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Research

Epiphytic cyanobacterial diversity in the sub-Himalayan belt of Garhwal region of Uttarakhand, India

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Abstract

Cyanobacteria constitute the largest, most diverse and widely distributed group of prokaryotes that perform oxygenic photosynthesis. These are known to comprise a diverse flora of morphologically distinct forms. Some species are epiphytic occurring on a variety of plants. The present study was undertaken to study the distribution pattern of epiphytic cyanobacterial flora in the foot-hills of Garhwal Himalaya. An extensive survey was carried out in different seasons at four cyanobacteria-rich localities (Dakpatthar, Kotdwar, Rishikesh and Laldhang) of Uttarakhand state of India. A total of 39 epiphytic cyanobacterial taxa (12 heterocystous and 27 non-heterocystous) belonging to 2 orders, 7 families and 17 genera were recorded from this region. Highest number of species (25) was reported from Rishikesh, followed by Kotdwar with 14 species and Laldhang and Dakpatthar each with 12 species. Principal Component Analysis showed significant variation for epiphytic cyanobacterial diversity among studied sites, whereas cluster analysis categorized epiphytic cyanobacterial diversity under two categories, viz. Cluster I with 9 species and Cluster II with 30 species. Study concludes that variation in epiphytic cyanobacterial diversity might be compared to physicochemical properties of soil and climatic conditions along altitudes.

Key-words: Cyanobacteria, diversity, epiphytic, foot-Hill, Garhwal Himalaya.

Introduction

Cyanobacteria belong to the most archaic organisms on the earth. The palaeobotanical records show that they were first to appear on the globe for over 2.5 billion years ago (Schopf and Walter 1982; Schopf and Packer 1987) and dominated the biota in the Proterozoic Era, an Era between 2.5 and 0.5 billion years ago. Due to the occurrence of blue-green algae, the Proterozoic Era is also known as “Age of Cyanophyceae” (Van den Hoek *et al*. 1993). Cyanobacteria grow by the asexual mode of reproduction due to the formation of the hormogonia or endospores or by the fragmentation of the colonies. No sexual reproduction has been reported in cyanobacteria till now. However, genetic recombination similar to bacteria has been observed in some cases (Kumar 1962).

They occur in great variety of natural habitats, but are often abundant in terrestrial and aquatic (freshwater and marine) environments. They exist in nature as free floating, epilithic, epipelic, epiphytic, endophytic and thermophilic forms (Fogg *et al*. 1973; Kumar 2002). Khare and Kumar (2009) have reported some Chroococcales growing as epiphytes in the foot-hills of Uttarakhand Himalaya. The members of Cyanophyceae also form dominant plant life in frigid rivers of Garhwal Himalaya, where they create an extensive benthic mat or scum under/over water ponds, streams and over the surface of moist soils. Ariosa *et al*. (2004) studied epiphytic cyanobacteria on *Chara vulgaris* and their role as main contributors to N_2 fixation in rice fields. They proposed that average nitrogen fixation rate associated with

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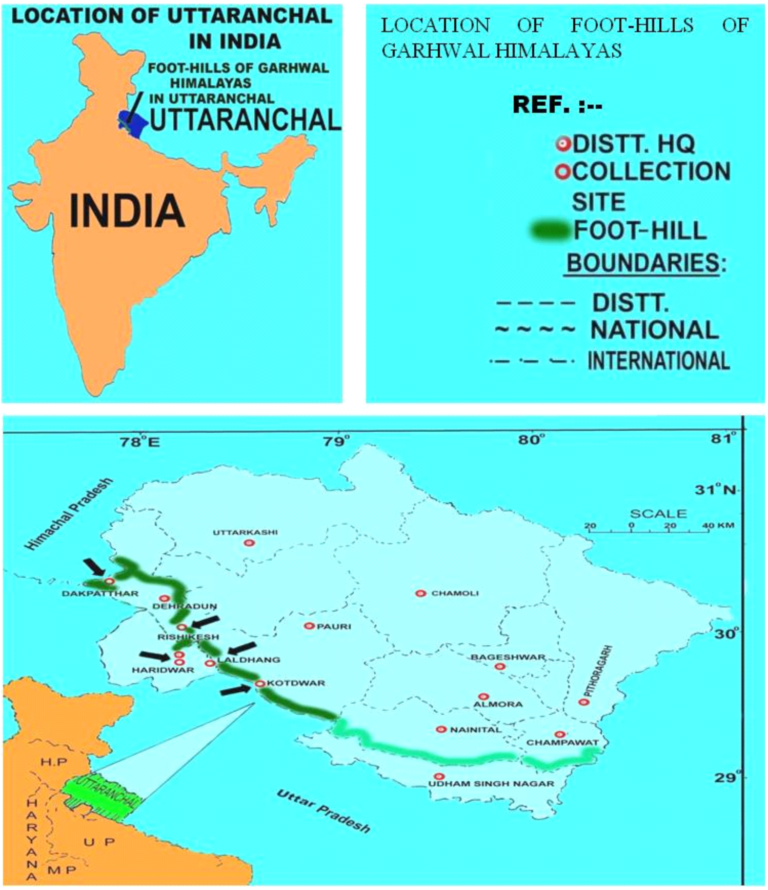

Figure 1. Location of the study sites (pointed by arrows) in the Garhwal Himalaya, Uttarakhand, India.

Chara was 27.53 kg of N ha^{-1} $crop^{-1}$. Fong *et al.* (2006) studied epiphytic cyanobacteria and found that they maintain shifts to macro-algal dominance on coral reefs. Williams *et al*. (2007) found a novel epiphytic cyanobacterium associated with reservoirs affected by avian vacuolar myelinopathy.

The abilities of cyanobacteria to withstand adverse ecological conditions, their capacity to thrive well in hostile environments, and response to the onset of dry conditions have distinguished this group as pioneers of plant succession. The light plays an important regulatory role with regard to distribution and abundance of cyanobacteria. Most of the species of cyanobacteria are obligate phototropic. pH is an important factor that affect the growth of cyanobacteria. Good cyanobacterial growth needs an optimum pH >7 of the medium and sometimes as high as 10 (Fogg *et al.* 1973). Temperature also plays an important role in stimulating the growth of cyanobacteria. Robarts and Zohary (1987) reported that cyanobacteria dominate generally at temperatures >20°C.

