Biomonitoring ecological status of two reservoirs of the Brazilian semi-arid using phytoplankton assemblages (Q index)

Biomonitoramento do estado ecológico de dois reservatórios do semiárido brasileiro utilizando assembleias fitoplanctônicas (índice Q)

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Abstract: Aim: Assess whether the assembly index is a suitable tool for biomonitoring of aquatic ecosystems of semi-arid environment. **Methods:** Monthly, samples were collected between October 2011 and May 2012 in Santa Cruz do Apodi (5°43'59"S; 46" 00 119 "W) and Pau dos Ferros (6°08'30.12" S; 038°10'59 880"W) reservoirs. **Results:** The Pau dos Ferros reservoir, shallow, turbid and eutrophic showed dominance of the functional group S_N throughout the sample period. Total phytoplankton biovolume ranged between 20 and 70 mm³.L⁻¹, the lowest values coincided with the increase of the mixing zone and transparency, which occasioned a change in composition of the phytoplankton community. Pau dos Ferros reservoir was categorized as poor for most of the sample period. The Santa Cruz do Apodi reservoir was characterized as meso-eutrophic, exhibiting low total phytoplankton biovolume (0.04 to 0,4 mm³.L⁻¹) and greater diversity in the phytoplankton composition. It showed moderate condition during most of the period. **Conclusion:** In summary, the index Q reflected well the changes in phytoplankton composition, being a good indicator for biomonitoring of these systems.

Keywords: phytoplankton; water quality; assemblage index; functional groups.

Resumo: Objetivo: Avaliar se o índice de assembléia é uma ferramenta adequada para o biomonitoramento dos ecossistemas aquáticos de ambiente semiárido. **Métodos:** Coletas mensais foram realizadas entre outubro de 2011 e maio de 2012 nos reservatórios Santa Cruz do Apodi (5°43'59" S; 46' 00.119" W) e Pau dos Ferros (6°08'30.12" S; 038°10'59.880" W). **Resultados:** O reservatório Pau dos Ferros, raso, turvo e eutrófico apresentou dominância do grupo funcional SN durante todo o período amostral. A biomassa fitoplanctônica variou entre 20 e 70 mm³. L⁻¹, os menores valores coincidiram com o aumento da zona de mistura e transparência, que ocasionaram mudança na composição fitoplanctônica. O reservatório Pau dos Ferros foi categorizado, ecologicamente, como ruim durante quase todo o período amostral. O reservatório Santa Cruz do Apodi apresentou baixa biomassa (0.04 a 0,4 mm³.L ⁻¹) e maior diversidade na composição fitoplanctônica. Ele apresentou condição moderada, durante a maior parte do período, influenciado por diferentes grupos funcionais típicos de ambientes meso-eutróficos. **Conclusão:** Em síntese, o índice Q refletiu bem às mudanças na composição fitoplanctônica, sendo um bom indicador para o biomonitoramento desses sistemas.

Palavras-chave: fitoplâncton; qualidade de água; índice de assembleia; grupos funcionais.

1. Introduction

The phytoplankton community has been used for several decades to the development of ecological models aimed at understanding patterns of succession and diversity (Sommer et al., 1986; Sommer, 1991). For its ability to respond quickly to environmental changes, it is considered efficient and useful when used as an indicator of natural and anthropogenic changes, through temporal and spatial fluctuations in their composition and biomass (Reynolds, 1984; Padisák, 1992; Barbosa & Padisák, 2004; Kruk et al., 2002).

Several studies have been developed over time in an attempt to predict the phytoplankton composition by addressing phytosociologic species (Hutchinson, 1967; Tuxen, 1955; Braun-Blanquet, 1964; Pianka, 1970). Most predictive models of

seasonal and spatial variations of phytoplankton species use large taxonomic divisions, however these groups are not considered an ecologically uniform by encompass organisms phylogeny and characteristics (Reynolds, 1984). The use of species lists to determine the quality of water based on the trophic spectrum also has a long history of studies (Padisák et al., 2006).

As pointed out by Reynolds (1999), the great challenge of the studies associated with the selective processes of phytoplankton is the understanding of what factors were decisive for changes in species composition in eutrophic systems since the trophic spectrum assumes an importance on the constitution of plankton in eutrophic or oligotrophic environments (Reynolds et al., 2002).

Recently, Reynolds et al. (2002), proposed a classification scheme of the functional groups of phytoplankton, in which species associations were determined in view of the functional units constitute basic system, which have originated from polyphyletic taxonomic groups and occupy similar ecological niches. In this system, each association is represented by different alphanumeric codons. To date, approximately 50 functional groups have been described (Reynolds et al., 2002; Padisák et al., 2009). Since then, many studies using the classification scheme of planktonic algae for being sensitive to environmental changes, such as smaller seasonal fluctuations or eutrophication, for example, stratification, and to help in understanding why certain species are more favored than others in the assembly of communities and the reason for the spatial and temporal variations. The approach of functional groups has been applied effectively to the temperate region (Becker et al., 2009; Lopes et al., 2005; Sarmento et al., 2006), tropical (Huszar et al., 2003) and subtropical (Fabbro & Duivenvoorden, 2000; Kruk et al., 2002). In the Brazilian semiarid, Huszar et al. (2000) identified that the constancy of the reservoirs favored the dominance of S and S_N assemblies, characterized by efficiently capturing light, are common to turbid and enriched environments. In this region, favored species are the ones that perform well in low latitude meso-eutrophic environments (S_N, S_1, M, H_1) as reported by Reynolds et al. (2002) and Padisák et al. (2009).

The successful application of functional groups suggested by Reynolds et al. (2002) lies in the fact that it can simplify the handling of long taxonomic lists traditionally used for species with overlapping ecological characteristics defined functional (Padisák et al., 2009).

