Cryptogamie, Algol., 2009, 30 (1): 135-152

Aerophytic cyanoprokaryotes from the Atlantic rainforest region of São Paulo State, Brazil: Chroococcales and Oscillatoriales

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(Received 16 April 2008, accepted 15 January 2009)

Abstract – Because algae are primarily aquatic, it seems almost paradoxical that there should exist a relatively diversified soil flora where aerophytic cyanoprokaryotes are especially abundant. However, there appear to be relatively few studies on this topic. This paper aims to improve the taxonomic knowledge on the chroococcalean and oscillatorialean cyanoprokaryote flora in tropical regions. Samples of cyanoprokaryotes were collected in the rainforest region of the São Paulo State, Brazil. Data on cyanoprokaryote mass type and color, substratum type, air and mass temperature and humidity, pH and absolute and relative irradiance were collected. The study revealed the presence of 24 species belonging to the orders Chroococcales and Oscillatoriales (12 species each). *Aphanothece* (four species) was the most species-rich genus. Overall, taxonomic resolution at the species level based on morphological and morphometric data can still be problematic.

Aerophytic algae / Brazil / Chroococcales / Cyanobacteria / Cyanoprokaryota / Oscillatoriales / taxonomy / tropical rainforest

Résumé – Cyanoprokaryotes aérophiles des forêts ombrophiles atlantiques de l'état de São Paulo, Brésil : Chroococcales et Oscillatoriales. Puisque les algues sont principalement aquatiques, il semble presque paradoxal qu'il existe une flore du sol relativement diversifiée où les cyanoprokaryotes aérophiles sont particulièrement abondantes. Cependant, les études dans ce domaine ne sont pas très nombreuses. Le présent article se propose de contribuer à la connaissance taxonomique de la flore des cyanoprocaryotes chroococcales et oscillatoriales dans les régions tropicales. Des échantillons de cyanoprokaryotes ont été prélevés dans une forêt ombrophile de l'état de São Paulo, Brésil. Les données sur le type et la couleur de la masse des cyanoprokaryotes, le type de substrat, la température et l'humidité de la masse et de l'air, le pH et les irradiances absolue et relative ont aussi été enregistrées. L'étude a montré la présence de 24 espèces appartenant aux ordres des Chroococcales et Oscillatoriales (12 espèces chacun). *Aphanothece* (quatre espèces) était le genre le plus riche en espèces. En général, la résolution taxonomique sur la base de données morphologiques et morphométriques peut parfois demeurer problématique.

Algues aérophiles / Brésil / Chroococcales / Cyanobacteria / Cyanoprokaryota / forêts ombrophiles / Oscillatoriales / taxinomie

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Communicating editor: Pierre Compère

INTRODUCTION

Because algae are primarily aquatic, it seems almost paradoxical that there should exist a relatively rich soil flora (Prescott 1984). However, several groups of algae (especially cyanoprokayotes, chlorophytes, diatoms and xanthophytes) are present in soil and on tree barks and rocks (Metting, 1981; Starks *et al.,* 1981; Prescott, 1984). Aerophytic algae are relevant primary colonizers (Metting, 1981) and important in stabilizing and improving the physical and chemical properties of the soil (Starks *et al.,* 1981).

Cyanoprokaryotes are well distributed and abundant in aerophytic environments, especially in soil habitats, and have important ecological functions in the ecosystem, acting in the retention of silt and clay and adding large amounts of organic carbon and nitrogen to the soil (De, 1939; Fletcher & Martin, 1948; Allen, 1956; Singh, 1961; Whitton, 2000). Some authors have reported that these algae produce growth promoting auxin-like compounds and vitamins, which are in part responsible for greater plant yield (Okuda & Yamaguchi, 1960; Venkataraman, 1975; Whitton, 2000). Several investigations have also pointed out the production of potentially useful medicinal compounds by terrestrial cyanoprokaryotes (Carmeli *et al.,* 1990; De Cano *et al.,* 1990; Smitka *et al.,* 1992; Jaki *et al.,* 1999; Reshef & Carmeli, 2002).

However, despite their ecological, economic and medical importance, studies on aerophytic cyanoprokaryotes are not very numerous and there are relatively few published surveys of these organisms, especially in tropical areas. According to Johansen & Shubert (2001), while there is a number of recent monographic works for other groups of soil algae, there are no comparable studies for cyanoprokaryotes.

Relevant taxonomic contributions on aerophytic cyanoprokaryotes pertaining to the orders Chroococcales and Oscillatoriales can be found within classical monographs such as Gomont (1892-1893), Tilden (1910), Gardner (1927), Frémy (1930), Geitler (1930-1932) and Desikachary (1959). The papers of Starmach & Siemińska (1979 – soil samples from Norway to Yugoslavia) and Hoffmann (1986 – Grand-duchy of Luxembourg) are also useful contributions to the aerophytic cyanoprokaryote flora from temperate environments. Floristic accounts by Komárek & Anagnostidis (2000, 2005) are also useful references for tropical studies even though they are mostly centered on temperate regions Other relevant taxonomic studies have been carried out on other tropical regions of the world, e.g., Papua-New Guinea (Hoffmann, 1989), French Guiana (Sarthou *et al.,* 1995), inselbergs of the Ivory Coast (Büdel *et al.,* 1997) and New Caledonia (Couté *et al.,* 1999). Other important contributions to the knowledge of epilithic cyanobacteria include Nováček (1929), Jaag (1945), Golubič (1967) and Abdelahad & Bazichelli (1991).

Studies on Brazilian aerophytic cyanoprokaryotes in particular are very scant. Sant'Anna (1984) studied the flora on rocky cliffs in Campina Verde (Minas Gerais State). Sant'Anna *et al.* (1991) identified the cyanoprokaryotes from a sunny cave in Ubatuba (São Paulo State). Azevedo (1991) surveyed the edaphic flora from the "Parque Nacional das Fontes do Ipiranga – PEFI" (São Paulo State). Büdel *et al.* (2002) studied the crusts of cyanoprokaryotes from inselbergs of eastern Brazil.

Johansen & Shubert (2001) suggested that a great many undescribed algal species may exist on soil. Several recent publications describing new algal taxa from aerophytic biotopes seem to lend support to this hypothesis, e.g. Hoffmann (1991), Azevedo & Sant'Anna (1994a, 1994b), Asencio *et al.* (1996), Flechtner *et al.* (2002), Komárek (2003) and Branco *et al.* (2006a, 2006b).

The present paper is aimed at improving taxonomic and ecological knowledge on the flora of aerophytic cyanoprokaryotes (Chroococcales and Oscillatoriales) from Brazil. It includes information on a number of environmental variables (substratum type, pH, irradiance, temperature and humidity) under which the observed populations occurred and brief notes on the biogeographical distribution of some taxa. This first contribution is part of a broader investigation dealing with all orders of cyanoprokaryotes from aerophytic habitats.

