Research Journal of Environmental Sciences

ISSN 1819-3412

Academic
Journals Inc.

www.academicjournals.com

Research Journal of Environmental Sciences 3 (1): 1-15, 2009
ISSN 1819-3412

Phytoplankton Primary Production and Distribution in a South Caspian Sea Basin Case Study in Tajan River Estuary

[1,2]M. Shapoori, [3]A. Javanshir, [4]S. Jamili, [5]M. Fallahi and [6]R. Changizi
[1]Science and Research Branch, Islamic Azad University, Iran
[2]Savadkoo Branch, Islamic Azad University, Iran
[3]Faculty of Natural Resources, University of Tehran, Karaj, Iran
[4]Iranian Fisheries Research Organization, Tehran, Iran
[5]Guilan Aquaculture Research Institute, Bandar Anzali, Iran
[6]Babol Branch, Islamic Azad University, Iran

Abstract: The phytoplankton community composition, abundance and size-fractionated biomass (chlorophyll a) along with various physical and chemical parameters were assessed in Tajan estuary, in South Caspian Sea Basin. Monthly sampling was conducted at 6 stations. Based on results, the mouth or formed estuary could be categorized in three different classes. Category 1: station essentially related to river input and low net production (vary between 13.8 and 46.4 mg m^{-3} $year^{-1}$. Category 2: consists of high net production (between 277.9 and 330.4 mg m^{-3} $year^{-1}$) and mild consumption of (8.4 to 32.5 mg m^{-3} $year^{-1}$). The 3rd category is considered to be in the middle of two above values from productivity point of view with (236.7 to 240.2 mg m^{-3} $year^{-1}$) and relatively mild consumptions of (20.9 to 92.4 mg m^{-3} $year^{-1}$). It seems that importance of such areas is much more in their nutrient inlet of the river from upper mouth. Net primary productions were high in the center of estuary with values near to 277 mg m^{-3} $year^{-1}$. Selected station in lower mouth situated in the adjacent area inlet also showed high concentrations of 330 mg m^{-3} $year^{-1}$, which suggests the existence of a nutrient front where fresh waters originated from rivers (rich in nutrient and phytoplankton decomposition materials) joint salt waters of the sea. In these stations phytoplankton has not enough time to be consumed because of soft sediments instability and inevitably is added to south Caspian basin production. Also primary production among months and seasons shows fluctuations, perhaps related to water inlet availability and residence time. There suggests a correlation between primary production and river discharge in different selected stations.

Key words: Caspian Sea, Tajan River, primary production, phytoplankton composition, chlorophyll a

INTRODUCTION

In coastal ecosystems, net phytoplankton primary production is regulated by the interaction of several a biotic (nutrient fluxes, light availability and physical variability) and biotic factors (grazing pressure and competition). In such systems, nutrients are highly influenced by anthropogenic activity and climatic variability via coastal upwelling events or continental inputs. Indeed, the functioning of coastal ecosystems are closely linked to that of freshwater systems, upstream of coastal systems as the nutrient concentrations and ratios of waters discharged to coastal areas largely depend on

---

Corresponding Author: Maryam Shapoori, Science and Research Branch, Islamic Azad University, Iran agricultural and industrial activities, but also on freshwater biological activity upstream to coastal areas as well as on the nature of the sediment in the drainage basin. Over the last decades, the increase of anthropogenic inputs of nitrogen and phosphorus have lead to severe eutrophication problems, inducing an enhancement of phytoplankton primary production in many coastal areas (Lohrenz *et al*., 1997; Cloern, 2001).

In addition to increasing primary production, the alteration of these nutrient ratios, such as the decline of Si:N ratios, has inevitable effects on the taxonomic composition of phytoplankton communities. For instance, anthropogenic fertilizations tends to diminish the relative Si availability when compared to N and P, resulting in a decline of diatom proportion in the phytoplankton communities (Justic *et al*., 1995) affecting trophic pathways and energy transfer efficiency (Turner *et al*., 1998). However, it is now recognized that there is large differences among coastal ecosystems in the magnitude and character of responses of phytoplankton biomass or primary production to nutrient enrichments (Cloern, 2001). In part, this is due to the complex interaction of nutrient limitation and light limitation in coastal systems (Cloern, 1999), as well as to the influence of residence time on community structure and ecological interactions, which will condition the export of nutrients and phytoplankton biomass (Lucas *et al*., 1999; Cloern, 2001).

Further, in some coastal ecosystems, the elevated abundance of suspension feeders which consume phytoplankton live crop reduces phytoplankton accumulation, even in the presence of increasing nutrient levels (Cloern, 2001). Therefore, due to the complex interaction of the factors that determine the sensitivity of coastal ecosystems to nutrients, a linear response of eutrophication to nutrient loading does not appear to apply in such systems. Thus, to develop appropriate management strategies, it appears necessary to fully understand the ecosystem functioning and first of all the relationships existing between phytoplankton primary production, its consumption and nutrient patterns. The objectives of this study were to define variability in the phytoplankton communities and to determine primary production and its consumption (consist of; dispersion by currents, its mortality and consumed by filter feeder of zooplankton, benthos community or filter feeding fishes) by benthic communities as a livestock in the Tajan river estuary in south Caspian Basin.

This river and its estuary do not suffer from an excess of nutrients and eutrophication signs have not yet been seen. However, the increase of anthropogenic pressure (biological exploitation, urban development, tourism, agricultural activities) and the occurrence, during the last few years, of increasing toxic events in the river makes this part of river a sensitive area.

Other pressures, such as decrease in water inflow due to agricultural needs in upstream part of the river, have been shown to aid in the early start of phytoplankton production within the year (i.e., February March) leading to subsequent phytoplankton blooms whose intensity and composition could be nutrient-controlled as early as the spring. The specific objective of this study is to characterize the primary production variability and its consumption in order to show the role of Tajan River and its estuary in nutrient flux of south Caspian Sea basin during an entire annual cycle in relation to environmental and biological parameters. In this study, we address the following questions: what factors explain the spatial and temporal variability of phytoplankton biomass in Tajan river estuary and more precisely, what are the consequences of blooms in different parts of this estuary on consumption by animal population (mainly benthic community)? The seasonal and spatial variability of phytoplankton primary production is here discussed in relation to residence time and inflow debit variability and the elemental nutrient ratios of the water body have been used to evidence potential limitation of phytoplankton primary production (Beardall *et al*., 2001). Finally, we give for the first time an estimation of the annual phytoplankton production and consumption in a river in south Caspian basin based on monthly sampling.

