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Corticolous cyanobacteria from tropical forest remnants in northwestern São Paulo State, Brazil[1]

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ABSTRACT – (Corticolous cyanobacteria from tropical forest remnants in northwestern São Paulo State, Brazil). Cyanobacteria are common in aquatic environments but are also well-adapted to terrestrial habitats where they are represented by a diversified flora. The present study aimed to contribute to our taxonomic knowledge of terrestrial cyanobacteria by way of a floristic survey of the main components of corticolous communities found in seasonal semideciduous forest fragments. Samples of visible growths of Cyanobacteria, algae, and bryophytes found on tree bark were randomly collected and their taxonomies examined. Eighteen species of Cyanobacteria were found belonging to the genera *Aphanothece, Chroococcus, Lyngbya, Phormidium, Porphyrosiphon, Hapalosiphon, Hassalia, Nostoc, Scytonema,* and *Stigonema*. Many genera and species observed in the present work have been reported in previous surveys of the aerophytic flora in several regions of the world, although six species were described only on the basis of populations found in the forest fragments studied, which highlights the importance of taxonomic studies of cyanobacteria in these habitats.

Key words - aerophytic environment, Cyanobacteria, seasonal semidecidous forest

INTRODUCTION

Cyanobacteria are among the most widely distributed photosynthetic organisms in the world but they are still poorly understood (López-Bautista et al. 2007), especially in light of their significant roles in community succession (Gerrath et al. 2000), nitrogen fixation, and toxin production (Gaylarde et al. 2005).

These organisms are quite diverse and abundant in aquatic environments (Sant'Anna 1984) but can also occur in terrestrial habitats on a variety of substrates such as rocks, in soils (Jaag 1945), and on tree bark (Desikachary 1959), and they are especially abundant in tropical regions (Nienow 1996).

Many terrestrial environments are considered extreme due to their very limited water resources or their very low or very high temperature and light levels – and in order to survive under frequent dry/rehydration cycles (Whitton 1992) and/or high UV levels (Garcia-Pichel et al. 1992, Matsunaga et al. 1993, Chazal & Smith 1994) many terrestrial cyanobacteria display distinct physiological and morphological adaptations. According to Hoffmann (1989), terrestrial cyanobacteria can be classified by their habitats of occurrence and can be defined as edaphic (soil inhabiting), lithophilic (rock inhabiting), epiphytic (growing on plants), or epizoic (growing on animals). Edaphic, lithophilic and epiphytic organisms are considered very common elements in tropical environments.

The algal and cyanobacterial flora of edaphic habitats have been relatively well studied as compared to other terrestrial habitats (Hoffmann 1989) and soils have been found to host a diverse and rich microbiota in addition to the microflora associated with other organisms such as lichens, bryophytes, and fungi (Büdel et al. 2002). Epilithic floras occur on exposed surfaces in different parts of the world under different climatic conditions but, in spite of being well-adapted, they show little diversities (Hoffmann 1989).

The epiphytic microflora that develops on the bark (corticolous) or leaves (epiphylic) of flowering plants are still generally very poorly known, especially in tropical regions, even though they show evidence of high taxonomic richness and possible biodiversity losses due to habitat degradation (López-Bautista et al. 2007).

There have been several studies on cyanobacteria from terrestrial environments in Brazil, including contributions by Sant'Anna (1984) who investigated the microflora associated with bryophytes in Minas Gerais State, Azevedo (1991) who studied edaphic organisms in the São Paulo Botanical Garden, Sant'Anna et al. (1991) in Ubatuba (SP), and Büdel et al. (2002) who carried out a survey on inselbergs in the Atlantic rainforest of eastern Brazil. Branco et al. (2006a, b), Sant'Anna et al. (2007), and Branco et al. (2009) have published more recent studies of the microflora of São Paulo State.

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The present paper aims to contribute to our knowledge of the diversity of aerophytic cyanobacteria based on studies of the more frequent morphotypes present in corticolous communities found in seasonal semideciduous forest fragments. This study is part of a wider project dealing with the taxonomic composition of the fauna and flora found in forest remnants.

MATERIAL AND METHODS

Field work was carried out in 18 fragments of seasonal semideciduous forest located in the northwestern region of São Paulo State (A1 to A18; table 1) during the rainy season between March and May/2007, which is considered the most favorable period for the growth of corticolous organisms (Lemes-da-Silva et al. 2010a). Visible growths of cyanobacteria, algae, and bryophytes were gathered from plant bark, and approximately 1800 samples were analyzed. Detailed descriptions of the collection and preservation methods, as well as the characteristics of study areas can be found in Lemes-da-Silva et al. (2010a).

