PHYTOPLANKTON OF THE SÃO FRANCISCO RIVER ESTUARINE REGION (NORTHEASTERN BRAZIL): A STUDY OF ITS DIVERSITY

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ABSTRACT

Melo-Magalhães, E. M. (2011) Phytoplankton of the São Francisco River estuarine region (northeastern Brazil): a study of its diversity. Braz. J. Aquat. Sci. Technol. 15(1): 95-105. ISSN 1808-7035. Studies aimed at determining phytoplankton composition, biomass (chlorophyll-a), some ecological and physical-chemical characteristics of the São Francisco estuary were conducted at 7 sampling stations located between the states of Sergipe and Alagoas (10º24'-10°30'S and 36º23'-36º27W) during the rainy and dry seasons. The samples were obtained from the subsurface layer at neap and spring tides, during high and low tides, using a plankton net with 45 μm mesh size. The waters from this estuary are characterized by low salinity, high temperatures, pH between alkaline and slightly acid, transparency greater than 1 meter. The phytoplankton was composed of 205 taxa, mainly distributed between the divisions Chlorophyta and Bacillariophyta, considered the most representative. The diatom *Aulacoseira ambigua* (Grunow) Simonsen was considered dominant. Most of the species identified were planktonic and of freshwater origin. Specific diversity and equitability were considered average and high, indicating conditions of environmental equilibrium in the studied area. The analysis of variance in taxonomic richness revealed higher averages for the dry season and for high tides. Chlorophyll a content ranged between 0.4mg/L and 24,4mg/L. The annual variation of phytoplankton and physical-chemical parameters was related to rainfall.

Keywords: ecology, microalgae, plankton, chlorophyll a.

INTRODUCTION

The São Francisco River is an important river in Brazil and due to its multiple uses it has been intensely explored throughout its length for generating electricity, irrigation, water public supply and as a receiver of organic and inorganic residues of different sources. Its mouth is located between the states of Alagoas and Sergipe, constituting an estuarine environment.

Estuaries are coastal transition environments between the continent and the adjacent ocean, where the sea water is diluted by freshwater from continental drainage. They are the only water systems where there is a dynamic interaction between freshwater, sea water, the land system and the atmosphere (Day Jr. et al., 1989; Miranda et al., 2002).

The distribution and composition of phytoplankton populations in the estuarine environment, their seasonal and spatial variations in both qualitative and quantitative terms are mainly controlled by factors like tolerance to salinity, luminosity, nutrients and grazing (Kinne, 1970; Santelices, 1977). The geomorphological characteristics, anthropogenic impacts and variations in the meteorological regime establish the taxonomic characteristics and the spatial-temporal dynamic of their communities (Brandini et al., 1997). Generally, the dominant groups are diatoms and dinoflagellates, while other important groups include cryptophytes, chlorophytes and chrysophytes (Day Jr. et al., 1989).

Regarding the study of planktonic microalgae in the estuary of San Francisco, there's only record of the study by Eskinazi-Leça (1967/1969), performed at the shelf of Alagoas and Sergipe , at adjacent areas of the São Francisco river mouth, being cataloged 46 species of diatoms. Thirty years later, Souza et al. (1999), performed studies at two stations located at Brejo Grande City, in Sergipe State, registering the occurrence of 59 taxa, highlighting the diatoms in the rainy period and, the chlorophyceae, in the dry period. In three stations, located at the Xingó Hydroeletric Power Plant's reservoir, Melo-Magalhães et al. (2000) identified 78 taxa, highlighting the Chlorophyta division as the most representative one.

Considering the scarcity of studies about ecology and diversity of the São Francisco River's phytoplankton, the present study aims to determine the phytoplankton diversity of the São Francisco River estuary in the dry and rainy periods.

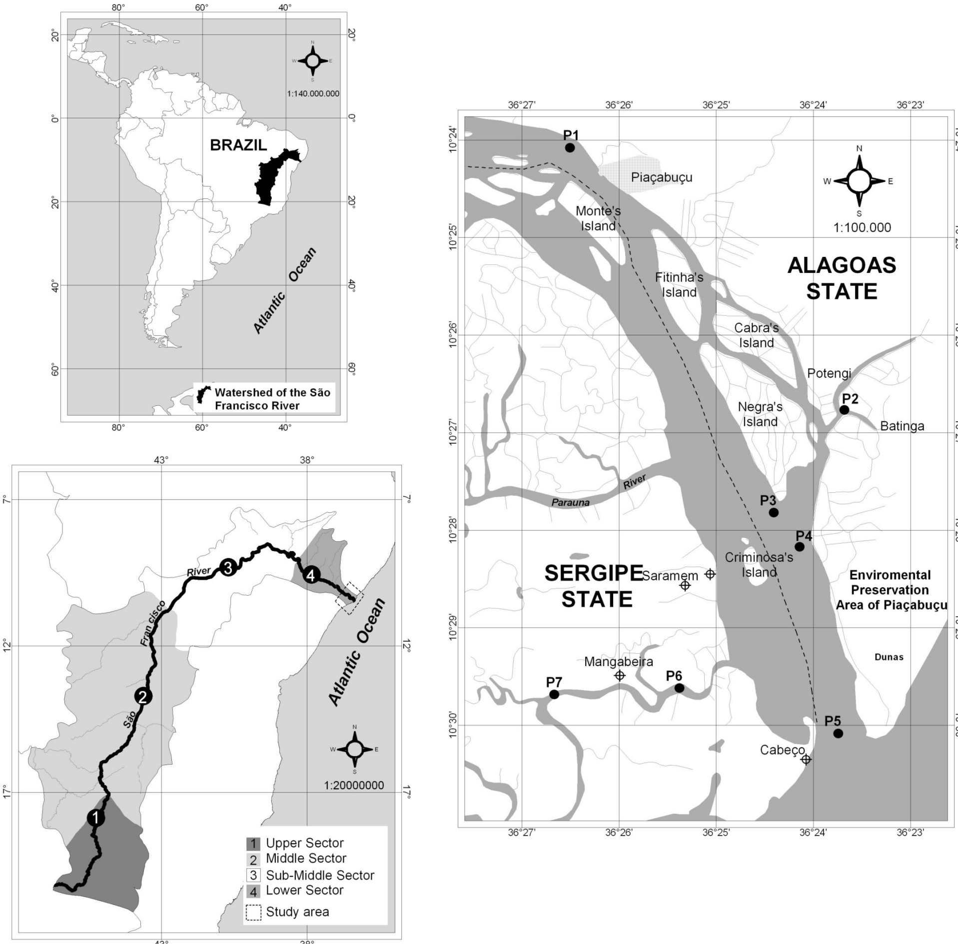

Figure 1 – Location of the sampling stations in the estuarine region of theSão Francisco River (Northeastern Brazil).

