Biodiversity of epilithic cyanobacteria from freshwater streams of Kakoijana reserve forest, Assam, India

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Abstract The biodiversity of epilithic cyanobacteria from one of the unexplored habitats of freshwater streams of Kakoijana reserve forest of Assam, India was estimated. This paper lists a total of 29 species representing 18 genera of 12 families and 4 orders as per recent system of classification. Morphological descriptions, common habitats and distribution pattern were described for each species identified that were represented systematically. Of these 29 species, 11 were unicellular, 9 non-heterocytous filamentous and 9

heterocytous filamentous forms. All the unicellular (*Aphanocapsa crassa*, *A. muscicola*, *Aphanothece nidulans*, *A. saxicola*, *Chlorogloea purpurea*, *Chroococcus cohaerens*, *C. minimus*, *C. minor*, *Cyanobacterium cedrorum*, *Cyanocystis versicolor* and *Gloeocapsopsis crepidinum*) and 13 (*Calothrix epiphytica*, *C. scopulorum*, *Leptolyngbya boryana*, *L. calotrichoides*, *L. fragilis*, *L. notata*, *Lyngbya arboricola*, *Nostoc humifusum*, *N. oryzae*, *N. punctiforme*, *Parthasarathiella prolifica*, *Porphyrosiphon ceylanicus* and *Scytonema millei*) of the remaining 18 species were recorded for the first time as freshwater epiliths. While, 5 species (*Hapalosiphon welwitschii*, *Leptolyngbya tenuis*, *Oscillatoria pseudogeminata*, *Phormidium laetevirens*, *Tolypothrix fragilis*) and 8 species (*Aphanothece saxicola*, *Calothrix scopulorum*, *Chlorogloea purpurea*, *Chroococcus minor*, *Gloeocapsopsis crepidinum*, *Leptolyngbya calotrichoides*, *L. fragilis* and *L. tenuis*) were reported earlier as freshwater- and marine-epilithic forms respectively. All are new records for Assam except 6 species (*A. nidulans*, *H. welwitschii*, *N. punctiforme*, *N. oryzae*, *O. pseudogeminata* and *P. ceylanicus*), while 3 species (*C. purpurea*, *L. boryana* and *L. calotrichoides*) are new records for India. Six nitrogen fixing heterocytous forms such as, *C. epiphytica*, *C. scopulorum*, *N. humifusum*, *N. punctiforme*, *N. oryzae* and *S. millei*, were common to the neighboring paddy fields.

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Introduction

Cyanobacteria (earlier known as blue-green algae) are morphologically diverse group of Gram-negative photo-

synthetic prokaryotes, which are unique in their cosmopolitan distribution ranging from Arctic to Antarctic habitats. They may thrive in extreme environments such as, rocky shores, hot springs; drought, desiccation, osmotic, salinity and UV stresses; photooxidation; heat and cold shock; anaerobiosis; nitrogen starvation; etc. (see reviews by Sinha & Häder, 1996 and Zehr et al., 2000; Kalib, 2002; Saha et al., 2003). Like the rocks/stones in marine habitats (usually harsh environment), rocks/stones surfaces either exposed or submerged in freshwater harbor a slippery layer of cyanobacterial growth. The presence of cyanobacteria on bare rock (though looks no life exists) can be identified by the slipperiness due to exopolysaccharides, immediately after rain or pouring water. Cyanobacteria occupy a central position in global nutrient cycling especially due to their inherent capacity to fix atmospheric CO₂ and N₂ through Rubisco and nitrogenase enzymes respectively (see Sinha et al., 1995; 1997). Until past few decades of research cyanobacteria were of academic interests only and were mostly ignored as nuisance but, now is proved as potential candidates for many biotechnological utilization (see reviews by Richmond, 1990; Sundararaman & Sekar, 2001; Thajuddin & Subramanian, 2005). Therefore, for several reasons, estimation and conservation of cyanobacterial biodiversity from yet unexplored habitats become very important, which need to be initiated with systematic survey followed by establishment of pure culture collection and their characterization. In general, very limited floristic studies of freshwater cyanobacteria and in particular, no freshwater epilithic cyanobacterial study have undertaken especially from Assam. Available information is restricted only to rice field soils of Assam and its neighboring states (Biswas, 1930, 1934; Bordoloi, 1980; Singh et al., 1997; Singh et al., 1997a, 1997b; Ahmed et al., 1999; Amita Devi et al., 1999; Rout & Dey, 1999). A study was therefore carried out to evaluate the biodiversity of epilithic cyanobacteria from freshwater streams of Kakoijana reserve forest, Assam. This paper emphasized in describing comparative morphology, common habitats and their geographical distribution.

Materials and Methods

Kakoijana reserve forest (KRF) is located between 26° 24' N – 26° 29' N latitude and 90° 36' E – 90° 39.5' E longitude with a total area of 17.201 square Kilometers. The region has a tropical monsoon climate receiving an annual average rainfall of about 100 centimeter with maximum and minimum temperature of 36 °C and 10 °C respectively. Altitudinal variation of KRF ranges between 35 meter and 60 meter above sea level. KRF is bounded on East by the river Aie and on West by rivulet Kujia with its tributaries. Remaining

sides of KRF possess paddy fields. Vegetation type of KRF is semi evergreen to mix-deciduous with a wide range of floral and faunal diversity; hence, it was declared as reserve forest for biodiversity conservation.

Samples of visually conspicuous cyanobacterial growth on submerged plus exposed stones were collected at every 25 meters in plastic vials containing native water and brought to laboratory for preliminary observation. Samples from neighboring rice fields where the streams ends, were also collected randomly for comparison of nitrogen fixing heterocytous forms. Cyanobacteria attached firmly were scrapped by one-sided blade or rock chips were removed using hammer and chisel. In some cases, small stones covered with cyanobacterial growth were considered as samples. After the preliminary observation, a set of sample was transferred to BG 11 complete medium (Rippka et al., 1979) while; another set was transferred to BG 11 medium devoid of combined nitrogen to enhance the growth of heterocytous forms. All samples were incubated at 25 ± 2 °C, 14/10 h light/dark cycle, with illumination of 20 µE m⁻² sec⁻¹ by cool white fluorescent tubes (Philips, India). After about two to three weeks of growth, samples were re-observed with the aid of microscope (Leica Leitz-Diaphan, USA) under light field, dark field and phase contrast conditions to characterize them morphologically. In case of rice field samples, only forms with heterocytes were observed carefully to compare their diversity with the epilithic forms of freshwater streams. To identify cyanobacteria with modern approach of classification system, the taxonomic publications of Anagnostidis & Komárek (1985, 1988, 1990), and Komárek & Anagnostidis (1986, 1989) were mainly used. However, the keys used in “Geitlerian” system (Geitler, 1932; Desikachary, 1959 and Starmach, 1966) were used for species level identification whenever found essential. Other taxonomic papers such as, Komárek et al. (1999), Kovalenko et al. (1999) etc. were also referred in certain cases.

In the present communication, we have used the orthographs ‘heterocytes’ and ‘hormogonia’ instead of ‘heterocysts’ and ‘hormogones’ respectively, as was recommended by the International Association for Cyanophyte Research (IAC) (Mollenhauer et al. 1994). The word ‘filament’ follows the usage of other authors, referring to a sheath and its trichome (uniseriate cells). Terminology used for ‘false-branching’ varied greatly from author to author. Borner & Flahault (1886–1888) used the word ‘geminate’ for paired branches that initiate as a hairpin loop, and the word ‘solitary’ for false-branches that arise laterally (usually tangentially to the primary filament); Geitler (1932) described both types of branching, but without applying any specific terms; Desikachary (1959) used ‘geminate’ and ‘single’;

Komárek & Anagnostidis (1989) used ‘Scytonema-type’ and ‘Tolypothrix-type’ respectively. However, we have retained the terms ‘geminate’ and ‘single’ to describe paired and lateral type of false-branching respectively.

