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Subaerial nonheterocytous and heterocytous cyanobacteria from Sirsi taluk, Uttara Kannada, Karnataka, India.

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ABSTRACT

The present study focuses on the diversity of subaerial filamentous cyanobacteria including both nonheterocytous (order Oscillatoriales) and heterocytous forms (Nostocales and Stigonematales). Subaerial algal samples were collected from Sirsi taluk, Karnataka, India and a total of 59subaerial cyanobacteria were documented. Out of 59 subaerial cyanobacteria, maximum taxa belonged to the family Scytonemataceae (19 taxa) and minimum taxa belonged the families Rivulariaceae, Microchaetaceae and Hapalosiphonaceae (2 taxa each). Among heterocytous cyanoabcteria,*Scytonema hofmannii* and *S. varium* were the most frequently occurring taxa while among nonheterocytous cyanobacteria *i.e.* Oscillatoriales members*Leptolyngbya cataractarum* and *L. valderiana* were the dominant subaerial cyanobacteria in Sirsi taluk. Shannon-Wiener diversity index was used to calculate the diversity of these subaerial cyanobacteria in the study area. Camera lucida drawings have been given in support of the description of the taxa.

KEYWORDS: Cyanobacteria, Western Ghats, tropical climate, taxonomy.

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INTRODUCTION

Western Ghats are one of the 34 biodiversity hotspots worldwide. Sirsi taluk is located at the *Heart of Western Ghats* in Karnataka state, India. Tropical climate of Sirsi taluk like high rainfall and high humidity encourage the luxuriant growth of subaerial cyanobacteria.

Cyanobacteria originated in Precambrian era (~3.5 billion years ago) and are oxygenic photoautotrophs.Cyanobacteria are of particular interest as they were responsible for origin of life on this planet during "Great Oxidation Event" (~2.35 billion years ago).Present study focuses on diversity and occurrence of subaerial nonheterocytous and heterocyotus cyanobacteria. Nonheterocytous forms *i.e.* Oscillatoriales members represent heterogenous group of organisms while heterocytous cyanobacteria represent monophyletic lineage consisting of two orders Nostocales and Stigonematales (subsection IV and V of Bergey's Manual).

Ecologically, cyanobacteria are extremely diverse organisms and inhabit wide range of habitats. Also, subaerial cyanobacterial forms (aerophytic terrestrial algae which are not submerged or not present in the soil, but *only afterintermittent water supply*) have enormous morphological plasticity which is because of their adaptations to varying environmental conditions during the course of evolution. Varying morphological topologies of cyanobacteria make their identification extremely difficult (Komarek and Anagnostidis, 1998).

Very less published data is available on the study of diversity of subaerial cyanobacteria and algae in Karnatakaand particularly in Sirsi taluk. So there is need to explore maximum subaerial algal diversity before it becomes extinct because of extreme environmental stress in coming years. In this regard, present study focuses on the filamentous heterocytous and nonheterocytous cyanobacteria. Nonheterocytous cyanobacteria come under Oscillatoriales while heterocytous cyanobacteria correspond to monophyletic lineage which contains the orders Nostocales and Stigonematales .

MATERIALS AND METHODS

Study area

Sirsi taluk has a geographical extent of 1322 sq km in which 78.11% is occupied by forest land. It lies between 14^{o} 28′ and 14^{o} 51′ N latitudes and 74^{o} 34′ and 75^{o} 04′ E longitudes and at an elevation of 600 m above mean sea level. Climate of Sirsi taluk is tropical which has average temperature 27 ºC, average rainfall 3878.35 mm and humidity up to 100% [13].

Sample collection

Samples were collected in the premonsoon (January to April), monsoon (May to August) and postmonsoon (September to December) season in the year 2015 and 2016. Subaerial algal samples were collected randomly from six sampling sites (Bakkal, Karasulli, Mattigatta, Sahasralinga, Shivganga water fall forested area and urban area *i.e.* Sirsi city) of Sirsi taluk from different habitats including forested area near waterfalls and streams; areca nut plantation; botanical garden and urban areas. Subaerial algal samples were scrapped and collected with the help of knife in air tight sterile plastic bags from different natural (bark, stem, areca nut trunk and rocks) and artificial substrata (Cemented walls, pots, pipes).

Identification of Cyanobacteria

After collection, samples were taken to the laboratory and immediately transferred into vials and preserved in 4% formalin solution for further observation. Identification was done with the help of light microscope and camera lucida sketches were drawn using Rotring Isograph. Monographs used for identification of taxa are: Desikachary (1959)[14], Komárek (2013)[15], Komárek and Anagnostidis (2005).

Diversity of subaerial cyanobacteria: Shannon-Wiener Index

Shannon-Wiener diversity is widely used for diversity between different habitats[17]. Based on abundance of species, this diversity index was used to check the diversity in different habitats[18]. In present study, species diversity of cyanobacteria in Sirsi taluk was calculated using Shannon-Wiener diversity index[19] using the following formula:

$$H' = \sum_{i=1}^{s} \text{pi ln pi}$$

Where, H′ = diversity index; pi=ni/N; pi = proportion of taxa belonging to i^{th} morphotypic group; ni= number of individuals in the i^{th} species; N= total number of individual of all the species; ln pi = natural logarithm of pi. Diversity of members of different families in all the sampling sites was calculated and it was observed which sampling site was having more diversity of these organisms using Microsoft Excel 2007 software.

RESULTS

The present study was carried out to observe the diversity of subaerial filamentous cyanobacteria (both nonheterocytous and heterocytous forms) from the Sirsi taluk which covers some of the thick forested area of Western Ghats of Karnataka state, India. A total of 59 subaerial

filamentous cyanobacteria have been documented from different six sampling sites of Sirsi taluk. Out of 59 taxa, 28 belonged to Oscillatoriales; 26 taxa belonged to Nostocales and 5 taxa belonged to Stigonematales. This data indicates that there is not much difference in the diversity and occurrence of taxa belonging to the orders Oscillatoriales and Nostocales while Stigonematales members were very less frequently occurring or in other words, were less diverse.

In the order Oscillatoriales, taxa documented from the study area belonged to four families namely Pseudoanabaenaceae (8 taxa), Schizotrichaceae (4 taxa), Phormidiaceae (8 taxa) and Oscillatoriaceae (8 taxa). While in the order Nostocales, taxa documented from the study area belonged to four families namely Scytonemataceae (19 taxa), Rivulariaceae (2 taxa), Microchaetaceae (2 taxa) and Nostocaceae (3 taxa). On the other hand, only two families, Hapalosiphonaceae (2 taxa) and Stigonemataceae (3 taxa) belonged to Stigonematales. This data indicates that maximum taxa have been documented from the family Scytonemataceae (19 taxa) and minimum taxa have been documented from the families Rivulariaceae, Microchaetaceae and Hapalosiphonaceae (only 2 taxa each). Here, it can be concluded that tropical climate supports the growth of Scytonemataceae members in Sirsi taluk.

The most dominantly occurring subaerial cyanobacteria belonged to the genera *Leptolyngbya, Scytonema, Desmonostoc, Porphyrosiphon* and *Stigonema*. Species belonging to these commonly occurring genera were*Leptolyngbya cataractarum, L. valderiana, Porphyrosiphon notarisii, Scytonema varium, S. hofmannii, S. drilosiphon, S. pseudohofmannii, Stigonema minutum, Desmonostoc sp* and *D. muscorum*which were present in four or more than four sampling sites (out of total six sampling sites in Sirsi taluk).

Using the Shannon-Wiener index, diversity of filamentous heterocytous and nonheterocytous subaerial cyanobacteria was observed (**Figure 2**) and it was observed that, in the year 2015, Bakkal showed the maximum diversity with maximum Shannon – Wiener diversity index 5.35 which was followed by the Sahasralinga (diversity index 5.12) while minimum diversity of these cyanobacterial organisms was accounted in Mattigatta (diversity index 3.9). While, in the year 2016, it was observed that Sahasralinga had the maximum diversity with maximum diversity index 5.19 which was quite close to the diversity index in Sirsi city *i.e.* 5.16 while minimum diversity was documented from Karasulli (diversity index 3.4).

Subaerial filamentous cyanobacterial taxa documented from the study area are as follows:

Order Oscillatoriales

Family Pseudoanabaenaceae

1. **Leptolyngbya fallax (Hansgirg *ex* Forti)** Komárek& Anagnostidis(Plate 1, Figure 1)*Lyngbya fallax* Hansgirg *ex* Forti Filaments variously bent or straight, attenuated towards the ends, 3.9 µm - 4.5 µm wide; trichome very light green, slightly constricted; sheath colourless, thin, hyaline and diffluent; cells shorter than wide or up to isodiametric (?) with granular cell content, sometimes granulated cross walls, 3.1 µm x 1.5-3.1 µm; apical cell rounded.