MATERIAL AND METHODS

Samples were taken at seven sampling stations located between the states of Sergipe and Alagoas (10º24'-10°30'S and 36º23'-36º27W; Figure 1).

The phytoplankton samples and abiotic data were obtained from the subsurface layer at neap and spring tides, during high and low tide. Measures of salinity, chlorophyll-*a,* pH, temperature, dissolved oxygen, saturation rate (%) and turbidity were carried out *in situ*, using a YSI 6600 multiparametric probe. Water transparency was measured with a Secchi disk and depth was measured with fathometer (Type: Eagle, model I.D.). Flow was obtained acoording to data from Hidroweb (2008). Correlation between salinity and chlorophyll was performed using the Spearman correlation ($p<0.05$). Phytoplankton sampling was done with a plankton net with 45 μm mesh size. Horizontal sub-surface hauls were made with towing speed of approximately 1 knot for five minutes. For the identification of the taxa samples were examined in a Leica Galen III binocular microscope and magnifications of 100x and 400x.

Relative abundance of each taxon was expressed in terms of percent (Lobo & Leighton, 1986). The species' frequency of occurrence was calculated taking into account the number of samples in which the organism was found, relative to the total number of samples collected, in percent (Mateucci & Colma, 1982). The specific diversity index was calculated as per Shannon (H') (1948), with the results expressed in bits.org.L^{-1}, where 1 bit equals an information unit (Valentin, 2000). Equitability (J) was calculated according to Pielou (1977).

Analysis of variance (ANOVA) was used to determine the degree of differences between: A - period (Rainy = July, October and Dry = January, March); B - tides (spring and neap); C – tidal regime (low tide and high tide). Species richness were used as dependent variables. The statistical analysis was performed using the SISVAR 4.3 (Ferreira, 2003). The Tukey test was applied to point out differences between the averages for treatments used (Cochran & Cox, 1957).

RESULTS AND DISCUSSION

The São Francisco River coastal region is characterized by meso tides (spring tide reaches 2.6 m), and it is considered semi-diurnal. There is a high-energy wave regime with NE and E-SE waves predominating over the year. Eastern waves are most important from January to May (summer-autumn) and September to November (spring), with southern waves occurring from March to August (Dominguez, 1996). In this study, the tide range varied from 0.2 meter (spring tide) to 2.1 meters (spring tide; Table 1).

Salinity content was very low, with higher values from 1.3 (average = 0.2) during the dry period and 4.3 (average = 0.6) during the rainy season, both at spring tide (Table1). In general, most of the sampling points had zero salinity. These results corroborate values obtained by Souza et al. (1999) who found, salinity near zero at most points sampled at the subsurface.

Due to the lack of spatial variability, little variation was observed in salinity content. It was higher only at point P7 (Figure 2A), possibly due to its location in channels with direct connection to the ocean, receiving less freshwater from the main channel.

Salinity in the São Francisco River estuarine system thus had a predominance of limnetic flow and according to the international classification of Smayda (1983) it can be classified as fresh-oligohaline (Table 1). This greater limnetic influence in the São Francisco River estuarine system is seen even at those stations located very near the mouth.

Acoording to data obtained from Hidroweb (2008),the São Francisco River flow maintained during most of the studied period (2006 and 2007), values greater than 2000 m^3/s. Higher values were recorded during the dry season, near 5000 m^3/s. During this period, by virtue of the greater volume of rain water, salinity had values of less than 1.3. Pereira et al. (2003)

Table 1 - Abiotic data at surface recorded in the São Francisco River estuary from July/2006 to March/2007, together with salinity and its classification according to Smayda (1983). N=112. “N”= Neap Tide; “S”= Spring Tide; “O”= Oligohaline; “F”= Fresh; “Max”= maximum value; “Min”= minimum, “Ave”= average.

