BLOOMS OF CERATIUM FURCOIDES (LEVANDER) LANGHANS 1925 AND *RAPHIDIOPSIS RACIBORSKII* (WOLOSZYNSKA) AGUILERA & AL. 2018 IN LOWER SÃO FRANCISCO (NORTHEAST OF BRAZIL)

MELO-MAGALHÃES, E. M..[1]*, BRANDINI, N., [2] ABREU, F. C.,[1] SANTOS-JÚNIOR, R. C.[3] & MEDEIROS, P. R. P.[1]

1. Laboratórios Integrados de Ciências do Mar e Naturais (LABMAR/PROPEP), Universidade Federal de Alagoas, Maceió, Alagoas, Brasil.
2. Programa de Geoquímica, Universidade Federal Fluminense, Niterói, Rio de Janeiro, Brasil.
3. Coordenação-Geral de Emergências Ambientais (CGEMA), Brasília, Distrito Federal, Brasil.

***Corresponding author: enaidemmm@gmail.com**

ABSTRACT

Melo-Magalhães, E. M., Brandini, N., Abreu, F. C., Santos-Júnior, R. C. & Medeiros, P. R. P. (2023). Blooms of *Ceratium furcoides* (Levander) Langhans 1925 and *Raphidiopsis raciborskii* (Woloszynska) Aguilera & AL. 2018 in Lower São Francisco (Northeast of Brazil).. Braz. J. Aquat. Sci. Technol. 27(1). eISSN 1983-9057. DOI: 10.14210/bjast.v27n1.18265. The study aimed to record blooming episodes of the dinoflagellate *Ceratium furcoides* (Levander) Langhans 1925 and the cyanobacterium *Raphidiopsis raciborskii* (Woloszynska) Aguilera & al. 2018 in some areas of the São Francisco River Basin (Northeast region of Brazil). Water collections for determination of nutrients, chlorophyll *a* and phytoplankton density were carried out in the surface layer were collected from May 2015 to December 2016 in seven stations located in the counties of Delmiro Gouveia (Alagoas), Piranhas (Alagoas) and Paulo Afonso (Bahia). The determination of density (cell.mL^{-1}) was performed in an inverted microscope (Zeiss Axiovert). During the study, the average water temperature varied between 26.38 ºC and 30.70 ºC. The pH remained alkaline. The dissolved oxygen contents were between 3.99 mg.L^{-1} and 17.54 mg.L^{-1}, the turbidity varied between 0.21 UNT and 26.4 UNT. The maximum value for nitrate was 509.16 µg.L^{-1} and total phosphorus 92.46 µm.L^{-1}. In May 2015, dark stains were visibly observed in some parts of the São Francisco River. These spots were caused by the accumulation of the dinoflagellate *Ceratium furcoides*. The bloom started in May 2015 with a maximum density of 5,600 cell.mL^{-1} (Biovolume 112.80 µm^3.L^{-1}), decreasing considerably in the subsequent months (June, July and November) with densities below 260 cell.mL^{-1} (Biovolume 5.24µm^3.L^{-1}). In February 2016 it reached another peak with a maximum density of 5,470 cell.mL^{-1} (Biovolume 113.97 µm^3.L^{-1}) declining again in June, August and December 2016, with densities below 140 cell.mL^{-1} (Biovolume 2.92 µm^3.L^{-1}). The highest density of *R. raciborskii* was observed in June 2016, with 198,000 cell.mL^{-1} (Biovolume 864.31µm^3.L^{-1}). *C. furcoides* blooms are normally not toxic, whereas *R. raciborskii* is considered toxic. These microalgae have harmful effects on the entire aquatic community, affecting the balance of the ecosystem. The record of blooms of this species is relevant, as it provides important information about its distribution and dispersion in Brazilian aquatic systems.

Key Words: Invasive Species. São Francisco River. Dinoflagellates. Cyanobacteria.

INTRODUCTION

Brazil has an extensive hydrographic area and among the largest and most important Brazilian rivers, the São Francisco River can be mentioned due to its multiple uses. This ecosystem has been intensively explored throughout its extension for electricity generation, irrigation and public supply, in addition to serving as a recipient of organic and inorganic waste from different sources.

In these ecosystems, knowledge of biodiversity becomes increasingly necessary, as they are systems that have been affected by an increasing anthropic impact capable of causing changes in water quality, initially reflecting on the structure of the phytoplankton community, It is generally accepted that communities of aquatic organisms can serve as indicators of environmental quality. Planktonic microalgae are of great ecological relevance, presenting many attributes as indicators of ecosystem integrity and environmental changes, mainly because they are sensitive and respond quickly to stressful factors in the environment (McCormick & Cairns-Junior, 1994).