2. Leptolyngbya cf gracillima (Zopf *ex* Hansgirg) Anagnostidis & Komárek (Plate 1, Figure 2)
Glaucothrix gracillima Zopf ex Hansgirg 1892*; Plectonema gracillima* (Zopf) Hansgirg 1885;?*Lyngbya gracillima* [Kützing] Hansgirg 1892
Filaments long, entangled, bent, 4.6 µm wide; sheath wide, fine, colourless, yellow unlamellated; trichome thin, blue green, 1.5 µm wide, not or slightly constricted; cells longer, 3.9-4.6 µm with homogenous content.

3. Leptolyngbya angustissima(W. *et* G. S. West) Anagnostidis &Komárek (Plate 1, Figure 3)
Phormidium angustissimum W. *et* G. S. West 1897, *Lyngbya angustissima* (W. et G. S. West) Iltis 1972Filaments long, thin, 1.5 µm wide; sheath not attached to trichome, colourless, unlamellated; trichome blue green, 0.7 µm wide, unconstricted; cells longer than wide, with ungranulated cross walls, ±1.5 µm long.

4. Leptolyngbya valderiana(Gomont) Anagnostidis *et*Komárek (Plate 1, Figure 4)*Phormidium valderianum* Gomont 1892, *Lyngbya valdriana* (Gomont) Compère 1974; *Phormidium valderiae* (Delponte) Schmidle 1901; incl. *Phormidium valderianum* f. medium Elenkin 1949?, P. *valderianum* f. *majus* Hollerbach 1934*?*, *P. valderianum* f. *circinata*Anagnostidis 1961, *P. valderianum* var. *tenuis* Voronichin 1923 (?).

Filament long, thin, mixed with other algae; sheath thin, colourless, unlamellated, hyaline, sometimes indistinguishable; trichome not constricted at the cross walls, not attenuated towards ends; cells blue green, mostly longer than wide with single granule at the cross wall, 2.3 µm x 1 µm; apical cell conical rounded or rounded.

5. Leptolyngbya compacta(Kützing *ex* Hansgirg) Komárek *et*Anagnostidis (Plate 1, Figure 5)
Lyngbya compacta [Kützing] Hansgirg *ex* Hansgirg 1892Filaments long, entangled, bent; sheath thin, firm, smooth, colourless, unlamellated; trichome blue green, slight constricted, 2.3 µm wide; cell isodiametric mostly, also slightly shorter or longer than wide, with homogenous content; apical cell rounded.

6. **Leptolyngbya cataractarum**(Rabenhorst *ex* Hansgirg) Komárek *et*Anagnostidis (Plate 1, Figure *Phormidium cataractarum* Rabenhorst 1853, *Lyngbya cataractarum* [Rabenhorst] Hansgirg *ex* Hansgirg 1892Thallus thick, mat like, dirty green; filaments long, grouped or entangled, sometimes

fasciculated, 4.7 µm wide; sheath thin, firm, colorless, unlamellated, closed at the ends; trichome green, deeply constricted and ungranulated cross walls, 2.8 µm wide, not attenuated; cells shorter, isodiametric, also longer than wide, on sides cell content dark colored; apical cell rounded; reproduction by hormogone.

7. Leptolyngbya sp1 Anagnostidis *et* Komárek (Plate 1, Figure 7)Filaments long, straight, with calcareous encrustation, 5.46 µm - 6.24 µm wide; trichome 2.9 µm wide, pale blue green, unconstricted and ungranulated at cross walls; sheath colourless; cells isodiametric or longer than wide, with granular or homogenous content; apical cell blunt or rounded.

8. Leptolyngbya sp2 Anagnostidis *et* Komárek (Plate 1, Figure 9)Filament long, thin, straight, ±3 µm wide; sheath colourless, very thin, hardly visible, unlamellated; trichome blue green, attenuated, bent or hooked at the ends, unconstricted or only slightly constricted; cells isodiametric or shorter with homogenous content; apical cell sharply pointed.

Family Schizotrichaceae

9. Schizothrix calcicola Gomont (Plate 1, Figure 10)*Oscillatoria calcicola* Agardh 1812, *Leptothrix calcicola* [Agardh] Kützing 1943, *Lyngbya calcicola* [Agardh] *ex* Hansgirg 1892]; *Schizothrix calcicola* var. *symplociformis* Hansgirg 1892, incl.

Filament long, densely entangled, no pseudobranched, ±1 µm wide (without calcium encrustations); sheath colourless, weakly or not lamellated, with 2-3 trichomes; trichome blue green, ±0.8 µm wide, unconstricted at granulated and translucent cross walls; cells longer than wide, ±3.9 µm long; apical cell cylindrical rounded.

10. Schizothrix lardacea Gomont (Plate 1, Figure 11-12)*Lyngbya rufescens* [Kützing] Kirchner *ex* Hansgirg 1892?

Thallus gelatinous, brownish green; filaments long, more than one filaments in colourless, 3.3 µm wide; sheath more or less lamellated, very thin; trichome blue green, unconstricted at sometimes granulated (single granule) cross walls, attenuated; cells longer than wide 1.2-3.1 µm x 1.2-1.5 µm; apical cell slightly narrowed or conical or rounded.

11. Schizothrix cf ericetorum Lemmermann (Plate 1, Figure 13)Filament long, many in one sheath, common sheath branched, yellow coloured with distinct lamellation and smooth; sheath of branching filament amorphous, diffluent, colourless, very wide with perpendicular lamellation, surface not smooth or yellow coloured; sheath is opened and in branching filaments sheath opened or closed but not conically pointed; trichome blue green, no or slight constriction; cell isodiametric to longer (in the middle), sometimes with single granule at cross walls, cell content granular or homogenous,

chloroplast parietal, 3.1-7.8 µm x 3.1-3.9 µm; apical rounded or rounded conical; reproduction by hormogone.

12. Trichocoleus sociatus Anagnostidis (Plate 1, Figure 15)Many filaments in common and colourless sheath, filaments fasciculated and entangled, with no sheath; sheath open at the ends and firm; cells longer, ungranulated and constricted, 4.5 µm x 2.8 µm; apical cell weakly conical

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Family Phormidiaceae

13. Phormidium cf puteale(Montagne *ex* Gomont) Anagnostidis *et*Komárek (Plate 1, Figure 8)

Lyngbya putealis Montagne *ex* Gomont 1892; *Lyngbya putealis* var. *minor* Geitler 1933 incl.; *Lyngbya putealis* f. *multigranulata* Prasad *et al.* 1978 incl.?Thallus blackish or brownish green, soft velvety; filaments entangled, straight or curved; sheath thin, diffluent, colourless and hyaline; trichome green or yellowish green with constrictions; cells shorter than wide up to isodiametric with slight homogenous content, 2.3-6.24 µm x 6.24 µm; apical cell rounded or conical rounded; reproduction by hormogone.

14. Phormidium kuetzingianum (Kirchner) Anagnostidis *et* Komárek (Plate 1, Figure 13)[*Phormidium obscurum* Kützing 1845]; *Lyngbya kuetzingiana* Kirchner 1878; incl. f. *symplociformis* (Hansgirg) Polanskij in Hollarbach *et al.* 1953Thallus compact mats, membranaceous, layered; filaments entangled, curved, 4.6-5.4 µm wide; sheath thin, firm, colourless; trichome blue green, 3.1 µm - 3.9 µm wide, unconstricted except at the ends; cells isodiametric, longer, cell content granular, sometimes granulations at the cross walls, 3.1-6.2 µm long; apical cell rounded, calyptra absent; reproduction by hormogone.

15. Phormidium ambiguum Gomont*ex* Gomont (Plate 2, Figure 1)*Lyngbya bourrellyana* Compère 1974Thallus blue green or dark green and rough; filament long; sheath thin, colourless, delimited; trichome bright blue green, not or unconstricted, 5.4 µm wide; cells distinctly shorter with granular content (granules at cross walls); apical cell rounded; capitates, sometimes with obtuse or round calyptra, reproduction by binary fission and by hormogone.

16. Phormidium aerugeneo-caeruleum (Gomont) Anagnostidis *et* Komárek (Plate 2, Figure 2)

Lyngbya aerugineo-coerulea Gomont 1892; *Lyngbya aerugineo-coerulea* f. *minor* Elenkin 1949 incl.; *Lyngbya aerugineo-coerulea* fa.*Sensu* Geitler in Geitler & Ruttner 1935; *Lyngbya aerugineo-coerulea* fa.*Sensu* Anagnosidis 1961; *Lyngbya tenuis* var. *aerugineo-coerulea* (Kützing) Kirchner *ex* Hansgirg 1892.

Filament solitary or grouped, 6.2 µm wide; sheath upto 1 µm thick, colourless, unlamellated; trichome pale blue green not or slightly constricted at the ends; cells smaller to slightly longer than wide, 3.9 µm x 4.6 µm; apical cell rounded, reproduction with hormogone

17. Phormidium sp(Plate 2, Figure 3)

Thallus green, soft mass on the palm tree bark; filaments not so long, variously bent, 7.8 µm -10.9 µm wide; sheath not so thick, but fine or diffluent, smooth or rough, unlamellated or lamellated, colourless or yellow, not attached to trichome; trichome dull blue green or green without constrictions, bent or straight; cells shorter, isodiametric and longer than wide, at the ends discoid with constrictions; apical cell rounded without calyptra; reproduction by hormogone which formed by necridic cells.

