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## Planktonic Cyanobacteria of the tropical karstic lake Lagartos from the Yucatan Peninsula, Mexico

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**Abstract: Las cianobacterias planctónicas del lago tropical cárstico Lagartos de la Península de Yucatán, México.** The tropical karstic lakes on the Mexican Caribbean Sea coast are numerous. However, there is an enormous gap of knowledge about their limnological conditions and micro-algae communities. In the present study, surface water samples were collected monthly from November 2007 to September 2008 to provide taxonomical composition and biovolume of planktonic cyanobacteria of the lake Lagartos from State of Quintana Roo, Mexico. Water temperature, pH, conductivity, salinity, soluble reactive phosphorus (SRP), dissolved inorganic nitrogen (DIN), and soluble reactive silica (SRSi) levels were also analyzed. A total of 22 species were identified. Chroococcales and Oscillatoriales dominated the phytoplankton assemblages during the study period. *Chroococcus pulcherrimus*, *Coelosphaerium confertum*, *Cyanoduction iac*, *Phormidium pachydermaticum* and *Planktolyngbya contorta* were recorded for the first time in Mexico. A surplus of DIN (mean value of 42.7 µM) and low concentrations of SRP (mean value of 1.0 µM) promoted the enhanced growth and bloom formation of cyanobacteria. The mean biovolume was 3.22X10<sup>8</sup> µm<sup>3</sup>/mL, and two biovolume peaks were observed; the first was dominated by *Microcystis panniformis* in November 2007 (7.40X10<sup>8</sup> µm<sup>3</sup>/mL), and the second was dominated by *Oscillatoria princeps* in April 2008 (6.55X10<sup>8</sup> µm<sup>3</sup>/mL). Water quality data, nitrates enrichment, and trophic state based on biovolume, indicated that Lagartos is a hyposaline, secondarily phosphorus-limited, and eutrophic lake, where the cyanobacteria flora was composed mainly by non-heterocystous groups. Rev. Biol. Trop. 61 (2): 971-979. Epub 2013 June 01.

**Key words:** cyanobacteria, bloom, water quality, nutrients, eutrophic, Quintana Roo.

The hydrogeology of the Yucatan Peninsula, in the Southeastern Mexico, is controlled by a karst system, where secondary porosity and high permeability promotes the formation of large caverns, dissolution cavities, sinkholes and channels conducting substantial quantities of water (Reddell 1981). Lakes can be formed when the superficial cavities in the limestone are filled permanently by the water table. These aquatic systems are called dissolution lakes according to Hutchinson (1957), or coastal lakes (Cole 1979). The karstic lakes occur

mainly in the tropical and subtropical carbonate platforms like the Caribbean Sea (Mylroie & Carew 1995), Florida (Florea & Vacher 2006), in countries bordering the Mediterranean Sea (Lopez *et al.* 2009, Casamayor *et al.* 2012) and South China Sea (Cerrano *et al.* 2006). When karstic water bodies are located near the coast, they tend to be smaller and shallower. These features make them highly vulnerable to significant inputs of organic matter from their surroundings, especially in densely populated and agricultural areas (McComb & Davis