Results

A total of 29 cyanobacteria including 6 heterocytous forms (*Calothrix epiphytica*, *C. scopulorum*, *Nostoc humifusum*, *N. oryzae*, *N. punctiforme* and *Scytonema millei*) common to neighboring paddy fields were recorded and described below with their systematic positions, morphological descriptions, earlier reports on their common habitat and distribution.

CYANOBACTERIA

CHROOCOCCALES WETTSTEIN

MICROCYSTACEAE ELENK.

APHANOTHECOIDEAE KOM. et ANAGN.

APHANOTHECE NÄGELI

Aphanothece nidulans RITCHER, P. (Fig. 1)

Geitler (1932: 168, fig. 75c), Desikachary (1959: 138, pl. 22, fig. 1), Starmach (1966: 95, fig. 102).

Thallus mucilaginous, irregularly expanded, epiphytic on *Scytonema millei*; cells cylindrical to ellipsoidal, single, seldom in pair, straight, 1.5–1.8 µm in length, 1–1.2 µm in diam., grass-green to blue-green in color; sheath diffuent and colorless; protoplasm homogenous. Cell divides transversely, depressed in diad state.

Both length and breadth of this species were not exactly similar to that of the originally described species, but remained within the range.

Common habitat: Epiphyte on *Lyngbya* (Silva & Pienaar, 2000), rice field (Singh et al., 1997; Singh et al., 1997b; Ahmed et al., 1999; Amita Devi et al., 1999) and sand (Ganapathi, 1940).

Distribution: Manipur, Nagaland, Tripura, Chennai and Nagaon in India; Mauritius; Sri Lanka.

Aphanothece saxicola NÄGELI (Fig. 2)

Geitler (1932: 169, fig. 123), Desikachary (1959: 138, pl. 22, fig. 11), Starmach (1966: 95, figs. 100–104).

Thallus mucilaginous, microscopic, cells are irregularly expanded within the common matrix, yellowish to hyaline; cells cylindrical with rounded ends, 2–2.4 µm in diam., 3–3.6 µm in length, mostly single, rarely in pairs or many in a common mucilage; cell contents blue-green and homogeneous. Cell divides transversely. After division, cells are depressed, smaller in length compared to single cell state.

The present species however, differed in size from the originally described species (1–2 µm in diam.) and therefore, could be a new variety.

Common habitat: Ornamental pools and fountains (Vinogradova, 1999), epilithic on rocky shore (Nagarkar, 1998), rice field (Rao 1936; Singh et al., 1997; Singh et al., 1997b; Amita Devi et al., 1999), open sea, stagnant seawater, salt pans (Thajuddin & Subramanian, 1992), mud and mangrove of marine environment (Aleem, 1980).

Distribution: Manipur, Nagaland, Tripura, Allahabad, Madurai, South East Coast and Varanasi in India; Hong Kong; Ukraine; Sussex in West Africa.

CYANOBACTERIUM RIPPKA et COHEN-BAZIRE

Cyanobacterium cedrorum (SAUVAGEAU) comb. nov. [basionym: *Synechococcus cedrorum* SAUVAGEAU; syn: *Cyanothece cedrorum* (SAUVAGEAU) KOMÁREK] (Fig. 3) Geitler (1932: 273), Desikachary (1959: 144), Starmach (1966: 56, fig. 23).

Cells single or in pairs, elongated, ellipsoidal to cylindrical with rounded ends, 3–3.5 µm in diam., 5–6 µm in length; sheath very thin, visible only in dark field at higher magnification, colorless; protoplasm blue-green and homogenous. Cell mainly divides by transverse division, rarely by longitudinal division also. After division, cells are attached, depressed and smaller in length or breadth.

Rippka and Cohen-Bazire (1983) created two new genera (*Cyanobacterium* and *Cyanobium*) that are morphologically close to the original *Synechococcus* sp., based on DNA-base composition and sensitivity to various cyanophages. However, Komárek et al. (1999) have described phenotypic diacritical characters especially based on the ultrastructural study to differentiate these genera and tentatively transferred the present species to newly established genus (i.e., *Cyanobacterium*), which still awaiting for revision to come up with the simple morphological features for species delimitation.

Common habitat: Red soil (Mitra, 1951)

Distribution: Chennai and Vandalur in India.

MERISMOPEDIOIDEAE (ELENK.) KOM. et ANAGN.

APHANOCAPSA NÄGELI

Aphanocapsa crassa GHOSE (Fig. 4)

Desikachary (1959: 136, pl. 22, fig. 6).

Cells generally single or in pairs immediately after division, irregularly arranged within the mucilaginous matrix, delicate, brownish green, globose, free floating or entangled within non-heterocytous filamentous forms; cell mass homogenous to slightly granular, sheath absent; cells 8.4–9 µm in diam., length of depressed cells in diad state ranges between 7.5 µm and 7.8 µm. Cell divides in two planes by insertion of plasma membranes.

Cells of similar size range (7–12 µm in diam.) as well as with similar other characteristics have been reported as

epiphytes on aquatic plants by Ghose (1927); however, in the present study we could find this as freshwater epilithic form.

Common habitat: Epiphyte on submerged aquatic plants, rice field (Amita Devi et al., 1999)

Distribution: Manipur in India; Rangoon in Myanmar.

Aphanocapsa muscicola (MENEHINI) WILLE (Fig. 5) Geitler (1932: 160), Desikachary (1959: 135, pl. 21, fig. 7), Starmach (1966: 90, fig. 88).

Thallus mucilaginous, microscopic, in the common mucilage of *Leptolyngbya* spp. and *Lyngbya arboricola*; cells spherical to hemispherical, 2–4 together, blue-green in color, 1.5–1.8 µm in diam.; cell division in one or two directions by insertion of the plasma membrane into the protoplasm, daughter cells are often together in a common thick mucilaginous envelope, which is colorless.

The present species however, differed slightly in size from that of the originally described species (2–3 µm in diam.) and therefore, could be a new variety.

Common habitat: Intertidal (Silva & Pienaar, 2000), bark of *Ficus* sp. (Kamat, 1962), epiphytic on *Croton* sp. (Skuja, 1949).

Distribution: Panhala in India; Rangoon in Myanmar; Mauritius.

CHROOCOCCACEAE NÄGELI

CHROOCOCCUS NÄGELI

Chroococcus cohaerens (BRÉB.) NÄGELI (Fig. 6)

Geitler (1932: 238, fig. 116e), Desikachary (1959: 111, pl. 26, figs. 3, 9), Starmach (1966: 122, fig. 135).

Thallus mucilaginous, blue-green to dark green; cells in pairs, single or up to 8 in groups, 2.4–3.6 µm in diam., 1.8–2.4 µm in length of depressed cells in diad state; sheath thin, unlamellated and colorless; protoplasm blue-green to dark green and highly granular. Cell divides transversely in two planes. Immediately after division, daughter cells are sub-spherical and remains adhere side by side to each other within the common mucilage.

Common habitat: Rice field (Singh et al., 1997a; Amita Devi et al., 1999), epiphytic on *Gnetum* sp. (Skuja, 1949).

Distribution: Arunachal Pradesh and Manipur in India; Rangoon in Myanmar.

Chroococcus minimus (KEISSLER) LEMM. (Fig. 7)

Geitler (1932: 232), Desikachary (1959: 106), Starmach (1966: 125, fig. 142).

Thallus mucilaginous; cells spherical to ellipsoidal, generally in pairs or many in spherical colonies, free floating or entangled in common mucilage of other cyanobacteria, without sheath 2–3 µm in diam., with sheath 3–4 µm in diam; sheath unlamellated and colorless; protoplasm blue-green and homogeneous. Cell divides by insertion of plas-

ma membrane in transverse positions. After division, cells are attached for some time in depressed condition and later separate from each other, but remains within the common mucilaginous envelope.

The thickness of sheath in the present species (1 µm in diam.) was less than the originally described species (2 µm in diam.), but fairly closer to Rao's (1937) description (1.4–1.5 µm in diam). This difference could be due to the ecological variations.