18. Phormidium chlorinum(Kützing *ex* Gomont) Anagnostidis (Plate 2, Figure 4)*Oscillatoria chlorina* Kützing *ex* Gomont 1892Thallus matlike thick, dark green; filaments clustered, fasciculated, 5.5 µm wide; sheath colourless, thin; trichome slightly constricted, cylindrical; cells shorter or isodiametric, dull blue green or slightly yellowish green.

19. Phormidium calcicola Gardner Filaments long or short, 6.2 µm wide; sheath having encrustations, colourless, thin, firm, unlamellated; trichome blue green, not or slightly constricted, cylindrical, not attenuated; cells isodiametric, slightly shorter or longer than wide with homogenous or granular content, 3.9-9.3 µm x 4.6 µm; reproduction by hormogone.

20. Porphyrosiphon notarisii Kützing *ex* Gomont (Plate 2, Figure 5)Thallus matlike on the bark; filaments long, fasciculated and sometimes entangled and variously curved, 10.9 µm - 14.8 µm wide; sheath colourless, thin and unlamellated, colourless to red brownish, thick and lamellated; trichome bright blue green; cells smaller, isodiametric and also longer than wide with very slight constrictions, finely granulated, 6.3-10.1 µm x 7.8-9.3 µm; apical cell rounded; reproduction by hormogonia and also cells become slight longer before dividing into two smaller daughter cells.

Family Oscillatoriaceae

21. Oscillatoria subbrevis Schmidle (Plate 2, Figure 6)*Oscillatoria subbrevis* f. *major* G.S. West 1907, incl.?

Filaments solitary, straight, 6.24 µm wide; sheath very thin, colourless, hardly distinguishable or may be absent; trichome bright blue green, unconstricted, not attenuated towards ends, cylindrical, 6.24 µm wide; cells discoid with ungranulated and homogenous content; reproduction by hormogone and binary fission.

22. Oscillatoria rupicola Vaucher *ex* Gomont (Plate 2, Figure 7)*Oscillatoria* sect.*Principes* Gomont 1892, *Oscillatoria* group I Kondrateva 1968Thallus thin, matlike, bright green; filaments

entangled, very long, thin, tightly fasciculated not or rarely solitary; sheath, thin, diffluent, colourless, hyaline, attached to trichome; trichome blue green, unconstricted, 5.4 µm wide, cylindrical except some 2-3 cells; cells always distinctly shorter than wide, finely granulated, 5.4 µm x 1.5 µm; apical cell conical rounded or rounded; reproduction by hormogone.

23. Lyngbya anomala (Rao) Anagnostidis (Plate 2, Figure 8)[syn.: *Phormidium anomalum* Rao 1937]Filament thick, bent or variously curved, 10.1 µm - 10.9 µm wide, solitary or in group; sheath colourless, unlamellated; trichome dull blue green, unconstructed, 8.58 µm wide; cells distinctly smaller than wide, 1.5 µm length with homogenous content; apical cell flattened or rounded, without calyptra; reproduction by hormogone.

24. Lyngbya maharashtrensis Kamat (Plate 2, Figure 9)Filaments long, straight or bent, 12.4 µm wide; sheath colourless, not so wide, unlamellated, rough surface; trichome 9.3 µm wide, unconstructed, dull or dirty blue green; cells always shorter than wide, 1.5-3.1 µm wide with homogenous content; apical cell rounded; reproduction by binary fission and by hormogone.

25. Lyngbya cf ocreata Gardner (Plate 2, Figure 10)Filaments long, straight or bent, solitary; sheath thick with rough surface, yellowish; trichome blue green, unconstricted, 5.4 µm wide; cells distinctly shorter than wide, 1.5-2 µm long with homogenous content, sometimes granulated; apical cells flat rounded, without calyptra; reproduction by binary fission and by hormogone.

26. Lyngbya kwangsiensis (Jao) Anagnostidis (Plate 2, Figure 11)[syn*.: Phormidium kwangsiense* Jao 1944]Thallus dark brown green; filament solitary, long; sheath yellow, hyaline, unlamellated; trichome pale blue green , 6.5 µm wide, not attenuated towards ends, unconstricted at the cross walls; cells always distinctly shorter than wide, 1-2.7 µm long with homogenous or granular content; apical cell rounded; reproduction by hormogone.

27. Lyngbya fritschii Anagnostidis (Plate 2, Figure 12)[syn.: *Lyngbya aestuarii* var. *antarctica* Fritsch 1912; non *Lyngbya antarctica* Gain 1911]Filaments solitary, straight, grouped, fasciculated, ±10.1 µm wide; sheath colourless, firm, thin, unlamellated; trichome blue green, not or indistinctly constricted; cells smaller and upto isodiametric, 2.3-6.24 µm x 7.8 µm; apical cell rounded, not capitate; cell divide by binary fission or by hormogone formation.

28. Lyngbya sp Agardh ex GomontFilaments long, mostly with other algae; sheath 2.3 µm thick, colourless or yellowish, lamellated (in some parts) or unlamellated, fine, not so smooth on surface; trichome cylindrical, not attenuated towards the ends, 5.4-7.02 µm wide, constricted; cells shorter, isodiametric, longer, homogenous content; reproduction by hormogone and by binary fission.

Order Nostocales

Family Scytonemataceae

29. Scytonema drilosiphon [Kützing] Elenkin *et*Poljanskij (Plate 2, Figure 13)Filaments with thick yellow coloured calcium encrusted and lamellated sheath, 9.3-10.9 µm wide; both geminate and single branching; trichome blue green with slightly or unconstricted cross walls; cells isodiametric and longer than wide, with granular content, 3.9-7.8 µm x 5.4-7.02 µm; heterocyst oval to cylindrical; reproduction by hormogone.

30. Scytonema varium Kützing *ex* Bornet *et* Flahault (Plate 2, Figure 14)*Scytonema julianum* Meneghini in Kützing 1849 (pro syn.); *Scytonema hofmannii* var. *julianum* Thuret in Bornet *et* Thuret 1880 *ex* Forti 1907; *Scytonema hofmannii* var. *calcicola* Hansgirg 1892?

Thallus dark green, velvety matlike; filaments entangled, 9.3 µm wide; branching both geminate and single, mother filament and the branched filaments of same width; sheath thick and colourless and yellow in some parts, lamellated; trichome blue green, constricted at cross walls; cells shorter to isodiametric, also longer than wide 6.24 µm x 3.1-6.24 µm, heterocyst intercalary with two polar nodules, oval to cylindrical.

31. Scytonema hofmannii Agardh *ex* Bornet *et* Flahault (Plate 2, Figure 15)*Scytonema hansgirgianum* Richter 1884 Thallus woolly, thick, velvety soft; filaments irregularly fasciculated and entangled, 7.02 µm - 9.3 µm wide; branching both geminate and single, mother filaments and branched filaments of same width; sheath yellow, thick, lamellated in developed filaments while thin, colourless, unlamellated sheath in young filaments; cells shorter to isodiametric and also longer than wide, with constricted cross walls but unconstricted in the middle, bright blue green, 3.1-7.16 µm x 5.4-6.24 µm; apical cell rounded; heterocyst solitary and intercalary, oval to cylindrical.

32. Scytonema javanicum[Kützing] Bornet *et* Thuret *ex* Bornet *et* Flahault (Plate 3, Figure 1)

Thallus green, thick, entangled mass of long thread like filaments; filaments long, variously bent, 10.9-17.9 µm wide; branching common, both single and geminate which run parallel at the base, sheath thick 3.12 µm thick, colorless sometimes yellow, lamellated, smooth; trichome cylindrical, not constricted except at the ends; cells green, smaller at the ends, isodiametric and longer than wide in the middle of the filament with granular content; apical cell rounded; heterocyst intercalary, oval or cylindrical; reproduction by hormogone.

33. Scytonema pseudohofmannii Bharadwaja (Plate 3, Figure 2)

Filament entangled, 8.5 -10.9 µm wide; branching both, single and geminate; sheath yellow or greenish yellow, initially colourless, thin unlamellated, later thick, yellow, lamellated; trichome dull blue green, no or slightly constricted in some parts; cells isodiametric, shorter and longer than wide,

homogenous content; heterocyst intercalary, oval or cylindrical; apical cell rounded, reproduction by hormogone.

34. Scytonema coactile Montagne*ex* Bornet *et* Flahault (Plate 3, Figure 3)Filaments upto 25 µm wide, long, variously curved; branching both single and geminate, geminate branching divergent; sheath thick, lamellated or unlamellated, yellow; trichome blue green, at the ends constricted, unconstricted in the middle or only slightly constricted; cells distinctly shorter at the ends, upto isodiametric in the middle; heterocyst present; apical cell rounded; reproduction by hormogone.