In this direction, the contribution of Padisák et al. (2006) to develop the index (Q), using the relative weight of the functional group, proposed by Reynolds et al. (2002), for total phytoplankton biomass, point a promising way to evaluate water quality of lakes and reservoirs. The index Q has 5 degrees of water quality and is designed to monitor the ecological status of European lakes meeting the requirements demanded by the Water Framework Directive – WFD (European Parliament & Council of the European Union, 2000) with the goal of becoming a useful approach to biomonitoring. Moreover, innovation in phytoplankton ecology studies relates the dynamics of assemblages present considering the existence of lakes and reservoirs with different morphometrics, which may constitute various phytogeographic regions. He is supported by case studies in three European lakes and applied to several lakes and reservoirs, such as Hungarian Lake Balaton (Hájnal & Padisák, 2008), four Pole shallow lakes (Pasztaleniec & Poniewozik, 2010), Spanish Sau reservoir (Becker et al., 2010) and Chinese Three Gorges reservoir (Wang et al., 2011).

In Brazil, Crossetti & Bicudo (2008) conducted a pioneering study applying the Q index to evaluate water quality in a eutrophic reservoir and indicated that phytoplankton could be successfully used as an indicator of the ecological status of the system in monitoring processes. Therefore, studies applying the approach of assembly index (Q) for assessment of water quality in reservoirs of the Brazilian semiarid region constitute the base of the discussion to support biomonitoring areas susceptible to various impacts, making this a fundamental research because show the use of phytoplankton as a discriminator of ecological status. This paper examines the application of the Q index as a tool to assess the ecological status in two Brazilian semiarid tropical reservoirs, based on the approach of the functional groups of phytoplankton.

2. Material and Methods

2.1. Study area

The study was conducted in two reservoirs, located in Rio Grande do Norte state in Brazilian northeastern semiarid region, predominantly hot and dry climate, high evaporation rates, average annual air temperature of approximately 27°C (± 5). Rainfall is scanty and irregular with annual averages generally below 900 mm (± 250), also occur shallow soils susceptible to erosion.

Santa Cruz do Apodi and Pau dos Ferros are artificial reservoirs (Figure 1), are water reserves for domestic supply a population of approximately 200.000 inhabitants, and are used for recreation, irrigation and fish farms. Diffuse nutrient load originates from activities such as agriculture and fishing, soil erosion and urban runoff impact the reservoirs promoting eutrophication.

The Pau dos Ferros reservoir is shallow (medium depth = 3.4 m, maximum depth = 19.9 m), with a surface area of 11.653.600 m² and a maximum length of 500 m, mean residence time of 1 year and historical annual average volume of 38.080.000 m³ staying most of the year with 55% of its maximum volume capacity.

The Santa Cruz do Apodi reservoir is relatively deep (medium depth = 16 m; maximum depth = 57.5 m) with a surface area of 34.136.600 m² and maximum length of 18 Km. The average residence time is considerably long (14 years). The annual historical average volume is 512.830.000 m³ and it stays most of the year with 75% of its maximum volume capacity.

2.2. Sampling and data analyses

Monthly, samples were collected between October 2011 and May 2012 in Santa Cruz do Apodi and Pau dos Ferros reservoirs, at a point near the main dam embankment. In each reservoir, were delimited six depths along the water column (three in the zone euphotic- 100%, 10% and 1%), according to Cole (1994), and three in the aphotic zone (middle, bottom, and between them). The samples were subsequently integrated to form a single representative rate for each compartment of the water column, totaling 32 samples.

Vertical profiles of water temperature, dissolved oxygen, pH and electrical conductivity probe were obtained by multiparametric sounder, every 0.5 from surface to bottom. The transparency (m) was measured using the Secchi disk. The mixed layer Zm was considered to be the depth at which the dissolved oxygen dropped below 1 mg.l⁻¹ (Zohary et al., 1998). The concentrations of nitrogen and total phosphorus in water were obtained by spectrophotometry according to the recommendations Valderrama (1981).

The trophic state of the reservoirs was obtained using the trophic index of Lamparelli (2004), which possess adaptations of Carlson's TSI for tropical environments. For the determination of Chlorophyll-a, the samples were filtered in filter from Whatman 934-AH with 47 mm diameter and extraction performed with 10 mL 95% ethanol *over night* (Lorenzen, 1967). The concentrations
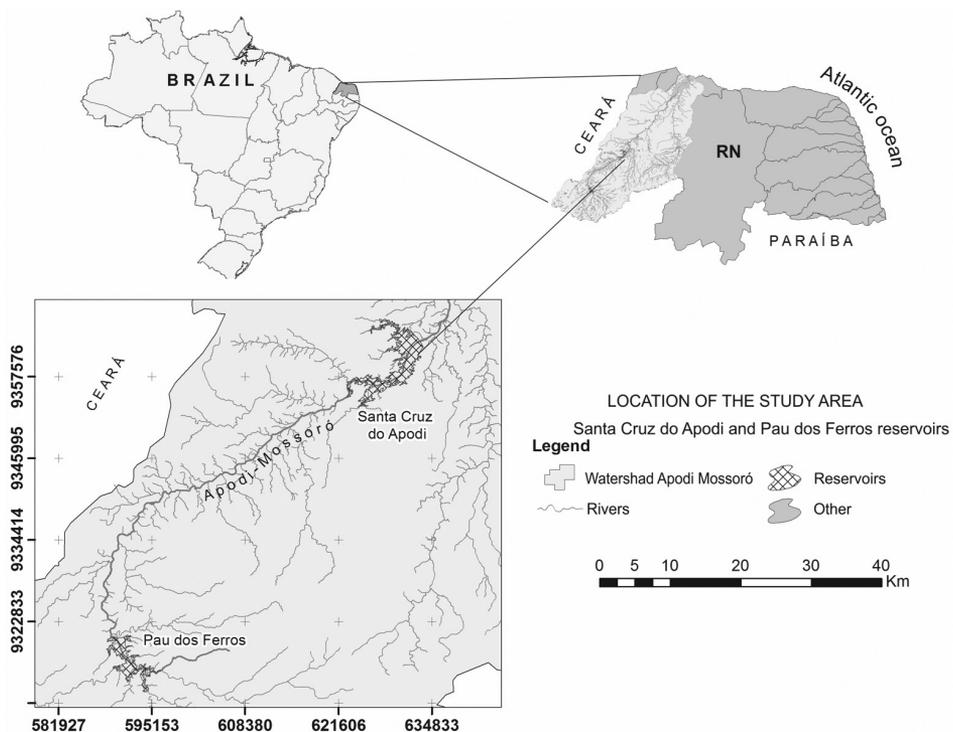

