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Phytoplankton diversity and physical-chemical aspects of water quality of Lake Jiqui, Rio Grande do Norte, Brazil.

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ABSTRACT: The aim of this study was to evaluate the phytoplankton diversity and water quality of Lake Jiqui on spatial and temporal scales. This freshwater ecosystem is an important source of water supply for the city of Natal and the adjacent municipality Parnamirim, Rio Grande do Norte. The water samples were collected from September, 2008 to August, 2009 at four different sites: lake margin, water catchment area, middle of the lake and a site dominated by rooted and floating macrophytes. The samples were collected from surface and bottom waters during the wet and dry season of an annual cycle. Limnological factors such as temperature, pH, transparency and electrical conductivity were measured *in situ*. Nutrient variables such as nitrate-nitrogen, ammonium-nitrogen and orthophosphate were analyzed in the laboratory. Chlorophyll *a* concentrations from the fresh samples were analyzed with 90% acetone extraction in the dark at 4°C in the laboratory. Ecological indices such as diversity, equitability (similarity), and species richness for phytoplankton were calculated. Biochemical Oxygen Demand (BOD) data were obtained from CAERN (Water and Sewage Company of Rio Grande do Norte). Significant results were obtained for limnological parameters on temporal scales (dry and wet season) but not on spatial scales. Phytoplankton diversity was moderate to low on both spatial and temporal scales, with the selected dominance of the species *Euglena gracilis, Trachelomonas* (Euglenophyceae) and *Gomphonema, Navicula cuspidata* var. *cuspidata, Navicula* spp, *Rhopalodia gibba* and *Cyclotella* sp (Bacillariophyceae). Chlorophyll *a* concentrations were low throughout the study period, with a mean of 1.07 μgL^{-1}. Chlorophyll concentration and BOD values remained within allowable water quality limits for human consumption. The Lake Jiqui is considered to be an oligotrophic ecosystem because of low chlorophyll concentrations, high transparency, few species of cyanobacteria and low nutrient content.

Key words: Phytoplankton, chlorophyll *a*, water quality, oligotrophic status.

RESUMO: Diversidade fitoplanctônica e aspectos físico-químicos da qualidade da água da Lagoa do Jiqui, Rio Grande do Norte, Brasil. O objetivo deste estudo foi avaliar a diversidade do fitoplâncton e a qualidade da água do Lago Jiqui em escalas espaciais e temporais. Este ecossistema de água doce é uma importante fonte de abastecimento de água para a cidade de Natal e do município adjacente Parnamirim, Rio Grande do Norte. As amostras de água foram coletadas em setembro de 2008 a agosto de 2009, em quatro locais diferentes: margem de lago, local de abastecimento de água, meio do lago e de um local dominado por macrófitas enraizadas e flutuantes. As amostras foram coletadas das águas superficiais e de fundo durante o período chuvoso e seco, de um ciclo anual. Os fatores limnológicos, tais como temperatura, pH, transparência e condutividade elétrica foram realizadas in situ. As variáveis de nutrientes como o nitrato, amônio e ortofosfato foram analisados em laboratório. As concentrações de clorofila *a* foram analisados a partir de amostras frescas com extração de acetona 90% no escuro a 4°C no laboratório. Os índices ecológicos, como a diversidade, equitabilidade (similaridade) e a riqueza de espécies de fitoplâncton foram calculados. Os dados de Demanda Bioquímica de Oxigênio (DBO) foram obtidos da CAERN (Companhia de Águas e Esgotos do Rio Grande do Norte). Houve diferenças significativas para os parâmetros limnológicos na escala temporal (estação seca e chuvosa), mas não em escala espacial. A diversidade do fitoplâncton foi moderada a baixa, em ambas as escalas espaciais e temporais, com o domínio selecionado das espécies de *Euglena gracilis, Trachelomonas* (Euglenophyceae) and *Gomphonema, Navicula cuspidata* var. *cuspidata, Navicula* spp, *Rhopalodia gibba* e *Cyclotella* sp (Bacillariophyceae). As concentrações da clorofila *a* foram baixas durante todo o período de estudo, com média de 1,07 μgL^{-1}. A concentração de clorofila e os valores de DBO mantiveram-se dentro dos limites admissíveis de qualidade da água para consumo humano. O Lago Jiqui é considerado um ecossistema oligotrófico por causa de baixas concentrações de clorofila, maior transparência, poucas espécies de cianobactérias e de baixo teor de nutrientes.

Palavras-chave: Fitoplâncton, clorofila *a*, qualidade da água, estado oligotrófico.

1. Introduction

Freshwater ecosystems support the growth of multiple biological species and also provide essential services important to human society. A daily supply of clean drinking water is imperative to human consumption and therefore, the water is treated and distributed to urban population (ARTHINGTON et al., 2010). Freshwater aquatic ecosystems of Brazil provide important basis for activities such as irrigation, water consumption and fishing. This is subjected to various degrees of natural and

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anthropic pressures which are linked to their use, in addition to the influence of hydrological and biogeochemical regimes and discharges of chemical products and pathogens that may alter the food chain (TUNDISI; TUNDISI, 2008). The water quality of freshwater resources has been a critical factor, especially in the Northeast of Brazil as it suffers from twin impacts such as drought polygon and cultural eutrophication (CHELLAPPA et al., 2009a). Systematic control of water quality and conservation of biological diversity are essential to maintaining high quality potable water and to the development of fishing, currently subjected to continuous human interventions and climatic changes (CHALAR, 2009; CHELLAPPA et al., 2009b).

The increasing demand for water, as a result of droughts and population growth in the city of Natal, Brazil, requires competent management of water resources aimed at sustainability and environmental safety. This is considered as one of the main concerns of contemporary society, posing a challenge to ecologists and environmental scientists to provide adequate supplies of clean water. Nutrient dynamics in freshwater ecosystems are largely based on the processes of internal and external transport, sedimentation rates, mixture regime and water discharge rates. The nature of nutrient entry is influenced by the climatic regime of the region, the hydrodynamic nature of the water body, characteristics of the basin and type of surrounding land use. A strong inter-reservoir variation was recorded between the two main nutrients, total nitrogen and phosphorus, when based on the flow of the river, erosion rates in the adjacent land, types of soil origin, sedimentation and resuspension processes (THORNTON et al., 1990). Since reservoirs in the Northeast are mostly used as drinking water supply sources and nutrient dynamics are part of the dynamic effect of this ecosystem, the distribution of nutrients in time and space must be assessed, owing to the significant differences in the annual flow regime in the reservoirs of the semi-arid between the dry and rainy seasons (BOUVY et al., 2003; CHELLAPPA et al., 2006).