Sub-Himalayan regions of Uttarakhand represent a habitat with a wide environmental heterogeneity in terms of temperature, rainfall, humidity and light intensity. These varied climatic conditions support cyanobacteria of different growth forms. However, extensive work on epiphytic cyanobacteria has not been done in the region. The present study has therefore been undertaken to study the distribution of cyanobacterial forms growing as epiphytes on various plants.

Materials and Methods

STUDY AREA

The study area is situated in south-west to east of Siwalik range of Garhwal Himalaya, Uttarakhand, India. The present study involves four sites, i.e. Dakpatthar (west), Rishikesh, Laldhang and Kotdwar (south-west) covering three districts, Dehradun, Haridwar and Pauri of Garhwal Himalaya (Figure

Table 1. Description of the research sites.

SN.	Sites Districts	Climatic/habitat variables*	Geographical location	Soil type	Localities of sampling
1.	Laldhang Haridwar	Mean temp (^{0}C) = 24.1 Rain fall (cm) = 13.0 Relative humidity (%) = 86.8 Light intensity (Lux) = 895	Longitude: 78^0 30' E Latitude: 29^0 81' N Altitude: 342 m asl Situated at the foot-hills of Western Himalaya at the banks of river Rawasan	Loam and red	Mango garden, Bus Stop, Rawasan river road, Chandi Devi Haridwar, Har Ki Pauri etc.
2.	Dakpatthar Dehradun	Mean temp (^{0}C) = 20.8 Rain fall (cm) = 18.3 Relative humidity (%) = 91.0 Light intensity (Lux) = 685	Longitude: 77^0 75' E Latitude: 30^0 47' N Altitude: 895 m asl Situated at the Siwalik range of Western Himalaya at the banks of river Yamuna	Sandy, loam clay, silt, conglomerate, calcareous tuffs gravel and alluvial	Guptsahasradhara, Drona cave, Sahastradhara Shiva temple, etc.
3.	Rishikesh Dehradun	Mean temp (^{0}C) = 21.1 Rain fall (cm) = 15.0 Relative humidity (%) = 88.1 Light intensity (Lux) = 730	Longitude: 78^0 28' E Latitude: 30^0 10' N Altitude: 356 m asl Situated at the inner range of Siwalik Himalaya at the basin of river Ganga	Loam containing gravel or alluvial type, clay humus, sandy, boulders and sand stones	Kalidhal, Luxman Jhoola
4.	Kotdwar Pauri-Garhwal	Mean temp (^{0}C) = 23.2 Rain fall (cm) = 12.4 Relative humidity (%) = 86.6 Light intensity (Lux) = 865	Longitude: 78^0 38 E Latitude: 29^0 46' N Altitude: 376 m asl Situated at the foot-hills of Garhwal Himalaya at the banks of river Khoh	Loam, conglo-merate sand stones, grits, pseudo conglo-merate, gravel, clay and alluvial	Durga Devi temple, Dugadda, Inspection House

*Mean values of the temperature and relative humidity were measured with the help of Thermohygrograph. Up and down peaks sketched by the equipment on the paper represent higher and lower limits of temperature and humidity. The intensity of light was directly taken by digital Lux meter. The values of sun shine were measured three times a day, i.e. morning, noon and evening and their mean has been used in the table.

1). The study sites comprise a group of low-lying hills with rivers, springs, streams, swamps, ravines, rivulets, pits and ponds situated at a longitude of 77^0 75' to 78^0 38' E and latitude 29^0 46' to 30^{0}47' N. The elevation of different sites ranges between 300–900 m above mean sea level (m asl). The study sites have sub-tropical climate with mean temperature ranging from 20.8^{0}C (Dakpatthar) to 24.1^{0}C (Laldhang) and annual rain fall from 12.4 cm (Kotdwar) to 18.3 cm (Dakpatthar) (Table 1).

SAMPLING

Cyanobacterial samples, for various taxonomic studies, were collected from all research sites in different seasons, i.e. summer, winter and rainy in the year 2002. The samples included aquatic, terrestrial, epilithic, epipelic, endophytic and epiphytic cyanobacterial forms. However, the present paper deals with the studies conducted only for the epiphytic forms of the cyanobacteria. The samples with visible growth of blue-green algae were collected into sterile plastic bottles. On returning to the laboratory, they were washed thoroughly with water, transferred to air-tight glass containers, and preserved in 4% formalin solution. The micro-slides were prepared from the fixed as well as fresh algal materials for microscopic observations. Temporary glycerin mounts prepared for the study were converted to semi-permanent slides by sealing the joints of slide and cover slips by nail polish with the help of slide ringing table.

IDENTIFICATION OF THE CYANOBACTERIA

The identifications were made by following Desikachary (1959) and Anand (1989), and also by the consultation of other pertinent literature (Kumar 1985; Mann 2000; Stal 2000) in the field. The cyanobacterial specimens were identified at the level of class, order, family, genus and species. Morphological variations of different specimens were also analyzed.

Table 2. Distribution of epiphytic cyanobacteria in the foot-hills of Garhwal Himalaya.

S.No.	Taxa	Dakpatthar	Kotdwar	Rishikesh	Laldhang
1	*Microcystis viridis*	-	-	+	-
2	*Microcystis aeruginosa*	+	-	-	-
3	*Microcystis robusta* v. *minor* var. nov.	-	-	+	-
4	*Microcystis lamelliformis*	-	-	+	-
5	*Chroococcus turgidus* var. *solitarius*	-	-	+	-
6	*Chroococcus indicus*	+	-	-	-
7	*Chroococcus minutus*	-	-	-	+
8	*Chroococcus hansgirgi*	+	-	+	-
9	*Chroococcus cohaerens*	+	-	-	+
10	*Chroococcus minor*	-	+	-	+
11	*Aphanocapsa koordersi*	-	-	-	+
12	*Aphanocapsa biformis*	+	+	+	+
13	*Aphanocapsa grevillei*	-	-	+	-
14	*Aphanocapsa pulchra*	+	-	+	+
15	*Synechocystis aquatilis*	-	+	-	+
16	*Merismopedia tenuissima*	-	-	+	-
17	*Xenococcus acervatus*	-	+	-	-
18	*Spirulina subsalsa*	-	-	-	+
19	*Spirulina gigantean*	-	-	+	-
20	*Oscillatoria foreaui*	-	+	-	-
21	*Oscillatoria tenuis*	-	+	+	-
22	*Phormidium fragile*	+	+	-	-
23	*Lyngbya mesotrica*	-	-	-	+
24	*Lyngbya kuetzingii*	+	+	-	-
25	*Lyngbya spirulinoides*	-	-	+	-
26	*Lyngbya dendrobia*	+	+	-	-
27	*Aulosira pseudoramosa*	-	-	+	-
28	*Aulosira ferttillissima* var. *tenuis*	-	+	+	-
29	*Plectonema hansgirgi*	-	-	+	-
30	*Scytonema malaviyaensis*	+	-	+	+
31	*Microchaete grisea* var. *brevis*	+	+	+	-
32	*Microchaete elongate*	-	-	+	-
33	*Calothrix parietina*	+	+	+	-
34	*Calothrix fusca*	-	+	+	-
35	*Calothrix scytonemicola*	-	-	+	+
36	*Calothrix braunii*	-	-	+	-
37	*Rivularia dura*	-	-	+	-
38	*Gleotrichia pilgeri*	-	+	+	+
39	*Gleotrichia raciborskii* var. *bombayense*	-	-	+	-
	Site-wise number of species	12	14	25	12

