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New records and distribution pattern of mangrove-associated cyanobacteria of South West Coast of India

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Diversity and species composition of mangrove-associated cyanobacteria from the South West Coast of India showed the occurrence of 16 species representing 3 orders, 6 families, and 10 genera based on morpho-taxonomic characterization, which is supported by the microscopic evaluation. The present study recorded planktic (7 spp.), epipsammic (4 spp.), epiphytic (2 spp.), corticolous (2 spp.) and 1 benthic species. Among these, six taxa were reported for the first time from the marine ecosystem of India. The present study aims to facilitate our knowledge of the taxonomy, diversity, habitat and geographical distribution of the mangrove-associated cyanobacteria in India.

[**Keywords**: Cyanobacteria, Mangrove ecosystem, Marine, New records, South West Coast of India, Taxonomy]

Introduction

Mangroves, the green woody plants that grow in tropical and subtropical latitudes at the interface between the land-sea, exist in high salinity conditions, extreme tides, strong winds, high temperatures and muddy anaerobic soils[1]. The mangrove ecosystem, considered as the most sustainable and biologically diverse in the world, provides an important role in coastal zones as a barrier against floods, cyclones, tsunamis, storms and hurricanes. Mangroves are highly productive in the estuarine system, which serves as a reservoir of organic materials and nutrients, and provides nursery grounds for many organisms. Mangrove forests at Alappuzha were a large area of different mangrove varieties, but now it exists only for namesake[2]. In Alappuzha district, mangrove forests are restricted only to one or two localities, *i.e.* Ezhupunna and Pathiramanal. In Ezhupunna, major mangrove species are *Bruguiera cylindrica* (L.) Blume, *Excoecaria agallocha* L., *Rhizophora mucronata* Lam., *Kandelia candel* (L.) Druce, *Avicennia officinalis* L., *Avicennia marina* (Forssk.) Vierh and *Bruguiera gymnorrhiza* (L.) Lam. Pathiramanal, a small island situated at the backwaters of Vembanad, harbours true mangroves like *Sonneratia caseolaris* (L.) Engl., *Excoecaria agallocha* L., *Rhizophora apiculata* Blume and *Bruguiera cylindrica* (L.) Blume[2-4].

The submerged parts of mangrove roots, tree trunks and branches function as islands of habitat that can attract rich epifloral and faunal communities, including bacteria, fungi, macroalgae and invertebrates[1]. Mangrove leaf litter and microflora has become the base of a characteristic food chain that feeds a wide range of marine and estuarine fauna. Mangroves are highly specialized ecosystems that support a wide range of microbial species that live on sediment, plant surfaces, and water, and they play an important role in biogeochemical cycles[5]. Cyanobacteria are the crucial component of microbiota in mangrove habitats along the tropical and subtropical coasts and supply an oxygenic atmosphere to our planet[1].

Mangrove-associated cyanobacteria are significant not because of their abundance but also for their high nitrogen fixation capability, which are natural candidates for future reforestation, restoration of destroyed mangroves and providing oxygen to the atmosphere through photosynthesis[6]. But only a few studies have been carried out on the diversity and distribution of mangrove-associated cyanobacteria in Kerala. The studies on these species associated with mangroves have been ignored or are comparatively

lesser[7,8], and no studies were undertaken regarding different zones[9-12] (seaward fringes and Landward end) of the mangrove ecosystem. The diversity of this particular group is unexplored on the Kerala coast due to the lack of exploration, seasonal collection of samples and above all, the availability of Cyanobacteriologists. Therefore, the present research was conducted to understand the occurrence of unexplored cyanobacterial diversity in mangroves on South West Coast of India.

Materials and Methods

The study was conducted through extensive field visits for three years, from December 2017 to January 2020, in the mangrove areas of Alappuzha district, Kerala, distributed along the South West Coast of India. Samples were collected from two sampling stations, Ezhupunna (9°49'19" N, 76°18'12" E) and Pathiramanal (9°37'28" N, 76°22'19" E) (Fig. 1). Cyanobacterial samples were collected from the water bodies, soil, bark and pneumatophores of mangrove plants in duplicate. With the help of sterile blades, the samples were scraped, transferred into sterile plastic bottles and transported to the Department of Botany, MES Asmabi College, Kodungallur, Kerala, for taxonomic and culture studies.

In the laboratory, within 6 – 8 h, one set of samples was preserved in a 4 % formaldehyde solution. The other set of live samples were observed under a compound microscope and then transferred to BG11 medium[13] for culture, and they were maintained in the culture room under a white fluorescent lamp (±3000 lux), 14”10 L/day at ±25 °C. Microscopic analysis was done in live conditions for the identification of cyanobacteria. Photomicrographs were taken using a Leica DM 1000 LED compound microscope. The cyanobacterial species were identified using the monographs and standard works of literature[14-20]. Using all available information, morpho-taxonomic identification was done up to the species level.