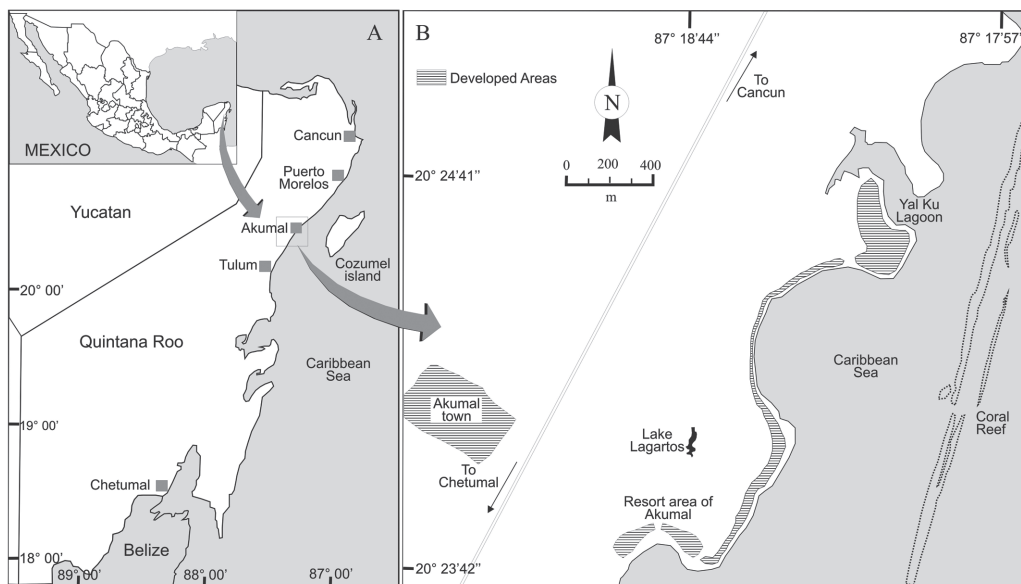
1993, Smith 2003). If there is a not light-limited condition, the nutrient enrichment will drive an increase of phytoplankton biomass (Reynolds 1984, McComb & Davis 1993). Thus, phytoplankton communities could constitute an important element for interpreting the functioning of lakes (Reynolds *et al.* 2002), but their successful application requires a precise understanding of species identities and limnological preferences.

Despite the presence of nearly 80 karstic aquatic bodies on the coast of Mexican Caribbean Sea (CONAGUA 2002), there is an enormous gap of knowledge about the limnology of these aquatic systems and their micro-algae communities. High nutrient input can cause eutrophication and a remarkable diminution in the water quality with the concomitant loss of phytoplankton biodiversity, much of it unknown until now. Recent studies particularly focused on taxonomic composition of phytoplankton communities of sinkholes and anchialine caves, have highlighted the importance of inland water bodies to harboring a large freshwater micro-algae diversity (López-Adrian & Herrera-Silveira 1994,

Sánchez *et al.* 2002, Schmitter-Soto *et al.* 2002, Torres-Talamante *et al.* 2011). However, there are not any references on planktonic or benthonic micro-algae communities structure and seasonal succession in coastal lakes from the Mexican Caribbean Sea shoreline. Therefore, the aim of this study was to provide the first report on the flora of planktonic cyanobacteria, their seasonal fluctuations in terms of biovolume in relation to climatic variability in the coastal karstic lake Lagartos from Quintana Roo, México.

## MATERIALS AND METHODS

**Study area:** Lake Lagartos (Fig. 1) is located at 5m above sea level on the Riviera Maya, at 90km South of Cancun, Quintana Roo, Mexico (20°24'02" N - 87°18'43" W). It is a small (4 850m<sup>2</sup> in surface area) and shallow (maximal depth 3m; average depth 1.7m) aquatic system, located at 450m from the Caribbean Sea shoreline. There is no surface inflow or outflow, which makes us suppose that the water level is maintained only by groundwater input. The bottom of the lake is covered by



**Fig. 1. (A)** Study area, the Yucatan Peninsula and the state of Quintana Roo, Mexico; **(B)** Location of Lake Lagartos and the developed coastline of Akumal.

submerged macro-algae, mainly *Cladophora glomerata* (Linnaeus) Kützing 1843 and its shores are surrounded by a belt of mangrove (*Rhizophora mangle* Linnaeus 1753, *Laguncularia racemosa* (Linnaeus) C. F. Gaertn 1807, and *Conocarpus erectus* Linnaeus 1753). The climate is characterized by three seasons. The cold fronts season occurs from November to February; this season has mean and maximum rainfall values of 72 and 92mm, respective. The dry season, occurs from March to May with a mean rainfall of 63mm and maximum of 96mm. The rainy season is from June to October and it is characterized by the higher values of rainfall with a mean of 173mm and maximum of 222mm. The dominant winds (mean velocity of 10km/h) caused complete mixing of the water column (SMN 2010). Numerous local residential districts, resorts and vacation homes that surround the lake, have caused pollution that has affected the water quality of the lake (Mutchler *et al.* 2007).