Taxonomic descriptions, photomicrographs, species occurrences in the study fragments, as well as taxonomic comments are provided for the species studied. The following abbreviations were used in the species descriptions: diam. (diameter) and L/D (the relationship of cell length/diameter). Minimum and maximum values are indicated in parenthesis. The classification system according to Hoffmann et al. (2005) was adopted.

Representative samples of populations of each species were deposited in the SJRP herbarium (IBILCE/UNESP – São José do Rio Preto) and their record numbers are presented together with the species distributions.

RESULTS

Eighteen species of Cyanobacteria belonging to the orders Chroococcales (five species, two genera), Oscillatoriales (four species, three genera), and Nostocales (nine species, five genera) were encountered in the forest remnants.

Order Chroococcales
Aphanotece Nägeli, 1849.

Taxonomic key for identification of the *Aphanothece* species found in the remnant fragments studied. Species descriptions according to Lemes-da-Silva et al. (2010b). All of the species were originally described on the basis of samples collected in this study.

Table 1. Localization and total area of the forest fragments sampled.

Fragment	Municipality	Latitude (S)	Longitude (W)	Area (ha)
A1	Novo Horizonte	21°31’15”	49°17’41”	635.0
A2	Sales	21°24’17”	49°30’01”	1799.6
A3	Planalto	21°00’05”	49°58’26”	207.5
A4	União Paulista	20°55’16”	49°55’34”	230.4
A5	São João de Iracema	20°28’25”	50°17’36”	1656.2
A6	Onda Verde	20°32’37”	49°14’47”	1359.7
A7	Barretos	20°29’05”	48°49’21”	597.3
A8	Bebedouro	20°53’06”	48°32’26”	393.9
A9	Matão	21°37’14”	48°32’14”	2189.6
A10	Vicentinópolis	20°55’34”	50°20’55”	128.2
A11	Macaubal	20°44’34”	49°55’45”	66.8
A12	Votuporanga	20°30’52”	50°05’12”	112.6
A13	Turmalina	20°00’13”	50°26’02”	108.3
A14	Palestina	20°17’18”	49°30’01”	117.1
A15	Palestina	20°19’16”	49°30’17”	95.5
A16	Barretos	20°38’14”	48°45’06”	90.7
A17	Taquaritinga	21°24’08”	48°41’14”	57.6
A18	Pindorama	21°13’12”	48°55’04”	108.8

Key to the identification of the *Aphanothece* species:

1. Cells ≥ 6.0 µm diam. ..... *A. excentrica*
1. Cells < 6.0 µm diam. 2

2. Cells > 3.2 µm diam. ..... *A. coacervata*
2. Cells ≥ 3.2 µm diam. 3
3. Cells densely aggregated in the center of the colony, blue-green, colonial margin wide, colonial mucilage yellowish-brown ..... *A. densa*
3. Cells aggregated, distributed throughout the entire colony, usually violet, colonial margin narrow, colonial mucilage hyaline, rarely reddish ..... *A. vaginata*

Aphanothece coacervata Lemes-da-Silva et al., Acta Bot. Bras. 24(4): 917, 2010.
Figure 1

Colonies microscopic, spherical or cylindrical; cells densely arranged, distributed throughout the entire colony; colonial sheath hyaline, margin well-defined; cells cylindrical, 3.2-4.8 µm long, (1.6-)2.4-3.2 µm diam., L/D 1.2 to 1.7(-2.0); cell contents homogeneous, light-green to brownish.

Occurrence: A7, A8, A9, A12 (SJRP 28278), A14 and A18.

Aphanothece densa Lemes-da-Silva et al., Acta Bot. Bras. 24(4): 917, 2010.
Figure 2

Colonies microscopic, spherical; cells densely agglomerated in the center of the colony; colonial sheath yellowish-brown, margin well-defined, wide; cells cylindrical, 4.0-7.0 µm long, 4.0-5.0 µm diam., L/D 1.0 to 1.7; cell contents homogeneous, blue-green.

Occurrence: A2, A5, A7, A8, A9, A10, A12 (SJRP 28276), A13 and A18.

Aphanothece excentrica Lemes-da-Silva et al., Acta Bot. Bras. 24(4): 918, 2010.
Figure 3

Colonies microscopic, spherical; cells densely arranged, distributed throughout the entire colony; colonial sheath hyaline, margin well-defined; cells cylindrical, 7.2-8.8(-10.8) µm long, (5.6-)6.4-7.2 (-8.0) µm diam., L/D 1.1 to 1.5; cell contents granular, green or grayish-green; some cells with individual, reddish, asymmetrical, granular sheath.

Occurrence: A12 (SJRP 28279), A13 and A18.