Results

The present study investigated the diversity and taxonomy of cyanobacteria associated with mangroves of Alappuzha district in Kerala. Based on microscopic observations, a total of 16 species - 2 unicellular and 14 filamentous (6 non-heterocytous and 8 heterocytous) belonging to 3 orders, 6 families, 10 genera were identified and characterized in detail, on the basis of their habitat and distribution. Morpho-taxonomic description of each species is presented together with the geographical distribution, place of collection and occurrence of their habitat.

Systematics

Order: Chroococcales

Family: Aphanothecaceae

1) *Aphanothece stagnina* (Sprengel) A. Braun in Rabenhorst, lgen Europa's, Fortsetzung der Algen Sachsens, Resp. Mittel-Europa's, 1863, (57-58):1561-1580.

References

(Komarek and Anagnostidis 1998; Desikachary 1959).

Synonyms

Coccochloris stagnina Sprengel 1807; *Palmella mooreana* Harvey 1841; *Aphanothece prasina* A. Braun 1863; *Aphanothece piscinalis* Rabenhorst 1865; *Aphanothece mooreana* (Harvey) Lagerheim 1883; *Aphanothece tuberculosa* Forti 1907; *Anacystis rupestris* var. *prasina* (A. Braun) F. E. Drouet & W. A. Daily 1942.

Description

Thallus gelatinous, distinct, spherical, ellipsoidal, brownish or violet; cells oblong, more or less ovoid or widely cylindrical with rounded ends, 3.6 μm – 4.9 μm broad, 6.7 μm – 12.3 μm long, densely or sparsely arranged, without individual envelopes, homogeneous mucilage.

Distribution

This species was reported from the rocks and sand of the mangrove environment[21], tree trunks and roots[22], planktic[23], epilithic[24], rock pool water and coastal water of the mangrove environment[25].

Habitat

Dark blackish or brownish mat collected from the mangrove soil surface.

Specimen examined

INDIA: Kerala; Alappuzha, Pathiramanal; MES 13716; Figure 2A.

Order: Chroococcales

Family: Chroococcaceae

2) *Chroococcus indicus* Zeller, Journal of the Asiatic Society of Bengal. 1873, 42(2): 175-193.

References

(Komarek and Anangnostidis 1998; Desikachary 1959)

Description

Thallus gelatinous, thin, pale brownish; cells single, oblong to sub-spherical, 3.4 μm – 10.8 μm