35. Scytonema ocellatum[Dillwyn] Lyngbye *ex* Bornet *et* Flahault (Plate 3, Figure 4)

Filaments long, entangled, bent, solitary or sometimes fasciculated; branching both geminate and single, geminate branching divaricated; sheath thick, colourless or yellow, lamellated or unlamellated; trichome cylindrical, bright blue green, unconstricted except at the meristematic zone; cells isodiametric or shorter, have granular content, at the ends cells are smaller or discoid; heterocyst oval or cylindrical; apical cell rounded; reproduction by hormogone, formed by necridic cells.

36. Scytonema crispum[Agardh] Bornet (Plate 3, Figure 5)Thallus olive green or brownish; filaments solitary or fasciculated, entangled or clustered, 23.4 µm – 26.5 µm wide; branching both single and geminate, geminate branching more common, branching filament and the main filaments of same width; sheath firm, 3.1-6.24 µm wide, colourless, sheath next to trichome yellow or brownish, slight parallel lamellation; trichome bright blue green, almost cylindrical along whole length, indistinctly lamellated; cells short or upto isodiametric with homogenous content; heterocyst cylindrical or quadratic; apical cell rounded or flat rounded, like disc shaped; reproduction by hormogone and binary fission.

37. Scytonema chengii Wang (Plate 3, Figure 6)Filaments long, fasciculated or entangled; branching both single and geminate; sheath thick, colourless, yellow and lamellated or colourless and unlamellated; trichome blue green, constricted or unconstricted; cell smaller, isodiametric or also longer than wide, homogenous content; apical cell rounded; heterocyst intercalary.

38. Scytonema cf millei Borne*tex* Bornet *et*Flahault (Plate 3, Figure 7)Thallus woolly, filamentous; filaments long, flexuous, 15-21 µm wide; branching common, both single and geminate; sheath colourless or yellow, thick, indistinctly lamellated; trichome cylindrical, unconstricted in the middle; cell blue green or purple sometime, smaller (at the ends) to isodiametric with sometime granular content; apical cell rounded; heterocyst intercalary, quadratic, reproduction by hormogone.

39. Scytonema insulare Sant' Anna (Plate 3, Figure 8)Filament long, fasciculated or entangled, 14 µm wide; branching common, geminate branching, branching mostly parallel, branching filaments of same morphology as that of the main filament; sheath colourless, yellow, lamellated; trichome blue

green, constricted or unconstricted, cylindrical, 8.58 µm wide; cells isodiametric, longer or shorter than wide with granular content; apical cell rounded; heterocyst quadratic, intercalary, cylindrical; reproduction by hormogone.

40. Scytonema (Myochrotes) tolypotrichoides[Kützing] sensu Kosinskaja (Plate 5, Figure 1)Filaments long, twisted or entangled, 10-16 µm wide; branching common, geminate branching more common; sheath colourless to brown yellow, with parallel and divergent lamellation; trichome blue green, broader at the ends; cells isodiametric, shorter or longer (upto 12.4 µm) than wide, in apical part cell with slight constriction.

41. Scytonema (Myochrotes) mirabile (Dillwyn) Bornet (Plate 3, Figure 9)[*Scytonema figuratum* Agardh 1824; *Scytonema sowerbyanum* Agardh 1824]; *Scytonema steindachneri* Krasser in Zahlbruckner 1900, *Scytonema wolleanum* Forti 1907; *Scytonema leprieurii* Kützing 1849 *ex* Bornet *et* Flahault 1887 Filament long, 7-18 µm wide; branching very common, both single and geminate; sheath yellow or yellow brown, mostly outer sheath colourless and inner sheath yellow brown, lamellation parallel and divergent; trichome slightly broader at the ends, slightly or unconstricted, 2.3-6.2 µm wide; cells bright blue green, barrel shaped to cylindrical, cell content homogenous or granular; apical cell rounded; heterocyst quadratic or smaller to cylindrical.

42. Scytonema (Myochrotes) myochrous[Dillwyn] Agardh ex Bornet *et* Flahault[*Scytonema cataracta* Wood 1869; *Scytonema brandegeei* Wolle 1877] Filaments long, entangled, 21-28 µm wide; branching very common, both single and geminate, both branching filaments run parallel sometimes, branching filaments long and slightly narrower than the main filament; sheath thick, yellow, divergently lamellated; trichome blue green, cylindrical, constricted, 11-20 µm wide; cells shorter or isodiametric, cell content granular, heterocyst intercalary, quadratic or cylindrical.

43. Brasilonema cf sennae(Komárek) Sant' Anna *et al.***[**syn.: *Camptylonemopsis sennae* Komarek 2003**]**Filaments not so long, 9.3 µm – 10.9 µm wide; sheath thick, not lamellated, colourless; branching very rare; trichome slightly constricted; cells blue green, shorter to isodiametric and longer than wide, 6.24 µm wide; heterocyst present; reproduction by hormogonia.

44. Brasilonema sp Fiore *et al* (Plate 5, Figure 2)Filaments long, entangled, straight or bent, 7.8 µm - 15.6 µm wide; branching both single and geminate but rare; sheath thick, lamellated, colourless or yellow; trichome dull blue green or blue green, constricted or unconstricted, 9.3 µm wide; cells isodiametric, smaller or longer than wide with granular content; apical cell rounded; heterocyst present; reproduction by hormogone.

45. Brasilonema cf epidendron Sant' Anna *et al*Filaments long, spirally arranged or coiled or variously bent, 9.3 µm wide; branching rare, single or geminate(?); sheath wide, yellow, lamellated, colourless and unlamellated when young; trichome unconstricted or indistinctly constricted,

cylindrical, blue green, 5.4 µm wide; cells isodiametric, shorter or longer than wide, cell content granular; apical cell rounded; heterocyst mostly oval; reproduction by hormocyst.

46. Petalonema crustaceum Agardh *ex* Kirchner (Plate 5, Figure 3)*Scytonema crustaceum* Agardh *ex* Bornet *et* Flahault 1887 Filaments entangled, repeatedly branched; branching both single and geminate, branches with same morphology as that of main filament, geminate branching usually grow parallel at the point of branching and later divergent; sheath yellow brown to dark brown, lamellation parallel or oblique; trichome slightly widened towards ends, not or slightly constricted; cells shorter, isodiametric or up to cylindrical, bright blue green; heterocyst cylindrical or square shaped.

47. Petalonema alatum Berkeley *ex* Kirchner (Plate 5, Figure 4)*Scytonema alatum* Nägeli in Kützing *ex* Bornet *et* Flahault 1887Thallus dark, dirty green, thick gelatinous; filament with very thick, yellow sheath, entangled or clustered rarely solitary, 31.2 - 43.6 µm wide; branching common, both geminate and single; sheath with divergent and also perpendicular lamellation; trichome blue green or dull blue green, constricted, broader at the ends (15 µm wide) and narrower in the middle (7.8 - 9.3 µm); cells barrel shaped in the middle and discoid in the ends or longer or isodiametric in the middle; heterocyst present, sometimes at the branching point or sometime basal, compressed spherical; 'U' shaped hormogone with heterocyst in the middle.

Family Rivulariaceae

48. Calothrix sp Agardh *ex* Bornet *et* Flahault (Plate 4, Figure 1)Filament long, polar, wider at base, tapering towards ends but no hair like structure formation, 9.3 - 10.9 µm wide; no branching; sheath colourless, thin, firm, open at the ends but not longer than wide, unlamellated, not smooth, 2.3 µm thick; trichome not cylindrical, broader at the base, 3 - 7.8 u wide, unconstricted, slightly constricted at the basal part; cell shorter or isodiametric, blue green or pale blue green, cell content homogenous; apical cell rounded; heterocyst basal, 1 or 2, not intercalary.

49. Rivularia sp [Roth] Agardh *ex* Bornet *et* Flahault (Plate 4, Figure 2)Colony hemispherical; filaments long, heteropolar; sheath yellow, broad, sometimes lamellated; trichome blue green, constricted or unconstricted, tapering towards ends hair like; cell isodiametric or shorter than wide in basal part, with homogenous content; heterocyst single, basal.

Family Microchaetaceae

50. Microchaete sp Thuret *ex* Bornet *et* Flauhault (Plate 4, Figure 3)*Coleospermum* Kirchner in Cohn 1878; *Fremyella* DeToni 1936Thallus olive green, velvety; filaments not so long, grouped and also fasciculated; 12.6 - 13.4 µm wide; heteropolar; branching rare, single branching tolypotrichoid; no geminate branching; sheath colourless or yellow, lamellated or unlamellated, rough surface;

trichome cylindrical, slightly constricted; cells shorter or isodiametric, rarely longer, bright blue green with single granule; heterocyst basal, intercalary hemispherical, spherical or cylindrical, 1-2 heterocysts at one end; apical cell rounded; reproduction by binary fission or by hormogone.

51. Tolypothrix tenuis Agardh *ex* Bornet *et* Flahault (Plate 4, Figure 4)Filaments long, fasciculated, 7.8 - 10.14 µm wide; single branching common; sheath thick, yellow when matured and colourless in young filaments, slightly lamellated; trichome blue green; cells slightly shorter, with constricted cross walls and granular content, 3.9 - 6.24 µm x 3.9 - 7.8 µm; heterocyst at the single branching point, rare geminate branching; heterocyst common, both intercalary and terminal, 1-2; apical cell rounded; reproduction by hormogone.