**Sampling and analyses:** Lake Lagartos was sampled monthly from November 2007 to September 2008, with exception of December 2007. Water temperature, pH, conductivity and salinity were measured *in situ* with a multi-parameter probe (Hydro lab<sup>®</sup> DS5). Water samples for chemical analyses were filtered through Whatman GF/F filters (0.45µm pore size), poured into polyethylene bottles and preserved immediately after collection. Soluble reactive phosphorous (SRP), nitrite (NO<sub>2</sub><sup>-</sup>), nitrate (NO<sub>3</sub><sup>-</sup>), ammonia (NH<sub>4</sub><sup>+</sup>) and soluble reactive silica (SRSi), were analyzed with a Skalar San Plus segment flow autoanalyzer, according to standard methods adapted by Grasshoff *et al.* (1983). Dissolved inorganic nitrogen (DIN) was considered as the sum of NH<sub>4</sub><sup>+</sup>, NO<sub>2</sub><sup>-</sup> and NO<sub>3</sub><sup>-</sup>.

Surface samples for planktonic cyanobacteria identification and counting were collected in the central part of the lake with a Van Dorn (2L) water sampler bottle. The samples were placed in polyethylene bottles of 250mL and fixed with a Lugol's acidified solution. Taxonomic identification was done by light microscopic observation (Zeiss PrimoStar) of living

and preserved samples. Specialized taxonomic monographs about cyanobacteria (Anagnostidis & Komárek 1985, 1988, Komárek & Anagnostidis 1998, 1999) were supplemented with recently published original literature for species identification. Algal numbers were counted with an inverted microscope Zeiss Axiovert 40 CFL at X400 according Utermöhl (1958). At least 30 individual cells of each species were measured and geometric shapes were used to determine biovolume, which is given in µm<sup>3</sup>/mL (Willén 1976, Rott 1981). At the end of this investigation, all samples were fixed with a 3% formaldehyde solution and they were deposited in the Water Sciences Unit-Center for Scientific Research of Yucatan, Micro-algae Collection (CM-CICY).

## RESULTS

**Abiotic variables:** The seasonal variation in physico-chemical parameters and soluble nutrients are shown in table 1. Air temperature values varied from 24 to 30°C, water temperature varied from 26 to 30°C, the electrical conductivity recorded values were between 13 and 18mS/cm, the salinity ranged from 8 to 10psu, while pH was mostly neutral and ranged between 7 and 8.

The concentrations of nutrients were high. Soluble reactive silica varied from 31.1 to 151.5µM, with a mean of 62.7µM. The high concentrations of SRSi reflect the huge influence of the aquifer in the lake, mainly during the cold fronts and rainy seasons. Concentrations of DIN varied between 11.3 and 105.1µM, with a mean of 42.7µM. Nitrates were the dominant nitrogen type from January to April and September 2008, whereas NH<sub>4</sub><sup>+</sup> was the dominant nitrogen type from May to August 2008. The mean NO<sub>2</sub> concentration was 0.7µM and its highest concentrations were measured in January and February 2008. Concentrations of SRP varied between 0.2 and 3.8µM, with a mean of 1.0µM.

**Phytoplankton flora and seasonal fluctuations in planktonic cyanobacteria:** The

TABLE 1  
Seasonal variation in physico-chemical parameters and soluble nutrients in lake Lagartos, México

Season	Cold fronts			Dry			Rainy				Mean
	Nov	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
Rainfall (mm) [total annual 1 098]	62.6	62.0	92.1	46.1	47.4	96.0	189.4	129.6	150.3	222.5	109.8
Air temperature (°C)	24.2	26.1	26.0	27.2	29.1	28.2	28.1	29.7	29.1	26.5	27.4
Water temperature (°C)	26.3	26.2	25.5	25.9	26.1	28.9	28.7	28.4	29.9	27.8	27.4
Electrical conductivity (mS/cm)	16.4	17.6	15.1	16.4	14.1	14.1	13.3	13.5	15.0	15.7	15.1
Salinity (psu)	9.6	10.4	8.8	9.6	8.2	8.1	7.6	7.8	8.7	9.2	8.8
pH	7.2	7.2	7.4	7.3	6.9	7.5	7.7	7.4	7.3	7.0	7.3
SRSi (µM)	64.9	100.4	151.5	49.7	60.5	17.9	115.6	31.1	39.6	40.6	67.2
Nitrates (µM)	8.0	43.5	59.4	102.5	33.8	14.2	2.6	9.8	2.7	38.9	31.5
Nitrites (µM)	0.4	1.1	2.3	0.4	0.5	0.4	0.1	0.5	0.1	0.8	0.7
Ammonia (µM)	2.8	4.9	3.8	2.2	2.5	20.1	21.4	15.3	29.1	2.8	10.5
SRP (µM)	0.5	2.6	3.8	0.4	0.5	0.3	0.6	0.3	0.2	0.3	1.0
DIN (µM)	11.3	49.4	65.6	105.1	36.7	34.7	24.1	25.6	31.9	42.5	42.7
DIN:SRP	23	19	17	263	73	116	40	85	159	142	94

