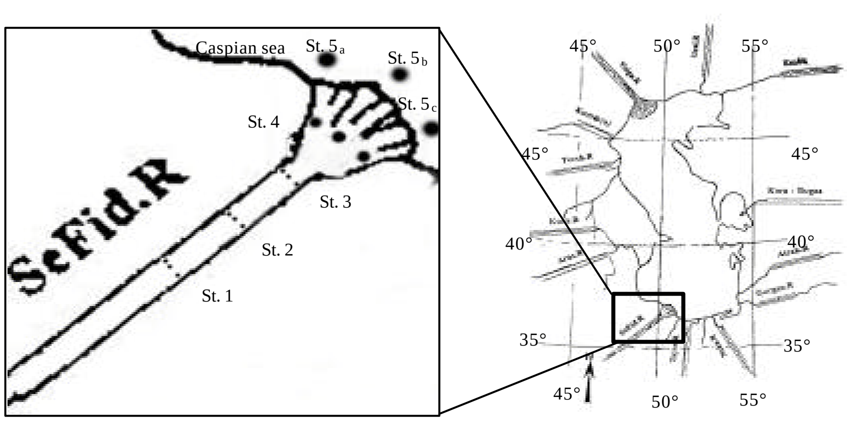

Fig. 1: A map showing the study area and sampling stations

Zooplankton samples were collected monthly at the five stations from November 2005- October 2006 at sub surface level, using 60 µm mesh size net and preserved in 4% buffered formaldehyed. The volume of water filtered through the net was monitored with a Hydrobios digital flowmeter.

Statistical Analysis

Three way analysis of variance (ANOVA) for site effects, water depth and sampling date was used to test the possible existence of significant difference among dates available. Two- and one-way ANOVA were also used to test the existence of significant differences between sites and sampling dates. Multiple comparison among pairs of means were performed using the T-method (Tukey's honestly significant differences method) when a significant ANOVA result occurred. Homogeneity of variances was tested using the Hierarchical cluster analysis and component plot analysis (Sokal and Rohlf, 1995).

RESULTS

Physical and Chemical Variable

Water temperatures ranged between 10°C in January and 26°C in August with a mean of 17.2±8.6 and no significant differences were found between sites. Salinity ranged between 1 and 13 throughout the year. These values were higher during Summer months and were reduced by increased in rainfall and river input (Fig. 2). pH values were constant throughout the year with an

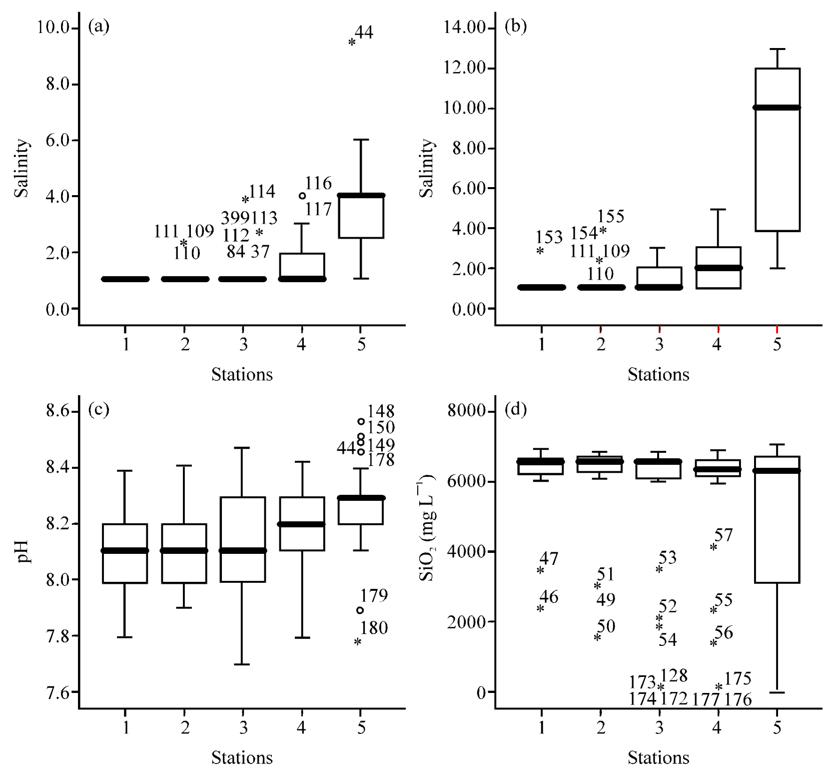

Fig. 2: Salinity of surface water (a), salinity of bottom water (b), pH of surface water (c) and SiO_2 of water (d) the study sites