Aphanothece vaginata Lemes-da-Silva et al., Acta Bot. Bras. 24(4): 920, 2010.
Figure 4

Colonies microscopic, spherical to cylindrical, cells densely arranged, distributed throughout the entire colony; colonial sheath hyaline, rarely reddish, margin well-defined; cells cylindrical, (4.8-)5.6-7.2(-8.0) µm long, (3.2-)4.0-4.8(-6.0) µm diam., L/D 1.2 to 1.6; cell contents homogeneous, green to violet.

Occurrence: A12 (SJRP 28280).

Chroococcus Nägeli, 1849.
Chroococcus helveticus Nägeli, Neue Denks. der Allg. Schweiz. Gesells. für die Gesam. Naturwiss. 10(7): 46, 1849.
Figure 5

Colonies microscopic, in groups of two to four cells; colonial sheath hyaline; cells usually hemispherical, rarely spherical, (4.8-)6.4-7.2 µm long, (6.4-)7.2-8.8 µm diam., L/D 0.6 to 1.0; cell contents homogeneous, grayish-blue.

Occurrence: A7 (SJRP 29701) and A9.

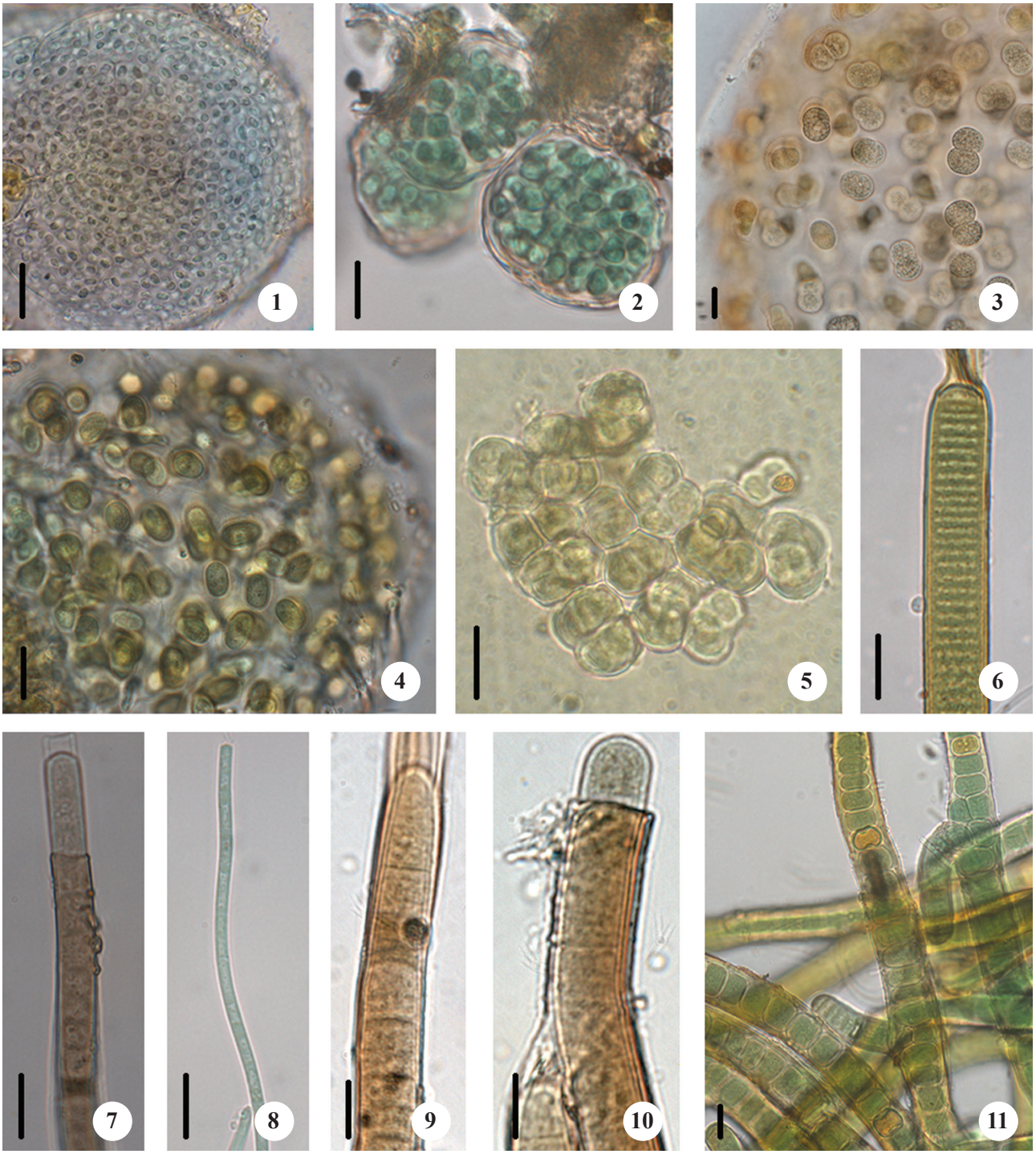
Comments: The populations observed correspond to the descriptions and figures presented by Komárek & Anagnostidis (1998). This species was reported as subaerophytic and probably cosmopolitan.