Figure 1. Study area location of the and collection points in the Santa Cruz do Apodi and Pau dos Ferros reservoirs in Rio Grande do Norte state, brazilian northeastern.

were determined by spectrophotometry (650 nm) according to the methodology of Jespersen & Christoffersen (1987).

Qualitative analysis of phytoplankton was done by collecting samples on horizontal and vertical hauls with plankton net (20 µm), which were fixed with 4% formaldehyde. The rating system adopted for cyanobacteria was Komárek & Anagnostidis (1998) for Chroococcales, Komárek & Anagnostidis (2005) for Oscillatoriales and Komárek & Anagnostidis (1989) for Nostocales. For other classes of phytoplankton were used the works of Round (1971) for Chloroficeae, Simonsen (1979) for Diatoms, and Bourelly (1981, 1985) for other groups.

Water samples to quantify Phytoplankton were collected with the aid of Van Dorn bottle and preserved with Lugol 1%. The measurement followed the method of Utermöhl (1958). The count of individuals (cells, colonies and filament) occurred in random fields, the error being less than 20% at a confidence coefficient of 95% at the discretion of Lund et al. (1958). The number of fields varied from one sample to another and the completion of the counting was done taking as the criterion score of at least 100 individuals of the dominant species for the Santa Cruz do Apodi dam. As for Pau dos Ferros, we used the criterion of 400 for a 10% error in view of high dominance of cyanobacteria in this environment (Chorus & Bartran, 1999).

The phytoplankton biovolume was calculated from geometric models approximate the shape of each species, using for the calculation measures of 30 individuals or cells of each specimen multiplied by its density (Hillebrand et al., 1999). The relative abundance was calculated according to the criteria established by Lobo & Leighton (1986). The species contributed to 5% or more of the total phytoplankton biomass were classified in functional groups, using the criteria of Reynolds et al. (2002) and Padisák et al. (2009). The index assembly (Q), developed by Padisák et al. (2006) was used to assess the ecological status of reservoirs.

Prior to analysis, data were log-transformed for statistical normality if necessary. ANOVA and Tukey's test were used to examine significant differences of the variables between reservoirs. Spearman correlation coefficient was used to determine significant correlation between pair variables. Multivariate analysis was used to examine the relation between limnological variables and phytoplankton biomass.

3. Results

3.1. Abiotic variables

There were significant differences in all investigated limnological variables (P> 0.05) between the reservoirs Pau dos Ferros and Santa Cruz do Apodi during the study. The mean values of the variables: temperature, turbidity, conductivity, total phosphorus (TP), total nitrogen (TN), hidrogenionic potential (pH) and trophic state indexes, are statistically much higher (P <0.000) in the reservoir Pau dos Ferros. In relation to the variables: volume of water, residence time, mean depth (Zm), and transparency index Q, the averages showed higher values for Santa Cruz when compared to Pau dos Ferros (Table 1).

In Pau dos Ferros reservoir, transparency varied between 0.3 and 0.5 m, the euphotic zone was reduced (1.2 m to 1.5 m) during the sampling period resulting in lack of seasonal difference (P>0.05). High values of turbidity, total phosphorus, chlorophyll and biovolume of total phytoplankton were recorded in this environment. The chlorophyll, total nitrogen and total biovolume showed similar distribution patterns.

In Santa Cruz, transparency varied ranging between 2.5 and 6 m, the euphotic area 7.5 to 18 m and increased according to the increase in tank volume, as well as conductivity and total phosphorus. In April 2012, it was announced the fullest extent of the euphotic zone corresponding to the total mixture of water column. This reservoir showed average values of lower turbidity (avg. 6.22), although it was the peak of 114.8 recorded during the month of May 2012.

The thermal gradient of the temperature and oxygen profile of the reservoirs Pau dos Ferros and Santa Cruz (Figure 2 and 3, respectively) showed the same pattern in the two reservoirs studied. The water column proved homogeneous featuring whit no thermocline, water temperature was elevated at the surface and decreased gradually through to the bottom. The temperature difference between each meters depth was always less than 1°C.

In relation to the dissolved oxygen, a clinograde type and anoxia in the hypolimnion was recorded for the two reservoirs in some periods. The mixing zone (Zmix) was considered the depth at which the oxygen concentration dropped below 1 mg.L^{-1}.

The reservoir Pau dos Ferros , as shallow lake, had a period of total mixture (Dec/11, March and April/12), with OD values in the hypolimnion ≥ 2 mg.L^{-1}.In the remainder of the period Zmix

Table 1. Mean values (± standard deviation) of environmental variables and outcome of ANOVA to test differences between Santa Cruz do Apodi and Pau dos Ferros reservoirs during the study.