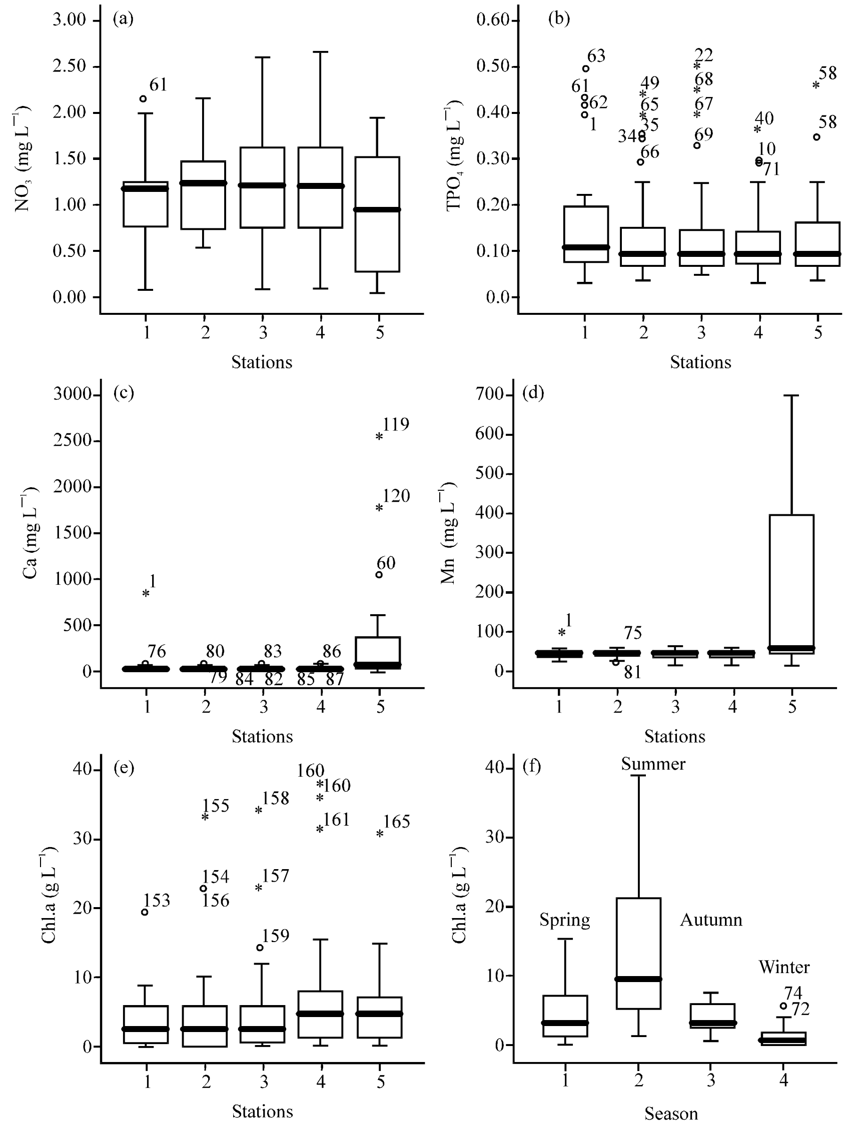

Fig. 3: (a) Ort-p, (b) NO^{-}_{3}, (c) Ca^{+}, (d) Mn, (e) chlorophyll a (f) in the study sites and chlorophyll a during four season

average value of 7.9 ±0.5. No significant differences were found for water temperature, salinity and pH in sites. River flow fluctuated greatly during the study period with a maximum value in November (525 m^3 sec^{-1}) and a minimum in August (122 m^3 sec^{-1}).

