



Original Paper

Planktonic cyanobacteria from urban lakes in Manaus (Amazonas - Brazil)

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Abstract

The aim of this research was to study the diversity of planktonic cyanobacteria in three urban lakes in Manaus, in the state of Amazon, by analyzing samples collected monthly with a plankton net from October 2009 to September 2010 (except March 2010). Twelve species were identified and classified. *Anathece* cf. *minutissima*, *Aphanocapsa annulata*, *Ap. stagnalis*, *Coelomorion microcystoides* and *Pseudanabaena mucicola* were recorded for the first time in the Brazilian Amazon region. Potentially toxic cyanobacteria blooms occurred in all three lakes, especially in Ceasa and Japiim, where *Microcystis aeruginosa* and *Planktothrix agardhii*, respectively, were the predominant species in all analyzed samples. Descriptions and illustrations of the identified species are presented as well as comments. In addition, environmental variables were presented (electrical conductivity, pH and water temperature). The waters of the studied environments ranged from slightly acid to alkaline and temperature varied from 23.2 to 30.5 °C.

Key words: biodiversity, Brazilian Amazonia, Cyanophyceae, taxonomy, tropical aquatic systems.

Resumo

O trabalho teve como objetivo conhecer a diversidade de cianobactérias planctônicas de três lagos urbanos de Manaus, no estado do Amazonas, a partir da análise de amostras coletadas com rede de plâncton, mensalmente, de outubro de 2009 a setembro de 2010, excetuando-se março de 2010. Foram identificadas 12 espécies, dentre estas, *Anathece* cf. *minutissima*, *Aphanocapsa annulata*, *Ap. stagnalis*, *Coelomorion microcystoides* e *Pseudanabaena mucicola* foram registradas pela primeira vez na Amazônia brasileira. Florações de cianobactérias potencialmente tóxicas ocorreram nos três lagos, destacando-se os lagos Ceasa e Japiim onde *Microcystis aeruginosa* e *Planktothrix agardhii* foram, respectivamente, as espécies predominantes em todas as amostras analisadas. São apresentadas descrições e ilustrações das espécies identificadas, bem como comentários taxonômicos. Adicionalmente, as variáveis ambientais (condutividade elétrica, pH e temperatura da água) foram apresentadas. As águas dos ambientes estudados oscilaram de levemente ácidas a alcalinas com valores de temperatura variando de 23,2 a 30,5 °C.

Palavras-chave: biodiversidade, Amazonia brasileira, Cyanophyceae, taxonomia, sistemas aquáticos tropicais.

Introduction

Several natural or artificial lakes in urban centers are used as water reservoirs for recreation and landscaping. However, many of these environments are highly eutrophic due to human activities and present cyanobacteria blooms.

Increasing amounts of nutrients in the water from different sources is the main cause of these blooms (Molica & Azevedo 2009). Along with eutrophication, global warming seems to enhance the effects of this increase in nutrients, altering these algae communities (Bicudo & Bicudo 2008).

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Taxonomic and ecologic studies mentioning cyanobacteria in Amazonia date back to the second half of the last century, e.g., Braun (1952), Schmidt (1982) and Huszar (1996). More recently, Vieira *et al.* (2003, 2005), Sá *et al.* (2010) and Silva *et al.* (2019) highlight cyanobacteria blooms and cyanotoxins production. A study on the phytoplankton ecology that reports a bloom of *Planktothrix isoethrix* (Skuja) Komárek & Komárková in the low precipitation period in a flooding lake near Manaus city was performed by Almeida & Melo (2011). Moreover, Genuário *et al.* (2018) described a new cyanobacteria genus and species, *Amazoninema brasiliense* Genuário *et al.*, from samples collected in the Solimões river in the state of Amazonas.

Amazonia, characterized by the great number and size of its aquatic environments, presents, in its urban centers, a number of small lentic water bodies that often contain a high density of algae and cyanobacteria. However, there are no taxonomic studies recording the species of these environments in Amazonas state.

Considering the relevance of cyanobacteria for the dynamics of aquatic environments and the importance of taxonomic knowledge in the management or preservation of ecosystems, this investigation aims at a taxonomic identification of the cyanobacteria diversity in urban lakes in Manaus.

Material and Methods

This study analyzed the taxonomy of cyanobacteria in samples collected in three lakes in the urban area of Manaus, in the state of Amazonas, Brazil, namely Japiim, Ceasa and Amazônico. Japiim Lake (03°06'32"S and 59°58'59"W, 155 meters length and 45 meters width) is located in Japiim Lake Park. Ceasa Lake (03°07'35"S and 59°57'10"W, 255 meters length and 45 meters width) is located 1.5 km from Negro River, though it is not directly influenced by this river. The third was Amazônico Lake (03°05'56"S and 59°59'06"W, 105 meters length and 35 meters width), which is located in a public area of the National Research Institute of Amazonia (INPA) called Bosque da Ciência (Fig. 1).

Collections were performed monthly from October 2009 to September 2010, with the exception of March 2010, at the same site in each lake. The samples collected with a 20 µm plankton net were stored in two separate 100 ml bottles. One was preserved in formaldehyde 4% while the other was not preserved for living material analyses. All

samples were deposited in the National Research Institute of Amazonia (INPA) Herbarium (Tab. 1).

Conductivity, pH and water temperature were measured by using a YSI model 63.

The taxonomic analyses were performed using a Leica compound light microscope with a built-in Leica DFC 290 digital camera and cells were measured by using a micrometer scale adapted to the microscope ocular. At least three slides of preferably living material of each sample were prepared. Whenever possible, five specimens of each species were measured at 1,000x magnification. The muscilaginous structure was evidenced using Indian ink.

The Komárek *et al.* (2014) classification system was adopted. The identification of the specimens was based on cyanobacteria taxonomy specialized literature.

The Brazilian geographic occurrence of the found species was based on publications such as Uherkovich & Schmidt (1974), Thomasson (1971), and Uherkovich (1981) in Amazonas state; Vieira *et al.* (2003, 2005) and Costa *et al.* (2014) in Pará state; Moura *et al.* (2018) in Ceará, Pernambuco, Rio Grande do Norte, Paraíba, and Bahia states; Train & Rodrigues (1998), Santos & Sant'Anna (2010) in Mato Grosso do Sul state; Nogueira & Leandro-Rodrigues (1999), Nogueira *et al.* (2008), and Nogueira *et al.* (2011) in Goiás state; Bicudo & Ventrice (1968), Laux *et al.* (2018) in Minas Gerais state; Huszar & Welp (2001) in Rio de Janeiro state; Sant'Anna *et al.* (2011), and Rosini *et al.* (2013) in São Paulo state; Oliveira *et al.* (1994) in Paraná state; Laudares-Silva (1999) in Santa Catarina state, and Martins *et al.* (2012), Werner *et al.* (2015), and Werner *et al.* (2018) in Rio Grande do Sul state; and Cronberg (1976, 1977) in Distrito Federal. Apart from those, the online list of cyanobacteria "Flora do Brasil" was used (<<http://floradobrasil.jbrj.gov.br/jabot/floradobrasil/FB123689>>).