phytoplankton was represented by 63 taxa belonging to six Divisions. The Bacillariophyta contributed with the highest number of species (28) followed by Cyanobacteria=Cyanoprokaryota (22), Dinophyta (six), Chlorophyta (three), Euglenophyta (two) and Cryptophyta (two). However, Cyanobacteria were the group with the highest contribution to total phytoplankton biovolume (between 96-99%) during the period of study.

The Cyanobacteria species list and species richness observed in Lagartos are given in table 2. Chroococcales was the order with the highest number of species (11) followed by Oscillatoriales (nine) and Nostocales (two). *Chroococcus pulcherrimus*, *Coelosphaerium confertum*, *Cyanoduction iac*, *Phormidium pachydermaticum* and *Planktolynghya contorta* were recorded for the first time in Mexico. Species richness was relatively low during the whole study (mean of 19) and the lowest value was recorded on February. The most frequent species were *Chroococcus minor*, *C. minutus*, *C. turgidus*, *Cyanoduction iac*, *Microcystis panniformis*, *Geitlerinema splendidum* and *Planktolynghya contorta*.

The mean cyanobacteria biovolume value was  $3.22 \times 10^8 \mu\text{m}^3/\text{mL}$  whereas the lowest biovolume values were recorded from June

to September (Fig. 2A). Two biovolume peaks occurred, the first in November 2007 ( $7.39 \times 10^8 \mu\text{m}^3/\text{mL}$ ) and the second in April 2008 ( $6.55 \times 10^8 \mu\text{m}^3/\text{mL}$ ). Chroococcales presented the highest contributions to total biovolume from November to February and from May to September, and Oscillatoriales from March to April. Nostocales was not abundant throughout the whole study (Fig. 2B). Monthly variation in relative abundance of selected species is illustrated in figures 2C-D. The dominant species were *M. panniformis* and *Oscillatoria princeps*, which accounted for 36% and 26% of the mean total biovolume, respectively, throughout the survey. Both species developed blooms, *M. panniformis* in November 2007 (Fig. 2A and C) and *O. princeps* in April 2008 (Fig. 2A and D). Both blooms constituted the first records for the State of Quintana Roo, México.

## DISCUSSION

Lagartos is a small shallow water body but it has importance as a typical example of a coastal karstic aquatic system in Southeastern Mexico. Water temperature of the lake followed air temperature rather closely, the circulation pattern was continuum warm polymictic, and