Table 3. Taxonomic categorization of cyanobacteria encountered in the foot-hills of Garhwal Himalaya.

Orders	Families	Genera	Number of species		
			Total	Heterocystous forms	Non-heterocystous forms
Chroococcales	Chroococcaceae	*Microcystis*	4	-	4
		Chroococcus	6	-	6
		Aphanocapsa	4	-	4
		Synechocystis	1	-	1
		Merismopedia	1	-	1
	Hyellaceae	*Xenococcus*	1	-	1
Nostocales	Oscillatoriaceae	*Spirulina*	2	-	2
		Oscillatoria	2	-	2
		Phormidium	1	-	1
		Lyngbya	4	-	4
	Nostococcaceae	*Aulosira*	2	2	-
		Plectonema	1	-	1
	Scytonemataceae	*Scytonema*	1	1	-
		Microchaete	2	2	-
	Microchaetaceae	*Calothrix*	4	4	-
	Rivulariaceae	*Rivularia*	1	1	-
		Gleotrichia	2	2	-
Total			39	12	27

NUMERICAL METHODS

Principal component analysis (PCA), an indirect gradient ordination method, was used to summarize the compositional differences among the research sites based on the abundance (presence-absence) on epiphytic cyanobacterial flora, using multivar option in PAST 1.92 (Hammer *et al*. 2001; Hall 2005). Cluster analysis (using Euclidean distance method) of the different cyanobacterial flora with reference to their occurrence in various sites has also been done by using the same software.

Results

DIVERSITY OF EPIPHYTIC CYANOBACTERIA

Cyanobacterial flora of the study area was represented by 39 species belonging to 17 genera and 7 families of 2 orders, namely Chroococcales and Nostocales (Table 2 and 3; Appendix 1). The members of Chroococcales and Nostocales represent whole the epiphytic cyanobacterial flora of the region by having 17 and 22 species, respectively. All the species cover a wide range of habitats i.e. they were collected from the roots and leaves of the grasses as well from the bark of the trees (Figures 2 and 3). Site-wise details of various taxa recorded in the present study are presented in Table 2. Whole of the species belonging to Chroococcales were non-heterocystous, while Nostocales represented 10 non-heterocystous and 12 heterocystous species (Table 3). *Chroococcus* (with 6 species), *Microcystis* (4), *Lyngbya* (4), *Aphanocapsa* (4) and *Calothrix* (4) were the best representative genera of this region with higher number of epiphytic taxa. These were followed by *Oscillatoria* (2 species), *Spirulina* (2), *Aulosira* (2), *Michrochaete* (2) and *Gloeotrichia* (2). Other genera included *Synechocystis* (with 1 species), *Merismopedia* (1), *Xenococcus* (1), *Phormidium* (1), *Plectonema* (1), *Scytonema* (1) and *Rivularia* (1). Highest number of species (25) was reported from Rishikesh, followed by Kotdwar with 14 species and Laldhang and Dakpatthar each with 12 species.

MULTIVARIATE ANALYSIS

PCA analysis required 3 components (axis) to account for 100% variation in the data set. The first two axes of PCA cumulatively explained 78.50% of variance (individually the first axis explained 48.13% and the second axis explained 30.37% of variance) (Figure 4). While Dakpatthar and