Results and Discussion

The temperature of the water of the studied environments varied from 23.2 to 30.5 °C, pH ranged from 5.6 to 8.5 and conductivity oscillated from 17.3 to 270 µS cm⁻¹ (Tab. 2). Under these conditions, the analyzed water samples allowed the identification of 12 cyanobacteria species that belong to Synechococcales (5), Pseudanabaenales (1), Chroococcales (4), Oscillatoriales (1) and Nostocales (1) orders. Descriptions, comments and illustrations of the species in their respective taxonomic categories are as follow:

Order Synechococcales**Family Synechococcaceae**

Anathece cf. *minutissima* (W. West) Komárek, Kaštovský & Jezberová, Eur. J. Phycol. 46(3): 322. 2011.

Basionym: *Microcystis minutissima* W. West, Proc. R. Ir. Acad., 31: 35. 1912.

Synonym: *Aphanothece minutissima* (W. West) Komárková-Legnerová & Cronberg, Algal. Studies, 7: 4. 1994. Fig. 2a

Colonies elongated, irregular, with irregularly and somewhat densely aggregated cells; mucilage colorless, wide, diffluent; cells elongated, slightly oval, 1.2–1.7 times longer than wide, (0.9–)1–1.2 mm long, 0.6–1 mm wide; cell content blue-green, without aerotopes.

Examined material: INPA 239880, INPA 239881, INPA 239882, INPA 239883, INPA 240181, INPA 240183, INPA 240184, INPA 240185, INPA 240186 and INPA 240187.

Anathece minutissima was originally described as *Microcystis minutissima* by West (1912) from Irish populations and was later classified in the genus *Aphanothece* Nägeli by Komárková-Legnerová & Cronberg (1994), based on morphologic analyses. Komárek *et al.* (2011), using polyphasic taxonomic analyses, reclassified the genus as *Anathece*.

According to Komárek & Anagnostidis (1998), *Aphanothece minutissima* (= *Anathece minutissima*) occurs in the plankton of different freshwater environments, from oligotrophic to eutrophic, from the central to the subpolar regions of temperate zones, and populations of tropical lakes identified as this species should be revised.

Accordingly, even though the studied specimens are in accordance with specialized bibliography, further studies are needed to confirm the species, such as the analyses of its phylogeny

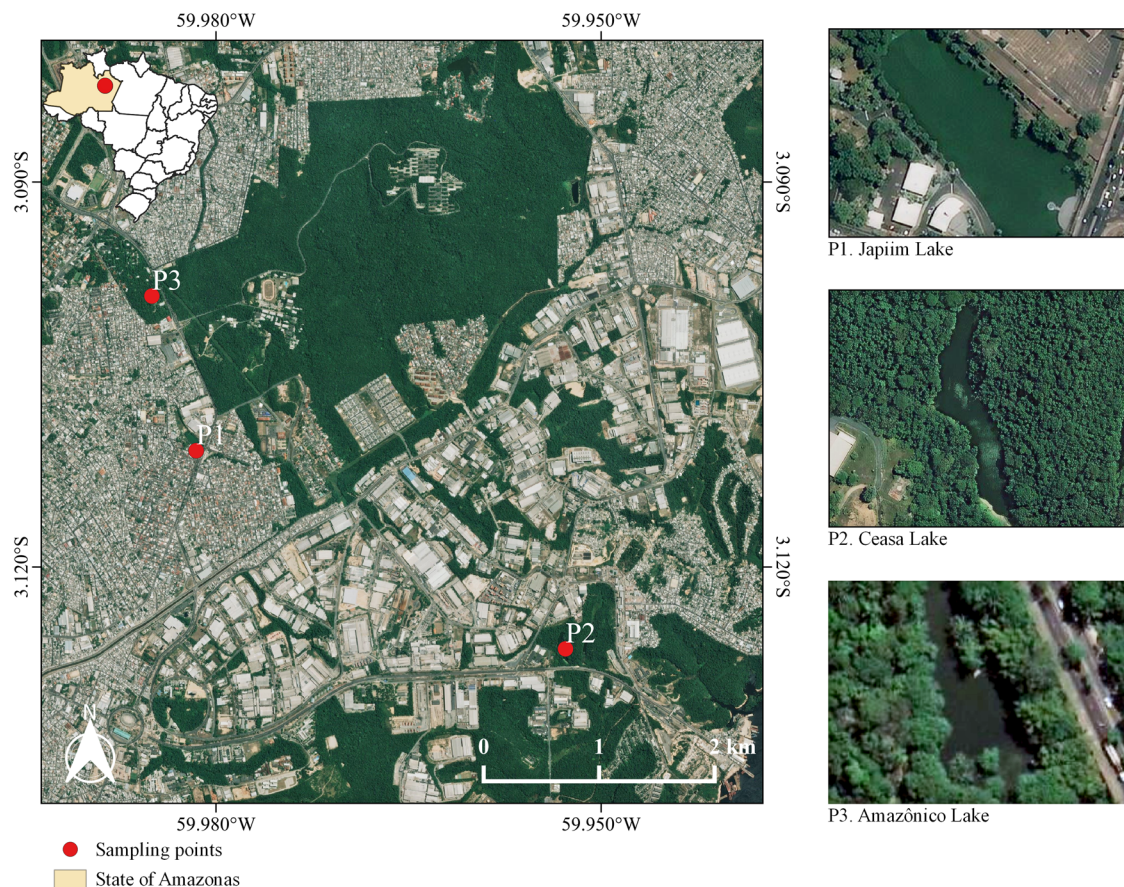


Figure 1 – Map of Manaus city showing the sampling lakes (P1 = Japiim Lake; P2 = Ceasa Lake; P3 = Amazônico Lake).

Table 1 – Analyzed samples data, including the register numbers in the National Research Institute of Amazonia (INPA) Herbarium.