Dissolved Inorganic Nutrients

NO_3 represented the predominant form of inorganic nitrogen in the water column. Concentrations showed a similar seasonal pattern for the five studied sites. NO_3 concentrations were higher (1.03-1.93 mg L^{-1}) in Winter reaching extremely low values in Summer (0.52-1.05 mg L^{-1}). NO^{-}_{2} concentrations were usually considerably lower than NO^{-}_{3} and concentrations found in the four studied stations were similar (Fig. 3). Values were higher (0.86 mg L^{-1}) in October but became

Table 1: Mean±SD water quality parameters measured in Sefid-Rood estuary

Months	Water T(°C)	Turbidity (FTU)	Secchi disk (cm)	DO	SiO_2	TP	Ort-p
				(mg L^{-1})			
Nov.	16.9±0.9	693.6±88	27.7±6	8.50±0.3	6.50±0.05	0.14±0.07	0.014±0.01
Dec.	11.8±0.1	>1000	9.6±1.1	6.50±0.1	6.50±0.5	0.20±0.09	0.18±0.06
Jan.	10.7±0.32	37.5±199.32	37.5±14.12	10.10±0.3	6.60±0.14	0.20±0.11	0.12±0.12
Fab.	11.8±2.2	13.33±16.25	79.7±25.6	9.50±0.5	2.90±1.3	0.13±0.14	0.03±0.01
March	10.6±0.17	563.8±235.8	13.7±10.4	10.10±0.7	6.70±0.1	0.32±0.11	0.02±0.01
April	11.6±0.3	160±182.2	20.3±5.8	9.40±0.4	6.70±0.2	0.13±0.03	0.09±0.03
May	20.4±0.4	51.8±23.1	33.0±7.2	8.70±0.3	5.80±0.9	0.09±0.03	0.05±0.01
June	23.5±0.6	2.3±2.8	57.4±13.6	7.70±0.2	5.70±1.6	0.07±0.01	0.01±0.005
July	23.4±0.1	433.7±79.3	28.7±3.8	6.10±0.2	5.60±1.5	0.10±0.1	0.06±0.005
Aug.	26.8±7.7	144±19.43	47.2±10.2	8.90±0.1	5.80±1.1	0.09±0.007	0.11±0.1
Sep.	23.2±6.2	137±13.7	60.0±16.1	7.10±0.1	6.60±0.09	0.07±0.005	0.05±0.01
Oct.	22.4±5.1	>1000	9.3±13.1	4.10±0.1	5.80±0.001	0.07±0.01	0.15±0.29
Annual average	17.2±8.6	311.86±345	36.5±25.33	8.69±2.88	5.68±1.91	0.13±0.1	0.103±0.13

Months	NH^+_4	NO_3	NO_2	Ca^+	Mg^+	TOC	Chlor a
	(mg L^{-1})						(µg L^{-1})
Nov.	0.20±0.10	1.13±0.17	0.02±0.04	65.0±1.2	52.0±2.2	9.04±1.3	3.87±1.8
Dec.	0.22±0.17	1.93±0.07	0.03±0.10	23.9.2	40.7±4.4	8.92±1.32	3.79±1.99
Jan.	0.28±0.15	1.57±0.42	0.01±0.005	12.0±0.9	46.8±0.7	2.70±2.5	1.18±1.38
Fab.	0.26±0.10	1.03±0.40	0.01±0.01	133.3±292	55.9±33	9.16±1.06	0.63±0.36
March	1.49±1.80	1.91±0.41	0.18±0.07	28.0±13.0	38.3±7.7	8.06±2.3	1.85±1.96
April	0.42±0.30	1.36±0.12	0.01±0.003	48.8±8.5	18.3±3.9	5.20±1.2	3.75±4.4
May	0.25±0.15	1.24±0.07	0.03±0.01	30.7±0.46	92.4±131	5.40±1.08	3.24±2.47
June	0.35±0.13	0.56±0.18	0.02±0.006	297.5±0.771	106.1±142	7.13±1.3	7.49±4.3
July	0.49±0.13	0.80±00.03	0.08±0.03	69.0±0.95	42.0±2.3	4.55±0.4	NO
Aug.	0.86±0.003	1.050±0.07	0.03±0.006	42.4±0.67	131.9±148	6.27±2.2	5.08±2
Sep.	0.50±0.02	0.52±0.004	0.05±0.04	77.47±0.110	125.30±21	20.80±2.4	22.85±2.5
Oct.	1.03±0.2	0.09±0.03	0.86±0.14	131.7±0.88	146.10±96	16.72±3.0	NO
Annual average	0.512±0.66	1.13±0.57	0.05±0.21	77.08±266.2	72.91±108.3	10.30±9.9	4.48±7.45