MATERIAL AND METHODS

Sampling area

The sampled area is located in the northern littoral region of São Paulo State, Brazil (Fig. 1). Its vegetation consists in dense ombrophilous forests. Mean annual temperatures vary according to the altitude. At sea level, temperatures range from 14 to 21ºC (Salati Filho & Cotas, 2003) and at the mountain ridge, from 18 to 19ºC (http://www.coneleste.com.br). Mean annual rainfall is around 2100 mm at sea level and up to 4600 mm at mountain ridge (http://www.coneleste.com.br). Relative air humidity is above 80% (Salati Filho & Cotas, 2003).

Samples of cyanoprokaryotes were collected through the rainforest region where a considerable amount of forest occurs along the "Sea Mountain Ridge", which is represented by a coastal mountain range with average altitudes varying from 800 to 900 m a.s.l. This ecosystem was chosen owing to the favourable environmental conditions for aerophytic growth, i.e. intermediate (under the canopy) to high (in open areas – road borders) levels of irradiance, high temperature and air humidity and availability of different substratum types (rocks, soil and tree barks).

A total of 39 samples collected from 19 distinct sampling sites in the studied area (Table 1) were examined which contained chroococcalean and/or oscillatorialean cyanoprokaryote taxa.

Fig. 1. Schematic map of São Paulo State with the remaining forest spots (source: BIOTA/FAPESP – SINBIOTA: http://sinbiota.cria.org.br/) and the sampled area (dotted line).

Table 1. Location and altitude of the collection sites and their respective samples.

Site	*Sample*	*Latitude (S)*	*Longitude (W)*	*Altitude (m a.s.l.)*
01	SAMA 01	23º35'51''	46º10'08''	800
02	SAMA 02	23º41'07''	46º05'52''	791
03	SAMA 04, SAMA 05, SAMA 06	23º41'09''	46º05'52''	787
04	SAMA 12, SAMA 14	23º46'14''	45º43'14''	55
05	SAMA 16, SAMA 17, SAMA 18, SAMA 19	23º49'28''	45º27'06''	1
06	SAMA 21, SAMA 22	23º36'10''	45º26'43''	183
07	SAMA 23, SAMA 24, SAMA 26	23º35'16''	45º26'57''	600
08	SAMA 28, SAMA 30, SAMA 31	23º31'15''	45º32'15''	791
09	SAMA 32	23º34'14''	45º29'28'	765
10	SAMA 33	23º32'56''	45º14'47''	23
11	SAMA 34, SAMA 35, SAMA 36, SAMA 37	23º29'39''	45º08'38''	66
12	SAMA 39, SAMA 41	23º23'06''	45º07'19''	122
13	SAMA 42	23º21'19''	45º07'51''	929
14	SAMA 43, SAMA 44	23º22'02''	45º07'24''	760
15	SAMA 45, SAMA 47	23º22'37''	45º07'07''	309
16	SAMA 49, SAMA 50	23º24'50''	45º01'43''	77
17	SAMA 51, SAMA 52	23º11'54''	44º50'08''	1034
18	SAMA 53	23º10'52''	44º50'00''	1239
19	SAMA 54, SAMA 55	23º09'54''	44º50'21''	1460

Collection, preservation and ecological data

Visible growths of cyanoprokaryotes were randomly collected with a spatula or penknife. After collection, samples were codified (named "SAMA" followed by the number of the sample) and preferably kept dry at room temperature in paper bags. When the masses were excessively mucilaginous, the specimens were preserved in glutaraldehyde (2%) or formaldehyde (4%) solutions.

For each collection, data on thallus type (prostrate or erect filaments or gelatinous mass), color and substratum type (rock, soil, tree bark…) were recorded. In addition, the following environmental data were recorded: global position and altitude (GPS Garmin, eTrex Summit), air and cyanoprokaryotean mass (inside the mass) temperature using a digital thermometer with a 11 cm long metal probe, air and cyanoprokaryotean mass humidity (as close as possible to the mass) using a Hana Instruments HI8564 thermohygrometer), pH (using Merck pH strips – pH was measured in a solution with distilled/deionized water and a sample of the substratum) and absolute and relative irradiance (using a Li-Cor Quantameter, with spherical sensor – the relative values are a ratio between the absolute value measured as close as possible to the mass and the absolute value measured at an open area).

Laboratory analyses

Dried samples were rehydrated with distilled water or other solutions (e.g. 5% acqueous detergent solution) when necessary. According to Büdel *et al.* (2002), these organisms can remain alive after several months of dry storage.

Masses were initially characterized under a stereomicroscope. Subsequently, for each sample at least five mounted slides were prepared. Slides were examined using Leica DMR and Olympus BX-50 light microscopes and taxonomic features such as colony, filament, trichome and cell size, cell shape and features of the sheaths or mucilage, constriction, tapering and hormogonia. At least 30 observations of each taxonomic feature were made. Photomicrographs were taken using a Sony Power HAD digital camera and an Olympus PM20 photomicrographic system.

Taxonomic identification

Only the most representative populations in each sample were analysed in this survey, thereby excluding all those specimens which were present in very low densities.

Genera and species were identified based mainly on Gomont (1892-1893), Tilden (1910), Gardner (1927), Frémy (1930), Geitler (1930-1932) and Desikachary (1959). Other works used were as follows: Komárek & Anagnostidis (1986, 2000) for the Chroococcales, Anagnostidis & Komárek (1988) and Komárek & Anagnostidis (2005) for the Oscillatoriales. Higher-level classification followed the system proposed by Hoffmann *et al.* (2005).

The following abbreviations are used in the description of ecological data: AT = air temperature (ºC), MT = plant mass temperature (ºC), ARH = relative humidity of the air (%), MRH = relative humidity close to the plant mass (%), Ir = irradiance measured close to the plant mass ($\mu mol.m^{-2}.s^{-1}$), PIr = percentage of irradiance reaching the plant mass in relation to the irradiance at an open near site (%), S = substratum type. When the taxa occurred in more than one sample, the values of the variables are presented as a range and the average values are provided.

RESULTS

The examination of the collected material revealed the presence of 24 cyanoprokaryote taxa belonging to the orders Chroococcales (12 taxa) and Oscillatoriales (12 taxa).

CHROOCOCCALES

MERISMOPEDIACEAE

Aphanocapsa intertexta Gardner 1927, *Mem. New York Bot. Gard.* 7: 4. Figs 2-3

Colonies with no defined limits, cell agglomerations with up to 50 cells, growing with other filamentous and coccoid cyanoprokaryotes; cells spherical, 2.0-2.8(-3.0) µm wide, surrounded by a thin mucilage or sometimes enveloped by a firm, delicate sheath; cell content homogeneous, with some small prominent granules, light green, chromatoplasm evident.