Family Nostocaceae

52. Nostoc communae Vaucher *ex* Bornet *et* Flahault (Plate 5, Figure 7)Colony micro or macroscopic, or many colonies are grouped together, tubular or spherical or saccate like; sheath intense yellow, thick, with sharp boundaries, sometimes lamellated; trichome blue green, deeply constricted, long, embedded in the colony; cells spherical or oval, 4.6-5.4 µm diameter, reproduction by binary division.

53. Desmonostoc muscorum(Agardh*ex* Bornet *et* Flahault) Hrouzek *et* Ventura (Plate 5, Figure 6)

*Nostoc muscorum*Agardh *ex* Bornet *et* Flahault1888 Colony spherical, common envelope greenish yellow, thick with sharp boundaries; filaments variously curved, trichome not having its own sheath; cells blue green with granular content, spherical or slightly shorter or longer than wide, 3.9 - 4.6 µm x 3.1 - 3.9 µm; heterocyst both intercalary and terminal; akinetes not distinctly larger; not more than 2-3 times wider than vegetative cells.

54. Desmonostoc sp Hrouzek *et* Ventura (Plate 5, Figure 5)Colony large, diffluent, amorphous, without firm periderm, colourless; filaments coiled, loosely or densely arranged; cells dull blue green, isodiametric or spherical; heterocyst terminal and intercalary both, oval or spherical, 6 µm x 5.5 µm; cell division by binary fission.

Order Stigonematales

Family Hapalosiphonaceae

55. Hapalosiphon pumilus Kirchner*ex* Bornet *et* Flahault (Plate 4, Figure 5)

Hapalosiphon fontinalis (Agardh)Bornet 1889, *H. braunii* Nägeli in Kützing 1849

Main and branching filaments differentiated on the basis of width, otherwise morphologically similar, both uniseriate, 14.04 µm wide; branching common, ‘V’ and ‘T’ shaped, branching at the base slightly narrow and sometimes broader towards ends; sheath thick, lamellated, yellow or

brownish yellow, colourless, lamellation parallel or divergent; cells cylindrical with individual yellow, thick, slightly lamellated sheath 9.3 µm x 4.6 µm; heterocyst commonly present.

56. Hapalosiphon luteolus West and West

Filament densely entangled; filaments cylindrical, 9 – 11 µm wide; branching similar to the main filament, not attenuated or narrowed towards ends; trichome cylindrical, constricted; cell isodiametric, barrel shaped or cylindrical, 6.24 - 7.8 µm wide; heterocyst cylindrical.

Family Stigonemataceae

57. Stigonema minutum(Agardh) Hassall *ex* Bornet *et* Flahault (Plate 4, Figure 7)Main filament uni- to bi- or tri- seriate, 13 – 19 µm wide; branching filament short; sheath yellow to brown; cells blue green with granular content, spherical or oval, cells divide perpendicular to the length and become hemispherical, individual sheath yellow to brown and lamellated, 7.8 µm x 5.5 µm; reproduction by hormogone which form along the entire length.

58. Stigonema turfaceum[Persoon] Cooke ex Bornet et Flahault (Plate 4, Figure 6)Colony dark or blackish green; filaments richly branched, 25 – 35 µm wide; branches of same width, at the ends slightly narrowed; sheath thick, lamellated, yellow to brownish yellow; trichome as well as branches multiseriate except at the ends in branches; cells blue green, spheroidal, with individual sheath; heterocyst present.

59. Stigonema sp Agardh *ex* Bornet *et* Flahault (Plate 4, Figure 8)Thallus dark brown, thick, soft; filaments 24 - 32.7 µm wide, main and branching filaments differentiated, multiseriate; branching common, true branching ‘Y’ or ‘T’ shaped, branching filament slightly narrow than main filament, 21.8 - 24.9 µm wide, branching filament also multiseriate, not attenuated towards ends; sheath yellow, thick, slightly lamellated; cells irregularly spherical, oval with broad ends, cell or group of cells having their own, thick, yellow, fine, lamellated sheath, blue green, cell content granular; heterocyst present.

DISCUSSION

Western Ghats is one of the major 34 biodiversity hotspots worldwide. Sirsi taluk, being a heart of Western Ghats, houses ample diversity of subaerial cyanobacteria and algae. Cyanobacteria are one of the most understudied and most overlooked organisms in India. Hence, aim of this study was to observe the occurrence and diversity of cyanobacteria belonging to the orders Oscillatoriales, Nostocales and Stigonematales from Sirsi taluk.

These organisms inhabit diverse habitats.In Sirsi taluk also, various substrata like bark, rocks, cemented walls, clay pots, wood logs and rope were inhabited by subaerial cyanobacteria. Members of Scytonemataceae were the most frequently occurring subaerial cyanobacteria (19 taxa; out of

which 2 taxa belonged to the genera *Petalonemai.e.P. alatum* and *P. crustaceum*; three taxa belonged to the genera *Brasilonema i.e. Brasilonema* cf *epidendron, B. sennae, Brasilonema* sp; three taxa belonged to the genera *Scytonema (Myochrotes*) *i.e. S. (Myochrotes) mirabile, S. (Myochrotes) myochrous, S. (Myochrotes) tolypotrichoides*; and remaining eleven taxa belonged to the genera *Scytonema i.e. S.drilosiphon, S. varium, S. hofmannii, S. javanicum, S. pseudohofmannii, S. coactile, S. ocellatum, S. crispum, S. chengii, S.* cf *millei, S. insulare*) in comparison to taxa belonging to other families. Komárek (2013) recorded frequent occurrence of species belonging to the genera *Scytonema* from SE Brazil. *S. guyanense, S. javanicum* and *S. stuposum* were the commonly occurring taxa in the study. In other study, taxa belonging to the genera *Scytonema* were among the main components of biofilms from building facades and monuments of Odisha, India.

Tropical climate supports prominently to the diversity and occurrence of subaerial cyanobacteria. In present study, maximum diversity and occurrence of subaerial cyanobacteria was reported in monsoon season in comparison to premonsoon and postmonsoon season in both the years 2015 and 2016. Members of Oscillatoriales and Nostocales were equally dominated in the climate of Sirsi taluk while Stigonematales members showed less occurrence and diversity. Forested area and botanical garden of Bakkal (in 2015), and Sahasralinga (in 2016) were providing the optimal climate for the luxuriant growth of subaerial cyanobacteria while minimum growth was observed in urban area *i.e.* Sirsi city in 2015 and forested area of Karasulli in 2016. This observation supports one fact that urban areas are not much suitable for subaerial cyanobacterial growth as urban areas are dominated by anthropogenic activities.

Some of the subaerial cyanobacterial taxa namely *Leptolyngbya cataractarum, Porphyrosiphon notarisii* and *Scytonema hofmannii* were documented in all the seasons in 2015 while in 2016 *Leptolyngbya angustissima, Leptolyngbya valderiana, Schizothrix calcicola, Porphyrosiphon notarisii, Scytonema drilosiphon, Scytonema varium, Scytonema hofmannii, Scytonema pseudohofmannii* and*Petalonema crustaceum* were occurring in all the three seasons. Furthermore, among these cyanobacteria *Leptolyngbya cataractarum* and *Scytonema hofmannii* were reported as the maximally occurring taxa in 2015 while *Leptolyngbya valderiana, Porphyrosiphon notarisii, Scytonema drilosiphon, Scytonema varium* and*Scytonema hofmannii* were frequently occuring taxa in 2016. Hence, it can be concluded that these cyanobacteria were present throughout the year.

A total of seven cyanobacterial taxa (*Schizothrix calcicola, Trichocoleus sociatus, Phormidium chlorinum¸ Oscillatoria subbrevis, Lyngbya fritschii, Scytonema (Myochrotes) tolypotrichoides* and *Scytonema (Myochrotes) myochrous*) were reported only in premonsoon season

while four cyanobacterial taxa (*Leptolyngbya* sp1, *Phormidium* sp, *Scytonema pseudohofmannii* and *Scytonema chengii*) were reported only in postmonsoon season in the year 2015. On the other hand in the year 2016, only one cyanobacterium namely *Schizothrix* cf *ericetorum* was documented in premonsoon season and seven subaerial cyanobacterial taxa (*Leptolyngbya* sp2, *Phormidium keutzingianum, Phormidium chlorinum, Phormidium calcicola, Lyngbya fritschii, Lyngbya* sp and *Brasilonema* sp) were documented only in postmonsoon season. With the documentation of these subaerial cyanobacteria (not in monsoon season), it can be concluded that some of the cyanobacteria may need particular environment for the growth and occurrence. Rare occurrence of these cyanobacterial taxa in Sirsi taluk in both the years *i.e.* 2015 and 2016 may support this fact.