SEASONS		**RAINY**				**DRY**			
		JULY		**OCTOBER**		**JANUARY**		**MARCH**	
TIDES		S	N	S	N	S	N	S	N
Tide amplitude	-	1.8	1.0	1.7	1.1	1.8	1.4	1.7	1.7
Tide height	min	0.2	0.8	0.3	0.6	0.3	0.5	0.3	0.3
	max	2.0	1.8	2.0	0.7	2.1	1.9	2.0	2.0
	Ave	1.1	1.4	1.2	0.7	1.2	1.2	1.2	1.2
Temperature (°C)	min	25.3	25.3	26.6	26.4	28.2	28.3	27.9	28.3
	max	26.2	26.9	28.9	29.4	29.6	29.8	29.1	30.8
	Ave	25.7	26.1	27.4	27.2	28.7	28.7	28.7	28.9
pH	min	6.9	7.2	7.3	7.2	7.3	7.4	6.8	6.6
	max	7.9	7.7	8.1	8.0	8.2	8.0	7.6	7.4
	Ave	7.6	7.5	7.7	7.8	7.7	7.6	7.4	7.3
Dissolved oxygen (mg/L)	min	5.4	6.8	6.8	6.4	5.6	6.4	4.7	3.3
	max	8.9	8.0	8.1	8.5	8.1	8.2	7.3	6.4
	Ave	7.7	7.7	7.7	7.5	7.8	7.5	6.8	5.9
Satturation rate (%)	min	66.8	84.7	90.1	80.6	71.6	82.3	60.2	42.2
	max	100.0	100.0	103.0	105.0	102.0	104.9	94.1	83.0
	Ave	93.3	95.0	97.7	94.4	97.7	97.2	87.2	76.6
Transparency (m)	min	0.5	1.0	1.2	1.4	1.0	1.4	0.5	0.5
	max	1.4	2.0	2.4	2.5	2.6	2.6	0.6	0.8
	Ave	1.1	1.6	1.8	2.0	2.1	2.1	0.5	0.6
Turbidity (NTU)	min	12.6	7.0	7.2	4.9	5.5	3.5	33.5	49.6
	max	23.1	19.0	21.3	16.2	18.2	14.2	49.3	59.5
	Ave	18.2	11.4	13.1	9.1	9.2	6.9	43.1	54.6
Chorophyll.*a* (µg/L)	min	0.8	0.6	0.5	1.0	0.6	0.4	2.5	2.2
	max	2.3	4.0	24.4	5.9	1.9	2.7	4.9	3.7
	Ave	1.4	1.8	2.9	1.6	1.2	1.0	3.3	2.6
Depth (m)	min	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	max	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
	Ave	5.3	5.3	5.1	5.1	5.1	5.1	5.1	5.1
Salinity	min	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	max	4.3	1.6	2.0	0.1	1.3	0.0	0.0	0.0
	Ave	0.6	0.4	0.4	0.1	0.2	0.0	0.0	0.0
Smayda (1983)	-	O	O	F	O	F	O	F	F

found long-lasting average flows in the lower São Francisco regions, ranging between 2000 and 2700m³/s

The tributary flows into the river are determining factors for salinity intensity in the estuary, as well as the degree of intrusion. According to Medeiros et al. (2008) flow is the main factor controlled by man that determines the magnitude and extension of the salt water wedge in the estuary. In this study, the São Francisco River estuary behaved like it had a predominant salt water wedge, with the maximum extension of the saline intrusion corresponding to 6000 meters from the mouth. Since in the current period being studied the flows remained constantly high, tidal variations were not effective for increasing salinity in the São Francisco River estuary. In low flow conditions (around 1000 m³/s) during the rainy season, greater intrusion of sea water was observed inside the estuary, slightly increasing salinity content.

Sampling station depth during the studied period had values between 2.5m and 9.5m (Table1) and water transparency was greater than 1 meter (average) at most sampled points. However, during the dry season, a strong reduction in transparency was recorded with values of less than 0.5 meter (march). Opposite results were obtained by Souza et al. (1999), where the dry period presented greater transparency. The period with least transparency coincided with the highest flows.

São Francisco River estuary waters have thermal uniformity with temperatures ranging between 25.3°C and 29.4 °C during the rainy season and 27.9°C and 30,8°C during the dry season. The pH varied between 6,9 and 8.1 (rainy period) and 6.6 and 8.2 (dry period). Small variations in temperature observed in tropical waters, probably do not exercise control over the growth and abundance of phytoplankton or determines the occurrence of an annual patterns (Agawin & Duarte, 2002).Values slightly higher during the dry season is a result of increased insolation plus weak winds, favoring greater solar penetration with consequent solar heating in the water column (Tenenbaum, 1995). Regarding to dissolved oxygen it varied between 5.4 mg.L^{-1} and 8.9 mg.L^{-1} (rainy period), and 3.3 mg.L^{-1} and 8.2 mg.L^{-1} (dry period).

Two hundred and five taxa were identified in the São Francisco River estuary (Table 2) distributed over the following divisions Cyanophyta (31), Dinophyta (01), Euglenophyta (8), Chrysophyta (01), Bacillariophyta (66) and Chlorophyta (98).

The Chlorophyta predominated numerically, representing 47% of the identified taxa, and the Bacillariophyta was the second group in number of taxa with 32.2%. These divisions also stood out due to their occurrence in all the samples and the two periods. The Chlorophyta are broadly distributed in the water environment, mainly found in continental waters, however, when the estuary were predominant limnetic flow, this group of microalgae begins to dominate (Falcão et al., 2002; Smayda, 1983). The predominance of diatoms has been mentioned for most tropical estuaries when there is greater influence of the marine flow (Patrick, 1967). Salinity values under five contributed towards the installation of typically limnetic phytoplankton populations, different from those often observed in other Brazilian estuaries with the presence of a considerable number of marine eurihaline diatoms. The greatest species richness recorded in the rainy season is probably due to the increase of nutrient load from inside the estuary.

During the rainy season, there was an occurrence of 75.1% of the taxa, and 58.5% in the dry season (Table 2).