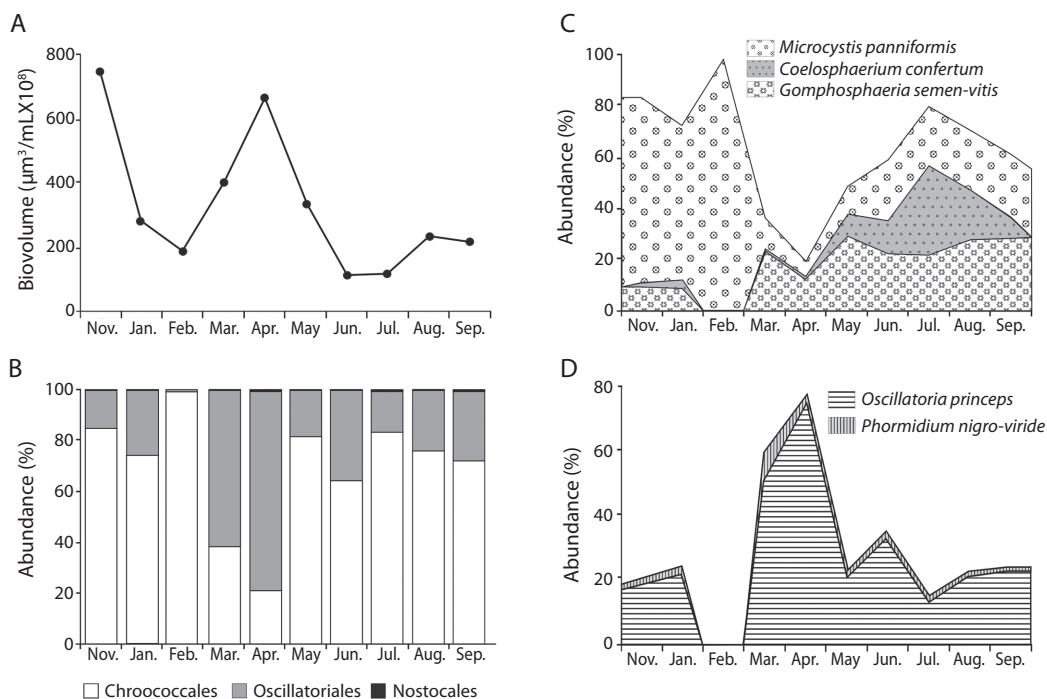
TABLE 2  
Species and richness observed in lake Lagartos, México

Season	Cold fronts			Dry			Rainy			
	Nov	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
<b>Chroococcales</b>										
<i>Chroococcus minor</i> (Kützing) Nägeli 1849	+	+	+	+	+	+	+	+	+	+
<i>Chroococcus minutus</i> (Kützing) Nägeli 1849	+	+	+	+	+	+	+	+	+	+
<i>Chroococcus pulcherrimus</i> Welch 1965	+	+	-	+	+	+	+	+	+	+
<i>Chroococcus turgidus</i> (Kützing) Nägeli 1849	+	+	+	+	+	+	+	+	+	+
<i>Coelosphaerium confertum</i> West et G. S. West 1869	+	+	-	+	+	+	+	+	+	+
<i>Cyanoduction iac</i> Cronberg et Komárek 1994	+	+	+	+	+	+	+	+	+	+
<i>Gomphosphaeria semen-vitis</i> Komárek 1989	+	+	-	+	+	+	+	+	+	+
<i>Johannesbaptistia pellucida</i> (Dickie) Taylor et Drouet 1938	-	-	-	-	-	+	-	-	-	+
<i>Merismopedia punctata</i> Meyen 1939	+	+	-	+	+	+	+	+	+	+
<i>Microcystis panniformis</i> Komárek, Komárková-Legnerová, Sant'Anna, Azevedo et Senna 2002	+	+	+	+	+	+	+	+	+	+
<i>Synechococcus nidulans</i> (Pringsheim) Komárek in Bourrelly 1970	-	-	-	+	+	+	+	-	+	+
<b>Oscillatoriales</b>										
<i>Geitlerinema splendidum</i> (Greville ex Gomont) Anagnostidis 1989	+	+	+	+	+	+	+	+	+	+
<i>Lyngbya hieronymusii</i> Lemmermann 1905	+	+	-	+	+	+	+	+	-	+
<i>Oscillatoria princeps</i> Vaucher ex Gomont 1892	+	+	-	+	+	+	+	+	+	+
<i>Phormidium nigro-viride</i> (Thwaites ex Gomont) Anagnostidis et Komárek 1988	+	+	-	+	+	+	+	+	+	+
<i>Phormidium pachydermaticum</i> Frémy 1930	+	+	-	+	+	-	-	+	+	+
<i>Planktolynghya contorta</i> (Lemmermann) Anagnostidis et Komárek 1988	+	+	+	+	+	+	+	+	+	+
<i>Planktothrix agardhii</i> (Gomont) Anagnostidis et Komárek 1988	+	+	-	+	+	+	+	+	+	+
<i>Porphyrosiphon martensianus</i> (Menenghini ex Gomont) Anagnostidis et Komárek 1988	+	-	-	+	+	+	-	+	+	+
<i>Spirulina labyrinthiformis</i> Kützing ex Gomont 1892	+	+	-	+	+	+	+	+	+	+
<b>Nostocales</b>										
<i>Anabaena</i> sp.	-	-	-	+	+	+	+	+	+	+
<i>Cylindrospermum</i> sp.	+	+	-	+	+	+	+	+	+	+
Richness	19	18	7	21	21	21	19	20	20	22