Lake	Date	Collector	INPA
Japiim	28/10/2009		240162
	28/11/2009		240163
	30/12/2009	<i>L. Ribeiro & S. Melo</i>	239886
	29/01/2010		240164
	25/02/2010		240165
	30/04/2010		240166
	28/05/2010		240167
	28/06/2010	<i>L. Ribeiro</i>	239887
	21/07/2010		240168
	25/08/2010		240169
	28/09/2010		240170
Ceasa	12/10/2009		240171
	18/11/2009		240172
	16/12/2009	<i>L. Ribeiro & S. Melo</i>	239884
	18/01/2010		240173
	23/02/2010		240174
	27/04/2010		240175
	17/05/2010		239885
	30/06/2010	<i>L. Ribeiro</i>	240176
	23/07/2010		240177
	27/08/2010		240178
29/09/2010		240179	
Amazônico	19/10/2009		239880
	28/11/2009		240181
	29/12/2009	<i>L. Ribeiro & S. Melo</i>	239881
	29/01/2010		240182
	26/02/2010		240183
	29/04/2010		240184
	28/05/2010		239882
	29/06/2010	<i>L. Ribeiro</i>	239883
	19/07/2010		240185
	23/08/2010		240186
28/09/2010		240187	

and the ultrastructure of tropical water body populations.

Anathece cf. minutissima was found in all analyzed samples from Amazônico Lake, except the ones collected in January 2010. The environmental conditions of the lake at the time of collection were pH 5.6–6.8 ($\bar{x} = 6.4 \pm 0.41$),

conductivity 17.3–25 $\mu\text{S}\cdot\text{cm}^{-1}$ ($\bar{x} = 20 \pm 2.20$) and water temperature 23.2–30.3 °C ($\bar{x} = 26.6 \pm 1.53$).

This is the first time the species is reported in the Brazilian Amazonia. The species was previously reported in the Southeast (Minas Gerais and Rio de Janeiro) and in the South (Rio Grande do Sul) regions.

Table 2 – Abiotic variables recorded in the samples of the studied lakes, from October 2009 to September 2010, with mean and standard deviation (SD).

Lake	Variable	Oct	Nov	Dec	Jan	Feb	Apr	May	Jun	Jul	Aug	Sep	Mean±SD
Japiim	Conductivity (µS cm ⁻¹)	225	219.2	245	231	181.8	167.8	165.7	166.2	166.8	215	270	204.9±36.92
	pH	6.9	7	7.2	8	6.4	7.6	7.5	6.7	6.9	6.6	6.5	7±0.50
	Water temperature (°C)	30	30.5	27.8	26	25.2	27.4	26.9	28.5	29	27.7	26.4	27.8±1.64
Ceasa	Conductivity (µS cm ⁻¹)	112.3	111.8	118	111.7	72.2	98.4	94.7	93.8	90	85.3	93.6	98.4±13.86
	pH	7.6	8.5	7.1	7.7	6.2	6.5	7	6.9	6.7	6.3	6.5	7±0.70
	Water temperature (°C)	29.6	28.5	27.2	28.2	25.7	26.4	30	28.6	29.9	27.4	26.5	28±1.48
Amazônico	Conductivity (µS cm ⁻¹)	18.6	19.4	19	19.2	18.7	19	18.8	17.3	19.1	22	25	19.6±2.09
	pH	5.9	5.6	6.8	6.8	6.8	6.7	6.7	6.2	6.8	6.5	6.3	6.5±0.41
	Water temperature (°C)	29.7	30.3	28.6	28.2	29	24.5	25.1	23.2	24.6	25	26.4	26.8±2.45

Family Merismopediaceae

Aphanocapsa annulata G.B. McGregor, Nova Hedwigia 84(3-4): 309-310. 2007. Fig. 2b

Colonies spherical to elliptical when young, later irregularly elongated, oval or annulate, with numerous cells, irregularly and densely aggregated; mucilage colorless, sometimes wide and clearly delimited; spherical cells, 2.5–3 µm diam.; cell content pale blue-green, without aerotopes.

Examined material: INPA 239881.

The species was originally characterized by small round colonies when young, then longer and C-shaped, becoming ringed colonies when mature (McGregor *et al.* 2007).

Only mature colonies that fit the description of the type material were recorded in the studied samples.

Aphanocapsa annulata was originally described from populations of a mesotrophic reservoir in Australia (McGregor *et al.* 2007). However, to this moment in Brazil, the species was observed in eutrophic tropical water bodies [in an urban artificial lake in Goiânia (GO) by Nogueira *et*

al. (2011), and in fishing ponds in the metropolitan area of São Paulo (SP) by Rosini *et al.* (2013)] and in subtropical water bodies [artificial urban lakes (Porto Alegre, RS) - (V.R. Werner, personal communication)]. This is the first time the species was reported in Brazilian Amazonia.

In this study, *A. annulata* was recorded only once (December 2009) in the eutrophic Amazônico Lake. It was recorded along with *Anathece cf. minutissima*, *Pseudanabaena mucicola* (Naumann & Hubber-Pestalozzi) Schwabe and *Dolichospermum planctonicum* (Brunn.) Wacklin, Hoffmann & Komárek. The environmental conditions at the time of the sampling were pH 6.8, conductivity 19 µS.cm⁻¹ and water temperature 28.6 °C.

Aphanocapsa stagnalis (Lemmermann) R.N.Beljakova. Novosti Sistematiki Nizshykh Rasteniy 37: 14. 2004.

Basionym: *Polycystis stagnalis* Lemmermann, Ber. Deutsch. Bot. Ges. 18: 24. 1900. Fig. 2c

Colonies spherical, oval or annulate when young, later elongated, cylindrical to vermiform,