Unfortunately, subaerial cyanobacteria are the most understudied and the most overlooked organisms in Sirsi, Karnataka especially in Western Ghats region which is a biodiversity hotspot in India and also worldwide. Human encroachment and anthropogenic activities are disturbing the natural habitats in forested areas of Western Ghats. Furthermore, cyanobacteria are a very good source of secondary metabolites and antioxidant properties and, hence, can be an extremely good candidate for pharmaceuticals, food and nutrition, cosmetics and textile industries. To go to these applied aspects, first, it is essential to know the wealth of diversity of subaerial cyanobacteria. Considering these facts, this study was done and hopefully, it will be informative to understand the diversity of subaerial cyanobacteria.

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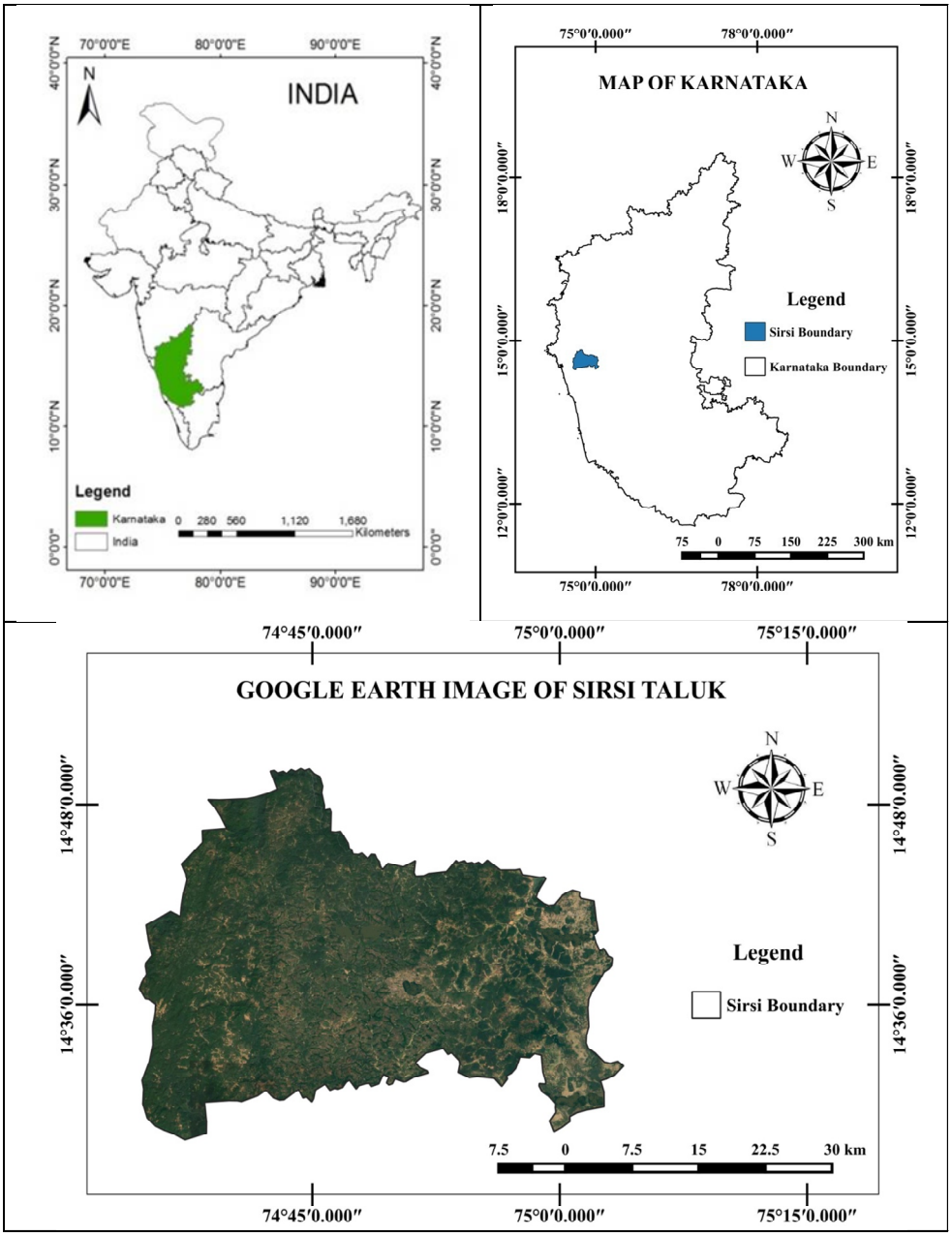

Figure 1:Google earth image of Sirsi Taluk

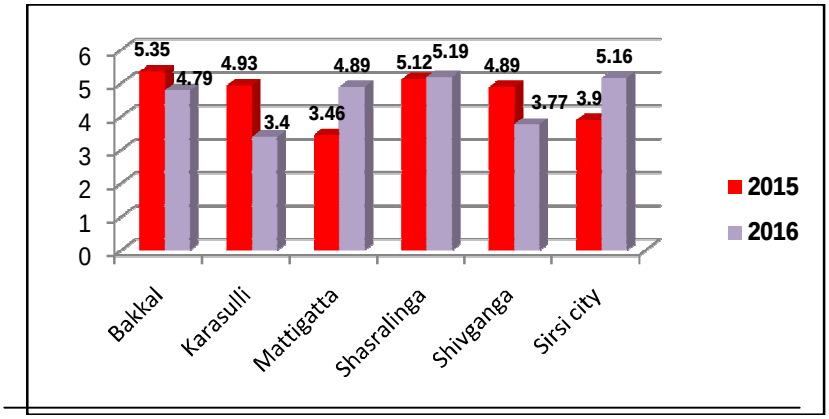

Figure 2: Shannon-Wiener diversity index in different sampling sites of Sirsi taluk in the year 2015 and 2016.

PLATE 1

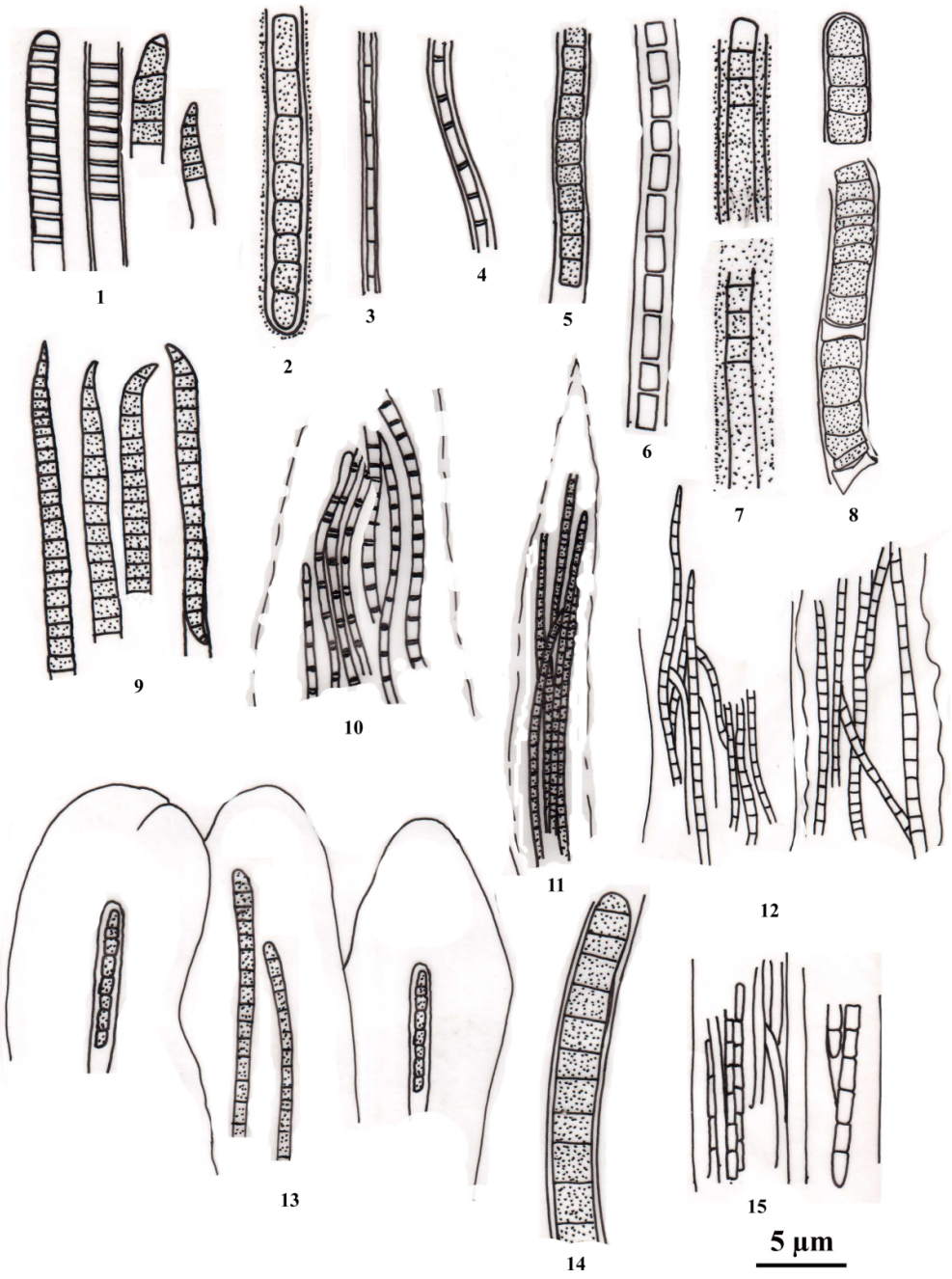

Plate 1.1. ***Leptolyngbya fallax*, 2. *L.* cf *gracillima*, 3. *L. angustissima*, 4. *L. valderiana*, 5. *L. compacta*, 6. *L. cataractarum*, 7. *L.* sp1, 8. *Phormidium* cf *puteale*, 9. *L.* sp2, 10. *Schizothrix calcicola*, 11-12. *S. lardacea*, 13. *S.* cf *ericetorum*, 14. *P.keutzingianum*, 15.*Trichocoleus sociatus***