Phytoplankton can be considered as a bioindicator of water quality in areas prone to anthropogenic disturbance (Bianchi et al., 2003). High trophic indicators can favour massive explosions of a single species. The occurrence of blooms of phytoplanktonic organisms is observed in eutrophic reservoirs around the world, mainly with microalgae of the Cyanophyta group of the genera *Microcystis*, *Anabaena* and *Cylindrospermopsis* (*Raphidiopsis*). The Dinophyta group, represented by the genus *Ceratium*, has also been frequently recorded (Matsumsmura-Tundisi et al., 2010).

The Dinophyta group, represented by the genus *Ceratium*, has increased density and flowerings, with records in Brazilian tropical reservoirs and

lagoons mainly associated with nutrient availability (Matsumura-Tundisi et al., 2010; Silva et al., 2012). On the other hand, the residence time of water masses associated with the entry of domestic sewage, such as aquatic systems related to the basins that flow into the Rio Paraiba do Sul and Rio Guandu (Macedo et al., 2021) and in the rivers that flow into the reservoir of the Furnas Hydroelectric Plant (UHE) (Dias & Tucci, 2020). This study aimed to record the occurrence of blooms of the dinoflagellate *Ceratium furcoides* (Levander) Langhans and the cyanobacterium *Raphidiopsis raciborskii* (Woloszynska) Aguilera & al., in Lower São Francisco.

MATERIAL AND METHODS

The sampling sites (7 spots) were positioned according to the visual identification of the blooming, covering the cities of Delmiro Gouveia (Alagoas), Piranhas (Alagoas) and Paulo Afonso (Bahia) (-9°26'25"S, -38°09'25" W and -9°36'27"S, -37°48'31"W (Figure 1). Collections were carried out from May 2015 to December 2016.

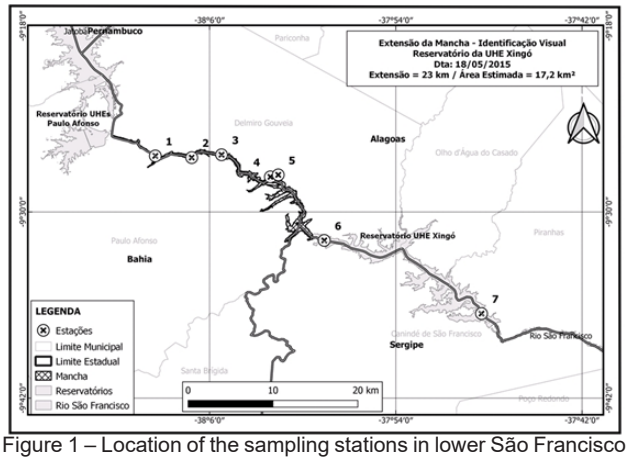

Figure 1 – Location of the sampling stations in lower São Francisco River. Source(modify) IBAMA-AL.

To obtain the parameters: temperature (ºC), electrical conductivity (µS/cm), dissolved oxygen (mg.L-1) and hydrogen potential – pH, a Multiparametric Probe model YSI 6,600 was used .

Water collections for determination of nutrients. chlorophyll *a* and phytoplankton density were carried out in the surface layer, with the aid of a "Van Dorn" type of bottle. The concentration of chlorophyll a was determined according to UNESCO (1966). The dissolved oxygen saturation rate was obtained using the International Oceanographic Tables (UNESCO, 1973). Nutrients: nitrite ($N\text{-}NO_2^-$), nitrate ($N\text{-}NO_3^-$) and ammonium ($N\text{-}NH_4^+$) were determined by the method described by Strickland and Parsons (1972) and silicate ($S\text{-}SiO_2^-$), inorganic phosphate ($P\text{-}PO_4^{3-}$) and total phosphate ($P\text{-}PO_4^{3-}$), according to the methodology Grasshoff's et al. (1983).

The determination of cell density (cell.mL^{-1}) was performed under an inverted microscope (Zeiss Axiovert) using the Utermöhl method (Karlson et al., 2010). The density of Cyanophyta taxa (cyanobacteria) was calculated taking into account the average values of the number of cells. In the case of *R. raciborskii* it was considered (10 cells per trichome). Biovolume was calculated as established by Hillebrand et al. (1999) and Sun & Liu (2003).

The samples of phytoplanktonic material obtained in the present study were deposited in the Herbarium of the State University of Londrina and in the Microalgae Collection of LABMAR/UFAL.

Analysis of variance (ANOVA) was applied for primary productivity. Multivariate analysis in main components (PCA), processed by the STATISTICA 12 program, was applied to order the chemical and physical variables, the densities of *Ceratium* and *Raphidiopsis*, and the relationships between them.