MATERIALS AND METHODS

Study Area

The Tajan estuary is one of the largest estuaries on the south east coast of Caspian Sea. The climate is mild with a mean air temperature of 16.3°C and total annual precipitation of 700 mm. The estuary has a broad shallow bay covering an area of about 2 km^2 (Fig. 1) and is located in the most populated area of North of Iran. Seawater enters the estuary through a deep narrow inlet channel and sea water is mixed with fresh water from the Tajan River. The Tajan River drains an area of 86000 km^2 and the estuary also receives effluent discharges, mainly from urban, industrial and agricultural sources. The river flow fluctuates seasonally with an average monthly discharge varying from 1.5 in summer to 81.3 m^{-3} sec^{-1} in winter, (Fig. 2) which corresponds to a water residence time of 26 and 8 days,

Fig. 1: Map of Tajan River estuary situation. Circles show the six selected stations in the studied area. Stations 1 to 4 and 6 being in the estuarine area, station 5 is located in the plume area in the sea

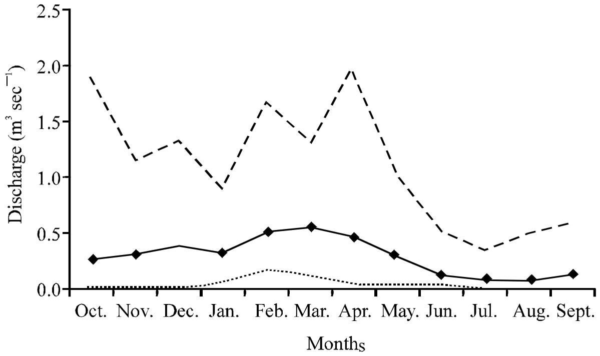

Fig. 2: Comparison among Tajan discharge in m^3 sec^{-1}. (- - - -) averages of 48 years maxima (—◆—) during our study and (··········) averages of 48 years minima. It is figure suggest that, this study was carried out in a relatively dry year compared to maximum points of discharge value. Also from June to September, river debit was not enough to allow water current inflow to the Caspian sea

respectively. The present study was conducted at an area located close to the Caspian Sea ecologic institute, in the middle Tajan estuary (Fig. 1). The exact location of the studied stations is shown in Fig. l. Six sampling stations were considered, selected after a pre-sampling of 12 stations and selected by multivariate analysis and clustering method, hereafter designed by stations l to 6. Stations differed in relation to distance from the estuary and also in relation to their planktonic communities and physical and chemical parameters.

The location of the sampling stations was chosen in order to study the phytoplankton communities located in a polluted area of the Tajan estuary, the Tajan River, where several industrial plants are located on its coasts. Therefore, station 1 and 2 were located along the Tajan River and station 3 at the same longitude but separated from the river by enlarging the river. Station 4, chosen as a control station, was located in the middle of the estuary, away from the influence of industrial discharges. Station 5 in the sea but influenced by Tajan estuary discharge and station 6 in the estuary of a river closely discharging to the estuary's estuary.

Sampling Strategy

Sampling stations were selected based on pre-sampling from 12 hypothesized stations randomly chosen in the area of Tajan river estuary and adjacent river. In each stations phytoplankton composition, nutrient content and physical parameters as pH, conductivity, salinity and temperature were measured. Then utilizing a multivariate analysis, 6 functioning stations were selected where differences among them (in term of Euclidian distance) were maxima. Sampling in these stations remaining constant in the rest of study. Sampling was carried out once per month in the same time for the whole stations. Sampled parameters consisted of biotic and a biotic components of water column (chemical and physical components, phytoplankton)

Methods

Daily river flow data for Tajan River were provided by Study Bureau of Mahab Ghods of Iran. Salinity and temperature measurements were obtained using thermosalinometer (WTW Tetracon 325). Discrete sampling was carried out sub-surface (1 m below the surface) by using 5 L Niskin samplers, fitted with non-toxic silicone tubing. Water samples for nutrient measurements were directly filtered either using glass fiber filters (Whatman GF/C for nitrate, nitrite and phosphate) or using cellulose acetate filters with nominal pore diameter of 0.4 mm (for orthosilicic acid) with a syringe filtration system and stored into 100 mL glass bottles (nitrate, nitrite and phosphate) or into 100 mL polypropylene (PP) bottles (orthosilicic acid). Nutrient samples were then either stored at 4°C for the orthosilicic acid, or frozen (20°C) for the nitrate, nitrite and phosphate.

The remaining water was collected on a 10 L PP carboy for further sub-sampling and filtrations. All samples were kept in an icebox until return to the laboratory (within 2 h). Phosphate (P), nitrate, nitrite (Bendschneider and Robinson, 1952) and orthosilicic acid (Si) concentrations were measured on a Technicon Auto Analyzer II. Ammonium was analyzed.

Samples for the identification of phytoplankton species composition were preserved on board with an acid lugol solution. Phytoplankton species were identified and counted by microscopic examination on an inverted microscope. A minimum of 400 cells was counted leading to an accuracy range of 10%. Net and gross primary production rates were measured during the entire year of study considering their absolute values differences. The experimental design was based on the measurement production of phytoplankton based on biomass and chlorophyll a variations upon months. Phytoplankton fluctuations during months and among stations was calculated, considering differences between two successive values in total biomass in mg m^{-3}, when values are additive, it suggest an addition compared to last sampling (here one month ago) and when there was a decrease of this value (here on month later) it is suggested that a consumption of this production compared to last month has happened. The origin of consumption could be of different kinds. It can be consumed in place by secondary zooplanktonic or benthic feeding activity or be derived from the place by currents or be decomposed by bacterial recycling in microbial loop. However, in our study these compartment are not studied per case and effect of all of them is expressed in consumption of primary production (net or gross).