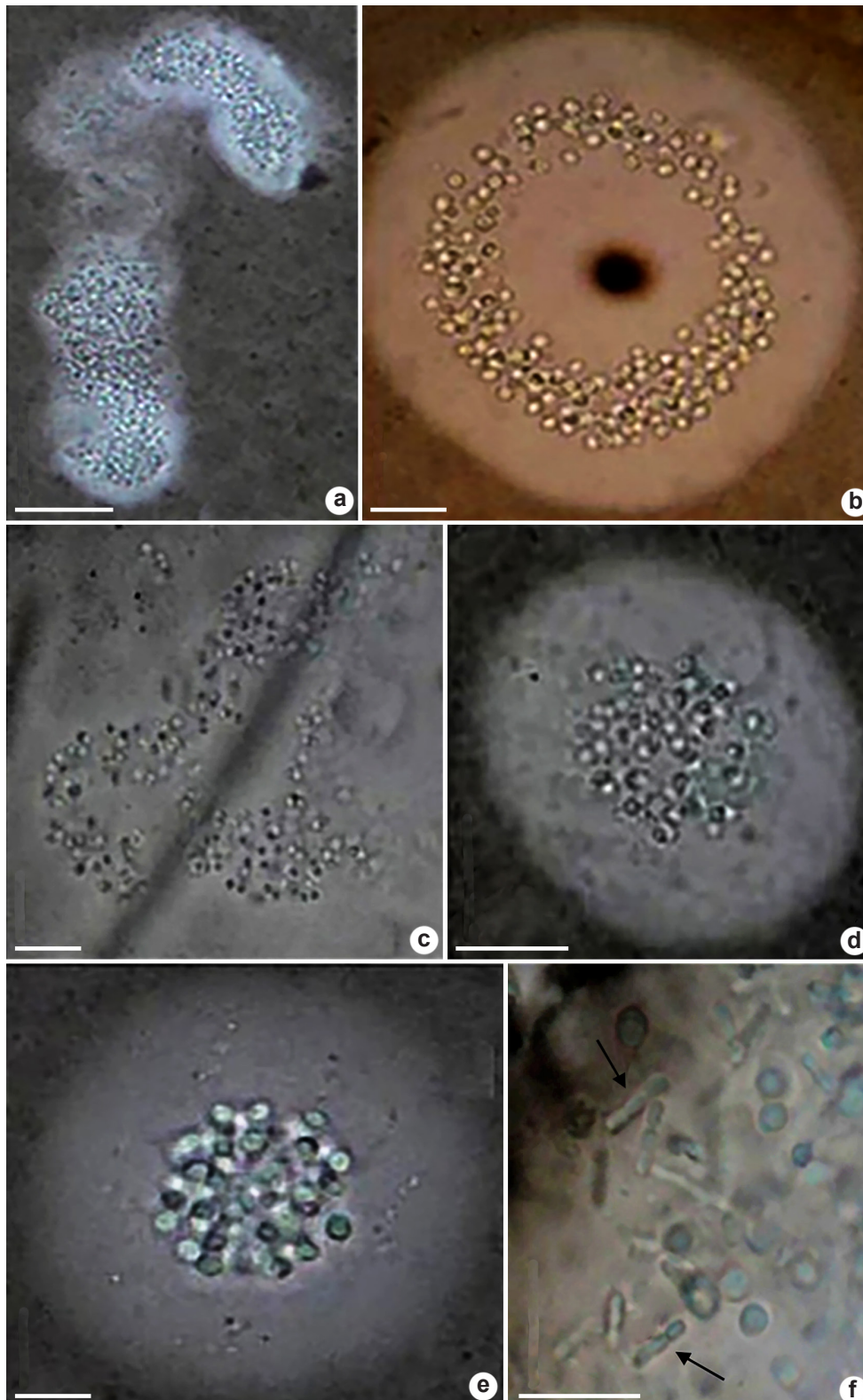


Figure 2 – a-f. Planktonic cyanobacteria from urban lakes – a. *Anathece* cf. *minutissima*; b. *Aphanocapsa annulata* - general aspect of an annulate colony; c. *A. stagnalis*; d. *Coelomonon microcystoides*; e. *Snowella lacustris*; f. *Pseudanabaena mucicola* - trichomes on *Anathece* cf. *minutissima* mucilage. Scale bars: a, f = 10 μ m; b, d, e = 20 μ m; c = 30 μ m.

sometimes reticulated, with numerous cells, irregularly and somewhat densely aggregated in the peripheral layer; mucilage colorless, wide, diffluent; cells spherical, oval or shortly cylindrical before division, 1.8–2 μm diam.; cell content pale blue-green, without aerotopes.

Examined material: INPA 239881, INPA 239882 and INPA 239883.

The morphologic and metric characteristics of the studied populations are in accordance with the material described by Joosten (2006).

Joosten (2006) and McGregor (2013) comment that, due to the elongated cylindrical and annulate colonies, *A. stagnalis* resembles *A. annulata*. However, in the former the cells are mainly distributed in the peripheral layer. Furthermore, cells of *A. stagnalis* are slightly smaller.

Aphanocapsa stagnalis was found only in Amazônico Lake in December 2009, and in May and June 2010. The species was observed in samples with pH 6.2–6.8 ($\bar{x} = 6.6 \pm 0.31$), conductivity 17.3–19 $\mu\text{S}\cdot\text{cm}^{-1}$ ($\bar{x} = 18.4 \pm 0.93$) and water temperature 23.2–28.6 $^{\circ}\text{C}$ ($\bar{x} = 25.6 \pm 2.74$).

This is the first record of the species in the Brazilian Amazonia, and it was previously observed in Goiás state.

Family Coelosphaeriaceae

Coelomoron microcystoides Komárek, Folia Geob. Phytot. 24: 85. 1989. Fig. 2d

Colonies somewhat spherical or irregular, with cells densely and radially aggregated in the periphery; mucilage colorless, sometimes large, diffluent; cells oval or hemispherical after division, 2.8–3 μm long, 2–2.4 μm wide; cell content blue-green, without aerotopes.

Examined material: INPA 239881, INPA 239882, INPA 239883 and INPA 240185.

The species was originally characterized by very thin diffluent colorless mucilage, only visible with the use of dye. However, among the recorded specimens, there were colonies surrounded by a large diffluent mucilaginous envelope.

The difference of mucilage thickness between the type material and the Amazonia one might be explained by the age of the colonies and even by the environmental conditions. Considering that the other morphologic and metric characteristics of the analyzed populations fit the Cuban ones originally described by Komárek (1989), they were identified as *C. microcystoides*.

Coelomoron microcystoides was only found

in Amazônico Lake in December 2009, and in May, June and July 2010. It was observed in samples with pH 6.2–6.8 ($\bar{x} = 6.6 \pm 0.28$), conductivity 17.3–19.1 $\mu\text{S}\cdot\text{cm}^{-1}$ ($\bar{x} = 18.6 \pm 0.84$) and water temperature 23.2–28.6 $^{\circ}\text{C}$ ($\bar{x} = 25.4 \pm 2.30$).

This is the first report of the species in Amazonia water bodies and the second in Brazil since it had been previously reported only in the southern region (Rio Grande do Sul state).

Snowella lacustris (Chodat) Komárek & Hindák, Arch. Hydrobiol./Suppl. 80(1–4) Algol. Studies 50–53: 282–302. 1988.

Basionym: *Gomphosphaeria lacustris* Chodat 1898, Bull. Herb. Boissier 6: 180. 1898. Fig. 2e

Colonies somewhat spherical or elongated, rarely irregular; mucilage colorless, thin, diffluent, outline evident or not; stalks mucilaginous thin, usually inconspicuous, somewhat pseudo dichotomously divaricated, radiating from the colonial center to the periphery; cells elliptical or obovoid, joined to the end of stalk, 3–3.8 μm long, 2.3–2.5 μm wide; cell content blue-green, without aerotopes.

Examined material: INPA 239881.