	Pau dos Ferros	*Santa Cruz*	F	P
	Med (± dp)	**Med (±dp)**		
Volume (m³)	30,531,044 (2,234,029)	458,251,631 (13,370,091)	7,965	*
Output (m³ s⁻¹)	1.06 (0.45)	1.03 (0.15)	0.037	**
Residence time (years)	1 (0.44)	14 (2.37)	228.1	*
Zm (m)	3.67 (0.12)	16.43 (0.19)	228.1	*
Lamparelli's TSI Trasparency	73 (2.32)	40.48 (4,47)	333.1	*
Lamparelli's TSI Chla	74.7 (1.08)	58.8 (2.16)	343.6	*
Lamparelli's TSI TP	67.4 (0.44)	63.3 (1.77)	40.56	*
Transparency (m)	0.41 (0.06)	4 (1.20)	71.87	*
Turbidity (NTU⁺)	24.4 (9.36)	6.22 (9.23)	84.85	*
Condutivity (µS.cm⁻¹)	486 (42.1)	281.73 (6.14)	308.4	*
pH	8.76 (0.45)	8.01(0.52)	28.48	*
Watertemperature (°C)	30 (1.25)	28.28 (0.92)	23.88	*
TN (µg.L⁻¹)	1.870 (0.80)	1,050 (0.77)	7.683	**
TP (µg.L⁻¹)	77.42(15.99)	33.96 (14.23)	54.77	*
Chlorophyll a (µg.L⁻¹)	126.42 (29.69)	5.51 (2.52)	194.2	*
Q Index	0.5 (0.42)	2.34 (1.03)	17.73	*
Total biomass (mm³.L⁻¹)	41.93 (15.51)	0.12 (0.04)	43.33	*

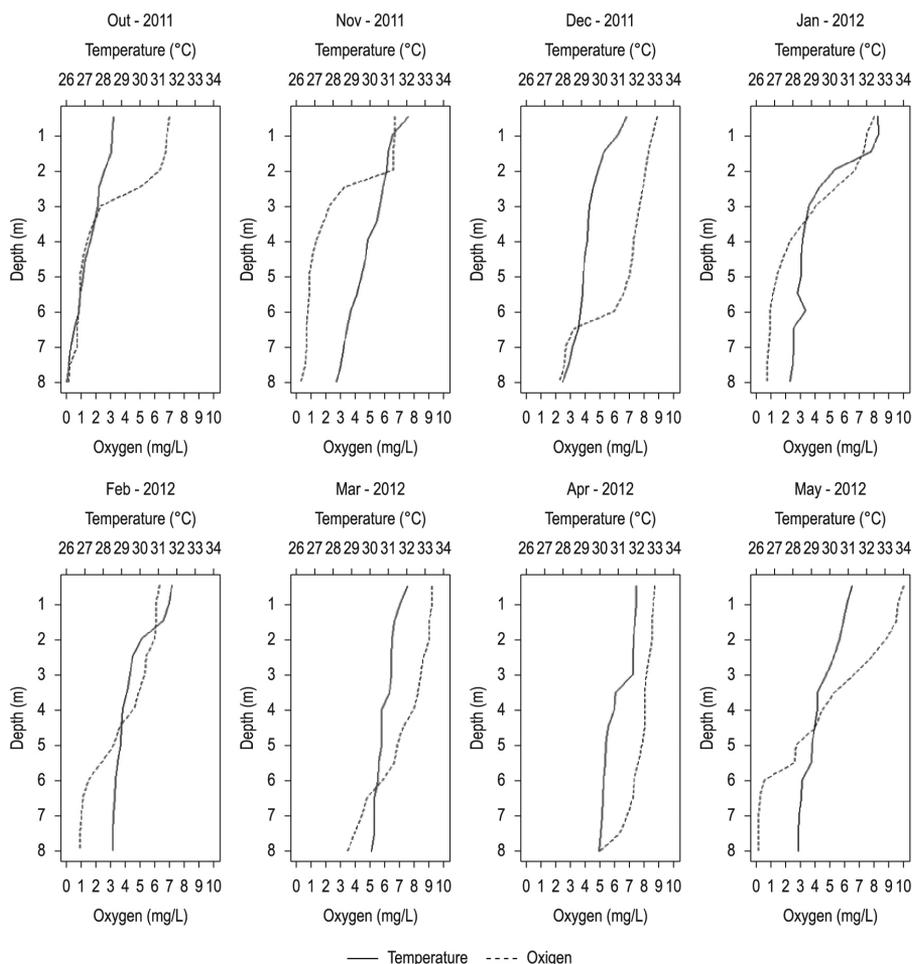Probalities are: * $p<0.001$; ** $p<0.005$; ns = not significant differences.

Figure 2. Vertical profile of temperature (°C) and dissolved oxygen (mg.L⁻¹) in the reservoir Pau dos Ferros during the study.
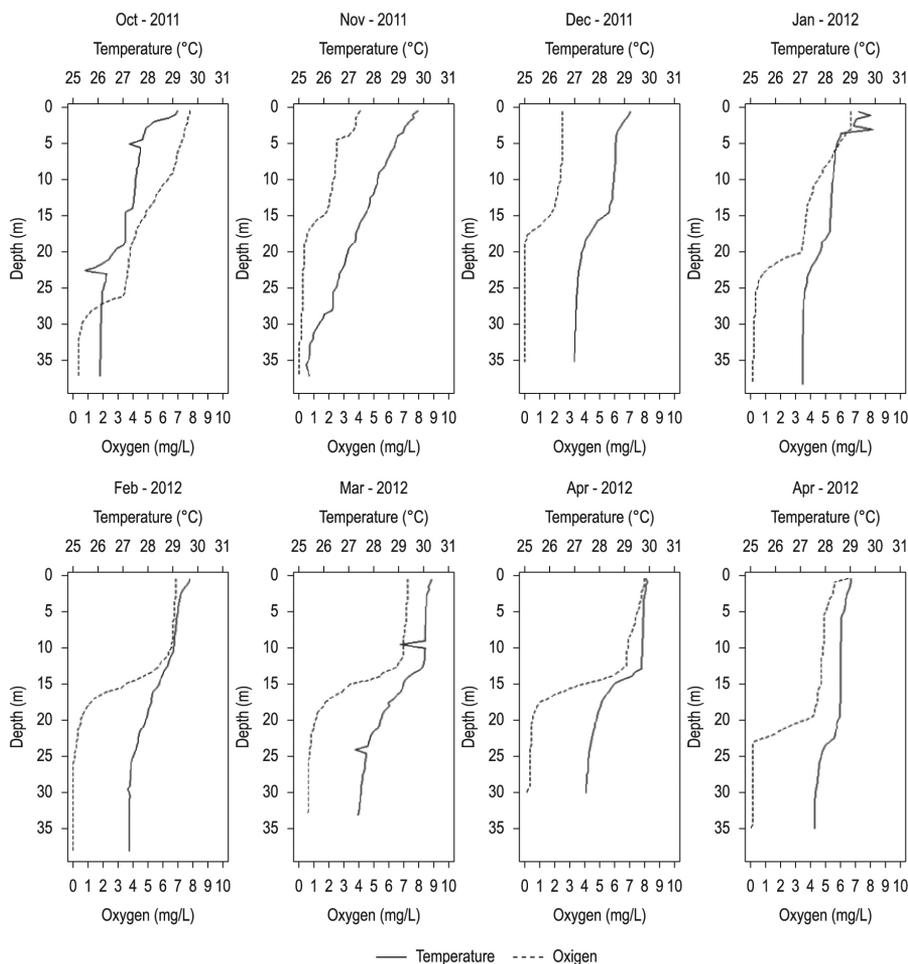
Figure 3. Vertical profile of temperature (°C) and dissolved oxygen (mg.L⁻¹) in the reservoir Santa Cruz do Apodi during the study.