In Brazil, several studies related to the phytoplankton community and focused on methodological, taxonomic, ecological and limnological aspects have been conducted (RANGEL et al., 2009; HUSZAR; GIANI, 2004; PETRUCIO et al., 2006; LOPES et al., 2005; FRAGOSO et al., 2008, NOGUEIRA, 2000; FIGUEIREDO; GIANI, 2001). However, studies on the phytoplankton community of the Northeast are limited and scarce, given that very few have been conducted in freshwater (BOUVY et al., 2003; MOURA et al., 2007; CHELLAPPA et al., 2002). There have been only few investigations on the phytoplankton composition of the water resources that supplies to the city of Natal (ARAÚJO et al., 2000; CHELLAPPA et al., 2004; ARAÚJO; GONDINHO, 2008). The ecological response of the phytoplankton community with respect to nutrient dynamics consists of variations and alterations in structure, diversity, spatial-temporal distribution, co-existence, biomass concentration (chlorophyll *a*) and the flourishing of competitively superior species (cyanobacteria), dependent on the availability of organic and inorganic nutrients in the water body (REYNOLDS, 1984).

Lake Jiqui provides drinking water supply to the municipalities of Parnamirim and Natal. In recent years, the accelerated process of development, modernization and urbanization of these areas has caused a slow degradation of the River Pitimbu which in turn feeds Lake Jiqui. This study aimed at two objectives: the first was to monitor the water quality of Lake Jiqui by tracking its physical-chemical characteristics, phytoplankton diversity and biomass production; the second was to provide ecological data for the management of clean, healthy and sustainable water.

2. Material and methods

Study area

Lake Jiqui (5°50’00” S and 35°23’19” W) is a freshwater ecosystem which supplies drinking water for 22% of the population of greater Natal, at a flow rate of 700 Ls^{-1}; the remaining 78% comes from tubular wells with high nitrate concentrations. Lake Jiqui receives its water supply mainly from the River Pitimbu, located in the city of Parnamirim, RN (Figure 1). The study area suffers human impacts such as urbanization, deforestation and pollution. Hydrological and morphometric characteristics of Lake Jiqui are shown in Table 1.

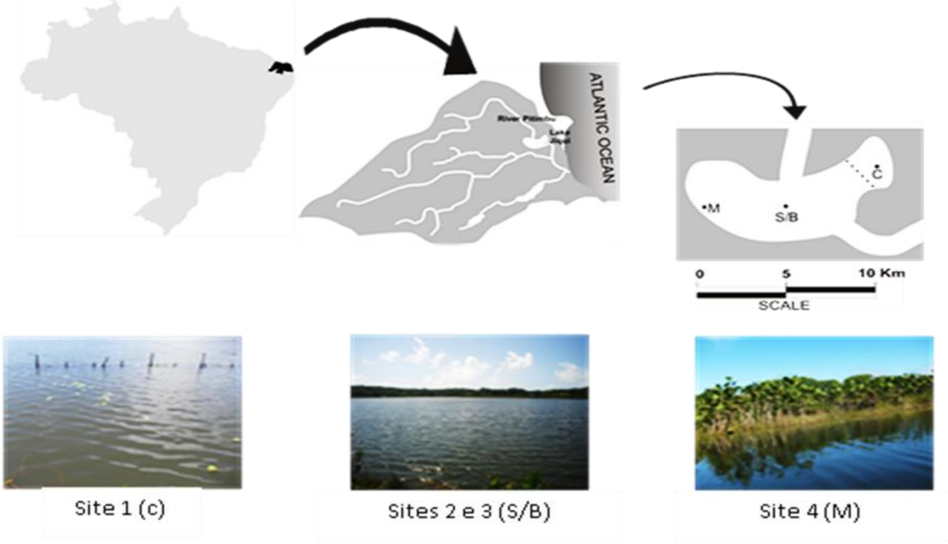

Figure 1. Pirangi hydrographic basin with the location of study sites at the Lake Jiqui, RN. Site 1 (C) fence, Site 2 (S) surface, Site 3 (B) bottom, Site 4 (M) macrophytes.

Table 1. Hidrological and morphometric characteristics of Lake Jiqui, RN.

Initial year of functioning	1934
Drainage area	153,895m^2
Water outlet	12.25m
Width	1210
Lengyh	200m
Maximum capacity	466,093m^3
Storage volume	466,000m^3
Flow input	1.5345m^3/S
Flow output	1.2729m^3/S
Hydraulic detention time	2.6 days
Maximum depth during study	4m
Annual rainfall	1562.6mm/year
Annual mean relative humidity	75%
Annual mean temperature	26.8°C
Total annual evaporation	1.553.5mm
Total annual insolation	2.954h
Atmospheric pressure	1,004.8 hPa
Average annual wind speed	4.9 m/s
Wind direction	Southeast

Sampling and Analysis

The water samples were collected from September, 2008 to August, 2009 at four different sites: the lake margin (site 1) near the fence, surface water of the catchment area (site 2), middle of the lake (site 3) bottom water, and a site dominated by rooted and floating macrophytes (site 4) (Figure 1). The samples were collected during the wet and dry season of an annual cycle.

Physical-chemical parameters such as temperature, pH, and electrical conductivity were measured *in situ* using the Multi-parameter 340i Kit (Horiba, Model U-52G/30), dissolved oxygen with the Lutron DO-5510 Oximeter, transparency using the Secchi disk and turbidity with a turbimeter. For nutrients, such as nitrate (N-NO_3) and ammonium (N-NH_4), the method described by Golterman et al. (1978) was used; for orthosphosphate (P–PO_4^-) the APHA method (1992) was used; light extinction coefficient values were calculated according to Poole and Atkins (1929).

Rainfall and wind speed data of the study area were obtained from EMPARN (Agricultural Research Company of Rio Grande do Norte), Natal, RN.

For qualitative analysis of phytoplankton, the water samples were collected by vertical towing of a phytoplankton net of 20 μm mesh size, and preserved in 4% formaldehyde. To count phytoplankton, water samples were collected with a Van Dorn bottle along vertical profiles. The phytoplankton samples were fixed with Lugol´s-iodine for subsequent identification and counting. Cell counts were done under a Nikon Eclipse E200 optical microscope, using 400x amplification and a Sedgwick–Rafter, with capacity for 1 ml of the sample (WETZEL; LIKENS, 2000). For analysis of chlorophyll *a*, the samples were placed in polyethylene bottles and kept under refrigeration for subsequent analysis in the laboratory, according to Marker et al. (1980).

The abiotic and biotic factors of each site in both the dry and rainy seasons were correlated by using Pearson’s correlation ($p<0.05$).

3. Results

The rainfall regime ranged from 0.0 mm in December to 370.2 in May, with a mean of 179.21 mm (± SD 127.57 mm). The highest volumes were found in May, June and July 2009. The dry season occurred between September and December 2008 (Figure 2). Wind speed was highest between September 2008 and December 2008. In general, transparency in the Lake Jiqui was higher in the rainy period, with a mean of 1.60m at the surface for the entire study period (Figure 3). Turbidity showed a significant difference between the dry and rainy seasons between the study sites (p = 0. 003).

The light extinction coefficient was lower at site 1 during the dry and rainy seasons. The site near the macrophytes also showed low values in the rainy season. The light extinction coefficient was significantly different among the sites (p= <0.001).