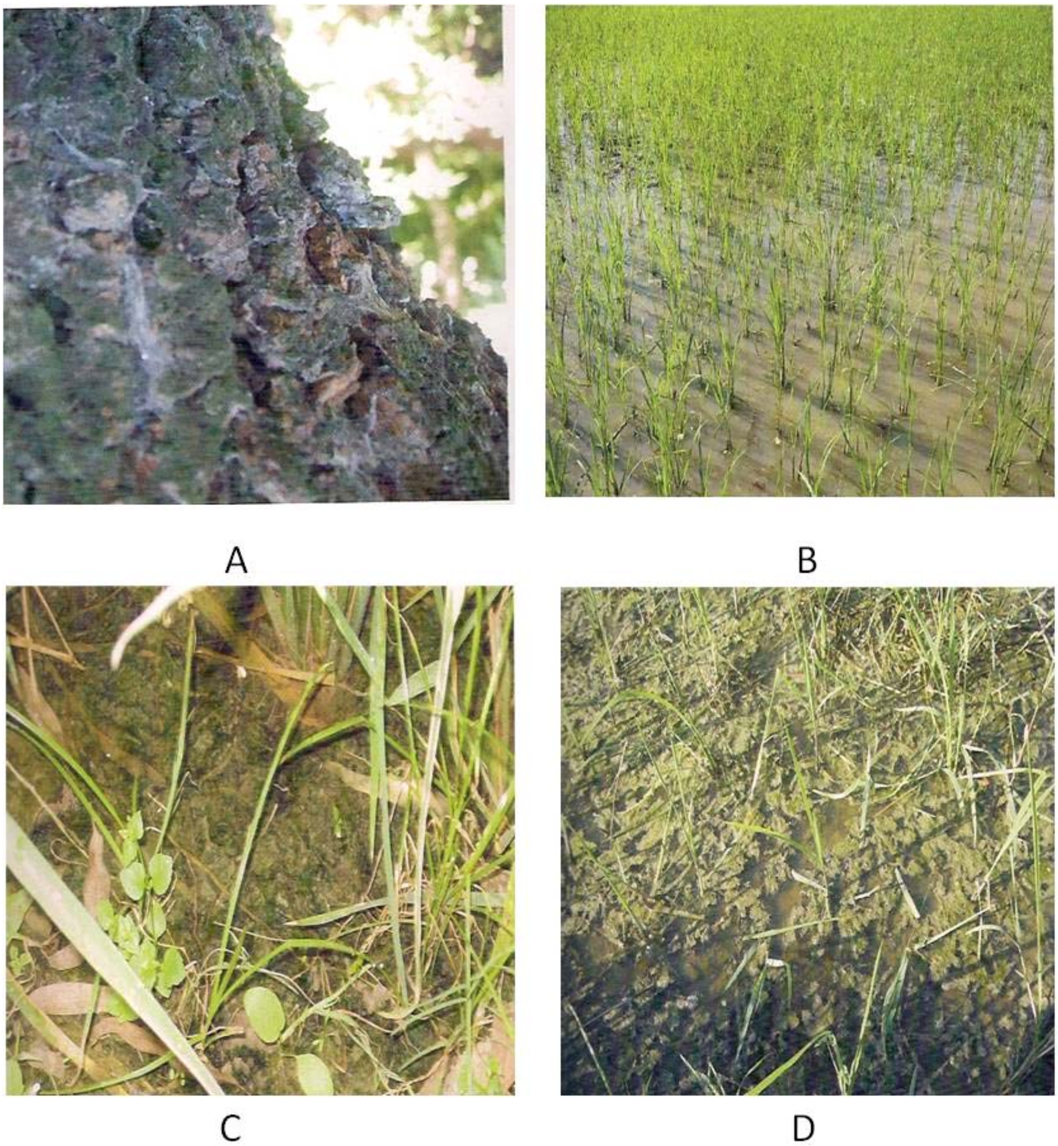

Figure 2. Photographs of some variable habitats of some epiphytic cyanobacteria in the foot-hills of Garhwal Himalaya, Uttarakhand, India. (A) Copious growth of cyanobacteria on moist mango tree bark at Dugadda, (B) cyanobacteria occurring on the leaves of paddy plants at Kotdwar, (C) cyanobacterial forms attached to the roots and the leaves of the plants growing near water at Rishikesh, (D) luxurious growth of cyanobacteria on the leaves of grasses growing in a ditch at Dakpatthar.

Kotdwar sites were separated towards the negative end of axis 1 and positive end of axis 2 in PCA ordination space, Rishikesh was separated toward positive end and Laldhang towards negative end of PCA axis 1 (Figure 4).

The cluster analysis revealed two groups (Figure 5): (i) CLUSTER – I with 9 species (*Aphanocapsa koordersi*, *Chroococcus cohaerens*, *Chroococcus minor*, *Chroococcus minutes*, *Lyngbya mesotrica*, *Oscillatoria foreaui*, *Spirulina subsalsa*, *Synechocystis aquatilis* and *Xenococcus acervatus*), and (ii) CLUSTER – II with 30 species (*Aphanocapsa biformis*, *Aphanocapsa grevillei*, *Aphanocapsa pulchra*, *Aulosira ferttillissima* var. *tenuis*, *Aulosira pseudoramosa*, *Calothrix braunii*, *Calothrix fusca*, *Calothrix parietina*, *Calothrix scytonemicola*, *Chroococcus hansgirgi*, *Chroococcus indicus*, *Chroococcus turgidus* var. *solitarius*, *Gleotrichia pilgeri*, *Gleotrichia raciborskii* var. *bombayense*,

A

B

Figure 3. Photographs of some variable habitats of some epiphytic cyanobacteria in the foot-hills of Garhwal Himalaya, Uttarakhand, India. (A) Various cyanobacterial forms attached to the stems of higher plants and the leaves of the grasses at Kotdwar, (B) algal growth in the vicinity of grasses as well as on their leaves.

Lyngbya dendrobia, *Lyngbya kuetzingii*, *Lyngbya spirulinoides*, *Merismopedia tenuissima*, *Microchaete elongate*, *Microchaete grisea* var. *brevis*, *Microcystis aeruginosa*, *Microcystis lamelliformis*, *Microcystis robusta* var. *minor* var. nov., *Microcystis viridis*, *Oscillatoria tenuis*, *Phormidium fragile*, *Plectonema hansgirgi*, *Rivularia dura*, *Scytonema malaviyaensis* and *Spirulina gigantean*).

Discussion

Taxonomic analysis of the species shows that the foot-hills of Garhwal Himalaya are rich in epiphytic cyanobacterial diversity. Present study represents 39 cyanobacterial species occurring as epiphytes at various research sites (Table 2). The foot-hills of the Himalayan range provide higher temperature, high moisture and high relative humidity as compared to the arctic zones (Chaudhary 2004). The higher temperature and moisture conditions coupled with moderate light intensity in the study area favor the growth and development of algae belonging to various classes. Particularly, the climate of Rishikesh favors the growth of the epiphytic cyanobacterial forms. Similar results of higher temperature (24-30^{0}C) and moisture contents (80-94%) favoring the growth of cyanobacteria have been reported by Kumar (2002), Chaudhary and Kumar (2005), and Khare and Kumar (2009) in the foot hills of Garhwal and Kumaon regions of Uttarakhand, India.

As suggested by PCA (Figure 4), the research sites Dakpatthar and Kotdwar show similar composition of cyano-bacterial flora as these sites share six common taxa (i.e. *Aphanocapsa biformis*, *Phormidium fragile*, *Lyngbya kuetzingii*, *Lyngbya dendrobia, Microchaete grisea* var. *brevis* and *Calothrix parietina*); whereas Rishikesh was mapped distinctly in PCA space due to its exclusive eleven taxa that were present only at this site (i.e. *Microcystis robusta* var. *minor* var. *nov*, *Microcystis lamelliformis*, *Chroococcus turgidus* var. *solitaries*, *Merismopedia tenuissima*, *Spirulina gigantean*, *Aulosira pseudoramosa*, *Plectonema hansgirgi*, *Calotrix scytonemicola*, *Calotrix braunii*, *Rivularia dura*, and *Gleotrichia raciborskii* var. *bombayense*). Further, the site Laldhang, due to its different assemblage of cyanobacterial flora, had four exclusive species (i.e. *Chroococcus minutes*, *Aphanocapsa koordersi*, *Spirulina susalsai*, *Lyngbya mesotrica*). The specimen *Microcystis robusta* var. *minor* (var. *novo*) differs from the type by having smaller cells with spherical to ellipsoidal shape (Appendix 1). Hence warrants as a new variety minor of *Microcystis robusta.*