Ecological data: n = 2, SAMA 24, SAMA 30; AT = 22.7-26.0ºC (24.3ºC), MT = 19.5-36.0ºC (27.7ºC), ARH = 55-79% (67%), MRH = 62-83% (72%), Ir = 120-1700 µmol.m^{-2}.s^{-1} (910 µmol.m^{-2}.s^{-1}), PIr = 24-100% (62%), pH = 4 (4), S = rock.

Note: Gardner (1927) found this aerophytic species on rocks in a stream with other filamentous cyanobacteria and on *Stigonema scytonematoides* Gardner on red soil in Porto Rico. *Aphanocapsa intertexta* is probably a (pan?)tropical species.

MICROCYSTACEAE

Gloeocapsa quaternata (Brébisson) Kützing 1846, *Tab. Phyc.* 1: 15. Figs 4-5

Plant mass macroscopic, irregular, gelatinous, firm, ca. 1 mm thick, light green to brownish green; colonies approximately spherical or slightly elongated, with up to 16 cells, usually two, four or eight, more or less densely arranged, 7.6-18.0 µm long, 5.6-12.0 µm wide; colonial mucilage firm, not very distinctly lamellate, hyaline, sometimes reddish; cells with individual stratified mucilage, spherical to hemispherical, sometimes slightly cylindrical, 3.2-5.2 µm long, 3.2-4.2 µm wide; cell content granulated, bright blue-green.

Ecological data: n = 3, SAMA 34, SAMA 35, SAMA 36; AT = 27.7ºC (27.7ºC), MT = 22.9-23.9ºC (23.4ºC), ARH = 74% (74%), MRH = 75-81% (78%), Ir = 35-330 µmol. m^{-2}.s^{-1} (182 µmol.m^{-2}.s^{-1}), PIr = 5-48% (11%), pH = 4 (4), S = rock.

Note: Sarthou *et al.* (1995) found *G. quaternata* (as *G. quaternaria*) in temperate areas of French Guiana and Couté *et al.* (1999) recorded the species (also as *G. quaternaria*) in the tropical New Caledonia. *G. quaternata* can be considered a cosmopolitan aerophytic species and its synonymy with *G. rupicola* Kützing (Komárek & Anagnostidis, 2000) ought to be re-evaluated.

Gloeocapsa cf. ***sanguinea*** (Agardh) Kützing 1843, *Phyc. Gen.*: 174. Figs 6-7

Colonies microscopic, among or on other cyanoprokaryotes, nearly spherical or slightly elongated, with up to eight cells, 26.0-45.0 µm long, 21.2-45.0 µm wide; colonial mucilage firm, not very distinctly lamellated, hyaline outside, light or intense reddish inside; cells with individual stratified mucilage, usually red, spherical, 4.2-5.7 µm wide; cell content granulated, pale blue-green.

Ecological data: n = 1, SAMA 52; AT = 20.1ºC, MT = 23.5ºC, ARH = 90%, MRH = 91%, Ir = 341 µmol.m^{-2}.s^{-1}, PIr = 57%, pH = 5, S = rock.

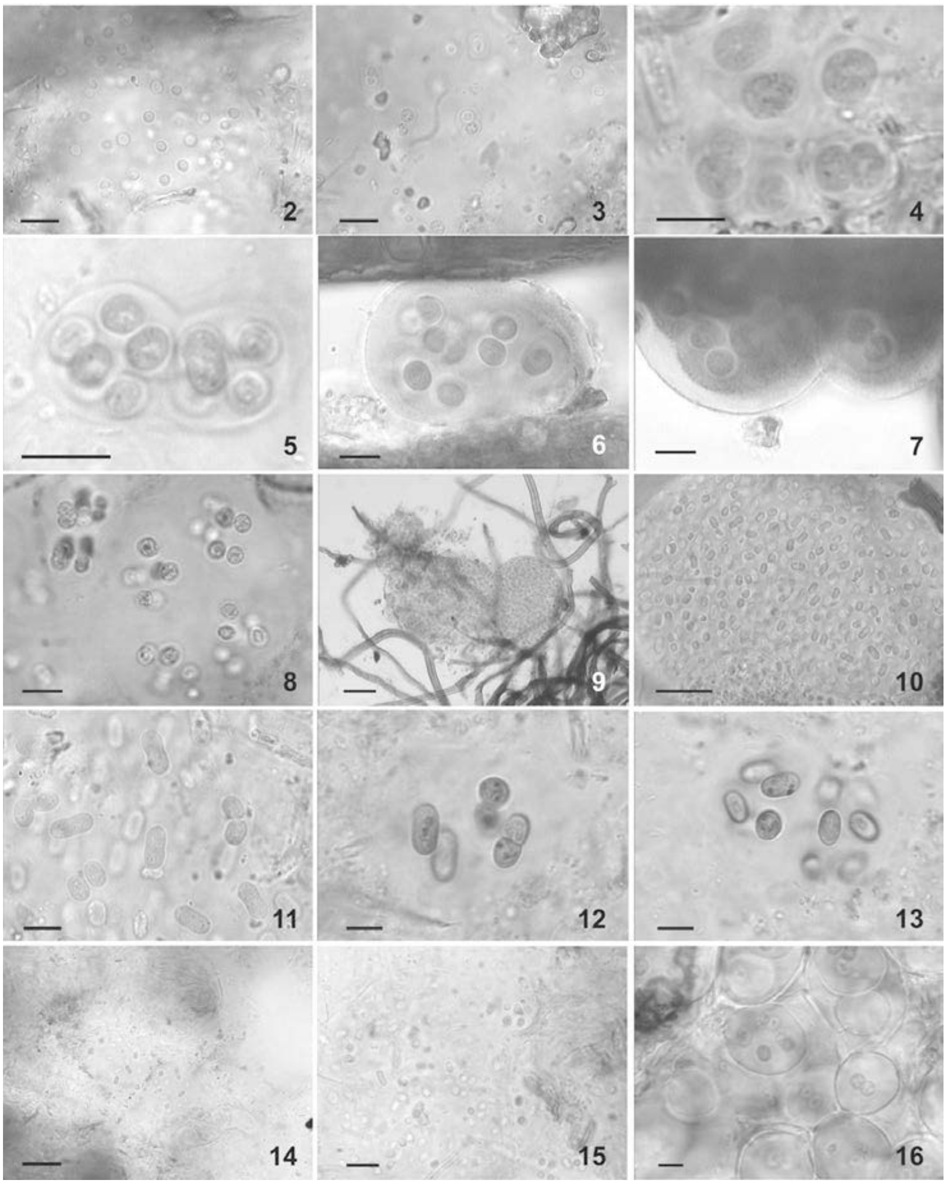
Note: *G. sanguinea* is widely distributed throughout the temperate zone. It has been recorded mainly from mountainous regions in Europe and probably has a cosmopolitan distribution (Komárek & Anagnostidis 2000). The studied population is morphologically very close to *G. sanguinea*; however, the biotope of occurrence is quite different from the one of temperate areas. In addition, the material from the Atlantic rainforest has also been found as an epiphyte on *Scytonema* sp. that is distinct from the usual life form of the species.