went up to 7 meters deep, reaching anoxia in the hypolimion. In Santa Cruz, which is deeper, the mixed layer ranged from 17 to 25 m. Minor Zmix occurred in Nov. and Dec/12 (17 meters), increasing in the remainder of the period for ≥ 25 meters.

The temperature of the water in the reservoir Santa Cruz do Apodi ranged from 31°C (Mar/12) at the surface to 25° at the bottom (Nov/11), with gradual reduction of maximum 2°C from the surface to the bottom. Similar results as Pau dos Ferros were observed, where the temperature in the water column ranged from 32°C (Apr/2012) to 28°C (Oct/2011) with the highest values between the months of January to April 2012.

When the Trophic State Index (TSI) proposed by Lamparelli (2004) was applied to the variables chlorophyll and phosphorus, the trophic level of the reservoir ranged from eutrophic to hypereutrophic (Pau dos Ferros) and meso to eutrophic (Santa Cruz). Taking into account the values of phytoplankton biomass recorded during the study period, this

reservoir was also classified as eutrophic (Pau dos Ferros) and mesotrophic (Santa Cruz do Apodi) (Figure 4).

In Pau dos Ferros reservoir, total nitrogen ranged from 630 to 2.640 µg.L⁻¹, the highest value being recorded in the period after the occurrence of mixing of the water column. The same pattern was observed for total phosphorus, which ranged between 52 and 99 µg.L⁻¹. In Santa Cruz, the total nitrogen ranged between 370 and 2.320 µg.L⁻¹. The maximum value was given in the month of Dec/11, total mixing period of the water column. The total phosphorus (13 to 46 µg.L⁻¹) showed upward trend after the mixing period (Table 1).

3.2. Biological variables

A total of 47 taxons, distributed between the taxonomic classes: *Cyanobacteria, Bacillariophyceae, Chlorophyceae, Chryptophyceae* and *Euglenophyceae* were identified during the study, which were classified into 17 functional groups (Table 2). Some
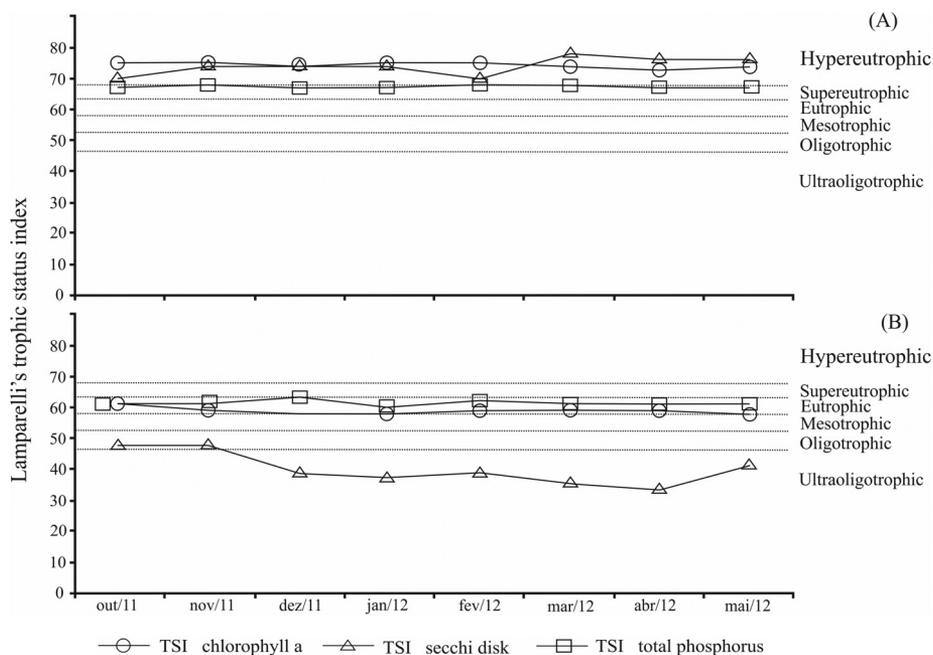
Figure 4. Temporal variation of the Trophic State Index (TSI) proposed by Lamparelli (2004) in Pau dos Ferros (A) and Santa Cruz do Apodi (B) reservoirs. (Ultraoligotrophic TSI = ≤ 47; Oligotrophic = 47 <TSI ≤ 52; Mesotrophic = 52 <TSI ≤ 59; Eutrophic = 59 <TSI ≤ 63; Supereutrophic = 63 <TSI ≤ 67; Hypereutrophic I TS => 67).