NO: Not observed

relatively constant (around 0.01 mg L^{-1}) during Winter. NH^+_4 Concentrations fluctuated between 0.22 and 1.49 mg L^{-1} and showed no consistent seasonal pattern. Phosphorus concentrations were normally very low throughout the study period. In some months the concentration of total phosphorous (TP) in the surface waters were 0.07–0.32 mg L^{-1}. The minimum phosphate levels were close to the limit of detection of the instrument (0.02 mg L^{-1}). Silica levels were relative consistently high throughout the study period. High values in March and April and low value was in February.

Total Organic Carbon (TOC) concentrations were 2.7 in January to 20.8 in September. Chlorophyll a concentration in surface waters showed a strong seasonal variation (0-22.8 µg L^{-1}) usually with higher values during Summer (Table 1).

Phytoplankton

Totally, 94 genus of phytoplankton were identified ranging from freshwater to Brackishwater species the results of which are shown in Table 2. The most abundant freshwater genus is Chlorophyceae. It is followed by Bacillariophyceae, Chrysophytes, Cyanophytes, Pyrophytes and Euglenophytes.

A total of 94 phytoplankton species were identified in the RSE (Table 2). There were five main groups including: Bacillariophyceae, Cyanophyceae, Chlorophyceae, Pyrrophyceae and Euglenophyceae. Phytoplankton was largely dominated by Bacillariophyceae throughout the year in

Table 2: Phytoplankton species list for all 5 stations in the Sefid-Rood estuary

Genus	Species	1	2	3	4	5
Bacillariophyceae						
Achnanthes	sp.				+	+
Amphora	*ovalis*			+	+	+
Bibbulphia	*mobiliensis*					+
Chaetoceros	*rigibus*					+
Chaetoceros	*simplex*					+
Chaetoceros	*subtilis*					+
Cocconieis	*costata*	+	+	+	+	+
Coscinodiscus	*granii*		+	+	+	+
Cyclotella	*affinis*	+	+	+	+	+
Cyclotella	*caspica*	+	+	+	+	+
Cyclotella	*meneghiniana*	+	+	+	+	+
Cymatopleura	sp.			+	+	+
Cymbella	*affinis*	+	+	+	+	+
Cymbella	*angustata*	+	+	+	+	+
Cymbella	*gibba*	+	+	+	+	+
Cymbella	*lanceolata*	+	+	+	+	+
Cymbella	*mexicata*	+	+	+	+	+
Cymbella	*prostrate*	+	+	+	+	+
Diatoma	*elongatum*	+	+	+	+	+
Diatoma	*vulgare*	+	+	+	+	+
Epithemia	sp.	+	+	+	+	+
Fragilaria	sp.	+	+	+	+	+
Gomphonema	*affine*	+	+	+	+	+
Gomphonema	*angustatum*	+	+	+	+	+
Gomphonema	*olivaceoides*	+	+	+	+	+
Gomphonema	*olivaceum*	+	+	+	+	+
Gomphonema	*ventricosum*	+	+	+	+	+
Gyrosigma	*acuminatum*	+	+	+	+	+
Gyrosigma	*fasciola*	+	+	+	+	+
Gyrosigma	*gaci*	+	+	+	+	+
Gyrosigma	*scalproida*	+	+	+	+	+
Gyrosigma	*wansbackii*	+	+	+	+	+
Hantzschia	sp.	+	+			
Melosira	*moniliformis*	+	+	+	+	+
Melosira	*varians*	+	+	+	+	+
Navicula	*creptocephala*	+	+	+	+	+
Nitzschia	*acicularis*	+	+	+	+	+
Nitzschia	*longissima*	+	+	+	+	+
Nitzschia	*reversa*	+	+	+	+	+
Nitzschia	*tenirustris*	+	+	+	+	+
Nitzschia	*termalis*	+	+	+	+	+
Nitzschia	sp.	+	+	+	+	+
Pinnularia	*interrupta*				+	+
Pinnularia	*nobilis*				+	+
Rhicosphenia	sp.			+	+	+
Rhizosolenia	*carcar-avis*			+	+	+
Rhizosolenia	*fragilissima*		+	+	+	+
Skeletonema	*costatom*				+	+
Skeletonema	*subsalsum*			+	+	+
Surirella	sp.				+	+
Synedra	*ulva*	+	+	+	+	+
Tabellaria	*fanestrata*	+	+			
Thalassiosira	*affinis*			+	+	+
Thalassionema	*nitzschoides*					+
Thalassionema	*variabilis*					+
Cyanophyceae						
Anabaena	*elabens*	+				
Anabaena	*nodsonii*	+				
Anabaena	*spiroides*	+	+			
Lyngbya	*limnetica*				+	+
Merismopedia	*punctata*	+	+	+	+	