Gloeocapsa sp. Fig. 8

Colonies microscopic, among other cyanoprokaryotes, nearly spherical, with up to 16 cells, 16.0-30.0 µm wide; colonial mucilage firm, distinctly lamellated, hyaline or occasionally light reddish; cells with individual stratified mucilage, spherical, 3.0-4.0 µm wide; cell content granulated, blue-green.

Ecological data: n = 1, SAMA 53; AT = 19.6ºC, MT = 18.3ºC, ARH = 73%, MRH = 82%, Ir = 210 µmol.m^{-2}.s^{-1}, PIr = 29%, pH = 4, S = rock.

Note: Owing to the size, this taxon is similar to *Gloeocapsa atrata* Kützing. The latter species is probably widespread in temperate areas, but, according to Komárek & Anagnostidis (2000), tropical records are doubtful and should be revised.



Figs 2-16. Cyanoprokaryote taxa from the rainforest region of São Paulo State, Brazil, light micrographs. **2-3.** *Aphanocapsa intertexta*. **4-5.** *Gloeocapsa quaternata*. **6-7.** *Gloeocapsa* cf. *sanguinea*. **8.** *Gloeocapsa* sp. **9-11.** *Aphanothece castagnei*. **12-13.** *Aphanothece pallida.* **14-15.** *Aphanothece* cf. *saxicola.* **16.** *Aphanothece* sp. (Scale bars: Figs 1-8, 11-13, 15-16 = 10 µm; Fig. 14 = 20 µm; Figs 9-10 = 50 µm).

SYNECHOCOCCACEAE

Aphanothece castagnei (Brébisson) Rabenhorst 1865, *Fl. Eur. Alg.* 2: 64. Figs 9-11

Colonies usually microscopic, among other algae, sometimes small macroscopic, amorphous up to almost spherical, with well defined margin, up to hundreds of cells; microscopic colonies up to 200.0 µm wide, macroscopic light green colonies around 0.5 mm wide; mucilage firm, homogeneous, hyaline; cells cylindrical, without individual mucilage, 5.0-8.8 µm long, 3.0-4.8 µm wide, 1.4 to 2.6 times longer than wide; cell content relatively homogeneous with some small granules, blue-green.
Ecological data: n = 2, SAMA 34, SAMA 39; AT = 24.6-27.7°C (26.1°C), MT = 23.9-26.4°C (25.1°C), ARH = 74-80% (77%), MRH = 81-83% (82%), Ir = 330-340 µmol.m^{-2}.s^{-1} (335 µmol.m^{-2}.s^{-1}), PIr = 48-78% (63%), pH = 4-10 (7), S = rock.
Note: Commonly recorded in temperate areas, this species is also found in the tropical zone and can be considered cosmopolitan (Couté *et al.,* 1999).

Aphanothece pallida (Kützing) Rabenhorst 1863, *Krypt. Fl. Sachsen*: 76. Figs 12-13

Colonies microscopic among other algae, irregular, margin more or less well defined, with up to 8 cells, 20-25 µm wide; mucilage diffluent, hyaline; cells cylindrical, 7.0-11.5(-12.5) µm long, 4.0-6.0(-6.5) µm wide, (1.3-)1.6 to 2.3 times longer than wide; cell content with prominent granules, purple.
Ecological data: n = 1, SAMA 19; AT = 25.5°C, MT = 23.5°C, ARH = 82%, MRH = 78.8%, Ir = 7.5 µmol.m^{-2}.s^{-1}, PIr = 30%, pH = 6, S = rock.
Note: Cell dimensions and colony features of *A. pallida* are close to those of *A. variabilis* (Schiller) Komárek, however *A. pallida* is considered as a cosmopolitan species (on damp walls) while *A. variabilis* occurs in the tropical zone (coastal swamps). Although the population studied here shares more morphological and ecological similarities with *A. pallida*, the re-evaluation of the two species ought to be considered.

Aphanothece cf. ***saxicola*** Nägeli 1849, *Gatt. einzell. Algen*: 60. Figs 14-15

Colonies usually microscopic among other algae, sometimes small macroscopic, amorphous, margin well defined; mucilage diffluent, homogeneous, hyaline; cells cylindrical, without individual mucilage, 2.5-4.0(-5.0) µm long, 1.2-2.5 µm wide, 1.2 to 2.8 times longer than wide; cell content relatively homogeneous, blue-green.
Ecological data: n = 6, SAMA 01, SAMA 02, SAMA 16, SAMA 18, SAMA 28, SAMA 32; AT = 19.6-25.5°C (22.6°C), MT = 19.8-23.8°C (21.3°C), ARH = 73-85% (79%), MRH = 68-90% (81%), Ir = 7-120 µmol.m^{-2}.s^{-1} (71 µmol.m^{-2}.s^{-1}), PIr = 24-37% (29%), pH = 4-6 (5.2), S = rock and soil.
Note: The populations found here are phenotypically very similar to the species description. However, according to Komárek & Anagnostidis (2000) *A. saxicola* occurs in the northern temperate zone only.

Aphanothece sp. Figs 16-18

Plant mass macroscopic, large, gelatinous, consistent, amorphous, brownish to yellowish green; colonies nearly rounded or spherical, margins well defined, generally with 2-16 cells, sometimes with more than 50 cells, 7.0-28.0 µm wide, in some cases two or more small colonies can be found inside an unique colonial envelope; mucilage firm, homogeneous, hyaline; cells cylindrical with

rounded ends, hemispherical after cell division, 2.4-5.0 µm long, 2.4-4.0 µm wide, 1 to 1.7 times longer than wide; cell content granulated, blue-green.
Ecological data: n = 1, SAMA43; AT = 19.2ºC, MT = 19.9ºC, ARH = 82%, MRH = 84.5%, Ir = 14 µmol.m^{-2}.s^{-1}, PIr = 37%, pH = 10, S = rock.
Note: This population does not correspond to any known species and it probably represents a new taxon. *Aphanothece saxicola* Nägeli is the most similar species but there are significant differences in metrical and ecological characteristics.

Gloeothece rhodochlamys Skuja 1949, *Nova Acta Reg. Soc. Sci. Upsal.*, Ser. 4, 14(5): 18. Figs 19-20

Plant mass macroscopic, gelatinous, large, amorphous with papillose surface, brownish red; colonies rounded or nearly spherical, margin well defined, with up to 16 cells inside a common sheath, generally 1, 2 or 4; mucilage firm, very stratified, hyaline, orangish red or deep red, up to 15.0 µm wide; cells cylindrical rounded to oval, individual stratified mucilage present, 2.0-4.3 µm long, 1.6-2.5 µm wide, 1.2 to 2.0 times longer than wide; cell content homogeneous, with distinct chromatoplasm, light green.
Ecological data: n = 8, SAMA 01, SAMA 02, SAMA 16, SAMA 18, SAMA 28, SAMA 31, SAMA 32, SAMA 37; AT = 19.6-27.7ºC (23.2ºC), MT = 19.8-24.0ºC (21.5ºC), ARH = 74-85% (78%), MRH = 68-90% (80%), Ir = 7-280 µmol.m^{-2}.s^{-1} (108 µmol.m^{-2}.s^{-1}), PIr = 24-41% (30%), pH = 4-6 (5), S = rock and soil.
Note: This species can be considered typically tropical. Populations were found in several sites along the mountain ridge in São Paulo State and the occurrence in supralittoral zones (Komárek & Anagnostidis, 2000) is also quite possible.