Table 2. Functional groups of phytoplankton (Reynolds et al., 2002), factor (F) used in the calculation of the index Q, frequency of occurrence according to Lobo & Leighton (1986) of the species identified during the study in the Pau dos Ferros and Santa Cruz reservoirs, from October 2011 to May 2012.

Funcional group	Species	Taxonomic group	Factor (F)	Frequency Occurrence	
				Santa Cruz	Pau dos Ferros
K	*Aphanocapsa delicatissima*	*Cyanobacteria*	5	dominant	
	Aphanocapsa incerta	*Cyanobacteria*	5	abundant	rare
M	*Microcystis wesenbergii*	*Cyanobacteria*	0	dominant	
	Microcysitis protocystis	*Cyanobacteria*	0	rare	
H1	*Aphanizomenon gracile*	*Cyanobacteria*	1	dominant	abundant
S1	*Planktolyngbya limnetica*	*Cyanobacteria*	0	abundant	abundant
	Geitlerinema unigranulatum	*Cyanobacteria*	0	rare	rare
	Pseudanabaena galeata	*Cyanobacteria*	0		abundant
	Pseudanabaena catenata	*Cyanobacteria*	0	rare	
	Phormidium sp	*Cyanobacteria*	0	rare	
L_0	*Synechocystis aquatilis*	*Cyanobacteria*	3	rare	rare
	Merismopedia tenuissima	*Cyanobacteria*	3	abundant	abundant
	Merismopedia glauca	*Cyanobacteria*	3		rare
	Chroococcus minutus	*Cyanobacteria*	3	rare	rare
	Merismopedia punctata	*Cyanobacteria*	3	rare	dominant
S_N	*Cylindrospermopsis raciborskii*	*Cyanobacteria*	0	rare	
L_M	*Coelomorom tropicalis*	*Cyanobacteria*	0	rare	abundant
MP	*Spirullina sp*	*Cyanobacteria*	5		rare
P	*Aulacoseira granulata*	*Bacillariophyceae*	5	abundant	
	Aulacoseira granulata variação angutissima	*Bacillariophyceae*	5		abundant
	Closterium acutum	*Chlorophyceae*	5		rare
D	*Nitzschia acicularis*	*Bacillariophyceae*	4	abundant	abundant
C	*Cyclotella ocellata*	*Bacillariophyceae*	4	abundant	

Table 2. Continued...

Funcional group	Species	Taxonomic group	Factor (F)	Frequency Occurrence	
				Santa Cruz	Pau dos Ferros
J	*Coelastrum astroideum*	*Chlorophyceae*	2	rare	
	Coelastrum microporum	*Chlorophyceae*	2	rare	
	Ankistrodesmus gracile	*Chlorophyceae*	2	rare	
	Crucigenia tetrapedia	*Chlorophyceae*	2	rare	
	Scenedesmus acuminatus	*Chlorophyceae*	2		abundant
	Selenastrum sp.	*Chlorophyceae*	2		rare
	Scenedesmus brevispina	*Chlorophyceae*	2		rare
	Scenedesmus ovalternus	*Chlorophyceae*	2		rare
	Scenedesmus quadricauda	*Chlorophyceae*	2		rare
	Tetraedron triangulare	*Chlorophyceae*	2		rare
F	*Oocystis lacustris*	*Chlorophyceae*	3	abundant	
	Eutetramorus sp.	*Chlorophyceae*	3	rare	
	Dictyosphaerium pulchellum	*Chlorophyceae*	3	rare	
	Botryococcus braunii	*Chlorophyceae*	3	dominant	
X1	*Monoraphidium contortum*	*Chlorophyceae*	3	rare	abundant
	Monoraphidium circinalis	*Chlorophyceae*	3	rare	abundant
	Monoraphidium irregulare	*Chlorophyceae*	3		abundant
	Monoraphidium nanum	*Chlorophyceae*	3		abundant
N	*Staurastrum leptocladum*	*Chlorophyceae*	2	rare	rare
	Staurastrum planctonicum	*Chlorophyceae*	2		rare
	Cosmarium punctunlatum	*Chlorophyceae*	0		rare
Y	*Chryptomonas sp.*	*Chryptophyceae*	3	rare	abundant
	Chryptomonas ovata	*Chryptophyceae*	3		rare
W2	*Trachelomonas volvocinopsis*	*Euglenophyceae*	3	rare	rare

groups like the subdivisions S1 and S_N persisted throughout the sample period.

In both reservoirs studied, the period of greatest Zmix corresponded to higher concentrations of phosphorus and total nitrogen, chlorophyll, total phytoplankton biovolume and greater diversity of functional groups. Increased functional group biovolume S_N was observed during periods of reduced Zmix.

The Pau dos Ferros reservoir (Figure 5) showed dominance of functional group S_N, whose representative *Cylindrospermopsis raciborskii* showed a relative contribution between 40 to 90% of total phytoplankton. In this reservoir, were recorded high values of total phytoplankton biovolume (20 to 70 mm³. L⁻¹) and chlorophyll (Max 150.48 mm³.L⁻¹). Change in species composition and taxonomic group coincided with the period of greatest Zmix, with increase in the relative contribution of groups D and X1, represented by diatoms and green algae, respectively. The group H1, represented by *Aphanizomenon gracile* was present in both reservoirs contributing up to 40% biomass between the months of October 2011 and February 2012.