Data Analysis

Spearman rank correlation analyses were performed on nutrient concentrations (nitrate, nitrite, phosphate and orthosilicic acid) and environmental variables (Tajan river, temperature and salinity) in order to examine significant relationship between environmental variables and nutrient concentrations. Cumulative sums were applied to primary production data to extract general trends in the series and thus, detect seasonal changes. This method involves subtracting a reference value (here the mean of the series) from each data and the successive accumulation of the residuals (Ibanez *et al*., 1993). Seasonal and spatial differences of integrated phytoplankton primary production averages were examined using a 2-way ANOVA.

RESULTS

Environmental Variables

The general pattern of the Tajan River flow rates recorded during the 2006 annual discharge (Fig. 2) followed a seasonal variation characterized by maximal values in fall and winter (seasonally averages; 1.45 and 1.30 m^{-3} sec^{-1}, respectively) and minimal values during summer (average of the season; 0.48 m^{-3} sec^{-1}). Many high discharges were observed during spring season in this study with an average of 1.16 m^{-3} sec^{-1}. Low discharge during summer led to high residence time beyond the lack of nutrient inflow from upper Tajan River.

Physical and Chemical Variables

Water temperatures ranged between 25.83°C in station 6 and 28.24°C in station 4 and no significant differences were found between stations (Table 1). Salinity ranged between 3.51 and 12.5% throughout the year. Salinity values were higher during summer months and were reduced by increased rainfall and river input. For whole water column, station 1 had significantly ($p<0.001$) lower salinity than other stations, because it is the closest station to the Tajan River; pH values were constant throughout the year with an average value of 8.01±0.45. TSS was relatively constant throughout the year and annual means ranged between 3142.96 and 11274.81 mg L^{-1} TSS values were significantly ($p<0.05$) higher for station 5 and significantly ($p<0.01$) lower for station 1 and 6. The studied period corresponded to a dry year and the Tajan annual river flow value was less than half of the average of the last 30 years. River flow fluctuated greatly during the study period with a maximum value in November (81.3 m^{-3} sec^{-1}) and a minimum in August (1.5 m^{-3} sec^{-1}). These values correspond, approximately, to water residence times in the upper estuary of 8 and 26 days, respectively. With the exceptions of June, October and November, water residence times were considerably higher than average values (Fig. 2).

Dissolved Inorganic Nitrogen

For most of the year, $N\text{-}NO_3$ represented the predominant form of inorganic nitrogen in the water column. Concentrations showed variability among stations. $N\text{-}NO_3$ concentrations were higher (20) in station 5, whereas extremely low values in station 3 (1.67 mg L^{-1}). Average annual concentrations of NO_3 were higher with increased distance from the river. In fact, $N\text{-}NO_3$ concentration at station 3

Table 1: Salinity, pH, water temperature, total suspended substances (TSS), N-NO_3, N-NO_2, Ammonium and chlorophyll a for water column of six station in the Tajan estuary. Values are averages from monthly sampling throughout one year

Stations	S (‰)	pH	T°C	TSS	N-NO_3	N-NO_2	N-NH_4	Chl a
1	3.51	7.99	27.76	3142.90	5.4	1.20	20.25	10.3
2	9.37	8.12	27.16	5780.98	7.6	0.00	17.07	13.4
3	9.03	8.27	27.30	8864.01	1.7	0.00	20.55	18.4
4	8.23	8.22	28.24	7552.37	3.3	0.00	22.40	53.6
5	12.50	7.13	26.24	11274.81	20.0	0.00	24.22	30.8
6	4.52	8.34	25.83	3878.50	12.3	0.00	21.55	14.4

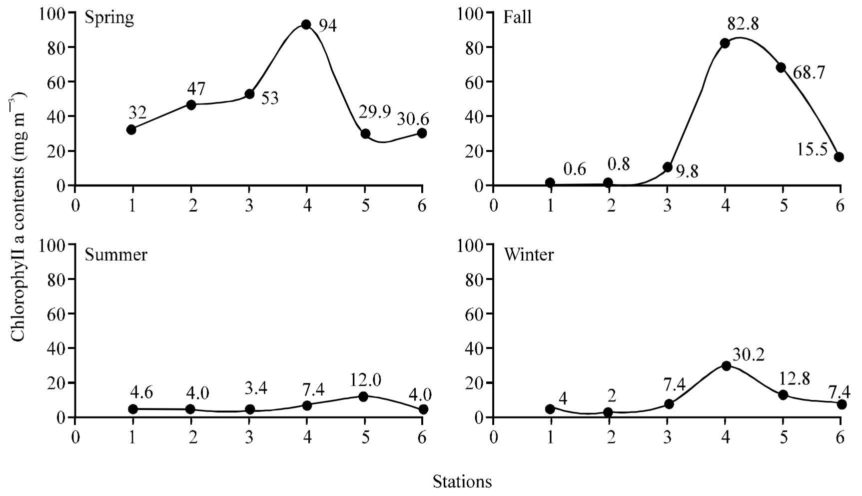

Fig. 3: Fluctuations of chlorophyll a (mg m^{-3}) in water columns of 6 stations during 4 seasons in study area. As it is noted high variations were observed only in spring and fall. Lower quantities and low variation in 6 stations during dry seasons of summer and winter is probably related to low water inflow to the Tajan estuary system. Among 6 stations in wet and dry seasons, approaching to the estuary system, chlorophyll a content increases, related to enhancement in water residence time. The marine station 4, predominate in photosynthetic activities in all seasons

was 8% of that at station 5. However, differences between stations regarding N-NO_3 concentrations were not statistically different. N-NO_2 concentrations were usually considerably lower than N-NO_3 concentrations. The spatial patterns of N-NO_2 concentrations found in the six studied stations were similar where in exception of station 1 in the other points NO_2 was absent. Values were higher (1.20 mg L^{-1}) in station 1 but zero in other stations. Concentrations were significantly higher for station 1 than others.