Gloeothece samoensis Wille var. ***maior*** Wille 1913, *Hedwigia* 53: 144. Fig. 21

Colonies microscopic among other algae, rounded, spherical or slightly elongated, margin well defined, with up to 16 cells inside a common sheath, generally 2 or 4; mucilage firm, very stratified, hyaline, rarely yellowish, up to 26.0 µm wide; cells cylindrical rounded, individual stratified mucilage usually present, (6.0-)7.0-9.8 µm long, 4.0-6.0 µm wide, 1.3 to 1.7(-2.1) times longer than broad; cell content heterogeneous (but no distinct chromatoplasm), sometimes with prominent granules, dark blue-green.
Ecological data: n = 4, SAMA 12, SAMA 14, SAMA 39, SAMA 43; AT = 19.6-31.0ºC (26.5ºC), MT = 19.2-26.7ºC (24.7ºC), ARH = 60-82% (70%), MRH = 68-84% (74%), Ir = 14-400 µmol.m^{-2}.s^{-1} (278 µmol.m^{-2}.s^{-1}), PIr = 16-78% (41%), pH = 5-10 (7.5), S = rock.
Note: This species (including all its varieties) is tropical.

Gloeothece sp. Fig. 22

Plant mass macroscopic, gelatinous, homogeneous, very large (a few m^2), reddish brown to yellowish brown; colonies rounded or spherical, margin well defined, with up to 16 cells inside a common sheath, generally 2 or 4; mucilage firm, abundant, stratified, hyaline to reddish, up to 35.0 µm wide; cells cylindrical rounded to nearly spherical, individual stratified mucilage usually present, 2.5-4.0 µm long, 1.8-2.3(-2.8) µm wide, 1.2 to 2.1 times longer than wide; cell content heterogeneous but with no prominent granules, green.
Ecological data: n = 1, SAMA 53; AT = 19.6ºC, MT = 18.3ºC, ARH = 73%, MRH = 82%, Ir = 210 µmol.m^{-2}.s^{-1}, PIr = 29%, pH = 4, S = rock.
Note: This population is related to *Gloeothece confluens* Nägeli, but there are significant morphological and morphometric differences.

Synechococcus cf. ***elongatus*** Nägeli 1849, *Gatt. einzell. Algen*: 56. Fig. 23

Cells isolated or grouped in small clusters among other algae; mucilaginous envelope absent; cells cylindrical, symmetrically divided, 4.0-5.7 µm long, 1.2-1.7 µm wide, 2.7 to 4.2 times longer than wide; cell content homogeneous, sometimes with small prominent granules, pale green. Involution cell forms not observed.

Ecological data: n = 1, SAMA 49; AT = 25.1ºC, MT = 23.8ºC, ARH = 90%, MRH = 93%, Ir = 3 µmol.m^{-2}.s^{-1}, PIr = 30%, pH = 5, S = rock.

Note: According to Komárek & Anagnostidis (2000), this species typically grows in subaerophytic conditions (e.g. soil, wet stones), which corresponds well to the habitat of the Atlantic rainforest population. However, Komárek & Anagnostidis (2000) emphasize that *S. elongatus* occurs all over the temperate zones and that records from tropical countries and/or other biotopes should be revised. Although the present population is morphologically and ecologically very closely related to *S. elongatus*, its identification is subject to confirmation following a more exhaustive biogeographical study.

OSCILLATORIALES

PHORMIDIACEAE

Dasygloea cf. ***lamyi*** (Gomont) Senna & Komárek 1998, *Algolog. Stud*. 88: 11. Figs 24-25

Filaments isolated or in small groups among other algae, branched, with up to 4, (usually 2 or 3) trichomes, 15.0-17.0 µm wide; sheath closed at the apex, lamellate when older, hyaline to yellowish; trichomes constricted, (2.5-)3.0-4.8 µm wide; cells 3.2-8.8(-9.6) µm long, (0.6-)1.0 to 2.5 times longer than wide; cell content granulated, blue-green; apical cell rounded conical.

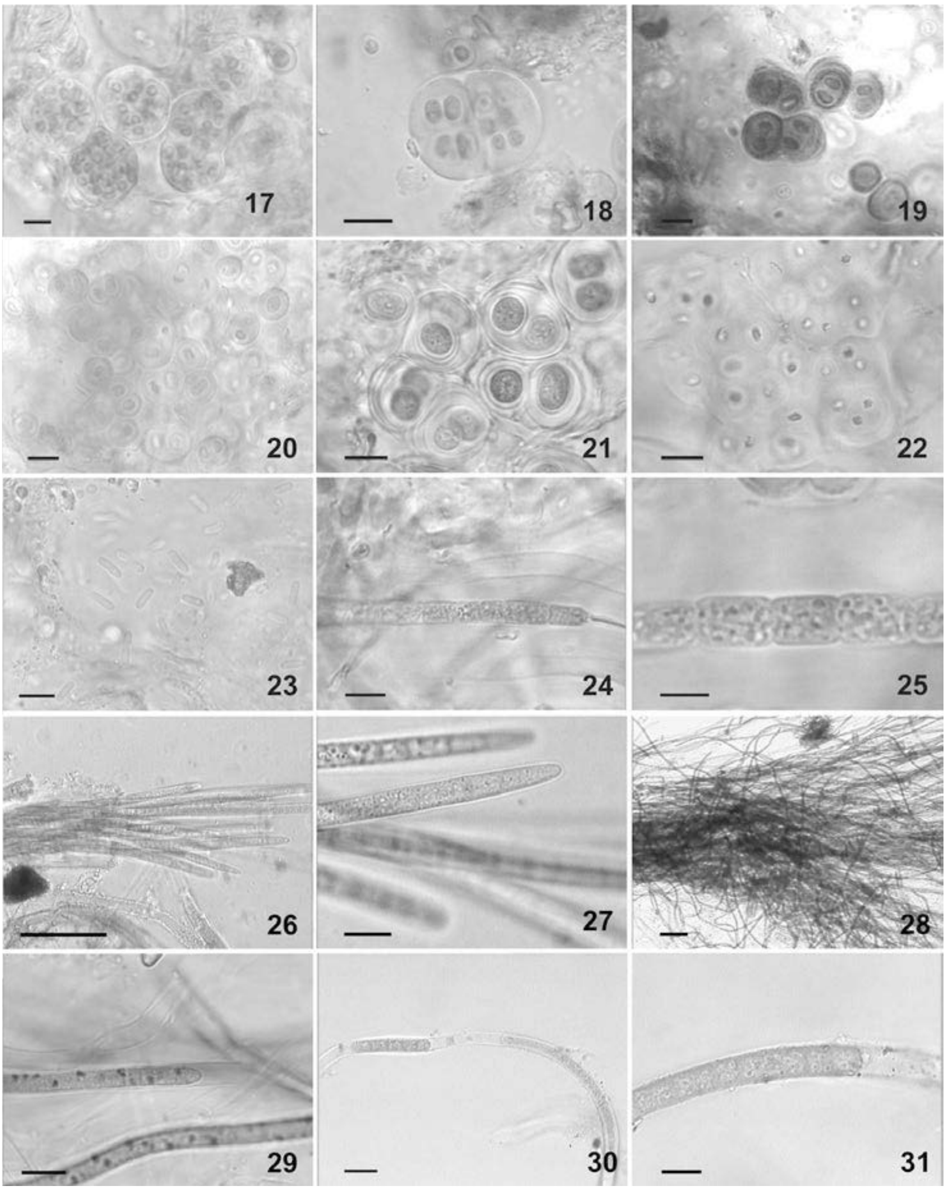
Ecological data: n = 7, SAMA 05, SAMA 17, SAMA 34, SAMA 35, SAMA 36, SAMA 37, SAMA 49; AT = 21.5-27.7ºC (26.0ºC), MT = 19.5-24.0ºC (23.0ºC), ARH = 74-90% (79%), MRH = 75-93% (84%), Ir = 2-330 µmol.m^{-2}.s^{-1} (163 µmol.m^{-2}.s^{-1}), PIr = 5-48% (31%), pH = 4-6 (4.6), S = rock.