Water temperature varied seasonally, showing higher values in the dry season at all the study sites. Dissolved oxygen values differed over the entire study period and between all the sites, and a significant difference (p = 0. 001) was observed between the dry and rainy seasons. The uniform electrical conductivity pattern of the surface waters was quite evident. Site B (bottom) showed a higher value in October and an increase in electrical conductivity was observed at all the sites in April, 2009. The pH of the water was neutral at all sites (6.5 – 7.5). The minimum, maximum, mean and standard deviation values of pH, temperature, DO, conductivity, transparency, NO_3, NH_4 and PO_4 of the sites during the study period are shown in Table 2.

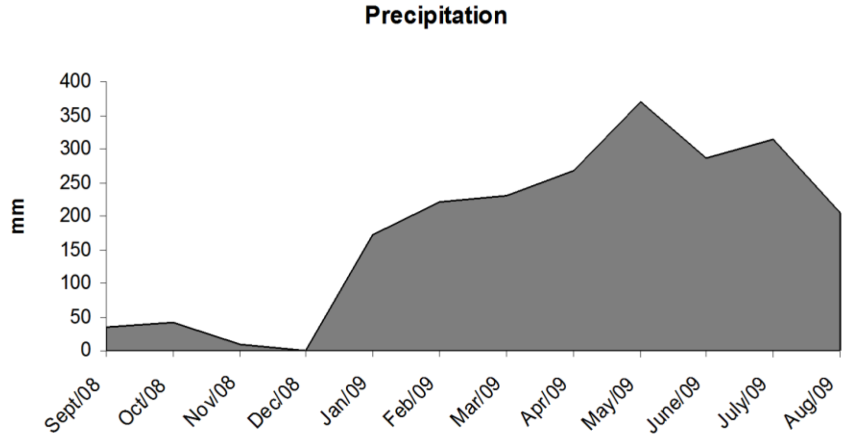

Figure 2. Rainfall variation at the Lake Jiqui during the period of September, 2008 to August, 2009. **Source**: Rainfall data of the study area were obtained from EMPARN (Agricultural Research Company of Rio Grande do Norte), Natal, RN.

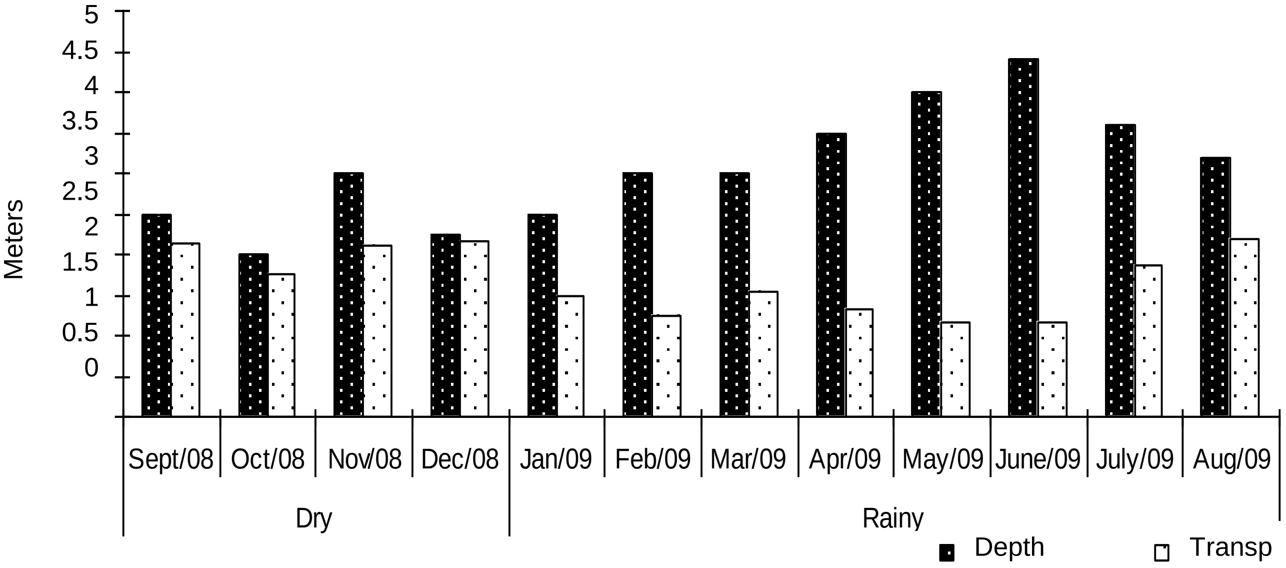

Figure 3. Variation of depth and transparency at the Lake Jiqui during the dry and rainy periods of September, 2008 to August, 2009.

Table 2. Minimum, maximum and mean values of the environmental variables of Lake Jiqui on spatial and temporal scales during an annual cycle 2008-2009 (S-surface, B- bottom, C- margin of the lake without macrophytes, M- site dominated by macrophytes, DO- dissolved oxygen, COND- electrical conductivity, Transp -Transparency, NO_3 – nitrate, NH_4 - ammonium , PO_4 – orthophosphate.

	DRY PERIOD				RAINY PERIOD			
Environmental Variables	S	B	C	M	S	B	C	M
pH	6.808 (6.80-7.57)	6.723 (6.72-7.42)	6.773 (6.77-7.34)	6.703 (6.70-7.56)	6.9 (6.5-7.41)	6.49 (6.28-7.01)	6.51 (6.13-7.13)	6.61 (6.11-7.0)
Temperature (°C)	27.8 (6.47-7.57)	26.5 (6.20-7.42)	28.5 (6.38-7.34)	28.5 (6.29-7.56)	28.813 (27-31.1)	28.2 (26.5-30.9)	28.8 (26.9-30.9)	28.7 (27-30.4)
DO (mg L^{-1})	7.6 (6.6-8.7)	6.7 (5-7.9)	7.9 (6.3-8.7)	7.32 (5.1-8.7)	5.9 (5-7.7)	5.2 (4.4-7.0)	5.9 (4.7-7.7)	5.4 (4.4-7.0)
Cond (mScm^{-1})	97.7 (94-100.0)	124.5 (95-205.0)	103 (100.0-111.0)	94.75 (91-98)	98.13 (80-136)	100.3 (79-132)	98.25 (81-135)	94.12 (79-114)
Transp (m)	2.04 (1.76-2.16)		1.12 (0.8-1.76)	2.01 (1.8-2.13)	1.43 (0.97-2.18)		1.386 (0.75-2.14)	1.528 (0.62-2.18)
NO3 (mg L^{-1})	0.37 (0.054-0.96)	0.73 (0.50-1.12)	0.4 (0.12-0.98)	0.57 (0.62-0.66)	0.5 (0.037-0.95)	0.63 (0.22-1.07)	0.41 (0.16-0.69)	0.47 (0.16-0.85)
NH4 (mg L^{-1})	0.13 (0.046-0.23)	0.19 (0.096-0.25)	0.08 (0.005-0.16)	0.13 (0.067-0.21)	0.113 (0.01-0.5)	0.18 (0-0.83)	0.15 (0.01-0.48)	0.26 (0.04-1.01)
PO4 (mg L^{-1})	0.24 (0.1-0.45)	0.24 (0.1-0.43)	0.26 (0.22-0.29)	0.29 (0.16-0.5)	0.307 (0.023-0.88)	0.25 (0.053-0.41)	0.2 (0.016-0.35)	0.21 (0.004-0.37)

Biochemical oxygen demand (BOD) showed a significant difference among the sites (p = 0.020) (Figure 4). Nutrient concentrations showed a pattern of spatial and seasonal variation. Nitrate, ammonium and orthophosphate exhibited peaks in the rainy season, but they were not significantly different (Figure 5).

