CYANOBACTERIAL DIVERSITY OF WESTERN GHAT FORESTS OF KERALA, INDIA

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by

MANU PHILIP

DEPARTMENT OF BOTANY
UNIVERSITY OF CALICUT
KERALA, INDIA – 673635

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DEPARTMENT OF BOTANY
UNIVERSITY OF CALICUT
Calicut University (PO), Kerala - 673 635, India

Dr. V.V. RADHAKRISHNAN
Professor & Research Guide

Mob: 9447524456
E-mail: rkvadakkan@gmail.com

CERTIFICATE

Certified that this thesis titled **"Cyanobacterial diversity of Western Ghat forests of Kerala, India"** embodies the results of a piece of bona fide research work carried out as part fulfilment of requirements for the degree of Doctor of Philosophy in Botany of University of Calicut by Mr. **Manu Philip** under my guidance and supervision and that no part of the thesis has been submitted for any other degree.

I further certify that such helps or sources of information availed of in this connection have been duly acknowledged.

UNIVERSITY DEPARTMENT OF BOTANY

(V.V. RADHAKRISHNAN)

Prof. (Dr.) V.V. Radhakrishnan
Professor & Head, Department of Botany
University of Calicut, Kerala - 673 635

Calicut University
18/12/2020

DECLARATION

I, **Manu Philip**, hereby declare that this thesis entitled **"Cyanobacterial diversity of Western Ghat forests of Kerala, India"** being submitted in part fulfilment of requirements for the degree of Doctor of Philosophy in Botany of University of Calicut embodies the results of a bona fide research work done by me under the guidance of **Dr. V.V. Radhakrishnan**, Professor & Head, Department of Botany, University of Calicut, Kerala, India and that no part of it has previously formed the basis for the award of any degree, diploma, associateship, fellowship, title or recognition.

Calicut University   Manu Philip

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MANU PHILIP

PREFACE

Study of diversity is always a critical subject which connects with the whole universe and organisms. The world is believed to be going through a process of self-modification where ‘unfit’ organisms are eliminated. Natural selection always favours the fittest. Cyanobacteria are one of the major microorganisms believed to be present in the Proterozoic era. They have survived the harsh process of evolutionary selection/rejection with evidently immutable characteristics. Many schools of thoughts consider them as a connecting link between evolutionary changes from bacteria to algae as they share many structural similarities with bacteria but also shows the presence of photosynthetic mechanisms like higher organisms.

Cyanobacteria are one of the most diverse as well as least explored microorganisms present in the world. They are cosmopolitan in distribution and are reported from extreme low temperature areas like Antarctica and extreme high temperature areas like the Sahara Desert. Their adaptability was the major feature that helped them to bypass major evolutionary changes. They survive the adverse conditions by forming sheaths, or developing into spore, that can germinate under favourable conditions. They also show noticeable variations in structural characters. They are basically classified as unicellular and filamentous forms. The filamentous forms are again classified as non-heterocystous and heterocystous forms. The heterocystous forms are either be heterocystous branched filamentous type or heterocystous unbranched filamentous type. Finally, the heterocystous branched filamentous forms are divided into false branched cyanobacteria and true branched cyanobacteria. The leading attractions that focus the attention of researchers worldwide on this group are their economical relevance. They are good nitrogen fixers, so many strains of them are used in the investigations for producing biofertilizers. Some of the strains show anti-bacterial, anti- fungal, anti-inflammatory as well as anti-HIV properties. Bio-fuels are also extracted from these microorganisms. Modern world is facing many a problem with fuels and pollution. By proper exploration and marketing of these cyanoprokaryotes, one can make a revolution in the field of fuel and also help to reduce the environmental pollution.

Forest areas are the vast source of cyanobacterial communities, but they are not explored properly. In the case of India, Western Ghats is one of the richest biodiversity spots in India as well as in the world. Reported cyanobacterial specimens from these forests are very limited. Among the regions of the Western Ghats, Kerala is the least explored area. Therefore, the present study was designed to record the cyanobacterial flora from Western Ghat forests of Kerala. This work is also meant to open a gateway for further application level studies on selected cyanobacterial taxa.

Chapter - I
INTRODUCTION

Cyanobacteria are believed to be the oldest prokaryotic organisms of earth. They are microscopic organisms popularly known as “Blue-Green Algae (BGA)”. Cyanobacteria are small and microscopic, and often seen as colonies. The colonial aggregations are macroscopic and large enough for naked eye vision. Earlier, they were considered as primitive algal groups, later their close characteristic similarities with eubacteria distinguished them from algae. Even though they show similarities with eubacteria, cyanobacteria are more advanced than them in all parameters. Some scientists believe that cyanoprokaryotes are the connecting link between bacteria and algae. Cyanobacteria have prokaryotic characters of bacteria like microorganisms as well as eukaryotic characteristics of higher organisms. They possess chlorophyll-a rather than bacterial chlorophyll.

These microorganisms played a key role in the development of atmospheric oxygen during earth’s evolutionary times. Studies on cyanobacteria revealed that they were present in the earth before Proterozoic era (before 2.7 billion years). According to recent evidence, it is believed that their present diversity was achieved more than 3.5 billion years ago. Since they are one of the key organisms responsible for huge amount of oxygen production, their oxyphototrophic metabolism differs them from other microbes. These microorganisms are also capable of fixing atmospheric nitrogen.

Cyanobacteria are economically important organisms in accordance with their potential capabilities. Nitrogen fixation is a complex process, which cannot be performed by plants. But some microorganisms have the ability to fix atmospheric nitrogen. Cyanobacteria are the most important group among them. They also perform photosynthesis and thereby contributes a major part of oxygen production in the earth. Some cyanoprokaryotes are used as food and feed for animals as well as humans. *Spirulina* is recognized as a protein rich nutritious food by many countries. *Spirulina* also contains amino acids essential for humans. Some strains of *Anabaena* and *Nostoc* are consumed by people of Africa and Mexico. *Azolla* is a common cattle feed, which shows symbiotic association with a cyanobacteria called *Anabaena azollae*. *Anabaena* and *Anabaenopsis* are used as fish food in the fisheries industry. The edible cyanobacterial species have high amount of proteins, carbohydrates, lipids, minerals and moisture. They are also rich sources of beta carotene, thiamine, riboflavin and vitamin B_{12}.

Many array of cyanobacterial strains offer pharmaceutical properties such as certain species of *Scytonema* that shows anti-HIV activities. They exhibit different pharmacological activities such as anti-cancerous property, anti-bacterial property, anti-fungal property, anti-viral property and also anti-inflammatory properties. Phycocyanin pigment produced by most of the cyanobacteria is a natural colourant used in many diagnostic methods. *Phormidium* species are very good source of phycocyanin.

The main reason for the demand of cyanobacteria in agricultural fields is their capacity to provide essential minerals to plants. They are used as biofertilizers. Cyanobacteria are eco-friendly and need minimal cost for their establishment. And the main benefit is that, once we introduce these microbes to the field, they multiply and no need for further caring. Evidence has shown that one of the probable causes for the ability of rice to grow year after year in the absence of manure is due to the fixation of atmospheric nitrogen by the cyanobacteria (De, 1936). Studies disclosed that some species of *Nostoc* and *Scytonema* growing in sugarcane fields produce beneficial effects on the growth of plants. Cyanobacteria not only fix atmospheric nitrogen but also aid in performing fixation of phosphorous and other minerals to the soil.

Waste water treatment was carried out using some combinations of cyanobacteria. Photosynthetic ability helps in the management of CO_2. They also perform as good source of food for aquatic organisms. *Phormidium valderianum*, a phenol tolerant cyanobacterium is used to treat phenolic effluents (Shashirekha *et al.* 1997). They are good indicators of pollution. They grow naturally in normal environmental conditions and the vegetative cells are in natural forms. If the condition is adverse such as high or low temperature, variation in pH, influence of chemicals etc., the growth of the cyanobacterial cells retard and become spores or thick walled spore like cells. In short, they are cosmopolitan in distribution and have high adaptability to different environmental conditions.

Cyanobacteria are taxonomically classified based on their morphological features. Recent studies included their phylogenetic analysis also. The classification was executed by analysing cell morphology, cell specialisation, colonial or filament morphology, ultra-structure, habit or ecology and habitat. Based on these characters, there are 3 major cyanobacterial types. First is the unicellular cyanobacteria. They are single celled microscopic cyanobacteria. Sometimes they are aggregated to form colonial structures and become macroscopic (*Aphanothece, Chroococcus, Cyanothece*). These cyanobacteria do not possess heterocysts or other specialised cells. They only have vegetative cells and most probably a mucilaginous envelope. The second group is non heterocystous filamentous cyanobacteria. They are made up of many cells arranged in a filamentous manner and these chains of cells are called trichomes. This group shows vegetative cells, akinetes and necridia in their filaments (*Oscillatoria, Phormidium, and Leptolyngbya*). The third type of cyanobacteria are heterocystous cyanobacteria. These cyanobacteria can be again divided into two groups; unbranched heterocystous type and branched heterocystous type. Unbranched heterocystous cyanobacteria like *Nostoc, Anabaena, Aulosira*, etc. have heterocysts in intercalary or terminal position. But they are always uniseriate and form chain like structures without branching. Branched heterocystous types possess both heterocysts as well as branches. The branches may be true branch (eg: *Stigonema* and *Hapalosiphon*) or false branch (eg: *Scytonema, Hassallia* and *Tolypothrix*).

Lower groups of microorganisms have specialised structures for their motion. But cyanobacteria do not have any specialised structures such as flagella. But, still most of them are motile. Hormogonia play a key role in the movement of cyanobacterial cells. Filaments show oscillation movement as well as gliding movement. Certain species shows clockwise or anti clockwise rotation.

Their cellular organisation is simple when compared to algae. The size and shape of vegetative cells may vary based on species. Some cyanobacteria are slightly more developed and possess akinetes along with vegetative cells. Akinetes help to survive under adverse environmental conditions. Some scientists believe that the advanced type cyanobacteria have heterocystous cells or heterocytes. Earlier, it was believed that nitrogen fixation was carried out inside heterocysts. Although it is right, some non-heterocystous cyanobacteria also perform nitrogen fixation. Heterocysts are helpful to fix nitrogen under aerobic condition. During unfavourable conditions, most of the cyanobacterial taxa undergoes sporulation. These spores withstand adverse condition and when favourable environment occurs, they germinate into normal vegetative cyanobacterial filaments.

Cyanobacteria are hydrophilic and their exponential growth is seen with constant availability of water. They need good moisture as well as humid condition for their ideal growth and development. Their cells are pigmented with different kinds of phycocyanin, phycobiliproteins and chlorophyll. They usually have blue-green colour and are abundantly found in streams, lakes, reservoirs, wetlands and rivers. They also exhibit symbiotic or epiphytic associations with almost all types of plant groups. A few cyanobacterial species show symbiotic associations with fungi and these associations are termed lichens. Some *Nostoc* and *Anabaena* species are found from the coralloid roots of *Cycas* (Gymnosperm). *Anabaena azolla* is a species of cyanobacteria showing symbiotic association with *Azolla* and is named after this association. Species of *Azolla* called *Azolla filiculoides* shows symbiotic association with the *Nostoc* species, *Nostoc azollae* (Eily *et al.*, 2019). The angiosperm genus *Gunnera* shows symbiotic association with *Nostoc punctiforme*.

Studies revealed that cyanobacteria can withstand extreme temperatures, extreme pH conditions, wide range of climatic changes, etc. A few *Oscillatoria* spp. reported from the bottom of Thames, lived in anaerobic conditions. Cyanobacterial strains have been reported from extreme cold Antarctic regions to the extreme hot Sahara desert. Cyanobacteria can withstand a wide range of ecological habitats including marine, fresh water, high altitude, low altitude, terrestrial and other adverse environments (Hedges *et al.*, 2001). A few cyanobacterial species are halophytes and salt tolerant, mostly found from mangrove ecosystems. This group of microorganisms show a wide range of variations as well as adaptation. They can withstand adverse conditions, and they also show cosmopolitan distribution. Diversity of cyanobacteria is expressed by their morphological, biochemical and physiological properties, which enable them to settle and persist in a wide range of habitats (Palinska *et al.*, 2011).

Compared to other prokaryotic and eukaryotic groups, cyanobacteria are easy to be cultured and multiplied. The cost and expenditure of cultivation or large scale production of cyanobacteria is comparatively less. Because, unlike other heterotrophic bacteria, cyanobacteria only need sunlight, CO_2, water and minimal amount of common nutrients for their mass development.

They require less area as compared with other plant groups and the productivity is comparatively higher than other organisms. The main advantage of cyanobacterial cultivation is to reduce the competition for space among plants, and their culturing do not affect negatively on any other type of cropping. Another important factor is that the usage of cyanobacteria for producing value added products will reduce wastage. The biomass remaining after the production of different kinds of products can be used as biofertilizers in agricultural fields.

Cyanobacteria deliver many beneficial characteristics as well as exhibit some hazardous features. Some species of *Microcystis*, *Oscillatoria*, *Nodularia* and *Lyngbya* excrete certain toxic chemicals. Algal bloom or cyanobacterial bloom was a problem faced by many countries. When blooming occurs, the water quality declines drastically and it becomes toxic. Some other cyanobacterial species cause allergic reactions after close contact with them. *Lyngbya majuscula* and *Schizothrix calcicola* shows symptoms of itching, vomiting and diarrhoea. Microcystin, one of the toxic substances which may cause death, is produced by a cyanobacterium namely *Microcystis aeruginosa*. They affect neurotic activities. Many Western countries are facing the problems caused by these cyanobacteria. Bloom formation in the waterbodies also cause the death of organisms living in that ecosystem.

Studies on the diversity of cyanobacteria were conducted all over the world. Still the total number of cyanobacteria under different groups remains uncertain. It is believed that the total number of described cyanobacterial species ranges from 2000-5000. No detailed studies were carried out to validate this. Their diversity was very high in agricultural fields. In India, most of the studies on cyanobacterial diversity are from agricultural lands. Majority of the cyanobacterial species recorded in India were collected and cultured from various agricultural lands. Very small percent of members were described from other areas like monuments, pilgrim sites, etc. Still the diversity of cyanoprokaryotes from forest regions were untouched. A few studies conducted on cyanobacterial diversity from forest areas revealed high diversity and abundance of cyanobacteria.

Kerala is one of the most resourceful areas with respect to forests and biodiversity. 97% of forests in Kerala are comes under Western Ghats. Western Ghats are considered as one of the richest forest regions with regard to its biodiversity. Still, these forest regions of Kerala are not explored to describe these useful cyanobacterial communities. The limited studies carried out on cyanobacterial diversity in Kerala were all focussed on coastal areas and agricultural lands. Internationally, the taxonomic and biotechnological aspects of cyanobacterial members are getting updated periodically whereas in our country, it is somehow entirely neglected. While examining the data from other states and countries, cyanobacterial diversity was found to be optimum in forests. The minimal availability of the literature shows the importance of study and identification of cyanobacterial strains.

A brief survey in forest regions of Kerala provides numerous information about the richness of cyanobacterial diversity in these forests. Preliminary studies provide many new reports and some interesting cyanobacterial strains. Considering all these facts, we propose a detailed exploration of forests of Kerala focusing on Western Ghats regions. Since these microscopic organisms are highly promising, the need of greater focus on cyanobacterial explorations is evident. This work will act as collective information of cyanobacterial diversity of forests of Kerala and this is the first time a work based on cyanobacterial diversity on forests of Kerala, focusing on Western Ghats region is implemented. There are lots of cyanobacterial taxa waiting for their discovery and no doubt, we will introduce many new members to the cyanobacterial community.

Chapter - II
REVIEW OF LITERATURE

Cyanoprokaryotes, the photosynthetic nitrogen fixers, are one of the most ancient group of organisms to inhabit earth. They are extremely diverse with regard to their cytomorphological, ecological and adaptive features, which makes them an especially challenging group to classify. This complex group of organisms has immense ecological and economical significance. Their impact on life on earth in general has made them the focus of many scientific explorations from time immemorial.

2.1. History of cyanobacteria

Desikachary (1959) classified cyanobacteria on the basis of cell morphology and the plane of cell division into five orders namely Chroococcales, Pleurocapsales, Oscillatoriales, Nostocales and Stigonematales. According to Anand (1989), cyanobacteria were divided into five orders as Chroococcales, Chaemosiphonales, Pleurocapsales, Nostocales and Stigonematales. During the 20th century, a number of floras regarding the available and known species of cyanobacteria in particular regions were published. Some of these publications provide information on cyanobacteria occurring all over the world. The distribution patterns are also being revealed by these regional floras.

Pithart (2002) reported that micro algal communities produce changes in the ecosystem development. Seasonal course of microorganisms was taken as an example of self-structuration of lake ecosystem. The author describes the role of microorganisms like cyanobacteria in the process of ecological succession and believed that algal community including cyanobacteria are the co-creators of ecosystems.

Kastovsky *et al.* (2010) listed the cyanobacterial species from Czech Republic. They were able to find only 392 species from the areas where studies from 1982 reported the occurrence of about 505 species. So, it is evident that a clear decrease in the cyanobacterial diversity has occurred in 20th century. They concluded the study with the finding that if the biotope of the occurrence is endangered, it will affect the cyanobacteria depending on that biotope. Some previously observed species such as *Gloeotrichia natans, Nostoc kihlmanii*, etc. which had shown good representation in the 19th century has disappeared from the country.

2.2. Taxonomy and diversity

A systematic study of microalgae from the Eastern Ghats and the Western Ghats was conducted by Suresh *et al.* (2012). They investigated the biodiversity of microalgae from Kodaikanal, Gudalur, Agasthiyar falls and Kolli hills. A total of 97 microalgal species were identified during this exploration. The results showed that the cyanophycean members dominated in diversity with 41 species than any other microalgal member. *Aphanothece, Chroococcus, Coelosphaerium, Oscillatoria, Nostoc, Calothrix, Tolypothrix, Scytonema* and *Gloeotrichia* have been reported abundantly from these sites.

Geitler (1957) observed that a certain degree of polarity occurs in reproductive cells, particularly in the case in which small solitary cells liberated from the divided (mother) cell or colony. In several simple types, no polarity occurs, but in several species with polarised (elongated) vegetative and reproductive cells showed apical polarity congruent with the original longer cell axis of the mother cell (*Stichosiphon*). On the other hand, the changed perpendicular (lateral) polarity of germinating exocytes is known in the genus *Cyanophanon*.

Bhavani *et al.* (2013) aimed to study the diversity of cyanobacteria from different temple ponds of Thanjavur District. Their work focused on five major temple ponds and they found a total of 215 cyanobacterial species including 70 different cyanobacterial taxa under 16 genera. Among them, eight genera namely *Lyngbya, Oscillatoria, Phormidium, Synechococcus, Aphanocapsa, Gloeocapsa, Plectonema* and *Nostoc* were common to all the temple ponds. In the case of diversity based on family statistics, Oscillatoriaceae members dominated others with a maximum representation of 48 species. Chroococcaceae members with 12 species, Scytonemataceae with five species, Nostocaceae with three species, Pleurocapsaceae and Stigonemataceae with one species in each showed representations during the study. *Lyngbya* was dominant over other species, followed by *Oscillatoria* and *Phormidium*. Authors believed that the abundance of cyanobacterial species in temple ponds might be because of the availability of nutrients and favourable pH.

The recent situation in taxonomy of cyanobacteria is rather complicated as morphology of the thalli was considered a unique distinguishing feature for the identification of taxonomic units (Komarek *et al.*, 2013a). During an exploration work on the Ghats region of Nelliyampathy forests, Philip *et al.* (2016) reported 15 cyanobacterial species under 4 families. They reported species from *Chroococcus, Aphanocapsa, Aphanothece, Gloeocapsa* and *Gloeothece* from unicellular cyanobacteria. *Nostoc, Scytonema, Calothrix* and *Tolypothrix* were found under filamentous cyanobacteria. Members of the family Chroococcaceae showed greater representation with 3 species and the study also reported poor representation of Oscillatoriaceae members from these forest regions.

An investigation of the fresh water reservoirs from different localities of Nashik and its surroundings to find out the diversity of genus *Oscillatoria* was conducted by Patil and Deore (2014). Their study focused on the lentic and lotic water reservoirs and found *Oscillatoria* abundantly and frequently from slight alkaline water from the reservoirs. Thirty-three *Oscillatoria* species were found from the study area. Some species such as *Oscillatoria perornata, O. ornata, O. boryana, O. jasorvensis, O. limnetica, O. brevis* and

O. subbrevis were found rarely in these reservoirs. This work described that cyanobacterial diversity of Nashik was comparatively high and need more attention to studying cyanobacterial specimens from here.

Bharadwaj and Baruah (2013) reported 47 cyanobacterial taxa from 20 genera. Among them, eight were non-heterocystous and 12 were heterocystous type of cyanobacteria. *Nostoc* and *Anabaena* showed maximum diversity and the study also revealed the abundance of *Anabaena circinalis* and *A. oryzae*. Major species observed were *Aphanocapsa, Chroococcus, Gloeocapsa, Anabaena, Cylindrospermum, Nostoc, Lyngbya, Phormidium, Tolypothrix, Microchaete* and *Westiellopsis*. Komarek (2005) studied the phenotypic diversity of the cyanoprokaryotic genus *Anabaenopsis* and 21 species were described taxonomically with morphological characters. *Anabaenopsis* is a filamentous, heterocystous cyanobacteria without branching. Recently the taxonomic position of the genus *Anabaenopsis* was confirmed by 16S rRNA sequencing (Iteman *et al.*, 2002) and among the 33 species of *Anabaenopsis* described so far 15 taxa have showed dissimilarities with the genus *Anabaenopsis* and hence transferred to respective genera with morphological and molecular similarities.

A study on cyanobacterial diversity in four rivers viz. Netravati, Kumaradhara, Sita and Shambhavi from the Western Ghats of Karnataka was carried out by Joishi (2014). His study focused on the occurrence of cyanobacterial species richness, and distribution with reference to water chemistry. He could find a total of 41 cyanobacterial species under 16 genera. Maximum number of cyanophycean members were obtained from leaf or litter substratum. *Oscillatoria* showed the highest representation with 11 species. *Microcystis* showed the second highest representation with seven species. *Scytonema* and *Phormidium* were represented by four species each. *Gloeocapsa* and *Aphanocapsa* showed two and three species respectively. There was only single species representation from *Anabaenopsis*, *Aphanothece*, *Calothrix*, *Camptylonemopsis*, *Chlorogloea*, *Dactylococcopsis*, *Lyngbya*, *Rivularia*, *Scytonematopsis* and *Synechococcus*.

Epilithic, benthic and epiphytic cyanobacteria from specific microhabitat such as wells in Brno surroundings were collected and identified by Uher *et al.* (2001). They reported 15 cyanobacterial species from four wells during the course of study. *Gloeothece rupestris*, *Aphanocapsa grevillea*, *Gloeocapsa atrata*, *Chroococcus minutus*, *C. turgidus*, *Chlorogloea rivularis*, *Pleurocapsa minor*, *P. fusca* and *Phormidium cebennesse* were the dominant species found during collection.

Komarek and Komarkova in 2004 conducted a review on cyanoprokaryotic genera *Planktothrix* and *Planktothricoides*, which are coming under phormidacean types and are filamentous planktonic forms. *Planktothrix* are separated from *Oscillatoria* in accordance with their life strategy, ultrastructure and phenotypic appearance. *Planktothricoides* were also separated from *Oscillatoria* based on molecular analysis. These are the two genetically delimited clusters, but both genera showed morphological similarities. They analyzed 15 species, among which 13 species belong to *Planktothrix* and the remaining 2 were from *Planktothricoides*. Most of them are differentiated from *Oscillatoria* or *Lyngbya*. These revision works revealed the importance of phylogenetic analysis of cyanobacterial taxa and the authors have proposed a revision work for 12 *Oscillatoria* members which showed Oscillatorian characters morphologically but molecular data was little confusing.

A study was carried out by Rehakove *et al.* (2014) for the sequencing of full 16s rRNA as secondary structure model from *Nostoc commune*. They recognized that the secondary structure of *N. commune* exhibits similarities with small subunit rRNA molecules in *Escherichia coli*. They concluded that secondary structure of RNA molecules plays a very significant role in the systematics and taxonomy of cyanobacteria. Cyanobacterial samples were collected from wells of two different localities by Hrouzek and Soun (2004). The collected cyanobacterial samples formed mats during their maximum growth phase. They found 12 cyanobacterial species from the randomly selected samples. Their work revealed that Chroococcoid cyanobacterial types were dominant in the wells of study area and species such as *Aphanothece pallida*, *A. saxicola*, *Chroococcus spelaeus*, *Phormidium autumnale*, *Leptolyngbya* spp., *Nostoc* spp. and unknown morphotypes of *Calothrix* sp. were observed. They found significant morphological differences in unknown morphotype of *Calothrix*. The changes mainly occurred were in the branching format and filament morphology. This study on subaerophytic cyanobacteria was purely based on traditional method by analysing morphological characters.

Kastovsky *et al.* (2011) explored the micro vegetation of the Mount Roraima of Venezuela. They found high diversity of cyanobacterial flora during their exploration that ranged for four years. During the course of collection, they could identify 44 cyanobacterial species and among them *Stigonema* showed dominance in comparison with other species. *Gloeocapsa*, *Chroococcus*, *Gloeothece* and *Scytonema* are the other species observed during the collection.

An extensive phylogenetic analysis of genus *Cyanospira* and *Anabaenopsis* was performed by Sili *et al.* (2011) to clarify the distinctiveness of *Cyanospira* from *Anabaenopsis*. They have documented the morphology, life cycle, akinete germination and development of vegetative cells. During the work, they also found that these two genera have entirely different development patterns for akinete and phylogenetic analysis showed a different cluster for *Cyanospira*. The authors concluded their findings with the statement that genus *Cyanospira* has a unique morphological trait that is different from the genus *Anabaenopsis*.

A survey was conducted by Ferrari *et al.* (2011) to report cyanobacteria from Lower Uruguay River. They identified a total of 24 species under 3 families and Chroococcales dominated the cyanobacterial population with 13 species. Nostocales have a solid representation of seven species followed by Oscillatoriales with 4 species. They reported that cyanobacterial bloom of *Dolichospermum* and *Microcystis* dominated these areas. The main attraction of this work was the first ever report of *Radiocystis fernandoi* from Uruguay and they also reported a species for the first time to South America namely *Dolichospermum pseudocompactum*.

Algal flora of Idukki District of Kerala, India was explored by Jose and Francis (2013) and they identified 50 cyanobacterial species under six families. They found that unicellular forms of cyanobacteria dominated the cyanobacterial flora compared to the filamentous forms. *Chroococcus*, *Aphanocapsa*, *Aphanothece*, *Merismopedia*, *Oscillatoria*, *Lyngbya*, *Nostoc*, *Anabaena*, *Calothrix*, *Tolypothrix*, *Arthrospira*, *Synechocystis*, *Coelospharium*, *Gloeocapsa*, *Spirulina*, *Cylindrospermum* and *Scytonema* were some of the genus observed during the study. Five genera such as *Oscillatoria*, *Phormidium*, *Lyngbya*, *Nostoc* and *Scytonema* were identified from hill stream in Kerala (Sebastian and Joseph, 2013).

Cyanobacteria from aquatic habitats were more studied than epilithic cyanobacteria. So, the details about epilithic cyanobacteria were very less in literature. Hauer (2008) conducted a study to give information regarding the present status of epilithic cyanobacterial communities. The work was carried out in the Mohalenska Hadcova Steppe nature reserve, which was established in 1933. The reserves were divided into three parts; the first part was the driest part with high temperature and low humidity. Here, coccoid cyanobacterial forms such as *Gloeocapsa* and *Gloeocapsopsis* were dominated. The second part was wetter and which had small streams and waterfalls. Genera such as *Nostoc*, *Aphanothece*, *Leptolyngbya* and sometimes

Gloeocapsa showed dominance here. The third portion was adjacent to the Jihlava River and had the highest air humidity. Filamentous cyanobacterial taxa such as *Hassallia, Tolypothrix* and *Stigonema* were showing domination here. Very low representations of *Gloeocapsa* and *Gloeocapsopsis* were also recorded from this area. The study revealed that the number of cyanobacterial taxa during research period 2004-06 (30 species) was lowered when compared with Novacek's (1934) work (32 species). He concluded that massive use of fertilizers and chemicals affected the diversity of cyanobacteria. Climate change also played a role in lowering the diversity of these microbes.

During a research work in paddy fields from Thanjavur District of Tamil Nadu, Madhumathi *et al.* (2012) identified 18 species of heterocystous cyanobacteria. Among the 18 species, eight were new reports from Thanjavur District. The study revealed that maximum species occurrence and abundance were recorded from the family Nostocaceae. Scytonemataceae and Rivulariaceae also showed good representations while Stigonemataceae showed poor occurrence from the sampled sites.

Palinska *et al.* (2011) identified three distinct groups of *Phormidium* like cells based on the cell width measurements. Group-I included cell width less than 1.5 µm, group-II with cell width between 1.5-2.5 µm and group-III with more than 2.5 µm cell width. They obtained 15 strains in group-I, six strains in group-II and eight strains in group-III. Constriction between adjacent cells was also considered for this classification. Researchers proposed for a detailed revision study on *Phormidium* classification because they showed similarities with other genera. This study also supports that the genus *Phormidium* represented a phylogenetically polyphyletic group. Distribution of cyanobacteria in the estuaries region of Southern coast of Tamil Nadu was inspected by Ramanathan *et al.* (2013). Thirtysix cyanophycean members were recorded from 14 genera under 5 families. *Oscillatoria*, *Lyngbya*, *Calothrix*, *Microcystis* and *Chroococcus* have showed dominance in the estuaries explored.