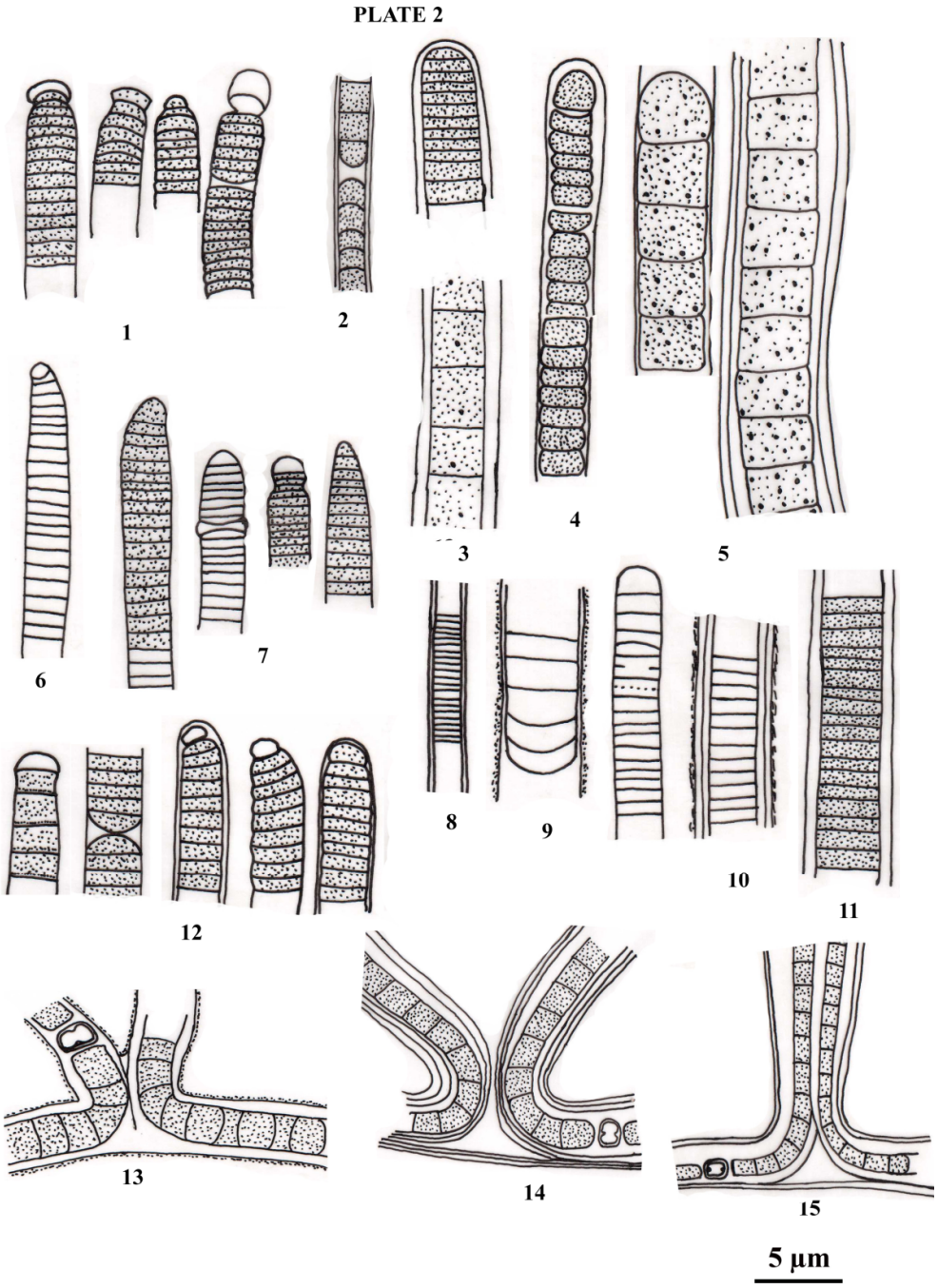

Plate 2: 1. ***Phormidium ambiguum,*** **2.** ***P. aerugeneo-caeruleum,*** **3.*Phormidium* sp, 4.** ***P. chlorinum,*** **5.** ***Porphyrosiphon notarisii*** **6.*Oscillatoria subbrevis,*** **7 .*O. rupicola,*** **8.** ***Lyngbya anomala,*** **9.** ***L. maharastrensis,*** **10.** ***L.*** **cf** ***ocreata,*** **11.** ***L. kwangsiensis,*** **12.** ***L. fritschii,*** **13.** ***Scytonema drilosiphon,*** **14.** ***S. varium,*** **15.** ***S. hofmannii***

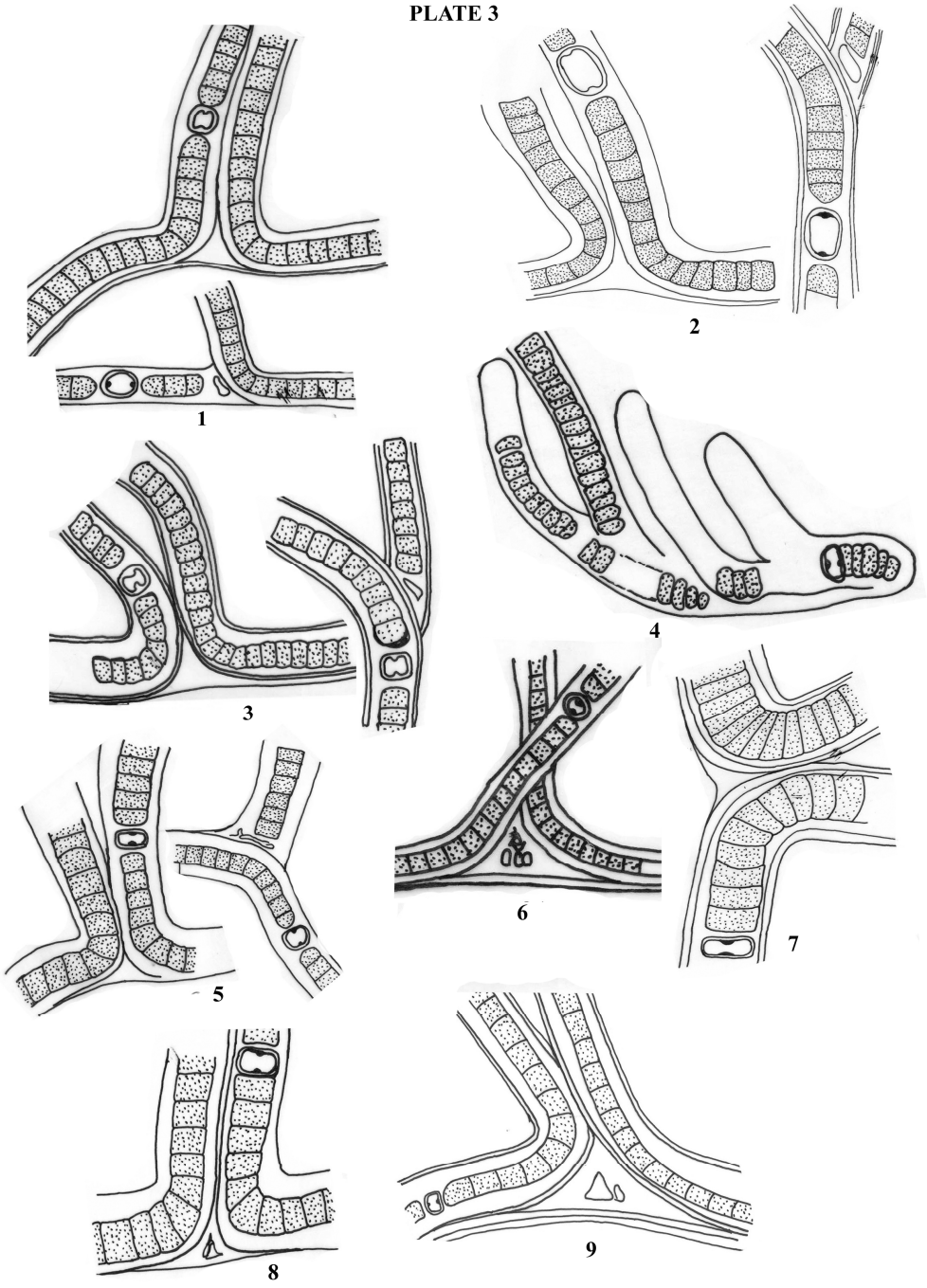

Plate 3: 1.*Scytonema javanicum*, 2.*S. pseudohofmannii*, 3.*S. coactile*, 4.*S. ocellatum*, 5.*S. crispum*, 6.*S. chengii*, 7.*S.* cf *millei*, 8.*S. insulare*, 9.*S. (Myochrotes) mirabile*