RESULTS

During the study. the water temperature ranged between 26.38 °C and 30.70 °C. The pH remained alkaline (7.25 - 10.44), and the electrical conductivity was between 70.00 µS/cm and 106.00 µS/cm. The dissolved oxygen contents were between 3.99 mg.L^{-1} with 50.00% saturation and 17.54 mg.L^{-1} with 230.30% saturation, the turbidity ranged between 0.21 and 26.40 UNT (Table 1).

Regarding nutrients dissolved in water (Table 1), the highest concentrations were observed in station P5 for nitrate (509.16 µg.L^{-1}), nitrite (13.04 µg.L^{-1}), ammonium (2569.30 µg.L^{-1}) and inorganic phosphorus (25.94 µg.L^{-1}). As for total phosphorus (92.46 µg.L^{-1}) and silica (17.02mg. L^{-1}), the highest means were observed in station P2.

Values of chlorophyll *a* in the evaluated periods (Table 1) indicated concentrations between 0.01 µg.L^{-1} (P3) and 281.89 µg.L^{-1} (P2). Concentrations greater than 100 µg.L^{-1} were observed in most stations, except for stations P6 and P7. As shown in Figure 2, in May 2015, peaks were observed at stations P1 (160.48

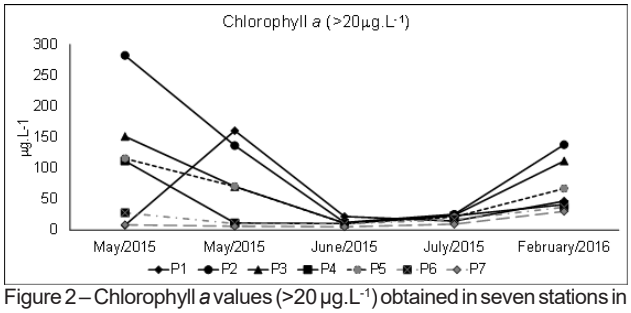

Figure 2 – Chlorophyll *a* values (>20 µg.L^{-1}) obtained in seven stations in lower São Francisco River in the period from May 2015 to December 2016.

Table 1 – Maximum, minimum and average values of abiotic and biological data obtained in the seven stations in lower São Francisco in the period from May 2015 to December 2016. In bold maximum and minimum values

Variables		P1	P2	P3	P4	P5	P6	P7
Temperature (°C)	Maximum	28.50	29.20	29.09	29.33	**30.70**	29.06	29.57
	Minimum	26.49	26.77	26.45	26.91	27.15	26.69	**26.38**
	Average	27.53	28.02	28.02	28.32	28.79	28.06	28.15
pH	Maximum	10.21	10.12	10.43	**10.44**	10.21	10.37	10.40
	Minimum	**7.25**	7.41	7.56	7.62	7.66	7.72	7.68
	Average	8.12	8.39	8.65	8.66	8.77	8.95	8.58
Conductivity (µS/cm)	Maximum	93.00	93.00	93.00	94.00	**106.00**	93.57	92.00
	Minimum	**70.00**	71.00	71.00	**70.00**	81.00	71.00	70.00
	Average	78.87	79.46	79.79	80.56	93.57	80.49	79.88
Dissolved Oxygen ($mgO_2.L^{-1}$)	Maximum	12.96	11.65	13.22	14.29	**17.54**	12.27	10.86
	Minimum	5.87	5.20	6.76	**3.99**	6.53	5.71	4.66
	Average	9.38	9.40	9.75	10.06	10.36	9.32	8.97
Saturation (%)	Maximum	165.70	149.90	170.10	186.00	**230.30**	158.90	142.30
	Minimum	74.00	68.50	84.40	**50.00**	82.20	71.20	57.90
	Average	118.76	120.04	124.49	129.70	138.54	120.00	115.16
Turbidity (UNT)	Maximum	22.20	**26.40**	19.30	7.20	21.10	14.20	16.90
	Minimum	0.32	0.64	**0.21**	0.44	0.86	0.60	0.30
	Average	7.60	7.02	4.93	2.81	4.69	4.36	4.88
Nitrate ($\mu gN.L^{-1}$)	Maximum	21.46	22.63	20.64	15.15	**509.16**	62.67	12.26
	Minimum	0.02	0.01	0.01	0.01	0.01	1.25	0.01
	Average	5.22	4.30	3.28	2.60	62.67	12.24	3.58
Nitrite ($\mu gN.L^{-1}$)	Maximum	5.96	5.96	5.22	5.22	**13.04**	2.98	12.26
	Minimum	0.02	0.02	0.02	0.02	0.08	0.01	0.01
	Average	1.50	1.47	1.30	1.33	4.77	0.93	3.58
Ammonium ($\mu gN.L^{-1}$)	Maximum	1,144.16	1,670.68	1,109.57	1,058.94	**2,569.30**	817.62	247.23
	Minimum	0.18	0.50	0.06	0.10	0.18	0.22	0.20
	Average	203.37	246.71	198.94	158.05	430.72	142.85	37.28
Innorganic Phosphorus ($\mu gP.L^{-1}$)	Maximum	12.21	**25.94**	21.36	9.15	**25.94**	10.68	9.15
	Minimum	0.02	0.04	0.04	0.04	0.01	0.04	0.04
	Average	2.40	3.95	3.34	2.13	8.62	2.89	2.73
Total Phosphorus ($\mu gP.L^{-1}$)	Maximum	32.36	**92.46**	66.26	33.90	67.80	35.44	36.98
	Minimum	0.24	0.14	0.19	0.19	1.13	0.35	0.19
	Average	10.43	22.07	17.92	12.13	29.50	14.92	14.29
Silica (mg $Si\text{-}SiO_2.L^{-1}$)	Maximum	15.29	**17.02**	14.89	14.89	15.35	15.49	15.35
	Minimum	4.89	7.17	7.01	6.66	6.29	5.75	5.62
	Average	10.36	11.65	10.77	10.72	10.82	10.69	11.13
Chorophyll *a* ($\mu g.L^{-1}$)	Maximum	160.48	**281.89**	151.23	111.52	115.43	36.80	30.21
	Minimum	0.82	1.10	**0.01**	1.10	0.55	5.49	2.47
	Average	29.39	67.87	42.81	24.07	26.04	15.49	10.00
Total density ($cell.mL^{-1}$)	Maximum	78,900	118,650	107,270	122,710	122,120	**200,760**	**183,880**
	Minimum	850	**680**	1,150	5,590	8,570	30,270	27,900
	Average	28,139	44,523	45,429	63,340	61,969	86,788	80,776