A study was conducted by Sharath and Rajashekar (2016) to evaluate the diversity of cyanobacteria from artificial tanks. The tanks were selected from four different Districts of Karnataka State, India. Collection of samples were carried out during different seasons of a three year period from 2008 to 2011. They identified 43 cyanobacterial species from 19 genera coming under 9 families. Phormidiaceae and Microcystaceae showed healthy representations compared to other families. *Oscillatoria limosa* was the only species found from all the four sites during different seasonal collections in the entire period. From statistical analysis it was found that non-heterocystous filamentous cyanobacteria showed 50.85% occurrence during the entire study which was followed by unicellular forms with 32.20% occurrence. Hetereocystous cyanobacterial forms were least in representation with 16.95%. This study also revealed that the species richness was the maximum during monsoon season followed by pre-monsoon. The minimum species richness was recorded during post-monsoon season with low humidity and high dryness.

The diversity and cyanobacterial assemblage investigated during rice cultivating season and post harvesting period from a paddy field located in Fujian province of China (Song *et al.*, 2005) revealed that some cyanobacterial strains were present only during the cultivation season of rice, while some other species occurred after harvesting of paddy. A study on cyanobacteria and diatoms was carried out by Naz *et al.* (2014) aiming to document the microorganisms present in the polluted river. During the study, they recorded a total of 40 taxa, among them 26 taxa were from cyanoprokaryote. The samples were collected from Padma river, and the areas located between the T-dam and I-dam which lies on Padma garden of Rajshahi District of Bangladesh. The major cyanobacterial members observed during the study are *Anabaenopsis*, *Aphanocapsa*, *Microcystis*, *Oscillatoria*, *Spirulina* and

Pseudanabaena. From the 26 species of cyanobacteria, 11 species were from the genus *Oscillatoria*.

Taxonomic identification of prokaryotic, phylogenetically old cyanobacteria were difficult because they produce too simple unicellular forms and filamentous branched forms with differentiated thallus. Komarek (2016) investigated a combination method for identification which includes molecular, cytomorphological and ecological information. But the taxonomical identification and classification of cyanobacteria require a combined use of conventional as well as molecular methods. This polyphasic approach is not only for taxonomic enumeration but also morphospecies or ecospecies identification which may be important for the development of cyanobacterial classification.

Dhanya and Ray (2015) conducted a field study on the ecology and diversity of cyanobacteria from paddy fields of Kuttanadu in Kerala State of India. The diversity of cyanophycean members from the wetland of Kuttanadu was untouched by any other researchers so far. So, this work generated new data about cyanobacteria from Kuttanadu. They found a well-established diversity of cyanobacteria with 64 species belonging to 22 genera under six orders. Genus *Oscillatoria* dominated in presence with 12 species followed by *Anabaena* (9 species) and *Nostoc* (7 species). *Leptolyngbya* and *Phormidium* were found to have five species each. With respect to orders, Oscillatoriales showed maximum representation with 24 species under five genera, which is almost 38% of all the taxa reported during this work. They found a positive correlation between species richness and the number of species with crop seasons. *Gloeothece rupestris* showed greater abundance in 'Kayal' lands while *Chroococcus turgidus* showed dominance and abundance in lower and upper Kuttanadu regions.

A study on the distribution of cyanobacteria from arid zones of Rajasthan reported *Nostoc* to be the predominant species. Other cyanobacteria reported in this investigation are non-heterocystous type like *Phormidium*, *Oscillatoria*, etc. and heterocystous type such as *Anabaena* and *Calothrix* (Tiwari *et al.*, 2005). Current taxonomic issues of the genus *Anabaena* with special reference to the morphological characters were carried out by Eliska (2006). Planktonic cyanobacterial species of Nostocaceae members which form algal blooms were analysed during this study and were classified with respect to their phenotypic features. This study also dealt with the changing growth condition in relation to morphological viability.

Genus *Scytonema* are a very rarely studied cyanobacteria due to difficulties in isolating them. Komarek *et al.* (2013a) studied *Scytonema* genera for analysing the morphological and phylogenetic features of *Scytonema* from SE Brazil to ensure their position and species level identification. Thirteen morphospecies were collected for the study from 28 populations and most of them are aerophytes. Seven strains from isolated species were also selected for the study. Morphologically described *Scytonema* species are as follows; *Scytonema guyanense*, *Scytonema* sp., *S. javanicum, S. arcangelii*, *S. hyalinum, S. ocellatum, S. bohneri*, *S. stuposum*, *S. crispum*, *S. schmidtii*, *S.* sp., *S. longiarticulatum*, *S. papillicapitatum* and *S. chorea*.

In order to classify the taxonomic position and classification of the *Geitleribactron*, Mares and Cantonati (2016) conducted a study using *Geitleribactron purpureum*, which is a heteropolar unicellular cyanobacteria. They isolated and purified single colonies of *G. purpureum* from the holotype obtained from the deep epilithon of lake Tovel in Italy. PCR and 16s rRNA sequencing analysis showed phylogenetic similarities with Leptolyngbyaceae. With this data, authors provide evidences for the polyphyly in Chaemosiphonaceae. A proposal was given suggesting that *Geitleribactron* should be reclassified in Leptolyngbyaceae. This work has generated confusion about the classification of cyanophycean members which were classified based only on traditional morphological analysis.

Presence of cyanobacteria from mangroves of Kadalundy, a mangrove rich area of Kozhikode District of Kerala State, India first reported by Shamina and Ram (2014). They reported *Oscillatoria ornata* var. *crassa* for the first time from marine habitats of India. This cyanobacterium was collected from pneumatophores of *Avicinnia officinalis*, a halophytic plant.

Study on the cyanobacterial diversity of a pond near the Empty Quarter desert of Oman was carried out by Abed *et al.* (2011) and they reported cyanobacteria such as *Microcoleus chthonoplastes*, *Spirulina subsalsa*, *Johennesbaptista pellucida*, *Chroococcidiopsis* sp., *Aphanocapsa* sp., *Chroococcus* sp., *Gloeocapsa* sp., *Schizothrix* sp. and *Leptolyngbya* sp. Palinska *et al.* (2006) analysed and characterised dried herbarium specimens of cyanobacteria which were deposited over 100 years ago. They aimed to introduce molecular data of described botanical type species deposited in the herbarium. The analysis was based on morphological as well as molecular evidences. The study was focused on six members of coccoid and filamentous cyanobacteria from 15 years old air dried samples. *Microcystis aeruginosa*, *Chroococcus turgidus*, *Microcoleus chthonoplastes*, *Trichodesmium erythreum*, *Nostoc muscorum* and *Nodularia spumigena* were analysed by 16s rRNA method.

A review work was carried out by Komarek (2001) on fresh water cyanobacterium *Romeria* which is traditionally classified as the simplest filamentous cyanobacteria. Globally there are 19 species reported from this genus. They were described based on morphological characters only due to the difficulty in culturing and isolating them which is essential for an extensive study. Some morphological studies synonymise *Oscillatoria*, *Spirulina* as well as *Synechococcus* species with *Romeria*. The study gives an information about the relationship of *Romeria* genus with other filamentous species and also with simple coccoid forms.

Komarek and Anagnostidis (1989) showed isopolar development of hormogonia in the Scytonemataceae family. This isopolarity was described by the symmetrical germination of hormogonia on both the ends. Germination of hormogonia was asymmetric in the population of *Brasilonema* (Becerra-Absalon *et al.*, 2013).

Cyanobacterial samples preserved in formalin or by use of other preservation methods in the herbarium or laboratories were studied by Pumann (2001). The accurate identification of dominant species in each samples were recorded. *Microcystis*, *Anabaena*, *Pseudanabaena*, *Planktothrix* and *Aphanizomenon* were the major genus examined by the author.

A polyphasic study based on the aspects of classical morphology and molecular data revealed two monospecific genera called *Iphinoe* and *Loriellopsis* from fresh water of Greek and Spanish caves (Lamprinou *et al.*, 2011). Both taxa are characterised by true (T-type and V-type) and false branching, presence of heterocysts and reproduction by hormocysts and akinetes. Lamprinou *et al.* (2013) studied the genus *Iphinoe* with regard to their branching pattern. These are true branched cyanobacteria exhibiting different kinds of branching pattern. V, T and Y shaped branching patterns were observed in *Iphinoe* genus. Patterns in branching played a significant role in the classification of filamentous cyanobacteria. *Iphinoe spelaeobios* was studied and found that most of the branching patterns are T-type and rarely produced V-type branching. They also found that the species showed false branching in rare occasions. But it was noticed that, this species does not exhibit a single Y-type branching. The same research team found a morphologically similar strain from a geographically isolated cave in Crete

Island, Greece. Collected strains displayed all the characteristic features of *I. spelaeobios* except V-type branching pattern and they exhibited Y-type branching pattern along with T-type.   After extensive analysis researchers suggested that the specimen collected from Crete Island is to be considered as *I. spelaeobios*.

Significance of the study on cyanobacterial diversity under different ecological conditions was conducted by Syiem *et al.* (2010) from Meghalaya. They collected 75 samples from 10 different ecosystems. Microscopic analysis and morphological characterisation resulted in 65 cyanobacterial species. A total of 11 genera viz. *Nostoc*, *Anabaena*, *Calothrix*, *Cylindrospermum*, *Gloeocapsa*, *Fischerella*, *Plectonema*, *Tolypothrix*, *Stigonema*, *Loriella* and *Westiellopsis* were reported. *Nostoc* was recorded most during the study, and the abundancy showed by *Nostoc* genus was remarkable.

Ten morphotypes of Chroococcales were described morphologically by Leon-Tejara *et al.* (2011) from mangrove of Mexican coasts. They reported species from *Aphanocapsa*, *Hydrococcus*, *Chroococcus*, *Chamaecalyx*, *Dermocarpella* and *Xenococcus*. Their work was purely based on members of Chroococcales. Some members of the identified species showed seasonal distribution on the pneumatophores of mangrove vegetation. To avoid the conflicts on the traditional morphospecies of *Microcystis*, Komarek and Komarkova (2002) conducted a review work. *Microcystis* are the major toxin producing cyanobacterial group, so they needed to clarify the morphospecies which caused problems to the waterbodies as well as ecosystem. They characterised the main species of *Microcystis* from Europe and found 10 morphospecies. They are *Microcystis natans*, *M. firma*, *M. ichthyoblabe*, *M. flos-aquae*, *M. novaceki*, *M. smithii*, *M. botr*, *M. aeruginosa*, *M. viridis* and *M. wesenbergii*. Komarek and Zapomelova (2007) reviewed 25 *Anabaena* morphospecies. Genus *Anabaena* are benthic and showed morphological similarities with *Dolichospermum*. This review work helped to eliminate the doubts regarding similarities of these two genera and coiled *Dolichospermum* was clearly separated from *Anabaena*. *Anabaena* genus represented a special generic entity. Subgenus *Dolichospermum* possess planktic cyanobacterial species. In a work, Komarek and Zapomelova (2008) reviewed 19 *Anabaena* species with critical analysis and diacritical features. They found that planktic species of *Anabaena* (*Dolichospermum*) with straight trichomes showed morphological modifications only in size and shape of cells and akinetes.

The cyanobacterial community in Grande coastal lagoon, Lima, Peru was mainly composed of coccoid colonies and filamentous cyanobacteria, diatoms and some green algae. A cohesive slimy layer formed mainly of the cyanobacteria *Chroococcus disperses*, *C. turgidus*, *Aphanothece stagnina*, *Oscillatoria tenuis*, *Lyngbya martensiana*, *L. diguetti* and *Phormidium valderianum* associated with *Chroococcus horenmannii* and *Rhizoclonium hieroglyphicum* (resting cells) *Aphanizomenon flos-aquae* (akinetes) and *Tetraselmis contracta* (cysts) (Montoya, 2009).

During phylogenetic and morphological evaluation of *Wollea saccata* Kozhevnikov and Kozhevnikova (2011) found a suitable placement for the genus which showed close morphological characteristics of *Anabaena*, *Cylindrospermopsis*, etc. *Wollea* is believed to be a totally different genus in comparison with *Nostoc* like cyanobacteria. *Wollea saccata* is a fresh water cyanobacteria and showed diacritical features of *Wollea bharadwajae*, but are different in cell shape and size. Niiyama *et al.* (2011) examined *Umezakia natans* coming under the family Stigonemataceae. They have both heterocysts and akinetes. Their morphological similarities agree with the taxonomic position in Stigonematales. But, the molecular analysis using 16s rRNA provideed information that *U. natans* was phylogenetically more related to *Aphanizomenon ovalisporum* and *Anabaena bergii*. These phylogenetic similarities questioned their position in Stigonematales. *U. natans* showed true branches that developed perpendicular to the mother trichome. And this work concluded that *U. natans* belonged to the family Nostocaceae.

A study was conducted by Saha *et al.* (2007) on the biodiversity of epilithic cyanobacteria from Kakoijana reserve forest of Assam. They listed 29 cyanobacterial species within 18 genera and 12 families coming under four orders as per recent system of classification. Among the 29 species, 11 were unicellular forms, nine non-heterocystous filamentous forms and the remaining nine species were heterocystous filamentous forms.

Komarek (2020) described the current issues faced by cyanobacteriologists in the case of taxonomy and classification of cyanobacteria. He discussed the evaluation of newly described cyanobacterial taxa, especially of the molecular sequenced genera. He mentioned that the taxonomy of cyanobacteria was traditionally based on ecological and cytomorphological markers. But, by the introduction of genetic methods, classification or taxonomy of cyanobacteria became entirely different from the earlier methods. Ultimately molecular sequencing was a great invention helpful for accurate classification. By analysing all the possibilities, author concluded that the most possible and valid method for improving current situation is to blend the conventional as well as molecular methods together. Collected taxa must be evaluated by these two methods to confirm the taxonomical position, then only it considered as cyanobacterial systematics. Dvorak *et al.* (2018) studied the difficulties in cyanobacterial systematics. They reported that about 51% of total known cyanobacterial species were not easy to culture and isolate. The remaining 49% were cultured and few of them were studied in detail. The polyphyletic nature of morphologically similar cyanobacteria resulted in increased effort for classification.

A species which was identified as *Pleurocapsa cuprea* under cyanobacterial community was reclassified into another algal group (Caisova, 2006). Cyanobacteria are prokaryotic microorganisms and the *P. cuprea* showed similarities with a eukaryotic red alga called *Hildenbrandia rivularis*. He found that *P. cuprea* is a eukaryotic microorganism and it does not belong to blue-green algae, which are prokaryotic.

2.2.1. Novel genus and species

During a research on combined genetic and phenotypic approach to describe a newly isolated cyanobacterial strain similar to *Pseudanabaena*, Dvorak *et al.* (2015) found a new genus showing some morphological similarity with *Pseudanabaena*. Detailed molecular studies provided more evidences to differentiate their phylogeny. Thus they proposed it as a new genus to the cyanobacterial community and named as *Pinocchia*. Morphologically similar and phylogenetically dissimilar genus provided information about polyphyletic origin of *Pseudanabaena*. However, the type species of new genus was introduced in the name of *Pinocchia polymorpha*.

Hentschke *et al.* (2017) studied six cyanobacterial strains from Brazilian Atlantic rainforest. They used morphological and molecular methods including 16s rRNA gene phylogenies and 16s-23s ITS secondary structures. The cyanobacterial strains from the sample showed resemblances with *Desmonostoc*, *Halotia* and *Mojavia*. But the phylogenetic studies showed that the collected strain did not exhibit close similarities with any of the above mentioned genera. Hence they described a new genus namely *Komarekiella* and the identified species was named *Komarekiella atlantica*. They observed the specimen under microscope continuously for seven days to prove the morphological plasticity. This newly found cyanobacteria formed a dense creeping mat under laboratory conditions that proved the morphological plasticity of *K. atlantica*. This cyanobacterium is commonly found from tree barks, woods and concrete.

A new genus of cyanobacteria named as *Chakia* was identified and reported by Komarkova *et al.* (2013) from the Central American region Belize. These strains were isolated from alkaline marshes. They compared the thallus differences under *in-situ* and *ex-situ* conditions. Newly introduced *Chakia* genus was with simple heteropolar filamentous and basal heterocytes. They also showed false branching like *Tolypothrix*. These cylindrical filamentous cyanobacteria have sheath with prominent lamellation. *Chakia* comes under Scytonemataceae and possessed almost all common characteristics of the other family members. The phylogenetic analysis provided enough data to eliminate confusion regarding morphological similarities with other members of the same family.

Roldan *et al.* (2013) characterised a unicellular cyanobacterium which appears to be new to the cyanobacterial world. Phylogenetic analysis showed 95% similarity with the genus *Chroococcus*. The genus is characterised with a spherical celled, thin sheathed, irregularly dividing specimen, which forms a diffluent mucilaginous layer. The specimen was collected from a cave in Collabato, Barcelona, Spain. Morphological characterisation was done using Transmission Electron Microscope and spectral confocal laser microscope. They named the new genus as *Chlorogloea* and the newly identified species as *Chlorogloea cavernicola*. But the critical analysis of phenotypic characters did not match with any of the currently described taxa. Cai *et al.* (2020) identified and reported a new cyanobacterial genus from Tibet, China. Primarily they defined the taxa with morphological features, later it was taxonomically and phylogenetically characterised. Thallus of this cyanobacterium appeared to be purple and hence was named as *Purpurea*. They normally growing in wet soil. Vegetative cells are barrel in shape and heterocysts are normally intercalary in position. The newly identified strain was named *Purpurea tibecum*, in reference to the place from where it was collected. *P. tibecum* showed characteristic resemblances with *Allinostoc*, *Trichormus*, *Desmonostoc*, *Halotia* and *Nostoc* in a range of 91-95%. Secondary structure of ITS between 16s rRNA in the strain revealed unique patterns. Distinguishing the genus *Purpurea* from other heterocystous genera *P. tibecum* was designated as the type species.

A new filamentous cyanobacterial genus was isolated from the Everglades National Park, Florida by Dvorak *et al.* (2017). The collected sample was characterised by morphological and molecular techniques. Morphological analysis of the collected specimen showed similarities with the genus *Leptolyngbya*. By applying 16s rRNA molecular analysis, they found that the strain showed some other unique characters as well. So, with the help of phylogenetic evidences they proposed that the collected specimen was a new genus. They named it as *Chamaethrix*. And the type species was named as *Chamaethrix vaginata*. The generic name originated from a Greek word meaning originated from ground, creeping hair. *C. vaginata* is reported to be $4.15 \pm 0.52 \mu m$ in diameter and to occasionally show false branching. A hyaline sheath is present.

A new genus namely *Limnoraphis* was identified and reported by Komarek *et al.* (2013b) during a study carried out on *Lyngbya robusta*. A lake in Guatemala showed aggressive growth of a cyanobacteria, believed to be *Lyngbya robusta*. This planktic, filamentous, non-heterocystous cyanobacteria were studied by authors in depth. They found phylogenetic variation of collected specimen in comparison with *Lyngbya* genus. The analysis resulted in the origin of a new genus called *Limnoraphis* and the species was named as *Limnoraphis robusta*. During the study, authors reclassified four *Lyngbya* species in to *Limnoraphis*. They are; *Lyngbya robusta* as *Limnoraphis robusta*, *Lyngbya heironimusii* as *Limnoraphis heironimusii*, *Lyngbya bergei* as *Limnoraphis bergei* and *Lyngbya cryptovaginata* as *Limnoraphis cryptovaginata*. Obligatory aerotops are present in *Limnoraphis* genus and are absent in *Lyngbya*.

Here two new cyanobacterial strains morphologically were identified by Cai *et al.* (2019) during an exploration work from wet rocky walls of mid-subtropical area of China. Primary assumptions concluded that the new specimen was related with *Nostoc* like genus. They used a blending method of conventional as well as molecular method for identification. Using 16s rRNA would resulted that dissimilarities of collected strain with any of the reported cyanobacteria. Comparing with similar heterocystous genera such as *Mojavia*, *Halotia*, *Desmonostoc*, *Allinostoc* and *Komarekiella* resulted mismatching. So, they confirmed that the collected specimen was from a new genus and named it as *Minunostoc*. Their cells are small and cylindrical in shape, so the type specimen named as *Minunostoc cylindricum*.

The heterogeneous cyanobacterial genus *Geitlerinema* was revisioned by Strunecky *et al.* (2017) and a total of 23 species were analysed. These are simple filamentous type cyanobacterial species. After revision, there is only one species included in the genus *Geitlerinema* based on morphological description. Other members are reclassified in to a new genus after molecular sequencing by 16s rRNA. The newly introduced genus was named *Anagnostidinema*. Authors demanded more studies on *Geitlerinema* with morphological and molecular characterisation. And they concluded that *Geitlerinema sandbergii* was synonymised to *Microcoleus vaginatus*.

Several cyanobacterial strains included under the genus *Nostoc* indicated variation during phylogenetic analysis. Hrouzek *et al.* (2013) placed some of these odd *Nostoc* species in to *Desmonostoc* lineage. The study revealed that *Desmonostoc* exhibited similarities with *Nostoc*, *Trichormus* and *Mojavia*. *Nostoc muscorum* reclassified to the genus *Desmonostoc* and now is known as *Desmonostoc muscorum*. Major features consist of long vegetative cells enveloped in a mucilaginous sheath, filaments almost densely coiled and trichome compact.

False branching cyanobacteria with heterocysts were found during a survey by Gonzalez-Resendiz *et al.* (2018). These cyanobacterial specimens were collected from rocky shores in the Pacific Ocean and Gulf of Mexico. They showed morphological analogy with the genus *Brasilonema* but the result of molecular sequencing showed deviations. By analysing the molecular evidences, they confirmed that the collected strain is new to cyanobacteria and the genus was named *Nunduva*. The first and foremost collected species was named *Nunduva fasciculata*. They also identified *N. kania*, *N. biania* and *N. britanica* in the course of the study. All cyanobacterial strains of *Nunduva* were found as marine species in this study.

A new cyanobacterium was recognized and reported as a new genus to the cyanobacterial community by Hasler *et al.* (2014). The primary discovery of this genus was from a pond in Florida, USA. These are filamentous cyanobacterium showed similarity with *Phormidium*, but molecular evidences supported their introduction as a novel genus. Ultra structure studies support the findings of authors. The generic name was given as *Ammassolinea* and the newly identified species named was *Ammassolinea attenuata*. The species name was given because of their attenuated nature on the tip cells. Trichomes were longer than broad. Radial orientation of thylakoid was a special character showed by *A. attenuata* during the ultrastructural studies. Akagha *et al.* (2019) disclosed a new genus from the Tropical America and named it as *Lagosinema*. The name was given in tribute to the collection area, called Lagos lagoon, Nigeria. The new cyanophycean member have peculiar features such as the presence of small rounded cyanophycean granules. *Lagosinema* is a filamentous, non-heterocystous cyanobacterium without any sheath like envelop. Trichome showed motile nature. The type species was named as *Lagosinema tenuis*. Molecular analysis provided evidence that, this new genus was sister to the large clade *Limnothrix*. But characters like operon dissimilarities in tRNA, etc. clearly distinguished *Lagosinema* from *Limnothrix*.

A new species was identified under the genus *Geitleria* and named as *Geitleria appalachiana* by Kilgore *et al.* (2018) from Great Smoky Mountains National Park, Tennessee. These strains have unique characters such as true branching which arise laterally and sometimes, pseudo-dichotomously. These are non-heterocystous type of cyanobacteria and are morphologically very distinct with calcareous incrustations inside the trichome. Phylogenetic analysis also provided evidences about the genus *Geitleria* and their differences with the families of Nostocales. Families of Nostocales does not show true branches, while these new species have two type true branches. Due to the reason and evidences, author proposed a new family called Gietleriaceae for this unique species.

A new cyanobacterial genus was described by Komarek (2008) and named it as *Macrospermum*. This genus *Macrospermum* showed close similarities with *Anabaena volzii* and shares some features with certain another *Anabaena* species. Molecular studies produced many dissimilarities with the confused species and phylogenetic dissimilarities were proved. Four species were removed from the genus *Anabaena* and reclassified under this new genus *Macrospermum*. They are *Macrospermum volzii*, *M. fuellebornii*, *M. mysorense* and *M. unisporum*. All of these species were described from aquatic biotopes in tropical region. Heidari *et al.* (2018) reported seven new species of cyanobacteria under six genera. Four out of the six genera were new to cyanobacterial community. The newly identified species including two earlier described species were transferred into newly established genus. The new genera are *Laspinema*, *Klisinema*, *Ramsaria* and *Persinema*. Seven species newly reported are *Planktothrix iranica*, *Nodosilinea radiophila, N. ramsarensis, Laspinema thermale*, *Klisinema persicum*, *Ramsaria avicinnae* and *Persinema komarekii*. They also found certain other species during the exploration. *Phormidium* spp., *Leptolyngbya* spp. and *Thermoleptolyngbya limosa* were the dominant species in the hot spring. *Nostoc* spp. and *Cylindrospermum licheniforme* also showed abundance in these radioactive soils.

During a floristic study, Beccera-Absalon *et al.* (2013) found several cyanobacterial species from central region of Mexico. These populations showed characteristic features of the genus *Brasilonema*. But, certain characters such as trichome and hormogonial structures distinguished it from the genus *Brasilonema*. They analysed both morphological and phylogenetic characters and concluded that the observed strain was of a new species to the cyanoprokaryote community. The newly reported species was named after the collection locality is Tolantongo as *Brasilonema tolantogensis*. These strains were found from sub-aerophytic habitat and they are always attached to a wet substratum.

Hentschke *et al.* (2019) described a new species of *Stigonema* and named it as *Stigonema jureiensis*. The sample was collected from Atlantic rain forest of Sao Paulo, Brazil. Genus *Stigonema* was an under explored genus mainly because of their difficult nature to culture. They analysed the cyanobacterial strain by morphological and phylogenetic data. This species differs from other *Stigonema* with the presence of mosaic ornate sheath and are very special. *S. juriensis* showed branches identical to the main filament. Trichomes showed uniseriate and multiseriate parts 16-25 µm in diameter. The work concluded with a note about the limitations of study on *Stigonema* genus and they were still unclear to the cyanobacterial world.

A new cyanobacterial species was introduced by Mares (2010) from the fresh water alkaline marsh of the Everglades in South Florida, USA. The collected cyanobacterium was a heterocystous filamentous one and named it as *Anabaena fuscovaginata*. This *A. fuscovaginata* showed sheathed filaments and trichome with a wavy appearance. It is a fresh water cyanobacteria mostly found along with other cyanobacterial or algal groups. Coloured sheath present in this species was the first report of coloured sheath in this genus. Rounded or cylindrical akinetes with a translucent yellowish smooth wall were also seen in this *A. fuscovaginata*. Warm spring was known to host many species of Oscillatoriales (Geitler, 1930; Geitler, 1932; Komarek and Anagnostidis, 2005). Similarly, a new species to the Oscillatoriales namely *Desertifilum fontinale* was discovered by Dadheech *et al.* (2014). This filamentous cyanobacterial species was reported from North-Western India, where the extreme hot and dry Thar Dessert lies. But the new species *D. fontinale* was described from an aquatic habitat of Kenya and which gives information about the wider distribution pattern of the genus *Desertifilum*. *D. fontinale* showed close resemblance with *D. tharense*, but the phenotypic features and 16s-23s ITS sequence revealed the differences among them. Habitat and the occurrence were also different from other members of the same genus. *D. fontinale* filaments ranging from 4-7 µm in width, was found from the floating mats in a lake. Attenuation on the tip was another peculiar feature observed in this species during the study.

Tapinothrix (Pseudanabaenaceae) is a genus commonly confused with the genus *Homoeothrix* (Oscillatoriaceae) because of their structural similarities. Johansen *et al.* (2011) collected 77 cyanobacterial samples from the streams and rivers of North America. They examined the samples and found three cyanobacterial species from the genus *Tapinothrix* and one among them doesn’t showed any features of described taxa of *Tapinothrix*. They concluded that, it is a new member to *Tapinothrix* genus and named it as *Tapinothrix ozarkiana*. They also found *T. varians* and *T. janthina* during the study time. Mainly this genus is found from Pacific coastal area, Rocky Mountains and Appalachian Mountains.

Based on the multilocus sequencing of 16s rRNA gene, a new non-heterocystous cyanobacterium was reported by Dadheech *et al.* (2013) from Etosha Pan, Namibia. This species was named after the collection locality as *Phormidium etoshii*. The filaments noticed in this species were long and blue-green in colour. Apical cells were commonly conical in shape and without roof calyptra and in rare situations, some filaments displayed round apical cells. They confirmed the new species with phylogenetic and ecological analysis. New strain doesn't show any characteristic features of reported cyanobacterial taxa. And the morphologically most similar species *Phormidium formosum* exhibited dissimilarities in the measurements of trichome and also in ecology as well as phylogeny. Molecular analysis showed certain similarities with *P. acuminatum*, but they were entirely different in morphological and ecological features.