Order Oscillatoriales
Lyngbya Gomont, 1892.
Lyngbya cf. *truncicola* Ghose, J. Linn. Soc., Bot. 46: 339, 1924.
Figure 6

Filaments entangled, straight, 10.0-12.0 µm diam.; sheath thin, hyaline, homogeneous; trichomes not constricted, 8.0-10.0 µm diam.; cells discoid, 1.5-2.0 µm long, L/D 0.18 to 0.25; apical cell conical-rounded; cell contents granulated, blue-green.

Occurrence: A2, A5, A9, A11, A12 and A13 (SJRP 29689).

Comments: According to Komárek & Anagnostidis (2005), *L. truncicola* has slightly larger dimensions than the specimens encountered, however the cell length/diameter ratio (0.2 to 0.3) and the habitat of occurrence (tree bark) are both similar to those observed for the cyanobacteria populations in the forest fragments. If this species identification is confirmed, it will represent the first recorded occurrence of this species in Brazil.



Figures 1-11. 1. *Aphanothece coacervata*. 2. *A. densa*. 3. *A. excentrica*. 4. *A. vaginata*. 5. *Chroococcus helveticus*. 6. *Lyngbya* cf. *truncicola*. 7. *Phormidium arboricola*. 8. *P.* cf. *corium*. 9-10. *Porphyrosiphon notarisii*. 11. *Hapalosiphon santannae*. (bar = 10 µm)

Phormidium Gomont, 1892.

Key to the identification of the *Phormidium* species:

Trichomes (7.0-)9.0-10.0 µm diam. ..... *P. arboricola*
Trichomes 3.0-4.0 µm diam. ..... *P.* cf. *corium*

Phormidium arboricola Lemes-da-Silva et al., Acta Bot. Bras. 24(4): 920, 2010
Figure 7

Filaments isolated or in small aggregates of entangled filaments; filaments slightly wavy, (8.0-)10.0-12.0 µm diam.; sheath thin, hyaline to brown, homogeneous; trichomes not constricted, (7.0-)9.0-10.0 µm diam.; cells cylindrical, (6.0-)8.0-10.0 µm long, L/D 0.6 to 1.0(-1.42); apical cell conical-rounded; cell contents homogeneous, grayish-green.

Occurrence: A1, A2, A4, A5 (SJRP 28277), A7, A9, A11, A12, A13, A15, A16 and A18.

Comments: This species was originally described based on populations encountered during the present study.

Phormidium cf. *corium* Gomont, Ann. Sci. Nat. bot., sér. 7, 16: 172, 1892.
Figure 8

Filaments entangled, slightly wavy, blue-green, 4.0-6.0 µm diam.; sheath thin, hyaline, homogeneous; trichomes not constricted, 3.0-4.0 µm diam.; cells cylindrical, 4.0-5.0(-6.0) µm long, L/D (0.8-)1.0 to 1.25(-1.67); apical cell conical-rounded; cell contents homogeneous.

Occurrence: A2, A5, A6, A7, A8, A9, A11, A12, A13 (SJRP 29688), A14, A15, A16, A17 and A18.

Comments: *Phormidium corium* was first described by Gomont (1892) based on populations occurring in aquatic and terrestrial environments. This taxon was reported occurring in Brazil in marine and brackish water environments (Sant'Anna et al. 1985, Branco et al. 1997, Crispino & Sant'Anna 2006), but these identifications probably do not correspond to this species due to the habitat occupied. This taxon probably represents a species-complex, and a taxonomic review will be necessary to clarify its morphological and ecological distinctions.

Porphyrosiphon Kützing ex Gomont, 1892.
Porphyrosiphon notarisii Kützing ex Gomont, Ann. Sci. Nat. bot., sér. 7, 15: 331, 1892.
Figures 9-10

Filaments entangled, 12.0-16.0 µm diam.; sheath red to brown, lamellate; trichomes not constricted, (9.0-)10.0-12.0 µm diam.; cells cylindrical, (6.0-)8.0-10.0 µm long, L/D (0.5-)0.7 to 0.8(-1.0); apical cell conical-rounded; cell contents granular, blue-green.

Occurrence: A7, A13 (SJRP 29697), A14, A15 and A18.