Common habitat: Planktonic in tanks and lakes (Rao, 1937), rice field (Singh et al., 1997; Singh et al., 1997a; Amita Devi et al., 1999).

Distribution: Arunachal Pradesh, Manipur, Nagaland and Varanasi in India; Sri Lanka.

Chroococcus minor (KÜTZING) NÄGELI (Fig. 8)

Geitler (1932: 240, fig. 116g), Desikachary (1959: 105, pl. 24, fig. 1), Starmach (1966: 123, fig. 140).

Thallus mucilaginous, deep blue-green; cells spherical to hemispherical, single or in pairs, seldom 4–8 together, without sheath 4.5–5 µm in diam., depressed cells in diad state are 2.5–3 µm long; sheath colorless, very thin, visible in dark field at higher magnification, lamellated, protoplasm blue-green to grass green and granular. Cell divides by insertion of the plasma membrane into the protoplasm. Cells are depressed immediately after division; hemispherical when two daughter cells remain attached and spherical when they separate.

The present species varied in size from the description of original specimen (3–4 µm in diam.) however; same species with similar size has been reported from the rocky shores of Hong Kong (Nagarkar, 1998).

Common habitat: Epilithic and endolithic on rocky shores (Nagarkar, 1998), Marine (Aleem, 1980; Anand et al., 1986; Silva & Pienaar, 2000), rice field (Singh et al., 1997; Singh et al., 1997a, 1997b; Amita Devi et al., 1999), open sea, stagnant seawater, back waters, saltpans (Thajuddin & Subramanian, 1992).

Distribution: Arunachal Pradesh, Manipur, Nagaland, Tripura, Chennai and South East Coast in India; Hong Kong; Mauritius; Myanmar; West Africa.

GLOEOCAPSOPSIS GEILTER

Gloeocapsopsis crepidinum (THURET) GEITLER [basinonym: *Gloeocapsa crepidinum* THURET] (Fig. 9)

Komárek and Anagnostidis (1986: 191, fig. 20), Geitler (1932: 190, figs. 85, 86), Desikachary (1959: 117, pl. 27, figs. 4, 5), Starmach (1966: 115, fig. 122).

Thallus mucilaginous, olivaceous; cells are in groups of 2–4, seldom more, colonies spherical or oval, 12–22 µm in diam.; cells without sheath 4–7 µm in diam.; sheath thin, unlamellated, yellowish to brownish in color; protoplasm

yellowish brown to blue-green and granular. Cell divides both transversely and longitudinally; daughter cells are compressed and remain within a common hyaline to yellowish envelope. Repeated divisions yield nannocytes.

Common habitat: Microbial mat, mangrove and epilithic in marine environment (Hussain & Khoja, 1993), epilithic on rocky shore (Nagarkar, 1998), open sea, stagnant seawater, back water, saltpans (Thajuddin & Subramanian, 1992; Thajuddin et al., 2002).

Distribution: South East Coast in India; Hong Kong; Saudi Arabia.

ENTOPHYSALIDACEAE GEITLER

CHLOROGLOEA WILLE

Chlorogloea purpurea GEITLER (Fig. 10)

Geitler (1932: 311, figs. 156a, 156b), Starmach (1966: 157, fig. 192).

Thallus mucilaginous, microscopic; cells are irregularly arranged, blue-green to dark green, 2 µm in diam., 2 µm in length but, slightly smaller immediately after division, without any individual sheath, spherical to sub-spherical, polygonal when cells are more compactly packed in the common mucilage; protoplasm granular, deep green.

Common habitat: Alpine lakes, benthic and on limestones (Geitler, 1932).

Distribution: Germany.

DERMOCARPELLACEAE GINSB.-ANDRÉ EX T. CHRIST

CYANOCYSTIS BORZI

Cyanocystis versicolor (BORZI) GEITLER [basonym: *Dermocarpa versicolor* (BORZI) GEITLER] (Fig. 11)

Komárek and Anagnostidis (1986: 202, fig. 24/3), Geitler (1932: 403, fig. 228d), Desikachary (1959: 175, pl. 33, figs. 16, 17), Starmach (1966: 167, fig. 204).

Sporangia spherical, attached in the mucilage of *Lyngbya* sp., up to 15–16 µm in diam., sessile; endospores 4–8, 2–4 µm in diam., blue-green, cell division in three directions, liberation of endospores is by gelatinization of the sporangial wall. Mucilage envelope is very thin and colorless.

The size of endospores in the present species was bigger than the earlier described species (1.3–2.6 µm) from the marine sample of Kurusadai Island (Desikachary, 1959). This is a new record of epilithic cyanobacteria from the freshwater habitat of Assam.

Common habitat: Rice field (Singh et al., 1997; Amita Devi et al., 1999).

Distribution: Manipur and Nagaland in India.

OSCILLATORIALES ELENK.

PSEUDANABAENACEAE ANAGN. et KOM.

LEPTOLYNGBYOIDEAE ANAGN. et KOM.

LEPTOLYNGBYA ANAGN. et KOM.

Leptolyngbya boryana (GOMONT) comb. nov. [basonym: *Plectonema boryanum* GOMONT] (Fig. 12)

Anagnostidis and Komárek (1988: 391), Geitler (1932: 693).

Thallus mucilaginous irregularly expanded; filaments variously bent, false-branch present, single or geminate, sheath very thin, hyaline, unlamellated; trichome 1.5–2 µm in diam., cross wall constricted, septa not granular; cells are 2–3 µm in length, protoplasm blue-green and homogenous, end cell conical round.

Common habitat: Freshwater (Geitler, 1932).

Distribution: Germany.

Leptolyngbya calotrichoides (GOMONT) comb. nov. [basonym: *Plectonema calotrichoides* GOMONT] (Fig. 13)

Anagnostidis and Komárek (1988: 391), Geitler (1932: 683, fig. 437b).

Thallus mucilaginous, irregularly expanded; filaments not perforating, but entangled, sheath thin, hyaline, visible at higher magnification in dark field; trichome 2.5 µm in diam., straight to variously bent, false-branched, single or rarely geminate, cross wall indistinct; cells are slightly shorter or similar as length, 2–2.5 µm long, protoplasm blue-green to yellowish green and homogenous.

The present species followed the description of Geitler (1932), however varied from the description given by Umezaki & Lewmanomont (1991).

Common habitat: On marine rocks (Umezaki & Lewmanomont, 1991).

Distribution: Massachusetts; Thailand.

Leptolyngbya fragilis (GOMONT) comb. nov. [basonym: *Phormidium fragile* (MENEHINI) GOMONT] (Fig. 14)

Anagnostidis and Komárek (1988: 391), Geitler (1932: 999, fig. 636b), Desikachary (1959: 253, pl. 44, figs. 1–4).

Thallus mucilaginous; filaments yellowish to dull blue-green, fragile, more or less flexuous, entangled or free, sheath diffuent, hyaline; trichomes 1.5–1.8 µm in diam., cross wall constricted, septa not granular, 2.2–2.4 µm in length, protoplasm homogenous and blue-green. End cells are acute conical to round, calyptra absent.

Common habitat: Microbial mat in marine environment (Stal & Krumbein, 1985; Hussain & Khoja, 1993), epilithic on rocky shore (Nagarkar, 1998), open sea, stagnant seawater, back water, salt pan (Anand & Venkatesan, 1985; Thajuddin & Subramanian, 1992; Thajuddin et al., 2002), moist soil, walls of pond, rice field (Amita Devi et al., 1999).

Distribution: New Delhi, Kerala, Manipur, Orissa, Chennai, Kolkata, Mumbai and South East Coast in India;

Mellum in Germany; Hong Kong; Saudi Arabia.

Leptolyngbya notata (SCHMIDLE) comb. nov. [basionym: *Plectonema notatum* SCHMIDLE] (Fig. 15)

Anagnostidis and Komárek (1988: 392), *Geitler* (1932: 999, fig. 636b), *Desikachary* (1959: 440, pl. 83, fig. 5).