The phytoplankton species found at the Lake Jiqui: 108 taxa were found, divided into 47 Bacillariophyceae, 41 Chlorophyceae, 9 Cyanobacteria, 1 Chrysophyceae, 2 Dynophyceae, 5 Euglenophyceae, 1 Raphidophyceae and 2 Xanthophyceae. Table 3 shows the phytoplankton species and the amount of individuals per milliliter encountered at the Lake Jiqui during the dry and rainy season at the four sites. Table 4 shows the distribution of classes during the dry and rainy seasons.

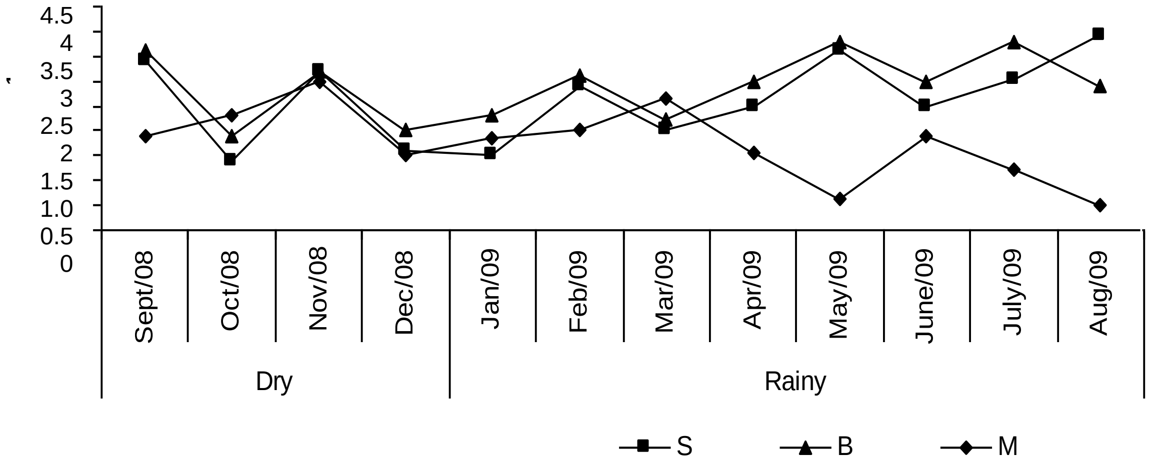

Figure 4. Variation in concentrations of Biochemical Oxygen Demand (BOD_5) at the Lake Jiqui in the sites of macrophytes (M), surface (S) and bottom (B), during the dry and rainy periods.

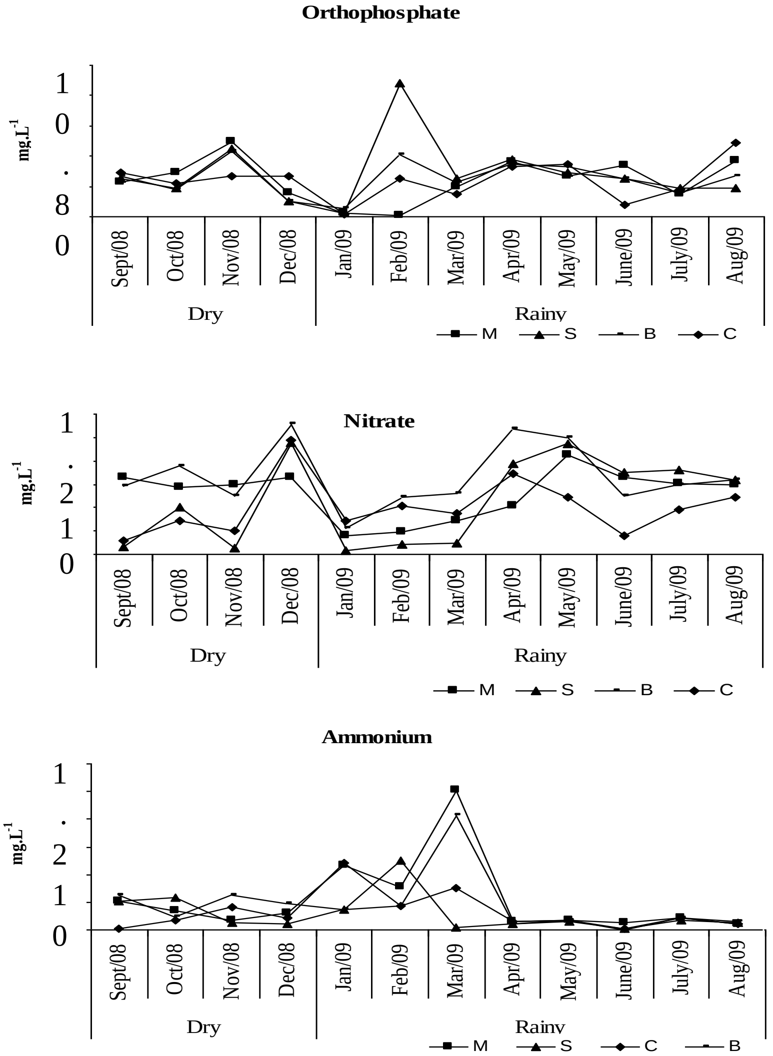

Figure 5. Variation in concentrations of nutrients (a) orthophosphate, (b) nitrate and (c) Ammonia at the Lake Jiqui during the dry and rainy periods. (M-macrophytes, S- surface, C- fence, B- bottom).

Table 3. The phytoplankton species and the amount of individuals per milliliter encountered at the Lake Jiqui during the dry and rainy season at the four sites, during September, 2008 to August, 2009 (S-surface, B- bottom, C- margin of the lake without macrophytes, M- site dominated by macrophytes).