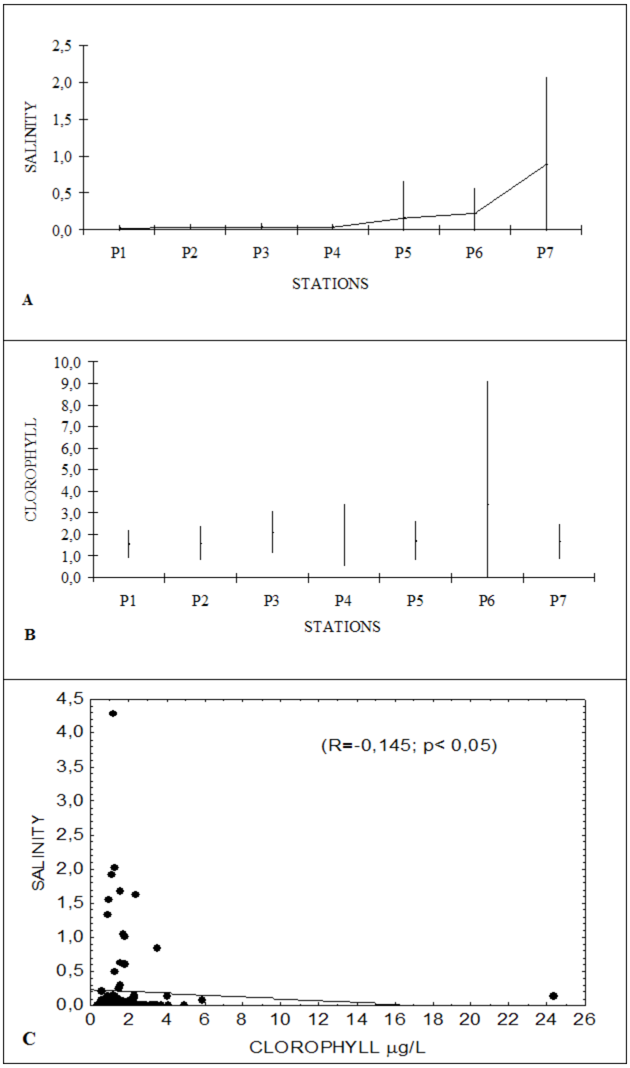

Figure 2 – Average variation of salinity, chlorophyll a and correlation between salinity and chlorophyll a in the collection points in the São FranciscoRiver estuary from July/2006 to March/2007.

Table 2 – Ecological data of taxa identified during the studied period (R=rainy; D=dry), at the stations located in the San Fracisco river estuary. "P"=Planktonic; "T"=Ticoplanktonic; "X"= Occurrence of Taxa; "-" = Absence of Taxa; Freshwater*; Marine**; Estuarine***.

CYANOPHYTA	**R**	**D**	**BACILLARIOPHYTA**	**R**	**D**
Anabaena circinalis Raben.*	P	P	*Aulacoseira ambigua* (Grun.) Sim.*	P	P
Anabaena spiroides Kleb.*	P	P	*A.*cf. *ambigua* (Grun.) Sim.*	P	-
Anabaena sp.	-	X	*A. ambigua* f. *spiralis* (Sk.) Lud.*	P	P
Anabaenopsis sp.	-	X	*A. granulata* (Ehr.) Sim.*	P	P
Aphanizomenon sp.	X	X	*Aulacoseira* sp.	X	-
Calothrix sp.	-	X	*Asterionellopsis glacialis* (Castr.) Rou.**	-	P
Chroococcus sp.	X	X	*Bacillaria* sp.	-	X
C.limneticus Lemm. *	P	P	*Biddulphia biddulphiana* (Sm.) Boy.**	-	T
Coelosphaerium sp.	X	X	*Biddulphia* sp.	X	X
C. kuetzingiannum Naeg.*	P	-	*Caloneis* sp.	X	-
Cylindrospermopsis raciborskii (Wol. exGeit.) Seen. Sub.-Raj.*	P	P	*Campylodiscus* sp.	X	-
Geitlerinema sp.	-	X	*Chaetoceros* sp.	-	X
Gloeotrinchia sp.	X	-	*Climacosphenia moniligera*(Lyng.) Kütz.**	T	-
Lyngbya limnetica Lemm.*	-	T	*Cocconeis* sp.	X	-
Lyngbya majuscule Gom.*	T	T	*Coscinodiscus* sp.	X	X
Lyngbya sp.	X	X	*Cyclotella*sp.	X	X
Merismospedia glauca(Ehr.) Nae.*	P	P	*Cymbellacistula* (Hem.) Grunow*	-	T
Merismopedia sp.	-	X	*C.obtusiuscula* (Küt.) Grunow*	T	-
Microcystis aeruginosa (Kütz.) Kütz.*	P	P	*Cymbella turgida* Gregory*	T	-
M. wesenbergii (Kom.) Kom.*	P	P	*Cymbella* sp.	-	X
Oscillatoria princeps (Vauc.) Gail.*	T	-	*Detonula* sp.	-	X
Oscillatoria sancta (Kütz.) Gom.*	T	T	*Diatoma* sp.	-	X
Oscillatoria tenuis C.A. Agar.*	-	T	*Entomoneis alata* (Ehr.) Ehr. *	P	P
Oscillatoria sp.1	X	-	*Epithemia* sp.	X	-
Oscillatoria sp.2	X	-	*Eunotia monodon* Ehr.*	P	P
Phormidium sp.	X	X	*Eunotia* sp.	-	X
Planktothrix agardhii (Gom.) Anag. Kom*	-	P	*Fragilaria capucina* Desm.*	P	-
Planktothrix sp.	-	X	*Fragilaria crotonensis* Kit.*	P	P
Rhaphidiopsis sp.	-	X	*Fragilaria* sp.	P	-
Romeria elegans Wolosz.*	-	P	*Frustulia rhomboides* (Ehr.) De Toni*	-	P
Spirulina sp.	-	X	*Gomphonema* sp.	X	X
			Gyrosigma balticum (Ehr.) Raben.***	T	T
DINOPHYTA	**R**	**D**	*Helicotheca tamensis* (Shru.) Ric.**	-	P
Peridinium sp.	-	X	*Hydrosera whampoensis* (Sch.) Deb.*	T	T
			Navicula sp.	X	X
EUGLENOPHYTA	**R**	**D**	*Nitzschia longissima* (Brèb.) Ral.**	T	-
Euglena acus Ehr.*	-	T	*Nitzschia scalaris* W. Sm.*	P	-
Euglena sp.	X	X	*Nitzschia sigma* (Kütz.) Grun.**	P	-
Phacus longicauda (Ehr.) Duj.*	P	-	*Nitzschia sigmoidea* (Ehr.) W. Sm.**	P	P
Phacus sp.	X	X	*Nitzschia* sp.	X	X
Strombomonas sp.	-	X	*Odontella mobiliensis* (Bai.) Grun.**	-	P
Trachelomonas armata (Ehr.) Stein*	-	P	*Paralia sulcata* (Ehr.) Cl.**	P	-
T.volvocina Ehr.*	-	P	*Pinnularia* sp.	X	-
Trachelomonas sp.	X	-	*Pleurosigma angulatum* (Que.) W. Sm.*	P	P
			Pleurosigma sp.	X	-
CHRYSOPHYTA	**R**	**D**	*Pleurosiralaevis* (Ehr.) Com. ***	T	T
Dinobryon sp.	X	-	*Stenopterobia intermedia*(W.Le.) V.Heu.*	-	T
			Surirella biseriata Brèb.*	T	T
BACILLARIOPHYTA	**R**	**D**	*Surirella robusta* Ehr.*	T	-
Achnanthes brevipes Agar.**	T	T	*Surirella ovate* Kütz.*	P	P
Achnanthes sp.	X	X	*Surirella* capronii Brèb.*	P	-
Actinocyclus normanii(Greg.) Hust. f.*normanii***	P	-	*Synedra goulardii* Brèb.	P	P
Actinoptychus senarius (Ehr.) Ehr.**	T	-	*Synedra* sp.	X	-
Actinoptychus splendens (Shad.) Ral.**	T	-	*Syndra ulna* (Nitzs.) Ehr.*	P	P
Actinoptychus sp.	-	X	*Tabellaria* sp.	X	X
Amphipleura lindheimeri Grun.*	T	T	*Tabularia tabulate* (Agar.) Wil.*	P	P
Amphora sp.	X	X	*Terpsinöe musica* Ehr.*	T	T