Snowella lacustris was only observed in Amazônico Lake in December 2009, where pH was 6.8, conductivity 19 $\mu\text{S}\cdot\text{cm}^{-1}$ and water temperature 28.6 $^{\circ}\text{C}$.

It was previously recorded in Brazil in the North (Amazonas and Pará states), Midwest (Distrito Federal and Goiás state), Southeast (São Paulo state) and South (Rio Grande do Sul state) regions.

Family Pseudanabaenaceae

Pseudanabaena mucicola (Naumann & Hubber-Pestalozzi) Schwabe, Gewässer und Abwässer H. 36: 7–39. 1964.

Basionym: *Phormidium mucicola* Naumann & Hubber-Pestalozzi, Ber. Dt. Bot. Gesellsch. 47: 86. 1929. Fig. 2f

Trichomes on the mucilage of other cyanobacteria, solitary, straight or slightly bent, short (usually only three cells), constricted, not attenuated; cells cylindrical, round at the ends to slightly barrel-shaped, (1.5–)2 μm long, 1–1.5 μm wide; cell content blue-green, usually not granulated, cross-walls not granulated.

Examined material: INPA 239881, INPA 239882, INPA 239883, INPA 240181, INPA 240182, INPA 240183, INPA 240184, INPA 240185, INPA 240186 and INPA 240187.

Studied specimens were uniform, considering their morphologic and metric features. Komárek & Komárková (2002) describe this species as cosmopolitan (temperate and tropical areas), planktonic, and mainly found in or on cyanobacteria mucilage, such as *Microcystis*, *Woronichinia*, *Chroococcus* and *Aphanothece* (Komárek & Anagnostidis 2005).

Pseudanabaena mucicola was observed in the Amazônico Lake throughout the studied period, growing on *Anathece* cf. *minutissima* mucilage, in samples where pH was 5.6–6.8 ($\bar{x} = 6.5 \pm 0.41$), conductivity 17.3–25 $\mu\text{S}\cdot\text{cm}^{-1}$ ($\bar{x} = 19.7 \pm 2.09$) and water temperature 23.2–30.3 °C ($\bar{x} = 26.8 \pm 2.45$).

This is the first record of the species in the Brazilian Amazonia, being previously cited in the Midwest (Distrito Federal and Goiás state), Southeast (São Paulo and Rio de Janeiro states) and South (Paraná and Rio Grande do Sul states) regions.

Order Chroococcales

Family Microcystaceae

Microcystis aeruginosa (Kützing) Kützing, Tab. Phycol. 1: 6, 1846.

Basionym: *Micraloa aeruginosa* Kützing, Linnaea 8: 371. 1833. Fig. 3a

Colonies irregular, usually elongated, reticulated or not, or composed of sub-colonies, with cells aggregated, irregularly distributed in the center of colonies; mucilage usually wide, homogeneous, colorless, diffluent; cells spherical, without individual mucilaginous envelopes, 4–5.9(–7) μm diam.; cell content blue-green, with aerotopes.

Examined material: INPA 239884, INPA 240171, INPA 240172, INPA 240173, INPA 240174, INPA 240175, INPA 240176, INPA 240177, INPA 240178 and INPA 240179.

Microcystis aeruginosa is a cosmopolitan species (Komárek & Anagnostidis 1998) and, in this study, it was recorded in all analyzed environments. The species is widely distributed in Brazil, being recorded from North to South (Sant'Anna & Azevedo 2000). However, its comprehensive distribution might be related to identification issues, especially due to its numerous morphotypes.

Microcystis aeruginosa has been frequently confused with other species of the same genus and even with species from *Radiocystis*, *Coelosphaerium* and *Pannus*, showing that its

distribution can be smaller than indicated by the literature (Komárek 1991; Sant'Anna *et al.* 2004). Cell division in three perpendicular planes is one of the diacritical characteristics that distinguish *Microcystis* from these genera.

The morphologic and metric characteristics of the analyzed populations are in accordance with the specialized literature. However, noticeably wider (7 μm diam.) than the usual cells referred for *M. aeruginosa* were observed. Nonetheless, they fit the maximum cell dimensions of Australian populations studied by McGregor *et al.* (2007).

According to Ribeiro (2011), who analyzed the quantitative samples in the same period studied, *Microcystis aeruginosa* was observed only in Cesa Lake, forming dense blooms along with *M. protocystis* Crow, *M. wesenbergii* (Komárek) Komárek, and *Radiocystis fernandoi* Komárek & Komárková-Legnerová. They are known worldwide as species that produce microcystins (hepatotoxins) in different continental aquatic systems (Sivonen & Jones 1999; Moura *et al.* 2018; Vieira *et al.* 2003, 2005).

During the studied period, the water of Cesa Lake varied from slightly acid to alkaline (pH 6.2–8.5 - $\bar{x} = 7 \pm 0.70$), conductivity from 85.3–18 $\mu\text{S}\cdot\text{cm}^{-1}$ ($\bar{x} = 98.4 \pm 13.86$), and water temperature from 25.7–29.9 °C ($\bar{x} = 28 \pm 1.48$).

Its presence in Brazil was reported in the North (Amazonas and Pará states), Northeast (Ceará and Paraíba states), Midwest (Goiás and Mato Grosso do Sul states, and Distrito Federal), Southeast (Minas Gerais, Rio de Janeiro, and São Paulo states) and South (Paraná and Rio Grande do Sul states) regions.

Microcystis protocystis Crow, New Phytol. 22(2): 62.1923. Fig. 3b

Colonies irregular, usually elongated, without distinct lobes, not reticulated, with cells sparsely distributed all over the colony; mucilage colorless, diffluent, irregular in outline; cells spherical, slightly elongated during division, 3–6 μm diam., usually surrounded by individual mucilaginous envelopes, 5–6 μm diam.; cell content blue-green, with aerotopes.

Examined material: INPA 239884, INPA 240171, INPA 240172, INPA 240173, INPA 240174, INPA 240175, INPA 240176, INPA 240177, INPA 240178 and INPA 240179.