	DRY PERIOD				RAINY PERIOD			
	S	B	C	M	S	B	C	M
BACILARIOPHYCEAE								
Amphicampa eruca Ehrenberg	-	100	100	-	-	-	-	-
Amphiprora sp	200	100	-	-	-	-	-	-
Amphora pediculus	600	100	150	3200	100	-	-	-
Aulacoseira granulata Simonsen	-	-	100	-	-	-	-	-
Aulacoseira sp	-	-	250	100	-	-	-	-
Ceratoneis arcus var.arcus	-	-	-	-	-	-	-	100
Caloneis ventricosa	-	-	-	100	-	-	-	-
Cocconeis placentula Rhr	100	-	-	-	-	-	-	-
Cyclotella sp	700	1300	600	3700	2900	1600	2000	2200
Cymbella afinnis Kützing	300	100	-	10120	-	-	-	-
Cymbella lanceolata (Agardh)	-	-	-	2900	-	-	-	-
Cymbella minuta Hilse	-	100	-	-	-	-	-	-
Cymbella microcephala Grun	-	-	-	4540	-	-	-	-
Eunotia flexuosa var. *flexuosa*	-	-	-	100	100	-	300	200
Eunotia serra	-	300	-	-	100	100	200	100
Fragillaria virescens var. *exigua*	300	-	250	100	100	-	200	100
Gyrosigma acuminatum	-	-	-	-	-	100	-	100
Gomphonema apuncto	350	400	1500	100	400	100	400	400
Gomphonema parvulum	300	-	-	-	-	-	-	-
Gomphonema truncatum	-	-	-	-	-	-	-	200
Melosira patagonica	-	100	100	2800	-	-	-	-
Melosira varians	200	100	-	300	100	-	-	-
Navicula contenta	-	100	100	800	-	-	-	-
Navicula cryptocephala	200	-	-	-	100	-	-	-
Navicula cuspidata var. *cuspidata*	6200	100	250	4700	500	100	300	1400
Navicula Mutica var. *cahinii*	100	-	-	-	-	-	-	-
Navicula sp	500	300	700	10640	500	300	300	700
Nitzschia cuspidata	-	-	-	-	-	400	-	200
Nitzschia kutizingiana	100	-	-	-	100	-	-	-
Nitzschia linearis	-	100	-	4400	-	-	-	-
Nitzschia reimerii Kociolek & Herbst	-	-	-	220	-	-	-	-
Nitzschia sigmoidea	100	100	-	-	200	-	-	-
Nitzschia sp	-	-	-	-	100	-	-	-
Nupela sp	100	-	-	-	-	-	-	-
Pinnularia lata	-	-	-	-	100	100	-	-
Pinnularia sp	700	300	-	600	300	200	200	100
Pinnularia viridis	-	-	-	-	-	100	-	-
Rhopalodia gibba	200	200	100	720	300	300	200	100
Stephanodiscus sp	600	100	-	2960	700	300	400	800
Surirella tenera	1350	200	400	11060	-	100	400	-
Tabellaria binalis (EHR) Grun	300	100	-	200	300	200	300	300
Subtotal	**$13.5x10^3$**	**$4.3x10^3$**	**$45.5x10^2$**	**$64.4x10^3$**	**$7x10^3$**	**$4x10^3$**	**$5.2x10^3$**	**$7 x 10^3$**
CHLOROPHYCEAE								
Actinastrum hantzschii	-	-	-	-	100	-	-	-

Ankistrodesmus bibraianus	-	-	-	-	100	-	-	-
Ankistrodesmus falcatus	400	100	200	-	400	-	-	-
Bambusina Brebissonii	200	-	-	-	-	-	-	-
Closterium ehrenbergii	100	-	-	-	100	-	-	-
Closterium rostratum	500	-	-	540	-	-	-	-
Coelastrum astroideum	-	-	-	-	100	500	100	400
Coelastrum microporum	-	100	100	-	200	-	-	-
Coelastrum reticulatum	-	-	-	100	100	-	300	-
Cosmarium bioculatum	100	-	-	-	-	-	-	-
Cosmarium sp	150	-	850	100	600	-	-	-
Cylindrocystis displora	-	-	100	-	200	-	-	-
Elakatothrix inflexa	-	100	-	-	100	200	-	100
Eudorina sp	-	-	-	-	-	400	200	-
Euastrum abruptum var.lagoense	-	-	-	100	-	-	-	-
Eustropsis richeteri	100	300	100	400	100	100	-	200
Golenkinia radiata	100	-	-	7480	-	-	-	-
Hialotheca dissiliens	100	-	-	-	-	-	-	-
Kirchneriella lunaris	-	-	-	-	100	-	-	-
Kirchneriella obesa	-	-	-	-	100	100	-	-
Micrasterias folícea	-	-	-	-	100	-	-	-
Micrasteris rotata	-	-	-	-	-	-	100	-
Monoraphidium irregulare	-	-	-	-	-	-	-	100
Oocystis sp	5250	100	200	-	2600	1300	-	-
Pandorina sp	450	200	200	100	400	100	800	1000
Pediastrum duplex var. *duplex*	100	-	-	-	500	-	200	500
Pediastrum duplex Meyen	200	-	-	-	-	-	-	100
Pleurotaenium tridentulum	-	100	5300	100	100	200	100	200
Radiofilum conjunctivum	-	-	-	-	-	100	-	-
Scenedesmus acuminatus	-	-	-	-	200	-	-	-
Scenedesmus acutus	-	-	-	100	100	-	100	300
Scenedesmus denticulatus	-	-	-	-	200	-	-	-
Scenedesmus dispar	100	-	-	-	-	-	-	-
Scenedesmus quadricauda	300	-	-	660	100	-	-	100
Schroederia setigera	300	-	-	1900	700	-	200	100
Selenastrum gracile	-	-	-	-	200	-	-	-
Sphaerozomas laeve	100	-	200	-	-	-	600	700
Sphaerozosma aubertianum	-	100	-	1200	-	-	-	-
Sphaerozosma vertebratum	-	-	-	100	200	100	-	-
Staurastrum avicula	500	-	-	-	-	-	-	-
Staurastrum gracile	-	-	-	-	-	-	200	-
Staurastrum rotula	-	100	200	200	-	-	-	100
Staurastrum vestitum	200	-	-	100	-	-	-	-
Staurastrum sp	450	100	200	5480	400	-	-	400
Staurastrum vestitum	-	-	-	100	-	-	-	-
Tetraspora gelatinosa	-	-	-	100	1700	800	-	100
Volvox sp	500	800	-	100	-	-	-	300
Subtotal	**10.15x103**	**2.1x103**	**76.5x102**	**18.96x103**	**9.8x103**	**3.9x103**	**2.9x103**	**4.7x103**
CYANOPHYCEAE /CYANOBACTERIA								
Anabaena circicalis	500	100	100	200	-	-	-	100
Anabaena sp	-	100	-	-	100	-	-	-
Chroococcus turgidus	100	100	200	200	-	-	200	100