Thallus mucilaginous, dull blue-green; filaments variously bent, entangled, 1.7–2 µm in diam., sometimes with false-branches, both single and geminate, sheath thin, colorless, visible at higher magnification in dark field; trichome 1.5–1.8 µm in diam., cross wall indistinct but, constricted; cells are 1.8–2.4 µm in length; protoplasm blue-green, homogenous to slightly granular; end cells are round to acute round.

In the present species no refractive granules were observed at the cross wall; however protoplasm was granular in certain cells.

Common habitat: Rice field (Singh et al., 1997a), soil crust (Tirkey and Adhikary, 2005)

Distribution: Arunachal Pradesh and Old Goa in India.

Leptolyngbya tenuis (GOMONT) comb. nov. [basionym: *Phormidium tenue* (MENEHINI) GOMONT] (Fig. 16)

Anagnostidis and Komárek (1988: 393), *Geitler* (1932: 1004, fig. 642d, 642e), *Desikachary* (1959: 259, pl. 43, figs. 13–15 and pl. 44, figs. 7–9).

Thallus membranous, irregularly expanded, pale blue-green; trichome olive-green or blue-green, straight or slightly bent, but densely entangled, 1–2 µm in diam., cross wall constricted; cells are 2–5 µm long, protoplasm homogenous to slightly granular. A very thin, diffuent and hyaline sheath as well as cross wall could be seen in dark field at higher magnification. The end cells are attenuated, mostly acute conical or round, calyptra absent.

Common habitat: Damp rock (Prasad & Khanna, 1986), muddy shore (Chidambaram Pillai, 1999), rice field (Gupta & Sen, 1987), epilithic on rocky shore (Nagarkar, 1998), open sea, stagnant seawater, back water, salt pan (Anand & Venkatesan, 1985; Anand et al., 1986; Thajuddin & Subramanian, 1992; Thajuddin et al., 2002), moist soil surface, hot springs (Biswas, 1929), desert soil (Bhatnagar & Bhatnagar, 2005).

Distribution: New Delhi, Allahabad, Calcutta, Chennai, Gangtok, South East Coast, Thar desert and Tuticorin in India; Henzadah and Rangoon in Myanmar; Hong Kong; Malaya, Setapak and Kuala Lumpur in Malaysia; Lahore in Pakistan; Sri Lanka.

PHORMIDIACEAE ANAGN. et KOM.

PHORMIDIOIDEAE ANAGN. et KOM.

PHORMIDIUM KÜTZING ex GOMONT

Subgenera: **GOMONTINEMA** ANAGN. et KOM.

Phormidium laetevirens (CROUAN ex GOMONT) comb. nov. [basionym: *Oscillatoria laetevirens* CROUAN ex GOMONT] (Fig. 17)

Anagnostidis and Komárek (1988: 405, fig. 25/10), *Geitler* (1932: 949, fig. 603c), *Desikachary* (1959: 213).

Thallus thin, membranous, blue-green; trichome single, straight, yellowish green, cross walls slightly constricted, 3.5–3.75 µm in diam., cells are shorter than broad, 2–2.5 µm in length, apices slightly bent and attenuated, end cells are more or less obtuse, without any calyptra. Sheath very thin, hyaline and lamellate, visible only in the dark field.

According to “Geitlerian” system of taxonomy, this organism was identified as *Oscillatoria laetevirens* and the presence of thin sheath was the only difference from that of the originally described species. This particular character might left unseen or ignored in earlier observations. Hence, adding this character to this organism, even by traditional taxonomy this becomes a member of ‘*Phormidium*’, which supports the combined approach of *Anagnostidis & Komárek* (1988) in re-naming this organism as *Phormidium laetevirens*.

Common habitat: Film on rocks, wood work and on the bottom of the marsh pools, littoral, sometime pelagic (Zaneveld, 1972), estuary (Anand et al., 1986), open sea, stagnant seawater, back waters, salt pans (Thajuddin & Subramanian, 1992; Thajuddin et al., 2002), salt lake (Biswas, 1926), river (Biswas, 1942), on mud and stagnant water (Skuja, 1949).

Distribution: Adyar, Kolkata, and South East Coast in India; American Coast; Europe; Rangoon in Myanmar.

PORPHYROSIPHON KÜTZING ex GOMONT

Porphyrosiphon ceylanicus (WILLE) comb. nov. [basionym: *Lyngbya ceylanica* WILLE] (Fig. 18)

Anagnostidis and Komárek (1988: 409), *Geitler* (1932: 1054, fig. 668a), *Desikachary* (1959: 299, pl. 54, fig. 4).

Thallus dull blue-green; filaments straight to somewhat flexuous, 16–17 µm in diam., sheath thin, colorless, firm, yellowish when old; trichome blue-green, 12.5–13.5 µm in diam., cross wall not constricted, not granular; cells are as long as broad or slightly shorter than broad, protoplasm granular, end cell rotund to rounded and without calyptra.

The size of the trichome differed from the description of *Desikachary* (1959), but slightly similar in diam. with the descriptions of *Rao* (1937). Hence, this character of the present species could be flexible according to the environmental conditions.

Common habitat: Rice field (Bongale, 1981; Singh et al., 1997a), moist soil (*Rao*, 1937), bark of *Hevea brasiliensis*, algal mat, brackish water pond (Biswas, 1934; Santra et al.,

Figs. 1–16 Diagrammatic morphological features of freshwater epilithic cyanobacteria. 1. *Aphanothece nidulans* RITCHER - dispersed cells including the daughter cells in diad state, 2. *A. saxicola* NÄGELI - colony with irregularly arranged rounded-elongated cells, 3. *Cyanobacterium cedrorum* (SAUVAGEAU) comb. nov. - cylindrical cells undergoing transverse division in two equal parts, 4. *Aphanocapsa crassa* GHOSE - colonies showing globose to sub-spherical cells, 5. *A. muscicola* (MENEHINI) WILLE - colonies with different stages of cell division, 6. *Chroococcus cohaerens* (BRÉB.) NÄGELI - irregularly arranged cohered cells after transverse division, 7. *C. minimus* (KEISSLER) LEMM. - two to four celled colonies, 8. *C. minor* (KÜTZING) NÄGELI - thin sheathed cells undergoing division, 9. *Gloeocapsopsis crepidinum* (THURET) GEITLER - mucilaginous colonies of two to eight cells, 10. *Chlorogloea purpurea* GEITLER - loosely and irregularly arranged cells of varying morphology, 11. *Cyanocystis versicolor* (BORZI) GEITLER - daughter cells due to repeated divisions, 12. *Leptolyngbya boryana* (GOMONT) comb. nov. - trichomes with false-branch surrounded by thin sheath, 13. *L. calotrichoides* (GOMONT) comb. nov. - filaments with false-branch, 14. *L. fragilis* (GOMONT) comb. nov. - trichomes with diffuent sheath, 15. *L. notata* (SCHMIDLE) comb. nov. - false-branched trichomes with acute rounded end cells and 16. *L. tenuis* (GOMONT) comb. nov. - trichomes with acute conical apical cells and with diffuent sheath.

1988), stagnant pool (Parukutty, 1940), soil crust (Tirkey & Adhikary, 2005).

Distribution: Arunachal Pradesh, Assam, Karnataka, Cherapunji, Goa, Namdur, Salbani, Tiruchirappalli and Varanasi in India; Myanmar; Sri Lanka.

OSCILLATORIACEAE (S.F. GRAY) HARV. ex KIRCHNER

OSCILLATORIOIDEAE GOMONT

OSCILLATORIA VAUCHER ex GOMONT

Oscillatoria pseudogeminata SCHMIDT (Fig. 19)

Geitler (1932: 966, fig. 616), Desikachary (1959: 228, pl. 41, fig. 10).

Thallus grass green; trichome bent to coiled; cells are 2–2.4 μm in diam.; shorter than broad, 1.2–1.8 μm in length, cross wall thick, not constricted, end cell rounded, calyptra absent, protoplasm blue-green and homogenous. No sheath could be seen even at higher magnification and in the dark field.