Cyanobacteria have been known for augmentation of organic nitrogen to diverse ecological habitats by converting molecular nitrogen into ammonium compounds with the help of enzyme ‘nitrogenase complex’ (Adams and Duggan 1999). Subsequently, they support the proliferation of eukaryotes and other non-nitrogen fixers in different ecological condition as free living, epiphytic and endophytic forms. Nitrogen contribution to rice fields by epiphytic cyanobacteria associated with *Chara* is well documented by Ariosa *et al.* (2004). The present study concludes that variation in epiphytic cyanobacterial diversity might be compared to physicochemical properties of soil and climatic conditions along altitudes. The enumeration of epiphytic cyanobacterial diversity might provide some basic understanding of

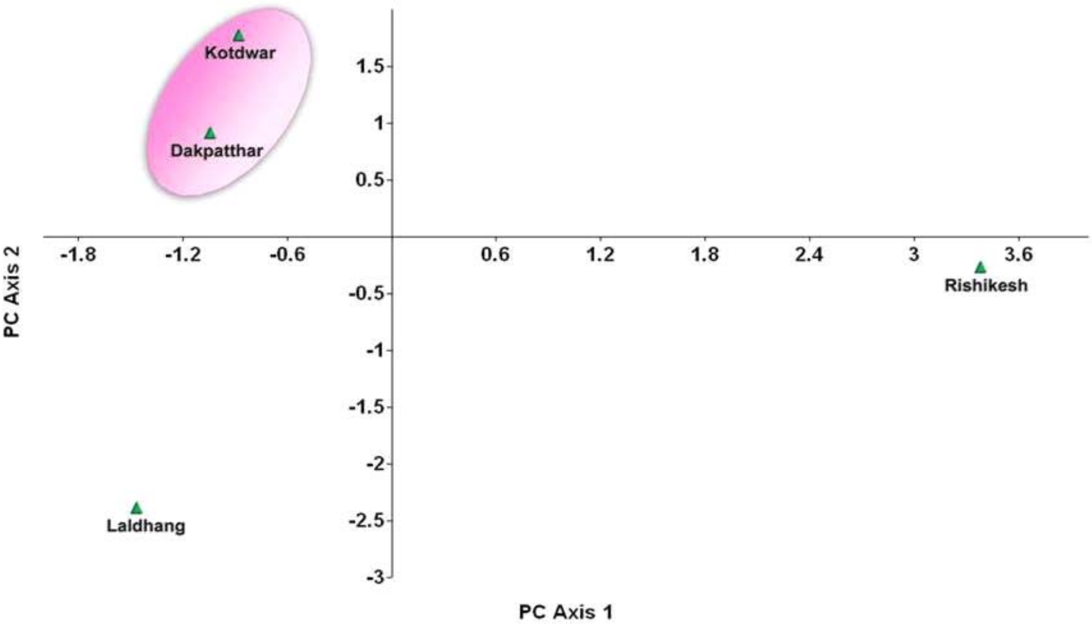

Figure 4. PCA ordination plot of four study sites: data showing compositional difference between sites, based on the abundance data of cyanobacterial flora of the studied sites.

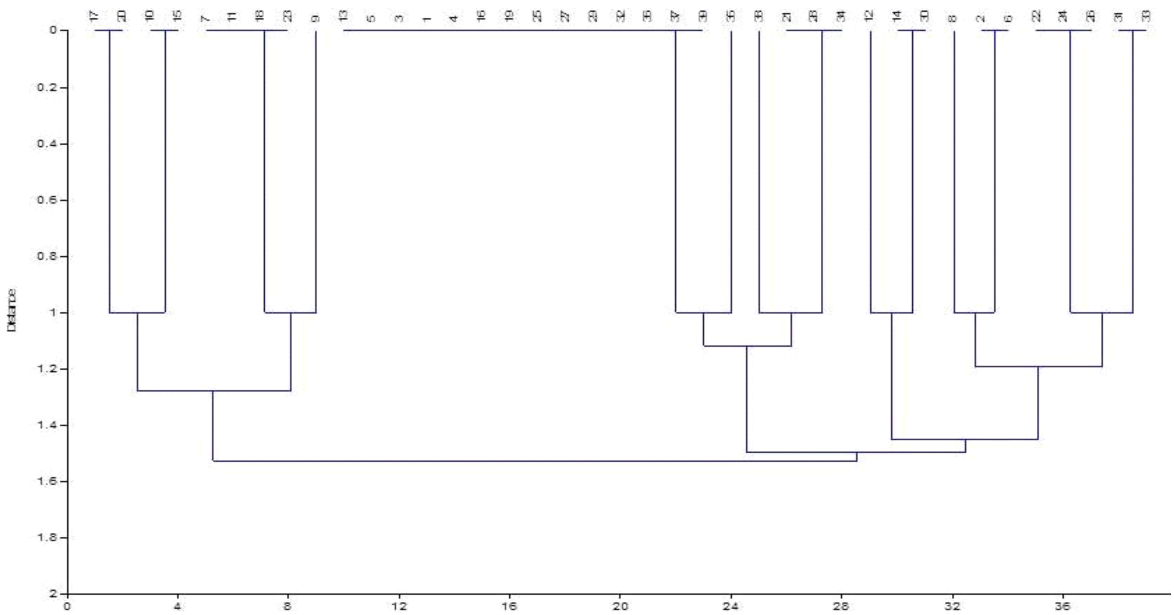

Figure 5. Cluster analysis of the different cyanobacterial flora with reference to their occurrence in various sites.

physiological and molecular adaptation and extent of nitrogen and other contribution to different plants.

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Appendix 1

SYSTEMATIC ENUMERATION OF THE SPECIES

Letters R, S and W in accession number represent rainy, summer and winter seasons, respectively. The details of a taxon including the measurements are the specific characters of a genus. The camera lucida drawings and microphotographs of some important epiphytic cyanobacteria have been placed in Figures 6-9.

1. *Microcystis viridis* (A. Br.) Lemm: Accession No. W-10; Sampling time: February 2002. Colony diameter 40.0-41.3 μ, cell diameter 3.5-7.0 μ, cell length 5.5-6.5 μ. Growing on an old stem submerged in a ditch at Kalidhal, Rishikesh.

2. *Microcystis aeruginosa* Kütz.: Accession No. W-16; Sampling time: February 2002. Cell diameter 3.0-4.5 μ. Attached to the leaves of *Selaginella* near Shiva Temple water fall, Guptsahastradhara, Dakpatthar.