Table 2: Continued

Genus	Species	1	2	3	4	5
Bacillariophyceae						
Nostoc	sp.					+
Oscillatoria	*limosa*	+	+	+	+	+
Oscillatoria	*tenuis*	+	+	+	+	+
Chlorophyceae						
Ankistrodesmus	*acicularis*	+	+			
Binuclearia	*lauterbornii*					+
Cladophora	sp.					+
Chalamydomonas	sp.	+	+	+	+	+
Closterium	*moniliferum*	+	+	+	+	+
Coelastrum	*microporum*	+	+	+	+	+
Oocystis	*solitaria*	+	+	+	+	
Oocystis	*borgei*	+	+	+	+	
Pandorina	*morum*		+	+	+	
Pediastrum	*duplex*		+	+	+	+
Pediastrum	*boryanum*		+	+	+	+
Scenedesmus	*acuminatus*	+	+	+	+	
Scenedesmus	*obliquus*		+	+	+	+
Spirogyra	*calospora*	+	+	+	+	+
Strastrum	*gracile*	+	+			
Ulothrix	sp.		+	+	+	+
Zygnema	sp.	+	+			
Pyrrophyta						
Ceratium	*corvatum*				+	+
Ceratium	*fusus*				+	+
Cryptomonas	*ovata*					+
Exuviaella	*cordata*					+
Exuviaella	*marina*					+
Procentrum	*micans*					+
Procentrum	*optusum*					+
Procentrum	*praximum*					+
Procentrum	*scutellum*					+
Euglenophyta						
Euglena	*acus*	+				
Euglena	*viridis*	+				
Phacus	*arbicuraris*					+
Trachelomonas	*crebea*	+	+	+	+	+
Trachelomonas	*spiculifera*	+	+	+	+	+

+: Observed

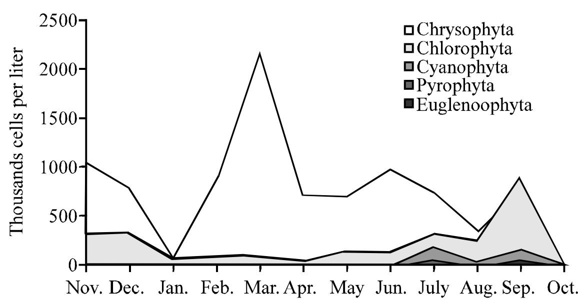

Fig. 4: Quantitative counts of dominate phytoplankton by groups for the November 2005 to October 2006 in Sefid Rood estuary

all five sampling stations (Fig. 4). Chlorophyceae like Bacillariophycea dominated in SRE all year long but in comparison to the population of diatoms its number was very low. Cyanophyceae was observation only during the summer (Fig. 5). Freshwater species were dominated in stations