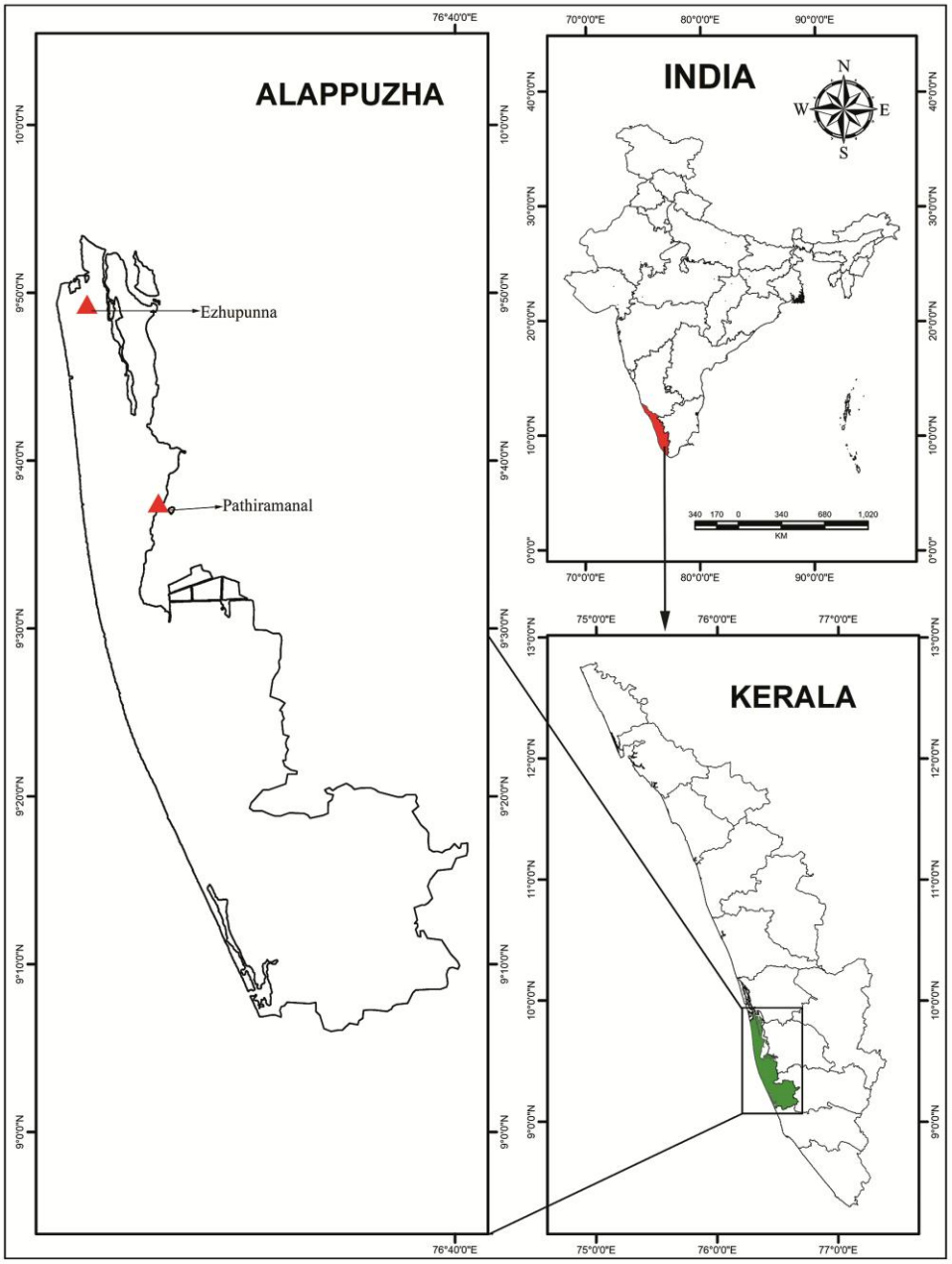

Fig. 1 — Map showing the location of sampling sites in the Alappuzha mangrove ecosystem

long, 3.5 µm – 7.5 µm broad, olive green; sheath hyaline, conspicuous, contents granular.

Distribution

This species was reported as a planktic form[26].

Habitat

Pneumatophores of *Avicennia officinalis* L. (dark brownish colour).

Specimen examined

INDIA: Kerala; Alappuzha, Ezhupunna; MES 13707; Figure 2B.

Order: Oscillatoriales

Family: Microcoleaceae

3) ***Kamptonema chlorinum*** (Kutzing ex Gomont) Strunecky, Komarek & J. Smarda, Preslia (Prague). 2014, 86:193-207.

Reference

(Strunecky *et al.* 2014)

Synonyms

Oscillatoria chlorina Kützing 1843, *Oscillatoria chlorina* Kutz. Ex Gomont, *Phormidium chlorinum*

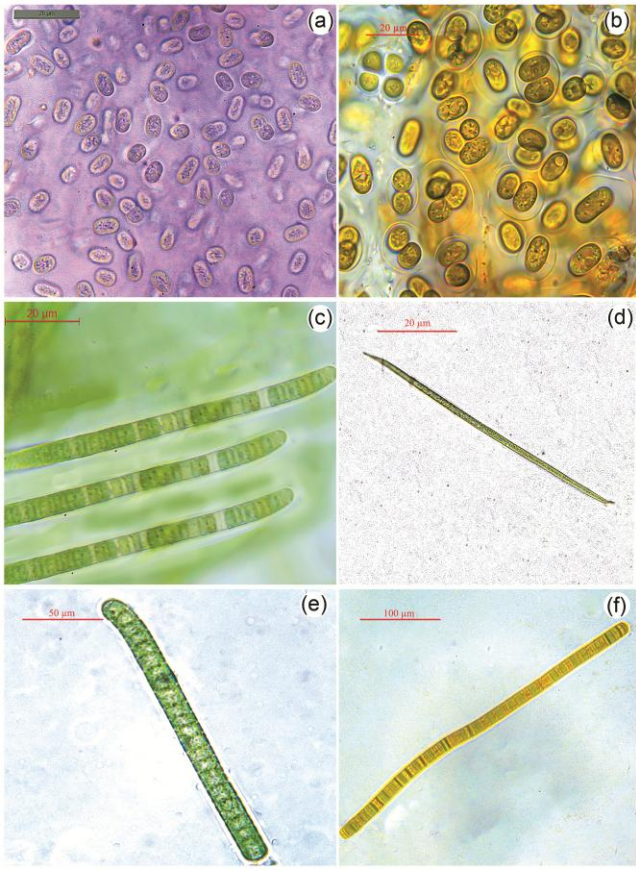

Fig. 2 — A) *Aphanothece stagnina* (Sprengel) A. Braun in Rabenhorst, B) *Chroococcus indicus* Zeller, C) *Kamptonema chlorinum* (Kutzing ex Gomont) Strunecky, Komarek, D) *Phormidium acula* (Bruhl & Biswas) Anangnostidis & Komarek, E) *Phormidium chalybeum* (Mertens ex Gomont) Anagnostidis et Komarek & J. Smarda, and F) *Oscillatoria subbrevis* Schmidle

(Kützing ex Gomont) Umezaki & Watanabe 1994, *Lyngbya chlorina* Hansgirg 1885, *Lyngbya amoena* var. *chlorina* Hansgirg ex Forti 1907.