no thermal stratification was recorded. The lake was classified as hyposaline according to Beadle (1959), with a mean salinity of 8.8psu. The mean depth was low and its bottom could be seen throughout the study. The clear water in this karstic water body can be attributed to dense macro-algae growth: *C. glomerata* and *Chara* sp., which serve like nutrients sink and as a factor to reduce sediment resuspension (Moss 1990, Scheffer 1998), despite to be a water body frequently mixed because of the dominant winds from the region. On the other hand, the nutrient concentrations were from one to two orders of magnitude higher

than other water bodies of the State of Quintana Roo (Alcocer *et al.* 1999, Schmitter-Soto *et al.* 2002, Torres-Talamante *et al.* 2011), and a remarkably high DIN:SRP ratio (mean value 94) suggests a permanent P-limitation in Lagartos according to Danielidis *et al.* (1996). Although limitation by phosphorus is usual in eutrophic water bodies, the seasonal patterns in Lagartos were more similar to secondary phosphorus limitation like in eutrophic lakes with excessive nitrogen input (Reynolds 1984). Consistent with our findings, Mutchler *et al.* (2007) attributed the nitrogen enrichment in Lagartos to excessive anthropogenic inputs,





**Fig. 2.** Monthly variation of: **(A)** Total biovolume; **(B)** Relative abundance of main cyanobacteria groups; **(C)** Relative abundance of major Chroococcales species; **(D)** Relative abundance of major Oscillatoriales species.

mainly as  $\text{NO}_3^-$ , into the groundwater from waste and sewage loading.

The composition of phytoplankton species in Lagartos reveals an accelerated process of eutrophication, with a predominance of non-heterocystous cyanobacteria. Despite their physico-chemical stability and no clear relation between nutrient concentrations and cyanobacteria biovolume values, the lake exhibited interesting differences in their cyanobacteria communities. The biovolume peak dominated by *M. panniformis*, was observed during the early cold fronts season, with a DIN:SRP=23. The dominance of *Microcystis* species in lakes with high nutrient concentrations may reflect their greater affinity to P and N (Jensen *et al.* 1994, Galat *et al.* 1981). Consistent with these observations, *M. panniformis* might deplete N and P concentrations from water column during its excessive growth in Lagartos. *Microcystis panniformis* blooms could be a potential risk for human health in the study region, since this

species has been characterized as a hepatotoxic peptides (microcystins) producer, which cause liver damage (Codd *et al.* 1999, Almeida *et al.* 2006, Carvalho *et al.* 2007, Vasconcelos *et al.* 2010).

After the *Microcystis* peak, a decrease in total biovolume and an increase in  $\text{NO}_3^-$  and SRP concentrations were observed from January to March. The increase of  $\text{NO}_3^-$  and SRP were attributed to groundwater input during the rainy months of the cold fronts season, and to recycling of organic detritus. On the other hand, Xie *et al.* (2003) suggested that *Microcystis* blooms also can induce massive release of both total P (TP) and SRP from the sediment and enhance internal loading, leading to a positive feedback loop. Under this scenery, DIN:SRP ratios between 17-19, with a maximum of 263 in March, favored an excessive growth of *C. glomerata* (field observations), and its success might limit the growth of planktonic cyanobacteria.

After the *C. glomerata* bloom, a peak of *O. princeps* arose in April 2008 under high  $\text{NO}_3^-$  concentrations, low SRP concentrations and  $\text{DIN:SRP}=73$ . *Oscillatoria princeps* has been observed in tropical and temperate shallow water bodies with P deficiency and high  $\text{NO}_3^-$  concentrations (McCormick *et al.* 1998, Lu *et al.* 2006, Tiwari & Chauhan 2008), similar to the conditions recorded in Lagartos.