µg.L^{-1}), P2 (281.89 µg.L^{-1}), P3 (151.23 µg.L^{-1}); in February 2016, the highest values occurred in stations P2 (137.85 µg.L^{-1}) and P3 (111.49 µg.L^{-1}).

The analysis of variance (ANOVA) performed with data from chlorophyll *a* did not show significant difference in regard to the sampling stations (F = 1,994; P = 0.0771), however it showed differences as to the evaluated periods (F = 5.156; P= 0.0017), with higher values for the months of May 2015 and February 2016.

Regarding to the main components (PCA) for physical and chemical data and for the densities of *C. furcoides*, the existence of correlations was observed, where the three components explain 76.17% of the total variance of the data. The interpretation of component one data, with 41.97% of the variance, allows the visualization of a grouping between pH, chlorophyll *a* and silica, inversely related, with Secchi, electrical conductivity, ammonium, nitrite, NID, PID and PT. Component two explained 21.48% of the data variance. The analysis of these results indicated a positive relationship with Secchi and an inverse relationship with temperature, dissolved oxygen and saturation. Factor three, with 12.72%. positively correlated Chlorophyll *a* with the density of *C. furcoides* and its inverse relationship, with the density of *R. raciborskii* (Table 2).

Table 2 – Correlation of physical-chemical variables and densities (*C. furcoides* and *R. raciborskii*) in three factors of the principal components analysis of the Lower São Francisco in the period from May 2015 to December 2016. In bold, significant variables (p > 0.5).

Variables	Factor 1 (41.97%)	Factor 2 (21.48%)	Factor 3 (12.72%)
Secchi	**-0.727**	**0.611**	-0.085
Temperature (°C)	-0.172	**-0.857**	-0.327
pH	**0.855**	-0.281	-0.264
Conductivity (µS/cm)	**-0.864**	-0.416	-0.064
Turbidity (UNT)	-0.397	0.071	0.482
Dissolved Oxygen (mgO_2.L^{-1})	0.259	**-0.846**	-0.042
Saturation (%)	0.226	**-0.881**	-0.086
N-NH_4^+	**-0.848**	0.162	-0.094
N-NO_2^-	**-0.747**	-0.451	0.216
N-NO_3^-	-0.491	-0.477	0.184
NID	**-0.889**	0.096	-0.068
PID	**-0.806**	-0.474	0.218
PT	**-0.879**	-0.314	0.184
Chl *a*	**0.528**	-0.222	**0.625**
Silica	**0.938**	-0.068	0.059
N:P	-0.375	0.193	-0.463
C. furcoides density	0.438	-0.191	**0.645**
R. raciborskii density	0.148	-0.305	**-0.813**
Expl. Var.	7.555	3.866	2.290
Prp. Totl.	0.420	0.215	0.127

The influence of silica, pH, dissolved oxygen and saturation on the densities of *C. furcoides* and *R. raciborskii* can be seen in Figure 3.A. Figure 3.B shows the strong influence of the periods studied, setting 2015 apart, where a higher concentration of *C. furcoides* was recorded, and 2016, where the values of density of *R. raciborskii* were higher.