Comments: According to Komárek & Anagnostidis (2005), *Porphyrosiphon notarisii* occurs in aerophytic environments and is probably cosmopolitan. This taxon was previously encountered in tropical regions such as New Caledonia (Couté et al. 1999, on soil and tree bark), and Brazil (Sant'Anna & Azevedo 1995, on rocks; Branco et al. 2009, on soil).

Order Nostocales
Hapalosiphon Nägeli ex Bornet & Flahault, 1886.
Hapalosiphon santannae Lemes-da-Silva et al., Acta Bot. Bras. 24(4): 920, 2010.
Figure 11

Filaments entangled forming caespitose tufts, blue-green; filaments 16.0-20.0 µm diam.; true T-branching abundant, 1-3 in each thallus; main and lateral filaments of similar widths, lateral branches up to 30 cells long; young parts of the sheath hyaline, older parts yellowish, homogeneous, 1.0-1.7 µm diam.; trichomes constricted, 1 to 2 rows of cells, 12.0-14.0(-18.0) µm diam.; cells cylindrical, 8.0-12.0 µm long, L/D 0.6 to 0.8; cell contents homogeneous, blue-green; heterocytes rounded, intercalary, or lateral, (8.0-)10.0-12.0 µm long, (12.0-)14.0-16.0 µm diam.

Occurrence: A3 (SJRP 28275).

Comments: This species was originally described on the basis of the populations found during the present study.

Hassallia Berkeley ex Bornet & Flahault, 1887.
Hassallia byssoidea Bornet & Flahault, Ann. Sci. Nat. bot., sér. 7, 5: 116, 1887.
Figure 12

Caespitose plant mass, blue-green; filaments entangled, 8.0-10.0(-12.0) µm diam.; false-branches unilateral, usually with heterocyte at base; sheath thin, hyaline, homogeneous; trichomes mainly constricted, sometimes not constricted, 8.0-12.0 µm diam.; meristematic zone present at the apex of the trichomes; cells cylindrical, 6.0-8.0(-10.0) µm long, L/D (0.28-)0.50 to 0.75(-1.0); cell contents homogeneous; heterocytes rounded to spherical, basal and intercalary, rarely in rows, (4.0-)6.0-8.0(-10.0) µm long, 6.0-8.0 µm diam..

Occurrence: A2, A4, A5, A7, A8, A10, A12, A13 (SJRP 29691), A15, A16 and A18.

Comments: Bornet & Flahault (1887) described *Hassalia byssoidea* based on populations found in aerophytic environments (tree bark) and the dimensions recorded were very close to those observed in the populations found in the present work. Sant'Anna

(1988) countered this species living on tree bark in urban environments in São Paulo State (Brazil).

Nostoc Vaucher ex Bornet & Flahault, 1886.
Nostoc sp.
Figure 13

Colonies gelatinous, microscopic, spherical or ovoid, 80.0-180.0 µm diam., grouped among mosses, algae, and other cyanobacteria; filaments 15-23 celled, densely entangled; cells rounded, 4.0-10.0 µm diam., 4.0-8.0(-10.0) µm long, L/D 0.67 to 1.0; cell contents homogenous; heterocytes rounded, intercalary or terminal, 6.0-10.0(-12.0) µm diam., 6.0-10.0 µm long; akinetes not observed.

Occurrence: A2, A5, A8, A10, A11, A12, A13 (SJRP 29690), A14, A16 and A18.

Comments: The populations encountered were similar to *Nostoc microscopicum* Carm. ex Bornet & Flahault, however its species identification cannot be confirmed as akinetes were not observed. Most colonies were infected by fungi, which often alter the colony morphology (e.g. flat colonies) and trichome structure (e.g. true-branched trichomes).

Scytonema Agardh ex Bornet & Flahault, 1886.

Key to the identification of the *Scytonema* species:

1. Filaments ≥ 16.0 µm diam. ..... *Scytonema* sp.
1. Filaments < 16.0 µm diam. 2
   2. Filaments < 10.0 µm diam. ..... *S.* cf. *hofmanni*
   2. Filaments ≥ 10.0 µm diam. 3
3. Filaments in erect fascicles, trichomes constricted ..... *S. javanicum*
3. Filaments prostrate, trichomes not constricted ..... *S. ocellatum*

Scytonema cf. *hofmannii* Agardh ex Bornet & Flahault, Ann. Sci. Nat. bot., sér. 7, 5: 97, 1887.
Figures 14-15

Filaments isolated or in small aggregates, prostrate, 8.0-9.0(-10.0) µm diam.; double and single false-branches rare; sheath thin, hyaline, homogenous; trichomes predominantly not constricted, 6.0-9.0 µm diam.; cells cylindrical, (3.0-)8.0-10.0 µm long, L/D 0.7 to 1.1(-1.4); cell contents granular, bluish-green; heterocytes cylindrical, intercalary, 6.0-7.0 µm diam., 8.0-12.0 µm long.