A new species of *Scytonematopsis* was described by Vaccarino and Johansen (2011) from Hawaiian Islands. They found the strains of new cyanobacterium from rocks in damp aerial habitat of water falls and streams. The most peculiar feature of the newly identified species is its ability to produce a spirally contorted trichome within a single filament and the species hence named, *S. contorta* to denote this peculiarity. *S. contorta* showed similarities with both *Rivularia* and *Calothrix* but it was traditionally being placed in Scytonemataceae. The colony of newly reported strain was greyish-green in colour and spreading from a central point. Filaments showed false branches and double false branches are present in common. Bohunicka *et al.* (2011) isolated a new cyanobacterial species to the genus *Tapinothrix*. The new strain was confusing and displayed similarities with five different genera such as *Ammatoidea*, *Homoeothrix*, *Leptolyngbya*, *Phormidiochaete* and *Tapinothrix*. Phylogenetic analysis indicated greater similarity for more with the genus *Tapinothrix*. So, the novel was species placed in the Pseudanabaenalean genus *Tapinothrix* and species name was given as *T.*

clintonii. The strain showed close similarities with *Leptolyngbya sensustricto*, but molecular analysis provided a very distinct secondary structure. Young filaments of the new species were observed to be tapering towards the end.

A water quality analysis was done by Niiyama *et al.* (2016) due to the nasty smell of tap water. They found a *Phormidium* like cyanobacterium which was the reason behind the foul smell. Primary identification by morphological characters concluded that the cyanobacterium was *Phormidium tenue*. But while analysing the culture, they found a different strain which displayed resemblances with *Pseudanabaena*. Then the molecular analysis revealed that the cultured samples have two cyanobacterial strains which do not showed any characteristic features of any described cyanobacterial species. Authors proposed these two cyanobacterial strains as two new species of *Pseudanabaena* and named as *Pseudanabaena foetida* and *P. subfoetida*.

Sant-Anna *et al.* (2011) investigated the cyanobacterial flora of Atlantic Rainforest and found some interesting cyanobacterial samples. Among them a special *Chamaesiphon* sp. was observed by the researchers. They proposed the name *Chamaesiphon stratosus* for the new strain. The new cyanobacteria showed morphological similarities with *C. britannicus*. The phylogeny and molecular studies set out evidences for the differences among *C. stratosus* and *C. britannicus*. They also reported that the subgenera *Godlewskia* possessed certain features similar to *Chamaesiphonopsis*. Authors proposed *Chamaesiphonopsis* as a synonym for *Godlewskia*. 27 *Oculatella* species from Atacama Desert were isolated and characterised by Osario-Santos *et al.* (2014). While the work was advancing, seven *Oculatella* species were reported as unfamiliar to cyanobacterial taxa. The newly encountered species were *Oculatella cataractarum*, *O. kauaiensis*, *O. hafnerensis*, *O. neakameniensis*, *O. mojaviensis*, *O. coburnii*, and *O. atacamensis*. *Oculatella* is a filamentous cyanobacterial genus without heterocysts. The study also disclosed that the species in *Oculatella* genus exhibited considerable morphological discrepancy. The soil forms showed dissimilarities with the water forms in morphological characters. But the molecular investigation expressed similarities, which authenticated the single phylogeny of *Oculatella* genus.

It was very difficult for the taxonomical identification of *Wollea* and *Anabaena* using traditional taxonomic methods. A censorious analysis of *Wollea* was done by Kozlikova-Zapomelova *et al.* (2016) and illustrated a new species namely *Wollea salina* from Southern Thailand. These are filamentous cyanobacteria which appeared as a rough mat during mass advancement. Researchers also leaded a study on the differentiation of *Wollea* and *Anabaena*. They found evident differences in morphological characters and also did molecular studies for confirmation. Their documentation displayed wide heterogeneity of the genus *Anabaena*. A new cyanobacterial species from the genus *Pseudanabaena* was detected by Kling *et al.* (2012) while inspecting some samples of *Aphanizomenon flos-aquae* from the waterbodies of North America. The new member was named as *Pseudanabaena rutilus-viridis*. This is a non-mucilaginous planktonic cyanobacteria. A brief analysis on the *P. rutilus-viridis* provided information about colouration. They produce a reddish appearance in common. Erratically, they appeared in violet or blue-green in colour.

Dolichospermum is a filamentous and heterocystous cyanobacterium that is one of the commonly occurring phytoplanktons in the Han river of Korea (Choi *et al.*, 2018). During an experimentation, researchers identified and reported a new cyanobacterial species and named it as *Dolichospermum hangangense*. They found this new species at the time of collecting a common *Dolichospermum* species from the river. Phylogenetic evaluation of the collected samples with contradictory appearance led to the discovery of a new species. *D. hangangense* has a different type of akinete with which was longer and also exhibited two bulged portions on one end. Trichomes are barrel shaped and heterocysts are round in shape with light green colour. Sometimes, they do not have any specific colouration.

During a study, Mesfin *et al.* (2020) found a cyanobacterium with morphological similarities of *Chroococcidiopsis kashayi* from Ethiopian soil crusts. When cultured in nitrogen less medium, these strains generated heterocystous cells. After the development of heterocysts, the cyanobacterium looks like a species of *Nostoc*. They established small colonies from the mother colony and developed into a group of colonies with a mass like appearance. Molecular analysis provided information that the observed strain did not show any characteristic features of described *Nostoc* types. But the phylogenetic analysis proved that the new strain was from the genus *Nostoc*. After confirming the taxonomic position, the novel species was named as *Nostoc oromo*. Colonies were bright blue to olive green in colour. Heterocysts are rare in occurrence and showed a width between 4-6 µm and a length of 3-4 µm.

Two novel species were reported by Kastovsky *et al.* (2011) from the Mount Roraima, Venezuela. *Entophysalis arboriformis* and *Albrightia roraimae* were the newly reported species during the microvegetation investigation.

2.2.2. Symbiotic association

Cyanobacteria demonstrated symbiotic associations with almost all forms of organisms including microorganisms, algae, bryophytes, pteridophytes, gymnosperms and angiosperms.

Since cycads and cyanobacteria date back to ancient times, the symbiotic partnership and co-evolution formed between the two may have developed millions of years ago (Usher *et al.*, 2007). Cyanobionts found in cycads are predominantly species of *Nostoc*, but in some studies species of

Calothrix, Scytonema and *Richelia* were also identified (Costa and Lindblad, 2002; Grobbelar *et al.,* 1986; Gehringer *et al.*, 2010).

In the case of two or more organisms being in a spatially close facultative association, the phenomenon is known as 'epibiosis'. In the description of such microbe-metazoan interactions, the metazoan is generally called as 'basibiont' and microbes are called as 'epibionts' (Wahl, 1989). A study was conducted by Radea *et al.* (2010) for the detection of iron-encrusted photosynthetic epibionts in a brackish water thermal spring of Greece. Five periphytic taxa of cyanobacteria including ecologically and taxonomically relevant morphospecies *Xenococcus pyriformis* and two endophytic cyanobacterial species were also recorded. The study was conducted on the iron coatings of the shell of *Ventrosia ventrosa*. The morphotype of *Xenococcus* found in association with *Chroococcus turgidus*, *C. thermalis*, *Synechocystis minuscula* and also with the only filamentous species *Spirulina subtilissima*. Euendolithic cyanobacteria were poorly infested in *V. ventrosa*. *Hyella* sp. and *Leptolyngbya terebrans* are the two species found as euendolithic cyanobacteria.

Looser association with cyanobacteria and bryophytes have been found in various habitats. Examples are the mosses *Bryum algovicum* (in dine valleys), *Ceratodon purpureus* and *Funaria hygrometrica* (burnt areas), species of *Grimmia* and *Racomitrium* (lava fields) and liverworts *Anthelia juratzkana* and *Porella navicularis* (on trees). In these associations, it was observed that the cyanobacteria had lower percentage of heterocysts than typical of free living forms. While the bryophytes took up nitrogen, in most cases, any benefit to the cyanobacteria was unclear. Cyanobacteria have also been found growing on *Sphagnum* plants in *Sphagnum* bogs and in some cases even inside the empty cells in *Sphagnum* leaves (Carr *et al.,* 1980; Brasell *et al.,* 1986; During and Tooran, 1990).

Most of the symbiotic cyanobacteria belong to the order Nostocales and Stigonematales (Castenholz *et al.*, 2001). Free living cyanobacteria also form associations with other life forms such as plants and fungi, and in some cases with tripartite-structured cyanolichens made up of fungi, green algae and cyanobacteria (Henskens *et al.*, 2012).

An epiphytic orchid namely *Dendrobium crumenatum* exhibiting cyanobacterial association on the aerial roots and substrate roots were reported by Ram and Shamina (2015a). A total of six cyanobacterial species displayed symbiotic associations with orchids. Identified species of cyanobacteria are coming under four genera. *Nostoc* was the dominating genus with three representations such as *Nostoc calcicola*, *N. carneum* and *N. spongiaeforme* var. *varians* and a filamentous heterocystous non branching species *Anabaena variabilis*. Furthermore, *Rivularia hansgirgii* a filamentous heterocystous cyanobacteria with false branches and a species from filamentous non branching non heterocystous type namely *Oscillatoria acuta* were recorded. In essence, six species from three families were reported from the aerial roots and substrate roots of *D. crumenatum*. Kokocinski and Soininen (2012) examined *Cylindrospermopsis raciborskii* and found that this cyanobacterium grew in association with certain *Aphanizomenon* species.

Jisha and Tessy (2014) analysed the environmental quality with respect to the blue green algal diversity of Koodalmanikkyam and Kodungallur temple ponds of Thrissur district.They recorded pollution tolerant blue green algal generas including *Phormidium, Anabaena, Lyngbya, Microcystis* and *Oscillatoria* from those ponds and reported it as an indication of water pollution.

Ram and Shamina (2015b) morphologically analysed and identified 12 cyanobacterial species growing in association with mangrove plants and pneumatophores from Kottayam District of Kerala, India. The identified species comes under four families such as Chroococcaceae, Oscillatoriaceae, Nostocaceae and Scytonemataceae. Genus *Oscillatoria* dominated the study with three species and followed by *Nostoc*, *Scytonema* and *Aphanocapsa* with two species in each. *Aphanothece*, *Lyngbya* and *Phormidium* produce one species from each.

An interesting study based on the cyanobacterial and algal strains found from the guts of four species of mosquito larvae was done by Rettich *et al.* (2001). *Aedes*, *Culex*, *Anopheles* and *Culiseta* larvae were investigated for the study and they found a total of 83 genera, 10 out of which were cyanophycean members. The amount or presence of cyanophycean members in the gut regions of mosquito were based on their presence in the water were mosquito breeding and feeding. Most of the species were in resting stage or in spore form and remain active for germination and undamaged. *Synechocystis* sp. is the commonly recorded cyanobacteria during this experiment. Hrouzek *et al.* (2013) found some species as symbionts from *Cycas*. Among this symbiotic cyanobacterial species, they found a new cyanobacterium from the new genus *Desmonostoc*. *Desmonostoc muscorum* is found as symbionts in *Cycas* plant as well as in other habitats.

A research work on symbiotic cyanobacterial species done by Douin (1953) revealed that the nodules of *Cycas circinalis* and *Stangeria paradoxa* *Anabaena cycadae*. They help in nitrogen fixation as well as oxygen production by performing photosynthesis.

Lithophytic cyanobacteria and associated fauna was studied by Lamprinou *et al.* (2009) from Leontari cave, Greece. 22 cyanobacterial species confined to 14 genera. *Chroococcus* showed clear dominance with the presence of six species. *Leptolyngbya* also showed abundance with four species. They also found taxonomically interesting morphotypes such as *Chroococcus spelaeus*, *Asterocapsa* sp. and *Chlorogloea* sp. Arthropods exhibited domination with nine taxa while considering the fauna. During a study in radioactive thermal springs, Heidari *et al.* (2018) found nine cyanobacterial species new to thermal springs viz. *Persinema komarekii*, *Ramsaria avicennae*, *Klisinema persicum*, *Laspinema etoshii*, *L. lumbricale*, *L. thermale*, *Nodosilinea ramsarensis*, *N. radiophila* and *Planktothrix iranica*.

Nostoc punctiforme has been identified as a symbiont of both fungi and plants, and many symbiotic *Nostoc* isolates are based on morphological characterisation, referred to as *N. punctiforme* (Zimmerman and Culley, 1991). Analysis of the genetic diversity of symbiotic *Nostoc* strains using molecular methods at low taxonomic levels has revealed heterogeneity reflecting high genetic diversity and low host specificity (Costa *et al.*, 1999).

2.3. Adaptability and variability

Diversity of cyanobacteria is expressed by their morphological, biochemical and physiological properties which enabled them to settle and persists in a wide range of habitats (Palinska *et al.*, 2011). A study based on the hypersaline environments of Brazil was conducted by Ramos *et al.* (2017). They observed a total of 36 cyanobacterial taxa growing normally in that adverse environmental conditions and the reported species were from Chroococcales, Oscillatoriales, Synechococcales and Spirunales.

Six strains of unicellular cyanobacteria belonging to *Euhalothece/ Halothece* were studied by Cepek and Komarek in 2010. All of the studied cyanobacteria were from the same group but have different hypersaline origin. Using DAPI fluorescent staining and light and transmission electron microscopy, they studied the cytomorphological characters. They examined six strains of cyanobacteria which were of the halotolerant coccoid type. They can be divided into two groups with their ultrastructure and cytomorphological characters. The first group has uniform type of cells with a broad oval shape. And the second group comprised of cells with smaller size. They confirmed the generic status of *Euhalothece* and treated as special halophytic genus. They also confirmed that *Cyanothece halobia* belongs to this generic unit. So, the first group was included in the sub cluster *Euhalothece* and second group belongs to the genus *Cyanobium*. All these species were tolerant to alkaline water and had the adaptability to survive under such circumstances.

Petalonema alatum is a cyanobacterial species which was earlier described as *Oscillatoria alata*. Uher (2010) conducted an experiment on the species variability and diversity of *P. alatum*. This is a euendolithic species accompanied by other trichal and coccal cyanobacteria. Author found that *P. alatum* showed significant variations in morphological characters under different environmental conditions. In natural populations, they showed broader cells or filaments. But under laboratory conditions, they become narrower in cell and filament size. Certain characters like heteropolarity, branching from heterocyst, trichomes with basal heterocyst and heteropolar germination become stable. This species was initially described as *O. alata*, and then was synonymised under *Scytonema alatum*. But, the study on the morphological changes under varying environmental conditions will help to conclude that *Petalonema* is a valid genus and the species *P. alatum* display more similarity with *Tolypothrix* of the Microchaetaceae than the genus *Scytonema*.

Mitra (1951) investigated the cyanobacterial flora from selected regions of India. The majority of cyanobacterial species vegetate in deep layers of soil during unfavourable conditions, and most of them survive by the production of spore like resting stages. Thajuddin *et al.* (2002) reported 89 cyanobacterial species from the East coast and 69 species from the West coast, of which 56 species were found common from both the coasts. From the identified cyanobacterial specimens, 36 species under 16 genera were reported from salt pans of Pudukkottai District, Tamil Nadu. Among them 18 species showed varying degrees of tolerance against salinity, i.e. 45-90 ppt.

Interaction of flood disturbances and nutrient resource regimes strongly influence the local taxonomic richness in stream benthic algal communities. It is important to measure resource supply at a scale that is relevant to the algae living within the mat (Biggs and Smith, 2002).

Bharadwaj and Baruah (2013) investigated cyanobacterial populations from Assam. They clarified the positive correlation of cyanobacterial population and soil quality parameter. They found a total of 47 cyanobacterial species during this study. Ram and Shamina (2015b) worked on the physico-chemical parameters of mangrove forest while studying the diversity of cyanobacterial flora in it. Parameters such as pH, temperature and salinity were recorded and they concluded that acidic soils were stressful for cyanobacterial growth and development. Still they found *Oscillatoria*, *Nostoc* and *Scytonema* with comparatively better growth rate and most of the cyanobacterial species were under dormant stage when analysed under microscope. Heidari *et al.* (2018) conducted a work to isolate cyanobacteria from radioactive thermal springs. They selected six geothermal springs for the investigation. By using morphological analysis, *Phormidium* spp., *Leptolyngbya* spp. and *Thermoleptolyngbya laminosa* were found dominant during the course of study. They reported nine new cyanobacteria such as *Persinema komarekii*, *Ramsaria avicennae*, *Klisinema persicum*, *Laspinema etoshii*, *L. lumbricale*, *L. thermale*, *Nodosilinea ramsarensis*, *N. radiophila* and *Planktothrix iranica* from thermal springs. This indicated the adaptability of cyanobacteria to radioactive thermal springs.

Adaptability of cyanobacterial species *Oscillatoria ornata* var. *crassa* to saline environments as well as its epiphytic growth on pneumatophores were reported from Kadalundy, Kerala by Shamina and Ram (2014). Cyanobacteria have a wide range of adaptability. So many factors influenced their growth, but they have the capacity to tolerate adverse conditions. Even climate and pH will not affect the cyanobacterial growth. But sometimes microclimate may play an important role in their development (Hrouzek *et al.*, 2013).

Local environmental conditions such as the availability of water, nutrients, etc. strongly influence the complex life cycle of *Nostoc commune* by the presence and sequence of phases as well as the differentiation of specialised cells (Mollenhauer, 1988). *Nostoc commune*, a heterocystous cyanobacteria showing high adaptive nature was studied by Ramirez *et al.* (2011). They investigated on the specimens' growth, throughout the season and found that *N. commune* change their morphological appearance for survive from adverse conditions. They exhibited exponential growth rate from start to finish of favourable wet season. In the beginning of dry season, they become resistant forms such as spores. Right through the next favourable season, they rehydrated and produced propagula. *N. commune* also showed adaptive strategies like reducing number of cells and the sheath becoming thicker during unfavourable season. They developed akinete for the survival. This study revealed that, adaptive strategies of *N. commune* will help them to endure extreme desiccation by acquiring increased resistance.

An experiment was conducted from a tombstone in a historic cemetery in Bratislava, Slovakia by Uher (2008). The work was focused on the composition of species and spatial distribution of cyanobacteria. Their distribution was analysed on the basis of available taxonomic data. Cyanobacteria such as *Phormidium autumnale*, *P. corium*, *Aphanothece stagnina*, *Chroococcus varius*, *Heteroleiblenia pusilla*, *Leptolyngbya fragilis*, *Microcoleus vaginatus* and *Nostoc microscopicum* were observed during this study. They found that humidity was the main factor affecting the cyanobacterial growth. The microclimatic factors like humidity will influence directly on the distribution, abundance and diversity of algae and cyanobacteria.

Soda lakes showed unexpected and dynamic shifts in species composition. Schagerl *et al.* (2015) conducted a study on *Arthrospira fusiformis* from Kenyan soda lakes. Algal community in this particular ecosystem is dominated by *A. fusiformis*. They summarised the work with an indication that the stability of cyanobacterial community is strongly connected with the physical habitat. *Arthrospira* biomass was altered by climatic changes in interdecadal changes. The changes in environmental conditions as well as climatic factors resulted in the change of entire population, but *A. fusiformis* withstood any alteration.

A study on the effect of pH on growth and morphology of *Anabaenopsis elenkinii* was carried out by Santos *et al.* (2011). *A. elenkinii* formed bloom in alkaline shallow lakes of Pantanal, Brazil. Authors used various pH to cultivate them and the longest trichome with 45 cells was found at pH 7 while pH 9.5, showed only a maximum of 32 cells. Trichomes with least number of cells (23 cells) were found in pH 10.5. Heterocyst appeared in all treatments but there was no report on the development of akinetes. *A. elenkinii* showed growth changes with reference to pH value. In lower pH, they retard their growth, cell yield and morphological variations would appear. A limitation in density and biomass was also found in the lower pH value.

Phosphate-deficient *Cylindrospermopsis raciborskii* showed a remarkable physiological flexibility in adapting to phosphate availability on a time scale from minutes to hours (Amaral *et al.*, 2014). The observations were made while investigating on the growth response of *C. raciborskii* isolated from Uruguay and USA. They cultured the same species, exposed to five different phosphate concentrations. The result was increased growth rate when the cyanobacterium was exposed to higher phosphate concentrations. *C. raciborskii* also showed plasticity in cell size and structure.

Dvorak and Hasler (2007) observed the variability and occurrence of one of the most difficult cyanobacterium *Cylindrospermopsis raciborskii*. Morphology of this species exhibited wide range of variations according to the changes in their ecological conditions. Heterocysts and akinetes displayed morphological transformations during development. Cells showed contrast in size and shape according to environmental variables.

Uher (2007) conducted an experiment on the morphological variability of three subaerial *Calothrix* species while analysing 15 *Calothrix* species. *Calothrix braunii*, *C. parietina* and *C. capitularis* was inspected throughout the study. Among the three species, *C. capitularis* was a novel species authenticated during this study. Characters like length and width of cells, length and width of filaments, sheath colour, heterocyst diameter and habit were observed right through the study. Observations indicated in considerable changes in cell shape, cell size as well as filament size.

Chatchawan *et al.* (2011) identified 16 cyanobacterial species from man-made solar saltern in Thailand. They found *Spirulina subsalsa*, *Coleofasciculus chthnoplastes* and *Oscillatoria lloydiana* were dominated in these saltern fields. Sampled area showed pH ranging from 7.9-8.1, and the conductivity showed 164-350 ds/m. They concluded that cyanobacteria exhibited maximum growth at small salt concentrations, anyhow they survived under all salt concentrations. Terrestrial cyanobacteria can live in diverse and harsh environments (Sand-Jensen, 2014) and are considered to be the most successful group of microorganisms on Earth (Stewart and Falconer, 2011).

Heidari *et al.* (2018) explored cyanobacteria from selected areas of Iran where natural radiation is comparatively high. The investigations were done at six geothermal springs with high natural radiation. Highest concentrations of ^{226}Ra were 13000 $Bq.Kg^{-1}$ in soil and 130 $Bq.l^{-1}$ in water. The result was quiet unbelievable that they found seven new species and four new genera. *Nostoc* spp. also showed high adaptability to radioactive soils of the selected areas. This work proves that cyanobacteria are more adaptable to adverse environmental conditions. The observed cyanobacterial species showed high adaptability towards radioactivity and high temperature.

Most of the heterocystous cyanobacteria also form a second cell type called as akinete, and which will germinate when the favourable conditions occurred. Akinetes were commonly observed in fresh water cyanobacteria, but they were uncommon in marine cyanobacteria because of the stability present in the marine environment. Desiccated akinetes in soil samples have survived for 70 years (Bristol-Roah, 1920).

65 cyanobacterial species from fresh water bodies of Similpal National Park in Orissa, India were reported by Dash *et al.* (2011) under three orders and seven families. Among the identified taxa, 24 genera were virgin to this biosphere reserve. Morphological descriptions, distribution pattern and common habitats in India for each species described systematically. Authors found 15 species had new distributional record for fresh water bodies in India and 11 species were from the fresh water bodies of Orissa.

Species of the genus *Nostoc* are conspicuous components of terrestrial microbial populations worldwide. Its persistence and success in terrestrial environments have been attributed to their ability for tolerating desiccation after an extended drought period and to rapidly rehydrated to recover metabolic activity once favourable conditions have been re-established (Dodds *et al.*, 1995). Venkataraman (1958) reported 11 Myxophyceae (Cyanophyceae) members from high altitude areas of India. The identified species were coming under the genera *Aphanocapsa*, *Chamaesiphon*, *Spirulina*, *Oscillatoria*, *Lyngbya* and *Scytonema*. Cameron (1962) studied the viability period of cyanobacteria and he reported that *Nostoc commune* can remain viable for more than 100 years.

2.4. Economic importance

Not only has cyanobacteria been an important element for forming the earth's oxygen atmosphere, but it has also contributed to many other attributes important to human life. They are also important providers of nitrogen fertilizer in the cultivation of rice and beans (Anonymous, 2020a). Cyanobacteria may sometimes be a nuisance. But they are of great ecological and agricultural significance. High input technologies have resulted in high agricultural productivity. Indiscriminate fertilizer application on soil would affect the soil productivity and environmental quality. The cosmopolitan nature of cyanobacteria makes them readily available for research and utilization. They offered an economically attractive and ecologically sound alternative to chemical fertilizer for improved production. There is therefore the need to enlighten us on their potentials in order to stimulate interdisciplinary research, harness the indigenous species of economic and ecological importance combat the obnoxious forms, investigate their potentials in biotechnology, disease causing ability and maximise their potentials (Nweze, 2009).

Spirulina is used as food supplement because of its excellent nutrient composition and digestibility. It has high protein content (60-70%), 20% carbohydrate, 5% lipids, 7% minerals and 6% moisture. It is also a rich source of beta-carotene, thiamine and riboflavin and is one of the richest source of vitamin B12. It is commercially available in the market in the form of powder, granules or flakes and as tablets and capsules (Thajuddin and Subramanian 2005).

Bashan (1998) has studied the different types of carriers used for the formulation of bio-agents and claimed the need to develop new formulations using organic components which can provide the essential and needful nutrients and kept the microorganism like cyanobacteria in effective physiological state. This is for delivering maximum number of living cells to the soil to achieve good result as bio-agent. Cyanobacteria like *Anabaena*, *Nostoc*, *Aulosira*, *Calothrix* and *Tolypothrix* are very helpful in the cultivation of paddy. The nitrogen assimilated in these cyanophycean members were utilised by rice plants during the degradation of cyanobacteria. And cyanobacteria can cultivate cheaply and abundantly by three various methods such as trough method, pit method and field method for large scale production (Palaniappan and Annaduraj, 2003).

Most of the works based on diversity of microalgae were focused on agricultural fields such as paddy, sugarcane, wetland ecosystems such as ponds, lakes, rivers, etc. But, a work was done by Suresh *et al.* (2012) focused on less studied high altitude areas. And their results may useful for designing future schemes and developing useful cyanobacterial products.

2.4.1. Photosynthesis and nitrogen fixation

Cyanobacteria also referred to as blue-green algae, are the oldest photosynthetic organism on Earth that originated approximately 2.6-3.5 billion years ago (Hedges *et al.,* 2001). Some filamentous cyanobacteria have evolved specialised cells known as heterocyst to carryout nitrogen fixation (Capone *et al.,* 2005). All cyanobacteria are capable of oxygenic photosynthesis, but some cyanobacterial species can switch to sulphide dependent anoxygenic photosynthesis (Cohen *et al.,* 1986).

The cyanobacteria offer an eco-friendly alternative to chemical fertilizers. In wetland ecosystems, cyanobacteria supply or fix atmospheric nitrogen and significantly incorporate nitrogen to the soil. They are eco-friendly and provide equal amount of nitrogen which obtained from chemical fertilizers. The harmless cyanobacteria also help to improve productivity and are cheaper as compared with other fertilizers (Mishra and Pabbi, 2004). A variety of cyanobacterial strains colonise rice fields wherein heterocystous species are capable of fixing atmospheric nitrogen. However, several non-heterocystous cyanobacteria are able to fix atmospheric nitrogen under microaerophilic conditions (Thajuddin and Subramanian, 2005).

Cyanobacteria like *Anabaena* and *Cylindrospermum* are capable of nitrogen fixation and they are widely distributed in fresh and salt waters of temperate, tropical and polar region (Fritsch, 1945). A cyanobacterium namely *Limnoraphis robusta* identified by Komarek *et al.* (2013b) fix atmospheric nitrogen comparatively higher than most of the cyanobacteria.

A single year study on the nitrogen fixing cyanobacterial populations from the lower Brahmaputra valley flood plains of Assam was done by Bharadwaj and Baruah (2013). They identified 47 cyanobacterial species with the ability to fix atmospheric nitrogen. They belong to 20 genera and eight families. Ramos *et al.* (2017) observed that microbial mats helped in photosynthesis and the reason was the cyanobacterial community found on the top layer of photosynthetic mats. His study was based on the hypersaline environments of Brazil and they found 36 cyanobacterial taxa. The dominant genera are *Aphanothece*, *Oscillatoria*, *Spirulina*, *Synechococcus*, *Pseudanabaena* and *Leptolyngbya*.

Cyanobacteria are unique amongst the prokaryotic organisms with diverse morphology and biochemistry. Few possessed specialised cells called heterocyst which contain nitrogenase enzyme enabled the organisms to fix atmospheric nitrogen (Stewart *et al.*, 1987; Hamed, 2007). While conducting an experiment, Palinska *et al.* (2012) noticed on culture independent tools used by microbial community. 12 cyanobacterial strains under *Aphanothece*, *Chlorogloea*, *Leptolyngbya*, *Phormidium*, *Pseudanabaena* and *Cyanocystis* were identified across the experiment. The strains showed distinct features in their morphological, physiological and genetic characters. The experiment resulted that these microbes can fix atmospheric nitrogen and they also perform chromatic adaptations.

Stokes (1940) give an account about the importance of cyanobacterial community in nitrogen fixation and in the same time Bortels (1940) isolated several species of nitrogen fixing cyanobacteria. *Tolypothrix*, *Gloeocapsopsis*, *Lyngbya*, *Phormidium* and *Plectonema* were dominant genera observed during the study. Agronomic potential of cyanobacteria in agricultural field was presented by Singh (1942). He reported the fertility of tropical paddy fields directly influenced by the nitrogen fixing cyanobacterium present.