Common habitat: Roadside stones (Kamat, 1962), among other algae, on submerged stones, leaves (Biswas, 1934; Rao, 1937, 1938; Rao, 1939; Parukutty, 1940), desert soil (Bhatnagar & Bhatnagar, 2005).

Distribution: Barpathar, Cuttack, Fatahil, Madhubani, Panhala, Sibsagar, Tampanur, Thar desert and Varanasi in India; Rangoon in Myanmar.

LYNGBYA C. AGARDH ex GOMONT

Lyngbya arboricola BRUHL et BISWAS (Fig. 20)

Geitler (1932: 1053), Desikachary (1959: 305, pl. 50, fig. 3 and pl. 55, fig. 1).

Filaments straight, blue-green, sheath colorless, very distinct even at lower magnification, unlamellate but firm; trichome 18–25 μm in diam., cross wall constricted, not granular; cells are 16–18 μm in length, blue-green, protoplasm somewhat transparent, homogenous to granular, reticulate, cells are depressed at the junction, apical cell of the trichome round, hormogonia present.

The characteristics of the present species resembled the description of Desikachary (1959); however, the trichome width of the present sample (18–25 μm) was wider than the original descriptions (18–22 μm with sheath). Rao also described narrower trichome (16–17.5 μm) (Desikachary, 1959). The diameter of the trichome of the present species was almost stable and, therefore, this could be a new variety.

Common habitat: Bark of *Mangifera indica* (Rao, 1937; Tripathi & Srivastava, 2001), soil crust (Tirkey & Adhikary, 2005).

Distribution: Bhubaneswar, Chennai, Kolkata, Tiruchirappalli and Varanasi in India.

NOSTOCALES (BORZI.) GEITLER

SCYTONEMATACEAE KÜTZING

SCYTONEMA AGARDH ex BORN. et FLAHL.

Scytonema millei BORNET ex BORN. et FLAHL (Fig. 21)

Komárek and Anagnostidis (1989: 281, fig. 12/a), Geitler (1932: 757, figs. 483a, 484), Desikachary (1959: 460, pl. 93, figs. 2, 3).

Thallus mucilaginous, but velvety, expanded, dull green; filaments almost parallel to interwoven, false-branch arises at 45–60° angle, single; trichome 17.5–20 μm in diam., vegetative cells are 5–7.5 (–10) μm in length, protoplasm highly granular, vacuolated, blue-green; heterocytes intercalary, single, similar or slightly compressed in size to that of vegetative cells, yellowish brown with two distinct polar nodules; apical cells are conical round.

Bharadwaja's (1934) species was slightly narrower than the type species, but, the present species was larger in diameter (17.5–20 μm) than the originally described species (10–15 μm), hence, this may be a new variety.

Common habitat: Aerophytic (Hoffmann, 1996), Immersed root surface, rice field (present study).

Distribution: India; Hanwella in Sri Lanka.

MICROCHAETACEAE LEMM.

TOLYPOTRICHIOIDEAE KOM. et ANAGN.

TOLYPOTHRIX KÜTZING ex BORN. et FLAHL.

Tolypothrix fragilis (GARDNER) GEITLER (Fig. 22)

Geitler (1932: 724, fig. 465), Desikachary (1959: 500, pl. 103, fig. 1).

Thallus membranous, slightly mucilaginous also; filaments short, straight or somewhat flexuous, sheath thin, colorless, not lamellated, false-branches many, single; trichome 3.5–3.75 μm in diam., cross wall indistinctly constricted, cells are as long as broad in older part of the trichome, however in the young stage, cells are shorter than broad, protoplasm yellowish green to pale blue-green, homogenous; heterocytes intercalary and basal, usually all axillary trichome is with one basal heterocyte, spherical or compressed, false-branch starts just below the intercalary heterocytes; hormogonia present, about 3–4 cell length.

The present species (3.5–3.75 μm diam.) varied in terms of cell diam. from the originally described species (4–5.5 μm diam.). However, earlier Indian species from Varanasi had broader trichome (4.9–6 μm diam.). These variations could be due to ecology and the present species might be a new ecotype.

Common habitat: On white washed wall (Rao, 1937)

Distribution: Varanasi in India.

RIVULARIACEAE KÜTZING

CALOTHRIX AGARDH ex BORN. et FLAHL.

Calothrix epiphytica W. et G.S. WEST (Fig. 23)

Geitler (1932: 606), Desikachary (1959: 543).

Filaments single or in groups, sheath thin, colorless; trichome straight to slightly bent; basal cells are slightly broader than rest, cells mid to the trichome are 3–3.6 μm in diam., cells at the apices are tapering, protoplasm blue-green and granular, cell length is gradually increases from the base, 6–8.4 μm at the mid of the trichome; heterocytes basal, single, small, conical-spherical to semi pear shaped.

Common habitat: On shells of *Thaia intha*, paddy field soil (Biswas, 1935; Gonzalves & Gangla, 1949; present study).

Distribution: Goregaon and Mumbai in India; Myanmar.

Calothrix scopulorum (WEBER et MOHR.) C. AGARDH ex BORNET et FLAH. (Fig. 24)

Geitler (1932: 600, fig. 374), Desikachary (1959: 524, pl. III, fig. 9).

Thallus caespitose or freely expanded, bright green to yellowish green; filaments slightly swollen at the base and attenuated into rounded apex, sheath hyaline, thick, unlamellated and dilated like a funnel; trichome 8–9.6 μm in diam. at the middle, base is slightly broader and apex is narrower; cells are 2.4–4.8 μm in length mid to the trichome, whereas at the base immediately after heterocyte, cells are 6 μm in length, protoplasm grass green and granular, cells are slightly depressed at the cross wall, heterocytes basal, yellowish, often many, hormogonia present.

Common habitat: Coral stones (Iyengar & Desikachary, 1944), rocks and concrete walls of marine habitat (Umezaki & Lewmanomont, 1991), microbial mat and mangrove of marine habitat (Stal & Krumbein, 1985; Hussain & Khoja, 1993), epilithic on rocky shore (Nagarkar, 1998), marine, open sea, stagnant seawater (Basson, 1979; Thajuddin & Subramanian, 1992), marine rocks (Aleem, 1980), paddy field (Bongale, 1981; present study).

Distribution: Karnataka, Goa, Kurusadai Island and South East Coast of India; Mellum in Germany; Hong Kong; Arabian Gulf Coast of Saudi Arabia; Thailand; West Africa.

NOSTOCACEAE DUMORT.

NOSTOCOIDEAE (BORZI) KOM. et ANAGN.

NOSTOC VAUCHER

Nostoc humifusum CARMICHAEL ex BORN. et FLAH. (Fig. 25)

Geitler (1932: 842), Desikachary (1959: 384).

Thallus mucilaginous, somewhat globose to irregular, variable sizes, sometimes even dot-like or expanded by merging several minute colonies, pale blue-green to brownish in color; filaments twisted, flexuous, densely entangled within the common mucilage, sheath mostly indistinct or thin, hyaline, visible only at higher magnification; trichome 2.4–3 μm in diam.; cells are sub-spherical, nearly as long

as broad, protoplasm blue-green, homogenous to slightly granular; heterocytes intercalary, 3 μm in diam. or slightly broader than the vegetative cells, sub-spherical; spores oval to sub-spherical, slightly bigger in size than the vegetative cells and heterocytes.

Common habitat: Rice field (Singh et al., 1997a; present study), stagnant freshwater, paddy field soil (Gonzalves & Gangla, 1949).

Distribution: Arunachal Pradesh, Khandala and Lonavla in India; Myanmar.

Nostoc punctiforme AGARDH ex BORN. et FLAH. (Fig. 26)

Geitler (1932: 860, fig. 548), Desikachary (1959: 390).

Thallus mucilaginous, soft, globose or ellipsoidal, variable in size, olivaceous or blue-green; filaments loosely entangled, bent to twisted, sheath thin, hyaline or rarely yellowish; trichome 5–6 μm in diam., cells are 3.6–4.8 μm in length, mostly little shorter than broad, barrel shaped or ellipsoidal; protoplasm blue-green and slightly granular; heterocytes intercalary, single, 6–7 μm in diam., larger than the vegetative cells, yellowish brown, sub-spherical, cell wall thick; spores are somewhat spherical, highly granular and bigger than heterocytes, grass-green in color.