Description

Thallus very thin, yellowish-green; trichome straight or curved, not constricted at the cross-walls; cells 3.8 µm – 7.6 µm long, 3.6 µm – 3.9 µm broad, cross-walls not granulated; calyptra absent.

Distribution

This species was reported from edaphic[25,24], epiphytic[27-29], soils[30], mangrove sediments[31] and estuary regions[32].

Habitat

Dark greenish planktic form.

Specimen examined

INDIA: Kerala; Alappuzha, Pathiramanal; MES 13711; Figure 2C.

Order: Oscillatoriales
Family: Oscillatoriaceae

4) *Phormidium acula* (Bruhl & Biswas) Anangnostidis & Komarek, Archiv für Hydrobiologie, Supplement. 1988, 80: 327-472.

Reference

(Komarek and Anagnostidis 2005).

Synonym

Oscillatoria acula Bruhl & Biswas 1922.

Description

Trichomes solitary or in fascicles, straight, narrow, not constricted at the cross-walls, 4.2 µm – 5.6 µm broad, 372.4 µm long; cells 3.1 µm – 3.8 µm long; terminal cells narrowed, hooked, non-capitate, non-calyptrate apex, which may be straight but is more often rather abruptly bent aside, contents bluish-green, finely granular.

Distribution

This species was reported from the mangrove sediments[26] and estuary regions[7,32].

Habitat

Dark Greenish mat collected from the bark of *Rhizophora mucronata* Lam.

Specimen examined

INDIA: Kerala; Alappuzha, Pathiramanal; MES 13718; Figure 2D.

Order: Oscillatoriales
Family: Oscillatoriaceae

5) *Phormidium chalybeum* (Mertens ex Gomont) Anagnostidis et Komarek, Archiv für Hydrobiologie, Supplement. 1988, 80: 327-472.

Reference

(Komarek and Anagnostidis 2005).

Synonyms

Oscillatoria chalybea (Mertens) Gomont 1892, *Lyngbya chalybea* Hansgirg 1892, *Oscillatoria chalybea* var. *genuina* Gomont 1892, *Oscillatoria chalybea* var. *anguina* Gomont 1892.

Description

Thallus blue-green to black-green, trichome straight, slightly constricted at the cross-walls, olive green, 3.5 µm – 7.7 µm long, 8.3 µm – 11.4 µm broad, attenuated at the apex and somewhat bent, end cell obtuse, not capitate, without calyptra.

Distribution

This species was reported from edaphic[24,25] and mangrove sediments[26].

Habitat

Green coloured planktic form.

Specimen examined

INDIA: Kerala; Alappuzha, Pathiramanal; MES 13713; Figure 2E.

Order: Oscillatoriales

Family: Oscillatoriaceae

6) ***Oscillatoria subbrevis*** Schmidle, Die von W. Goetze am Rukwa-See und Nyassa-See sowie in den zwischen beiden Seen gelegenen Gebirgsländern, insbesondere dem Kinga-Gebirge gesammelten Pflanzen, nebst einigen Nachträgen (durch bezeichnet) zu Bericht III. 1901, 243.

References

(Komarek and Anangnostidis 2005; Desikachary 1959).

Description

Trichomes single, yellow-grey to green yellowish, not occurring in a mass, free-floating, long, straight, not constricted at the ungranulated cross-walls, not attenuated at the apices; cells 1.5 μm – 2.0 μm long, 5.3 μm – 5.9 μm broad, end cell rounded, without calyptra.

Distribution

This species was reported from the dried-up riverbed at Sundarbans[26], epiphytic[21,27,33], planktic[34, 35,47] and mangrove water samples[36].

Habitat

Planktic (dark greenish colour), slightly thread-like appearance.

Specimen examined

INDIA: Kerala; Alappuzha, Pathiramanal; MES 13709; Figure 2F.

Order: Oscillatoriales

Family: Oscillatoriaceae

7) ***Oscillatoria limosa*** C. Agardh ex Gomont, Annales des Sciences Naturelles, Botanique, Série 7. 1892, 16: 91-264.

References

(Komarek and Anagnostidis 2005; Desikachary 1959).

Synonyms

Conferva limosa Dillwyn 1802, *Oscillatoriella limosa* (Dillwyn) Gaillon 1833, *Oscillatoria tenuis* var. *limosa* (Dillwyn) Kirchner ex Forti 1907, *Phormidium limosum* (Dillwyn) P.C.Silva 1996.

Description

Thallus dark green, extended, thick, often layered, free-floating tufts at the water level. Trichomes olive green, straight, not constricted at the cross-walls, cells 2.3 μm – 4.6 μm long, 13.2 μm – 15.4 μm broad, cross-walls granulated, not attenuated at the ends, apical cells flatly rounded with slightly thickened.

Distribution

This species was reported as periphytic on dead submerged substratum from Sundarbans[30], epipelic mats and epiphytic[27,37,29], benthic[38], planktic[39], mangrove water samples[36], mangrove backwaters[40], epiphytic and mangrove swamps[24].