Note: Morphologically these populations agree well with the original description by Gomont (1892), a small difference being the cell length/width ratio (up to 2.5 in the Brazilian material, up to 2 in Gomont's description). Ecologically, the species is also recorded (as *Schizothrix lamyi*), in aerophytic environments of tropical areas (e.g. Gomont, 1892). However, Komárek & Anagnostidis (2005) suggested that tropical records probably represent different taxa.

Microcoleus amplus Gardner 1927, *Mem. New York Bot. Gard.* 7: 56. Figs 26-27

Filaments in small groups or isolated among other algae, sometimes branched, with up to 15 trichomes densely arranged, 20.0-74.0 µm wide; sheath open at the apex, hyaline; trichomes predominantly not constricted, sometimes slightly tapering to the apex, 4.0-5.0 µm wide; cells 4.0-9.0 µm long, 1.0 to 2.2 times longer than wide; cell content granulated, pale blue-green; apical cell pointed and long rounded cylindrical, calyptra occasionally present.

Ecological data: n = 3, SAMA 47, SAMA 50, SAMA 55; AT = 21.9-25.1ºC (23.1ºC), MT = 22.5-28.1ºC (25.2ºC), ARH = 67-92% (83%), MRH = 68-141% (101%), Ir = 4-2200 µmol.m^{-2}.s^{-1} (754 µmol.m^{-2}.s^{-1}), PIr = 40-92% (72%), pH = 5-9 (6), S = soil, soil sediment on the road and rock.



Figs 17-31. Cyanoprokaryote taxa from the rainforest region of São Paulo State, Brazil, light micrographs. **17-18.** *Aphanothece* sp. **19-20.** *Gloeothece rhodochlamys*. **21.** *Gloeothece samoensis.* **22.** *Gloeothece* sp. **23.** *Synechococcus* cf. *elongatus.* **24-25.** *Dasygloea* cf. *lamyi.* **26-27.** *Microcoleus amplus*. **28-29.** *Phormidium abronema*. **30-31.** *Phormidium corium* (Scale bars: Figs 17-25, 27, 29-30 = 10 µm; Fig. 31 = 20 µm; Fig. 26 = 50 µm; Fig. 28 = 100µm).

Note: From the point of view of morphology and ecology, the specimens from the Atlantic rainforest agree well with the description given by Gardner (1927). Slight differences can be observed regarding the sheath, which is wider in the type population, and the absence of a calyptra according to Gardner's description.

Phormidium corium Gomont 1892, *Ann. Sci. Nat.*, *Bot.*, ser. 7, 15: 172. Figs 28-29

Plant mass formed by entangled filaments, grouped in fascicles, prostrated, purple; filaments flexuous, 3.5-4.0 µm wide; sheath thin, hyaline; trichomes not or very slightly constricted (mainly at the ends), 3.0-4.0 µm wide; cells 4.0-6.0 µm long, 1.1 to 1.7 times longer than wide; cell content granulated, purple or light green; apical cell rounded cylindrical or rounded conical.

Ecological data: n = 1, SAMA 19; AT = 25.5ºC, MT = 23.5ºC, ARH = 82%, MRH = 79%, Ir = 7.5 µmol.m^{-2}.s^{-1}, PIr = 30%, pH = 6, S = rock.

Note: *P. corium* is recorded in a wide range of climatic zones and habitats. It may represents a species complex of organisms with very similar morphology.

Phormidium* cf. *pachydermaticum Frémy 1930, *Arch. Bot [Caen] Mém.* 3: 156. Figs 30-33

Plant mass formed by entangled filaments, prostrated, expanded, thin, firm, brownish, dark green or blackish; filaments straight or curved, 5.5.-9.0 µm wide; sheath thin to relatively thick, rarely lamellate, hyaline; trichomes not constricted, 5.0-6.0 µm wide; cells 3.5-6.0(-9.0) µm long, 0.7 to 1.2 (-1.5) times longer than wide; cell content granulated, bright blue-green, chromatoplasm usually visible; apical cell rounded cylindrical, thickened outer membrane sometimes present.

Ecological data: n = 2, SAMA 26, SAMA 50; AT = 25.1-30.7ºC (27.9ºC), MT = 25.0-33.3ºC (29.1ºC), ARH = 55-90% (72.5%), MRH = 63-141% (102%), Ir = 4-2700 µmol.m^{-2}.s^{-1} (1352 µmol.m^{-2}.s^{-1}), PIr = 40-100% (70%), pH = 5, S = soil.