During the rainy season, the total biovolume reached its lowest values, the cyanobacteria assemblage was represented by coccoid and filament forms,  $\text{NH}_4^+$  concentrations were high (15–21  $\mu\text{M}$ ) and  $\text{DIN:SRP}$  ratio was high (40–159). Melack (1979), suggests that the rainy season can cause the wash-out of large quantities of phytoplankton from tropical shallow lakes, reducing significantly phytoplankton populations, as was observed in Lagartos. In addition, important growth of *Cladophora* and *Chara* (field observations) at the bottom of the lake might compete with a strong uptake of N and P, with the subsequent decrease of planktonic cyanobacteria.

After analyzing the seasonal variation of cyanobacteria communities in Lagartos, it was not possible to find a plausible explanation about its dynamic. No clear relation between nutrient concentrations and cyanobacteria biovolume values was detected. Paerl (1988) and Oliver & Ganf (2000) suggested that in freshwater bodies, the most recognized causative agents for cyanobacteria dominance are eutrophication, warm water temperatures, high light intensity and stable weather conditions, very similar to the recorded conditions in Lagartos. Thus, the stability of physical and chemical conditions could favor the dominance of one or two cyanobacteria species in Lagartos. However, there is a range of factors that can be expected to affect cyanobacteria development in this lake. These may include dispersal in this highly mixed habitat, variations in important abiotic parameters (e.g. trace elements, dissolved organic matter), and the impact of selective grazing not measured in this study.

To conclude, water quality data, nitrate enrichment, and trophic state based on

biovolume, indicated that Lagartos is a hypersaline, secondarily phosphorus-limited, and eutrophic lake, where the cyanobacteria flora was composed mainly by Chroococcales and Oscillatoriales. Among them, *C. pulcherrimus*, *C. confertum*, *C. iac*, *P. pachydermaticum* and *P. contorta* were recorded for first time in Mexico. *Microcystis panniformis* and *O. princeps* were the dominant species. The cyanobacteria assemblages in this shallow system could have negative impacts on the ecosystem structure, including blooms of toxic microalgae, like *Microcystis*, and probably losses of diversity, in agreement with the low richness found during the study period.

## ACKNOWLEDGMENTS

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## RESUMEN

Los lagos cársticos tropicales en la costa del Caribe mexicano son numerosos. Sin embargo, existe un enorme desconocimiento acerca de sus condiciones limnológicas y de las comunidades de microalgas que se desarrollan en ellos. El objetivo del presente estudio fue estudiar las condiciones limnológicas en las que crecen las poblaciones de cianobacterias planctónicas del lago Lagartos, Quintana Roo, México. Las recolectas se realizaron de forma mensual entre noviembre 2007 y septiembre 2008. Las especies fueron identificadas y su biovolumen determinado. Se midieron *in situ* la temperatura del agua, pH, conductividad y salinidad. También, se analizaron las concentraciones de fósforo reactivo soluble (SRP), nitrógeno inorgánico disuelto (DIN) y sílice reactivo soluble (SRSi). Se identificaron 22 especies de cianobacterias. *Chroococcus pulcherrimus*, *Coelosphaerium confertum*, *Cyanodactylon iac*, *Phormidium pachydermaticum* y *Planktolyngbya contorta* fueron nuevos registros para México. Un exceso de DIN (valor promedio de 42.7  $\mu\text{M}$ ) y bajas concentraciones de PRS (valor promedio de 1.0  $\mu\text{M}$ ) promovieron la proliferación de cianobacterias. El biovolumen presentó dos picos: el primero en noviembre 2007, dominado por *Microcystis panniformis* (7.40  $\times 10^8 \mu\text{m}^3/\text{mL}$ ) y el segundo en abril 2008, representado por *Oscillatoria princeps* (6.55  $\times 10^8 \mu\text{m}^3/\text{mL}$ ). Los datos de calidad del agua, el enriquecimiento por nitratos y el estado trófico basado en



el biovolumen, indican que Lagartos es un lago hiposalino, eutrófico, con limitación secundaria por fósforo, donde los crecimientos masivos de cianobacterias sin heterocitos fueron recurrentes.

**Palabras clave:** cianobacteria, proliferación, calidad del agua, nutrientes, eutrófico, Quintana Roo.

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