Table 2 (cont.)

CHLOROPHYTA	R	D	CHLOROPHYTA	R	D
Actinastrum sp.	X	X	*Pediastrum* sp.	X	X
Ankistrodesmus sp.	P	P	*Penium cilyndricum*(Tur.) Sch.*	P	P
Arthrodesmus convergens Ehr. ex Ralfs*	P	-	*Penium* sp.	X	-
A.heimii (Bour.) Com.*	P	P	*Pleodorina* sp.	X	X
A.maximus Ehr.*	P	-	*Pleurotaenium* sp.	X	-
Asterococcus sp.	X	X	*P. trabecula* (Ehr.) Naei*	P	-
Bambusina brebissonii Kütz.ex Kütz.*	-	P	*Pseudosphaerocystis* sp.	X	-
Chaethophora sp.	X	-	*Pseudostaurastrum* sp.	X	-
Cladophora sp.	-	X	*Royaobtusa* W. et G. S. We.*	P	-
Closterium ehrenbergii Men.*	P	P	*Scenedesmus acuminatus* (Lag.) Cho.*	P	-
Closterium gracile Brèb.*	P	-	*S. quadricauda* (Turp.) Brèb.*	P	-
Closterium libellula (Focke) Nordst.*	P	P	*S.serratus* (Cor.) Boh*	-	P
Closterium parvulum Naeg.*	P	-	*Scenedesmus* sp.	X	X
Closterium setaceum Ehr.*	P	P	*Sphaerocystis schroeteri* Cho.*	P	P
Closteriopsis sp.	X	X	*Sphaerocystis* sp.	X	X
Coelastrum cambricum Archer*	P	-	*Sphaerozosma* sp.	X	X
Coelastrum microporum Naegeli*	-	P	*Spirogyra majuscule* (Kütz.) Cz.*	P	P
Coelastrum reticulatum (Dan.) Senn*	P	P	*Spirogyra margaritata* Wol.*	P	P
Coelastrum sp.	X	X	*Spirogyra mirabilis* (Hassall) Kütz.	P	-
Cosmarium moniliforme (Turp.) Raf.*	-	P	*Spirogyra setiformis* Kütz.	P	P
Cosmarium quadrum Lundell*	P	P	*Spirogyra* sp.1	X	X
C.reniforme (Ralfs) Archer*	P	P	*Spirogyra* sp.2	X	X
Desmidium aptogonum Brèb.*	P	-	*Spondylosium planum* (Wol.) We.*	P	-
Desmidium baileyi (Ralfs) Bary*	P	-	*Spondylosium* sp.	-	X
Dictyosphaerium pulchellum Wo.*	P	P	*Staurastrum brebissonii* Arc.*	P	-
Dimorphococcus sp.	-	X	*S.gracile* Ral.and Ral.*	-	P
Euastrum oblongum (Grev.) Ral.*	-	P	*S.leptocladum* Nord.*	P	P
Eudorina elegans Ehr.*	P	P	*S.nudibranchiatum* Bor.*	-	P
Gloeocystis sp.	X	-	*S.obductum* Bor.*	P	-
Golenkinia sp.	-	X	*Staurastrum rotula* Nors.*	P	P
Gonatozygon brebissonii De Bary*	P	-	*Staurastrum saltans* Jos.*	-	P
Gonatozygon monotaenium Bary*	P	-	*Staurastrum setigerum* Cl.*	P	P
Gonatozygon pilosum Wolle*	P	-	*Staurastrum tohopekaligense* Wol.*	P	-
Gonatozygon sp.	X	X	*Staurastrum* sp.	X	X
Kirchneriella lunaris (Kirc.) Möb.*	P	P	*Staurodesmus dickiei Ral.* *	P	P
Micractinium sp.	X	X	*Staurodesmus lobatus* (Börg.) Bour.*	P	-
Micrasterias apiculata (Ehr.) Men.*	P	-	*Staurodesmus triangularis* (Lag.) Teil.*	P	-
M. mahabuleshwarensis Hob.*	P	-	*S. cuspidatus* (Brèb.Ral.) Tei.*	-	P
Mougeotia japonica Yam.*	P	-	*Staurodesmus* sp.	X	X
M. laetevirens (A. Bra.) Wit.*	P	-	*Stigeoclonium lubricum* (Dil.) Kutz.*	P	-
Oedogonium borisianum (Lec.) Wittr*	P	-	*Streptonema trilobatum* G.C.Wa.*	P	-
Oedogonium franklinianum Wittr.*	P	-	*Tetraëdron* sp.	-	X
Oedogonium sp.	X	-	*Tetraspora* sp.	-	X
Oocystis sp.	X	X	*Ulothrix aequalis* Kutz.*	P	-
Pediatrum biwae Neg.*	P	P	*Ulothrixzonata*(We.et Mo.) Kutz.*	P	P
P. boryanum (Tur.) Men.*	P	-	*Volvox* sp.	X	-
P. duplex Mey.*	P	P	*Xantidium fasciculatum* Ehr.*	P	-
P. duplex var.*retangulare* Boh.*	P	P	*Xanthidium*s p.	X	X
P. simplex Mey.*	P	P			

Taking into account the distribution of taxa along the sampling transect, higher species richness was observed at station P5 in January (spring tide – high tide) with a total of 48 taxa, mostly Chlorophyta (25). In March (neap tide – low tide), station P4 also deserves mention with the participation of 41 taxa, 21 of which were Bacillariophyta.