Habitat

Dark greenish coloured planktic form.

Specimen examined

INDIA: Kerala; Alappuzha, Pathiramanal; MES 13710; Figure 3A.

Order: Oscillatoriales

Family: Oscillatoriaceae

8) ***Oscillatoria curviceps*** Agardh ex Gomont, Annales des Sciences Naturelles, Botanique, Série 7. 1892, 16: 91-264.

References

(Komarek and Anagnostidis 2005; Desikachary 1959).

Description

Thallus dark blue-green; trichomes more or less straight, long, motile, somewhat bent at the ends, not attenuated, not constricted at the cross walls; cells 2.0 μm – 4.2 μm long, 10.4 μm – 15.2 μm broad, cross-walls granulated, end cells flat rounded, not capitate.

Distribution

This species was reported from planktic[41], mangrove swamps[44], planktic[34], epiphytic[41] and mangrove sediments[31].

Habitat

Dark Greenish mat collected from the soil surface.

Specimen examined

INDIA: Kerala; Alappuzha, Pathiramanal; MES 13717; Figure 3B.

Order: Nostocales

Family: Hapalosiphonaceae

9) ***Hapalosiphon welwitschii*** West & G. S. West, Journal of Botany, British and Foreign. 1897, 35: 242.

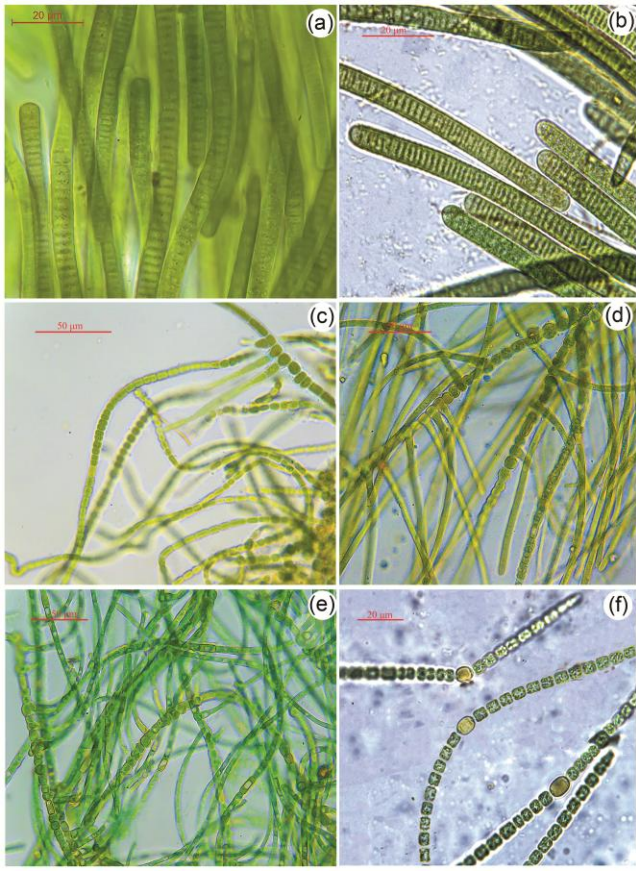

Fig. 3 — A) *Oscillatoria limosa* C. Agardh ex Gomont, B) *Oscillatoria curviceps* Agardh ex Gomont, C) *Hapalosiphon welwitschii* West & G. S. West, D) *Westiellopsis prolifica* Janet, E) *Westiellopsis interrupta* Kanthamma, and F) *Anabaena inaequalis* (Kutzing) Bornet et Flahault

References

(Komarek 2013; Desikachary 1959).

Description

Thallus dark green, filaments densely entangled with branches, prostrate and erect; cells cylindrical, barrel-shaped, quadrate, 5.5 µm – 7.2 µm broad, 3.3 µm – 5.2 µm long. Lateral branches short, as broad as the main filament or narrower, 3.5 µm – 4.2 µm long, 5.4 µm – 6.0 µm broad, slightly attenuated at the end. Heterocytes intercalary, long cylindrical, 5.6 µm – 7.2 µm long, 4.6 µm – 5.9 µm broad.

Distribution

This species was reported from mangrove water samples[43,47].

Habitat

Green coloured planktic.

Specimen examined

INDIA: Kerala; Alappuzha, Pathiramanal; MES 13708; Figure 3C.

Order: Nostocales

Family: Hapalosiphonaceae

10) *Westiellopsis prolifica* Janet, Annals of Botany. 1941, 5(1): 167-170.

References

(Komarek 2013; Desikachary 1959).

Synonym

Parthasarathiella prolifica Suba Raju 1962.

Description

Main filaments cylindrical, flexuous, with short barrel-shaped cells, monoseriate trichomes, which are distinctly constricted at the cross walls, cells in main trichomes barrel-shaped to irregular rounded which are as long as broad, 7.8 µm – 11.7 µm broad, or slightly longer, 8.6 µm – 14.1 µm long. Branched filaments thinner than main filaments, which are arising from the horizontal system and are not constricted at the cross walls, with elongate cylindrical cells, 7.5 µm – 13.1 µm long, 5.5 µm – 6.0 µm broad. Heterocytes intercalary, either quadrate or oblong-cylindrical, 5.5 µm – 6.2 µm broad, 10.5 µm – 21.6 µm long.