Occurrence: A7, A8, A13 (SJRP 29700), A15 and A18.

Comments: The populations studied here were morphologically and ecologically similar to *S. hofmannii*. However, that species was described as having erect fascicles, differing from the prostrate growths observed in the populations studied here.

Scytonema javanicum Bornet & Flahault, Ann. Sci. Nat. bot., sér. 7, 5: 95, 1887.
Figures 16-17

Filaments forming erect fascicles, blue; filaments 12.0-16.0 µm diam.; double and single false-branches frequent; meristematic zone present at the apex of the trichomes; sheath thin, hyaline, homogenous; trichomes predominantly constricted, (8.0-)10.0-12.0 µm diam.; cells cylindrical, 6.0-10.0 µm long, L/D 0.6 to 0.8(-1.3); cell contents granular, bluish-green; heterocytes cylindrical or rounded, intercalary, (10.0-)12.0-14.0 µm diam., (6.0-)8.0-10.0(-14.0) µm long.

Occurrence: A1, A2, A4, A6, A7, A8, A9, A10, A11, A12, A13 (SJRP 29693), A14, A15, A16, A17 and A18.

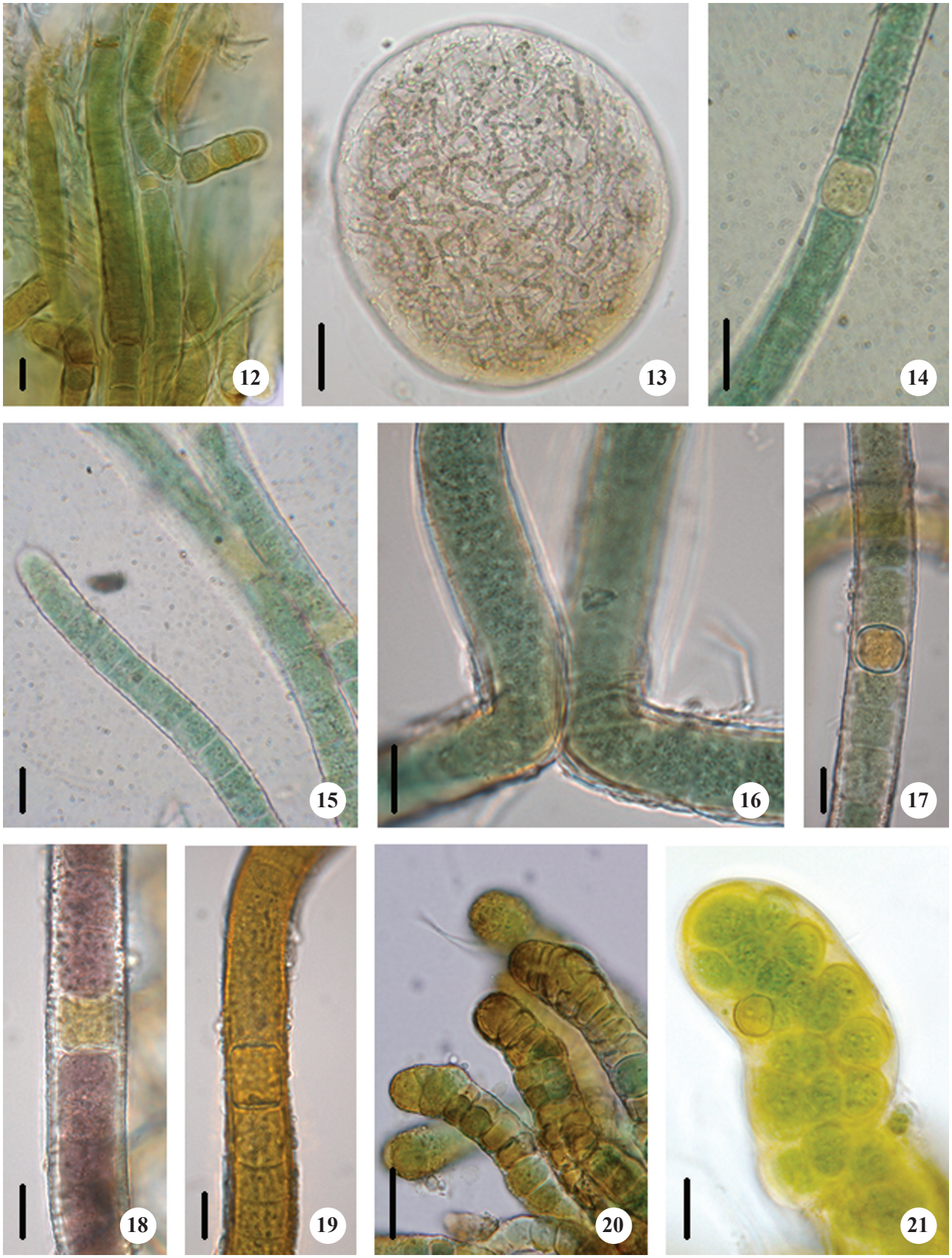
Comments: The populations studied correspond well (both morphologically and ecologically) to the descriptions of Bornet & Flahault (1887). The species had already been reported in Brazil (São Paulo Botanical Garden; Azevedo 1991, Azevedo et al. 1996).