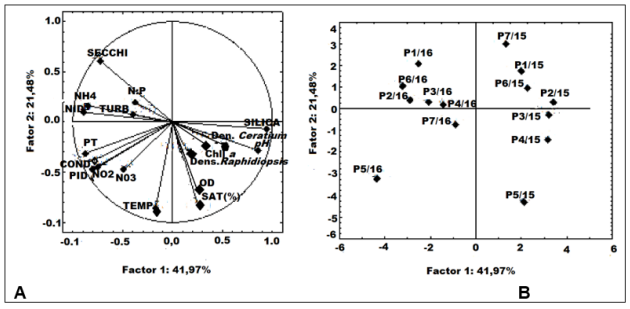

Figure 3 – Analysis of the principal components (PCA) between the physicochemical and biological variables of the Lower São Francisco in the period from May 2015 to December 2016. Abiotic and biological data (A); period and stations (B).

The phytoplankton community was represented by 66 taxa, destroyed in the following divisions: Cyanophyta, Heterokonthophyta, Cryptophyta, Dinophyta, Euglenophyta and Chlorophyta. The total density (Table 1), showed maximum average values of 200,760 cell.mL^{-1} (P6) and 183,880 cell.mL^{-1} (P7). The lowest density value was observed in station P2 with 680 cell.mL^{-1}.

Considering the taxonomic groups found during the study period, the Dinophyta (dinoflagellates) and Cyanophyta (cyanobacteria) groups stood out quantitatively, recording the highest density values. Regarding dinoflagellates, in May 2015 dark stains were visibly observed in some parts of the São Francisco River (Figure 4). These spots were caused by the accumulation of the dinoflagellate *C. furcoides* (Figure 5).

The bloom of *C. furcoides*, started in May 2015 with a maximum density of 5,600 cell.mL^{-1} (Biovolume 112.80 mm^3.L^{-1}), decreased considerably

Figure 4 – Photograph showing stains caused by the bloom of *C. furcoides* in the São Francisco River in May 2015. Source: IBAMA-AL.

in the subsequent months (June, July and November) with densities below 260 cell.mL^{-1} (Biovolume 5.24 mm^3.L^{-1}). In February 2016 it reached another peak with a maximum density of 5,470 cell.mL^{-1} (Biovolume = 113.97 mm^3.L^{-1}) and declined again in June, August and December/2016, with densities below 140 cell.mL^{-1} (Biovolume 2.92 mm^3.L^{-1}) (Table 3).

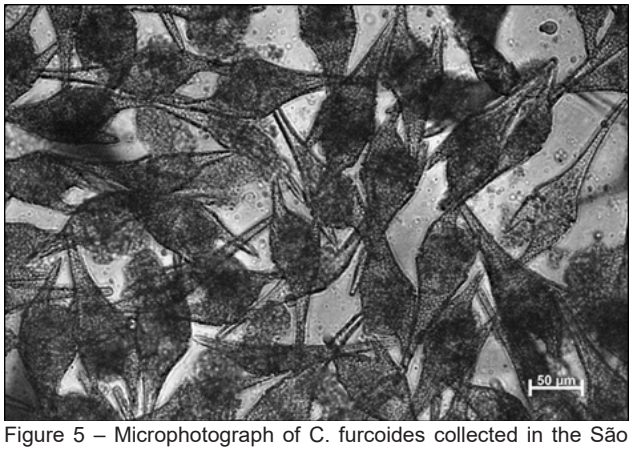

Figure 5 – Microphotograph of C. furcoides collected in the São Francisco River during the period from May 2015 to December 2016.

In addition to the bloom of *C. furcoides*, blooms of the cyanobacterium *R. raciborskii* were also observed.

Densities of *C. furcoides* greater than 1,000 cell.mL^{-1} were observed in the months of May 2015 and February 2016. On the other hand, *R. raciborskii* presented densities above 100,000 cell.mL^{-1} in the months of May, June and July 2015 and in June and December 2016 (Table 3, Figure 6).