Distribution

This species is recorded for the first time from the marine habitat.

Habitat

Green coloured planktic.

Specimen examined

INDIA: Kerala; Alappuzha, Ezhupunna; MES 13705; Figure 3D.

Order: Nostocales

Family: Hapalosiphonaceae

11) *Westiellopsis interrupta* Kanthamma in Jeeji-Bai, Desikachary T.V. (ed.) Taxonomy and biology of blue-green algae. University of Madras, Madras, 1972, 62–74.

References

(Jeeji-Bai 1972; Komarek 2013)

Description

Main filaments cylindrical, irregularly coiled, mono-seriate, from which grow perpendicularly (unidirectional T-shaped) branches, which are thinner, constricted at the cross-walls. Cells in main filaments barrel-shaped, 2.7 µm – 7.7 µm long, 3.3 µm – 6.7 µm broad, in branches elongate, oval or long oval up to cylindrical cells, 3.3 µm – 10.8 µm long, 2.4 µm – 4.2 µm broad; intercalary cells divide in clusters of

wide, short and rounded cells. Heterocytes intercalary, quadrate to oblong cylindrical, 4.2 µm – 12.3 µm long, 3.4 µm – 5.2 µm broad.

Distribution

This species is recorded for the first time from the marine habitat.

Habitat

Dark green coloured planktic.

Specimen examined

INDIA: Kerala; Alappuzha, Ezhupunna; MES 13706; Figure 3E.

Order: Nostocales

Family: Nostocaceae

12) *Anabaena inaequalis* (Kutzing) Bornet et Flahault, Annales des Sciences Naturelles, Botanique, Septième Série 1886-1888, 7: 177-262.

References

(Komarek 2013; McGregor 2018).

Synonyms

Anabaena californica O. Borge 1909, *Anabaena laxa* f. *californica* (O. Borge) Canabaeus 1929.

Description

Filaments joined in blue-green mats; trichomes straight or slightly flexuous, constricted at the cross-walls, not attenuated towards the ends. Cells shortly barrel-shaped, isodiametric, blue-green, 5.8 µm – 6.8 µm long, 4.2 µm – 5.3 µm broad, end cell rounded or rounded conical. Heterocytes intercalary, solitary, spherical, oval or elongated cylindrical, 5.5 µm – 7.8 µm long, 4.5 µm – 7.5 µm broad.

Distribution

This species is recorded for the first time from the marine habitat.

Habitat and ecology

Dark greenish coloured benthic cyanobacterial mat.

Specimen examined

INDIA: Kerala, Alappuzha, Pathiramanal; MES 13714; Figure 3F.

Order: Nostocales

Family: Nostocaceae

13) *Anabaena laxa* (Rabenhorst) ex Bornet et Flahault, Bull. de la Soc.bot.de Fr., 1885, 32: 120; Revision des Nostocasees heterocystees. 1888, 233.

References

(Komarek 2013; Desikachary 1959).

Description

Thallus floccose, dark green; trichomes straight or slightly flexuous, constricted at the cross-walls, cells 3.7 µm broad, 3.8 µm long, cells barrel-shaped, isodiametric or shorter or longer than wide, apices hardly attenuated; heterocytes spherical to cylindrical, intercalary, solitary, 4.4 µm – 5.1 µm broad, 5.5 µm – 7.6 µm long; akinete cylindrical, single or binary, 4.6 µm – 6.7 µm broad 11.6 µm – 19.3 µm long.

Distribution

This species is recorded for the first time from the marine habitat.

Habitat

Occurred on the bark (dark greenish mat-like structure) of the mangrove *Kandelia candel* (L.) Druce.

Specimen examined

INDIA: Kerala; Alappuzha, Ezhupunna; MES 13701; Figure 4A-B.