Scytonema ocellatum Lyngbye ex Bornet & Flahaut, Ann. Sci. Nat. bot., sér. 7, 5: 95, 1886.
Figure 18

Filaments entangled, prostrate, reddish; filaments (12.0-)14.0-16.0(-18.0) µm diam.; double false-branches rare; meristematic zone present at the apex of the trichomes; sheath thin, hyaline, homogenous; trichomes not constricted, (10.0-)12.0-14.0 µm diam.; cells cylindrical, (6.0-)8.0-10.0 µm long, L/D 0.6 to 0.8; cell contents granular, reddish; heterocytes quadratic, 12.0-14.0(-16.0) µm diam., 12.0-14.0(-18.0) µm long.

Occurrence: A1, A2, A4, A5, A6, A7, A8, A9, A10, A11, A12, A13 (SJRP 29692), A14, A15, A16, A17 and A18.

Comments: The morphometric and ecological characteristics observed in the survey populations were



Figures 12-21. 12. *Hassalia byssoidea*. 13. *Nostoc* sp. 14-15. *Scytonema* cf. *hofmannii*. 16-17. *S. javanicum*. 18. *S. ocellatum*. 19. *Scytonema* sp. 20. *Stigonema hormoides* var. *constrictum*. 21. *S. ocellatum*. Bar = 10 µm (12-13, 15-19, 21); 20 µm (14-20).

similar to those reported in the original description of *Scytonema ocellatum* (Bornet & Flahault 1886). The species was first encountered in Brazil (São Paulo State) growing on rocks and wet walls among bryophytes, algae, and other cyanobacteria (Sant'Anna 1988). This species has also been reported in Brazil on inselbergs in the Atlantic rainforest (Büdel et al. 2002).

Scytonema sp.
Figure 19

Filaments isolated, prostrate, (16.0-)17.0-21.0 µm diam.; false-branches not observed; meristematic zone present at the apex of the trichomes; sheath thick, yellowish, homogenous; trichomes not constricted, (14.0-)15.0-18.0 µm diam.; cells cylindrical, 6.0-9.0(-11.0) µm long, L/D 0.3 to 0.6(-0.7); cell contents granular, bluish-green; heterocytes rounded, intercalary, abundant, 14.0-18.0 µm diam., 10.0-12.0(-15.0) µm long.

Occurrence: A4 and A12 (SJRP 29684).

Comments: The closest species to *Scytonema* sp. are *S. ocellatum*, *S. javanicum,* and *S. stuposum. Scytonema* sp. differs from *S. ocellatum* in terms of their L/D cell ratios and filament colors, and differs from *S. javanicum* by its dimensions, and the characteristics of its sheath and its habit. The presence of deep constrictions in the trichomes of *S. stuposum* and the absence of constrictions in *Scytonema* sp. separate these two species. Additional observations will be required to improve the species identification.

Stigonema Agardh ex Bornet & Flahault, 1886

Key to the identification of the *Stigonema* species:

1. Filaments 8.0-12.0 µm diam., trichomes 1-2 rows of cells ..... *S. hormoides* var. *constrictum*
1. Filaments 30.0-40.0 µm diam., trichomes 1-4 rows of cells ..... *S. ocellatum*

Stigonema hormoides var. *constrictum* Gardner, Mem. New York Bot. Garden 7: 87, 1927.
Figure 20

Thallus caespitose, reddish; filaments entangled, 8.0-12.0 µm diam.; true branches irregular; main and lateral filaments with similar diameters; apex dilated, usually with three cells; sheath very thin, young parts hyaline and older parts yellowish, homogeneous; trichomes constricted, 1-2 rows of cells, 7.5-11.5 µm diam.; cells spherical or barrel-shaped, 4.0-8.0 µm long, L/D 0.6 to 0.75; cell contents granular, green; heterocytes spherical, cylindrical, or subquadratic, 2.2-5.1 µm diam., 4.5-6.6 µm long, L/D 0.1-1.3, lateral; hormogones lateral.