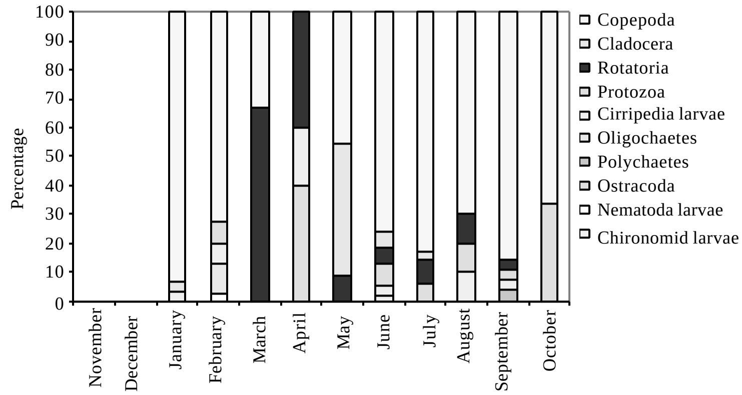

Fig. 5: Percentage of the main zooplanktonic groups from SRE in the sampling period

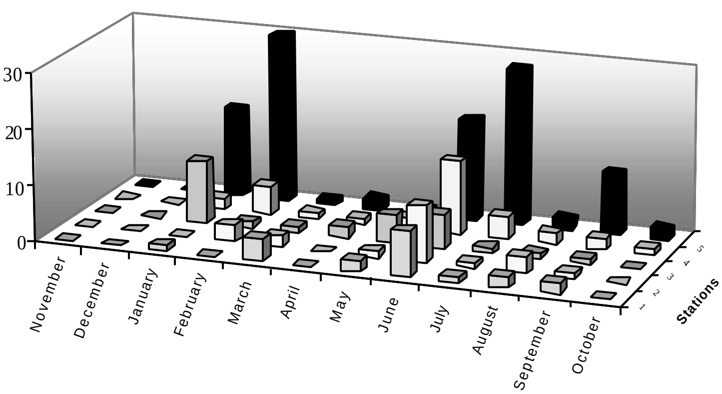

Fig. 6: Zooplankton abundance at various sampling station in the SRE

1, 2 and 3 whereas brackish and marine water species specially had dominated the station 5. The two-way ANOVA analysis showed that the season was a significant source of variation and fluctuations of density species.

A total 34 zooplankton taxa were identified during sampling period (Table 3). The community was dominated estuary and estuarine/marine copepods (68/72%) and other groups were Rotifera (9.61%), Cladocera (5.65%), Protozoa (5.5%), Nematoda larvae (0.5%), oligocheata larve (1.6%), polychaeta larve (0.5%), *Ostracoda* sp. (1.6%), *Cirrpedia* sp. (5.1%) and Chironomid larvae (1.1%). During the year copepod were dominant groups but Rotifere was main zooplankton taxa in SRE in April. However, no zooplankton groups have been identified in this estuary during the months of November and December. Along the sampling stations the taxa *Acartia clausi*, *Copepoda nauplii* and *Brachionidue leydigi* have been observed indicating that toward the sea total number of zooplankton specially in station 5 increase dramatically (Fig. 6).

The zooplankton densities showed no significant differences between station but the densities of copepod and Rotatoria were significant. The two-way ANOVA analysis showed Nauplii copepod, Cladocera, Rotatoria had a significant differences between seasons.