Kannaiyan (1985) reported that Azolla supplied 150-300 tonnes per hectare per year of green manure, which supported the growth of soil microorganisms including heterotrophic nitrogen fixers like cyanobacteria. The cyanobacterial symbiont called as *Anabaena azollae* fixed atmospheric nitrogen and are used as bio-fertilizers in agricultural fields. It is calculated that 120-312 kg N_2 was fixed by this cyanobacterium in one hectare. The functional role of filamentous algae and cyanobacteria were related to autotrophic production and support of food web (Biggs and Smith, 2002).

2.4.2. Biotechnological applications

A study on the potential applications of cyanobacteria was conducted by Thajuddin and Subramannian (2005). They reported that cyanobacteria are occurring as both free living and as endosymbionts. In the recent past, many advanced biotechnological aspects of cyanobacteria were revealed. Many researchers working on the potential application of cyanobacteria as food, feed, fuel, fertilizer, colourant and also for the production of various secondary metabolites such as vitamins, toxins, enzymes, pharmaceuticals, etc. Very rarely cyanobacterial strains were utilized for commercial purpose such as *Spirulina* sp. used for astronauts. Authors also mentioned about N_2 fixing ability of cyanoprokaryotes and the most important of all cyanobacteria performs the basic requirements of food and feed. Some species of *Nostoc* and *Anabaena* were consumed by peoples of Chile, Mexico, Peru and Philippines.

Abed *et al.* (2009) presented an overview of cyanobacterial applications in biotechnology. They investigated the applications of cyanobacteria in the field of industrial and service sector. Anti-bacterial, anti-fungal, anti-viral as well as anti-cancerous properties of cyanobacteria were mentioned in this review work. They proposed for large scale industrial production of cyanobacteria. Potential applications in the agricultural field for biofertilizers were compensated by the use of cyanobacteria. Many genera such as *Nostoc*, *Anabaena*, *Gloeocapsa*, etc. showed high capacity for nitrogen fixation. Prasanna *et al.* (2013) investigated a combination of cyanobacterial strains used by a vermicompost based carrier, for their promise as inoculants in paddy fields. *Nostoc carneum*, *N. piscinale*, *Anabaena torulosa* and *A. doliolum* were used for this study. They recorded a significant enhancement of humus content. The work also revealed that microbial biomass carbon, root weight and microbial flora were also beneficially increased by cyanobacterial inoculated treatments.

Lau *et al.* (2015) worked on the biotechnological aspects of cyanobacteria. They recorded immense applications of cyanobacteria because of their simple growth pattern and growth requirements. They also referred that cyanobacterial products are cost effective, eco-friendly and merely produce zero percentage waste. By using them properly, we can produce efficient and cost effective photosynthetic bioreactors with minimum operational cost. They also found some cyanobacterial species like *Westiellopsis prolifica*, *Hapalosiphon hibarnicus*, *Nostoc muscorum*, *Fischerella* sp. and *Scytonema* sp. showed antibacterial activity against many bacteria such as *Pseudomonas*, *Bacillus*, *Escherichia coli* and *Bradyrhizobium*. Another cyanobacterium called *Spirulina* has high valuable vitamin content such as vitamin B12, beta carotene, thiamine and riboflavin. Isoprene and biopolymers are also produced by some cyanobacterial strains.

2.4.2.1. Pharmaceutical applications

Thajuddin and Subramannian (2005) mentioned about anti-HIV properties of *Lyngbya lagerheimii* and *Phormidium tenue*. Rajishamol *et al.* (2016) studied the antioxidant activity of cyanobacteria which isolated from Cochin estuary. They used three cyanobacterial species such as *Synechocystis aquatilis* var. *minor*, *Oscillatoria limosa* and *Synechococcus elongatus* for the study. They analysed and reported that cyanobacteria possess many kinds of biologically active molecules. They isolated these substances from cyanobacteria will more helpful than using synthetic products. They found that the antioxidative ability of cyanobacteria was a co-responsibility of cell components such as phycobiliproteins, phenolic compounds and antioxidative substances present. *Oscillatoria limosa* showed maximum activity in total phenolic contents, total antioxidant activity, and nitric oxide scavenging activity. While superoxide radical scavenging activity was maximum in *Synechococcus elongatus* and lowest in *Synechocystis aquatilis*. Authors also highlighted the potential use of selected cyanobacterial specimens as supplement in aquaculture feed because of their antioxidant activity.

Martel *et al.* (2017) selected several microalgae and cyanobacteria to identify their radical scavenging activity. *Nostoc*, *Nodularia*, *Leptolyngbya*, *Phormidiochaete* and *Arthrospira* were the cyanobacterial genera used for this study. Aqueous and methanolic extracts are used to study the radical scavenging activity against stable radical-1, 1-dephenyl—picrylhydrazil. The highest extraction yield was found from the cyanobacterial genus *Nodularia* and *Arthrospira*. Free radical scavenging activity merely nil in *Arthrospira* sp. and *Nostoc commune*. *Leptolyngbya protospira* showed low level scavenging capacity against free radical DPPH. Their study resulted that several cyanobacteria and microalgae from the selected taxa showed effectiveness as scavengers of free radicals. This is because of the phenolic compounds detected in the strains of cyanobacteria and it may help in the production of phenolic compounds from some cyanobacterial species.

During a study on bioactive compounds from cyanobacteria, Vijaykumar and Menakha (2015) reported 17 biomedically important bioactive compounds against deadly diseases. They included i. Borophycin has effective cytotoxicity against human carcinoma, ii. Borophycin-8 is a boron contained antibiotic, iii. Apratoxin A has the capacity to arrest apoptosis and due to this they used to develop anticancer derivatives, iv. Cryptophycin were extracted from *Nostoc* sp. has cytotoxic activities against tumour cells of human, v. Cryptophycin-5 has comparatively less activity against cancer cells, but are useful, vi. Cryptophycin-8 has a powerful property helpful in chemotherapy of drug resistant tumours, vii. Stipoldione induces cell division and used in many treatments against cancer, viii. Largazole were obtained from *Symploca* sp. has high inhibitory action against cell growth. Recent studies progressing on this compound include osteogenic and anticancer activities, ix. Dolastatin metabolite and combined with other compounds and it showed good results against breast carcinoma and lung carcinoma in mice. x. Dolastatin-15 is a linear peptide which used against various cancer cell lines and are very effective, xi. Calothrixin A extracts from *Calothrix* sp. which inhibited the growth of human Hela cancer cells in accordance with dosage, xii. Symplocin A extracts from the *Symploca* sp. and it exhibited potent activity as an inhibitor of cathepsin E, xiii. Lyngbyatoxin A is highly inflammatory metabolite isolated from *Lyngbya majuscula* has anti-HIV property, xiv. Microcolin A were suppressing the murine mixed lymphocyte reaction, xv. Curacin A has been found to have activity against the cancer cells of breast, xvi. Cyanovirin-N isolated from *Nostoc ellipsosporum* showed potent *in-vitro* and *in-vivo* activities against HIV and other lentiviruses, xvii. Scytovirin isolated from *Scytonema varium* bound to the envelop glycoprotein of HIV, and inactivates the virus.

2.4.3. Pigments

During a study on *Phormidium* strains, Palinska *et al.* (2011) observed three types of phycobilin pigment composition from 29 *Phormidium* like strains. They found phycocyanin in 23 strains but there was no presence of phycoerythrin. Another group with four *Phormidium* like strains contained both phycoerythrin and phycocyanin, but phycoerythrin dominated phycocyanin in a huge difference. While the third group comprised to two strains showed high phycoerythrin: phycocyanin ratio. They also studied eight major carotenoids and three mycosporins obtained during the work. There was a remarkable difference in the composition of carotenoids.

Rajishamol *et al.* (2016) analysed phycobiliproteins and observed that phycocyanin and allophycocyanin pigments were available majorly in *Oscillatoria limosa* and *Synechocystis aquatilis*. *Synechococcus elongatus* displayed phycoerythrin as major pigment. *Phormidium valderianum* is known to be an excellent source of phycocyanin (Thajuddin and Subramannian, 2005). Lau *et al.* (2015) states that considerable amount of useful vitamins, pigments and enzymes can be produced from cyanobacterial strains. Phycobiliproteins and carotenoids are the two major pigments observed in cyanobacteria and which already have high commercial value in the bio-industry.

Pigments such as phycoerythrin, chlorophyll-a, phycocyanin and allophycocyanin from a novel cyanobacterial species *Chalicogloea cavernicola* were described by Rolden *et al.* (2013). Pigment analysis of cyanobacterial samples collected from a pond near to desert of Oman was conducted by Abed *et al.* (2011). Five pigments such as chlorophyll-a, scytonemin, chlorophyllid-a, beta carotene and fucoxanthin were reported as a result of this work. *Schizothrix*, *Aphanocapsa*, *Chroococcus* and *Gloeocapsa* were the prominent species observed while the exploration.

2.5. Toxicity

Toxin producing cyanobacterial blooms were reported repeatedly from all corners of world in recent times. The extensive blooms in some places cause many serious issues. This exponential growth of cyanobacteria may decrease the amount of light entering into water and that cause depletion of dissolved oxygen and becoming the reason for death of aquatic organisms. To observe the factors affecting the growth of cyanobacteria Berg and Sutula (2015) conducted a project on the cyanobacterial blooms. They found that few principle drivers causing the sudden growth of cyanobacteria such as water temperature, salinity, water clarity, etc. and cyano HABS are not correctly monitored, it will also help them to grow fast. A potential change in the climate may alter the activity and behaviour of cyanobacteria and it may cause bloom. Exposure to chemicals such as herbicides, pesticides and fertilizers is also one of the major reasons for the exponential growth of cyanobacteria. This work aimed to help people to reduce the algal bloom by decreasing the pollution problems.

An investigation on the intracellular toxicity mechanism of potentially anti-cyanobacterial agent hydrogen peroxide in the cyanobacterial species *Microcystis aeruginosa* was done by Mikula *et al.* (2012). *M. aeruginosa* represented one of the most dangerous toxin producing cyanobacterial species in the waterbodies of Europe. They found that metabolic activity of *M. aeruginosa* was highly sensitive towards the exposure of hydrogen peroxide. In dark treatment, there was no significant change in cyanobacterial cell count. While treating in light condition, there were significant changes observed in the total cell count. The experimental result concluded that the change in the decomposition kinetics of hydrogen peroxide under different illuminations will strongly influence the H_2O_2 toxicity in *M. aeruginosa*.

Joishi (2014) mentioned that the pollution tolerant and toxin producing species such as *Oscillatoria limosa* and *Microcystis aeruginosa* found abundantly from Western Ghats region of Karnataka. Kokocinski and Soininen (2012) conducted a detailed study on *Cylindrospermopsis raciborskii*, which discussed for their invasive capacity and toxicity. They sampled 46 lakes from North-Eastern limit geographical range of Poland. They found that *C. raciborskii* was present in 43% of samples. The statistical analysis was also done and t-test revealed that lakes with *C. raciborskii* was more turbid, shallower and more eutrophic than lakes without *C. raciborskii*. Redundancy analysis (RDA analysis) resulted that the presence of *C. raciborskii* was more in lakes showed variable environmental conditions. But they are comparatively less in reservoirs with more depth.

Due to the activity of cyanobacteria, a pond in dessert of Oman showed increased salinity. There is up to 75% of increase recorded. They also noted that the increase in temperature up to 49%. The salt composition was almost similar to sea water and the causing factor was the exponential growth of cyanobacteria (Abed *et al.*, 2011). A lake in Guatemala was showed epidemic growth of cyanobacteria as reported by Komarek *et al.* (2013b). The cyanobacterial species was identified as *Limnoraphis robusta*, which is a new genus to the cyanobacterial community. They lack cytotoxins but showed high amount of carotenoids.

Niiyama *et al.* (2016) tested tap water to identify the reason behind nasty smell detected from the water. The water samples collected and cultured for identifying microbial populations in it. They identified *Pseudanabaena foetida* and *P. sub-foetida*, which were the cause behind the foul smell of tap water.

A brief analysis on the *Pseudanabaena ritilus-viridis* provided information about their ability to produce the toxin namely microcystin. They are also significant because of their reddish appearance. Sometimes violet or blue-green colours are also seen. Kling *et al.* (2012) recommended for pigment analysis to get further information about their pigment composition and toxic activity. Krientitz *et al.* (2013) studied about lesser flamingos and their favourite food *Arthrospira fusiformis*. These cyanobacteria are commonly established in saline-alkaline habitats. They found that these filamentous *A. fusiformis* cause changes also in water chemistry.

A historic overview of *Cylindrospermopsis raciborskii* was done by Kling (2009). This species is considered as one of the major water polluting cyanobacteria. A cyanotoxin called cylindrospermopsin was produced by *C. raciborskii*, which was the main reason behind water contamination. These cyanobacterial taxa are more adaptive to unfavourable conditions of other cyanobacteria. They prefer temperature between 20-35^{0}C for development. But they also have the capacity to tolerate unfavourable temperature and light in some cases.

All these research works on cyanobacteria revealed enormous applications of these microbes. They possess a wide range of diversity, cosmopolitan distribution and high adaptability to adverse conditions. Cyanobacteria are ecologically and economically relevant group with huge importance in pharmaceutical, biotechnological as well as bio-fertilizer industries. In India, cyanobacterial studies are very scanty and need more attention. The taxonomic and ecological aspects of many cyanobacteria from forests are yet to be discovered. This study has focused on the scarcely explored Western Ghats forest regions of Kerala State of India.

Chapter - III

MATERIALS AND METHODS

Cyanobacteria, also known as blue-green algae (BGA) are prokaryotic organisms capable of doing photosynthesis and nitrogen fixation. They have immense applications in daily life but are least known to us. Even though they have immense applications in daily life, they are almost neglected by researchers due to the difficulty to study. Morphological identification was quite complicated in the case of cyanobacteria, because of the changes in characteristics based on environmental factors. No new species were reported from Western Ghats region of India. Also almost zero percentage research works have been carried out from forest regions of Kerala. Hence a plan was executed to collect and report all the available cyanobacteria species from forest regions of Kerala. During the course of research, collection, photomicrographing, culturing, identification and documentation of all the collected cyanobacterial specimens were done. Collected samples were maintained in the germplasm collection of cyanobacteria, Department of Botany, University of Calicut.

3.1. Systematic treatment

Cyanobacteria are microorganisms which show variations in cell structure and pattern in accordance with genera or species change. The commonly found different cell shapes are spherical, oval, rod-shaped, quadrate, irregular, cylindrical, etc. Their arrangement and formations may vary according to genus as well as species. Environmental factors such as temperature, pH and seasons play a key role in the cell development, structure and arrangement. Normally cyanobacteria occur in 3 different forms unicellular, unbranched filamentous and branched filamentous. Unicellular forms are single, but they aggregate to form colonies. Sometimes these colonies look like multicellular organisation. Filamentous forms are divided into the remaining two forms; unbranched filamentous and branched filamentous. Unbranched filamentous forms have heterocystous and non-heterocystous type of cyanobacterial species. The third form, branched filamentous type possess true branched cyanobacteria and false branched cyanobacteria.

The cells or filaments also show differences based on their morphological characters. Presence or absence of sheath, granules, vacuoles and pigments are the basic factors used for cyanobacterial identification and classification. Cell division, reproduction and thallus structure also have peculiar role in the classification of these microbes. Size of the cells, heterocytes (heterocysts), vacuoles and spores and other measurements have specific importance during the identification of cyanobacteria up to genus or species level.

In this study, the taxa were identified up to species or variety level based on the classical taxonomic manuals of cyanobacteria authored by Desikachary (1959), Anand (1989) and modern taxonomic manual by Komarek and Anagnostidis (1998, 2005) and Komarek (2013). Author citations of cyanobacteria were confirmed using the website AlgaeBase (Anonymous, 2020b)

3.2. Study area

Forest regions of Kerala State were selected for the current research work (Fig. 1). 97% of the Kerala forest regions come under Western Ghats. Kerala is a small state with a geographical area of 38863 km^2 and divided into 14 districts. This state has 44 rivers and most of them are entirely monsoon fed. Many of these rivers will become rivulets or dry completely during the summer season. According to Kerala Forest Statistics 2018 by Kerala Forest Department, total forest area in Kerala is 11521.813 km^2. Forest area of Kerala forms 29.65% of the total geographical area of Kerala State. Seventeen Wild

Life Sanctuaries (WLS), six National Parks, one Community Reserve and two Biosphere Reserves are coming under Kerala Forest Department (Anonymous, 2020b).

3.2.1. Western Ghats

Kerala is one of the biodiversity rich states in India. The main reasons for this biodiversity richness are monsoon seasons and Western Ghats. Western Ghats lie in the Southern States of India and almost parallel to the Arabian sea (Fig. 2 & 3). Geographical area of Western Ghats starts from the southern region of Gujarat and extends through Maharashtra, Goa, Karnataka, Tamil Nadu and Kerala. Western Ghats, also called as "*Sahyadri*", ends in Tamil Nadu, southern tip of India. Western Ghats mountain range area covers 1,40,000 km^2. If we consider 25 peak points from Western Ghats, 17 are from Kerala State. Among them Anamudi is the highest peak of Western Ghats with a height of 2695 m (8842 ft.) from the mean sea level. These statistics show the richness of Western Ghats forest in Kerala. Unfortunately, researchers invaded this place only for flora and fauna research. Not even a preliminary study on cyanobacteria has been conducted yet from these forest regions. There are no reports on cyanobacteria from forest regions, only a few agricultural field studies were conducted by researchers in Kerala. Literature available on cyanobacterial taxa of Kerala forests are scanty. A preliminary survey on cyanobacteria from Kerala forests gave incredible results that these forest areas are highly diverse with cyanobacteria. Hence the present study was designed and executed.

3.2.2. Types of forests in Kerala

Kerala has 5 different types of forests;

1. Evergreen forests
2. Deciduous forests
3. Shola forests

4. Grasslands
5. Mangroves

3.2.2.1. Evergreen forests

These forest types are made up with evergreen trees and have great diversity of species. In Kerala most evergreen forests are coming under the sub type semi-evergreen forests, which is considered as a transitional stage between evergreen and moist deciduous forests. Another forest type under this category is Southern hill top tropical evergreen forests. It is an inferior variety of typical evergreen forest. Another one is West coast tropical evergreen forests. Here, a large number of species are found mixed together. And the last category in evergreen forests found in Kerala is West evergreen and semi-evergreen climax forests. These are mostly confined to the windward side of Western Ghats (Anonymous, 2020c).

3.2.2.2. Deciduous forests

These forests are classified based on moisture regime. Secondary dry deciduous forests are one among them and are inferior climax forest with poorly shaped small trees. Another type forest is southern dry deciduous forest. Teak forests are coming under this category. Next one is secondary moist deciduous forests. This forest type covers larger area than the primary type. Mostly they are found like dense forests. Dry deciduous type is another category and is comparatively rare in Kerala. Other types such as AAG (*Albizia-Acacia-Gyrocarpus*) type, is only found in Chinnar WLS. Similarly, Mannarkad division has APT (*Anogeissus-Pterocarpus-Terminalia*) type forest. It is also found in a small area which is above 600m from mean sea level in Chinnar WLS. ATT (*Anogeissus-Tectona-Terminalia*) type forests are found only in South Wayanad WLS. It is represented by dense forests and woodland to savannah woodlands (Anonymous, 2020c).

3.2.2.3. Shola forests

These type forests are commonly found in South Indian Mountains. Shola patches are mainly found in valleys and montane regions. Grassland and shola combinedly known as climax vegetation. These type of forests are rich with vegetation and many endangered and endemic species are living here (Anonymous, 2020c).

3.2.2.4. Grasslands

In Kerala, grasslands are found in association with almost all type of forests. Generally vast areas of grasslands are found above 1500m, but in Kerala they are found from 700m above the mean sea level. Shrub savannah is a synonym of grasslands. Common plants found in grasslands are herbaceous and shrubby plants. Sometimes, minimum temperature in grasslands falls below zero degree Celsius in Anamudi hills (Anonymous, 2020c).

3.2.2.5. Mangroves

These are wetland ecosystems formed by specialised plants which are adapted to saline environment. Wetland forests are not considered for this study.

Current work is focused on the forest areas of Kerala, which comes under Western Ghats region (Anonymous, 2020c).

3.3. Sampling methods

Samples were collected from all possible sites of forest regions across Kerala. These areas include waterbodies like river, lake, ponds, waterfalls, dam sites, reservoirs and other areas like soil, rock surfaces, bark of trees, tree leaves, roots of trees, etc. Cyanobacterial samples are found in all types of forests during the post-monsoon and monsoon seasons. Pre-monsoon season provides only limited number of cyanobacterial samples. Specimens were collected by using spatula, forceps, needles and scalpels. Samples were collected in collection bottles and a collection number was given according to collection area and number of collections from each area. Samples were collected in separate bottles in accordance with their morphological appearances.

3.4. Photomicrographing

Collected samples were photomicrographed using microscope installed with camera. Leica DM 1000 LED compound microscope and Leica DM 2000 LED compound microscope were used for taking photos of cyanobacteria from collected samples. Photographs were taken in different magnifications and marked the scale for easier identification. Measuring parameters such as length, breadth, diameter, etc. were measured using the inbuilt microscope application named LAS.

3.5. Culturing

Collected samples were cultured for further studies. It is helpful to analyse the changes happening to cyanobacterial species under natural conditions as well as laboratory conditions. Primarily, samples were cleaned by using distilled water to wash away all impurities like soil, wastes and other plant or microorganism parts. Then cleaned with BG-11 medium (Rippka *et al*., 1979). And the cleaned samples were cultured in BG-11 medium. Laminar air flow chamber (LAF) is used for transferring cleaned cyanobacterial specimens in to culturing bottles. Autoclaved conical flasks, test tubes, bottles with cap or petri dishes can be used for the culturing of cyanobacterial samples. The test tubes and conical flasks were stoppered by non-absorbent cotton wool plugs. Cultured specimens were kept in clean laboratory racks with a room temperature of 24 ± 1^0C and 1000 lux light by altering light/dark periods of 16:8 hours. Cultures were provided with nutrients in proper time period (Fig. 4).

3.5.1. Preparation of BG-11 medium (Rippka *et al*., 1979)

$NaNo_3$	-	01.5 mg
$K_2HPO_4.3H_2O$	-	40.0 mg
$MgSO_4.7H_2O$	-	75.0 mg

$CaCl_2.2H_2O$	-	36.0 mg
Citric acid	-	06.0 mg
Ferric ammonium citrate	-	06.0 mg
EDTA (Na_2Mg salt)	-	01.0 mg
Na_2CO_3	-	20.0 mg
Glass distilled water	-	1 lit
Trace metal solution	-	1 ml

For prepare N- free medium $NaNO_3$ may be omitted.

3.5.1.1. Composition of trace metal solution (Rippka *et al.*, 1979)

H_3BO_3	-	2.86 g/l
$MnCl_2.\ 4H_2O$	-	1.81 g/l
$ZnSO_4.\ 7H_2O$	-	0.222 g/l
$Na_2MoO_4.\ 2H_2O$	-	0.390 g/l
$CuSO_4.\ 5H_2O$	-	0.079 g/l
$Co\ (NO_3).6H_2O$	-	0.0494 g/l

After autoclaving and cooling the pH of the medium is adjusted to 7.1 to 7.4

3.6. Identification

Cyanobacterial identification is mainly based on two methods; conventional taxonomic method and molecular or phylogenetic method. The present experiment is purely based on the conventional taxonomic methods. Morphology of cyanobacteria is being used as the main character for identification. Shape of cells and heterocyst, size of cells and heterocyst (length, width and diameter), characteristics of sheath, trichome, filaments and colony are the important features used to identify the collected cyanobacteria up to species level. Classical taxonomic manuals of Desikachary (1959), Anand (1989) and latest taxonomic manual of Komarek and Anagnostidis (2008, 2013) were used to identify the taxa. Recent literatures were used for confirmation of identified taxa.

3.7. Temperature and pH

pH of the water medium in which the cyanobacteria was growing and the atmosphere temperature was recorded using multiparameter apparatus. Temperature and pH of the area from where the samples were collected was recorded for the comparison of cyanobacterial diversity in connection with ecological changes.

Chapter - IV

RESULTS AND DISCUSSION

4.1 CHROOCOCCALES

Family **Synechococcaceae** Komarek et Anagnostidis 1995

Cells solitary or in mucilaginous colonies with irregular arrangement or more or less in one direction in a colony. Sometimes forming pseudofilamentous rows. Mucilaginous colonies usually structureless, amorphous, but some genera also occur with spherical colonies and cells distributed at their periphery or at the ends or inside of mucilaginous stalks. Several genera have special gelatinous envelopes around the cells. Cells occasionally or rarely spherical, usually slightly or distinctly elongate, widely oval, oval, ellipsoidal, fusiform, cylindrical, rod like to pseudofilamentous.

Cell division always in one plane only in successive generations, usually perpendicular to the longitudinal axis of the cell. This family is divided into two subfamilies according to the ability to form irregular or filamentous involution cells. The first one is Aphanothecoideae and the next is Synechococcoideae.

I. Subfamily **Aphanothecoideae** Komarek et Anagnostidis 1995

Cells solitary or in mucilaginous colonies. Usually with irregular arrangement. Several genera have cells in the periphery of mucilaginous spheres or at the ends of or within gelatinous stalks, radiating from the colonial centre. In several genera cells are surrounded by their own, sometimes lamellated or coloured envelopes. Cells almost spherical, oval, widely oval or rod shaped. Cell length/width ration usually less than 3:1. Involution cells irregular if present, not filamentous. Pseudofilaments are usually absent.

Cell division by binary fission, only in one plane in successive generations, perpendicular to the longer cell axis. Cells divide in to two isomorphic cells growing to the original size before the next division. Nanocytes facultatively present in some but not all species.

Key to the genera

1a. Cells solitary or in groups, usually not forming mucilaginous colonies, more or less widely oval, sometimes with narrow diffluent gelatinous envelopes around single cells …………………..……………………… 2

1b. Cells in gelatinous colonies, usually with more or less distinct envelopes, almost spherical, oval or cylindrical ……………….…………………… 4

2a. Cells cylindrical to widely oval, small, striated, 0.4-15 µm long ………. 3

2b. Cells oval to widely oval, 6-40 µm long …………….……... **Cyanothece**

3a. Cells oval, 0.4-10 µm long, 0.2-6 µm wide …………..…… **Cyanobium**

3b. Cells cylindrical to widely oval, 2-15 µm long, 1.7-10 µm wide……….. ……………………………………….....……….. **Cyanobacterium**

4a. Cells at least in the centre of a colony, usually without individual envelopes ……..…………………………………..…...…………. **Aphanothece**

4b. Cells usually with individual envelopes, lamellated or coloured ……….. ………………………………………….....…..…........... **Gloeothece**

i. **Cyanobium** Rippka et Cohen-Bazire 1983

Cells usually solitary or in pairs after division, not forming mucilaginous colonies. Small, normally about 1-4 µm long and 1-3 µm wide, without sheaths. Oval, ellipsoidal or shortly rod shaped. Usually with well visible chromatoplasma. Granular contents fine, cells may be hemispherical or spherical after division. Cell division by binary fission and the cells grow into the original size and shape before the next division.

Key to the species

1a. Cells short, 1.5-4.5 µm long, 0.5-1.5 µm wide ……………. ***C. diatomicola***

1. ***Cyanobium diatomicola*** (Geitler) Komarek, J. Kopecky et Cepak

Cells solitary or in pairs after division, sometimes in short rows, one after another in the case of rapid repeated division, without mucilage, or sometimes enveloped by fine, colourless, diffluent and distinct slime; cells short, rod shaped or elongated, hemispherical or spherical after division, ends rounded; 1.5-4.5 µm long and 0.5-1.5 µm wide; cellular content homogenous, pale blue-green content; cells pale green to dull blue-green in colour.

Recorded a temperature of 20.2°C during post-monsoon season. pH recorded as 6.9 during post-monsoon season.

Habitat	: Edaphic and occasionally epiphytic
Locality	: Pongalappara, Thiruvananthapuram
Specimen number	: CU No. 153143
Figure	: 5 A & B

ii. **Cyanobacterium** Rippka et Cohen- Bazire 1983

Cells solitary or in groups of two after division, regular, sometimes in irregular in clusters. Free floating, never forming colonial structures. Gelatinous envelopes absent, more or less cylindrical, oval or rod shaped. Ends rounded or up to widely oval, straight or slightly arcuate. Cells content homogenous, without separation of centroplasma and chromatoplasma, occasionally forming lengthwise striations. Granules present, rarely prominent. Cell division by binary fission, transversely to the longer cell axis which produces two isomorphic, very rarely isomorphic daughter cells. Cells almost looks like mother cells and also in size before next cell division.

Key to the species

1a. Cells spherical or elongate, 6-8 µm wide ………………..…***C. epiphyticum***

1b. Cells oval, 5-6 µm wide ……………………………….……… ***C. notatum***

1. ***Cyanobacterium epiphyticum*** Komarek et M. Watanabe

Cells solitary, single, groups of two after division sometimes in small, loose, groups, without mucilaginous envelope, pale green, olive green, or greenish brown colour; cells spherical, or slightly elongate, subspherical after division, 7-11 µm length and 6-8 µm breadth; granules present, highly granulated in sometimes; single, prominent, irregularly located dark brown granules present in several cells.