Geitlerinema sp	-	-	100	-	100	-	-	-
Microcystis aeruginosa	100	-	200	-	300	100	-	200
Nostochopsis lobata	-	-	-	-	-	-	1400	-
Phormidium favosum	-	-	-	-	-	-	100	-
Raphidiopsis curvata	-	-	-	-	100	-	-	-
Synecocystis aqualis	8200	300	-	2500	300	1000	400	4400
Subtotal	**8.9x103**	**6x102**	**6x102**	**2.9x103**	**9x102**	**11x102**	**2.1x103**	**4.8x103**
CHRYSOPHYCEAE								
Dinobryon behningii	-	-	-	-	3800	100	700	1700
Subtotal					3.8x103	1x102	7x102	1.7x103
DINOPHYCEAE								
Peridinium sp	-	-	100	-	700	1000	1800	700
Stylodinium globosum	1100	100	700	-	500	100	-	300
Subtotal	**11x102**	**1x 02**	**8x102**		**1.2x103**	**11x102**	**1.8x103**	**1x103**
EUGLENOPHYCEAE								
Euglena gracilis	4600	1000	1650	1700	5700	2600	1500	4400
Euglena spirogyra	2800	-	-	-	-	-	-	-
Phacus dujardin	400	-	-	2640	400	900	900	1000
Phacus tortus	-	-	-	-	-	200	-	-
Trachelomonas sp	12350	1200	300	2800	5700	2100	1800	3800
Subtotal	**20.15x103**	**2.2x103**	**19.5x102**	**71.4x102**	**11.8x103**	**5.8x103**	**4.2x103**	**9.2x103**
RAPHIDOPHYCEAE								
Tetraplektron acutum (Pascher)	-	-	-	-	-	-	-	100
Subtotal								**1x10^2**
XANTOPHYCEAE								
Isthmochloron lobulatum	-	-	-	-	100	-	-	-
Pseudostaurastrum limneticum	300	-	-	-	-	-	-	-
Subtotal	**3x10^2**				**1x10^2**			**1x10^2**

In relation to the spatial scale, the mean values of chlorophyll *a* showed a variation among the different sites. The mean was 1.05µgL^{-1} in the vertical column, 1.04 µgL^{-1} at the surface and 1.07 µgL^{-1} at the bottom. The mean of chlorophyll *a* was 0.64µg.L^{-1} in the catchment area and 0.72 µg.L^{-1} in the macrophyte area (Figure 6).

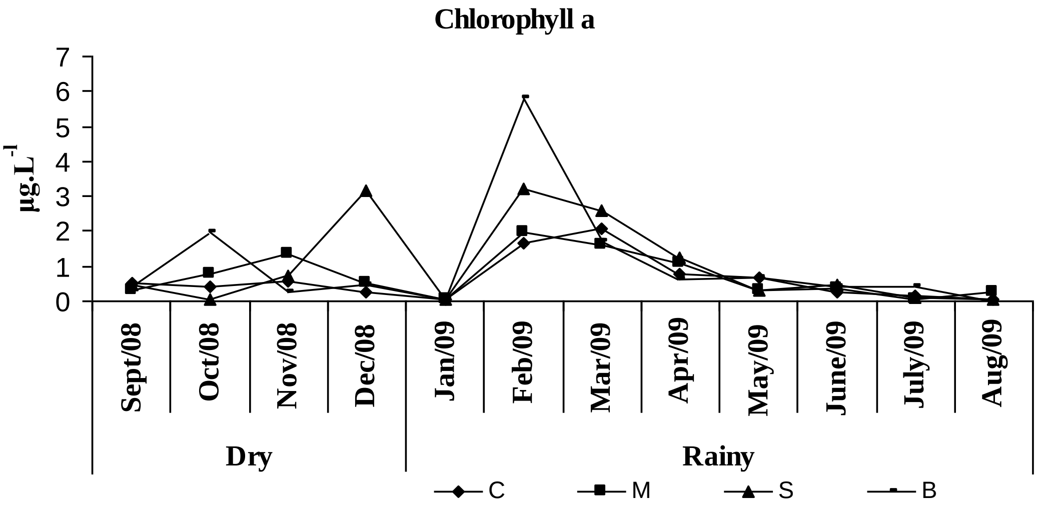

Figure 6. Variation in the concentration of chlorophyll *a* in the Lake Jiqui during the dry and rainy periods (M-macrophytes, S- surface, C- fence, B- bottom).

Table 4 illustrates the distribution of phytoplankton during the dry and rainy season at the four sites. The temporal pattern exhibited a difference in the number of species.

The class Chlorophyceae was the most diverse, with a significant difference between the seasons (p=0.003). The species *Pandorina* sp was found at all the sites during both the dry and rainy seasons. At all sites in the rainy season there were few species of Bacilariophyceae (p=0.001), with the emergence of Chrysophyceae and an increase in Euglenophyceae. A significant abundance of Euglenophyceae in both the dry and rainy seasons was found at the sites, represented by *Euglena gracilis* and *Trachelomonas* sp, with a significant difference (p=0.001). The Bacillariophyceae were represented by an average of 19 and 15 species during the dry and rainy season, respectively. *Cyclotella* sp, *Gomphonema apuncto, Navicula cuspidata* var. *cuspidata, Navicula* sp and *Rhopalodia gibba* were the dominant species of the diatom group, which were found regularly in both the dry and rainy seasons and in all the sites. The class Chrysophyceae was represented by a single species (*Dinobryon behningii*), which appeared regularly during the rainy season with small abundance. The Dynophyceae were represented by only two species (*Peridinium* sp and *Stylodinium globosum*), present in both seasons, although more abundant in the rainy season. The species *Tetraplektron acutum* (Pascher), of the class Raphidophyceae, along with macrophytes, were found only in the rainy season. The class Xanthophyceae was represented by the species *Pseudostaurastrum limneticum,* during the dry season, at the surface site and *Isthmochloron lobulatum*, appeared on the lake surface in the rainy season.

During the dry period, a direct and positive correlation was observed between the Chlorophyceae and K (light extinction coefficient) on the surface (r= 0.97), while on the bottom the correlation was between Chlorophyceae and conductivity (r=0.99) and ammonium (r=0.98). There was a negative correlation between Bacillariophyceae and water transparency (r=-0.76) and nitrate (r=- 0.72) in the macrophyte area, during the rainy season (Table 5).

Table 4. Distribution of phytoplanktonic species at the Lake Jiqui during the dry and rainy periods (S-surface, B- bottom, C- margin of the lake without macrophytes, M- site dominated by macrophytes).

	Dry period				Rainy period			
	S	B	C	M	S	B	C	M
Bacillariophyceae	21	20	13	22	18	14	12	15
Chlorophyceae	21	11	11	19	27	11	11	16
Cyanophyceae/Cyanobacteria	4	4	4	3	5	2	4	4
Chrysophceae	0	0	0	0	1	1	1	1
Dinophyceae	1	1	2	0	2	2	1	2
Euglenophyceae	4	2	2	3	3	4	3	3
Raphydiphyceae	0	0	0	0	0	0	0	1
Xantophyceae	1	0	0	0	1	0	0	0
Total taxons	52	38	32	47	57	34	32	42

Table 5. Pearsons correlations between phytoplankton classes and biotic factors during dry and rainy periods. (S-surface, B- bottom, C- margin of the lake without macrophytes, M- site dominated by macrophytes).