The analysis of variance (ANOVA) carried out on species richness revealed the existence of significant differences between the tidal period ($F=6.462$; $P=0.0005$) and regime ($F=6.246$; $P=0.0142$) factors. The Tukey test demonstrated that the higher averages occurred at January and March (dry season) and for high tide.

Table 3 – Abundance (%) of the most representatives phytoplanktonic taxa, in samples obtained in neap and spring tides (low tide and high tide) in the São Francisco River estuary in rainy period (july and october/2006) and dry period (january and march/2007).

RAINY PERIOD														
Tides	LOW TIDE							HIGH TIDE						
Taxa/Stations	P1	P2	P3	P4	P5	P6	P7	P1	P2	P3	P4	P5	P6	P7
NEAP TIDE (JULY/2006)														
Aulacoseira ambigua	--	00	7	--	11	10	16	1	21	4	--	92	17	0
A. ambigua f. *spiralis*	--	35	56	--	38	42	48	44	32	47	--	0	49	30
Aulacoseira granulata	--	16	5	--	11	16	8	20	10	18	--	13	5	36
Eudorina elegans	--	6	3	--	13	9	6	14	12	4	--	8	7	8
Pediastrum duplex	--	4	1	--	1	7	2	13	20	12	--	2	5	13
Pediastrum simplex	--	23	17	--	23	7	9	1	0	4	--	10	8	1
NEAP TIDE (OCTOBER/2006)														
Aulacoseira granulata	16	18	10	16	23	17	7	9	4	3	7	1	11	10
Fragilaria crotonensis	41	28	40	33	36	34	39	37	44	41	32	69	35	35
Pediastrum simplex	27	39	42	35	26	37	40	46	39	38	49	16	40	39
SPRING TIDE (JULY/2006)														
Aulacoseira ambigua	13	8	3	--	7	23	7	6	6	7	--	12	6	16
A. ambigua f.*spiralis*	15	42	18	--	38	26	65	36	8	33	--	19	60	37
Aulacoseira granulata	11	8	16	--	3	8	2	0	3	5	--	13	7	17
Entomoneis alata	0	0	16	--	0	0	0	1	0	0	--	0	0	0
Fragilaria crotonensis	3	0	1	--	10	0	3	5	14	4	--	1	5	1
Synedra ulna	1	1	5	--	1	24	0	1	1	1	--	1	0	3
Pediastrum simplex	14	6	9	--	4	3	7	16	17	15	--	6	9	4
SPRING TIDE (OCTOBER/2006)														
Aulacoseira granulata	5	15	62	10	8	14	12	16	11	15	9	8	5	11
Fragilaria crotonensis	46	28	43	48	51	47	50	47	34	41	34	51	41	42
Pediastrum simplex	43	45	45	32	31	36	29	27	38	37	49	29	43	34
DRY PERIOD														
NEAP TIDE (JANUARY/2007)														
Fragilaria crotonensis	21	16	28	34	41	18	37	23	13	35	24	31	24	34
Pediastrum biwae	40	23	38	39	26	43	34	40	48	29	33	47	36	32
Staurastrum rotula	3	0	4	3	5	10	4	2	3	3	3	1	1	2
NEAP TIDE (MARCH/2007)														
Planktothrix sp.	--	5	6	2	6	1	2	11	13	4	4	3	2	8
A. ambigua f. *spiralis*	--	10	8	5	5	8	9	17	6	11	7	6	6	10
Aulacoseira ambigua	--	30	59	73	71	76	57	59	69	71	72	58	59	49
SPRING TIDE (JANUARY/2007)														
Aulacoseira granulata	--	0	0	0	10	9	2	4	6	11	5	7	8	0
Fragilaria crotonensis	--	14	30	44	25	18	26	48	4	26	28	30	13	38
Pediastrum biwae	--	27	38	42	34	50	39	25	49	37	51	41	44	33
SPRING TIDE (MARCH/2007)														
*A. ambigua*f. *spiralis*	21	19	24	15	31	15	18	--	17	40	25	27	10	21
Aulacoseira ambigua	62	53	56	71	47	72	70	--	64	34	60	44	75	55

Although not numerically more important, the diatoms stand out in relation to relative abundance, with *Aulacoseira ambigua* (Grunow) Simonsen the only taxon considered dominant (≥70%) in this study (Table 3). This microalgae is characteristic of freshwater and it can live in environments with very restricted saline content, values under five (Moro et al., 1997).

The *Aulacoseira* has been reported as dominant in various Brazilian ecosystems, notably in rivers and reservoirs, was considered a good indicator of turbulence, since its heavy frustules have a high rate of sedimentation and require a turbulent environment to remain in the water column (Tundisi, 1990; Wolin & Duthie, 1999). This genera has been cited in previous studies conducted on the São Francisco River by Souza et al. (1999) who studied estuary phytoplankton at points located in Brejo Grande city, along the side of the river, finding a larger number of species considered limnetic and highlighting *Aulacoseira granulata* (Ehrenberg) Simonsen and *Aulacoseira islandica* (Ehrenberg) f. *curvata* Otto Muller as the most significant taxa. Eskinazi-Leça (1967/9), concentrated the study on the marine side, near the mouth of the São Francisco river, and found a larger number of marine diatoms, also registering the occurrence of *Aulacoseira granulata* in three of the sampled points.