Chlorophyll a

Chlorophyll a concentration in water column showed a strong seasonal variation (0.6-94 mg m^{-3}) usually with higher values during spring and fall (Fig. 3). Always in stations 3, 4 and 5 showed higher values of chlorophyll a, than other stations. In summer and winter the chlorophyll a content in riverine station (1 and 6) showed similar low contents. A spring bloom (94 mg m^{-3}) and a fall bloom (82.8 mg m^{-3}) were visible only at stations 4. This station had significantly ($p<0.05$) higher concentrations of chlorophyll a than others (Table 1). Samples showed slight higher chlorophyll a content at all stations, especially during the spring bloom. Concerning our estimation of spatial and

Table 2: List of phytoplankton species and their salinity preference as was resulted from our study identified in Tajan river estuary. Diatoms (Bacillariophycea) showed dominant phylum present among station and month, whilst, cyanophytes presented few species in our study

	Stations						
Genera and species	1	2	3	4	5	6	Salinity preference
Bacillariophycea							
Actinocyclus octonqrius	√	√	√	√	-	√	B (F)
Thalassionema nitzschoides	-	√	√	√	√	-	B (M)
Nitzschia sp.	-	√	√	√	√	√	M (B)
Coscinodiscus perforatus		√	√	-	√	-	M
Cyclotella menenghiniana		√	√	√	√	-	M
Gyrosigma attennutum	-	-	-	-	-	-	M
Cyclotella menenghiniana	-	-	-	-	√	-	M (B)
Scletonema costataum	-	-	√	√	√	-	B
Rhizosolenia sp.		√	√	√	√	√	M (B)
Navicula cryptocephala	√	√	√	√	√	√	B
Thalassiosira variabilis	-	√	√	√	√	-	B (M)
Pyrrophyta							
Exuviaella cordata	-	√	√	√	√	-	M
prorocentrum scutllum	-	√	√	√	√	-	M
Gymnodinium sp.	√	√	√	√	√	-	M
Goniaulax spinifera	-	-	-	-	√		M
Goniaulax polyedra	-	-	-	-	-		M
Cyanophyta							
Anabaena sp.	√	√	√	√	-		B (F)
spirulina	√	√	√	√			B (F)
Nostoc	√	√	√	√			B (F)
Oscillatoria sp.	√	√	√	√	-		B (F)
Chlorophyta							
Ankistrodesmus falcatus	-	-	-	-	√		F
Scenedesmus sp.	√	√	√	√			F
Chlorella vulgaris	√	√	√	√			F
Spirogyra sp.	√	√	√	√			F
Oocystis solitaria	-	-	-	-	√		F
Euglenophyta							
Euglena acus	√	√	√	√	√		F (B)
Phacus sp.	√	√	√	√	-		F

F, B and M indicate abbreviations of Fresh, Brackish and sea (Marine) waters preference for phytoplanktonic species, St is abbreviation of saltion

temporal phytoplankton consumption, data of chlorophyll a didn't allow designing the same pathway as net primary production compared to its consumption. The occurred problem can be related to the fact, in river there was another sources of chlorophyll such as detritic plant material issued from agriculture, forests and river's own macrophytes. It seems that in stead of calculate the biomass from chlorophyll a in this river, the estimation of biomass from sample itself was much more precise.

Composition and Abundance of the Phytoplankton

Table 2 lists the identified phytoplankton specie; at the studied estuarine area, the corresponding salinity range, habitat features from literature and the species already referred for the Tajan estuary in previous studies. The great majority of the species found were related to Bacillariophycea, such as *Skeletonema costatum*, *Thalassionema nitzschoides* and *Nitzschia sigma* and *Navicula cryptocephala* were also detected. Most freshwater species, including Chlorophyceae, were limited to station l, the other stations being colonised by assemblages of brackish and marine algae such as *Oocystis* sp. and *Ankistrodesmus falcatus*.

Shannon's Wiener diversity index for the phytoplankton community ranged between 0.5 and 2.5, with higher values during summer months. Station 2 presented a smaller number of species compared to the other five stations. It is clear the continuous accumulation of phytoplankton from May to July. *Thalassionema nitzschoides* and *Rhizosolenia* sp. small diatoms of marine and brackish waters and several pyrrophyta were responsible for the phytoplankton bloom in July in station 5.

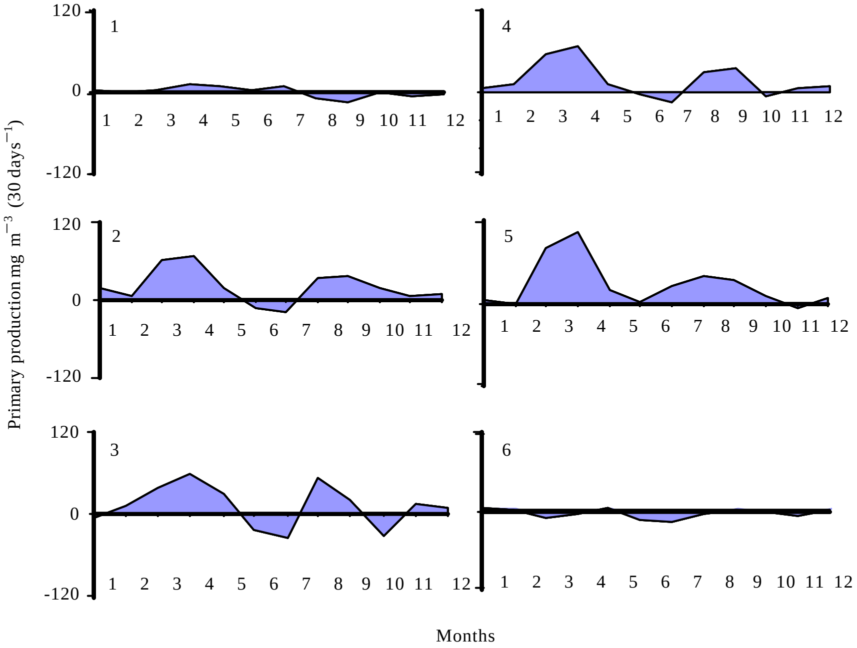

Fig. 4: Monthly fluctuations of primary productions and their consumptions in six stations of study area in Tajan estuary during 12 months. One can observe that there is different maners of fluctuations. In stations 2, 4 and 5 where situated in the interface of the estuary and the sea, perhaps due to the front existence, the production dominate the consumption. Whilst, in station 3 (in the west of the estuary) consumption of material production start to be important. In station 6 where is in the estuary of the little river inflow to the estuary, the consumption of primary production dominate in whole year

Phytoplankton Specific Primary Production, Consumption and Composition

As a general noteworthy feature, most of the phytoplankton primary production was achieved during a 9 months productive period, from April to October (Fig. 4).