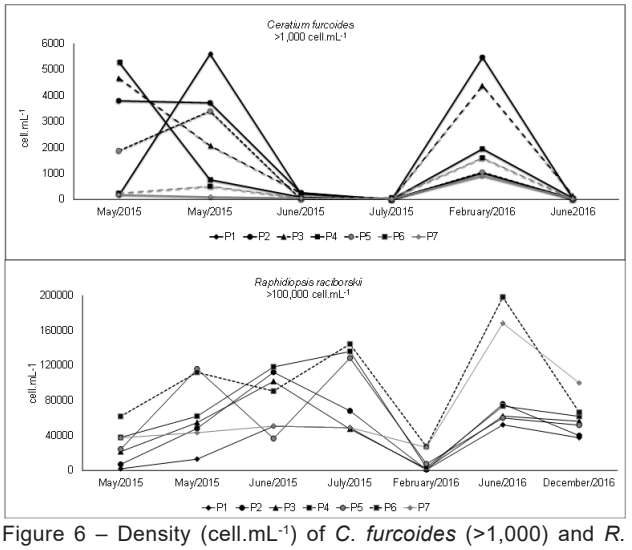

Figure 6 – Density (cell.mL^{-1}) of *C. furcoides* (>1,000) and *R. raciborskii* (>100,000) from the Lower São Francisco in the period from May 2015 to December 2016 in the 7 sampling stations.

The highest density of *R. raciborskii* was observed in June 2016, at station P6. which presented 198,000 cell.mL^{-1} (Biovolume = 864.31 mm^3.L^{-1}) and at P7, 168,200 (Biovolume = 734.22 mm^3. L^{-1}). Other peaks were observed in May 2015 at stations P5 and P6; in June 2015 at stations P2, P3 and P4; in July 2015 at stations P4, P5 and P6 and in December 2016 at P7 (Table 3, Figure 6).

The analysis of variance (ANOVA) performed with data on the densities of *C. furcoides* and *R. raciborskii*, showed a significant difference in relation to the density of *C. furcoides* and the periods evaluated (F = 5,333; P = 0.0014), highlighting the months of February and May. although it did not show differences in relation to the sampling stations. For *R. raciborskii* no significant differences were highlighted.

DISCUSSION

Phytoplanktonic organisms are responsible for part of the primary production transferred to other trophic levels in aquatic ecosystems. In these environments, the different polluting sources reflect the composition and density of the phytoplankton community. Disturbances in pelagic populations, represented by the appearance of single-species blooms, are attributed to sudden changes in vertical stability, nutrient depletion and underwater changes (Reynolds, 1997).

In this study, high concentrations of phosphate and nitrogen elements, were observed at all collection spots, especially at station 05, where effluents (untreated) from the city of Delmiro Gouveia (AL) were discharged. The high concentrations of phosphate compounds and nitrogenous elements, mainly ammonia characterize the studied environment as eutrophic. The availability of phosphorus in natural systems significantly affects biological production, with the rate of primary production and the increase in phytoplankton biomass being influenced by the concentration of this nutrient (Bradford & Peters, 1987; Flores-Montes et al., 1988). Ammonia nitrogen and nitrate are the most commonly used forms of phytoplankton (Esteves, 2011). In a watercourse, the stage of pollution eventually caused by some upstream sewage discharge can be determined. If the pollution is recent, nitrogen will basically be in the form of organic nitrogen or ammonia and, if old, basically nitrate (Lira et al., 2015; Liliamtis, 2007). The high concentrations of ammonia during the study phase suggest recent pollution in the sampling stations during the study phase.

At all periods and seasons, surface pH values remained alkaline, probably due to photosynthesis, as observed through the high values of chlorophyll a. The blooming of phytoplankton is one of the main responses of the eutrophication process. In tropical regions. during the last three decades, cyanobacterial blooms

Table 3 – Densities (cell.mL^{-1}) and Biovolumes (mm^3.L^{-1}) of *R. raciborskii* and *C. furcoides* from the Lower São Francisco in the period from May 2015 to December 2016 in the 7 sampling stations. The most relevant values in bold.