Recorded a temperature of 24.0°C during post-monsoon season and 28.6°C during summer season. pH recorded as 7.5 during post-monsoon season and 7.1 during summer season.

Habitat : Epilithic
Locality : Ambalappara (Kakkayam), Kozhikode
Specimen number : CU No. 153048
Figure : 5 C & D

2. ***Cyanobacterium notatum*** (Skuja) Komarek, J. Kopecky et Cepak

Cells in a homogenous content; cells solitary or two together during division, oval or widely oval, tip broadly rounded, blue-green, deep blue green or green colour, 7-12.3 µm length, 5-6 µm breadth; mucilaginous envelopes or sheaths absent; granules present, large, sometimes prominent; vacuoles often present.

Recorded a temperature of 20.2°C during post-monsoon season. pH recorded as 6.8 during post-monsoon season.

Habitat : Edaphic
Locality : Agasthyamala, Thiruvananthapuram
Specimen number : CU No. 153144
Figure : 5 E & F

iii. Cyanothece Komarek 1976

Cells solitary or in two after division, sometimes few cells in rows after repeated rapid divisions. Without gelatinous envelopes; sometimes with narrow fine indistinct, hyaline, gelatinous margin around single cells. Cells widely oval, rod shaped to almost cylindrical. Ends widely rounded or rounded. Always longer than wide. Cell contents net like keratinization. Some species showing motile characteristics. Cells always divided by binary fission and into two morphologically similar equal, hemispherical cells. Cells grow into original shape and size before the next division. Reproduction by cell division and succeeding separation of daughter cells.

Key to the species

1a. Cells roundly oval, 6-8.5 µm broad .... ***C. halobia***

1. Cyanothece halobia Roussomoustakaki et Anagnostidis

Cells solitary, during division two, motile, roundly oval or sub-cylindrical, ends widely rounded, cell content olive green or yellowish green in appearance, 8-11.5 µm long, 6-8.4 µm broad; gelatinous envelopes rarely found; small scattered granules present, not prominent, without aerotops.

Recorded a temperature of 21.6°C during post-monsoon season and 29.9°C during summer season. pH recorded as 7.3 during post-monsoon season and 6.9 during summer season.

Habitat : Epilithic

Locality : Soochippara, Wayanad

Specimen number : CU No. 158533

Figure : 5 D & H

iv. Aphanothece Nageli 1849

Colonies multicellular, initially microscopic, later become macroscopic. Cells arranged irregularly, loosely or densely in a common mucilage, mucilage gelatinous, usually spherical, and occasionally amorphous. Greenish, blue-green or brown in colour. Normally mucilage fine, colourless or less frequently coloured, homogenous, sometimes diffluent. Occasionally structureless, distinct, more or less smooth, delimited or lamellated in the marginal parts. Cells in their own indistinct or distinct individual sheaths. Cells widely oval to cylindrical in shape, rarely rod shaped, with rounded ends. Occasionally with clearly visible chromatoplasma. Cell content granular, prominent or fine. Planktic species with few aerotopes, cell division by binary fission, usually by cleavage. Reproduction by fragmentation of colonies. Sometimes fragmented into solitary cells.

Key to the species

1a. Cells without individual sheath ………………………………………… 2

1b. Cells with individual sheath …………………………………………….. 3

2a. Cell width 3-5.6 µm ………………………...……………….. ***A. bullosa***

2b. Cell width 5-7.5 µm ……………………………….....…… ***A. hegewaldii***

3a. Individual sheath absent, with colonial sheath ……………….....……. 4

3b. Individual and colonial sheath present ………………..………………… 6

4a. Cells narrow, less than 3 µm wide ………………...…………. ***A. smithii***

4b. Cells broad, more than 3 µm wide ……………………………………… 5

5a. Cells 4-8 µm long ………………………………………………. ***A. stagnina***

5b. Cells 8.5-11.9 µm long ………………………………….. ***A. microscopica***

6a. Cells with sheath, unlamellated ……………………………………… 7

6b. Cells with sheath, lamellated …………………………….....… ***A. pallida***

7a. Sheath thin, cells 1-3 µm wide ……………...……… ***A. elabens*** var. ***minor***

7b. Sheath thick, cells 3-5.2 µm wide …………………………… ***A. castagnei***

1. Aphanothece pallida (Kutzing) Rabenhorst

Colonies microscopic or macroscopic, fine, diffluent, with delimited margins, mucilaginous, amorphous, brownish green or greyish brown in colour; cells loosely or densely arranged; mucilage colourless or slightly brownish, structureless, cells near the colonial surface with their own envelopes, these envelopes lamellated and intensively yellowish brown in colour; cells elongate, long oval or rod shaped, sometimes cylindrical, blue-green, olive green or brownish green colour; granules present, fine, prominent. Cells 8-12 µm long, 5-6.5 µm wide, rounded ends.

Recorded a temperature of 23.1°C during post-monsoon season and 30.3°C during summer season. pH recorded as 7.1 during post-monsoon season and 6.5 during summer season.

Habitat : Epilithic and edaphic

Locality : Peruvannamuzhi, Kozhikode

Specimen number : CU No. 153193

Figure : 6 A

2. Aphanothece stagnina (Sprengel) A. Braun

Colonies initially microscopic, then become macroscopic, brownish green or dull green in colour, mucilaginous, gelatinous, distinct and firm margin, delimited, spherical or elongate, usually with sub colonies, bright blue-green or dark olive green in colour, rarely dull green colour; cells loosely arranged, sometimes densely aggregated; mucilage colourless; individual sheath usually present, diffluent, colourless, unlamellated, sometimes more diffuse and confluent; cells oval or elongate or widely cylindrical in shape, ends rounded, 4-8 µm long, 3-5.6 µm wide, dull green or pale blue-green colour; granules present, fine, not prominent.

Recorded a temperature of 20.7°C during post-monsoon season. pH recorded as 7.2 during post-monsoon season.

Habitat : Epilithic and epiphytic

Locality : Kattadikkadavu, Idukki

Specimen number : CU No. 153195

Figure : 6 B

3. *Aphanothece bullosa* (Meneghini) Rabenhorst

Colonies microscopic, mucilaginous, irregular and amorphous, surface firm, olive green or dull blue green in colour; mucilage usually colourless, without definite shape, cells irregularly arranged, occasionally with individual envelopes, gelatinous, mostly near to colonial margins; cells oval or elongate cylindrical with rounded ends, pale blue green or olive green in colour, 3-7 µm long, 3.5-5 µm wide; finely granular, cell content homogenous, not prominent or occasionally prominent.

Recorded a temperature of 18.8°C (Ranipuram) and 23.1°C (Peruvannamuzhi) during post-monsoon season and 30.3°C (Peruvannamuzhi) during summer season. pH recorded as 7.3 (Ranipuram) and 7.1 (Peruvannamuzhi) during post-monsoon season and 6.5 (Peruvannamuzhi) during summer season.

Habitat : Epilithic and corticolous
Locality : Ranipuram, Kasaragod & Peruvannamuzhi, Kozhikode
Specimen number : CU No. 153191 & CU No. 153193
Figure : 6 C & D

4. *Aphanothece elabens* var. ***minor*** Nygaard

Colonies usually microscopic, later macroscopic, spherical, sometimes colonies aggregate together, blue green or olive green in colour; homogenous mucilaginous envelope, occasionally concentrically lamellate, delimited, rarely diffluent; cells oval, cylindrical or rod shaped, very rarely elongated spherical, blue green or olive green in colour, 1-3 µm wide, 3.5-6 µm long; aerotopes usually absent, sometimes present in planktonic species; granules present, rarely prominent.

Recorded a temperature of 19.4°C during post-monsoon season and 29.7°C during summer season. pH recorded as 7.5 during post-monsoon season and 7.2 during summer season.

Habitat : Epilithic

Locality : Sholayar, Thrissur

Specimen number : CU No. 153192

Figure : 6 E

5. *Aphanothece hegewaldii* Kovacik

Colonies initially microscopic, later become macroscopic, spherical, elongate or oblong in shape, inside a mucilaginous sheath, sometimes irregular in outline, green, dull blue green or blue green in colour; mucilaginous envelope hyaline, unlamellate, firm in the primary development, then become diffluent; cells elongate, oval or rod shaped with round ends, 5-7.5 µm broad, 8.5-18 µm long, dull blue-green or green in colour; aerotopes absent or present; granules present, occasionally prominent.

Recorded a temperature of 22.5°C (Charpa) and 22.6°C (Gavi) during post-monsoon season and 31.8°C (Charpa) during summer season. pH recorded as 7.4 (Charpa) and 7.4 (Gavi) during post-monsoon season and 7.1 (Charpa) during summer season.

Habitat : Edaphic and epiphytic

Locality : Charpa, Thrissur & Gavi, Pathanamthitta

Specimen number : CU No. 153079 & CU No. 153075

Figure : 6 F-G

6. *Aphanothece castagnei* (Kutzing) Rabenhorst

Colonies macroscopic, irregular, mucilaginous, amorphous, dirty blue green or brown in colour, cell more or less densely arranged; cells oval or cylindrical with rounded ends, 4.2-7.8 µm length and 3-5.2 µm breadth, blue green or dull green colour; with thick envelopes, hyaline or olive green colour, not lamellate; granules present, rarely prominent; vacuoles absent.

Recorded a temperature of 20.7°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.1 during summer season.

Habitat	: Epilithic and edaphic
Locality	: Nelliyampathy Ghats, Palakkad
Specimen number	: CU No. 191207
Figure	: 6 H

7. ***Aphanothece microscopica*** Nageli

Colonies mucilaginous, delimited, hyaline, unlamellate, more or less spherical in shape, diffluent; cells densely arranged, green or blue green colour, without specific sheath, widely oval to cylindrical in shape, 8.5-11.9 µm long, 5.2-5.8 µm broad; granule present, without aerotopes.

Recorded a temperature of 22.0°C during post-monsoon season and 30.2°C during summer season. pH recorded as 7.2 during post-monsoon season and 6.9 during summer season.

Habitat	: Epilithic and edaphic
Locality	: Virakuthode, Chimminy, Thrissur
Specimen number	: CU No. 150090
Figure	: 7 A & D

8. ***Aphanothece smithii*** Komarkova-Legnerova et Cronberg

Colonies microscopic, initially spherical and then become irregular in shape, free floating, freely arranged, mucilaginous, mucilage hyaline, not lamellate; cells oval, elongated, spherical or cylindrical, dull green or yellowish green colour, 3.2-5.7 µm length, 1.9-3 µm broad; granules present, not prominent, sometimes with minute aerotopes.

Recorded a temperature of 14.8°C during post-monsoon season. pH recorded as 7.3 during post-monsoon season.

Habitat : Epiphytic and edaphic

Locality : Meesapulimala, Idukki

Specimen number : CU No. 153194

Figure : 7 C & D

v. Gloeothece Nageli 1849

Colonies usually small in size, composed of groups of cells. Cells may or may not sheathed. Commonly 2-4 cells are seen, but after division more cells are found within a single envelope. Cells enclosed within their own gelatinous envelopes and sometimes also surrounded by common mucilage. Usually found as groups and are irregularly distributed in large agglomerations. Many colonies united to become macroscopic cells and groups of cells enclosed in colourless or concentrically lamellated, occasionally coloured and are delimited at the margins. Cells widely oval, oblong, elongated or rod shaped, usually with rounded ends. Blue-green, pale blue-green, olive green or brownish green colour. Granular content normally fine, usually not prominent, but occasionally prominent; aerotopes found from planktic species; cell division transverse to the longitudinal axis. They usually produce their own sheaths after division. Reproduction by disintegration of colonial aggregations. A few species showed nanocyte production.

Key to the species

1a. Cells solitary with individual sheath …………………………………… 2

1b. Cells 1-8 with individual and common sheath ……………….………… 3

2a. Sheath coloured, 5-11 μm long ……………………………... ***G. confluens***

2b. Sheath partially coloured, cells 1.5-3 μm long ………………… ***G. incerta***

3a. Cells oval or rod shaped …………………………………………………… 4

3b. Cells spherical or hemispherical ………………...………… ***G. rupestris***

4a. Up to 2 cells inside common sheath ……..…………………………... 5

4b. more than 2 cells inside common sheath ………………………… ***G. palea***

5a. Sheaths highly lamellated …………..……….………. ***G. membranacea***

5b. Sheaths sparsely lamellated ………………………...…… ***G. tepidariorum***

1. Gloeothece incerta Skuja

Colonies microscopic, very rarely macroscopic, mucilaginous, without definite shape, yellowish brown colour, forming mat like structures in stony substrates, composed of sub colonies with single to several cells, colonies 15-20 µm in diameter; cells oval, cylindrical or elongated with rounded ends, blue-green colour, 1.5-3 µm long and 1-2 µm in width; individual sheaths firm, delimited, hyaline or yellowish brown colour, distinctly lamellate, occasionally diffluent; granules present, not prominent.

Recorded a temperature of 20.7°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.1 during summer season.

Habitat : Epipelic

Locality : Nelliyampathy Ghat, Palakkad

Specimen number : CU No. 191207

Figure : 7 E & F

2. Gloeothece membranacea (Rabenhorst) Bornet

Colonies gelatinous, small cell clusters joined by mucilage, sometimes spherical or membranous, olive green or brownish colour; sheaths usually colourless, hyaline, distinctly lamellate, occasionally diffluent at margins; cells usually short cylindrical or oval, ends round, olive green or light brownish green colour, 4-6 µm wide, 5.5-10 µm long; granules present, sometimes prominent.

Recorded a temperature of 23.1°C during post-monsoon season and 30.3°C during summer season. pH recorded as 7.1 during post-monsoon season and 6.5 during summer season.

Habitat : Epilithic and edaphic

Locality : Peruvannamuzhi, Kozhikode

Specimen number : CU No. 158535

Figure : 7 G & H

3. Gloeothece tepidariorum (A. Braun) Lagerheim

Colonies are irregular agglomerations of grouped cells, cells are sheathed, microscopic to macroscopic, dirty green, brownish green or yellowish brown colour; sheaths colourless or very slightly brownish, usually hyaline, unlamellated or slightly lamellate; cells rod shaped in normal, elongate, oval or cylindrical shapes are also observed, olive green, pale blue-green or brownish green colour, ends rounded, 4-7 µm wide and 7.5-14 µm long; granules present, prominent, aerotopes only present in planktic species.

Recorded a temperature of 23.1°C during post-monsoon season and 30.3°C during summer season. pH recorded as 7.1 during post-monsoon season and 6.5 during summer season.

Habitat : Edaphic and epactiphytic

Locality : Peruvannamuzhi, Kozhikode

Specimen number : CU No. 158537

Figure : 7 I-K

4. Gloeothece confluens Nageli

Colonies mucilaginous, yellowish, greenish or slightly brownish gelatinous macroscopic or microscopic aggregates; cells solitary or in pairs, short, cylindrical, ends rounded, with sheath 13.5-18.5 µm long, 6.6-8.7 µm broad, without sheath 2.8-5 µm broad, 5.5-10.5 µm long, pale blue-green or yellowish brown colour, sometimes cells united together irregularly by common envelopes, sheath thick, up to 5 µm in thickness, wide, hyaline or brown colour, unlamellated; granules present, prominent.

Recorded a temperature of 20.2°C during post-monsoon season. pH recorded as 6.9 during post-monsoon.

Habitat	: Corticolous and epilithic
Locality	: Karamanayar, Thiruvananthapuram
Specimen number	: CU No. 153140
Figure	: 8 A & B

5. **_Gloeothece palea_** (Kutzing) Nageli

Colonies macroscopic, regular colonies of 2-4 cells, sometimes many celled types are also seen, 20-35 µm in diameter, many colonies united into dirty blue-green, gelatinous agglomerations; cells oval, cylindrical or spherical in shape, blue-green or pale green colour, 7.5-13 µm long, 4-6.3 µm in wide; sheath thick, hyaline, rarely yellowish colour, more or less wide, not lamellate or 1-2 indistinct layers, distinctly delimited; granules present, prominent.

Recorded a temperature of 21.2^{o}C during post-monsoon season and 28.3^{o}C during summer season. pH recorded as 7.3 during post-monsoon season and 6.8 during summer season.

Habitat	: Epilithic
Locality	: Mangaladevi hills, Idukki
Specimen number	: CU No. 153083
Figure	: 8 C & D

6. **_Gloeothece rupestris_** (Lyngbye) Bornet

Colonies microscopic, sometimes forming agglomerations leads to macroscopic size, 2-32 celled colonies, covered by a common sheath, cells inside have a solitary sheath in most cases, colonies irregular in arrangement, spherical or oval in shape, 30-50 µm in diameter, mucilaginous; cells oval, hemispherical, spherical or ellipsoidal, pale blue-green or brownish green colour, 4.5-14.3 µm in long, 4.8-8.5 µm broad, ends rounded; sheaths around the cells are wide, hyaline or yellowish colour, concentrically lamellate, delimited, rarely not stratified; granules present, prominent.

Recorded a temperature of 24.9°C during post-monsoon. pH recorded as 7.3 during post-monsoon.

Habitat : Epilithic and epiphytic

Locality : Kochupamba, Pathanamthitta

Specimen number : CU No. 153064

Figure : 8 E & F

II. Subfamily **Synechococcoideae**

Cells solitary, usually without mucilage or forming mucilaginous colonies. Rarely irregularly arranged. Usually oriented in one direction, sometimes forming pseudofilamentous rows of cells. Mucilaginous envelope absents, homogenous or structureless, usually colourless or occasionally coloured, diffluent at the margin. Cells oval, widely oval, rod shaped, short cylindrical or elongated cylindrical. Commonly found as clusters, facultatively filamentous involution clusters are present. Cell division perpendicular to the axis of the cell. Nanocytes usually absent.

Key to the genus

1. Cells cylindrical, 2 to several times longer than wide …….. **Synechococcus**

i. **Synechococcus** Nageli 1849

Cells usually solitary or in microscopic or macroscopic irregular clusters. Not forming mucilaginous colonies. Sometimes cells forming pseudofilamentous formations after rapid repeat divisions. 2-20 cells are found to be in same row. Mucilage absent or very fine, diffluent and colourless. Homogenous and around solitary cells. Cells long oval or cylindrical in common, sometimes more longer than wide and rod shaped. Straight, arcuate or sigmoid, 1.5-20 µm long and 0.4-11 µm wide. Thylakoids parietal, dull green, pale green to bright and dark blue-green in colour. Cell division normally by binary fission. Reproduction by cell division along the longitudinal axis.

Key to the species

1a. Cells solitary or in pairs …...…………………………………………….. 2

1b. Cells forming chain like structures ………...………..………. ***S. elongatus***

2a. Cells up to 7.8 µm long ……………………………………… ***S. mundulus***

2b. Cells more than 8 µm long ……………………………….…….. ***S. subsalsus***

1. Synechococcus subsalsus Skuja

Cells solitary, after division two together, long elliptical to cylindrical, tip rounded, blue-green to pale blue-green, fine mucilage present, rarely enveloped by thin sheath, diffluent, hyaline; Cells pale blue-green to blue-green, 6.8-12.8 µm long, 4-5.5 µm wide; granules present, not prominent; aerotopes absent.

Recorded a temperature of 22.6^{o}C during post-monsoon. pH recorded as 7.4 during post-monsoon.

Habitat	: Epactiphytic
Locality	: Gavi, Pathanamthitta
Specimen number	: CU No. 153076
Figure	: 8 G & H

2. Synechococcus elongatus (Nageli) Nageli

Cells solitary or in clusters, sometimes forming a chain like structure, up to 4 cells united to form chains, mucilaginous content very fine; cells mostly cylindrical, rarely oval, straight, very rarely showing an irregular curve, blue green in colony 2.5-5.2 µm long, 2-3.5 µm in broad, Granules present, prominent; vacuoles present.

Recorded a temperature of 20.2^{o}C during post-monsoon. pH recorded as 6.8 during post-monsoon.

Habitat : Edaphic and epactiphytic

Locality : Agasthyamala, Thiruvananthapuram

Specimen number : CU No. 1553144

Figure : 9 A & B

3. Synechococcus mundulus Skuja

Cells solitary, after division two together, cylindrical to oval, straight in common, blue-green or dull blue-green, rarely showing a curve, ends broadly rounded, 4-7.8 µm long, 2.7-4.5 µm broad; mucilaginous layer very fine indistinct; granules present, prominent; vacuoles present.

Recorded a temperature of 20.2^{o}C during post-monsoon. pH recorded as 6.9 during post-monsoon.

Habitat : Epactiphytic

Locality : Pongalappara, Thiruvananthapuram

Specimen number : CU No. 153139

Figure : 9 C & D

Family **Merismopediaceae** Elenkin 1933

Living as solitary cells or in irregular, flat or spherical colonies. Mucilage colourless, without definite shape, sometimes form spherical colonies with a special central stalk system. Gelatinous envelope present, facultatively simple or fine. Cells spherical, oval, rod shaped or obovate. Cell division by binary fission. Always in two planes, which is perpendicular to one another. Nanocyte formation very rare. Reproduction is by disintegration of colonies, very occasionally by solitary cells.

I. Subfamily **Merismopedioideae**

Cells single or in colonies. Colonies usually microscopic, sometimes become macroscopic. Usually free living, occasionally attached to a substrate.

Irregular or flat. Cells spherical in common, rarely obovate, oval or elongate to rod shaped. Several species possess individual gelatinous envelopes. Sheaths striated or without striation. Cell division by binary fission. Reproduction by disintegration of colonies.

Key to the genera

1a. Solitary, free living cells ……………..…………………… **Synechocystis**

1b. Cells in colonies or groups, sometimes attached to a substrate ………… 2

2a. Cells spherical, regularly arranged ……..…………………… **Aphanocapsa**

2b. Cells elongate, irregular arrangement ……………...……….. **Microcrocis**

i. **Synechocystis** Sauvageau 1892

Cells solitary, spherical in shape, after division hemispherical and two cells together for a short time. Never forming colonies. Mucilaginous envelopes absent or with narrow, fine, colourless, hyaline and diffluent indistinct mucilaginous envelopes. Cells usually spherical or widely oval. Granules prominent in some conditions, otherwise cell content fine. Cell division by binary fission. Two hemispherical daughter cells reach the original globular shape before next division. If the mucilaginous envelope present, the split together with dividing cells. Aerotopes or gas vesicles occasionally present.

Key to the species

1. Cells spherical, 5-8 µm in diameter …………………………… ***S. aquatilis***

1. ***Synechocystis aquatilis*** Sauvageau

Cells globular or widely oval, two together after division, pale-blue green or brownish green colour, rarely with thin individual envelopes, cells 5-8 µm diameter; mucilaginous content absent or very fine; granules present, rarely prominent; vacuoles present.

Recorded a temperature of 25.2°C during post-monsoon. pH recorded as 7.4 during post-monsoon.

Habitat : Epilithic and epiphytic

Locality : Moozhiyar, Pathanamthitta

Specimen number : CU No. 153058

Figure : 9 E & F

ii. Aphanocapsa Nageli 1849

Colonies microscopic or macroscopic, more or less spherical, irregular or regular; numerous cells sparsely or densely irregularly arranged. Colonial mucilage usually colourless, homogenous with distinct margin. In macroscopic colonies, margin firm, shapeless but clearly delimited. Cells usually without individual gelatinous envelope. But sometimes produce individual sheaths due to adverse conditions. Sheaths narrow and diffluent if it is present. Cells more or less spherical, sometimes elongate or oval in shape. After division hemispherical. Aerotopes usually absent. But some planktic species possess aerotopes in limited numbers. Cell division usually by binary fission. Reproduction by the disintegration of colonies. Nanocyte production were recorded in certain species.

Key to the species

1a. Colonies with definite sheath …………………………………………… 2

1b. Colonies without definite sheath ……………………………...……… 4

2a. Cells up to 3 µm in diameter …………………………………………… 3

2b. Cells more than 3 µm in diameter ………………………………… ***A. orae***

3a. Cells 1 µm in diameter ……………………………...…….. ***A. holsatica***

3b. Cells 1.5-3 µm in diameter ……………………..…...………. ***A. nubila***

4a. Cells usually less than 2 µm in diameter ……………………….……….. 5

4b. Cells usually more than 2 µm in diameter ………………..…………….. 6

5a. Cells up to 1 µm in diameter …………………………..….. ***A. delicatissima***

5b. Cells 1-2.5 µm in diameter ………………………….……..…… ***A. elachista***

6a. Colonies large, up to 400 µm in diameter …………………….. ***A. grevillei***

6b. Colonies small, less than 50 µm in diameter …………………. ***A. fonticola***

1. ***Aphanocapsa holsatica*** (Lemmermann) Cronberg et Komarek

Colonies more or less spherical in young stages, become irregular when mature, lobate, elongate or clathrate, more than 300 µm in diameter, mucilaginous, clearly visible, hyaline, irregular in outline; cells sparsely or densely arranged, pale greyish or blue-green, spherical or slightly elongated, about 1 µm in diameter; individual envelopes absent; granules present, not prominent.

Recorded a temperature of 24.2°C during post-monsoon season and 28.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.2 during summer season.

Habitat	: Epilithic
Locality	: Kakkayam, Kozhikode
Specimen number	: CU No. 153052
Figure	: 9 G

2. ***Aphanocapsa fonticola*** Hansgirg

Colonies fine, delimited, initially spherical, later become formless; cells densely aggregated, dark blue green colour; spherical in usual, occasionally elongate with round ends, hemispherical after division, 1.5-5 µm in diameter, rarely up to 6.5 µm; mucilaginous envelope colourless, initially firm, later diffluent, not lamellate; granules present, not prominent; aerotopes usually absent.

Recorded a temperature of 22.5°C during post-monsoon season and 31.8°C during summer season. pH recorded as 7.4 during post-monsoon season and 7.1 during summer season.

Habitat	: Epilithic and epiphytic
Locality	: Charpa, Thrissur
Specimen number	: CU No. 153079
Figure	: 9 H

3. ***Aphanocapsa delicatissima*** West et G.S. West

Colony spherical or slightly elongate, up to 50 µm in diameter, found with other cyanobacterial or microalgal strains; mucilage hyaline, unlamellate, diffluent; cells loosely arranged, small, spherical, 0.5-1 µm in diameter, blue green, pale blue green or brownish green colour; granules not prominent; aerotopes absent.

Recorded a temperature of 23.5°C during post-monsoon season and 33.4°C during summer season. pH recorded as 6.8 during post-monsoon season and 6.3 during summer season.

Habitat	: Planktic
Locality	: Pothundi, Palakkad
Specimen number	: CU No. 191208
Figure	: 10 A

4. ***Aphanocapsa elachista*** West et G.S. West

Colonies microscopic, mostly spherical, rarely oval or irregular, up to 120 µm in diameter; mucilaginous, sheath colourless, unlamellate, sometimes diffluent towards the periphery; cells solitary, after division in pairs, spherical, green, pale blue green or greyish green in colour, 1.2-2.2 µm in diameter; granule prominent; aerotopes absent.

Recorded a temperature of 20.7°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.1 during post-monsoon season and 7.1 during summer season.

Habitat	: Epipelic
Locality	: Nelliyampathy Ghat, Palakkad
Specimen number	: CU No. 191207
Figure	: 10 B

5. ***Aphanocapsa grevillei*** (Berkeley) Rabenhorst

Colonies spherical or irregular in shape, large, more than 400 µm in diameter; mucilaginous, yellow or light green colour, unlamellate, rarely lamellate; occasionally subcolonies are seen; cells irregularly and densely arranged, spherical or slightly oval shaped, 3.2-6.3 µm diameter, bright green or blue green colour; granules present, prominent; aerotopes absent.

Recorded a temperature of 23.5°C during post-monsoon season and 33.4°C during summer season. pH recorded as 6.8 during post-monsoon season and 6.3 during summer season.

Habitat : Planktic
Locality : Pothundi, Palakkad
Specimen number : CU No. 191208
Figure : 10 C

6. ***Aphanocapsa nubila*** Komarek et Kling

Colonies small, microscopic, irregularly spherical or cloud shaped, up to 30 µm in diameter; rarely composed of subcolonies; mucilage hyaline, occasionally diffluent towards the outer region, unlamellate; cells spherical or elongate, densely aggregated, distribution irregular, pale blue green colour, 1.8-3 µm in diameter; granules rare; without aerotopes or gas vesicles.

Recorded a temperature of 24.9°C during post-monsoon season and 30.1°C during summer season. pH recorded as 6.9 during post-monsoon season and 6.5 during summer season.

Habitat : Corticolous
Locality : Nadukani, Malappuram
Specimen number : CU No. 153190
Figure : 10 D & E

7. ***Aphanocapsa orae*** (Kosinskaja) Komarek et Anagnostidis

Colonies macroscopic, mucilaginous, formless and irregular, greenish yellow or yellowish brown mass; sheath absent or occasionally seen, yellowish; cells sparsely or densely aggregate within colonies, green or dull green colour, mostly spherical, rarely elongate, 3.8-5.3 µm diameter; granules prominent; aerotopes absent.

Recorded a temperature of 20.7°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.1 during summer season.

Habitat	: Epilithic
Locality	: Nelliyampathy Ghat, Palakkad
Specimen number	: CU No. 191207
Figure	: 10 F-H

iii. **Microcrocis** Richter 1892

Colonial, colonies initially microscopic, later become macroscopically visible. Flat, tubular, free living, mucilaginous, composed of one layer of densely packed cells. Sometimes composed of subcolonies. Sometimes cells arranged in perpendicular rows, then becoming irregular. Mucilaginous, mucilage colourless, without individual sheaths. Cells ellipsoidal, elongate, spherical, oval or rod shaped with rounded ends. Cells divide lengthwise in two perpendicular planes in successive generations. Reproduction by disintegration of colonies.