This species requires careful identification since it can be easily confused with other *Microcystis* species, such as *M. aeruginosa*, mainly

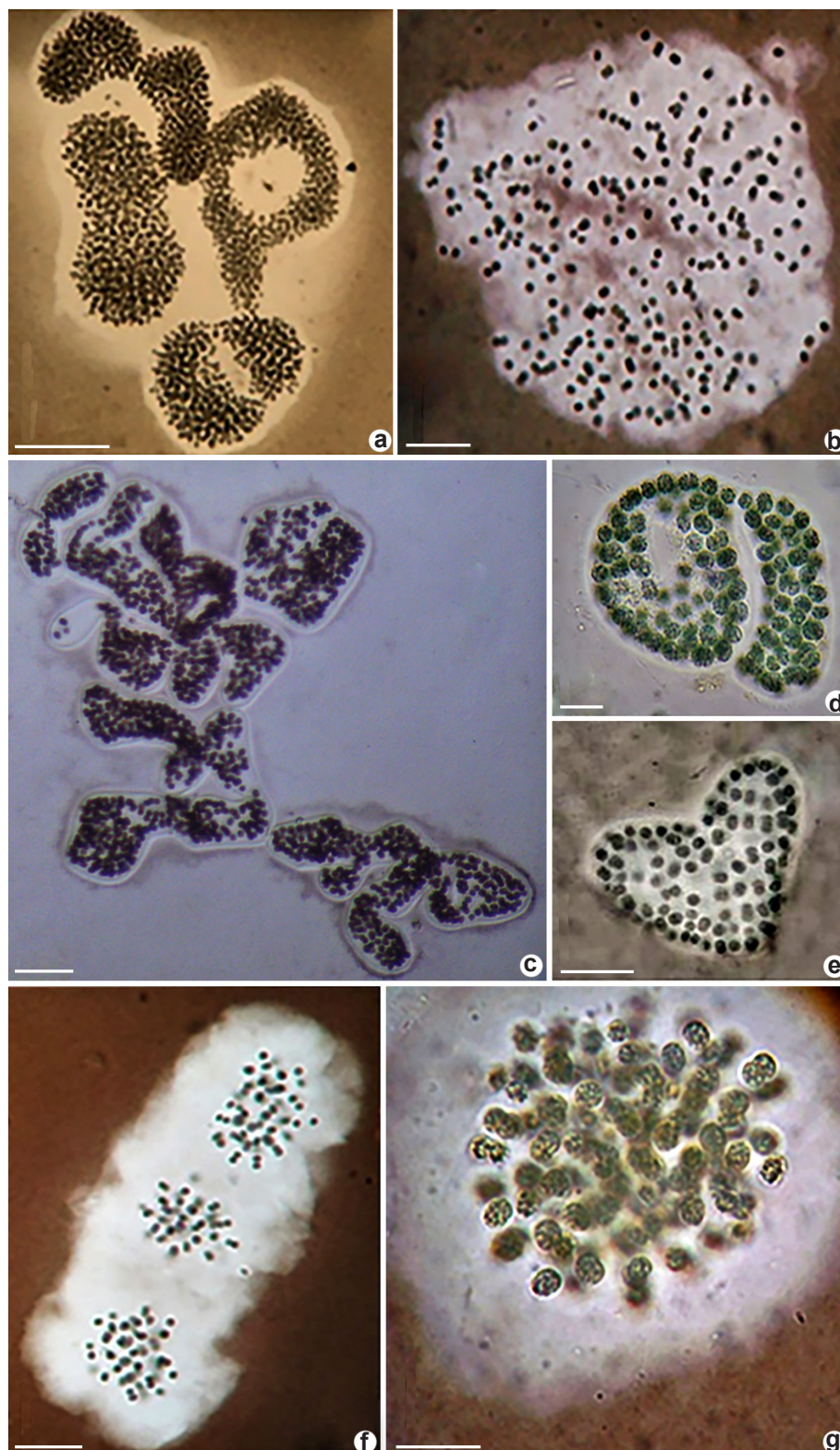


Figure 3 – a-g. Planktonic cyanobacteria from urban lakes – a. *Microcystis aeruginosa*; b. *M. protocystis*. c-e. *M. wesenbergii* – colonies morphologic variability; f-g. *Radiocystis fernandoi* – colonies morphologic variability. Scale bars: a = 10 μm ; b, d, e, g = 20 μm ; c, f = 50 μm .

due to their cell dimension similarities. In addition, sparsely distributed *M. protocystis* cells are similar to senescent adult colonies of other *Microcystis* species (Sant'Anna *et al.* 2004). However, it is easily distinguished from other species of the genus by its irregular mucilage outline and the usual individual mucilaginous envelopes of its cells.

Microcystis protocystis was only registered in Ceasa Lake during the studied period. The water varied from slightly acid to alkaline (pH 6.2–8.5 - $\bar{x} = 7 \pm 0.74$), conductivity from 85.3–118 $\mu\text{S}\cdot\text{cm}^{-1}$ ($\bar{x} = 98.7 \pm 14.55$), and water temperature from 25.7–29.9 °C ($\bar{x} = 27.8 \pm 1.40$).

It had been reported in the North (Amazonas state), Northeast (Paraíba and Pernambuco states), Southeast (São Paulo and Rio de Janeiro states) and South (Rio Grande do Sul state) regions.

Microcystis wesenbergii (Komárek) Komárek in Kondrateva, Cvetenie vody, p. 32, 1968.

Basionym: *Diplocystis wesenbergii* Komárek in Komárek & Ettl, Algol. Studien, p.68. 1958.

Fig. 3c-e

Colonies somewhat spherical, elongated, irregular, reticulated or not, lobate, usually with sub colonies, with cells aggregated, irregularly distributed; mucilage colorless, with thick, firm, refractive outline, sometimes with external diffluent, hyaline mucilage; cells spherical, (4.5–)5–7 μm diam.; cell content blue-green, with aerotopes.

Examined material: INPA 239881, INPA 239882, INPA 239883, INPA 239884, INPA 240171, INPA 240172, INPA 240173, INPA 240174, INPA 240175, INPA 240176, INPA 240177, INPA 240178, INPA 240179, INPA 240180, INPA 240181, INPA 240182, INPA 240183, INPA 240184, INPA 240185, 240186 and INPA 240187.

Microcystis wesenbergii is one of the most typical species of the genus *Microcystis*, easily identified by its refringent homogeneous colorless conspicuous mucilage outline.

The species was reported in Ceasa and Amazônico Lakes, where pH varied from 5.6–8.5 ($\bar{x} = 6.8 \pm 0.56$), electric conductivity 17.3–118 $\mu\text{S}\cdot\text{cm}^{-1}$ ($\bar{x} = 59.2 \pm 8.36$) and water temperature 23.2–30.3 °C ($\bar{x} = 27.14 \pm 1.88$).

It had been observed in Brazil in the North (Pará and Amazonas states), Midwest (Goiás state), Southeast (Minas Gerais, São Paulo and Rio de Janeiro states) and South (Santa Catarina and Rio Grande do Sul states) regions.

Radiocystis fernandoi Komárek & Komárková-Legnerová, Preslia 65: 357. 1993. Fig. 3f-g

Colonies somewhat spherical, elongated or irregular, formed by one or more groups of cells somewhat radially arranged; mucilage homogeneous, colorless, diffluent; cells spherical 6–6.5(–7) μm diam.; cell content blue-green, usually with aerotopes.