The most representative Chlorophyta were among the abundant taxa(70% |– 40%) and the not so

Table 3 – Abundance (%) of the most representatives phytoplanktonic taxa, in samples obtained in neap and spring tides (low tide and high tide) in the São Francisco River estuary in rainy period (july and october/2006) and dry period (january and march/2007). "0"= Taxa absence; "—" = without samples.

	RAINY PERIOD													
Tides	LOW TIDE							HIGH TIDE						
Taxa/Stations	P1	P2	P3	P4	P5	P6	P7	P1	P2	P3	P4	P5	P6	P7
	NEAP TIDE (JULY/2006)													
Aulacoseira ambigua	--	00	7	--	11	10	16	1	21	4	--	92	17	0
A. ambigua f. *spiralis*	--	35	56	--	38	42	48	44	32	47	--	0	49	30
Aulacoseira granulata	--	16	5	--	11	16	8	20	10	18	--	13	5	36
Eudorina elegans	--	6	3	--	13	9	6	14	12	4	--	8	7	8
Pediastrum duplex	--	4	1	--	1	7	2	13	20	12	--	2	5	13
Pediastrum simplex	--	23	17	--	23	7	9	1	0	4	--	10	8	1
	NEAP TIDE (OCTOBER/2006)													
Aulacoseira granulata	16	18	10	16	23	17	7	9	4	3	7	1	11	10
Fragilaria crotonensis	41	28	40	33	36	34	39	37	44	41	32	69	35	35
Pediastrum simplex	27	39	42	35	26	37	40	46	39	38	49	16	40	39
	SPRING TIDE (JULY/2006)													
Aulacoseira ambigua	13	8	3	--	7	23	7	6	6	7	--	12	6	16
A. ambigua f.*spiralis*	15	42	18	--	38	26	65	36	8	33	--	19	60	37
Aulacoseira granulata	11	8	16	--	3	8	2	0	3	5	--	13	7	17
Entomoneis alata	0	0	16	--	0	0	0	1	0	0	--	0	0	0
Fragilaria crotonensis	3	0	1	--	10	0	3	5	14	4	--	1	5	1
Synedra ulna	1	1	5	--	1	24	0	1	1	1	--	1	0	3
Pediastrum simplex	14	6	9	--	4	3	7	16	17	15	--	6	9	4
	SPRING TIDE (OCTOBER/2006)													
Aulacoseira granulata	5	15	62	10	8	14	12	16	11	15	9	8	5	11
Fragilaria crotonensis	46	28	43	48	51	47	50	47	34	41	34	51	41	42
Pediastrum simplex	43	45	45	32	31	36	29	27	38	37	49	29	43	34
	DRY PERIOD													
	NEAP TIDE (JANUARY/2007)													
Fragilaria crotonensis	21	16	28	34	41	18	37	23	13	35	24	31	24	34
Pediastrum biwae	40	23	38	39	26	43	34	40	48	29	33	47	36	32
Staurastrum rotula	3	0	4	3	5	10	4	2	3	3	3	1	1	2
	NEAP TIDE (MARCH/2007)													
Planktothrix sp.	--	5	6	2	6	1	2	11	13	4	4	3	2	8
A. ambigua f. *spiralis*	--	10	8	5	5	8	9	17	6	11	7	6	6	10
Aulacoseira ambigua	--	30	59	73	71	76	57	59	69	71	72	58	59	49
	SPRING TIDE (JANUARY/2007)													
Aulacoseira granulata	--	0	0	0	10	9	2	4	6	11	5	7	8	0
Fragilaria crotonensis	--	14	30	44	25	18	26	48	4	26	28	30	13	38
Pediastrum biwae	--	27	38	42	34	50	39	25	49	37	51	41	44	33
	SPRING TIDE (MARCH/2007)													
*A. ambigua*f. *spiralis*	21	19	24	15	31	15	18	--	17	40	25	27	10	21
Aulacoseira ambigua	62	53	56	71	47	72	70	--	64	34	60	44	75	55

abundant taxa (40% |– 10%) like *Pediastrum simplex* Meyen*, Pediastrum biwae* Negoro*, Eudorina elegans* Ehrenberg, *Pediastrum duplex* Meyen and *Staurastrum rotula* Norstedt (Table 4).

In the samples obtained during neap tide, those that stood out with very frequent taxa (≥ 70%) were the Bacillariophyta *Aulacoseira granulata* (100% at high tide 96% at low tide), *Synedra ulna* (Nitzsch) Ehrenberg (90% at high and 73% low tide), *Tabularia tabulata* (Agardh) Williams et Round (83% at high tide),*Aulacoseira ambigua* f. *spiralis* (Skuja) Ludwig (73%) at high and 72% at low tide), *Aulacoseira ambigua* (72% at high tide); Chlorophyta *Eudorina elegans* Ehrenberg (83% at high and 88.5% low tide), *Pediastrum duplex* Meyen (76% at high and 77% low tide) and *Pediastrum simplex* (76% at high and 81% low tide).

The Bacillariophyta were most frequent at spring tide: *Aulacoseira granulata* (93% at high tide), *Fragilaria crotonensis* Kitton (89% at high tide),*Synedra ulna* (89% at high tide and 71% at low tide), *Pleurosira laevis* (Ehrenberg) Compère (74% at high tide) and the Chlorophyta: *Pediastrum simplex* (93% at high and 75% at low tide),*Pediastrum duplex* (82% at high tide), *Eudorina elegans* (78% at high and 43% low tide) and *Pediastrum biwae* (71% at low tide). Most taxa identified at the sampling stations during neap and spring tides were considered of low frequency or sporadic.

Taking into account the ecological characteristics of the phytoplankton it was observed that of those taxa identified at a specific level, 108 (87%) were freshwater in origin, 13 (10%) were marine in origin (neritic or neritic/oceanic) and only three species (3%) were estuary. These results revealed greater influence of the limnetic flow in the studied environment. In tropical estuaries, where temperature variations are minimal, the distribution and abundance of plankton are closely tied to salinity.