1a. Cells oval, 4.5-6 µm long ……………………………..……. ***M. sabulicola***

1. ***Microcrocis sabulicola*** (Lagerheim) Geitler

Colonies few celled and microscopic in the young stages later many celled and become macroscopic, during young stage cells almost arranged in a perpendicular pattern, later irregularly and densely packed together, more than hundred cells together, sometimes showing wavy nature, irregular outline, cells oval or elongated, brownish green, 4.5-6 µm long and 3.5-5 µm broad; Granules present, not prominent; vacuoles absent.

Earlier reports were from marine and brackish water habitat. First report from fresh water ecosystem. Marine species showing bright green colour. Fresh water species showing blue-green in habit but microscopic view provide brownish green cells.

Recorded a temperature of 24.4^{o}C during post-monsoon season and 31.3^{o}C during summer season. pH recorded as 6.6 during post-monsoon season and 6.2 during summer season.

Habitat	: Epilithic
Locality	: Pattathippara, Thrissur
Specimen number	: CU No. 153161
Figure	: 11 A & B

II. Subfamily **Gomphosphaerioideae** (Elenkin) Komarek and Hindak 1988

Colonies more or less spherical, oval or irregularly spherical, free floating, rarely sessile. Radially oriented in one or more layers. Colonies microscopic, rarely macroscopic. Sometimes composed of several subcolonies, mucilaginous. Enveloped usually by distinct or indistinct gelatinous colourless mass. Cells arranged radially on one or more peripheral layers, more or less distant one from another or densely agglomerated. Spherical, ellipsoidal, oval or obovate in shape. Rarely almost cylindrical with rounded ends. Cell division by binary fission. Reproduction by the disintegration of colonies.

Key to the genus

1a. Colonies spherical, without individual sheath ………… **Coelosphaerium**

i. **Coelosphaerium** Nageli 1849

Colonies microscopic, usually spherical, rarely oval. Sometimes composed of subcolonies. Usually floating in plankton, enveloped by fine, colourless, usually not sharply defined, sometimes indistinct mucilage. Mucilage delimited to the periphery. Cells more or less one layer on the colonial periphery. Usually spherical, hemispherical or elongated during division. With or without aerotopes. Mucilage homogenous. Cell division in two planes in successive generations. Reproduction by disintegration of colonies.

Key to the species

1a. Cells 5-7 µm in diameter ………………………………………… ***C. dubium***

1. Coelosphaerium dubium Grunow in Rabenhorst

Colonies usually spherical in shape, rarely oval, sometimes composed of 2-3 subcolonies, up to 150 µm diameter, with more or less densely arranged cells in a layer; colonial mucilage colourless, distinct, diffluent and not refractive at the margins, unlamellated; cells spherical, blue-green or pale blue-green colour, 5-7 µm diameter; granules present; aerotopes usually present.

Recorded a temperature of 22.8°C during post-monsoon season and 30.5°C during summer season. pH recorded as 7.2 during post-monsoon season and 6.8 during summer season.

Habitat	: Planktic
Locality	: Chimminy, Thrissur
Specimen number	: CU No. 150100
Figure	: 11 C

Family **Microcystaceae** Elenkin 1933

Colonial, cells arranged in a mucilaginous colony, colonies may three dimensional. Cell arrangement irregular and with or without gelatinous sheaths. Cells spherical, after division hemispherical. Aerotopes may or may not see. Mucilage homogenous, occasionally with lamellated envelopes around cells. Cell division regularly in three planes. Reproduction by disintegration of colonies. Nanocyte production is facultative.

Key to genera

1a. Cells irregularly arranged, without gelatinous envelope …..… **Microcystis**

1b. Cells irregularly arranged with gelatinous envelope ……..…. **Gloeocapsa**

i. **Microcystis** Kutzing ex Lemmermann1907.

Colonies microscopic or macroscopic, spherical, oval, lobate or irregular, sometimes elongate, free floating, sometimes composed of subcolonies or clustered together. Cells in a common mucilage, which irregularly, sparsely or densely arranged. Mucilage fine, normally colourless, homogenous in usual or indistinctly lamellate. Different or distinct and delimited. Several species showing refractive surface. Individual cells do not possess gelatinous envelopes. Cells spherical in common, rarely elongate or oblong. After division, cells showing hemispherical shape. Gas vesicles present, sometimes joined into distinct aerotopes. Cell division was by binary fission. Cells grow into its original size and shape before next division.

Key to the species

1a. Cells loosely arranged, brownish in colour ……………………….…….. 2

1b. Cells compactly arranged, blue-green ……………………..…… ***M. viridis***

2a. Colonies large, cells 4-9 µm in diameter ………..………. ***M. aeruginosa***

2b. Colonies small, cells 3-6 µm in diameter ……………………. ***M. smithii***

1. *Microcystis smithii* Komarek et Anagnostidis

Colonies mucilaginous, free floating more or less spherical, or slightly elongate or irregular, with scattered, sparsely arranged cells; Cells free, arranged throughout the colony, single in usual, pairs after division, spherical, after division hemispherical, 3-6 µm in diameter, blue-green, pale blue-green or dull green colour; granules present, not prominent; gas vesicles present, one or several brownish aerotopes in each cells.

Recorded a temperature of 19.9^{o}C during post-monsoon season and 30.7^{o}C during summer season. pH recorded as 6.9 during post-monsoon season and 6.4 during summer season.

Habitat : Edaphic

Locality : Ambalavayal, Wayanad

Specimen number : CU No. 158531

Figure : 11 D

2. *Microcystis aeruginosa* (Kutzing) Kutzing

Colonies microscopic, mucilaginous, usually spherical, rarely elongate, irregular, large in size when mature, usually net like mass with distinct holes, outline irregular, cells densely packed towards the periphery, sparsely arranged in the central portion; cells spherical or slightly elongate, pale blue-green or dull green colour, 4-9 µm diameter; mucilage colourless, without a definite shape, different, unlamellate, rarely forming a fine boundary line; granules present, not prominent; aerotopes present.

Recorded a temperature of 20.3^{o}C during post-monsoon season and 28.6^{o}C during summer season. pH recorded as 7.5 during post-monsoon season and 7.1 during summer season.

Habitat : Epilithic

Locality : Attappadi Ghats, Palakkad (also recorded from Chulliyar and Kanjirappuzha (Palakkad), Pazhassi dam (Kannur))

Specimen number : CU No. 158553

Figure : 11 E

3. ***Microcystis viridis*** (A. Braun) Lemmermann

Colonies microscopic, free floating, more or less rounded, packet like, later become macroscopic, mature colonies irregularly spherical or elongate with many cells; mucilage hyaline, not lamellate, narrow or slightly distant from cell clusters, delimited by partially diffluent outline; cells spherical; 4-7.5 µm diameter, yellowish brown or brown colour; granules present, prominent; aerotopes present.

Recorded a temperature of 18.8^{o}C during post-monsoon season. pH recorded as 7.3 during post-monsoon season.

Habitat : Epilithic

Locality : Ranipuram, Kasaragod

Specimen number : CU No. 158554

Figure : 11 F

ii. **Gloeocapsa** Kutzing 1843

Colonies initially microscopic, later become macroscopic. In certain cases, they remained as microscopic. Usually single cells divide to form multicellular colonies. Mucilaginous, amorphous, epilithic, epiphytic or planktic. Composed of small groups of cells which are irregularly arranged. Enveloped by wide, lamellated or unlamellated gelatinous sheaths, joined together into a formless mass. Cells and cell groups surrounded by wide gelatinous delimited or formless mucilaginous sheath. Sometimes concentrically lamellated, coloured or colourless. Intensely or partially coloured by sheath pigments. Yellow, yellowish brown, orange, red, blue, violet or olive green in colour. Envelopes do not copy exactly the cell shape. Sheaths become diffluent under special conditions. Cells always spherical, rarely oval or elongated, after division hemispherical. Blue-green, pale blue-green, bright green, brownish green or yellowish green in colour. Granules usually present, fine, occasionally prominent. Sometimes with solitary granules. Gas vesicles or aerotopes only found in planktic species. Reproduction by liberation of group of cells without sheath. Cell division by binary fission within gelatinous envelope. Cells grow to the original size and shape before next division.

Key to the species

1a. Cells spherical, sheath coloured …………………………………….... 2

1b. Cells spherical or oval, sheath not coloured ………………………..… 4

2a. Cells more than 3.5 µm in diameter ………………………………….. 3

2b. Cells less than 3.5 µm in diameter …………………...……. ***G. fuscolutea***

3a. Cells 2-4, 6-9 µm in diameter …………………………….……….. ***G. atrata***

3b. Cells 2-8, 3-6.5 µm in diameter ………….…………..……***G. sanguinea***

4a. Sheath lamellated …………………………..………………………… 5

4b. Sheath unlamellated ……………………………………….…………… 6

5a. Cells 1.5-3.5 µm in diameter ……………………..………. ***G. compacta***

5b. Cells 4.5-7.8 µm in diameter …………………...……. ***G. conglomerata***

6a. 2-8 celled, blue-green colour ……………………………… ***G. decorticans***

6b. 2-16 celled, brownish green colour ……………..…………… ***G. rupestris***

1. ***Gloeocapsa atrata*** Kutzing

Colonies initially microscopic, then become macroscopic, dirty greyish green colour, composed of many subcolonies, sometimes confluent; sub colonies usually have 2-4 cells, occasionally more cells observed; mucilaginous envelope thick, irregularly spherical, vaguely lamellated, sometimes oval or ellipsoid, cells with sheath 15-30 µm diameter, hyaline or slightly greenish colour; cells spherical or slightly elongated, pale blue-green or dull green colour, 4-9 µm diameter; granules present, often prominent.

Recorded a temperature of 21.5°C during post-monsoon season and 28.7°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.2 during summer season.

Habitat : Edaphic and epiphytic

Locality : Meenmutti, Wayanad

Specimen number : CU No. 158528

Figure : 11 G

2. Gloeocapsa conglomerata Kutzing

Colonies microscopic, mucilaginous, 8-32 subcolonies inside an envelope, outer envelope hyaline, unlamellated; cells 2-8 inside a sheath, blue-green, brownish green or olive green colour, spherical, elongate or rarely oval, 4.5-7.8 µm in diameter; sheath hyaline, unlamellate, thick, firm; granules present, not prominent; vacuoles absent.

Recorded a temperature of 24.2°C during post-monsoon season and 31.6°C during summer season. pH recorded as 6.8 during post-monsoon season and 6.1 during summer season.

Habitat : Edaphic

Locality : Vazhani, Thrissur

Specimen number : CU No. 158542

Figure : 12 A & B

3. Gloeocapsa decorticans (A. Braun) Richter

Colonies microscopic, 11-27.7 µm diameter, sometimes composed with subcolonies, subcolonies more or less 30 µm long; mucilaginous, envelope colourless, delimited, wide, thick, distinctly lamellate; cells spherical or slightly oval, blue-green colour, 5-7 µm diameter; granules present, prominent.

Recorded a temperature of 19.4°C during post-monsoon season and 29.7°C during summer season. pH recorded as 7.5 during post-monsoon season and 7.2 during summer season.

Habitat : Epilithic

Locality : Sholayar, Thrissur

Specimen number : CU No. 191203

Figure : 12 C

4. Gloeocapsa fuscolutea Nageli ex Kutzing

Colonies microscopic, occasionally macroscopic, irregular, mucilaginous, brown or yellowish brown in appearance, composed of several celled subcolonies, colonies up to 65 µm in diameter; cells solitary or groups, spherical, elongate or cylindrical, pale blue-green or brownish green colour; thick gelatinous sheath present, yellow or brown in appearance, up to 7 µm thickness, lamellate, delimited; granules present, not prominent.

Recorded a temperature of 20.7°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.1 during summer season.

Habitat : Epilithic

Locality : Nelliyampathy Ghat, Palakkad

Specimen number : CU No. 191207

Figure : 12 D & E

5. Gloeocapsa rupestris Kutzing

Colonies microscopic or macroscopic, irregular, gelatinous, dirty greyish brown in appearance, composed of many subcolonies, up to 200 µm in diameter; subcolonies with 2-16 cells, surrounded by wide and distinctly lamellate sheath, hyaline; cells spherical, slightly elongate pre division phase and post division phase, 5.7-8 µm diameter, blue-green or olive green colour;

individual sheath hyaline, thick, firm, unlamellate or lamellate; granules present, not prominent.

Recorded a temperature of 23.8°C during post-monsoon season and 31.2°C during summer season. pH recorded as 7.4 during post-monsoon season and 6.7 during summer season.

Habitat : Epilithic

Locality : Pottachira, Thrissur

Specimen number : CU No. 153150

Figure : 12 F & G

6. ***Gloeocapsa sanguinea*** (Agardh) Kutzing

Colonies initially microscopic and later become macroscopic, mucilaginous, amorphous, composed with numerous subcolonies, up to 8 cells inside a subcolony, cells have their own individual envelopes; mucilaginous sheath firm, rarely diffluent on outer side, highly or slightly lamellate, 10-15 µm diameter; cells spherical or elongate, sometimes oval, pale blue green or brownish green colour, 3.5-6.5 µm diameter, elongated cells up to 9 µm long; granules present, occasionally prominent.

Recorded a temperature of 23.8°C during post-monsoon season and 31.2°C during summer season. pH recorded as 7.4 during post-monsoon season and 6.7 during summer season.

Habitat : Epilithic

Locality : Pottachira, Thrissur

Specimen number : CU No. 153151

Figure : 12 H

7. ***Gloeocapsa compacta*** Kutzing

Colonies microscopic, later become macroscopic, irregular, firm, subcolonies tightly or compactly arranged, irregularly spherical or oval; subcolonies containing 2 or more loosely or densely arranged cells, with or without envelope, mucilaginous envelope wide, hyaline, unlamellated, rarely more coloured, cells spherical, elongate or oval, blue green or emerald green colour, 1.5-3.5 µm diameter; individual sheath firm; granules present, not prominent, distinct, wide, delimited, unstratified homogenous mucilage.

Recorded a temperature of 22.4°C during post-monsoon season. pH recorded as 7.4 during post-monsoon season.

Habitat : Epilithic

Locality : Variyamkuthu, Ernakulam

Specimen number : CU No. 150043

Figure : 13 A

Family **Chroococcaceae** Nageli 1849

Coccal, colonial; cells rarely solitary, more or less packet like into mucilaginous, few celled, rarely many celled, usually microscopic, irregular spherical colonies or groups, clustered densely together or distant from one another. Colonies occasionally aggregated into macroscopic mats and layers. Mucilage diffluent or firm, thin, gelatinous, stratified. Cells oval, spherical, hemispherical, irregular, rounded-polyhedral. Cell division in three or more different planes, later forming small, packet like colonies and reach the original shape before next division.

Key to the genera

1a. Colonies many celled, densely packed, irregular ……….. **Gloeocapsopsis**

1b. Cells arranged more or less in regular pattern …………………………... 2

2a. Cells many, aggregate, perpendicular rows ………………...**Cyanosarcina**

2b. Cells limited, usually free ………………………………….. **Chroococcus**

i. Gloeocapsopsis Geitler ex Komarek 1993

Cells in groups, rarely solitary, mostly micro or macroscopic, irregular, without definite shape and granular colonies. Cells irregularly aggregate into small or large groups within a mucilaginous envelope. Cells sub-spherical or elongate in young, when older it become more or less irregular rounded in outline. Enveloped by a narrow, thin, delimited, more or less diffluent and occasionally lamellated sheath. Sheaths usually hyaline, often coloured by yellow, red rusty red, etc. Cell division irregular in various planes. Nanocyte production was reported in some species. Presence of occasional enlarged resting cells with firm, thick and coloured envelopes.

Key to the species

1a. Cells within a common envelope ……………………………… ***G. magma***

1b. Cells without common envelope ………………………………..………. 2

2a. Cells more than 8 µm in diameter ………………………………………. 3

2b. Cells less than 8 µm in diameter …………………..…. ***G. pleurocapsoides***

3a. Cells dark blue-green, usually hemispherical ………………… ***G. dvorakii***

3b. Cells olive green, usually spherical ………………..…. ***G. chroococcoides***

1. Gloeocapsopsis dvorakii (Novacek) Komarek et Anagnostidis ex Komarek

Cells in groups, occasionally solitary, with simple and gelatinous envelopes, usually aggregated to form colonial masses; colonies microscopic in initial stages, then become macroscopic, irregular, rusty red or brownish black appearance, attached to stony substrates in usual, crustaceous, many celled, up to 140 µm diameter; cells irregularly spherical, irregularly polygonal, hemispherical or oval, blue-green or pale blue green colour, 11-15.5 µm diameter.

Recorded a temperature of 23.1^{o}C during post-monsoon season and 30.3^{o}C during summer season. pH recorded as 7.1 during post-monsoon season and 6.5 during summer season.

Habitat : Epilithic

Locality : Peruvannamuzhi, Kozhikode

Specimen number : CU No. 158534

Figure : 13 B

2. ***Gloeocapsopsis pleurocapsoides*** (Novacek) Komarek et Anagnostidis ex Komarek

Cells in 2-16 celled groups to forming colonies, gelatinous, normally groups of cells with individual, thin, unstratified mucilaginous mass; sheath or envelope hyaline, not lamellate, thick; cells spherical, later hemispherical or irregular, with envelope 6-7.5 µm in diameter, without envelope 4-6.8 µm diameter, pale blue green, olive green or yellowish brown colour; granules present, not prominent.

Recorded a temperature of 24.7°C during post-monsoon season and 31.1°C during summer season. pH recorded as 6.4 during post-monsoon season and 6.0 during summer season.

Habitat : Edaphic

Locality : Karikkadu, Kottayam

Specimen number : CU No. 158550

Figure : 13 C

3. ***Gloeocapsopsis chroococcoides*** (Novacek) Komarek

Colonies microscopic, composed of several subcolonies, pale green or olive green colour, main colonies disintegrate into small groups of sheathed cells; cells more or less irregular, rounded, pale yellowish green or olive green colour, cell content homogenous, 8-15 µm diameter; sheaths thin in usual, sometimes thick, following the cell outline, lamellate or unlamellate, usually colourless and hyaline, occasionally coloured, not diffluent; granules prominent.

Recorded a temperature of 25.6°C during post-monsoon season. pH recorded as 7.3 during post-monsoon season.

Habitat : Edaphic

Locality : Vandiperiyar, Gavi route, Pathanamthitta

Specimen number : CU No. 153081

Figure : 13 D

4. Gloeocapsopsis magma (Brebisson) Komarek et Anagnostidis ex Komarek

Colonies irregular or spherical, composed of numerous subcolonies, subcolonies are subspherical, usually 30-60 µm in diameter, colourless to brownish colour, mucilaginous sheath firm; cells spherical or irregularly spherical, polygonal rounded in outline, 5-11 µm in diameter, with thin coloured, hyaline individual sheaths, sometimes slightly widened, lamellated; cell content fine, blue green or brownish green; granules present, occasionally prominent; sheath of subcolonies thin, hyaline, individual sheath up to 5 µm thickness.

Recorded a temperature of 23.1°C during post-monsoon season and 30.3°C during summer season. pH recorded as 7.1 during post-monsoon season and 6.5 during summer season.

Habitat : Epiphytic and corticolous

Locality : Peruvannamuzhi, Kozhikode

Specimen number : CU No. 158537

Figure : 13 E & F

ii. Chroococcus Nageli 1849

Unicellular cyanobacterial group with cells surrounded by a mucilaginous envelope. Envelopes colourless, yellow or light green in colour. Centrically lamellate, or lamellation absent. A well-defined margin was present, only a few species lack of margin and possess diffluent or irregularly disposed hyaline margin. Cells solitary in the initial stages. Usually with a limited cell number of 2-16. Rarely develop into many celled agglomerations, with irregular cell arrangements. Colonies gelatinous and microscopic in general. Colony shape may be irregular, but sometimes spherical ball like structures were also formed. Cells develop within multicellular colonies sometimes 2-8 celled packet like groups. Cells may have surrounded by individual sheaths. Initially the cells are spherical or oval, later may become hemispherical or sub-spherical due to cell division. Cell content showing wide range of colouration. Grey, grey-green, green, blue-green, olive green, yellow, reddish and sometimes violet colours may appear. Both the dark and pale shades of all these colours are observed in various species. Granules present in almost all species, but only a several species showing the presence of prominent granules. Gas vesicles (visible aerotopes) were observed in a few species. The members of this genus have wide variety of habitat adaptation. They are free living, epilithic, saphophytic, epilithic, cryptophytic, benthophytic, epactiphytic, planktophytic or epiphytic in nature.

Cells divide by binary fission and the division takes place in 3 planes. They rarely produce nanocytes. Under adverse or unfavourable conditions, these species are capable of developing into spores with minimal metabolic activities and can survive those conditions.

Key to the species

1a. Mucilaginous envelope lamellate ……….………..…………….............. 2

1b. Mucilaginous envelope not lamellate ………………………………..…….. 7

2a. Cells below 6 µm in diameter …………………..……………..… ***C. varius***

2b. Cells more than 6 µm in diameter ……………………….……………..... 3

3a. Cells more than 35 µm in diameter ……………………….…… ***C. giganteus***

3b. Cells below 35 µm in diameter ……………………………………….… *4*

4a. More than 8 cells in a colony ……………………………………………… *5*

4b. Less than 8 cells in a colony ……………………………………….……… *6*

5a. Cells blue-green, 12-18 μm in diameter ………………………….… ***C. tenax***

5b. Cells yellowish green, 8-32 μm in diameter ………………..…… ***C. turgidus***

6a. Sheath hyaline, usually not coloured ………………..……… ***C. ercegovicii***

6b. Sheath not hyaline, coloured ……………………….….. ***C. schizodermaticus***

7a. Cells more than 12 μm in diameter ………………………….………...…... 8

7b. Cells less than 12 μm in diameter ……………………………………… 10

8a. Up to 4 cells in a sheath …………………………………….………………… 9

8b. Up to 8 cells in a sheath ……………………………..……… ***C. quaternarius***

9a. Cells more than 17 μm in diameter ………………………..…. ***C. subnudus***

9b. Cells less than 17 μm in diameter …………..………………. ***C. turicensis***

10a. 16 or more cells in an envelope ……………...……………………... 11

10b. Less than 16 cells in an envelope …………………………………..…. 13

11a. Cells without individual sheath within envelope …………………….. 12

11b. Cells with individual sheath within envelope ………………. ***C. prescottii***

12a. Cells subquadrate, green in colour ……………………… ***C. mipitanensis***

12b. Cells spherical, olive green in colour ……………………… ***C. cohaerens***

13a. Cells subquadrate …………………………….…...…... ***C. obliteratus***

13b. Cells subspherical or spherical …………….……………………………. 14

14a. Cells more than 7 μm in diameter ……………….………………………. 15

14b. Cells less than 7 μm in diameter ……………………………… ***C. indicus***

15a. Up to 8 celled, 7-12 μm in diameter ……………….……………………. 16

15b. Up to 4 celled, 8-14 μm in diameter ………………………… ***C. pallidus***

16a. Sheath diffluent, 4-8 μm in thick ……………….…………… ***C. minutus***

16b. Sheath firm, 1.5-3 μm thick ………………….. ***C. minutus*** var. ***thermalis***

1. Chroococcus cohaerens (Brebisson) Nageli

Cells in 2-16 celled groups to forming colonies, gelatinous, normally groups of cells with individual, thin, unstratified mucilaginous mass; sheath or envelop hyaline, not lamellate, thick; cells spherical, later hemispherical or irregular, with envelop 6-7.5 µm diameter, without envelope 4-6.8 µm diameter, pale blue green, olive green or yellowish brown colour; granules present, not prominent.

Recorded a temperature of 23.5°C during post-monsoon season and 33.4°C during summer season. pH recorded as 6.8 during post-monsoon season and 6.3 during summer season.

Habitat : Planktic

Locality : Pothundi, Palakkad

Specimen number : CU No. 191208

Figure : 13 G & H

2. Chroococcus ercegovicii Komarek et Anagnostidis

Colonies microscopic, usually 2-4 celled, rarely 8 celled, up to 30 µm in diameter, irregularly spherical, gelatinous, dark brown in appearance; cells pale green or brownish green colour, sometimes olive green, spherical or elongated, spherical cells 5.5-10.3 µm diameter, elongated cells 5.5-7.8 µm long, 3.6-6.7 µm broad; sheath thick, stratified, lamellated, hyaline or brown colour; granules present, prominent.

Recorded a temperature of 24.3°C during post-monsoon season and 31.4°C during summer season. pH recorded as 7.5 during post-monsoon season and 6.3 during summer season.

Habitat : Epilithic and epiphytic

Locality : Thusharagiri, Kozhikode

Specimen number : CU No. 191272

Figure : 14 A & B

3. Chroococcus pallidus Nageli

Colonies usually microscopic, gelatinous, colourless or yellowish, free or mixed with other algae; cells in a firm sheath, hyaline or yellowish brown coloured, 2-4 cells in a sheath, unlamellate or rarely lamellate, thick, 4-8 µm wide; cells spherical, after division hemispherical to spherical, olive green or pale blue green colour, single or in pairs, 8-14 µm in diameter.

Recorded a temperature of 23.5°C during post-monsoon season and 33.4°C during summer season. pH recorded as 6.8 during post-monsoon season and 6.3 during summer season.

Habitat : Planktic
Locality : Pothundi, Palakkad
Specimen number : CU No. 191208
Figure : 14 C

4. ***Chroococcus minutus*** (Kutzing) Nageli

Cells solitary, microscopic, few celled, usually 2-8 cells, enclosed in a mucilaginous mass; cells spherical or hemispherical, pale blue green, yellow or grey colour, 6.8-11 µm in diameter; granules present, sometimes prominent; sheath 4-8 µm thick, firm, diffluent towards margin, hyaline, usually unlamellate.

Recorded a temperature of 22.8°C during post-monsoon season and 30.5°C during summer season. pH recorded as 7.2 during post-monsoon season and 6.8 during summer season.

Habitat : Epipelic
Locality : Chimminy, Thrissur
Specimen number : CU No. 150093
Figure : 14 D

5. ***Chroococcus minutus*** var. ***thermalis*** Nageli

Cells solitary, microscopic, few celled, usually 2-8 cells, mucilaginous; cells spherical or hemispherical, pale blue green, yellow or olive green colour, 7-12 µm diameter; granules present, prominent; sheath 1.5-3 µm thick, firm, not diffluent towards margin, hyaline, unlamellate.

Recorded a temperature of 21.2°C during post-monsoon season and 28.3°C during summer season. pH recorded as 7.3 during post-monsoon season and 6.8 during summer season.

Habitat : Epilithic

Locality : Mangaladevi Hills, Thekkadi, Idukki

Specimen number : CU No. 153082

Figure : 14 E

6. Chroococcus mipitanensis (Wolszynska) Geitler

Cells in groups, microscopic, few celled, usually 4-16 cells, mucilaginous; cells spherical, hemispherical and rarely irregular, blue green colour, 2.5-6 µm diameter; usually granules absent, not prominent if it present; sheath thick, firm, hyaline to light green colour, not diffluent, unlamellate.

Recorded a temperature of 20.7°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.1 during summer season.

Habitat : Epilithic

Locality : Nelliyampathy Ghat, Palakkad

Specimen number : CU No.191212

Figure : 14 F & D

7. Chroococcus quaternarius Zelessky

Colonies microscopic, forming nest like thallus composed of subcolonies with 2-8 more or less clustered cells, packet like arrangement, mucilaginous, mucilage colourless; cells more or less spherical, hemispherical after division, later irregular rounded, brownish green or blue green colour, 12-20 µm diameter; sheath thick, firm, unlamellate, slightly diffluent towards the periphery.

Recorded a temperature of 21.6°C during post-monsoon season and 29.9°C during summer season. pH recorded as 7.3 during post-monsoon season and 6.9 during summer season.

Habitat	: Epilithic
Locality	: Soochippara water falls, Wayanad
Specimen number	: CU No.158515
Figure	: 14 H

8. Chroococcus subnudus (Hansgirg) Cronberg et Komarek

Colonies microscopic, usually 2-4 celled, wide enveloping mucilage absent, cells round to oval, hemispherical after division, intensely blue green or blackish colour, 17-25 µm in diameter; granules present, prominent; sheath thin, firm, hyaline or light yellowish, unlamellate or rarely lamellate, sometimes diffluent at the margins.

Recorded a temperature of 20.7°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.1 during summer season.

Habitat	: Epilithic
Locality	: Nelliyampathy Ghat, Palakkad
Specimen number	: CU No.191207
Figure	: 15 A

9. Chroococcus turgidus (Kutzing) Nageli

Colonies microscopic, usually 2-8 celled, sometimes up to 32 celled, without wide enveloping mucilage; cells widely oval to spherical, hemispherical or in the form of segment of a sphere after division, green, intensely green, yellowish or olive green colour, 8-32 µm diameter; sheath thick, firm, lamellated or unlamellated, colourless, up to 10 µm thick; granules present, occasionally prominent.

Recorded a temperature of 23.5°C during post-monsoon season and 33.4°C during summer season. pH recorded as 6.8 during post-monsoon season and 6.3 during summer season.