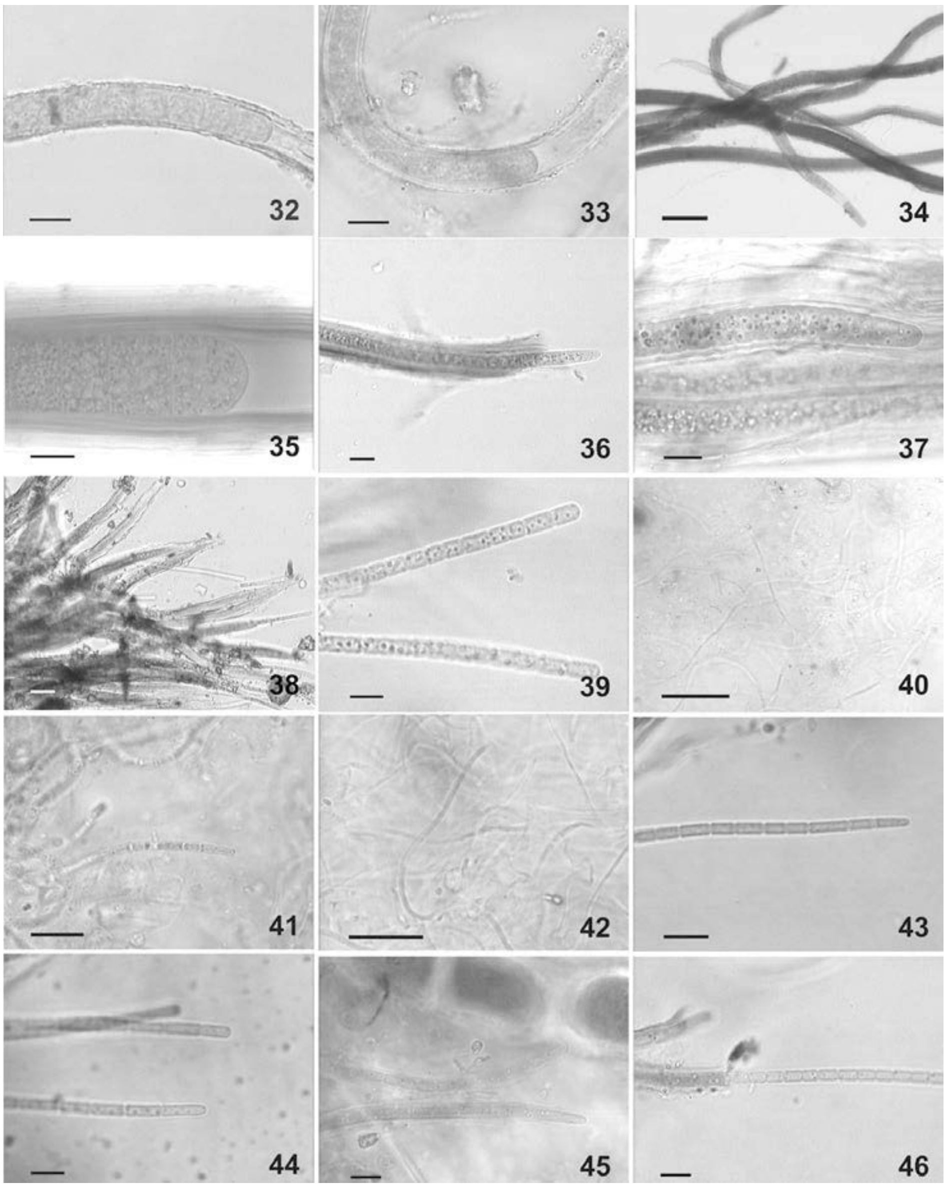
Note: The studied populations are morphologically very similar to *P. pachydermaticum* except for the apical cell which is slightly obtuse. The species has been recorded mainly in tropical aquatic environments but some aerophytic records are available.

Porphyrosiphon notarisii Kützing ex Gomont 1892, *Ann. Sci. Nat., Bot.*, ser 7, 15: 331. Figs 34-35

Plant mass formed by filaments grouped in loose bundles, prostrated, dark reddish brown to reddish; filaments (22.0-)28.0-34.0 µm wide; sheath thick, lamellate, containing up to two trichomes, sometimes coalescent, orangish red; trichomes predominantly not constricted, 11.0-15.0 µm wide; cells 5.0-11.0 µm long, 0.3 to 0.7(-0.9) times longer than wide; cell content granulated, light green; apical cell rounded cylindrical, hemispherical or rounded conical.

Ecological data: n = 1, SAMA 51; AT = 20.7ºC, MT = 26.5ºC, ARH = 80%, MRH = 93%, Ir = 380 µmol.m^{-2}.s^{-1}, PIr = 58%, pH = 5, S = soil.

Note: The characters of this population correspond very well to the description by Gomont (1892) of *P. notarisii*, including the habitat type. However, Komárek & Anagnostidis (2005) commented that this species, originally described from Italy, is typically subaerophytic on mountainous wetted rocks and that it probably has a cosmopolitan distribution in similar localities (e.g. Alps, Pyrenees, Himalayas, Andes). Although collected in a tropical region, our specimes was collected from



Figs 32-46. Cyanoprokaryote taxa from the rainforest region of São Paulo State, Brazil, light micrographs. **32-33.** *Phormidium pachydermaticum.* **34-35.** *Porphyrosiphon notarisii.* **36-37.** *Symplocastrum purpurascens*. **38-39.** *Symplocastrum selvaticum.* **40-41.** *Leptolyngbya orientalis*. **42.** *Leptolyngbya* sp. **43-44.** *Pseudanabaena* sp. **45-46.** *Schizothrix* cf. *minor* (Scale bars: Figs 32-33, 35, 37, 39, 41, 43-46 = 10 µm; Fig. 36 = 20 µm; Fig 38, 40, 42 = 50 µm; Fig. 34 = 100µm).

soil at an altitude of 1034 m a.s.l., which agrees well with the environment and habitat distribution originally described for this species.

Symplocastrum purpurascens (Gomont) Anagnostidis 2001, *Preslia* 73: 372. Figs 36-37

Plant mass formed by entangled filaments, prostrated, reddish brown; filaments sparsely branched, with up to 5 trichomes, 19.0-29.0 µm wide; sheath opened at the apex, rarely closed, lamellate, hyaline to reddish; trichomes constricted, occasionally slightly tapering to the apex, 6.0-7.0 µm wide; cells 4.0-7.5 µm long, 0.6 to 1.2 times longer than wide, predominantly shorter than wide; cell content granulated, blue-green; apical cell rounded (long) conical to rounded cylindrical.
Ecological data: n = 1, SAMA 41; AT = 23.8ºC, MT = 25.3ºC, ARH = 84%, MRH = 83%, Ir = 122 $\mu mol.m^{-2}.s^{-1}$, PIr = 74%, pH = 5, S = soil.
Note: This species is considered cosmopolitan and common in tropical areas.