Table 3: List of most abundant zooplankton taxa at stations Collected from the SRE during the Sampling period

	S1	S2	S3	S4	S5		S1	S2	S3	S4	S5
Copepod						*Polyarthera* sp.	+	+			
Acartia clausi	+	+	+	+	+	*Rotaria* sp.	+	+			
Acartia nauplii					+	*Syxcheatidae*				+	
Harpacticoids			+			*Trichoceridae*	+	+			
Paracyclops fimbratus				+		**Cirripedia**					
Cyclops sp.	+	+	+	+		*Cirripedes nauplii*		+	+	+	+
Copepoda nauplii	+	+	+	+	+	*Balanus nauplii*				+	+
Cladocera						*Cypris Balanus*				+	+
Bosmina coregoni		+	+	+	+	**Protozoa**					
Chydorus sphaericus			+			*Arcella volgaris*				+	
Diaphanosoma brachyurum	+					*Centropyxis* sp.				+	+
Daphnia longis pina			+			*Ciliophora*				+	+
Macrothrix laticornis	+					*Didinium* sp.			+	+	
Monia rectirostris	+					*Pelecypoda*					+
Rotatoria						**Oligochaetes larvae**		+	+	+	+
Brachionidue leydigi	+	+	+	+	+	**Polychaetes**				+	+
Cephalodella sp.	+					**Chironomida larvae**			+	+	
Keratella valga	+	+	+	+	+	**Ostracoda**			+	+	+
Mytilin ventralis	+					**Nematoda larvae**					+
Platyias xuadricormis				+							

+: Observation

DISCUSSION

Since the Caspian Sea lacks tides, the water input from sea into the Sefid-rood River is affected by winds and waves. But the results obtained during this study were interestingly similar to the other meso and tidal estuaries.

In Sefid-Rood estuary, salinity is fluctuated between partially stratified during summer and vertically homogeneous during fall, winter and spring.

No difference was observed in several physical, chemical and biological variables, such as temperature or chlorophyll a concentration among sites and results were very similar to the other shallow temperate estuaries.

The measured mean chlorophyll a was 4.46±7.45 μg L^{-1} and a mean dissolved inorganic nitrogen (DIN) concentration of 1.7 mg L^{-1} was observed with seasonal variation relating to the river flow.

For phytoplankton, NO^{-}_{3} and NH^{+}_{4} are the most important source of nitrogen (Wetzel and Likens, 2000). There was a strong fluctuations throughout the year which is considered to be related to the seasonal changes.

For equivalent river flow values, DIN average concentrations were alike and chlorophyll a values were within the same range. The consistency between data from different periods result from the fact that general climatic and meterological parameters and modeling approaches in all shallow temperate estuary were very similar (Monbet, 1992; Cloern, 2001). For example, in the Riade Aveiro estuary (in Portugal), chlorophyll a concentration was between 0.4-67 μg L^{-1} and the highest values occurred during spring blooms (Capriulo *et al*., 2002). In the Tagos river estuary in the west of Europe is 5.4 μg L^{-1} (Gameiro *et al*., 2004) and in the Nakdong River in Korea is 30 μg L^{-1} (Kyong *et al*., 2002).

The annual measurements of chlorophyll a are the best indicators for primary production and eutrophication in the estuaries (Harding and Pervy, 1997). In the aquatic ecosystems fluctuations of chlorophyll is related to the amount of dissolved nutrients and weather characteristics (Hardling *et al*., 1986). In Sefid-Rood estuary the important factors are water temperature, salinity (Fig. 7) and turbidity, noticing dissolved inorganic nutrients are less important.

According to Nasrollahzadehsaravi and Hosseini (2004) study the maximum concentration of chlorophyll a had occurred during the spring while these results showed that this maximum occurs during the Summer.