Habitat : Planktic

Locality : Pothundi, Palakkad (also recorded from Mattampuram (Thrissur) and Chulliyar (Palakkad))

Specimen number : CU No. 191208

Figure : 15 B

10. Chroococcus turicensis (Nageli) Hansgirg

Colonies microscopic, few celled colonies, gelatinous, diffluent, sometimes composed of subcolonies with 2-4 cells; cells pale blue green or olive green colour, spherical or oval shape, 13.5-16 µm diameter; sheath present, firm, usually unlamellate, rarely lamellate, colourless, sometimes light yellow colour; granules present.

Recorded a temperature of 20.7°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.1 during post-monsoon season and 7.1 during summer season.

Habitat : Epilithic

Locality : Nelliyampathy Ghat, Palakkad

Specimen number : CU No. 158548

Figure : 15 C

11. Chroococcus indicus Bernard

Colonies microscopic, gelatinous, mucilage brownish-green in colour, sometimes diffluent; cells spherical to oval, brownish green colour, with sheath 10-10.5 µm long, 7.6-8.1 µm broad, without sheath 4.4-5.7 µm broad and 4.2-4.6 µm long; sheath firm, hyaline, unlamellate, 0.7-2.1 µm thick; granules present, not prominent.

Recorded a temperature of 20.7°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.1 during summer season.

Habitat : Epilithic

Locality : Nelliyampathy Ghat, Palakkad

Specimen number : CU No.191207

Figure : 15 D-F

12. Chroococcus schizodermaticus West

Colonies microscopic, usually only 2-4 celled, common mucilage absent or occasionally present, brown in appearance; cells spherical, hemispherical or irregularly rounded, blue-green or pale blue-green colour, 6.5-10 µm in diameter; sheath firm, thick, wide, yellow or yellowish brown colour, concentrically lamellate; granules present, prominent.

Recorded a temperature of 20.7°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.1 during summer season.

Habitat : Epilithic

Locality : Nelliyampathy Ghat, Palakkad

Specimen number : CU No.191207

Figure : 15 G

13. Chroococcus varius A. Braun

Colonies microscopic or macroscopic, slimy and mucilaginous, dirty brown or greenish brown in colour, 2-4 cells in a group, rarely up to 8 celled, irregular; cells brown or brownish green colour, rarely yellowish brown content, spherical, after division subspherical, 2.3-5.2 µm diameter; sheaths thick, concentrically lamellate, delimited, brown, greenish brown or yellowish brown colour; granules present, not prominent.

Recorded a temperature of 24.2°C during post-monsoon season and 28.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.2 during summer season.

Habitat : Epilithic

Locality : Kakkayam, Kozhikode

Specimen number : CU No. 153016

Figure : 15 H & I

14. Chroococcus prescottii Drouet et Daily

Colonies microscopic, 4-32 cells arranged in clusters, sometimes with 2-4 loosely packed cells; cells spherical, rarely hemispherical or elongated, blue-green or olive green colour, 5.3-9.2 µm in diameter; sheath thick, wide, hyaline and delimited, usually not lamellate, rarely showing lamellation; granules present, occasionally prominent.

Recorded a temperature of 24.2°C during post-monsoon season and 28.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.2 during summer season.

Habitat : Epilithic

Locality : Kakkayam, Kozhikode

Specimen number : CU No. 153056

Figure : 16 A & B

15. Chroococcus tenax (Kirchner) Hieronymus

Cells solitary or in colonies with 2-16 cells, usually microscopic, mucilaginous; mucilaginous envelope thin to thick, highly lamellated, initially hyaline, later become yellowish brown, with envelope up to 27 µm in diameter; cells usually hemispherical, spherical or elongated, blue-green or olive green colour, 12-18 µm diameter; granules present, occasionally prominent.

Recorded a temperature of 23.1°C during post-monsoon season and 30.3°C during summer season. pH recorded as 7.1 during post-monsoon season and 6.5 during summer season.

Habitat : Epilithic

Locality : Peruvannamuzhi, Kozhikode (also recorded from Mattampuram (Thrissur))

Specimen number : CU No.158534

Figure : 16 G-I

16. *Chroococcus giganteus* West

Colonies microscopic, up to 75 µm diameter, cells solitary or in groups, usually 2-4 celled; sheaths delimited, hyaline or rarely yellowish coloured, thick, distinctly lamellated; individual cells surrounded by an individual sheath, hyaline, markedly lamellated, conspicuous; cells bright blue-green, yellowish brown or olive green colour, spherical or oblong, 45-53 µm diameter; granular content fine, occasionally prominent.

Recorded a temperature of 23.5°C during post-monsoon season and 33.4°C during summer season. pH recorded as 6.8 during post-monsoon season and 6.3 during summer season.

Habitat : Planktic

Locality : Pothundi, Palakkad

Specimen number : CU No. 191208

Figure : 16 C & D

17. *Chroococcus obliteratus* Richter

Cells solitary or in 2-8 celled colonies after division, rarely with more cells, common wide, firm and thick, mucilaginous envelope very rarely found, sheath fine, hyaline, more or less diffluent, unlamellate, up to 5 µm wide; cells spherical in shape, subspherical or hemispherical after division, or in the form of a segment of a sphere or quadrate cells, pale blue green or olive green or brownish green colour, rarely yellowish green, before division 4-9 µm in diameter, after division 4-6 µm long, and 4-8 µm broad, granular content brown or yellow colour, prominent.

Recorded a temperature of 24.2°C during post-monsoon season and 28.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.2 during summer season.

Habitat : Epilithic
Locality : Kakkayam, Kozhikode
Specimen number : CU No.153027
Figure : 16 E & F

iii. Cyanosarcina Kovacik 1988

Colonies microscopic, subspherical, spherical or irregularly spherical, packet like, more or less rounded. Cells densely aggregate, enveloped by firm, usually thin, hyaline or occasionally coloured sheaths, adjacent to cell clusters. Finally, in dense, sarcinoid packets, forming agglomerations of macroscopic irregular mats. Cells usually spherical, subspherical, oval, hemispherical or irregularly rounded shapes are also found. Mucilaginous, usually packed closely to one another. Reproduction by the liberation of cells or groups cells from sheath. Cell division irregular. Nanocytes lacking.

Key to the species

1a. Cells more than 4 µm in diameter ………………………………….……… 2
1b. Cells below 4 µm in diameter …………………………….……………….. 3
2a. Cells 7.5-9.5 µm in diameter ………………………….. ***C. chroococcoides***
2b. Cells up to 6 µm in diameter ……………….…………..………. ***C. thallassia***
3a. Sheath diffluent, not coloured ……………………………… ***C. burmensis***
3b. Sheath firm, greenish in colour ……………………….. ***C. parthenonensis***

1. ***Cyanosarcina thalassia*** Anagnostidis et Pantazidou

Colonies microscopic, contain 2-32 cells, irregularly spherical or irregular in shape, up to 14 µm diameter, composed of many celled colonies, cells arranged almost in a packet like aggregation pattern; thin, hyaline, structure less envelopes, mucilaginous, not lamellated, rarely brownish or yellow coloured; cells more or less spherical, after division hemispherical or quadrate with soft edges, rarely subspherical, 2-4 µm diameter, rarely 6 µm in diameter, blue-green or brownish green colour, rarely olive green; protoplasts finely granulated, not prominent.

Recorded a temperature of 23.4°C during post-monsoon season and 30.8°C during summer season. pH recorded as 7.5 during post-monsoon season and 7.0 during summer season.

Habitat : Planktic
Locality : Ilanjipparakuthu, Thrissur
Specimen number : CU No. 153110
Figure : 17 A& B

2. ***Cyanosarcina parthenonensis*** Anagnostidis

Colonies microscopic, olive green or blue-green colour, consists of 2-16 celled colonies, occasionally up to 32 cells are seen, more or less cubic, densely packet like aggregations, colonies 15-30 µm diameter, sheath thin, hyaline or rarely green, firm, later diffluent, mucilaginous; cells spherical, after division subspherical or subglobose, 2.3-5 µm diameter, green, olive green, yellow green or rarely dark blue-green colour; granules present, not prominent.

Recorded a temperature of 24.2°C during post-monsoon season and 28.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.2 during summer season.

Habitat	: Epilithic and epactiphytic
Locality	: Kakkayam, Kozhikode
Specimen number	: CU No. 153029
Figure	: 17 C

3. ***Cyanosarcina burmensis*** (Skuja) Kovacik

Colonies microscopic, many colonies together to form macroscopic colonies, brownish in colour, up to 64 cells inside a colony, mucilaginous, cells covered by an envelope, spherical in initial, later become irregularly spherical; sheaths hyaline, not lamellate, firm, later slightly diffluent; cells round or elongated, pale blue-green colour, many aggregated together, packet like, 2-4 µm diameter; granules present, not prominent.

Recorded a temperature of 25.2°C during post-monsoon. pH recorded as 7.4 during post-monsoon season.

Habitat	: Epactiphytic and epilithic
Locality	: Moozhiyar, Pathanamthitta
Specimen number	: CU No. 153058
Figure	: 17 D & E

4. ***Cyanosarcina chroococcoides*** (Geitler) Kovacik

Colonies microscopic, spherical, subspherical or irregular, composed of irregularly arranged cells; cells spherical, hemispherical or elongated, blue-green or green colour, 7.8-9.2 µm diameter; mucilaginous sheath around the colonies thin, up to 1 µm thick, hyaline or light yellow colour, tightly surrounding the cell clusters, sometimes diffluent; granules present, not prominent; vacuoles absent.

Recorded a temperature of 20.7°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.1 during summer season.

Habitat	: Epilithic and epactiphytic
Locality	: Nelliyampathy Ghat, Palakkad
Specimen number	: CU No. 191207
Figure	: 17 F & G

Family **Entophysalidaceae** Geitler 1925

Colonies mucilaginous, more or less spherical, cells in young colonies spherical, subspherical, oval or irregular rounded, in groups, usually distant from one another. Mucilage firm, distinct, fine, or delimited. Cell division successive in various planes, or in one plane, perpendicular to the radially oriented cells. Reproduction by monocytes, solitary cells, or by clusters of cells; nanocyte division lacking.

Key to the genera

1a. Thallus irregular, cells in rows only in young colonies and the colonial margins, cells without or with envelopes ………………...………**Chlorogloea**

i. Chlorogloea Wille 1900

Colonies mucilaginous, multicellular, in outline more or less spherical or hemispherical. Sometimes flattened or granular irregular with rough surface, often composed of subcolonies. Initially microscopic later become macroscopic. Attached to substrates like plants or stones, later become free living, epipelic or metaphytic. Occasionally forming a large gelatinous mass composed of single microcolonies. Mucilage common, inside that cells irregularly arranged. Sometimes forming short irregular rows of cells. Orientation usually radial. Sometimes rows are perpendicular to the substrate. Cells usually spherical or oval, sometimes irregularly spherical. Sometimes rounded polygonal. With or without indistinct, diffluent or firm, delimited individual mucilaginous envelopes. Blue-green, greyish, pale olive green, yellowish, brownish or reddish finely granular content. Many cells aggregate to form a multicellular mass.

Key to the species

1a. Cells 2-3 µm in diameter, spherical ………………………… ***C. novacekii***

1. Chlorogloea novacekii Komarek et Montejano

Colonies mucilaginous, initially microscopic, later become macroscopic, small more or less spherical or irregularly spherical, sometimes amorphous yellowish to blackish in colour, cells densely aggregated together, irregular, in distinct rows, distant from one another, each cells surrounded by an individual, firm, structureless, marginally diffluent sheath, hyaline or slightly greenish or yellowish, older parts sometimes showing yellowish brown colour; cells spherical, 2-3 µm diameter, sometimes elongate, 2-3 µm wide and 2-8 µm long; gelatinous, envelopes thick, up to 10 µm thickness; granules present, not prominent; aerotopes not observed.

Recorded a temperature of 24.9°C during post-monsoon season and 30.2°C during summer season. pH recorded as 6.8 during post-monsoon season and 6.4 during summer season.

Habitat : Epactiphytic and epipelic

Locality : Vazhikkadavu, Malappuram

Specimen number : CU No. 145515

Figure : 17 H

4.2. OSCILLATORIALES

Family **Pseudanabaenaceae** Anagnostidis & Komarek 1988

Trichomes are cylindrical, uniseriate, immotile or motile, without sheaths, with colourless, homogenous and diffluent gelatinous envelopes. Filaments can be straight, waved or screw like coiled, 3 µm wide, solitary or clustered in fine, thin, indefinite and prostrate colonies, forming sometimes hemispherical, bubble like formations with tangled trichomes. Sheaths fine, thin, or firm, can occur exceptionally and facultatively in several genera. Cells are mainly longer than wide, rarely isodiametric or shorter than wide, and all capable of division; aerotopes lacking or localized only in terminal or central parts of cells; thylakoids situated; characteristic array of pore patterns in cell walls occur. Cells divide perpendicularly to the trichome length, daughter cells growing to their original size before the next division. Reproduction by fragmentation of trichomes, motile hormogonia or immotile hormocytes, without necridic cells, or by help of simple, irregular scarified cells. Fragmentation by solitary cells.

I. Subfamily **Pseudanabaenoideae** Anagnostidis & Komarek 1988

Filaments can be solitary or in colonies, simple, without sheaths and branching, sometimes enveloped by colourless, very fine, homogenous and diffluent slime, occasionally disintegrating easily. Aerotopes and gas vesicles sometimes occur, but always situated within cells in their central or terminal parts. Immotile (with exception of young hormogonia). Reproduction by disintegration into solitary cells, hormocytes or hormogonia.

Key to the genera

1a. Trichomes solitary, highly constricted, aerotopes occur facultatively……
………………………………………………………...…….. **Pseudanabaena**

1b. Trichomes more, occasionally constricted, with or without aerotopes …. 2

2a. Trichomes always motile, mainly in clusters, rarely in mats ….. **Jaaginema**

2b. Trichomes motile, mainly in mats, rarely in clusters …...…**Geitlerinema**

i. **Pseudanabaena** Lauterborn 1915

Trichomes usually solitary in plankton, metaphytic or in fine mats, usually straight, less frequently waved, cylindrical, short, with several cells, or long with many cells. Usually with conspicuous constrictions at the cross walls, rarely almost constricted. Trichomes with sheath or occasionally absent. Sometimes with wide, fine, diffluent mucilaginous envelopes. Apical cells not differentiated. Usually without calyptra or thickened outer cell walls. Usually non motile, several species showing some kind of motions. Sometimes slight gliding without rotation cells usually cylindrical, barrel shaped or quadrate with rounded ends. Mostly longer than wide, occasionally shorter than wide. Rarely tending to become isodiametric. Aerotopes or gas vesicles may or may not see. Cell division by binary fission in perpendicular to the long axis. Reproduction by hormogonia or by trichome fragmentation. Cell contents finely granular, sometimes prominent. Thylakoids concentrically arranged, parallel to the long axis.

Key to the species

1a. Apical cells rounded ……………………………………..……………… 2

1b. Apical cells conical …………………………..……………………… 4

2a. Cells more than 3 µm wide ………………………………..…….. ***P. crassa***

2b. Cells less than 3 µm wide ……………………………………………….. 3

3a. Cells 1.6-1.8 µm wide …………………………………..…… ***P. galeata***

3b. Cells 2-3 µm wide ……………………………………..…….. ***P. thermalis***

4a. Cells more than 2 µm wide …………………………..……………….. 5

4b. Cells less than 2 µm wide ……………………….………. ***P. franquetii***

5a. Apical cells conical, brown in colour …………………………… ***P. skujae***

5b. Apical cells broad, pointed ……………………….……………... ***P. biceps***

1. ***Pseudanabaena biceps*** Bocher

Trichomes usually short gelatinous up to 30 celled, normally with less than 15 cells, solitary or forming clusters of small groups, straight, occasionally curved, highly constricted at the cross walls, 2.6-2.9 µm wide; cells cylindrical to barrel, dark blue-green or blue-green colour, sometimes bright blue-green in appearance, occasionally isodiametric or slightly longer than wide, 2.6-2.9 µm wide and 3-6.5 µm long; apical cells rounded, occasionally narrowed, rounded pointed usually with terminal aerotopes or with few small aerotopes; cell content usually with distinctly separated central and chromatoplasmic regions; sheath absent; granules present, not prominent.

Recorded a temperature of 22.5°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.4 during post-monsoon season and 7.1 during summer season.

Habitat : Epiphytic and epactiphytic

Locality : Poringalkuthu, Thrissur

Specimen number : CU No. 191252

Figure : 18 A & B

2. *Pseudanabaena crassa* Uherkovich

Thallus brownish green colour; filaments gelatinous, straight or flexuous, comparatively long; trichomes usually long, solitary or groups, sometimes entangled together, straight or irregularly waved, flexuous, deeply constricted at the cross walls, 3.5-5 µm wide, 2.5-7 µm long, greenish brown or brown colour; apical cells widely rounded, with aerotopes, almost all cells have aerotopes; cell content fine, granules present, concentrated towards the periphery, not prominent; sheath absent.

Recorded a temperature of 23.4°C during post-monsoon season and 31.8°C during summer season. pH recorded as 7.5 during post-monsoon season and 6.9 during summer season.

Habitat : Epilithic and epactiphytic

Locality : Peechi, Thrissur

Specimen number : CU No. 191234

Figure : 18 C & D

3. *Pseudanabaena franquetii* Bourrelly (Bourelly)

Trichomes usually solitary, short few celled, pale blue-green to dull green colour, constricted at the cross walls, sometimes slightly curved; cells usually longer than wide, occasionally shorter than wide, flexuous or sometimes wavy, filaments not narrowed towards the end; cells barrel or elongated, 1.8-2.3 µm wide, 5.4-8 µm long, occasionally up to 12 µm, dull green or pale green colour; apical cells elongated, conically narrowed, sharply pointed; cells are without aerotopes; sheaths absent; granules present, fine, not prominent.

Recorded a temperature of 24.6°C during post-monsoon season and 29.9°C during summer season. pH recorded as 7.3 during post-monsoon season and 6.8 during summer season.

Habitat : Epipelic

Locality : Mottakkunnu, Thrissur

Specimen number : CU No. 153168

Figure : 18 E

4. *Pseudanabaena galeata* Bocher

Filaments usually solitary, thin, long, sometimes forming mat like colonies, bright blue-green, emerald green or olive green colour; trichomes flexuous, variously curved or wavy in nature, sometimes straight, entangled together, occasionally parallelly arranged, less frequently circular in arrangement, up to 2 µm in width, cells usually up to 50 in numbers, sometimes up to 250 cells are also found, deeply constricted at the cross walls, not or slightly attenuated towards the tip; cells bright blue-green or blue-green colour, cylindrical or quadrate, connected with cross walls, usually longer than wide, rarely shorter than wide, 1.6-1.8 µm wide, 1.7-2.3 µm long, occasionally with polar aerotopes; apical cells rounded, rarely conical rounded, motile, without rotation; sheath absent; granules present, prominent, clearly or indistinctly differentiated in chromatoplasma and centroplasma.

Recorded a temperature of 25.9°C during post-monsoon season and 33.0°C during summer season. pH recorded as 6.7 during post-monsoon season and 6.2 during summer season.

Habitat : Epactiphytic

Locality : Poomala, Thrissur

Specimen number : CU No. 191247

Figure : 18 F & G

5. ***Pseudanabaena skujae*** Claus

Trichome solitary or in small groups among other cyanoprokaryotes, blue-green coloured or yellowish green, usually straight, occasionally flexuous, short, sometimes longer, 2.2-2.5 µm in width, deeply constricted at the cross walls, motile, slow gliding motion, slightly attenuated towards the tip; cells usually longer than wide, sometimes shorter, 2.2-2.5 µm wide, 1.8-4 µm long, dull green to yellowish green colour; apical cells elongated or short, conically pointed, with aerotopes; sheath absent; granules present, not prominent, cell content may or may not visibly differentiated into chromatoplasma and centroplasma.

Recorded a temperature of 19.4°C during post-monsoon season and 29.7°C during summer season. pH recorded as 7.5 during post-monsoon season and 7.2 during summer season.

Habitat : Epilithic
Locality : Sholayar, Thrissur
Specimen number : CU No. 191203
Figure : 18 H & 19 A

6. ***Pseudanabaena thermalis*** Anagnostidis

Thallus mat like, yellowish brown colour; filaments solitary or groups, usually joined to fine, indefinite colonies, forming usually characteristic spherical or hemispherical bubble-like clusters, green, olive green or yellowish brown colour; trichomes usually curved, entangled, occasionally coiled or straight, frequently screw-like or ring like circled; usually long, rarely few celled, up to 3 µm wide, constricted at the cross walls, not attenuated towards the end; cells brownish green or greyish green in colour, cylindrical, connected with hyaline bridges, usually longer than wide, rarely shorter, 2-3 µm wide, 2.5-5 µm long; apical cells rounded, with characteristic aerotopes; motile with waving and rotation movement; granules present, prominent; aerotopes present.

Recorded a temperature of 18.1°C during post-monsoon season and 27.4°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.1 during summer season.

Habitat : Edaphic and epiphytic

Locality : Parunthumpara, Idukki

Specimen number : CU No. 145507

Figure : 19 B & C

ii. Jaaginema Anagnostidis et Komarek 1988

Trichomes more or less flexuous, solitary or entangled in clusters, sometimes forming thin membraneous thallus. Straight or occasionally wavy. Sheath absent, sometimes fine sheath like mucilaginous layers found. Immotile, trichomes up to 5 µm wide. Usually not constricted at the cross walls, rarely constrictions observed. Sometimes attenuated towards the end. Not capitate. Cells cylindrical, barrel shaped or quadrate, longer than wide, rarely isodiametric. Cell content homogenous, usually without aerotopes, rarely gas vesicles observed. Apical cells almost rounded, or conical, without calyptra or thickened cell wall. Reproduction is by fragmentation of trichomes. Necridic cells absent.

Key to the species

1a. Cells 2.2-4.5 µm wide, emerald green in colour …………... ***J. geminatum***

1. Jaaginema geminatum (Schwabe ex Gomont) Anagnostidis et Komarek

Thallus expanded, emerald green or yellowish green colour, sometimes blue green or olive green; trichomes straight or variously curved, emerald green or bright blue-green colour, 2.2-4.5 µm wide, immotile, distinctly constricted at the cross walls, not attenuated towards the end, cross walls translucent; cells mostly longer than wide, rarely shorter than wide or isodiametric, 2.2-4.5 µm wide, 2.5-13 µm long, blue green or emerald green colour; apical cell rounded or rounded –conical, calyptra absent, without thickened outer cell wall; sheath absent; granules present, not prominent; gas vesicles occasionally present.

Recorded a temperature of 19.4°C during post-monsoon season and 29.7°C during summer season. pH recorded as 7.5 during post-monsoon season and 7.2 during summer season.

Habitat	: Planktic and Benthophytic
Locality	: Sholayar, Thrissur
Specimen number	: CU No. 150027
Figure	: 19 D & E

iii. **Geitlerinema** (Anagnostidis et Komarek) Anagnostidis 1989

Thallus thin, rarely thick, delicate, mostly bright blue green, rarely brownish or violet in colour, diffluent, occasionally fascicle like, forming thin mats. Trichomes up to 7 µm wide, parallel arrangement, cylindrical, straight, rarely flexuous, very rarely screw like coiled in the end portion. Sheaths absent, mostly unconstructed at the cross walls, occasionally constricted. Attenuated or not attenuated at the ends. Trichomes motile, having intense gliding capacity. Sometimes possess a clockwise and anticlockwise rotation. Cells commonly longer than wide, cell content usually with large cyanophycean granules, which are prominent. Aerotopes normally absent, present in certain planktic species. Apical cells usually conical or rounded, hooked or bent and mostly acuminate or rounded. Rarely spherical and capitate. Reproduction by disintegration of trichomes in to motile hormogonia.

Key to the species

1a. Trichome 4.5 µm wide, cells 4-8.5 µm long ……………… ***G. amphibium***

1. *Geitlerinema amphibium* (Agardh ex Gomont) Anagnostidis

Thallus blue green, dull green or deep green colour, expanded, commonly forming mats; trichomes straight or slightly flexuous, parallel arranged, rarely coiled or curved, pale to bright blue green colour, sometime dull green to yellowish green colour, motile with gliding and oscillation, without rotation, up to 4.5 µm wide, not constricted at the cross walls, not or very slightly attenuated towards the end; cells isodiametric or longer than wide, rarely shorter than wide, 2.5-4.5 µm wide, 4-8.5 µm long, pale blue green or dull blue green in colour; apical cells rounded not capitate, without calyptra or thickened outer cell wall, sometimes hemispherical; sheath absent; cyanophycean granules present either or both sides of the cross walls, blue green colour, prominent; cellular content fine.

Recorded a temperature of 21.7^{o}C during post-monsoon season and 29.4^{o}C during summer season. pH recorded as 7.1 during post-monsoon season and 6.6 during summer season.

Habitat : Edaphic

Locality : Kanthanpara, Wayanad

Specimen number : CU No. 158508

Figure : 19 F-H

II. Subfamily **Leptolyngbyoideae** Anagnostidis & Komarek 1988

Filaments solitary, simple, in clusters or in mats, always with facultative sheath, rarely or exceptionally with false branching. Cell content homogenous, occasionally with scattered granules, aerotopes absent, or only exceptionally with localized aerotopes near the cross walls. Trichomes free living, very thin, usually not over 3 µm wide, uniseriate, immotile, cylindrical. Reproduction by trichome disintegration in hormocytes, hormogonia.

Key to the genera

1a. Filaments in clusters or mats, flexuous ……………………. **Leptolyngbya**

i. **Leptolyngbya** Anagnostidis et Komarek 1988

Filaments rarely solitary, usually seen as clusters, attached to a substrate or floating. Forming compact colonies in rare situations, or participating in crust formations. Flexuous, finely waved, rarely almost straight, long solitary or in fascicles; not capitate usually, not attenuated at the ends, sheath firm, thin, hyaline or occasionally coloured. Producing pseudobranches in very rare occasions. Sheaths frequently varies according to species, and it highly depends on the environmental factors. Trichomes comparatively narrow, motile or non-motile. Sometimes with indistinct trembling. Cells cylindrical, isodiametric, longer or shorter than wide. A homogenous content is present, often with recognizable chromatoplasma and centeroplasma. Gas vesicles usually absent. Chromatic adaptations detected in several species. Reproduction mainly by trichome fragmentation. Hormogonia indistinctly motile or immotile.

Key to the species

1a. Filaments without pseudobranches …………………...……... ***L. subtilis***

1b. Filaments with pseudobranches ……………………………... ***L. terebrans***

1. ***Leptolyngbya subtilis*** (West) Anagnostidis

Filaments attached to a substrate, later free floating, usually straight, slightly curved in certain conditions, up to 2 µm wide, not attenuated at the ends; cells isodiametric, as long as wide, or slightly longer or shorter than wide, 1.5-2 µm wide and 1.7-2 µm long, apical cells rotund, blue-green or green colour; sheath thin, firm, not diffluent, usually hyaline, rarely a slight greenish in appearance, unlamellate; cell content delicately granular.

Recorded a temperature of 24.1°C during post-monsoon season and 31.5°C during summer season. pH recorded as 7.4 during post-monsoon season and 6.8 during summer season.

Habitat	: Planktic
Locality	: Marottichal, Thrissur
Specimen number	: CU No. 153115
Figure	: 20 A

2. ***Leptolyngbya terebrans*** (Bornet et Flahault ex Gomont) Anagnostidis et Komarek

Thallus blue green to pale green, euendolithic, filaments penetrating vertically into substrate; filaments flexuous, long, with pseudobranches, mostly single; trichomes blue-green or pale green colour, 1-2.5 µm in width, straight to variously curved, not constricted at the cross walls; cells longer than wide, occasionally isodiametric, 1-2.5 µm wide and 1.8-4.5 µm long; apical cells rotund, longer than other vegetative cells; sheaths very thin, mucilaginous, unlamellated, colourless or slightly greenish; granules present, not prominent; pseudobranches as same as the main filaments.

Recorded a temperature of 23.8°C during post-monsoon season and 31.2°C during summer season. pH recorded as 7.4 during post-monsoon season and 6.7 during summer season.

Habitat	: Epilithic
Locality	: Pottachira, Thrissur
Specimen number	: CU No. 153153
Figure	: 20 B-D

Family **Phormidiaceae** Anagnostidis & Komarek 1998

Filaments solitary, or in mats, coiled together or fasciculated, rarely in clusters. Sheaths lacking or present, firm or fine, homogenous or stratified, thin or thickened, usually hyaline, less frequently coloured, consisting one or two and more trichomes. Trichomes straight or variously coiled, cylindrical, not constricted or constricted at cross walls, 4-14 µm wide, facultatively motile. False branching facultative in several ensheathed genera. Cells isodiametric, or somewhat longer or shorter than wide, apical sometimes with calyptra, in various planktic genera with gas vesicles; thylakoids located principally radially, sometimes more agglomerated in peripheral parts; heterocysts and akinetes always absent. Motility of trichomes common, but facultative in various genera. All cells capable of division with exception of apical cells. Reproduction by fragmentation of trichomes into immotile hormocytes or motile hormogonia, usually through help of necridic cells.