This productive period accounted for 84 and 92% of the integrated annual primary production in the marine stations of 4 and 5, respectively.

Based on the monthly patterns and the cumulative sum series (Fig. 4) of the 2006 primary production and consumption rates at both stations, major changes have been distinguished and used to divide the annual cycle into 4 periods characterized by various distinctive features.

- The winter period is the period of lowest primary production rates with values well lower than the annual average (i.e., decreasing slope of cumulative sum series). Also consumption rates dominates in the last three months of the year
- High primary production was occurred during the half end of spring season. One can note that the consumption have not been still started. This can be because of match miss match phenomenon managed by zooplankton community or other potential consumers of phytoplankton in the Tajan river estuary
- In station 1(the river) and 6 (stream inflow to the Tajan estuary) where the residence time is visibly lower than Tajan estuary, primary productions values are near to their lowest rates and it is consumed just after the production. Thus it can be resulted that in flowing stations

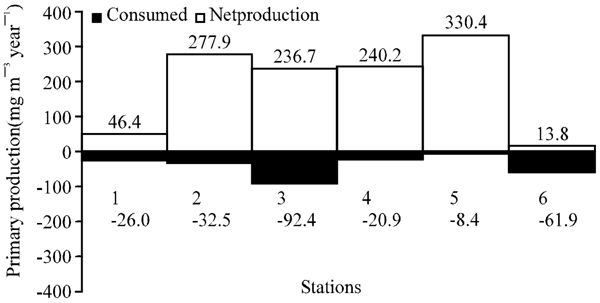

Fig. 5: Comparison between net primary production and consumed quantity of phytoplankton produced among six stations of the study area in Tajan river estuary. Ordinate axis indicates dry weight of phytoplankton produced during one year in one cubic meter. As it is mention in Fig. 4, the two stations of river and little stream (which import nutrient and chemical requirements) have little participation in primary production of Tajan river estuary, but they were our consuming stations in present study. In stations 2 to 6 where stagnation of water or its residence time was longer, one can observe the domination of net primary production compared to its acute consumption. In station 5 that is situated in marine condition, the consumption of net primary production is in its minimum value and suggests that the soft sediments of this station doesn't allow to its consumption in the area of this station

where the resident time is so weak, the low quantity of phytoplankton produced in place is consumed by benthic communities such as insect larvae which due to the optimal habitat conditions, are in numerous quantities.

- In station 3 consumption of phytoplankton production in summer and winter is compensated by important primary production of spring and fall, respectively. This data shows also that 1/4 primary production is consumed in place and the rest is exported to the sea.

Figure 5 compares the fluctuation of net production and its consumption among stations in term of mg m^{-3} $year^{-1}$. Based on these data stations could be classified in 3 categories:

- Stations 1 and 6 which have low net productions of 46.4 and 13.8 and mg m^{-3} $year^{-1}$ consumptions of 26.0 and 61.9 mg m^{-3} $year^{-1}$, respectively. The effectiveness of productivity (the relation of net production into consumption) in these two stations were; 1.78 and 0.22 mg m^{-3} $year^{-1}$. These low productions can be related to their residence time and their nature which is a river point. Thus perhaps phytoplankton has not enough time to reproduce and/or, the produced crop can not remain in place following to the current activity. In station 6 the important consumption of 61.9 mg m^{-3} $year^{-1}$ which is among the highest values in our observations, can be due to its situation near to the little estuary and affected most by the Tajan river estuary than the stream itself the effectiveness of station 6 is below one which confirms its consumption (benthic, zooplanktonic or microbial) is higher than phytoplanktonic activity
- Stations 2 and 5 which among 6 stations have high net productions of 277.9 and 330.4 mg m^{-3} $year^{-1}$ and mild consumptions of 32.5 and 8.4 mg m^{-3} $year^{-1}$, respectively. Their high productions in opposite to the previous case are directly related to their long residence time in the upper part of estuary (station 2) and in the estuary of the sea (station 5). The opposition of fresh and salty waters in station 2 can oblige the water body to reside more time in the area, thus more phytoplankton production in this station. In the station 5 situated in the opposite of

the estuary in the sea, the residence time can not be so long, the existence of a front between salty water of the sea and the fresh water of the river can cause such a high production. In both of these stations, high productions can not be consumed in place and is exported to the sea. In station 2 the composition of benthic substrata follow still its river conditions thus the consumption of crop produced follow the station 1. In station 5 which is situated in instable soft sediments of the south Caspian Sea region, there are not so many benthic animals and this weak benthos has not enough time to consume the crop produced

- The 3rd category consist of stations 3 and 4; which play a medium role in our observations with net productions of 236.7 and 240.2 mg m^{-3} year^{-1} and consumptions of 92.4 and 20.9 mg m^{-3} year^{-1}, respectively. The effectiveness of productivity in these two stations were 2.56 and 11.49 mg m^{-3} year^{-1}, respectively. The low values of effectiveness in station 3 suggest that consumption activity approach to the production. It can be because of formation of benthic or zooplanktonic communities in the heart of estuary related to creation of optimal condition in this point. Station 4 situated near to the extern part of the estuary, play the same role as station 5 with high net production (perhaps due to the existence of nutrient front) and low relatively low consumption (the role of instable soft sediment)

Gross production (net production plus consumption values) show the same aspect as for the net production fluctuations of six stations (Fig. 6). In this case also station can be categorized in 3 classes:

- Two stations of 1 and 6 with gross productions of 20.4 and -48.1 mg m^{-3} year^{-1} and consumptions of 26.0 and 61.9 mg m^{-3} year^{-1}. The negative gross production of station 6 indicates that the high consumption of existing crop in this station is much more than its production capability. These results suggest that this station can not assume its consumption with its so weak net production of 13.8 mg m^{-3} year^{-1}. The difference between the consumption value and the gross production indicate that consumers of this point obtain their feeding requirement from their neighboring area such as 4, 5 and 6 station areas. Weak production of