3. *Microcystis robusta* var. *minor* (var. novo): Accession No. R-29; Sampling time: August 2002. Colony size 44.0-46.0 μ, Cell diameter 3.4-4.2 μ. Attached to the decaying roots floating over water in rivolut, Kalidhal, Rishikesh.

4. *Microcystis lamelliformis* Holsinger: Accession No. R-17; Sampling time: October 2002. Colony size (L×B): 58.0-61.0 × 33.0-34.0 μ, Cell diameter 3.5-5.0 μ. Attached to a plant flowing in canal water, Rishikesh.

5. *Chroococcus turgidus* var. *solitarius* Ghose: Accession No. R-02; Sampling time: September 2002. Cell diameter with sheath 10.2-11.8 μ, cell diameter without sheath 5.1-6.8 μ. Attached on moist bark of *Calamus* forming a dense covering among mosses and lichens at Garunchatti, Laxman Jhula, Rishikesh.

6. *Chroococcus indicus* Zeller: Accession No. W-18; Sampling time: February 2002. Cell diameter with sheath 6.8-9.0 μ, cell diameter without sheath 6.5-8.5 μ. Attached to the mosses in running water at Dron Temple, Sahastradhara, Dakpatthar.

7. *Chroococcus minutus* (Kütz.) Näg.: Accession No. W-04; Sampling time: February 2002. Cell diameter with sheath 9.8-11.0 μ, cell diameter without sheath 7.2-8.5 μ. Attached to an

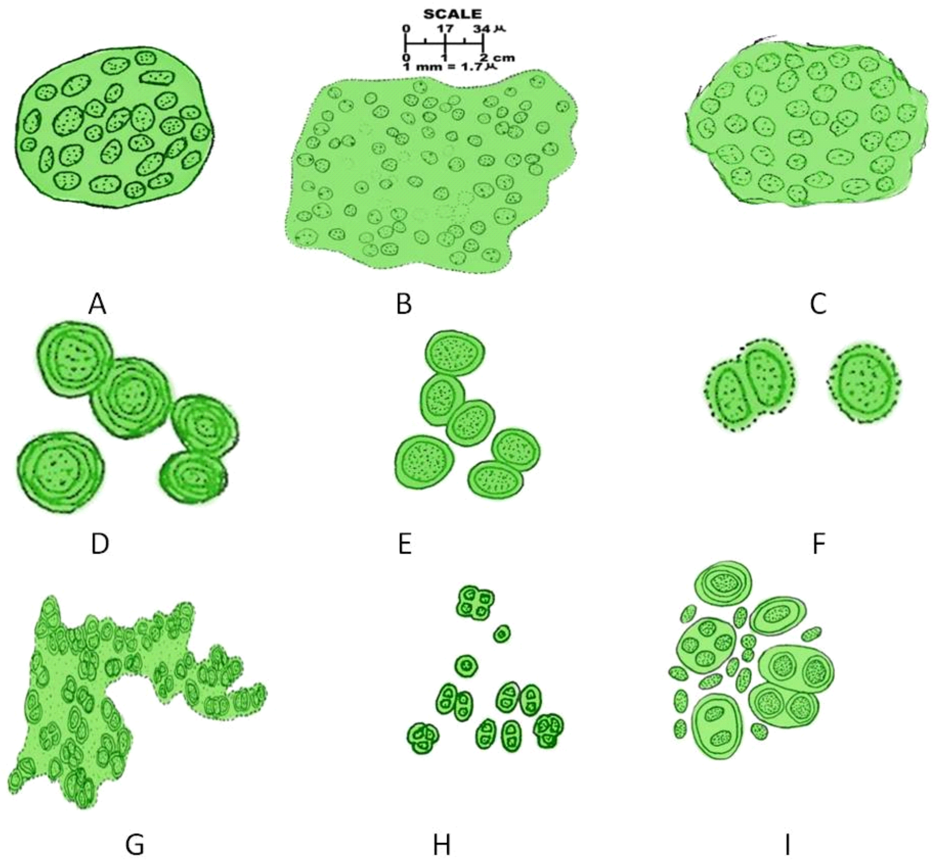

Figure 6. Outline diagrams of some epiphytic cyanobacteria from the Sub-Himalayan belt of Garhwal Himalaya, Uttarakhand, India. (A) *Microcystis viridis*, (B) *M. aeruginosa*, (C) *M. robusta* var. *minor* (var. novo), (D) *Chroococcus turgidus* var. *solitarious*, (E) *C. indicus*, (F) *C. minutus*, (G) *C. cohaerens*, (H) *C. minor*, and (I) *Aphanothece bullosa*.