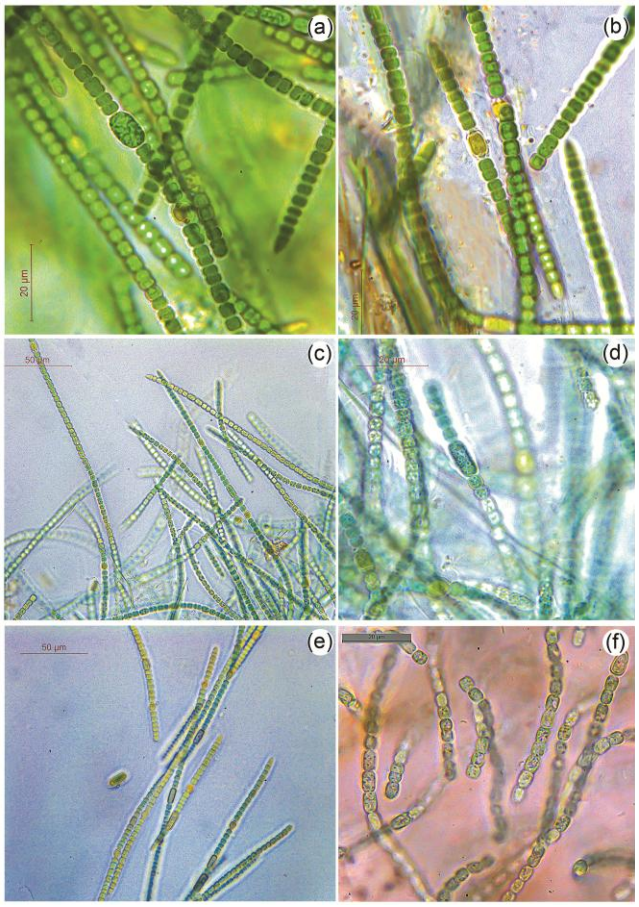

Fig. 4 — A-B) *Anabaena laxa* (Rabenhorst) ex Bornet et Flahault, C-D) *Trichormus ellipsosporus* (Fritsch) Komarek et Anagnostidis, E) *Trichormus kashiensis* (Bharadwaja) Komarek, and F) *Nostoc carneum* (Lyngbye) Agardh ex Bornet et Flahault

Order: Nostocales

Family: Nostocaceae

14) *Trichormus ellipsosporus* (Fritsch) Komarek et Anagnostidis, Algological Studies. 1989, 56: 247-345.

Reference

(Komarek, 2013).

Synonyms

Anabaena variabilis var. *ellipsospora* Fritsch 1949, *Anabaena ellipsospora* (F. E. Fritsch) Obuchova 1959.

Description

Thallus mucilaginous, thin, blue-green; trichome flexuous, solitary, cylindrical, distinctly constricted at the cross-walls; cells barrel-shaped, isodiametric, slightly shorter or longer than broad, 4.0 µm – 5.0 µm long, 4.2 µm – 4.8 µm broad, apical cell conical, up to 5.0 µm long. Heterocytes solitary, intercalary, spherical to ovate, 7.1 µm long, 6.2 µm broad. Akinetes solitary, widely cylindrical, ellipsoidal, sometimes seems slightly concave at the middle of sides, flatly rounded at the ends, 11.6 µm – 17.6 µm long, 4.6 µm – 9.0 µm broad.

Distribution

This species was reported from the mangrove water samples[44].

Habitat

Found attached to the pneumatophores (dark greenish mat-like structure) of *Avicennia officinalis* L.

Specimen examined

INDIA: Kerala; Alappuzha, Ezhupunna; MES 13702; Figure 4C-D.

Order: Nostocales

Family: Nostocaceae

15) *Trichormus kashiensis* (Bharadwaja) Komarek, Fottea. 2012, 12(1): 141-148.

Reference

(Komarek 2012).

Synonyms

Anabaena kashiensis Bharadwaja 1935, *Anabaena variabilis* var. *kashiensis* (Bharadwaja) Fritsch 1949.

Description

Thallus dense, soft, mucilaginous, filaments olive to green in colour, trichomes 3.2 µm – 4.0 µm long, 4.2 µm – 4.6 µm broad, slightly constricted at the cross walls, attenuated at the ends, without mucilaginous sheaths; cells cylindrical to barrel-shaped, isodiametric, terminal cell conical, often with sharply pointed at the ends. Heterocytes solitary, intercalary, cylindrical, 8.6 µm – 11.2 µm long, 3.9 µm – 5.2 µm broad. Akinetes ellipsoidal or barrel-shaped, 6.2 µm – 8.4 µm long, 4.6 µm – 5.4 µm broad, with thick, smooth and colourless outer wall.

Distribution

This species is recorded for the first time from the marine habitat.

Specimen examined

INDIA: Kerala; Alappuzha, Ezhupunna; MES 13704; Figure 4E.

Habitat

Found on the mangrove soil (green in colour).

Order: Nostocales

Family: Nostocaceae

16) *Nostoc carneum* (Lyngbye) Agardh ex Bornet et Flahault, Annales des Sciences Naturelles, Botanique, Septième Série. 1888, 7: 177-262.

References

(Desikachary 1959; Komarek 2013).

Synonyms

Nostoc rufescens C. Agardh 1824, *Anabaena rufescens* (C. Agardh) Kirchner 1878, *Nostoc spongiiforme* C. Agardh ex Bornet & Flahault 1886.

Description

Thallus floating free, gelatinous, reddish-violet, flesh-coloured; filaments flexuous, usually freely entangled; sheaths unclear, colourless or yellowish; cells long, usually barrel-shaped up to cylindrical, 4.0 µm to 6.7 µm long, 3.1 µm to 3.7 µm broad. Heterocytes oblong, 5.1 µm to 7.6 µm long, 4.1 µm to 5.2 µm broad.