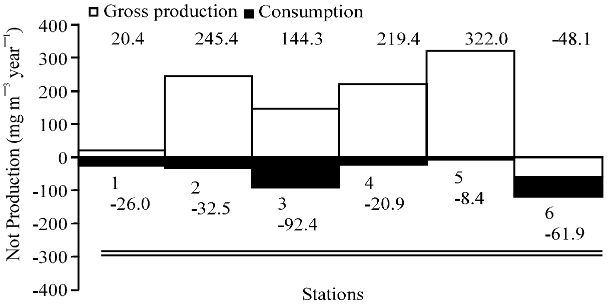

Fig. 6: The comparison between gross production and consumption (dispersion, mortality and consumed) of this production by autochthon animal communities or driven by water flow out of the Tajan river estuary. Ordinate axis show the production in term of dry weight of phytoplankton produced in one cubic meter during an entire year. Two analogous stations of 1 and 6 show low gross productions that are consumed in place just after they are produced. In these two stations, consumption dominates the production. In stations 2 to 5 where they are in the center of the little estuary of Tajan estuary or near to the front built in the sea coast, the production dominates its proportionally little consumption in the area and suggest that the main part of production is exported to the sea. These histograms suggest also the importance of estuarine estuary of the Tajan River in nutrient discharge of the south Caspian basin

station 1 (20.40) oppostation to its consumption of 26.0 mg m^{-3} $year^{-1}$ also indicates that due to its flowing behavior (upper Tajan estuary) the production can not assume consumption. In these two stations, consumption exceeded their productions. Regarding to their situations in this study area, both of them are located in the estuary of the river. It is suggested that their role in Tajan estuary to be nutrient charging than a productive point. While their consumption remain independent of their productive capacity

- Two stations of 2 and 5 show as previous results gross productions of 245.4 and 322.0 mg m^{-3} $year^{-1}$, respectively. The high net production effectiveness (8.5 and 39.3) in these two stations suggests that in stead of consumption these two areas have important roles in Tajan estuary estuarine productivity; the productivity which will be exported to the sea or fed later estuary consumers
- The last category consists of two stations of 3 and 4 with gross productions of 144.3 and 219.4 mg m^{-3} $year^{-1}$. Station 3 as noted above, has beyond its relatively high production, an important consumption. This area has not so many live crops to export to other area or to the sea and the main part of its production (approx. 2. 3rd) is consumed in place. This station suggests being one of the more stable areas in studied points of our observations, where production versus consumption is relatively in equilibrium

DISCUSSION

Nitrogen Variability in Relation to Freshwater Inputs

In Tajan River estuary, over the year 2006, all formes of nitrogen concentrations (ranges: 1.7 to 20.0 mg L^{-3} for NO_3, 0.0 to 1.20 for NO_2, 17.07 to 24.22 for NH_4) were well below those of typical nutrient- enriched areas such as San Francisco Bay (Cloern, 1996), Chesapeake Bay, the Pearl River estuary and the Guadiana estuary (Domingues *et al*., 2005). Among the three forms of Nitrogen, NO_2 concentrations were particularly low, in the same order of magnitude than those measured in non-polluted coastal areas. Thus, Tajan river estuary and its little estuary formed, do not suffer from an excess of nutrients and eutrophication signs have not yet been seen (i.e., high Macroalgae biomass compared to Phanerogams biomass, stability of Macrozoobenthic assemblages as it was observed in other oligotrophic systems such as Arcachon Bay (Castel *et al*., 1996; Bachelet *et al*., 2000). In such fluvial ecosystem, both, water inflows from the river and rainfall, are important parameters which generally control the ecosystem sensitivity to nutrient enrichment (Monbet, 1992; Lucas *et al*., 1999; Cloern, 2001).

The high frequency survey performed in Tajan river estuary permitted to show that major nutrient peaks were often observed. This observation highlighted the importance of the residence time, higher after inundations, that leads to higher nutrient accumulation in the little estuary of the estuary but also to greater exchanges with the sediment interface when the water column depth is shallower. Indeed, during winter, when phytoplankton primary production was low, nitrate and Ammonium concentrations were on average roughly higher in the outer part of the estuary. Concerning Nitrite, comparison of concentrations between upper Tajan estuary and stations situated in the sea (4 and 5) reflect a rapid transformation on this nutrient just after station 1.

In shallow coastal ecosystems, the major sources of nutrients are from rivers, groundwater, atmospheric transport and benthic fluxes (Nowicki and Nixon, 1985; Conley, 2000). In Tajan river estuary, during the wet season (i.e., winter and the early spring), the contribution of groundwater and atmospheric inputs are relatively moderate and the major part of nutrient inputs comes from upper River inputs The insignificant correlation between nitrate, nitrite and Si concentrations in the bay with Tajan River discharges during 2006 confirmed that the estuary is much rather influenced by the sea than inflow of the Tajan inputs. These nutrient loads from the sea are intense but punctual, depending on occurrence of wet or dry state. These rapid nutrient inputs are of considerable importance since

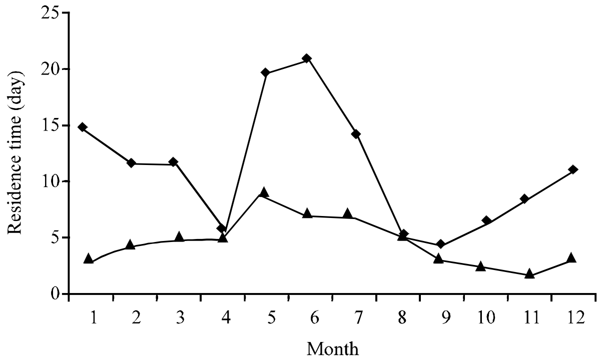

Fig. 7: Tajan river residence time during the studied period (—◆—) and average of last 30 years (—▲—). Being in a dry year caused long residence times of water flow due to low discharges. High values of primary production in term of chlorophyll a are estimated to be related to the combination of these two impacts

they can modify the phytoplankton community structure as phytoplankton can respond rapidly to pulsed nutrient loading events. Ammonium levels did not show exactly the same trend of nitrate, nitrite and Si concentration.