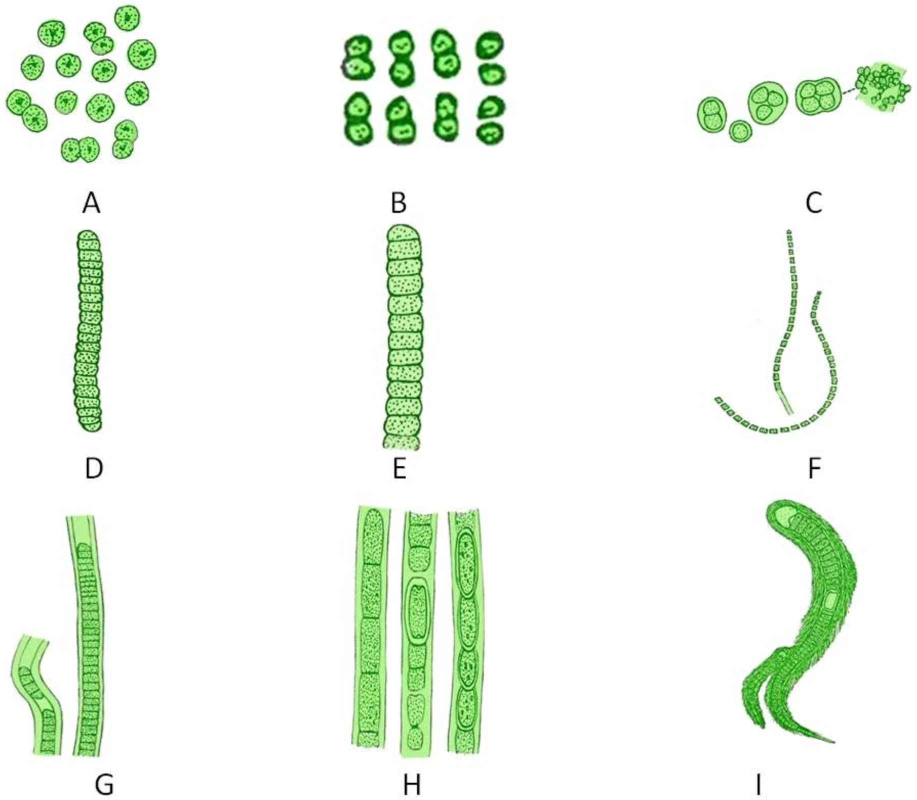

Figure 7. Outline diagrams of some epiphytic cyanobacteria from the Sub-Himalayan belt of Garhwal Himalaya, Uttarakhand, India. (A) *Synechocystis aqualis*, (B) *Merismopedia tenuissima*, (C) *Xenococcus acervatus*, (D-E) *Oscillatoria tennuis*, (F) *Phormidium fragile,* (G) *Lyngbya dendrobia*, (H) *Aulosira fertilissime* var. *tenuis*, and (I) *Calothrix parietina*.

old wood piece submerged in a puddle of a mango garden, near Bus Stand, Laldhang.

8. *Chroococcus hansgirgi* Schmidle: Accession No. R-08 and W-22; Sampling time: September 2002 (Rishikesh) and February 2002 (Dakpatthar). Cell size (L×B) 15.6-16.5 × 7.5-12.0 μ. Growing on dead grasses and also on stones submerged in running water, Laxman Jhoola, Rishikesh. Attached with grasses in the form of an algal mass in slow running water of a drain, Sahastradhara, Dakpatthar.

9. *Chroococcus cohaerens* (Breb.) Näg.: Accession No. W-07 and S-06; Sampling time: February 2002 (Dakpatthar) and June 2002 (Laldhang). Colony diameter 10.2-13.8 μ, cell breadth with sheath 5.0-8.5 μ, cell breadth without sheath 2.0-6.8 μ. Attached to some pteridophytes, Sahastradhara, Dakpatthar. On moist bark of *Mangifera indica*, Mango garden near Bus Station, Laldhang.

10. *Chroococus minor* (Kütz.) Näg.: Accession No. R-10, W-04; Sampling time: August 2002 (Kotdwar) and Kumar 2002 (Laldhang). Cell breadth without sheath 3.0-4.0 μ. Attached on moist bark of mango tree opposite to inspection House, Dugadda, Kotdwar. Attached to an old wood piece dipped in a puddle, mango Garden near Bus Station, Laldhang.

11. *Aphanocapsa koordersi* Storm: Accession No. W-04; Sampling time: February 2002. Cell diameter 1.4-3.1 μ. Attached on a piece of wood submerged in water of a puddle, Mango garden, Bus Station, Laldhang.

12. *Aphanocapsa biformis* A. Br.: Accession No. R-02, R-40, R-12, S-06; Sampling time: September 2002 (Rishikesh), September 2002 (Dakpatthar), August 2002 (Kotdwar) and Jun 2002 (Laldhang) respectively. Cell diameter without sheath 4.3-7.0 μ, cell diameter with sheath 10.7-12.9 μ. Present on moist bark of Calamus, Luxman Jhoola, Rishikesh. Attached on small piece of wood near a waterfall at Sports College, Sahastradnara, Dakpatthar. Growing on moist bark of a mango tree, Gadighat, Kotdwar. Growing on moist bark of mango tree, Mango garden near Bus Stop, Laldhang.

13. *Aphanocapsa grevelli* (Hass.) Rabenh.: Accession No. S-08; Sampling time: June 2002. Cell diameter 3.7-5.2 μ. Attached on roots of trees in slow running water, Kalidhal, Rishikesh.

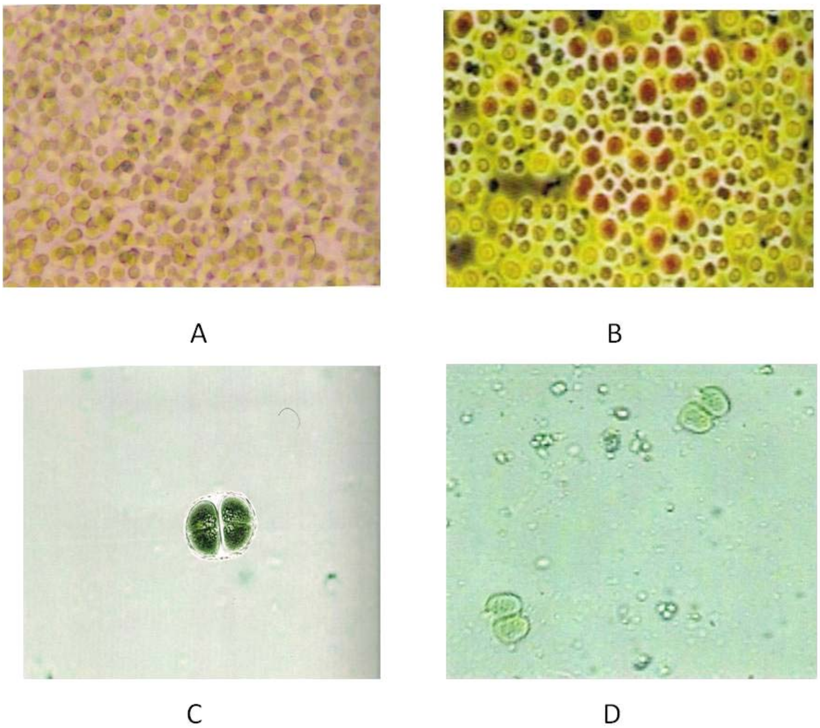

Figure 8. Microphotographs of some taxa of epiphytic cyanobacteria from the foot-hills of Garhwal Himalaya, Uttarakhand, India. (A) *Microcystis aeruginosa*, (B) *M. Robusta* var. *minor* (var. novo), (C) *Chroococcus turgidus* var. *solitarious*, and (D) *Synechocystis aqualis*.