Period	Variable	Stations						
		P1	P2	P3	P4	P5	P6	P7
		Ceratium furcoides						
06/05/2015	Density	180	**3,800**	**4,660**	**5,280**	**1,880**	240	180
	Biovolume	3.75	79.18	97.10	110.02	39.17	4.83	**3.75**
18/05/2015	Density	**5,600**	**3,720**	**2,070**	760	**3,400**	510	100
	Biovolume	112.80	74.93	41.70	15.31	68.49	10.27	2.01
18/06/2015	Density	220	260	250	90	10	50	50
	Biovolume	4.43	5.24	5.04	1.81	0.20	1.01	1.01
16/07/2015	Density	10	0	5	10	10	**70**	25
	Biovolume	0.20	0.00	0.10	0.20	0.20	1.41	0.50
21/11/2015	Density	15	30	230	0	5	220	90
	Biovolume	0.31	0.63	4.79	0	0.10	4.58	1.88
24/02/2016	Density	**1,020**	**5,470**	**4,380**	**1,950**	**1,050**	**1,600**	910
	Biovolume	21.25	113.97	91.26	40.63	21.88	33.34	18.96
01/06/2016	Density	20	10	140	40	20	10	20
	Biovolume	0.42	0.21	2.92	0.83	0.42	0.21	0.42
16/08/2016	Density	0	20	0	0	10	20	20
	Biovolume	0	0.42	0.00	0.00	0.20	0.42	0.42
06/12/2016	Density	0	0	40	0	0	0	0
	Biovolume	0	0	0.83	0	0	0	0
		Raphidiopsis raciborskii						
06/05/2015	Density	2,000	7,000	21,600	37,800	24,400	61,800	37,400
	Biovolume	8.73	30.56	94.29	165.00	106.51	269.77	163.26
18/05/2015	Density	13,000	48,100	54,700	62,000	**115,900**	**112,100**	43,200
	Biovolume	56.75	209.97	238.78	270.64	505.92	489.34	188.58
18/06/2015	Density	50,600	**112,200**	**101,800**	**118,300**	36,550	90,700	50,800
	Biovolume	220.88	489.77	444.38	516.40	159.55	395.92	221.75
16/07/2015	Density	48.800	68.100	47.350	**135,900**	**128,500**	**144,500**	49.045
	Biovolume	213.02	297.27	206.69	593.23	560.93	630.77	214.09
21/11/2015	Density	1,100	18,500	22,600	56,500	83,700	72,400	50,500
	Biovolume	4.80	80.76	98.65	246.63	365.37	316.04	220.44
24/02/2016	Density	900	1,100	2,100	3,600	7,500	27,400	26,400
	Biovolume	3.93	4.80	9.17	15.71	32.74	119.61	115.24
01/06/2016	Density	52,200	76,000	62,200	73,600	60,000	**198,000**	**168,200**
	Biovolume	227.86	331.75	271.51	321.28	261.91	864.31	734.22
16/08/2016	Density	77,000	62,800	57,800	70,600	59,800	51,200	75,200
	Biovolume	336.12	274.13	252.31	308.18	261.04	223.50	328.26
06/12/2016	Density	37,400	39,800	56,200	61,800	51,800	66,400	**100,000**
	Biovolume	163.26	173.73	245.32	269.77	226.12	289.85	436.52

have been very frequent in water supply reservoirs (Di Bernardo et al., 2002). However, very recently, blooms of an invasive species of dinoflagellates have been frequently observed in reservoirs in tropical regions (Nishimura et al., 2015).

Algal bloom events in general can cause harmful effects on aquatic communities, affecting the balance of the ecosystem. In Lower São Francisco, from May 2015 to December 2016, the total phytoplankton density presented high values, caused mainly by the blooms of the dinoflagellate *C. furcoides* and the cyanobacterium *R. raciborskii*. Organisms belonging to the genus *Ceratium* are generally found in eutrophic waters, living in association with organisms belonging to the Cyanophyceae (Matsumsmura-Tundisi et al., 2010).

Species of the genus *Ceratium* are known in freshwater environments in South America as invasive species and are associated with environmental changes (Boltovoskoy et al., 2013; Cavalcante et al., 2013; 2016). Records of the occurrence and expansion of *C. furcoides* in different Brazilian freshwater ecosystems have already been documented by several authors. Blooming episodes have been reported in the Furnas Reservoir in Minas Gerais (Santos-Wisniewski et al., 2007; Silva et al., 2012). in the Billings Reservoir in São Paulo (Matsumura-Tundisi et al., 2010) and in the Itaúba reservoir in Rio Grande do Sul (Cassol et al., 2014).

Density increases with the formation of *C. furcoides* blooms in tropical reservoirs are mainly associated with nutrient availability (Matsumura-Tundisi et al., 2010). The genus *Ceratium* can be found in waters rich in nutrients, especially phosphorus and nitrate, which are usually also associated with cyanobacteria (Lund, 1965).

These microalgae can develop blooms due to their mobility and their ability to form resistant spores in the sediment. *Ceratium* cysts are often found on the surface of sediments (Moya & Ramon, 1984). The occurrence of *C. furcoides* blooms in the Billings Reservoir and in areas with great turbulence in the Capibaribe Basin-PE reservoir can be attributed to the presence of resistance forms in the sediments, removed by the mixing effect (Matsumura-Tundisi et al., 2010; Oliveira et al., 2016). The higher densities of *C. furcoides* observed in the Lake Paranoá region may also be related to the greater tendency for resuspension of sediment cysts (Roriz et al., 2019). In the present study, the possibility that the *C. furcoides* bloom may have been caused by the transport of sediment cysts by anthropic action cannot be ruled out, since just before the emergence of the bloom, one of the HPP floodgates in Paulo Afonso opened on the Alagoas/Bahia border, releasing sediment accumulated in the river for at least 30 years (Globo.com, 2015). This procedure possibly involves the mixing of water bodies, increasing the resuspension of nutrients and the removal of cysts from the sediment, thus favoring the rapid growth of the population of this species.