Highest primary production rates were observed in spring (i.e., from the end of February to April) in Tajan River estuary. During this period, phytoplankton community structure was largely varied upon station and season. Stations 1 in upper Tajan estuary dominated by cyanophyta during spring but euglenophyta were abundant during fall and winter. The fast euglenophyta developments coupled to stronger freshwater inputs led to recurrent increase of nutrient levels, especially Nitrogen compounds as early as February-March (Fig. 4, Table 1). In station 2, 3 and 5, pyrrophyta (a marine phytoplankton) were dominant phytoplanktonic group during the whole period of observation regardless of the season. Phytoplanktonic structures of these stations are thus mainly regulated by level fluctuations of the river related to the sea. Pyrrophyta were dominating group of station 4, in spring, while Bacillariophyta were the most abundant in fall and winter. Station 6 in the estuary of stream inlet to the estuary of the Tajan estuary which was dominated by Cyanophyta during spring, fall and winter, showed a freshwater dominated system.

Phytoplankton Primary Production in Relation to Nutritional Environment

In Tajan river estuary, the greatest variability of phytoplankton primary production rates was driven by seasonal changes (Fig. 4). Indeed, during winter periods, primary production rates were lower at all stations due to low solar radiation levels as typically observed in temperate coastal ecosystems (Longhurst, 1998; Cloern, 1999). As early as February- March, an increase of depth-averaged irradiance in the water column provoked the start of the productive period (Gle′ *et al.*, in press). During the productive period (i.e. spring and summer), most of the seasonal, spatial and inter-annual variability of phytoplankton primary production observed seems to be driven by nutrients inflow and high water residence time (Fig. 7).

Among studied stations along Tajan river estuary from upper estuary to the sea, all points were productive in term of primary production except station 6 which were a consumer one. Table 3 show results of sum of primary production and consumption in phytoplankton in studied stations; as it is mentioned, in station 6, there was 9.46 versus 31.46 mg m^{-3} $year^{-1}$ of consumption. This station was an exception in our studies with low primary production and high consumption, but we can suggest that its low capacity of production is rapidly compensated by optimal production conditions by arriving to the estuary of Tajan River (station 2) where production compared to consumption, was 277.38 and 32.49 mg m^{-3} $year^{-1}$, respectively.

Table 3: Showing dominating phytoplankton taxa and species related to net primary production and its consumption. As it is mentioned Bacillariophycea are marine phytoplankton in the estuary system

	Dominant	Prud	Cons	Phylum	Dominant	Prod	Cons	Phylum
Station 1					**Station 4**			
1	Euglena	24.00	-	Euglenaphyta	Exuviaella	8.03		Pyrrophyta
2	Navicula	0.99	-	Bacillariophyta	Exuviaella	13.19		Pyrrophyta
3	Oscillatoria	5.25	-	Cyanophyta	Exuviaella	56.91		Pyrrophyta
4	Oscillatoria	12.45	-	Cyanophyta	Oscillatoria	68.53		Cyanophyta
5	Oscillatoria	8.89	-	Cyanophyta	Oscillatoria	13.52		Cyanophyta
6	Euglena	4.51	-	Euglenaphyta			1.44	
7	Euglena	8.33	-	Euglenaphyta			14.67	
8	Euglena	-	7.81	Euglenaphyta	Exuviaella	28.65		Pyrrophyta
9	Euglena	-	12.92	Euglenaphyta	Synedra	36.36		Bacillariophyta
10	Euglena	1.77	-	Euglenaphyta	Synedra		4.74	Bacillariophyta
11	Euglena	-	3.87	Euglenaphyta	Thalassionema	5.42		Bacillariophyta
12	Euglena	-	1.42	Euglenaphyta	Thalassionema	9.62		Bacillariophyta
Sum		66.19	26.02			240.23	20.85	
Station 2					**Station 5**			
1	Rhizosolenia	19.02	-	Bacillariophyta	Exuviaella	4.87		Pyrrophyta
2	Exuviaella	6.67	-	Pyrrophyta	Exuviaella		1.80	Pyrrophyta
3	Exuviaella	61.11	-	Pyrrophyta	Exuviaella	81.17		Pyrrophyta
4	Exuviaella	67.37	-	Pyrrophyta	Exuviaella	105.08		Pyrrophyta
5	Exuviaella	17.48	-	Pyrrophyta	Exuviaella	19.85		Pyrrophyta
6			12.97		Exuviaella	1.76		Pyrrophyta
7			19.52		Exuviaella	26.15		Pyrrophyta
8	Exuviaella	31.75	-	Pyrrophyta	Exuviaella	39.81		Pyrrophyta
9	Exuviaella	37.93	-	Pyrrophyta	Rhizosolenia	34.21		Bacillariophyta
10	Exuviaella	19.65	-	Pyrrophyta	Exuviaella	9.68		Pyrrophyta
11	Exuviaella	7.19	-	Pyrrophyta	Exuviaella		6.62	Pyrrophyta
12	Exuviaella	9.75		Pyrrophyta	Exuviaella	7.82		Pyrrophyta
Sum		277.38	32.49			330.40	8.42	
Station 3					**Station 6**			
1	Exuviaella		5.16	Pyrrophyta	Oscillatoria	3.81		Cyanophyta
2	Exuviaella	11.26		Pyrrophyta	Oscillatoria	2.05		Cyanophyta
3	Exuviaella	39.61		Pyrrophyta	Actinocyclos		11.17	Bacillariophyta
4	Exuviaella	57.88		Pyrrophyta	Actinocyclos		6.09	Bacillariophyta
5	Exuviaella	29.25		Pyrrophyta	Actinocyclos	3.6		Bacillariophyta
6							14.20	
7							17.14	
8	Exuviaella	52.77		Pyrrophyta	Oscillatoria		4.10	Cyanophyta
9	Exuviaella	20.04		Pyrrophyta	Oscillatoria	2.28		Cyanophyta
10	Exuviaella		31.17	Pyrrophyta	Oscillatoria		2.09	Cyanophyta
11	Exuviaella	15.67		Pyrrophyta	Oscillatoria		7.13	Cyanophyta
12	Exuviaella	10.21		Pyrrophyta	Oscillatoria	2.08		Cyanophyta
Sum		138.00	5.16			9.46	31.46	