Biological variables	S		B		C		M	
	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy
Chlorophyceae and transparency	-0,97							
Chlorophyceae and K.	0,97							
Cyanophyceae and transparency	-0,99							
Cyanophyceae and K.	0,99							
Euglenophyceae and pH	0,97							
Bacillariophyceae and pH		0,72						
Bacillariophyceae and temperature		0,76						
Bacillariophyceae and orthosphosphate		0,74						
Euglenophyceae and orthosphosphate		0,76						
Xantophyceae and orthosphosphate		-0,87						
Xantophyceae and BDO		-0,71						
Chlorophyceae and ammonium			0,98					
Chlorophyceae and electrical condut.			0,99					
Bacillariophyceae and rainfall					0,98	-0,82		
Cyanophyceae and nitrate				-0,76				0,86
Cyanophyceae and orthosphosphate				-0,75				0,86
Bacillariophyceae and nitrate						-0,72		
Bacillariophyceae and turbidity						-0,76		
Chlorophyceae and dissolved oxygen						0,76		
Chlorophyceae and turbidity						-0,7		
Euglenophyceae and turbidity						-0,74		
Euglenophyceae and rainfall						-0,79		
Crysophyceae and dissolved oxygen						0,84		
Crysophyceae and nitrate						-0,85		
Crysophyceae and orthosphosphate						-0,91		
Raphidiophyceae and transparency						-0,77		
Raphidiophyceae and turbidity						0,83		
Raphidiophyceae and K.						0,77		
Dinophyceae and transparency						0,99	0,99	

The four ecological indices analyzed for the phytoplankton community of Lake Jiqui are shown in Figure 7. On the spatial scale, the highest index of species diversity was recorded for the surface waters, during both the rainy and dry seasons, with a gradual decline in the macrophyte area, catchment area and bottom. There was a significant difference between the seasons at the macrophyte area (p=0.029) and in the bottom (p= 0.008). The temporal pattern of the species richness index ranged from 4.45, during the dry season, to 3.0 in the rainy season, with a significant difference between the seasons at the bottom site (p=0.028) and catchment area (p=0.028). The equitability index showed no marked variation among the sites. For the temporal pattern there was a significant difference at the macrophyte area (p=0.047) and in the bottom (p=0.043). The dominance index was represented by selective phytoplankton such as *Euglena gracilis, Trachelomonas* sp, and *Oocystis* sp.

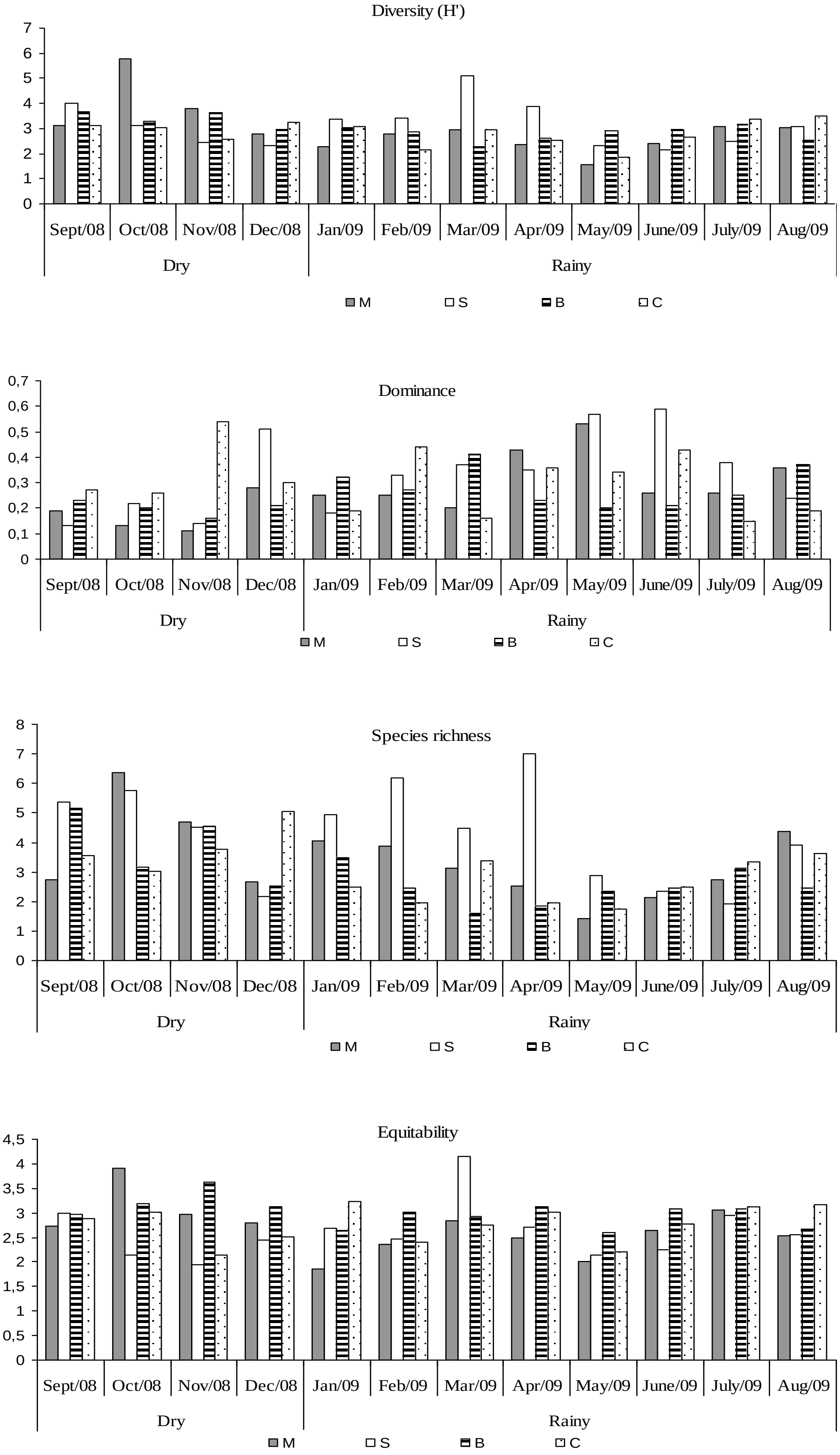

Figure 7. Temporal and spatial variation of ecological indices in Lake Jiqui, RN. (a) Diversity; (b) Dominance; (c) Richness; (d) Equitatibility. **Source**: SEMARH/ RN, 2008 (Secretaria de Estado do Meio Ambiente e dos Recursos Hídricos) and CAERN, 2008 (Companhia de Água e Esgotos do Rio Grande do Norte).