At sampling stations in Lower São Francisco, the dinoflagellate *C. furcoides* reached higher densities in May 2015, with 5,600 cell. mL^{-1} and February 2016 with 5,470 cell.mL^{-1}. For Cavalcante et al. (2016), densities above 1,000 ind.mL^{-1} can already be considered as blooming.

The density values found in this study were considered very high when compared to *C. furcoides* blooms recorded in other Brazilian ecosystems, as reported by Campanelli et al., (2017) in a fish pond in São Carlos (SP.), with 978 org.mL^{-1}; Cassol et al. (2014) in the Itaúba reservoir (RS) with 2,036 cell.mL^{-1}; Cavalcante et al. (2016) in the Maestra and Faxinal (RS) reservoir with 2,819 cells.mL^{-1} and by Silva et al. (2018), in the Corumbá Reservoir (GO) with 4,000 cell.mL^{-1}. However, higher density values were found by Matsumura-Tundisi et al. (2010) in the Billings Dam (SP), with 21,544 cell.mL^{-1}; Silva et al. (2012) at the Furnas (MG) HPP with 28.564 org.mL^{-1} and Hackbart et al. (2015) in the Jaguari dam with 131.954 org.mL^{-1} and in the Jacarei reservoir (SP), with 17.556 org.mL^{-1}.

In the present study, the density peaks of *C. furcoides* and the concentration of chlorophyll *a* reflected in statistically significant differences for the periods, highlighting the months of February and May as the most favorable for the development of this microalgae in the studied area. In addition to the blooming of *C. furcoides*. the high concentrations of chlorophyll are also due to the blooming of other microalgae, mainly *R. raciborskii* cyanobacteria.

Cyanobacterial blooms are the result of the overgrowth of these organisms in quantities greater than 103 cells per mL, causing a negative impact on water quality, in addition to making the environments unsuitable for fishing and recreation (Carmichael & Falconer, 1993). The occurrence of Cyanobacteria *R. raciborskii* has been frequently recorded as blooming species in Brazilian ecosystems and the success of this microalgae is mainly due to competitive advantages over other phytoplanktonic groups, such as the presence of cells specialized in nitrogen fixation (heterocyte), nutrient stock through akinetes that provide high dispersibility, air vesicles (aerotopes) that allow their permanence on the water surface, in addition to their high affinity for ammonium and also the storage capacity of phosphorus (Padisák, 1997; Tucci & Santana, 2003). Cyanobacteria have the property of fixing atmospheric nitrogen, which gives this group a great competitive advantage over other groups when environmental conditions are nitrogen deficient (Paerl,1991; Graham & Wilcox, 2000). As a result of these ecological and physiological characteristics,

cyanophyceae assume the role of opportunists, as they depend on the stability of environmental factors to develop and reproduce. The development of these microalgae is mainly attributed to high temperatures, alkaline pH, reduced water transparency and high phosphorus availability (Padisák & Reynolds, 1998).

The physicochemical conditions of Lower São Francisco waters during the study phase were very favorable to the formation of blooms observed in the studied sites, such as well oxygenated waters, alkaline pH, high temperatures and high phosphorus concentrations. Alkaline pH is reported as one of the factors conditioning the dominance of cyanobacteria (Watson et al., 1997). In this study, the high densities of *R. raciborskii* cyanobacteria may be related to the high pH values that remained alkaline throughout the study phase.

The cyanobacterium *R. raciborskii* is one of the most mentioned microalgae in studies from the northeast region as a cause of blooming (Bouvy et al., 2000). In parts of the Piranhas-Açú River Basin, in the semiarid region of northeast Brazil, Cardoso et al. (2017), reported the dominance of cyanobacteria. highlighting *R. raciborskii* with a density of up to 2,354,17 cell.mL^{-1}. In Lagoa do Peri, Florianópolis-SC, (Grellmann, 2006), densities higher than those recorded in the present study were also found, with values of up to 1,026,970 cell.L^{-1}.

Ceratium blooms are generally not toxic, although they can cause ecological, economic and landscape impacts. However, in the case of cyanobacteria, its control is important due to its toxic potential. In the present study, at all collection spots, *R. raciborskii* presented densities greater than 20,000 cell. mL^{-1}, representing a risk to public health because it is a potentially toxic species.

High values of total phytoplankton density in the sampling stations during the present study are due to the bloom of the dinoflagellate *C. furcoides* and the cyanobacterium *R. raciborskii*. The record of blooms of these species is relevant, as it provides important information about their distribution and dispersion in Brazilian aquatic systems.

The blooms of *C. furcoides* and *R. raciboskki* in Lower São Francisco suggest a change in environmental conditions, with high concentrations of nutrients favorable to their proliferation, possibly associated with an anthropogenic eutrophication process.

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