The Santa Cruz do Apodi reservoir had lower values of total phytoplankton biovolume (0.04 to 0,4 mm³. L⁻¹) and chlorophyll (Max 10.39 µg.L⁻¹)

in comparison to Pau dos Ferros. *Aphanocapsa delicatissima* and *Aphanocapsa incerta,* codon K, as *Planktolyngbya limnetica,* codon S1, were present throughout the sample period. The green algae and diatoms (C, F, J, E, D and N) typical in meso-eutrophic environments, contributed to 60% biomass, showing a possible tolerance to the amounts of nutrients and luminosity or the fact that they have characteristics of low latitudes environments. It might also identify two distinct phases of dominance, the first, between the months of lowest Zmix (October 2011 to March 2012), in which the phytoplankton dominance was represented by colonial and filamentous cyanobacteria and the second, framed between April and May 2012, more Zmix where colonial (F) and individual (N) chlorophytes had representative biomass.

The flow variables (P 0.031) and total Nitrogen and (P 0.046) explained 60% of variation in total biovolume of phytoplankton in the reservoir Pau dos Ferros during the study. In the reservoir Santa Cruz, temperature (P 0.046), transparency (0.019) and total phosphorus 0.013 explained 70% of variation.

Nitrogen and total phosphorus were positively correlated with the biomass (P= 0.046 and P =
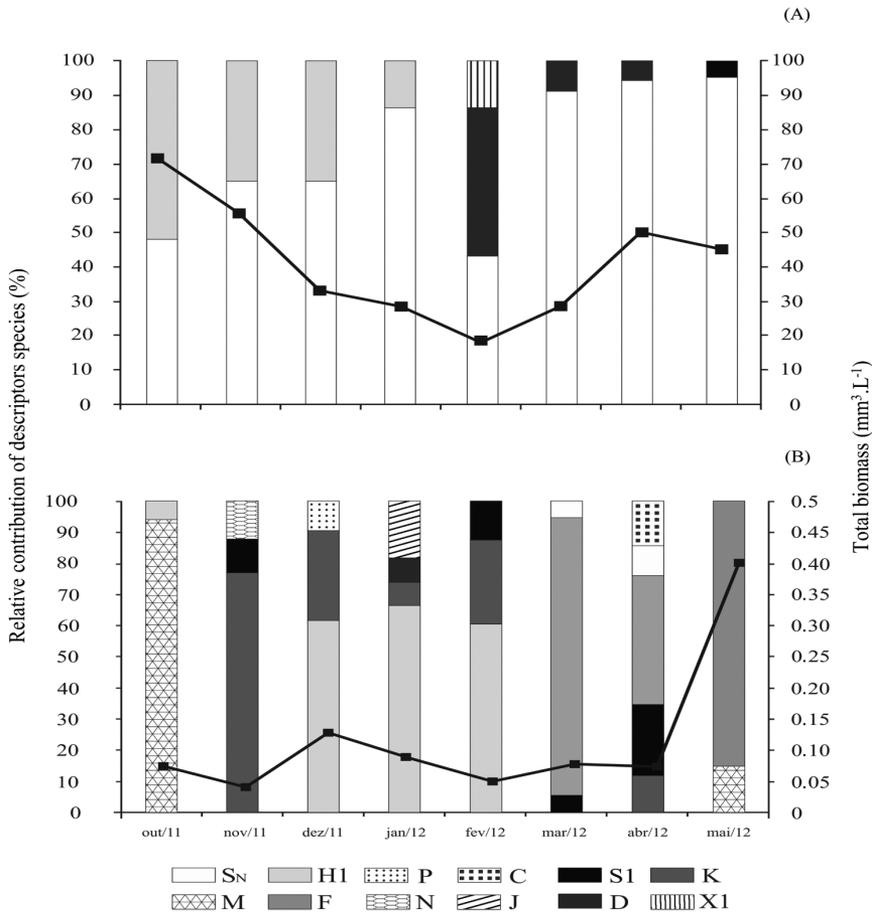
Figure 5. Relative contribution of phytoplankton functional groups (Reynolds et al., 2002) and total biomass (mm³.L⁻¹) from October 2011 to May 2012 in the Pau dos Ferros (A) and Santa Cruz do Apodi (B) reservoirs.

0.064, respectively) of phytoplankton in the two reservoirs. The correlation *Spermam* showed that the variables temperature *(r = P* = 0.46), volume (r = P = –0.73) and transparency (r = P = –0,73-0,74) were significantly important in the two reservoirs.

3.3. Index Assemblage (Q)

The index assembly (Q) (Figure 6) showed differences between the two studied reservoirs (F = 17.73, P = 0.001). The Pau dos Ferros reservoir classification ranged from bad to tolerable, predominantly state "bad" for almost the entire sample period. This result coincides with higher values of eutrophy and dominance of the functional group S_N. Only in February/2012 was recorded a tolerable value, caused by the increase in the contribution of groups D and X1.

In Santa Cruz do Apodi reservoir, the mild state prevailed during most of the period studied, correlated with oligotrophy and mesotrophy conditions of and greater diversity and of different functional groups representation typically of mesoeutrophic environments (K, S_0, H1, C, F, J,
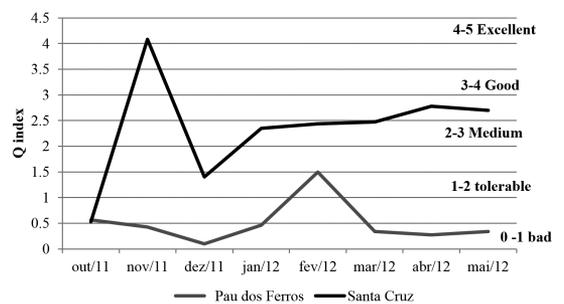

Figure 6. Variation of ecological status according to the application of the index Q in the Pau dos Ferros and Santa Cruz do Apodi reservoirs from October 2011 to May 2012.

P, D and N). The index Q showed smaller values with increasing contribution of the groups H1 and K, and higher values with increasing contribution from group F.

4. Discussion

The entire study period was characterized by a prolonged drought and gradual reduction of average

monthly volumes of the two reservoirs. The water volume reduction of the reservoirs coincides with decreasing water quality of the reservoirs relative to the index Q and trophic state measured by means of biovolume of the phytoplankton functional group, transparency, chlorophyll-a and total phosphorus. Thus, the higher turbidity, nutrients availability and lower photic zone coincides with the dominance of cyanobacteria functional groups adapted to these environments, alternating with periods of greater photic zone and greater diversity of species.