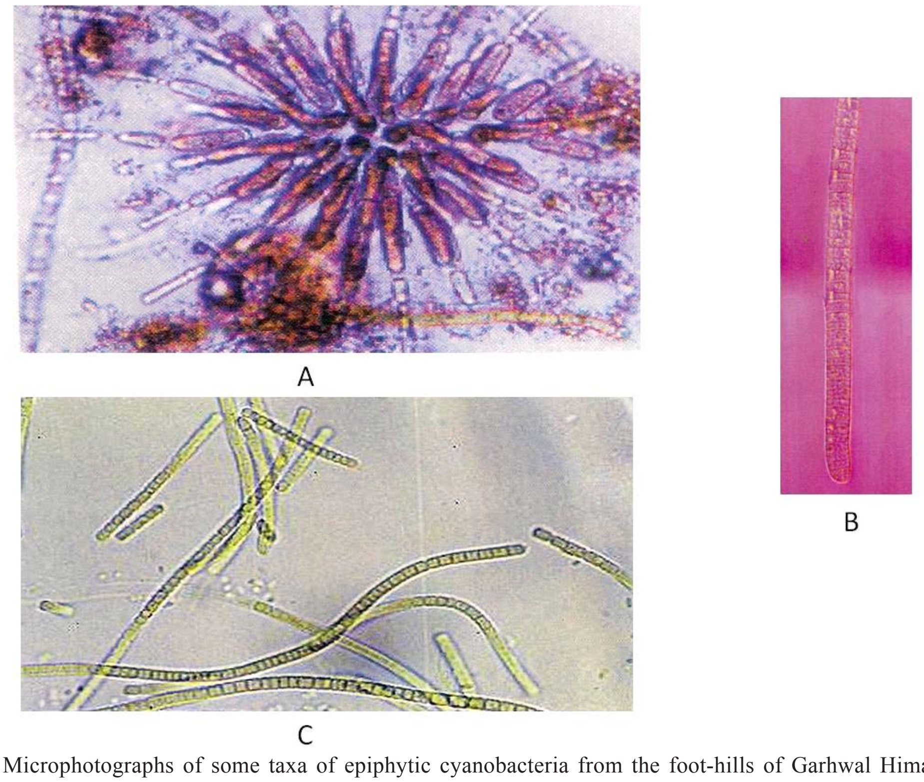

Figure 9. Microphotographs of some taxa of epiphytic cyanobacteria from the foot-hills of Garhwal Himalaya, Uttarakhand, India. (A) *Calothryx parietina*, (B) *Phormidium fragile*, (C) *Oscillatoria tennuis.*

14. *Aphanocapsa pulchra* (Kütz.) Rabenh.: Accession No. R-12, S-12, R-12; Sampling time: October 2002 (Dakpatthar), June 2002 (Rishikesh) and October 2002 (Laldhang). Cell diameter 3.4-4.3 μ. Attached on mosses in a drain, Dakpatthar. Attached on dead plants at the bank of canal, Rishikesh. Attached on pteridophytes near Bus Stand, Laldhang.

15. *Synechocystis aquatilis* Sauv.: Accession No. S-26; Sampling time: June 2002 (Kotdwar). Cell diameter 5.7-8.5 μ. Growing on a decaying bamboo stem in a stagnant water of a Gaud (river), Kotdwar.

16. *Merismopedia tenuissima* Lemm.: Accession No. R-26; Sampling time: October 2002. Cell breadth without envelope 2.5-3.4 μ. Attached on stem of a cut tree in running water of a rivulet, Kalidhal, Rishikesh.

17. *Xenococcus acervatus* Setchell et Gardner: Accession No. W-19; Sampling time: February 2002. Cell breadth 4.5-6.8 μ. Attached on moist wooden log dipped in polluted water at Badrinath road, Dugadda, Kotdwar.

18. *Spirulina subsalsa* Oerst. ex Gomont: Accession No. W-04; Sampling time: February 2002. Trichome breadth 1.3-1.9 μ, spiral breadth 3.1-4.2 μ, distance between spirals 3.1-5.2 μ. Attached on a piece of wood dipped in a small dirty pond, Mango garden, Bus Station, Laldhang.

19. *Spirulina gigantean* Schmidle: Accession No. S-10; Sampling time: June 2002. Trichome breadth 3.4-4.0 μ, spiral breadth 9.3-10.4 μ. Attached on tree bark near Bus Stand, Rishikesh.

20. *Oscillatoria foreaui* Fàemy: Accession No. S-26; Sampling time: June 2002. Trichome breadth 2.5-3.0 μ, cell length 1.4-1.7 μ. Attached on dead bamboo stem dipped in stagnant water of Gaud (river), Dugadda, Kotdwar.

21. *Oscillatoria tenuis* Ag. ex Gomont: Accession No. R-10, R-02; Sampling time: August 2002 (Kotdwar) and September 2002 (Rishikesh). Trichome breadth 6.4-14.4 μ, cell length 3.1-6.8 μ. Growing on the moist bark of mango tree at Dak Banglow, Dugadda, Kotdwar. Occurring on the moist bark of mango tree, Rishikesh

22. *Phormidium fragile* (Meneghini) Gomont: Accession No. W-25, R-09; Sampling time: February 2002 (Dakpatthar) and August 2002 (Kotdwar). Trichome breadth 2.0-3.4 μ, cell length 3.4-4.0 μ. Attached on grass of a street drain, Dakpatthar. Growing on the leaves of a plant in running water of drainage, Gadighat, Kotdwar.

23. *Lyngbya mesotricha* Skuja: Accession No. R-29; Sampling time: October 2002. Filament breadth 3.5-5.4 μ, trichome breadth 2.7-3.2 μ, cell length 4.9-8.0 μ. Attached on wood under water in a pond, Mango garden near Bus Stop, Laldhang.

24. *Lyngbya kuetzingii* Schmidle: Accession No. R-19, W-04; Sampling time: October 2002 (Dakpatthar) and February 2002 (Kotdwar). Filament breadth 2.1-3.7 μ, trichome breadth 38.0-63.0 μ, cell length 1.5-2.2 μ. Attached on pteridophytic plants in running water of Baldi River, Sahastradhara, Dakpatthar. Growing on the algae, mosses and pteridophytes in slow running water at Durga Devi temple, Dugadda, Kotdwar.

25. *Lyngbya spirulinoides* Gomont: Accession No. S-08; Sampling time: June 2002. Filament breadth 85.0-98.0 μ, trichome breadth 13.7-15.9 μ, cell length 3.8-5.6 μ. Growing on roots of some aquatic plants in running water, Kalidhal, Rishikesh.

26. *Lyngbya dendrobia* Bruhl et Biswas: Accession No. W-23, R-11; Sampling time: February 2002 (Dakpatthar) and August 2002 (Kotdwar). Filament breadth 10.5-12.2 μ, Sheath thickness 1.5-2.0 μ, trichome breadth 6.7-7.4 μ, cell length 3.4-5.1 μ.