Examined material: INPA 239882, INPA 239883, INPA 239884, INPA 240171, INPA 240172, INPA 240173, INPA 240174, INPA 240175, INPA 240176, INPA 240177, INPA 240178 and INPA 240179.

Radiocystis fernandoi is typically tropical, being described from the plankton of a mesotrophic reservoir located in the state of São Paulo.

It can produce microcystin and, in Amazonia, Vieira *et al.* (2003) found a concentration of 3.83 $\mu\text{g mg}^{-1}$ in a bloom in a water reservoir in Belém, Pará state, which was the first report on the toxicity of the genus *Radiocystis*.

The species was found in two of the three studied environments. In Amazônico Lake, blooms of the species were observed in samples collected in May and June 2010, along with *Dolichospermum planctonicum*. In those samplings, pH ranged from 6.2–6.7 ($\bar{x} = 6.5 \pm 0.35$), conductivity 17.3–18.8 $\mu\text{S}\cdot\text{cm}^{-1}$ ($\bar{x} = 18.1 \pm 1.06$) and water temperature 23.2–25.1 °C ($\bar{x} = 24.1 \pm 1.34$). In Ceasa Lake, *R. fernandoi* was found in all analyzed samples, without forming blooms.

Radiocystis fernandoi had already been reported in other Brazilian water bodies in the North (Pará and Amazonas states), Midwest (Goiás state), Southeast (Minas Gerais and São Paulo states) and South (Rio Grande do Sul state) regions.

Order Oscillatoriales

Family Microcoleaceae

Planktothrix agardhii (Gomont) Anagnostidis & Komárek, Arch. Hydrobiol. Suppl. 80(1–4), Algol. Studies 50-53: 409. 1988.

Basionym: *Oscillatoria agardhii* Gomont, Ann. Sci. nat. 7, 16: 205. 1892. Fig. 4a-c

Trichomes solitary, straight or flexuous, slightly attenuated, not or slightly constricted at the sometimes granulated cross-walls, without sheath; cells shorter than wide, (1–)1.5–2 μm long, (3.5–)4–6.5 μm wide; apical cells convex, sometimes conical or pointed, rarely capitate, thickened cell wall; cell content blue-green, with numerous aerotopes.

Examined material: INPA 239886, INPA 239887, INPA 240162, INPA 240163, INPA 240164, INPA 240165,

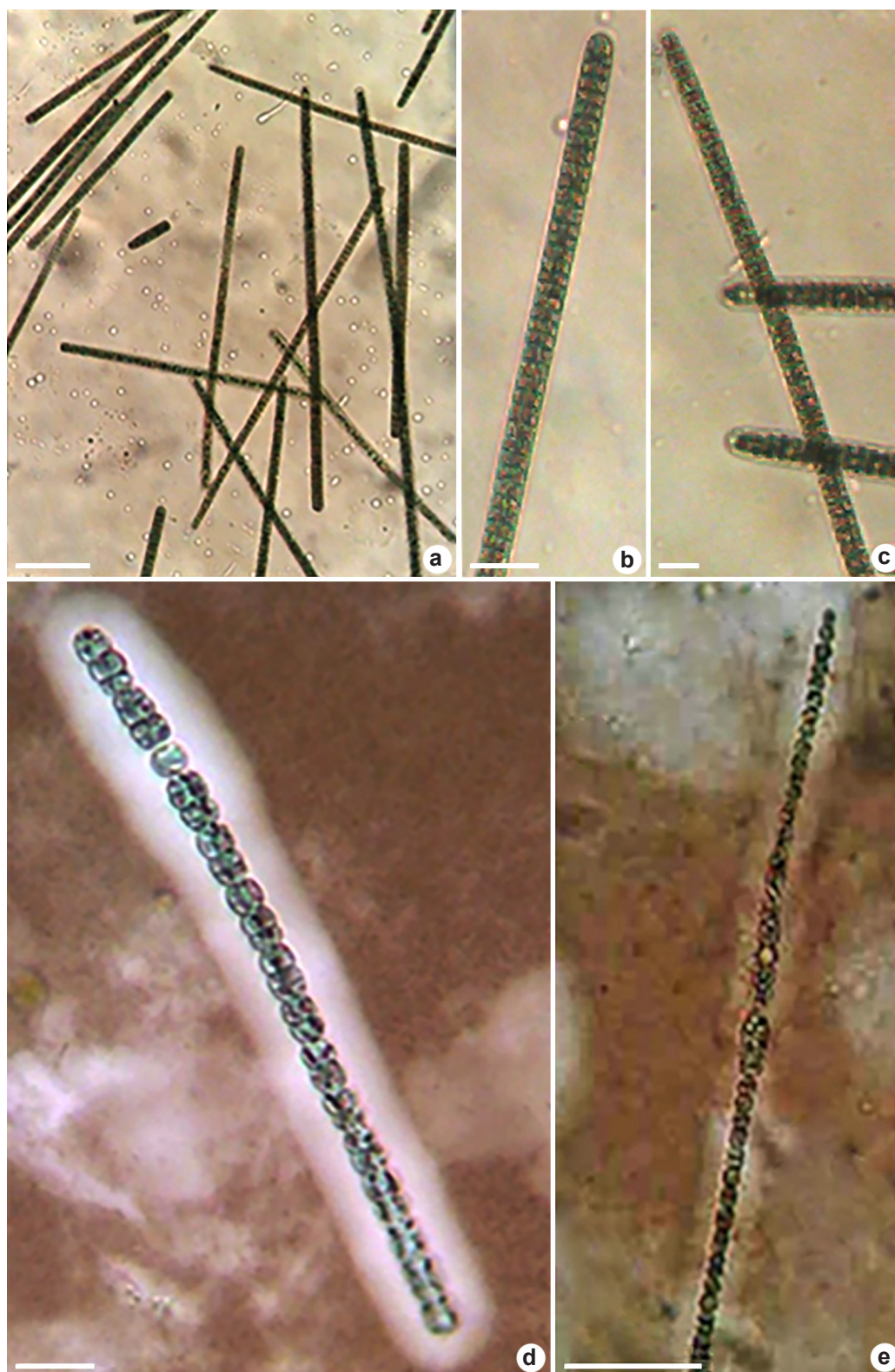


Figure 4 – a-e. Planktonic cyanobacteria from urban lakes – a-c. *Planktothrix agardhii* – a. general aspects of trichomes; b. slightly attenuated trichome with somewhat thickened apical cell; c. trichome with slightly capitate apical cell. d-e. *Dolichospermum planctonicum*. Scale bars: a = 30 μm ; b, c = 10 μm ; d = 20 μm ; e = 50 μm .