The present species was similar to Desikachary (1959) and Geitler's (1932) description. However, Santra et al. (1988), reported with narrower trichome (3–4 μm diam.).

Common habitat: Rice field (Bongale, 1981; Santra et al., 1988; Singh et al., 1997; Singh et al., 1997a, 1997b; Ahmed et al., 1999; Amita Devi et al., 1999; present study), banana field (Mahajan & Mahajan, 1989), acidic soil (Dominic & Madhusoodanan, 1999), soil crust (Tirkey & Adhikary, 2005), desert soil (Bhatnagar & Bhatnagar, 2005).

Distribution: Arunachal Pradesh, Tripura, Manipur, Nagaland, Karnataka, West Bengal, Jammu & Kashmir, Kerala, Bhubaneswar, Kodaikanal, Mumbai, Nagaon, Old Goa, Tiruchirappalli and Thar desert in India; Lahore in Pakistan.

Nostoc oryzae (FRITSCH) comb. nov. [basonym: *Anabaena oryzae* FRITSCH] (Fig. 27)

Komárek and Anagnostidis (1989: 304), Desikachary (1959: 396, pl. 72, fig. 3).

Thallus mucilaginous, soft, blue-green to grass-green, membranous; trichomes short, straight or slightly bent, entangled in common mucilage, 3–3.5 μm in diam.; cells are more or less barrel shaped, 4–4.8 (–6) μm in length; protoplasm blue-green and highly granular; heterocytes mostly terminal, seldom intercalary, slightly broader than vegetative cells, barrel shaped to sub-spherical; spores in long chains or detached into single cells, bigger than vegetative cells, highly granular, dark green, sheath thick.

Figs. 17–29 Diagrammatic morphological features of freshwater epilithic cyanobacteria. 17. *Phormidium laetevirens* (CROUAN ex GOMONT) comb. nov. - thin diffluent sheathed trichome with bent apex, 18. *Porphyrosiphon ceylanicus* (WILLE) comb. nov. - straight to flexuous filaments, 19. *Oscillatoria pseudogeminata* SCHMIDT - bent trichome with thick cross wall, 20. *Lyngbya arboricola* BRUHL et BISWAS - reticulate-granular trichome with firm sheath, 21. *Scytonema millei* BORNET ex BORN. et FLAH - false-branched filament with intercalary heterocytes, 22. *Tolypothrix fragilis* (GARDNER) GEITLER - false-branched filament with basal and intercalary heterocytes, 23. *Calothrix epiphytica* W. et G.S. WEST - filament with basal pear shaped heterocyte, 24. *C. scopulorum* (WEBER et MOHR.) C. AGARDH ex BORNET et FLAH. - filament with broader base and basal heterocyte, 25. *Nostoc humifusum* CARMICHAEL ex BORN. et FLAH. - twisted filaments with intercalary heterocytes, 26. *N. punctiforme* AGARDH ex BORN. et FLAH. - filament containing barrel to ellipsoidal cells and intercalary heterocyte, 27. *N. oryzae* (FRITSCH) comb. nov. - heterocytes bearing trichome with barrel shaped cells and chain of highly granular spores, 28. *Parthasarathiella prolifica* SUBBA RAJU - true-branched filaments with heterocyte and 29. *Hapalosiphon welwitschii* WELWITSCHII W. et G.S. WEST - true-branched filaments with intercalary heterocyte.

Common habitat: Rice field (Santra et al., 1988; Singh et al., 1997; Singh et al., 1997a, 1997b; Ahmed et al., 1999; Amita Devi et al., 1999; present study), banana field (Mahajan & Mahajan, 1989).

Distribution: Arunachal Pradesh, Tripura, Manipur, Nagaland, Maharashtra, Uttar Pradesh, South 24-Pargana, Faridpur and Nagaon in India.

STIGONEMATALES GEITLER

FISCHERELLACEAE ANAGN. et KOM.

PARTHASARATHIELLA SUBBA RAJU

Parthasarathiella prolifica SUBBA RAJU (Fig. 28)

Subba Raju (1962: 50-58), Kovalenko et al. (1999: 121, figs. 6, 7).

Thallus grass-green to dark green, spots or semi balls on the rock surface, soft, mucilaginous, glistening; filaments with prostrate and creeping branches, densely entangled to form a compact mass, branching true, on one or all side of the filament, prostrate filament with single row of short, barrel shaped, rounded, spherical or compressed spherical cells, 5-7.5 µm in diam.; cells of erect branches are somewhat elongated, 2.5-5 µm in diam., 7-10 µm long, end cells are elongated and attenuated; heterocytes cylindrical, sometimes nearly quadrate, slightly narrower in diam., than the vegetative cells, 3.2-7 µm, protoplasm blue-green, granular; sheath absent, but at the end of the filament a thin sheath like structure is visible; hormogonia present, usually single celled at the end of the branch; endospores present, single, spherical or oval located in mono-endosporangium, granular, liberates by rupture at one end of the sporangium.

This species was found growing luxuriously on damp stones in highly shaded places, which served as the major food material for some migrating birds (personal observation). The species is a new record for Assam.

Common habitat: Soil (Kovalenko et al., 1999), paddy field, algal mat on soil surface (Subba Raju, 1962).

Distribution: India; Hanoi; Vietnam.

MASTIGOCLADACEAE GEITLER

MASTIGOCLADOIDEAE (ELENK.) ANAGN. et KOM.

HAPALOSIPHON NÄGELI in KÜTZING ex BORN. et FLAH.

Hapalosiphon welwitschii WELWITSCHII W. et G.S. WEST (Fig. 29)

Geitler (1932: 531, fig. 328a), Desikachary (1959: 588, pl. 137, fig. 5).

Thallus dark green, elevated; filaments densely entangled with true branches, prostrate and erect, sheath thin, firm and hyaline; cells are somewhat barrel shaped, quadrate or slightly longer than broad, 3.75-6.2 µm in diam. of prostrate

trichome, 5-10 m in length, erect branches short, as broad as the main filament or narrower, attenuated at the end, end cells are more elongate and pointed; heterocytes rare, intercalary, barrel shaped or elongated, somewhat narrower in diam. than the vegetative cells, 4-6 µm in diam., 6-8 µm long; spores are not seen in the present observation.

Common habitat: Rice field (Singh et al., 1997; Singh et al., 1997a, 1997b; Ahmed et al., 1999; Amita Devi et al., 1999), submerged bark (Gonzalvez & Kamat, 1960), marshy place in forest, paddy field soil, on moist bricks (Rao, 1937; Gonzalves & Gangla, 1949), soil crust (Turkey and Adhikary, 2005).

Distribution: Arunachal Pradesh, Tripura, Manipur, Nagaland, Karnataka, Goregaon, Mumbai, Nagaon, Old Goa, Salbani, Tiruchirappalli and Varanasi in India; Myanmar.