Also our results, (Table 2) suggest that different algal composition play the role of responsible of primary productions in different stations and seasons and dominating algae vary related to seasons and stations. It is clear, when nutritive composition changes, phytoplanktonic composition will change also. This point of view of algal composition can play a crucial role on fish and benthic communities which come to the Tajan River estuary for spawning, feeding and other needs. As it was observed personally, this estuary is often a kind of Fish Park for initial stages of many Caspian Sea anadromous fishes. On the other hand, that is several years (from 1973) Iranian Fisheries Organization and similar organizations in Caspian riparian countries (few years before) attempt to release fingerlings of many endangered fishes issued from artificial fish husbandry into river estuary of this sea, in order to rebuilt of fish community stocks.

Endangered fishes of south Caspian basin and those which are highly fished and consumed by local people consist of ; sturgeon fishes (beluga; *Huso huso*, persian sturgeon; *Acipenser persicus*, Russian sturgeon;*A. güldenstaadtii*, Stellate;*A. stellatus*, Ship;*A. nudiventris*) and white fish or kutum (*Rutilus rutilus frissi* kutum).

It is clear that, demographic situation and pollution conditions in south Caspian Rivers during last decades has changed abruptly. Beyond, agricultural activities have largely grown in this narrow area, limited in south, by Alborz mountain chain and in north side by the Caspian Sea coasts. Results showed that during summer months, Tajan discharge was so limited and water inflows from Upper River were rare and irregular during main part of this season. Dissolved nutrients input to the river estuary were also limited and no any algal proliferation was observed. In this condition, river consumption in stations which are dependent to the river, were in their minima (stations 1 and 6). Other parts of the estuary system (stations related to the sea and estuary's own ecosystem) could support this lack of nutrient input during summer which is a result of accumulation of nutrient in a closed system influence by so long residence time.

This study try to show the capacity of a river estuary as an example of other river estuarys where are main places for fish releasing to the sea has variability of production related to space and time. This point of view is crucial when important number of fingerlings which are destinated to be released to the river estuary. Its capacity of reception, time of releasing in the year and species of fish to be released (in relation to food composition in the river) should be already considered.

ACKNOWLEDGMENTS

Special thanks to all of colleagues who cooperated in this projected. This article was complied from Ph.D Shapoori project. This research project was conducted from May 2006 to July 2007. My Research Project was partially or fully sponsored by Ecology Department, Caspian Sea Ecology Research Academy, Sari, Iran

REFERENCES

Bachelet, G., X. de Montaudouin, I. Auby and P.J. Labourg, 2000. Seasonal changes in macrophyte and macrozoobenthos assemblages in three coastal lagoons under varying degrees of eutrophication. ICES J. Mar. Sci., 57: 1495-1506.

Beardall, J., E. Young and S. Roberts, 2001. Approaches for determining phytoplankton nutrient limitation. Aquatic Sci. Res. Across Boundaries, 63: 44-69.

Bendschneider, K. and R.J. Robinson, 1952. A new spectrophotometric determination of nitrite in seawater J. Mar. Res., 2: 87-96.

Castel, J., P. Caumette and R. Herbert, 1996.. Eutrophication gradients in coastal lagoons as exemplified by the Bassin d'Arcachon and the Etang du Prevost. Hydrobiologia, 329: ix-xxviii.

Cloern, J.E., 1999. The relative importance of light and nutrient limitation of phytoplankton growth: a simple index of coastal ecosystem sensitivity to nutrient enrichment. Aquatic Ecol., 33: 3-15.

Cloern, J.E., 2001. Our evolving conceptual model of the coastal eutrophication problem. Mar. Ecol. Prog. Ser., 210: 223-253.

Conley, D., 2000. Biogeochemical nutrient cycles and nutrient management strategies. Hydrobiologia, 410: 87-96.

Domingues, R.B., A. Barbosa and H. Galvao, 2005. Nutrients, light and phytoplankton succession in a temperate estuary (the Guadiana, south-western Iberia). Estuarine, Coastal Shelf Sci., 64: 249-260.

Ibanez, F., J.M. Fromentin and J. Castel, 1993.. Application de la méthode des sommes cumulées à l'analyse des séries chronologiques en océanographie. Comptes Rendus de l'Académie des Sciences de Paris. Sciences de la Vie, 316: 745-748.

Justic, D., N.N. Rabalais and R.E. Turner, 1995. Stoichiometric nutrient balance and origin of coastal eutrophication. Mar. Pollut. Bull., 30: 41-46.

Lohrenz, S.E., G.L. Fahnenstiel, D.G. Redalje, G.A. Lang and X. Chen *et al*., 1997. Variations in primary production of northern Gulf of Mexico continental shelf waters linked to nutrient inputs from the Mississippi river. Mar. Ecol. Progress Series, 155: 45-54.

Longhurst, A., 1998. Ecological Geography of the Sea. 7th Edn., Academic Press, San Diego,.

Lucas, L.V., J.R. Koseff, S.G. Monismith, J.E. Cloern and J.K. Thompson, 1999. Processes governing phytoplankton blooms in estuaries. II: The role of horizontal transport. Mar. Ecol. Progress Series, 187: 17-30.

Monbet, Y., 1992. Control of phytoplankton biomass in estuaries: A comparative analysis of microtidal and macrotidal estuaries. Estuaries, 15: 563-571.

Nowicki, B.L. and S.W. Nixon, 1985. Benthic nutrient remineralization in a coastal lagoon ecosystem. Estuaries, 8: 182-190.

Turner, R.E., N. Qureshi, N.N. Rabalais, Q. Dortch and D. Justic *et al*., 1998. Fluctuating silicate: Nitrate ratios and coastal plankton food webs. Nat. Acad. Sci. United States Am., 95: 13048-13051.