Distribution

This species is recorded for the first time from the marine habitat.

Habitat

Reddish-violet or brownish mat collected from the soil surface.

Specimen examined

INDIA: Kerala; Alappuzha, Pathiramanal; MES 13715; Figure 4F.

High diversity of cyanobacteria was recorded as 7 planktic forms *i.e*., occurred from the mangrove water bodies (*Kamptonema chlorinum* (Kutzing ex Gomont) Strunecky, *Phormidium chalybeum* (Mertens ex Gomont) Anagnostidis et Komarek, *Oscillatoria*

subbrevis Schmidle, *Oscillatoria limosa* C.Agardh ex Gomont, *Hapalosiphon welwitschii* West & G. S. West, *Westiellopsis prolifica* Janet, *Westiellopsis interrupta* Kanthamma), 4 epipsammic (*Aphanothece stagnina* (Sprengel) A. Braun, *Oscillatoria curviceps* Agardh ex Gomont, *Trichormus kashiensis* (Bharadwaja) Komarek and *Nostoc carneum* (Lyngbye) Agardh ex Bornet et Flahault), 2 epiphytic (*Chroococcus indicus* Zeller, *Trichormus ellipsosporus* (Fritsch) Komarek et Anagnostidis), 2 corticolous (*Phormidium acula* (Bruhl & Biswas) Anangnostidis & Komarek, *Anabaena laxa* (Rabenhorst) ex Bornet et Flahault) and 1 benthic species (*Anabaena inaequalis* (Kutzing) Bornet et Flahault).

Discussion

The present study investigated the diversity and taxonomy of cyanobacteria associated with the mangrove environment of Alappuzha, Kerala. Based on microscopic observations, a total of 16 species - 2 unicellular and 14 filamentous (6 non-heterocytous and 8 heterocytous) were identified. Their habitat and geographical distribution are also described in detail according to the recent combined taxonomic classifications[14-20,45].

The current study reports six species namely *Westiellopsis prolifica* Janet, *Westiellopsis interrupta* Kanthamma, *Anabaena inaequalis* (Kutzing) Bornet et Flahault, *Anabaena laxa* (Rabenhorst) ex Bornet et Flahault, *Trichormus kashiensis* (Bharadwaja) Komarek, and *Nostoc carneum* (Lyngbye) Agardh ex Bornet et Flahault which are the first report to the Indian marine cyanobacterial flora. Besides, the rare species *Westiellopsis interrupta* Kanthamma has occurred in Ezhupunna as a dark greenish planktonic form. It occurred currently after its original description and this genus had only been described and isolated from the paddy field soils of Madras, India[46].

Here, 6 cyanobacteria families, *viz*., Aphanothecaceae (1), Chroococcaceae (1), Microcoleaceae (1), Oscillatoriaceae (5), Hapalosiphonaceae (3) and Nostocaceae (5) have been identified. Heterocytous forms (Nostocales) dominate the study area more than non-heterocytous forms. The distribution pattern of *Aphanothece stagnina* (Sprengel) A. Braun, *Oscillatoria subbrevis* Schmidle, *Oscillatoria limosa* C. Agardh ex Gomont, *Oscillatoria curviceps* Agardh ex Gomont and *Hapalosiphon welwitschii* West & G. S. West support with the previous studies in the marine ecosystem[21,31,34,35,39,43,47].

Cyanobacterial species were higher in Pathiramanal (10 species) than Ezhupunna (6 species) stations. Ezhupunna mangrove area (2.5 ha) is under private ownership which is in patches or discrete. The mangrove habitat area in this station is destroying due to increased population and various aquaculture activities. On the other hand, Pathiramanal Island is a place covered with 19.6 ha of mangrove forest and has natural vegetation. This could be the reason for the rich biodiversity of cyanobacteria recorded from Pathiramanal.

Studies on marine cyanobacteria keep their integrity since they provide a scientific basis for the validation of biogeography and biodiversity of most neglected microorganisms. Incorporating the ecological and field data in the biomonitoring of the documentation of cyanobacteria should provide a firm basis for determining taxonomic validation and identification. The insufficient number of cyanobacterial diversity studies in the mangrove ecosystem of Kerala makes the records a vital contribution to the marine cyanobacterial flora and its biogeographical distribution in the country.

Conclusion

To date, there is no extensive exploration of the diversity and distribution pattern of cyanobacterial flora in the mangrove ecosystems of Kerala, India. Their diversity and assessment of distribution patterns are prerequisites for future research activities and should adopt conservation strategies from being depleted from the ecosystem. Comprehensive research on cyanobacterial diversity and their interaction with the mangrove environment has to be studied.

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Conflict of Interest

The authors have no conflict of interest.

Author Contributions

ATR: Sample collection, preservation, identification and manuscript preparation. ATR &

TPP: Research design and identification. TPP: Revision and validation of the manuscript.

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