Discussion

The biodiversity of epilithic cyanobacteria from the freshwater streams of Kakojana reserve forest was remarkable. A total of 29 species (11 unicellular, 2 trichomatous, 7 non-heterocytous filamentous and 9 heterocytous filamentous) were recorded and described in detail including their common habitats and geographical distribution both regional as well as global. The taxa represent 4 orders, 12 families, 18 genera and 29 species based on recent combined taxonomical approach (Anagnostidis & Komárek, 1985; 1988; 1990; Geitler, 1932; Desikachary, 1959; Komárek & Anagnostidis, 1986; 1989). However, the original number of species may vary if an extensive and complete revision of cyanobacterial species with modern diacritical features is made. In the present study, there was a dominance of members of the order Chroococcales (38%), followed by Oscillatoriales (31%), Nostocales (24%) and Stigonematales (7%). However, this percentage dominance may not reflect a real picture for the order Chroococcales, since Komárek & Anagnostidis (1986, 1998) merged all the subsections of unicellular cyanobacteria into subsection I (i.e., Chroococcales) containing seven families. Furthermore, the phylogenetic analyses of 16S rRNA gene sequences neither support the unification of unicellular forms into a single order, nor the proposed family concept (Wilmoite and Herdman 2001). This study recorded for the first time, 11 unicellular (*A. crassa*, *A. muscicola*, *A. nidulans*, *A. saxicola*, *C. purpurea*, *C. cohaerens*, *C. minimus*, *C. minor*, *C. cedrorum*, *C. versicolor* and *G. crepidinum*) and 13 filamentous (*C. epiphytica*, *C. scopulorum*, *L. boryana*, *L. calotrichoides*, *L. fragilis*, *L. notata*, *L. arboricola*, *N. humifusum*, *N. oryzae*, *N. punctiforme*, *P. prolifica*, *P. ceylanicus* and *S. millei*) cyanobacteria as freshwater

epilithic forms. Of the 29 species described, except 6 species (*A. nidulans*, *H. welwitschii*, *N. punctiforme*, *N. oryzae*, *O. pseudogeminata* and *P. ceylanicus*), all are new records for Assam in particular, and 3 species (*C. purpurea*, *L. boryana* and *L. calotrichoides*) are new records for the country in general. All 6 heterocytous forms recorded in the study from the neighboring rice fields were also occur as epilithic on submerged stones and pebbles. The distribution of these heterocytous forms might be indicating the lower nitrogen status in both the environments (streams and rice fields). Presence of these heterocytous cyanobacteria in the paddy fields might be contributing to certain extent towards the nitrogen budget. Moreover, they are able to colonize almost all biotopes with their inherent adaptation capacity in response to environmental conditions (Sinha & Häder, 1996; Zehr et al., 2000; Kalib, 2002; Saha et al., 2003; Komárek, 2003). The distribution of these cyanobacteria in varied ecological conditions might be interrupting in proper taxonomic delimitation of species, since the morphologically similar species could have different genotype (Komárek, 2003). Further, if similar morphotypes from very different habitats represent different genotype, all the 24 species that were recorded for the first time from freshwater habitat might be new species, which needs further investigation. In conclusion, the present study documented a remarkable biodiversity of freshwater epilithic cyanobacteria that are distributed in various habitats suggesting their wide adaptability or varied genotype, which could be explored through future research.

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References

- Ahmed SU, Kalita MC, Deka M, Hazarika S & Medhi B (1999) Distributional pattern of blue-green algae in rice field soils of Nagaon sub-division. *Phykos* 38:101–107
- Aleem AA (1980) Marine cyanophyta from Sierra Leone (West Africa). *Bot. Mar.* XXIII:49–51
- Amita Devi G, Dorycanta H & Singh NI (1999) Cyanobacterial flora of rice field soils of Manipur. *Phykos* 38:13–18
- Anagnostidis K & Komárek J (1985) Modern approach to the classification system of cyanophytes 1 – Introduction. *Algol. Stud.* 38/39:291–302
- Anagnostidis K & Komárek J (1988) Modern approach to the classification system of cyanophytes 3 – Oscillatoriales. *Algol. Stud.* 50–53:327–472
- Anagnostidis K & Komárek J (1990) Modern approach to the classification system of cyanophytes 5 – Stigonematales. *Algol. Stud.* 59:1–73
- Anand N & Venkatesan N (1985) Note on blue-green algae from salt pans. *Seaweed Res. Utilin.* 7:101–103
- Anand N, Mohan E, Hopper RSS & Subramanian TD (1986) Taxonomic studies on blue-green algae from certain marine environments. *Seaweed Res. Utilin.* 9:49–56
- Basson PW (1979) Marine algae of the Arabian Gulf coast of Saudi Arabia. *Bot. Mar.* XXII:47–82
- Bharadwaja Y (1934) The taxonomy of *Scytonema* and *Tolypothrix* including some new records and new species from India and Ceylon. *Rev. Algol., Paris.* 7:149–178
- Bhatnagar A & Bhatnagar M (2005) Microbial diversity in desert ecosystems. *Curr. Sci.* 89 (1):91–100
- Biswas K (1926) Flora of the salt lakes, Calcutta. *J. Dept. Sci., Calcutta Univ.* 8:1–47
- Biswas K (1929) Papers on Malayan aquatic biology. Freshwater algae with addendum. *J. Federated Malay States Museums.* 14:404–435
- Biswas K (1930) Contributions to the knowledge of the freshwater algae of Manipur, Assam. *J. Bombay Nat. Hist. Soc.* 34:189–192
- Biswas K (1934) Observations on the algal collections from the Khasia and Jaintia Hills, Assam, India. *Hedwigia.* 74: 1–28
- Biswas K (1935) Association of some of the common algae with animals in Indian waters. *Hedwigia.* 76:114–130
- Biswas K (1942) The role of common algal communities of the river Hoogly on the drinking water, Calcutta. 150th Ann. Vol. *Royal Bot. Garden*:189–206
- Bongale UD (1981) On soil algae from paddy fields of Panjim (Goa) and Chikkamanchali (Raichur Dist., Karnataka), India. *J. Indian Bot. Soc.* 60:326–329
- Bordoloi RP (1980) Studies on the algal flora of Assam and Meghalaya. In: *Taxonomy of Algae*, University of Madras, pp 173–179
- Bornet E & Flahault C (1886–1888) Révision des Nostocacées hétérocystées. *Ann. Sci. Not. Bot.*, 7. Ser., 3:323–381, 4:343–373, 5:51–129, 7:177–262
- Chidambaram Pillai S (1999) Cyanobacteria as bioindicators of power station hot water effluents. *J. Environ. Pollution.* 6: 157–160
- Desikachary TV (1959) A monograph on Cyanophyta. - Indian Council of Agricultural Research, New Delhi, India
- Dominic TK & Madhusoodanan PV (1999) Cyanobacteria from extreme acidic environments. *Curr. Sci.* 77: 1021–1023
- Ganapathi SV (1940) Studies on the chemistry and biology of the slow sand filters at the Madras water works. *Proc. Natl. Inst. Sci., India.* 6:237–300
- Geitler L (1932) Cyanophyceae. In: von Deutschland, österreich und der Schweiz, (eds.), L Rabenhorst's Kryptogamen Flora. Akademische Verlagsgesellschaft, Leipzig
- Ghose SL (1927) The myxophyceae of Rangoon, III. *J. Burma Res. Soc.* 17:237–243
- Gonzalves EA & Gangla KS (1949) Observations on the algae of paddy-field soils. *J. Univ. Bombay.* 18:51–59
- Gonzalves EA & Kamat ND (1960) The Myxophyceae of the Karnataka II. *J. Univ. Bombay.* XXVIII:20–27