Studies in Brazilian semi-arid reservoirs show that factors such as the prolonged drought, intense evaporation and long residence time of the water, act decisively in determining the hydrologic conditions of the watershed and is even related to the establishment of eutrophic conditions (Costa et al., 2009). Bouvy et al. (2003) also reported that rainfall events irregularly distributed throughout the year in this region, resulting in intense seasonal fluctuations in water level. These periods are usually characterized by the trophic status change of the system, resulting in poor water quality due to increased turbidity and algal biomass consequently occurring unfeasibility of the use of most reservoirs for various human activities.

In this sense, the temporal response of phytoplankton in reservoirs of Pau dos Ferros and Santa Cruz, despite the difference in their depths, seem to follow the hypothesis of "alternative balance" for shallow lakes proposed by Scheffer (1998) e Scheffer et al. (2001), which shows that abrupt differences in this "balance state" causes different changes in phytoplankton community structure.

The functional groups of phytoplankton identified reveal adjustments and tolerances to meso-eutrophic low latitude environments (Reynolds et al., 2002 and Padisák et al., 2009) and correlated with conditions of eu/hypereutrophy found for the reservoir Pau dos Ferros and trace oligo-mesotrophy to the reservoir Santa Cruz.

In reservoirs of Santa Cruz and Pau dos Ferros, phytoplankton showed distinct patterns of distribution. Pau dos Ferros was categorized as shallow reservoir, in which light and nutrients acted jointly as important limiting factors for phytoplankton (Scheffer, 2004). The turbid waters influenced the composition and biomass of phytoplankton, which showed dominance of the functional group S_N whose relative contribution, covered up to 90% of total phytoplankton. The species *Cylindropermopsis raciborskii,* main

representative of this group, has ecological success associated with the ability of vertical migration in the water column, tolerance to low light, affinity for phosphorus and ability to fix nitrogen (Padisák, 1993). Moreover, several studies show that *C. raciborskii* acquired several adaptive mechanisms that not only helped to increase their survival but also to make it an invasive species due to present competitive advantage over other phytoplankton species (Sinha et al., 2012), so it has emerged as dominant in eutrophic reservoirs in tropical northeastern Brazil (Bouvy et al., 2000; Huszar et al., 2000; Chellappa & Costa, 2003), where the high temperatures are recorded throughout the year alongside with the stability of the water column favoring its dominance.(Tucci & Sant'Anna, 2003).

The increase in the relative contribution of cyanobacteria has been reported in turbid reservoirs where light availability for phytoplankton is low and shows a remarkable increase in water temperature. Further, increased turbidity threatens submerged plant growth and habitat of different fish species (Kosten et al., 2012).

Low light availability in the water column was also evident in other reservoirs in the Brazilian semi-arid (Huszar et al. 2000), and turbidity in these environments is also determined by the organic and inorganic fractions of seston (Sousa et al., 2008). In general, inorganic particulate matter carried from drainage basin is a major source of abiogenic turbidity in aquatic environments of semi-arid regions (Thornton & Rast, 1993), where soils with low organic matter concentration, as is the case of semi-arid Rio Grande do Norte, are susceptible to erosion (Lal, 1985).

It might also be noticed that the low values of biomass coincided with the period in which it was recorded greater mixing zone and transparency, as showed what happened in February 2012, the reservoir of Pau dos Ferros, where these conditions influenced the change in species composition community, increasing the relative contribution of groups D and X1 despite constant predominance of S_N group**.** The morphology of the reservoir along with seasonal cycles allowed the ''best'' adapted species to dominate in certain periods of seasonal succession (Padisák et al., 2006). Therefore, the functional groups described for Pau dos Ferros reservoir are common in eutrophic environments of low latitude, where are registered: high amount of sunlight, high levels of phosphorus, nitrogen and turbidity.

The reservoir Santa Cruz, with the highest average depth, greater water volume and greater photic zone had lower biomass values and a greater diversity of species, including the participation of the group F, composed of colonial chlorophytes with affinity for clear water in the months where was recorded greater transparency, and diatoms and desmids were also identified the groups P and D, which are common in shallow aquatic ecosystems, nutrient-rich with muddy and well ventilated waters (Reynolds et al., 2002). Species of green algae J and diatoms P, tolerant to turbidity and high nutrient levels, did not present high biomass, but were related to populations of cyanobacteria.

In depth reservoirs, cyanobacteria generally dominate in the deeper layers. The strong mixing of the water column promotes homogenization of the column causing the cyanobacteria to be dominant or absent due to competitive exclusion (Scheffer et al., 1997).

The model functional group proposed by Reynolds et al., (2002), showed sensitivity to environmental conditions of the reservoirs in this study. The index assembly (Q) developed by Padisák et al. (2006) highlights the importance of including the approach of functional groups in monitoring processes in order to be a different method and sensitive to errors identification.

The assessment of ecological reservoirs status using the Q index showed a high sensitivity to changes in species composition and functional groups. The reservoir of Pau dos Ferros was categorized as poor for most of the sample period in view of the high biomass of functional groups S_N, S1 and H1, in Santa Cruz do Apodi, the lowest index values were recorded when there was dominance of the group M. A similar result was also recorded by Crossetti & Bicudo (2008) in an eutrophic urban reservoir in southeastern Brazil, they also reported that Q index values were inversely proportional to the dominance of functional groups S_N, S1, M, H1.

In summary, the index Q satisfactorily reflected the changes in phytoplankton composition and functional group approach displayed itself as sensitive and responsive to environmental and hydrodynamics changes of the studied reservoirs, revealing itself as a suitable tool for monitoring water quality in the tropical semi-arid region.

Acknowledgments

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