Among the freshwater organisms, the tycoplankton species (T) constituted the largest part of local micro-phytoplankton (79%) and only 21% were tycoplankton (P). Of the marine species, 54% were plankton (P) and 46% tycoplankton (T); the 3 estuarine species were tycoplankton (T). All the species of Cyanophyta (15), Euglenophyta (4), Dinophyta (1) and

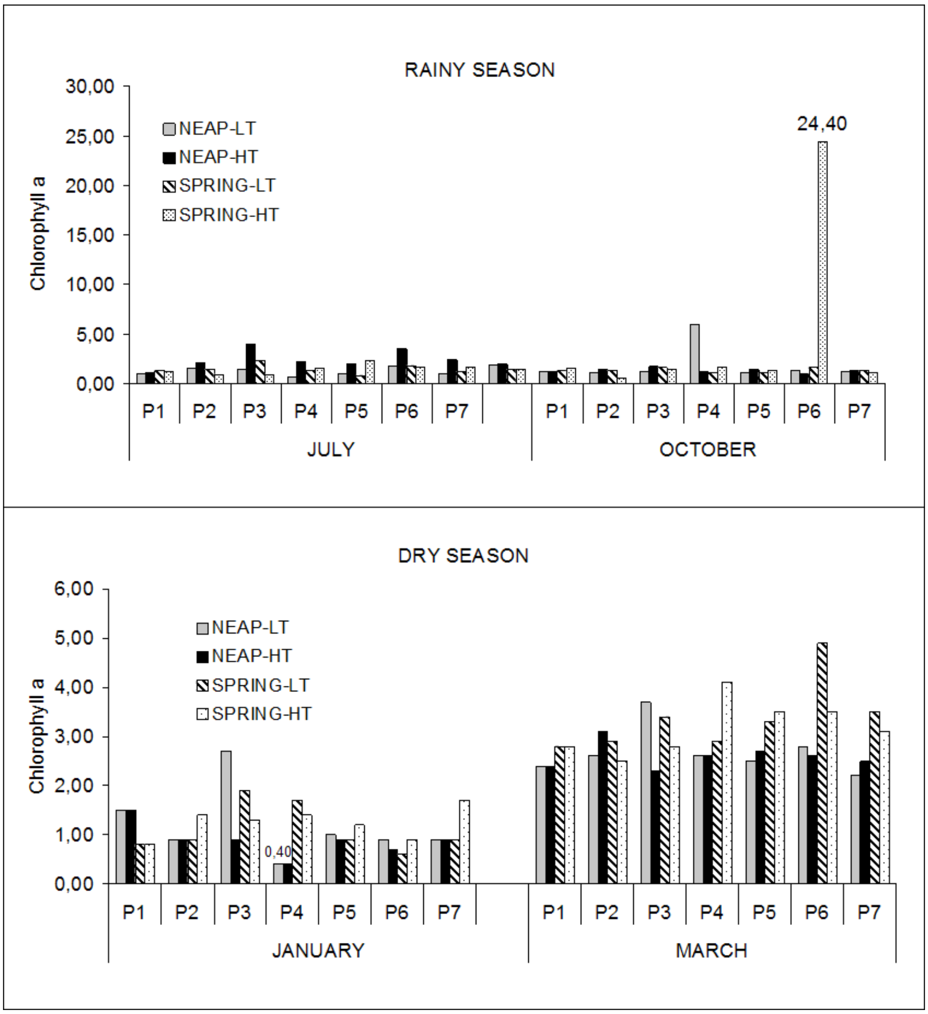

Figure 3 – Diversity and Equitability of phytoplankton taxa during spring and neap tides (high and low tides) in the São FranciscoRiver estuary from July/2006 to March/2007. P1-P7= collection points; LT=Low tide; HT= High tide.

Chlorophyta (65) were freshwater in origin. Only the Bacillariophyta had taxa of freshwater (22), marine (15) and estuarine (3) origin.

Phytoplankton community diversity and equitability were considered between high and low tides during the period under study (Figure 3). Maximum diversity was 3.9 bits.org.L^{-1} with equitability of 0.9 recorded at station 2 in January (dry period). Minimum diversity was 1.6 bits.org.L^{-1} with corresponding equitability of 0.3 was observed at station 5 in March (dry period).

The low values for diversity and equitability recorded in March (dry season) are due to dominance of the diatom *Aulacoseira ambigua.* Diversity drops off when the community becomes dominated by one or another species and could be very low under conditions of phytoplankton blooms (Omori & Ikeda, 1984; Parsons et al., 1984).

In the rainy season the chlorophyll *a* values ranged between 0.5µg/L and 24.4 µg during spring tide. More uniform values were seen during the dry season, especially during spring tide where phytoplankton biomass values ranged between 0.4 µg/L during neap tide (average of 1.0 µg/L) and 4.9µg/L during spring tide, Table 1. Isolated peaks of chlorophyll *a* were observed at point 6 (average of 34 µg/L; Figure 2B).

In tropical regions, there is no defined seasonal standard in terms of chlorophyll *a* concentrations, since high phytoplankton biomass can be observed during the dry as well as rainy season. According to Lehman (1981), the concentration of chlorophyll *a* for a natural population can vary in response to diverse variables such as the availability of nutrients or due to the physiological state of cells or the difference between cells.

In general, chlorophyll *a* contents ranged between 0.4 µg/L and 24.4 µg/L anddid notrevealany significant correlation withsalinity (Figure 2C).

The waters of the São Francisco River estuary shows thermal homogeneity, high transparency and low salt content. These characteristics exhibit slight annual variations related to seasonal patterns of rainfall and rainfall drainage, leading to the occurrence of plankton flora comprised of limnetic water indicating species and conditions of environmental balance at all assessed stations.

The lowest value for diversity coincided with the blooming of *Aulacoseira ambigua* recorded in the dry season. Phytoplankton biomass revealed an uniform distribution at all sampling stations, with isolated peaks during the rainy season. An atypical behavior was thus ascertained for the phytoplankton of the São Francisco estuary, with great predominance of freshwater species, possibly as a result of low saline values in the estuary.

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