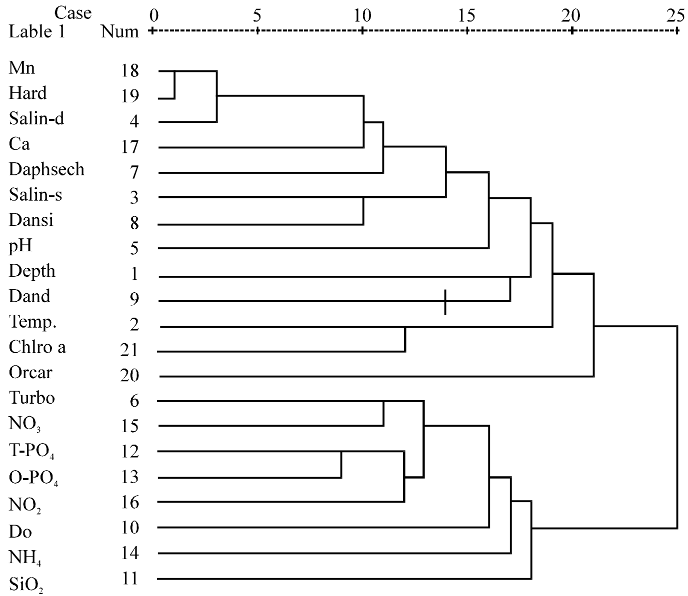

Fig. 7: Dendogram using average linkage (Between groups)

Turbidity is known to be an important factor limiting phytoplankton productivity in estuaries (Cloern *et al*., 1983; Irigoien and Castel, 1997). The turbid conditions in December and October, where chlorophyll a concentration was lower, may have resulted in reduction of phytoplankton production and biomass accumulation. In the high upstream, a dam had been build on this river regulating the water flow and abrupt discharges resulting in phytoplankton biomass seasonal fluctuation control within the estuary environment (Cloern *et al*., 1983).

The SRE appears to be a good estuary ecosystem for the investigation of plankton variation because it is much less polluted and its main species are also observed in other similar temperate estuary.

The study on phytoplankton communities in the southern Caspian has revealed the dominance of Chrysophyta (73 species) and Pyrrophyta (20 species). Moreover, the dominant species of the region are *Rhizosolenia calearavis* and *Exuviella cordata*. The density and biomass of Chrysophyta is 75 and 17% for the Pyrrophyta (Ganjian and Makhlogh, 2003). Respectively *Rhizosolenia*, *Skeletonema* and *Exuviaella* exist in the Caspian Sea which had entered the station 5 by wind and wave actions.

Binuclearia, *Anabean* and *Euglena* were observed in station 1 that is a freshwater environment. However, along the estuary the 4 dominant genus were diatoms (*Diatoma*, *Navicula*, *Nitzchia* and *Cyclotella*).

Earlier studies on southern Caspian Sea mentions silicon as the most effective element on biomass of diatoms with concentration levels at 3-16 mg L^{-1}. However this study showed that the most effective factors in this regard are river flow and water temperature.

In Sefid-Rood estuary Bacillariophyceae are dominant throughout the year but Chloropycea, Cyanophycea, Pyrophycea and Eglenophycea observed in a short period of time. Seasonal and temperature change are the most important factors in the Sefid-Rood estuary controlling the density of phytoplankton (Fig. 8).

Mesozooplankton densities follow a seasonal pattern of variation which is well known in different areas all around the world (Licandro and Ibanez, 2000) and is always much more important

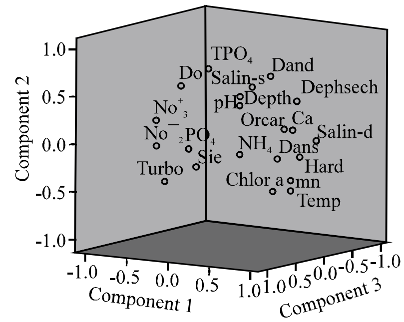

Fig. 8: Component plot between physical and chemical factors and chlorophyll *a* concentrations in Sefid-Rood estuary

than annual variability. The dominant species in the SRE are the Calanoid Copepoda Species. This is typical brackish water constituent abundant in many European (Sautour and Castel, 1995) as well as American Estuaries. During the period of investigation no significant differences were observed for salinity between surface and bottom waters: the water column appeared non homogeneous and Oligohaline area, might explain why the Copepoda Species were homogeneously distributed over the water column. Turbidity is the main factor controlling the longitudinal distribution of zooplankton of species in SRE, Unlike North European estuary (Sautour and Castel, 1995). Acartia spp. is dominant Copepod species in the SRE like other turbid estuaries (Irigoien *et al*., 1995).

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