PLATE 4

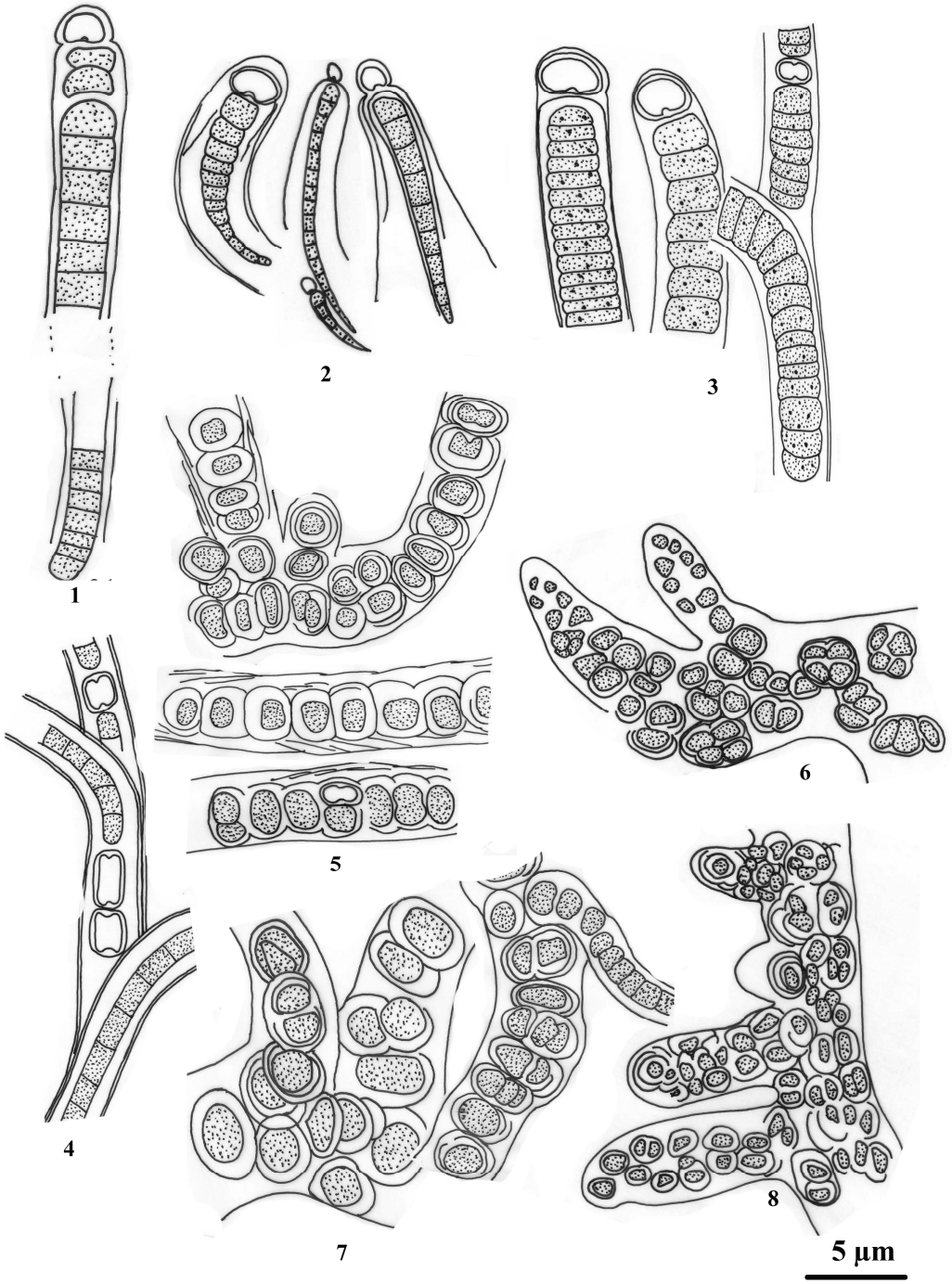

Plate 4:1.*Calothrix* **sp,** 2.*Rivularia* **sp,** 3.*Microchaete* **sp,** 4.*Tolypothrix tenuis,* 5.*Hapalosiphon pumilus,* 6.*Stigonema turfaceum,* 7.*S. minutum,* 8.*Stigonema* **sp**

PLATE 5

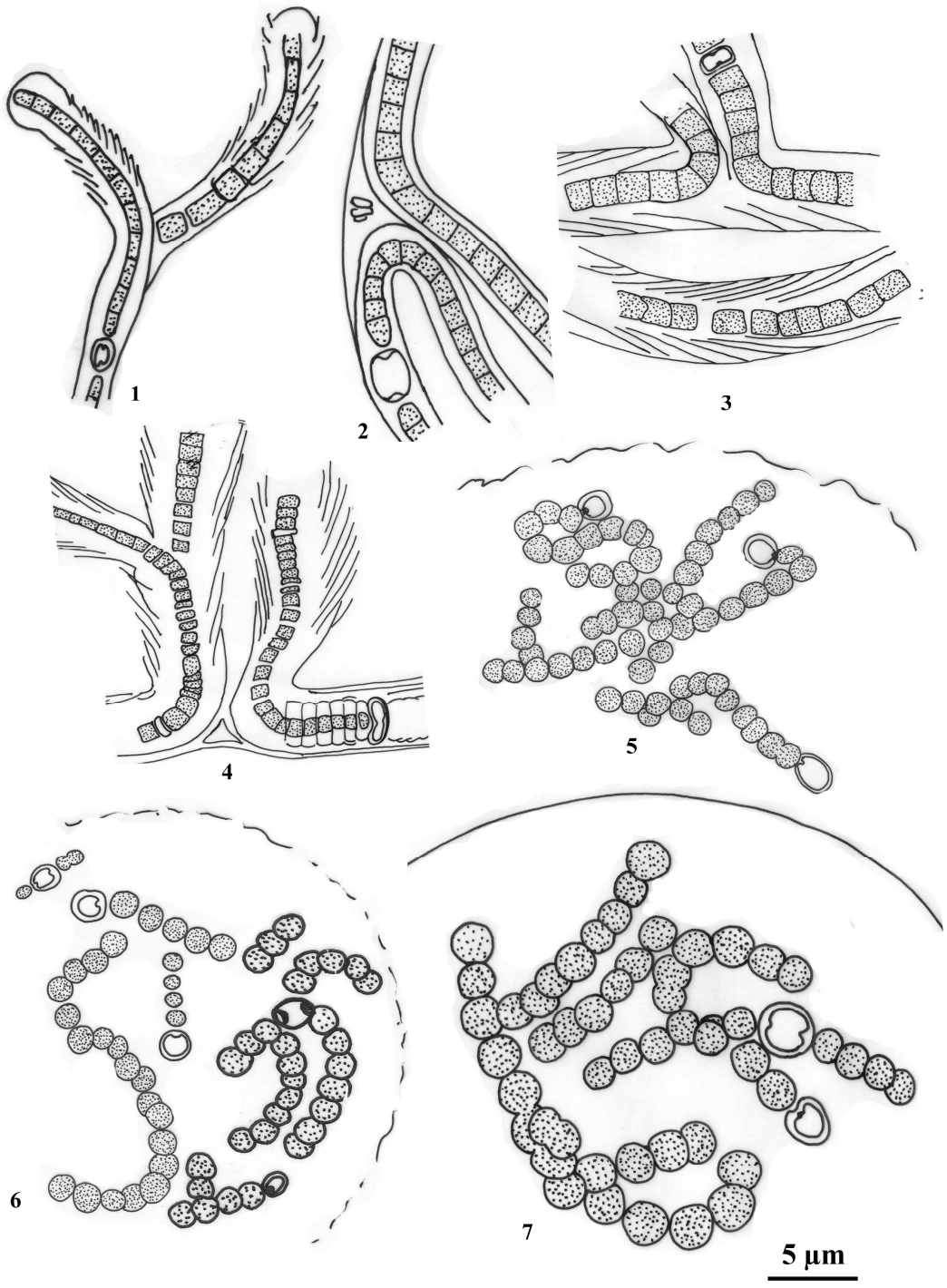

Plate 5:1.*S. (Myochrotes) tolypotrichoides*, 2. *Brasilonema* sp, 3.*Petalonema crustaceum*, 4.*P. alatum*, 5.*Desmonostoc* sp, 6.*D. muscorum*, 7.*Nostoc commune*