29. Gupta D & Sen C (1987) Observations on blue-green algae of paddy-field soils of Gangetic West Bengal, I. Burdwan District. *Indian Agriculturist*. 31:221–225
30. Hoffmann L (1996) 4. Geographic distribution of freshwater blue-green algae. *Hydrobiologia*. 336:33–40
31. Hussain MI & Khoja TM (1993) Intertidal and sub tidal blue-green algal mats of open and mangrove areas in the Farasan Archipelago (Saudi Arabia), Red Sea. *Bot. Mar.* 36: 377–388
32. Iyengar MOP & Desikachary TV (1944) A systematic account of some marine myxophyceae of the South Indian coast. *J. Madras Univ.* 16:37–68
33. Kalib A (2002) Studies on cyanobacterial tolerance to desiccation. Unpublished Ph. D. Thesis, Bharathidasan University, Tiruchirappalli, India
34. Kamat ND (1962) The cyanophyceae and the chlorophyceae of Panhala. *J. Univ. Bombay*. XXX:22–31
35. Komárek J & Anagnostidis K (1986) Modern approach to the classification system of cyanophytes 2 – Chroococcales. *Algol. Stud.* 43:157–226
36. Komárek J & Anagnostidis K (1989) Modern approach to the classification system of cyanophytes 4 – Nostocales. *Algol. Stud.* 56:247–345
37. Komárek J & Anagnostidis K (1998) Cyanoprokaryota. 1. Teil chroococcales. G. Fischer, Jena
38. Komárek J, Kopecký J & Cepák V (1999) Generic characters of the simplest cyanoprokaryotes *Cyanobium*, *Cyanobacterium* and *Synechococcus*. *Cryptogamie. Algol.* 20(3): 209–222
39. Komárek J (2003) Areas of distribution in cyanobacteria; specificity of the cyanoprokaryotic microflora in the Mediterranean region. In: Boccone-16, Raimond, F.G. (ed.), *Proc. X OPTIMA Meet., Herbarium Mediterranean Panormitanum, Palermo*. pp 341–354
40. Kovalenko OV, Hoa NV & Belikova OA (1999) Representatives of cyanophyta new for Vietnam. *Int. J. Algae*. 1: 115–124
41. Mahajan AD & Mahajan N (1989) Addition to Nostocaceae Kuetz. from banana field of Jalgaon district, Maharashtra. In: *Advances in Applied Phycology-II, Today & Tomorrow's Printers & Publishers, New Delhi*. pp 187–191
42. Mitra AK (1951) The algal flora of certain Indian soils. *Indian J. Agric. Sci.* 21:357–373
43. Mollenhauer D, Büdel B & Mollenhauer R (1994) Approaches to species delimitations in the genus *Nostoc* Vaucher 1803 ex Bornet et Flahault 1888. *Algol. Stud.* 75: 189–209
44. Nagarkar S (1998) New records of marine cyanobacteria from rocky shores of Hong Kong. *Bot. Mar.* 41:527–542
45. Parukuty PR (1940) The myxophyceae of the Travancore State, India. *Proc. Indian Acad. Sci.* 11:117–124
46. Prasad BN & Khanna P (1986) The cyanophycean flora of Sikkim-I. Oscillatoriaceae. *J. Indian Bot. Soc.* 66: 253–260
47. Rao CB (1936) The myxophyceae of the United Provinces, India-II. *Proc. Indian Acad. Sci.* 3:165–174
48. Rao CB (1937) The myxophyceae of the United Provinces, India-III. *Proc. Indian Acad. Sci.* 6:339–375
49. Rao CB (1938) The myxophyceae of the Madras Presidency, India-I. *J. Indian Bot. Soc.* 17:81–96
50. Rao CS (1939) The myxophyceae of the Bihar Province, India-I. *Proc. Indian Acad. Sci.* 9:142–150
51. Richmond A (1990) Large scale microalgal culture and applications. In: *Algal Biotechnology- progress in phyco-logical research*, vol. 7, Round FE & Chapman DJ (eds.), Biopress Ltd, Bristol, U.K. pp 1–61
52. Rippka R & Cohen-Bazire G (1983) The cyanobacteriales: A legitimate order based on the type strain *Cyanobacterium stanieri*?. *Annales de Microbiologie (Institut Pasteur)*. 134B: 21–36
53. Rippka R, Deruelles J, Waterbury JB, Herdman M & Stanier RY (1979) Generic assignments, strain histories and properties of pure cultures of cyanobacteria. *J. Gen. Microbiol.* 111:1–61
54. Rout J & Dey A (1999) A study of algal flora from rice fields of Irongmara, Barak valley, Assam. *Phykos*. 38:19–25
55. Saha SK, Uma L & Subramanian G (2003) Nitrogen stress induced changes in the marine cyanobacterium *Oscillatoria willei* BDU 130511. *FEMS Microbiol. Ecol.* 45 (3): 263–272
56. Santra SC, Pal UC, Maity H & Bandyopadhyaya G (1988) Blue-green algae in saline habitats of West Bengal: A systematic account. *Biol. Mem.* 14:81–108
57. Silva SMF & Pienaar RN (2000) Some benthic marine cyanophyceae of Mauritius. *Bot. Mar.* 43:11–27
58. Singh NI, Dorycanta H, Devi GA, Singh NS & Singh SM (1997) Blue-green algae from rice field soils of Nagaland. *Phykos*. 36:115–120
59. Singh NI, Singh NS, Devi GA & Singh SM (1997a) Blue-green algae from rice growing areas of Arunachal Pradesh. *Phykos*. 36:21–26
60. Singh NI, Singh NS, Devi GA, & Singh SM (1997b) Cyanobacterial flora of rice field soils of Tripura. *Phykos*. 36: 121–126
61. Sinha RP & Häder D-P (1996) Photobiology and ecophysiology of rice field cyanobacteria. *Photochem. Photobiol.* 64: 887–896
62. Sinha RP, Kumar HD, Kumar A & Häder D-P (1995) Effects of UV-B irradiation on growth, survival, pigmentation and nitrogen metabolism enzymes in cyanobacteria. *ACTA Protozool.* 34:187–192
63. Sinha RP, Singh N, Kumar A, Kumar HD & Hder D-P (1997) Impacts of Ultraviolet-B irradiation on nitrogen-fixing cyanobacteria of rice paddy fields. *J. Plant Physiol.* 150: 188–193
64. Skuja H (1949) Zur Süßwasseralgenflora Burmas. *Nova acta Regiae Societatis scientiarum Upsaliensis*, series IV. 14:1–188
65. Stal LJ & Krumbein WE (1985) Isolation and characterization of cyanobacteria from a marine microbial mat. *Bot. Mar.* XXVIII:351–365
66. Starmach K (1966) Cyanophyta-Sinice, Glaucophyta-Glaucophyta, Flora slodkowodna Polski, tom 2, Warszawa
67. Subba Raju N (1962) *Parthasarathiella prolifica* gen. et sp. nov. a new number of the Stigonemataceae. *Transactions Ame. Microscopical Soc.* 81:50–58
68. Sundararaman M & Sekar S (2001) Biotechnological potential of cyanobacteria. In: *Algal biotechnology*, Trivedi PC (ed.), Pointer Publishers, Jaipur, India. pp 31–52

69. Thajuddin N & Subramanian G (1992) Survey of cyanobacterial flora of the southern east coast of India. *Bot. Mar.* 35: 305–314
70. Thajuddin N & Subramanian G (2005) Cyanobacterial biodiversity and potential applications in biotechnology. *Curr. Sci.* 89 (1):47–57
71. Thajuddin N, Nagasathya A, Chelladevi R & Saravanan L (2002) Biodiversity of cyanobacteria in different salt pans of Pudukkottai district, Tamil Nadu. *Seaweed Res. Utilin.* 24:1–11
72. Tirkey J & Adhikary SP (2005) Cyanobacteria in biological soil crusts of India. *Curr. Sci.* 89 (3):515–521
73. Tripathi SN & Srivastava P (2001) Presence of stable active oxygen scavenging enzymes superoxide dismutase, ascorbate peroxidase and catalase in a desiccation-tolerant cyanobacterium *Lyngbya arboricola* under dry state. *Curr. Sci.* 81:197–200
74. Umezaki I & Lewmanomont K (1991) The marine blue-green algae of Thailand. *Thai Marine Fisheries Res. Bull.* 2:31–45
75. Vinogradova ON (1999) Species composition and distribution of cyanophyta in water bodies of the Mountain Crimea (Ukraine). *Int. J. Algae.* 1:76–87
76. Wilmotte A & Herdman M (2001) Phylogentic relationships among the cyanobacteria based on 16S rRNA sequences. In: *Bergey's manual of systematic bacteriology*, 2nd edition, vol. 1, Boone DR & Castenholz RW (eds.), Springer-Verlag, New York. pp 487–493
77. Zaneveld J (1972) The marine algae of the American coast between Cape May, N.J. and Cape Hatteras, N.C. *Bot. Mar.* 9:101–128
78. Zehr JP, Carpenter EJ & Villareal TA (2000) New perspectives on nitrogen-fixing microorganisms in tropical and subtropical oceans. *Trends Microbiol.* 8 (2):68–73