Symplocastrum selvaticum Branco, Azevedo, Sant'Anna et Komárek 2006, *Algolog. Stud.* 121: 27. Figs 38-39

Plant mass composed of entangled filaments forming erect bundles, up to 2 mm high, dark red to orange-red; filaments branched, with up to 2-3 trichomes, commonly only 1 trichome, 12.0-19.0 µm wide; sheath closed at the apex, lamellate, hyaline to orangish red; trichomes constricted, 3.2-3.6 µm wide; cells 3.6-6.0 µm long, 1.1 to 2.0 times longer than wide; cell content granulated, chromatoplasm usually visible, blue-green; apical cell rounded cylindrical.
Ecological data: n = 2, SAMA 21, SAMA 33; AT = 27,0-30.6ºC (28,8ºC), MT = 26,5-38.4ºC (32,4ºC), ARH = 65-67% (66%), MRH = 70-71% (70%), Ir = 1900-2740 $\mu mol.m^{-2}.s^{-1}$(2320 $\mu mol.m^{-2}.s^{-1}$), PIr = 100%, pH = 4 (4), S = rock, soil.
Note: Records of *S. selvaticum* are still restricted to the Atlantic rainforest in Brazil but its distribution is probably wider in tropical area of the world.

PSEUDANABAENACEAE

Leptolyngbya valderiana (Gomont) Anagnostidis et Komárek 1988, *Algolog. Stud.* 50-53: 393. Figs 40-41

Filaments densely entangled among other algae, 2.0-3.5 µm wide; sheath relatively thick, hyaline; trichomes not constricted, 1.0-2.0 µm wide; cells 4.0-8.8(-9.6) µm long, 2 to 6 times longer than wide, with 1 large granule on each side of the septum; cell content homogeneous, pale blue-green; apical cell rounded cylindrical.
Ecological data: n = 7, SAMA 04, SAMA 06, SAMA 28, SAMA 35, SAMA 36, SAMA 37, SAMA 53; AT = 19.6-27.7ºC (23.7ºC), MT = 18.3-24.0ºC (21.3ºC), ARH = 73-83% (75%), MRH = 75-88% (80%), Ir = 35-330 $\mu mol.m^{-2}.s^{-1}$ (156 $\mu mol.m^{-2}.s^{-1}$), PIr = 5-48% (26%), pH = 4-5 (4.4), S = rock.
Note: Records of *L. valderiana* are relative to very diverse habitats in temperate and tropical areas, and aquatic and aerophytic habitats.

Leptolyngbya sp. Fig. 42

Plant mass composed ofdensely entangled filaments, expanded, very consistent gelatinous, reddish brown to dark green; filaments flexuous, 1.0-1.2 µm wide; sheath hyaline; trichomes constricted, 0.8-1.2 µm wide; cells 2.8-4.8 µm long,

2.8 to 4.8 times longer than wide; cell content granulated, pale blue-green; apical cell rounded cylindrical.
Ecological data: n = 1, SAMA 51; AT = 20.7ºC, MT = 26.5ºC, ARH = 80%, MRH = 93%, Ir = 380 µmol.m^{-2}.s^{-1}, PIr = 58%, pH = 5, S = soil.
Note: The closest described species is *L. perelegans*, but there are several differences in size, qualitative characters and ecology.

Pseudanabaena sp. Figs 43-44

Trichomes isolated or few together among other cyanoprokaryotes, constricted, slightly tapering to the apex, 1.9-2.0 µm wide; cells 5.0-7.0 µm long, 2.5 to 3.5 times longer than wide; cell content granulated, blue-green; apical cell long rounded to pointed cylindrical.
Ecological data: n = 1, SAMA 44; AT = 19.6ºC, MT = 19.1ºC, ARH = 82%, MRH = 25%, Ir = 25 µmol.m^{-2}.s^{-1}, PIr = 66%, pH = 5, S = tree bark.
Note: This population is morphologically and morphometrically very close to *P. catenata* Lauterborn but it is ecologically distinct since the latter species occurs in aquatic biotopes.

SCHIZOTHRICACEAE

Schizothrix cf. ***minor*** (Gardner) Anagnostidis 2001, *Preslia* 73: 368. Figs 45-46

Filaments isolated or in small groups among other algae, sparsely branched, with up to 2 or 3 trichomes, mostly with only one trichome, 3.5-7.5 µm wide; sheath opened or closed at the apex, lamellate in older filaments, hyaline to orangish red; trichomes constricted, 1.5-2.5(-3.0) µm wide; cells 3.0-7.5(-8.5) µm long, 1.7 to 3.5(-4.2) times longer than wide; cell content homogeneous with some prominent dark granules, blue-green; apical cell rounded conical to rounded cylindrical.
Ecological data: n = 6, SAMA 02, SAMA 22, SAMA 23, SAMA 24, SAMA 34, SAMA 37; AT = 21.8-27.7ºC (26.0ºC), MT = 20.6-36.0ºC (27.8ºC), ARH = 55-74% (66%), MRH = 62-81% (72%), Ir = 280-1900 µmol.m^{-2}.s^{-1} (1003 µmol.m^{-2}.s^{-1}), PIr = 34-100% (71%), pH = 4 (4), S = rock and soil.
Note: Although the Brazilian specimens are very similar to the original description there are differences in filament width and cell length/width ratio (15-20 µm and up to two times as long as wide, respectively). Brazilian populations are close to the description and illustrations of New Caledonian populations presented by Couté *et al.* (1999) as *Scytonema thelephoroides* var. *minor* Gardner.

DISCUSSION AND CONCLUSIONS

The orders Oscillatoriales and Chroococcales were represented by 12 specific taxa each. Synechococcaceae, with eight infra-generic taxa, was the richest family in terms of number of species, whereas the most diverse genus was *Aphanothece*, with four species.

The observed species richness of taxa within the cyanoprokaryote orders corresponded to the pattern found by other authors (Sant'Anna, 1984; Hoffmann, 1986). However, they considerably differ from the results obtained by Couté *et al.*

(1999). It is possible that these patterns are dependent on local environmental conditions or particular sampling methodologies and design.

Several taxa could not be identified unambiguously down to species level and therefore they were designated with “cf.”. In most of these cases, the main differences from the typical form of the species were relative to ecological features and/or geographical distribution. Some recorded populations may represent new taxa but more detailed studies are needed in order to investigate this possibility.

Komárek & Anagnostidis (2000, 2005) emphasized the need for a consideration of environmental and geographical characteristics in the identification process. During the present study work this suggestion was followed in order to facilitate identification. However, it is still very difficult to ensure that two identical (or very similar) morphotypes belong to distinct taxa only because there is some deviation from the type habitat. The central problem is that it is still unclear if identical genotypes can withstand distinct environmental pressures or conditions without phenotypic changes, and how extensively distributed they are biogeographically. According to Komárek (1994), the idea that the occurrence of most species is ubiquitous ought to be discarded.

Molecular and other modern approaches might help to clarify some aspects of morphological variation and ecological/geographical distribution in the cyanoprokaryotes. However, biodiversity studies are still needed, especially in tropical areas and special biotopes. It is to be hoped that the results of these investigations will contribute to a better understanding knowledge of this important group of organisms.

Acknowledgements. The authors are indebted to FAPESP (04/12494-9), CNPq (500252/2003-3, 307243/2006-0, 502044/2004-7 and fellowships to JPT and JCMF) and CAPES (fellowship to VF). We are also grateful to the referees for their comments, corrections and suggestions.

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