4. Discussion

Lake Jiqui consists of a shallow polymictic ecosystem, with spatial temperature variation of only 4-5% between surface and bottom water, classifying the system as homogeneous. Lewis Jr. (1983), Talling (1969) and Tundisi (1977) suggested that small temperature gradients may be significant in stratification formation. Thus, thermal structure (stratified or isothermal) may determine the distribution pattern of a lake's phytoplankton (REYNOLDS, 1984). In Brazil, the thermal pattern of Lake Monte Alegre, in the state of Rio Grande do Sul, has an influence on the distribution of the phytoplankton community during cold and dry periods (RANGEL et al*.,* 2009). In the present study, the absence of thermal stratification that occurs along the vertical profile may have caused the low variation in phytoplankton distribution at the Lake Jiqui, mainly among the study sites.

The choice of the four sampling sites was based on the concept of niche differentiation, to determine the variation pattern in the vertical and horizontal profile. The significant variations in the horizontal distribution of phytoplankton species, observable in small lakes over short periods of time, are invariably related to the direction and speed of the wind, thermal stability of the column and resuspension of sediment nutrients. Hydrodynamic force causes phytoplanktonic species to float with positive buoyancy, thereby contributing to the abundance of biomass over a short period of time in the horizontal plane (REYNOLDS, 1984).

The seasonal variations in the physical, chemical and biological parameters of Lake Jiqui were due to the environmental and hydrological conditions of the study area, whereas the spatial variations show no significant differences because of the morphometric properties of the water and the short time that it remains in the lake. This might be because a number of parameters such as dissolved oxygen, inorganic nutrients and BOD exhibit similar values among the study sites and different ones between the dry and rainy seasons, showing strong significant correlations with the presence of phytoplankton groups. On the other hand, transparency and turbidity were the only parameters that showed a significant difference, mainly between point C (catchment area) and the others, during the dry season. This is due to the high wind speed and the fact that it is located near the catchment area of the treatment plant, where water is constantly submitted to mixing and sediment suspension during pumping, which causes mixing and low water transparency because of particulate material accumulation. The reduced euphotic zone in the present study was similar to the Apipucos, reservoir in the state of Pernambuco (CHAMIXAES, 1984).

The phytoplankton community was influenced mainly by the seasonal variation in physical-chemical parameters at the study sites. The increase in phytoplankton species diversity found at the Lake Jiqui during the rainy season was caused mainly by the increase in nutrients, which led to the appearance of Chrysophyceae and a strong correlation between interannual climatic variability and interannual variability in microalgal community dynamics. In this sense, the present study corroborates the observations made by Bowden (1970) and Harris (1986), who explained the spatial-temporal distribution of phytoplankton as being the interconnection with the water mixture in shallow lakes and pelagic ocean systems.

The dynamics of phytoplankton classes was related to seasonal variation. The Bacillariophyceae, Chlorophyceae and Euglenophyceae showed significant differences in relative abundance between the dry and rainy seasons, owing to the increased concentration of nutrients and the higher light extinction coefficient in the rainy season, also causing the appearance of Chrysophyceae. Considering the phytoplankton community as a whole, the higher concentrations of chlorophyll *a* occurred in the rainy period, regardless of the spatial scale, corroborating the results obtained at reservoirs in the state of Rio Grande do Norte and differing with respect to chlorophyll *a* in the rainy season (CHELLAPPA et al., 2009b).

The presence of phytoflagellates (Euglenophyceae and Chrysophyceae) at all the Lake Jiqui sites in the rainy season was similar to that found in a study conducted by Taniguchi et al. (2005) at Lake Diogo, São

Paulo. These classes show development peaks after periods of disturbance (mixing in the water column by wind or periods of rainfall), since they acquire a competitive advantage over other groups of algae. For this reason they are considered opportunist species and are benefited by the increased concentrations of organic matter and dissolved phosphorus levels in the water. Pearson's correlation showed a positive significance at site S (surface), where the Euglenophyceae were positively correlated with the orthophosphate. The higher density of Cyanophyceae found at the macrophyte area in the rainy season may be related to the greater availability of nutrients (phosphorus and nitrogen), due to macrophyte decomposition and the greater transport of nutrients to the lake.

Hecky and Kilham (1988) described the relationship between nutrients and phytoplankton ecology, in which phytoplankton cells require dissolved inorganic nutrients, necessary for growth, multiplication, increase in biomass and primary productivity, and limited by the spatial-temporal variability of the nutrients and by light, temperature and sedimentation. In freshwater, phytoplankton is limited by phosphorus and in the sea, by nitrogen. Phytoplankton may decrease the requirement for nutrients, which explains the lack of preferential assimilation in the different ecosystems.

The rainy season provokes a disturbance in freshwater ecosystems through the entry of water, by turbulence and the force of circulation, thereby facilitating greater nutrient availability (REYNOLDS, 1984). In this study, a positive significant correlation was found between the phytoplanktonic biomass and the orthophosphate, corroborating the results obtained by Dillon and Rigler (1974). Beyruth (2000) found high levels of phytoplankton biomass in the Guarapiranga reservoir, after physical disturbances caused by the rains, demonstrating a rapid response of the phytoplankton to the entry of nutrients. At Lake Jiqui, the water flow of the River Pitimbu during the rainy season facilitated the higher number of flagellate species, stimulating the increase in chlorophyll *a*, representing a temporal cycle, a natural event of the limnetic ecosystem in the state of Rio Grande do Norte.

Biodiversity, a key factor in ecology, is directly linked to the regulation and function of ecosystems, whose biotic and abiotic processes contribute to the variability of phytoplankton diversity in aquatic ecosystems, on different time and space scales (CHALAR, 2009). This seasonal variation in the phytoplankton communities of Lake Jiqui is related to changes in temperature, hydrodynamic force and nutrient availability. The phytoplankton community of this lake showed high diversity at all the sites, mainly in the dry season, where turbidity, temperature and the light extinction coefficient were lower, different from the study performed by Chalar (2009), who showed the standardization of plankton diversity in the Salto Grande reservoir in Uruguay, directly interlinked to the light extinction value in the vertical profile.

According to Taniguchi et al. (2005), in shallow environments it is difficult to establish habitat limits for the algal population, given that there is an interaction between the compartments of the system, influenced mainly by morphometry, hydrology and stability in the water column.

Aquatic systems deserve greater attention, owing to their importance for human water consumption and because reduced supplies of freshwater and pollution have compromised human health and biosphere equilibrium.

5. Conclusion

Lake Jiqui is a shallow water body, lacking thermal stratification, characterized by constant mixing of water, neutral pH, low electrical conductivity and moderate oxygen values. The concentration of inorganic nutrients and chlorophyll *a* were low confirming the good water quality of the Lake Jiqui fit for human consumption, as per the standards of CONAMA 357/2005. The phytoplankton diversity is considered moderate to high, with high species richness. The occurrence of cyanobacteria was low on spatial and temporal scales. There was selected dominance of the species *Euglena gracilis, Trachelomonas* sp, C*yclotella* sp, *Gomphonema apuncto, Navicula* *cuspidata* var. *cuspidata, Navicula* sp e *Rhopalodia gibba* and *Cyclotella* sp. Lake Jiqui is considered oligotrophic, due to low chlorophyll *a* concentration, high transparency and low nutrient content.

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