INPA 240166, INPA 240167, INPA 240168, INPA 240169 and INPA 240170.

Komárek & Komárková (2004) claim that *Planktothrix* belongs to one of the most important bloom-forming genera. Sant'Anna *et al.* (2008) cite *Pl. agardhii* as a potentially toxic species distributed in tropical and subtropical environments in Brazil.

According to Ribeiro (2011), blooms of *Pl. agardhii* were observed during the whole studied period in Japiim Lake, making the water greenish and frequently presenting dense scum on the surface.

The sample environmental conditions where the species was observed were pH 6–8 ($\bar{x} = 7 \pm 0.58$), conductivity 165.7–270 $\mu\text{S}\cdot\text{cm}^{-1}$ ($\bar{x} = 204.9 \pm 36.90$) and water temperature 25.2–30.5 °C ($\bar{x} = 27.8 \pm 1.64$).

Planktothrix agardhii had already been reported in the North (Roraima and Amazonas states), Midwest (Goiás and Mato Grosso do Sul states), Southeast (São Paulo and Rio de Janeiro states) and South (Rio Grande do Sul state) regions.

Order Nostocales

Family Anabaenaceae

Dolichospermum planctonicum (Brunn.) Wacklin, Hoffmann & Komárek, Fottea, 9(1): 2009.

Basionym: *Anabaena planctonica* Brunn., Sitzungsber. K. Akad. Wiss. Wien, mat.-nat., 112(1): 4. 1903. Fig. 4d-e

Trichomes straight or slightly curved, not attenuated, constricted, with thick (14–20 μm), diffuent, mucilaginous envelope; cells short barrel-shaped, 6–8.5(–9.5) μm wide, (4–)4.5–6(–6.5) μm long; apical cell rounded; cell content blue-green with numerous dark aerotopes; heterocytes somewhat spherical, intercalary, solitary, 7–7.5 μm diam.; akinete intercalary, solitary, distant from the heterocyte, elliptical, 10.5 μm wide, 23.9 μm long; epispore smooth, colorless.

Examined material: INPA 239881, INPA 239882, INPA 240181, INPA 240182, INPA 240183, INPA 240184 and INPA 239883.

Dolichospermum planctonicum can be easily distinguished from other species of *Dolichospermum* due to its trichomes surrounded by thick mucilage and compressed barrel-shaped cells, usually shorter than wider, and by the shape of its akinetes (elliptical) (Komárková-Legnerová & Eloranta 1992).

In the studied populations, slightly thinner specimens than the ones usually found in literature

were recorded [9–15 μm - Komárková-Legnerová & Eloranta 1992; 10–14 μm - Sant'Anna & Azevedo 2000, and Sant'Anna *et al.* 2007; (7.76–)8–15 μm - Komárek & Zapomělová 2008]. However, Li *et al.* (2000) found, in Japanese cultures, specimens with thinner trichomes than the ones recorded in the aforementioned populations [6.9–10.4 μm (TAC434) and 6.7–10.2 μm (TAC435)]. Moreover, specimens displaying thinner trichomes ($\bar{x} = 5.4$ –6.5 μm) were observed in cultures studied by Rajaniemi *et al.* (2005).

Based on these results, a certain variability in the diameter of *D. planctonicum* trichomes was verified. Therefore, the Amazonian material was identified as *D. planctonicum* since it lines up with the other characteristics of the species in the literature.

Most trichomes observed in this study were formed by vegetative cells and heterocytes, and only one specimen presenting an akinete and heterocytes was found (Fig. 4e).

The species was observed only in Amazônico Lake, forming blooms, along with *Radiocystis fernandoi*, in May and June 2010 (Ribeiro 2011), in slightly acid water samples (pH 5.6–6.8 - $\bar{x} = 6.5 \pm 0.46$), conductivity 17.3–19.4 $\mu\text{S}\cdot\text{cm}^{-1}$ ($\bar{x} = 18.7 \pm 0.69$) and water temperature 23.2–30.3 °C ($\bar{x} = 27.0 \pm 2.68$).

Dolichospermum planctonicum had already been found in the North (Pará state), Midwest (Goiás state), Southeast (São Paulo state) and South (Rio Grande do Sul state) regions.

The studied environments presented high water temperatures and electric conductivity, especially in Japiim and Cesa Lakes (Tab. 2). These lakes presented a close average pH, -7 ± 0.50 in the former and 7 ± 0.70 in the latter. On the other hand, Amazônico Lake presented slightly lower pH (6.5 ± 0.41). Its average conductivity and water temperature were also lower (19.6 ± 2.09 $\mu\text{S}\cdot\text{cm}^{-1}$ and 26.8 ± 2.45 , respectively).

The greatest richness of cyanobacterial species (nine taxa) was registered in the Amazônico Lake, while in Cesa Lake four species were recorded, and in Japiim Lake only *Planktothrix agardhii* was registered. The low cyanobacterial diversity, especially in Cesa and Japiim lakes, can be justified by the occurrence of blooms in these water bodies in the studied period, as reported by Ribeiro (2011).

Among the recorded species, some are recognized as potentially producing cyanotoxins.

According to the literature, *Pl. agardhii* is potentially neurotoxin-producing (anatoxin and saxitoxin), and hepatotoxin-producing (microcystins) (Sivonen & Jones 1999; Sant'Anna *et al.* 2008; Moura *et al.* 2018). These *Microcystis* species and *R. fernandoi* are potentially microcystin-producing (Sant'Anna *et al.* 2008), and *D. planctonicum* is potentially anatoxin-, saxitoxin- and microcystin-producing (Bruno *et al.* 1994; Sant'Anna *et al.* 2008; Chernova *et al.* (2017).

Microcystis wesenbergii and *R. fernandoi* were the only two species common to two studied environments (Ceasa and Amazônico Lakes). *Anathece cf. minutissima*, *Aphanocapsa annulata*, *Ap. stagnalis*, *Coelomoron microcystoides*, *D. planctonicum*, *Pseudanabaena mucicola* and *Snowella lacustris* were observed only in Amazônico Lake while *Pl. agardhii* was found only in Japiim Lake.

Lastly, this study has expanded the knowledge on the diversity of cyanobacteria in the Brazilian Amazonia as well as their geographic distribution. Five out of the 12 identified species (*A. cf. minutissima*, *Ap. annulata*, *Ap. Stagnalis*, *C. microcystoides*, and *P. mucicola*) were reported for the first time in the Brazilian Amazonia.

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Data availability statement

In accordance with Open Science communication practices, the authors inform that all data used in this manuscript is publicly available.

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