Occurrence: A9 and A13 (SJRP 29698).

Comments: *Stigonema hormoides* is characterized by small-diameter filaments with few rows of cells (1-2; usually 1) and the variety *constrictum* has short filaments, constricted trichomes, and thin sheaths that become colored when senescent (Gardner 1927). This species was reported for Brazil by Silva & Sant'Anna (1996) and Büdel et al. (2002), but this is the first recorded occurrence of the variety *constrictum* for Brazil.

Stigonema ocellatum (Dillwyne) Thuret ex Bornet & Flahault, Ann. Sci. Nat. bot., sér. 7, 5: 69, 1887.
Figure 21

Filaments isolated or in small groups, prostrate, green; filaments (26.0-)30.0-40.0(-52.0) µm diam.; main filaments with three to four rows of cells, lateral filaments with one to two rows of cells; young parts of sheath hyaline, older parts yellowish, homogeneous; cells spherical to ovoid, 10.0-16.0(-18,0) µm diam., 10.0-14.0 (-16.0) µm long, L/D 0.7-1.0; cell contents granular, green; heterocytes spherical, intercalary, or lateral; 6.7-8.5 µm diam., hormogones lateral.

Occurrence: A2, A7, A8, A9, A10, A11, A12 (SJRP 29683), A13, A15 and A18.

Comments: the dimensions and ecological characteristics of the study populations agree with the descriptions of *S. ocellatum* by Bornet & Flahault (1887) and Geitler (1932). This species was previously found in Brazil (São Paulo State) in stream, swamp, lake, and wet-rock wall environments (Silva & Sant'Anna 1996).

DISCUSSION

Eighteen species of corticolous Cyanobacteria were recorded in the present study and three of them, *Chroococcus helveticus*, *Lyngbya* cf. *truncicola* (if this identification is confirmed), and *Stigonema hormoides* var. *constrictum* are new records for Brazil. Six new corticolous cyanobacteria (*Aphanothece excentrica*, *A. coacervata*, *A. densa, A. vaginata*, *Phormidium arboricola,* and *Hapalosiphon santannae*) were described by Lemes-da-Silva et al. (2010b) in the same remnant forest areas in northwestern São Paulo State.

The species richness found in this study was higher than in other tropical areas. Neustupa & Škaloud (2008) studied cyanobacterial and corticolous algal communities in tropical mountain habitats in Indonesia and found eight filamentous cyanobacteria species. More recently, Neustupa & Škaloud (2010) found 12 cyanobacteria species on tree bark in tropical forests in Singapore, mainly filamentous organisms (as was observed in the present study).

Many species and genera encountered in this study were reported in surveys in several regions around the world. In Africa, Frémy (1930) encountered *Tolypothix byssoidea* (= *Hassallia byssoidea*) and *Scytonema javanicum* on tree bark, while Büdel et al. (1997) recorded *Nostoc*, *Scytonema,* and *Stigonema* on inselbergs. In Brazil, Azevedo (1991) reported *Scytonema javanicum*, *Hassallia*, *Phormidium,* and *Nostoc* in soils from Botanical Garden of São Paulo, and Büdel et al. (2002) found species of *Scytonema* and *Stigonema* on inselbergs in the Atlantic rainforest. Genera such as *Aphanothece, Phormidium, Nostoc,* and *Scytonema* were reported occurring on tree bark by Neustupa & Škaloud (2008).

Cyanobacteria are well-adapted to survival in terrestrial environments due to several mechanisms, such as their thick and lamelated sheaths that improve drought resistance (Bharadwaja 1933, Flechtner 2007). Some cyanobacteria, such as species of *Scytonema* and *Nostoc,* can produce pigments (such as scytonemin) in their sheaths that protect them from the harmful effects of excess solar radiation (Garcia-Pichel & Castenholz 1991). Other cyanobacteria accumulate disaccharides, which act like compatible solutes, to keep their cell proteins hydrated even during periods of water stress (Flechtner 2007).

Another important characteristic for the successful growth of cyanobacteria under aerophytic conditions is there tenacious reproduction, which can occur under low moisture conditions by way of hormogones or by simple division (Sant'Anna 1984). Akinetes and heterocytes are also important in terrestrial environments because they are able to remain dormant for long periods of time and can germinate when environmental conditions are suitable to filament development (Bourrely 1970).

Although Cyanobacteria are among the most abundant organisms of the terrestrial flora they are still poorly known, due, in part, to the difficulties encountered in using morphological characters to identify their species (López-Bautista et al. 2007). This survey added new records to the Brazilian cyanobacterial flora as well as new species (Lemes-da-Silva et al. 2010b), supporting the view that Cyanobacteria from aerophytic environments are still poorly known.

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