I. Subfamily **Phormidioideae** Anagnostidis & Komarek 1988

Filaments solitary or in colonies, in layered or fine fascicles, mats. Trichomes straight, wide, constricted or not constricted at cross walls, coiled or regularly screw like coiled, generally facultatively motile. Cells with peculiar pore patterns on cell walls. Sheaths absent or facultatively present, obligatory containing only one trichome, false branching rare. Reproduction by fragmentation of trichomes, motile hormogonia.

Key to the genera

1a. Trichomes usually without envelopes ……………………… **Planktothrix**

1b. Trichomes with or without envelopes ……………………… **Phormidium**

i. **Planktothrix** Anagnostidis & Komarek 1988

Trichomes usually solitary, free floating, straight, curved or irregularly wavy in nature. Isopolar, cylindrical, not constricted or constricted at the cross walls. Usually planktic, developing water blooms or irregular clusters. Non motile, but occasionally with movements like gliding, oscillation, trembling, etc. Slightly attenuated or not attenuated towards the end. Rarely with terminal calyptra. Envelopes or sheaths are usually absent. Sometimes developing thin, fine sheath during unfavourable conditions. Branches absent. Cells cylindrical, barrel shaped or quadrate with or without soft edges. Slightly shorter or longer than wide. Sometimes isodiametric in nature. Apical cell rotund, widely rounded or slightly conical; sometimes with thickened outer call wall or calyptras. Aerotopes usually absent. Heterocysts absent. Akinetes present. Reproduction usually by disintegration of trichomes and also by hormogonia. Granules present, may or may not prominent.

Key to the species

1a. Filaments highly constricted, with aerotopes …………………………..... 2

1b. Filaments not or slightly constricted, usually without aerotopes ……….. 3

2a. Trichomes wavy, up to 3.1 µm long ………………………………. ***P. clathrata***

2b. Trichomes straight, up to 4.5 µm long …………………. ***P. cryptovaginata***

3a. Filaments straight, cells up to 6.5 µm long …………………….. ***P. isothrix***

3b. Filaments curved or coiled, Cells up to 3.5 µm long ……… ***P. planctonica***

1. ***Planktothrix isothrix*** (Skuja) Komarek et Komarkova

Trichomes dark blue-green, mucilaginous mass, initially attached to a substrate, later become free floating, often forming water bloom, usually straight, sometimes filaments are without specific arrangement, long up to 12 µm wide, slowly motile with peculiar oscillation, very slightly constricted at the cross walls; cells nearly isodiametric, shorter or longer than wide, 5-12 µm wide, 2-6.5 µm long; apical cells cylindrical, widely rounded or flat rounded, very rarely slight conical, not capitates, without calyptra or thickened outer cell wall; sheath absent; granules present prominent, blue-green colour; aerotopes occasionally present.

Recorded a temperature of 22.5°C during post-monsoon season and 31.8°C during summer season. pH recorded as 7.4 during post-monsoon season and 7.1 during summer season.

Habitat : Planktic and epactiphytic

Locality : Charpa and Athirappilly, Thrissur

Specimen number : CU No. 153079 & CU No. 153080

Figure : 20 E & F

2. Planktothrix cryotovaginata (Schkorbatov) Anagnostidis et Komarek

Filaments solitary or in loose clusters, free floating, free living, almost straight, rarely irregularly curved, or wavy; trichomes pale blue-green in colour, 7-9.5 µm wide, constricted at the cross walls, not attenuated towards the tip; cells blue-green or bright blue-green colour, isodiametric or slightly shorter than wide, 7-9.5 µm wide, 2.3-4.5 µm long; sheath present, not distinctly visible, hyaline, firm, not lamellated; granules present, not prominent; aerotopes present; apical cells rounded, or widely rounded.

Recorded a temperature of 20.5°C during post-monsoon season and 29.9°C during summer season. pH recorded as 7.3 during post-monsoon season and 6.8 during summer season.

Habitat : Edaphic

Locality : Vazhachal, Thrissur

Specimen number : CU No. 153171

Figure : 20 G & H

3. Planktothrix clathrata (Skuja) Anagnostidis et Komarek

Trichomes solitary, free floating, phytoplankton in habitat, vegetation period starting from benthos state, blue-green or dark greenish mass; trichomes straight or slightly curved, flexuous, constricted at the cross walls, cylindrical, not attenuated towards the end, 6-9 µm wide, sometimes a movement was seen; cells always shorter than wide, 6-9 µm wide and 1.8-3.1 µm long, blue-green or pale green colour, apical cells cylindrical, rounded or widely rounded, without calyptra or thickened outer cell wall; sheath absent; granular content brownish green, prominent; aerotopes present.

Recorded a temperature of 24.0°C during post-monsoon season and 28.6°C during summer season. pH recorded as 7.5 during post-monsoon season and 7.1 during summer season.

Habitat : Epilithic

Locality : Ambalappara, Kozhikode

Specimen number : CU No. 153048

Figure : 21 A & B

4. Planktothrix planktonica (Elenkin) Anagnostidis et Komarek

Trichomes usually solitary, free living, rarely in small clusters, cylindrical, 9-12.6 µm in width; towards the centre irregularly wavy and curved or straight, apical portion straight or coiled, not attenuated towards the ends, blue-green colour, not constricted or distinctly constricted at the cross walls; cells isodiametric, shorter than wide, 9-12.6 µm wide, 2-3.5 µm long, apical cells convex, rounded, without calyptra, thickened outer cell wall and capitates; sheath absent; granular content green colour, not prominent; aerotopes occasionally present.

Recorded a temperature of 23.1°C during post-monsoon season and 30.3°C during summer season. pH recorded as 7.1 during post-monsoon season and 6.5 during summer season.

Habitat : Epilithic and epiphytic

Locality : Peruvannamuzhi, Kozhikode

Specimen number : CU No. 158535

Figure : 21 C-E

ii. **Phormidium** Kutzing ex Gomont 1892

Thallus usually thin or cohesive, expanded, more or less fine, gelatinous and mucilaginous. Membranous, almost leathery. Initially attached to a substrate or partially free. Certain species free floating or always attached to a substrate. Sometimes floating masses, clusters, penicillate tufts or occurred as solitary filaments. Filaments straight or variously curved, branches or pseudobranches absent. Many filaments entangled together, rarely loosely arranged. Sheaths present according to environmental conditions. All species produces sheath under unfavourable conditions. Sheaths may thin or thick, lamellate or unlamellate, coloured or hyaline, expanded or not. Adherent to the trichome, rarely diffluent towards the margin. Certain sheaths showing serrate sheath. Trichomes cylindrical, long rarely short, slightly or strongly waved or loosely and irregularly screw like coiled. Usually unconstructed at the cross walls, or distinctly or slightly constricted. Showing motile nature, gliding, creeping and trembling with or without oscillation and rotation. Cells isodiametric in general, or shorter or longer than wide. Aerotopes normally absent, occasionally present. Apical cells with or without calyptra, sometimes with thickened outer cell wall, conical, narrowed, pointed or rounded. Granular content more or less fine. Reproduction by disintegration of trichomes. Hormogonia also present.

Key to the species

1a. Filaments with sheath ………………..……………………………………. 2

1b. Filaments without sheath ……………………..……………………… 6

2a. Sheath lamellate ………………………..…………………………….. 3

2b. Sheath unlamellate ……………………….…………………………... 4

3a. Apical cells with thick outer cell wall ……………….……… ***P. calcicola***

3b. Apical cells without thick outer cell wall ……………………… ***P. teylorii***

4a. End cell with thick outer cell wall ………………..……………. ***P. corium***

4b. End cell without thick outer cell wall ……………..…………………….. 5

5a. Cells 3.5-8 µm long ……..………….……………***P. aerugino-caeruleum***

5b. Cells 6-12 µm long ………………………….…………… ***P. crassior***

6a. Apical cells rotund ………………………...…………………7

6b. Apical cells conical …………………………………………….. 11

7a. Filaments more than 5 µm wide ……………..………………………….. 8

7b. Filaments less than 5 µm wide ……………………………. ***P. articulatum***

8a. Filaments more than 9 µm broad …………….………… ***P. tergestinum***

8b. Filaments 5-9 µm broad ………………….....…………………………. 9

9a. End cells round, not broad ……………...…………………………… 10

9b. End cells broadly rounded ……………………………….. ***P. chlorinum***

10a. Filaments long, flexuous …………………….………….… ***P. hamelii***

10b. Filaments short, straight ……………………………...…. ***P. insigne***

11a. Apical cells capitate …………………………...………………… 12

11b. Apical cells not capitate ……………………….………………… 13

12a. Cross walls with many aerotopes ……………..………….. ***P. favosum***

12b. Cross walls without aerotopes …………………………….. ***P. subsalsum***

13a. Filaments constricted at the cross walls ……………….……………… 14

13b. Filaments not constricted at the cross walls ……….……… ***P. formosum***

14a. Trichomes 5-11 µm wide ………………………….……… ***P. boryanum***

14b. Trichomes 4.5-6 µm wide …………….…………….. ***P. karakalpakense***

1. Phormidium aerugineo-caeruleum (Gomont) Anagnostidis et Komarek

Thallus mucilaginous, greenish or green in colour, occasionally blue green or dark green in appearance, solitary, scattered filaments, variously curved, up to 8 µm in width; trichomes pale to bright blue green or pale brownish in colour, not constricted at the cross walls, not attenuated towards the end; cells isodiametric, rarely longer or shorter than wide, 3.5-7.5 µm in width, 3.5-8 µm in length, pale green in colour; apical cells not capitate, rarely constricted, longer than normal cells, up to 10 µm long, ends broadly rounded; cell content homogenous, granulated, not prominent, rarely with large prominent granules; gas vesicles occasionally observed; sheath hyaline, extending, sometimes a yellow colour in the marginal parts, unlamellated, thin, firm, not diffluent.

Recorded a temperature of 25.6°C during post-monsoon season. pH recorded as 7.3 during summer season.

Habitat : Edaphic

Locality : Vandiperiyar, Pathanamthitta

Specimen number : CU No. 153081

Figure : 21 F-H

2. Phormidium articulatum (Gardner) Anagnostidis et Komarek

Thallus blue green in colour, thin, usually as solitary trichomes among other algae or cyanobacteria, sheath indistinct or lacking, rarely present, if present thin; trichomes blue green, 2.5-5 µm wide, unconstricted or slightly constricted at the cross walls, cross walls thick, granulated, not attenuated towards the tip; cells isodiametric or shorter than wide, 1.5-3.5 µm long, 2.5-4.5 µm wide, blue green colour; apical cell rounded, without calyptra and thickened wall; granules present, deposited near to the cell walls; trichomes rarely showing wavy or curved nature.

Recorded a temperature of 22.5°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.4 during post-monsoon season and 7.1 during summer season.

Habitat : Epilithic and edaphic

Locality : Poringalkuthu, Thrissur

Specimen number : CU No. 145501

Figure : 22 A & B

3. ***Phormidium boryanum*** (Bory ex Gomont) Anagnostidis et Komarek

Trichomes solitary, free floating, rarely aggregated together, microscopic, later become macroscopic, olive green colour, green or rarely greyish violet colour also observed, straight, sometimes curved or coiled towards the end, trichomes 5-11 µm wide, motile, occasionally showing oscillation, slightly constricted at the cross walls, shortly or gradually attenuated towards the end; end cells not capitate, without thickened outer cell wall, narrowly rounded or conical; cells isodiametric, or shorter or longer than wide, 3-7 µm wide, 2-5 µm long, olive green or green in colour; sheath absent; granules present, cross walls finely granulated, not prominent.

Recorded a temperature of 20.2°C during post-monsoon season. pH recorded as 6.8 during post-monsoon season.

Habitat : Edaphic and epiphytic
Locality : Agasthyamala, Thiruvananthapuram
Specimen number : CU No. 145503
Figure : 22 C-F

4. ***Phormidium calcicola*** Gardner

Thallus encrusted, thick or thin, green or blue green in colour; trichomes straight, rarely showing slight wavy nature, pale blue green or green colour, not constricted at the cross walls, not attenuated towards the end, up to 8 µm in width; cells isodiametric or slightly longer than wide, rarely shorter than wide, 5.2-7.8 µm wide, 5-9 µm long; apical cells rounded with cap like thickened outer wall; sheath firm, thin, hyaline to light greenish yellow colour, extending rarely diffluent towards margin, unlamellate or distinctly lamellate towards the margin; granules present, not prominent.

Recorded a temperature of 21.6°C during post-monsoon season and 29.9°C during summer season. pH recorded as 7.3 during post-monsoon season and 6.9 during summer season.

Habitat : Epilithic

Locality : Soochippara, Wayanad

Specimen number : CU No. 158527

Figure : 22 G & H

5. Phormidium crassior (Behre) Anagnostidis

Thallus mat like, densely entangled, filaments coiled, wavy or straight, blue green tufts in appearance, rarely occurred as solitary; trichomes blue green or yellowish green colour, up to 8 µm in width, not constricted at the cross walls, occasionally showing constrictions, at the distinct cross walls, not attenuated towards the end, straight or wavy; cells usually isodiametric or longer than wide, rarely shorter than wide, blue green or pale green colour, 6-12 µm long, 5-8 µm broad; apical cells rotund, without calyptra or thicker outer cell wall; sheath very thin, hyaline, not lamellate, sometimes diffluent, extending; granules present, rarely prominent.

Recorded a temperature of 20.2^{o}C during post-monsoon season. pH recorded as 6.9 during post-monsoon season.

Habitat : Corticolous

Locality : Karamanayar, Thiruvananthapuram

Specimen number : CU No. 153141

Figure : 23 A & B

6. Phormidium favosum Gomont

Thallus olive green, blue green, dark green or blackish colour, occasionally encrusted with $CaCO_3$, dried specimen showing dark steel blue colour; filaments long, more or less curved or straight, sometimes irregularly, loosely coiled at the ends; trichomes blue green or pale green colour, 4.5-9 µm wide, 5-10 µm long; apical cells capitate, with obtuse conical to nearly hemispherical calyptra, rarely rotund apical cells observed; sheath absent; granules present, prominent at cross walls.

Recorded a temperature of 21.7°C during post-monsoon season and 29.4°C during summer season. pH recorded as 7.1 during post-monsoon season and 6.6 during summer season.

Habitat : Edaphic and epactiphytic

Locality : Kanthanpara, Wayanad

Specimen number : CU No. 158508

Figure : 23 C-H

7. Phormidium formosum (Bory ex Gomont) Anagnostidis et Komarek

Thallus dull blue green to dark blue green colour, free floating or rarely attached to a substrate; trichomes straight, long, blue green, bright blue green or dull blue green colour, sometimes olive green, yellowish green or pale green in colour, up to 6.5 µm wide, highly motile with intense oscillation and clockwise rotation, not constricted at the cross walls or very slightly constricted, slightly attenuated towards the end, and a small bent is present; cells nearly isodiametric, always shorter than wide, 5-6.5 µm wide, 2.5-4.5 µm long, green or light blue green colour; apical cells obtuse conical, broadly conical, rounded conical, or acutely rounded, not capitate, without thickened outer cell wall, calyptra absent; sheath rarely present, usually missing, if present very delicate; cell content finely granulated, sometimes large cyanophycean granules observed; tip region may constricted.

Recorded a temperature of 21.7°C during post-monsoon season and 29.4°C during summer season. pH recorded as 7.1 during post-monsoon season and 6.6 during summer season.

Habitat : Edaphic and epactiphytic

Locality : Kanthanpara, Wayanad

Specimen number : CU No. 158508

Figure : 24 A-E

8. ***Phormidium hamelii*** (Fremy) Anagnostidis et Komarek

Trichomes usually solitary, occasionally in clusters, greyish blue, blue green or green in colour, flexuous, straight or curved, not coiled, up to 6.5 µm wide, constricted at the cross walls, not attenuated towards the end; cells isodiametric, as long as wide, 4.8- 8 µm wide, 5-9 µm long, rarely slightly longer than wide, blue green colour; apical cells rounded, without calyptra, not capitate, without thickened outer cell wall; sheath absent; granules present, not prominent; gas vacuoles occasionally present.

Recorded a temperature of 20.6°C during post-monsoon season and 30.1°C during summer season. pH recorded as 7.5 during post-monsoon season and 6.9 during summer season.

Habitat	: Epilithic
Locality	: Seetharkund, Palakkad
Specimen number	: CU No. 153186
Figure	: 24 F-H

9. ***Phormidium karakalpakense*** (Muzafarov) Anagnostidis et Komarek

Thallus straight or wavy, green, pale green or olive green colour; trichomes solitary, rarely entangled together, pale blue green or pale green colour, 4.5-6 µm wide, not constricted or slightly constricted at the cross walls; attenuated towards the end; cells isodiametric sometimes longer or shorter than wide, 4.5-6 µm wide, 3-5 µm long, pale blue green or pale green colour; apical cells conical or pointed-rounded, not capitate, without calyptra and thickened outer cell wall; sheath usually absent; granules present, not prominent.

Recorded a temperature of 22.5°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.4 during post-monsoon season and 7.1 during summer season.

Habitat	: Epactiphytic
Locality	: Poringalkuthu, Thrissur

Specimen number : CU No. 191254

Figure : 25 A & B

10. Phormidium tergestinum (Rabenhorst ex Gomont) Anagnostidis et Komarek

Thallus mucilaginous, thin, bright blue green, blue green or olive green colour, rarely blackish green; trichomes of varying length, colour and width, usually straight, sometimes curved, very rarely spirally coiled, pale to dark blue green colour, up to 11 µm in width, motile, with oscillation and clockwise or anticlockwise rotation, not constricted at the cross walls, not attenuated towards the end; cells usually shorter than wide, rarely isodiametric, 4-11 µm wide, 2-6 µm long; apical cells rounded or hemispherical, without thickened outer cell wall, not capitate, calyptra absent; sheath usually absent, rarely develop under stressed condition; sometimes translucent and granulated cross walls, cellular content fine, granules not prominent, cell content homogenous, rarely with large granules.

Recorded a temperature of 23.4^{o}C during post-monsoon season and 30.8^{o}C during summer season. pH recorded as 7.5 during post-monsoon season and 7.0 during summer season.

Habitat : Planktic

Locality : Ilanjipparakuthu, Thrissur

Specimen number : CU No. 153110

Figure : 25 C & D

11. Phormidium taylorii (Drouet et Strickland) Anagnostidis

Thallus tufts like, blue green or yellowish green colour, composed of parallely arranged filaments, more or less flexuous, blue green or yellowish green colour, sometimes radiating and penicillate; trichomes cylindrical, not tapering towards the end or very slightly attenuated, slightly constricted at the cross walls or not constricted, cross walls not granulated, 4-7 µm wide; cells isodiametric or little shorter than wide, rarely longer than wide, 4-7 µm wide, 3-5 µm long, blue green, yellowish green or pale blue green colour; apical cells broadly convex, usually without thickened outer cell wall, rarely with thickened outer cell wall, not capitate, without calyptra, sheath thin to thick, slightly diffluent towards the periphery, hyaline, firm, extending, not lamellate or sparsely lamellate; granules present, rarely prominent.

Recorded a temperature of 22.5^{o}C during post-monsoon season and 30.6^{o}C during summer season. pH recorded as 7.2 during post-monsoon season and 6.2 during summer season.

Habitat : Epactiphytic

Locality : Periya, Wayanad

Specimen number : CU No. 145506

Figure : 25 E-G

12. Phormidium subsalsum Gomont

Thallus green, yellowish green or olive green colour, clathrate; filaments straight, parallel arranged; trichomes pale blue green, up to 6 µm broad, not constricted at the cross walls, cross walls mostly granulated; cells isodiametric or slightly shorter or longer than wide, 4-6 µm wide, 4.5-7 µm long, pale green, olive green or yellowish colour; apical cells conical or rounded conical, with calyptra, attenuated towards the end, slight bent observed; sheath usually absent, rarely observed under stressed conditions; granules present, not prominent, mucilaginous.

Recorded a temperature of 21.6^{o}C during post-monsoon season and 29.9^{o}C during summer season. pH recorded as 7.3 during post-monsoon season and 6.9 during summer season.

Habitat : Epilithic

Locality : Soochippara, Wayanad

Specimen number : CU No. 158527

Figure : 25 H

13. Phormidium chlorinum (Kutzing ex Gomont) Umezaki et Watanabe

Thallus fasciculated, yellowish green colour; filaments solitary, or in groups; trichomes cylindrical usually straight, sometimes flexuous, yellowish green colour, up to 7 µm wide, not or very slightly constricted at the cross walls; cells usually shorter than wide, occasionally isodiametric or longer than wide, 3.5-7 µm wide, 2-5.5 µm long; apical cells widely rounded, without calyptra or thickened outer cell walls, not attenuated; sheath absent; granules present, prominent.

Recorded a temperature of 20.9°C during post-monsoon season and 31.1°C during summer season. pH recorded as 7.1 during post-monsoon season and 6.3 during summer season.

Habitat : Benthophytic
Locality : Karimanal, Idukki
Specimen number : CU No. 145504
Figure : 26 A & B

14. Phormidium insigne Anagnostidis

Thallus looks like mats, olive green or dull blue green colour; trichomes fine, solitary or with other algae or cyanoprokaryotes, sometimes free floating, motile, normally straight, occasionally flexuous, greyish blue or greyish green colour, slightly attenuated or not attenuated, cylindrical, slightly constricted at the cross wall, up to 7 µm wide; cells usually isodiametric, or slightly longer or shorter than wide, 4.5- 7 µm wide, 4.3-7.5 µm long, green or dull green in colour; apical cells rounded, without calyptra or thickened outer cell wall; sheaths absent, rarely develop under unfavourable conditions; granular contents fine, not prominent.

Recorded a temperature of 20.6°C during post-monsoon season and 30.1°C during summer season. pH recorded as 7.5 during post-monsoon season and 6.9 during summer season.

Habitat : Epilithic

Locality : Seetharkund, Palakkad

Specimen number : CU No. 153186

Figure : 26 C & D

15. Phormidium corium Gomont ex Gomont

Thallus thin, net like, blue green, brownish green or blackish green colour; filaments long, straight or flexuous, variously curved, occasionally coiled, densely elongated, rarely solitary; trichomes blue green or brownish green in colour, rarely blackish green, up to 10 µm wide, not constricted at the cross walls, not attenuated towards the end; cells usually shorter than wide, sometimes isodiametric, rarely longer than wide, 5-10 µm wide, 3.5-7.3 µm long, brownish green or dull blue green in colour; apical cells rounded or rounded conical, without calyptra, with or without thickened outer cell wall; sheaths firm thin, colourless or slight yellow colour, mucilaginous, unlamellate; granules present, fine.

Recorded a temperature of 20.9°C during post-monsoon season and 31.1°C during summer season. pH recorded as 7.1 during post-monsoon season and 6.3 during summer season.

Habitat : Epactiphytic

Locality : Karimanal and Periyar TR, Idukki

Specimen number : CU No. 145505

Figure : 26 E

II. Subfamily **Microcoleoideae** Hansgirg 1892

Thallus gelatinous, forming thin, fine or compact mats on substrate, rarely hemispherical up to stratified colonies or crusts, generally with fasciculated trichomes within sheaths, creeping on the substrate; sheaths open or closed, diffluent or firm, fine, thick, homogenous, usually slightly distant from trichomes, occasionally joined to the trichomes, sometimes with transversal constrictions. Trichomes motile, cylindrical. Reproduction by trichomes fragmentation into long, motile hormogonia.

Key to the genus

1a. Many filaments within a common envelope ……………..…. **Microcoleus**

i. Microcoleus Desmazieres ex Gomont 1892

Filaments solitary of in flat mats, creeping on the substrate, not branched, very rarely pseudobranched. Trichomes within a widened sheath, many trichomes densely aggregated, nearly parallel arranged and tightly fasciculated. Often overpassing the ends of sheath which open, not or slightly constricted at the cross walls. Straight, often rope like contorted, mostly attenuated towards the ends. Cells cylindrical or barrel shaped, almost isodiametric, with radially arranged thylakoids and granular content. Apical cells usually acute conical or sub-conical, less frequently capitate, rarely with calyptra. Sheath wide, many filaments inside sheath, homogenous, only occasionally indistinctly and irregularly length wise striated. Usually colourless, rarely coloured. Firm, sometimes diffluent when old, occasionally wrinkled, tapering towards the end, ends open, lamellated or unlamellated. Reproduction is by trichome disintegration and also by hormogonia.

Key to the species

1a. Cells 3-6.5 µm long, apical cells conical …………………. ***M. steenstrupii***

1b. Cells 6-12 µm long, apical cell rounded ……..........…… ***M. subtorulosus***

1. Microcoleus subtorulosus Gomont ex Gomont

Thallus expanded, blue-green or brownish green in colour, filaments amorphous, fragile; trichomes straight, blue green in colour, parallel arrangement, distinctly constricted at the cross walls, 6-8 µm in width; gradually attenuated towards the end; cells barrel shaped or cylindrical, almost isodiametric or longer than wide. 6-9 µm wide, and 6-12 µm long, apical cells not capitate, rotund; sheath wide, tapering towards the ends, ends open hyaline, not lamellated; granules rare, not prominent.

Recorded a temperature of 21.5°C during post-monsoon season and 28.7°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.2 during summer season.

Habitat : Epilithic
Locality : Meenmutti, Wayanad
Specimen number : CU No. 158525
Figure : 26 F-H

2. *Microcoleus steenstrupii* J.B. Petersen

Filaments 30-75 µm wide with sheath; sheaths hyaline, or lightly brownish in appearance, unlamellated or distinctly lamellated, containing many trichomes inside, ends are opened; trichomes attached together, sometimes enclosed in an individual envelope; cells 4-7.5 µm wide and 3-6.5 µm long, slightly constricted at the cross walls, slightly tapering towards the end, apical cells long, conical, not capitate and without calyptra, brownish green or yellowish brown in colour; granules present, not prominent.

Recorded a temperature of 19.4°C during post-monsoon season and 29.7°C during summer season. pH recorded as 7.5 during post-monsoon season and 7.2 during summer season.

Habitat : Epilithic
Locality : Sholayar, Thrissur
Specimen number : CU No. 150015
Figure : 27 A-D

Family **Oscillatoriaceae** (S.F. Gray) Harvey ex Kirchner 1898

Filaments compact or layered, prostrate, rarely in fascicles, trichomes solitary or in clusters. Trichomes straight or slightly waved, cylindrical, not constricted or slightly constricted at the cross walls, 6-35 µm wide, facultatively motile or immotile without or within sheaths. Sheaths absent or occurring obligatorily or facultatively, firm, opened, consisting one or more trichomes, with or without false branching. Cells commonly shorter than wide, discoid, with rapid cell division; aerotopes lacking or rare; apical cells in full grown trichomes generally with thickened outer cell wall, or with calyptra. Thylakoids are short, irregularly displayed throughout the whole cell content and concentrated in the periphery, they are sometimes widened, forming intra-thylakoidal spaces. Cell division proceeds transversally, perpendicular to the trichome axis, occasionally in meristematic zones. Reproduction by disintegration of trichomes in motile hormogonia or immotile hormocytes from apical parts of trichomes or from the whole trichome, dividing by help of necridic cells.

I. Subfamily **Oscillatorioideae**

Fully grown trichomes are with or without sheaths, which may have composed 1-2 or more trichomes. Sheaths wide, thin or gelatinous and firm, lacking, or facultative, or obligatory, open at the ends, rarely closed, occasionally lamellated and rarely coloured. All cells in trichomes are shorter than wide. Filaments with ensheathed trichomes sometimes falsely branched.

Key to the genera

1a. Trichomes usually with sheath …………...………..…………… **Lyngbya**

2a. Trichomes usually without sheath ……………...…...………. **Oscillatoria**

i. **Oscillatoria** voucher ex Gomont 1892

Thallus usually in the form of macroscopic, smooth layered, rarely leathery mats, very rarely as solitary trichomes. Trichomes cylindrical, straight, slightly waved, sometimes coiled, irregularly flexuous. Motile with gliding oscillation, usually with clockwise rotation, rarely anticlockwise. Thin or thick in width. 4-70 µm in width variation. Not constricted or constricted at the cross walls. Sheaths absent, rarely present but not distinguishable. Sheaths usually develop under stressed conditions. Cells short, discoid, quadrate or barrel shaped. Sometimes compressed. Usually shorter than wide. Occasionally longer than wide. Homogenous cell content, sometimes with large prominent granules. Aerotopes usually absent. Reproduction is by disintegration into short hormogonia, which are motile. Also by the help of necridia.

Key to the species

1a. Apical cells with thick outer cell wall …………………….……………….. 2

1b. Apical cells without thick outer cell wall ………………….……………. 4

2a. Cells more than 3 µm long …………………...………………………. 3

2b. Cells less than 3 µm long ……………………………………….. ***O. refrigens***

3a. Trichomes constricted ……………………………………………. ***O. sancta***

3b. Trichomes not constricted ………………………………..……. ***O. princepes***

4a. Cells below 8 µm wide …………………………………………………….. 5

4b. Cells more than 8 µm wide ………………...…………………………. 6

5a. Cells 0.5-1.5 µm long …………………………….……………… ***O. lutea***

5b. Cells 1.8-3.3 µm long …………………………..……………. ***O. nitida***

6a. Trichomes constricted at the cross walls …………..……………………. 7

6b. Trichomes not constricted at the cross walls ……………….…………... 9

7a. Apical cells widely rounded ……………………………….….. ***O. curviceps***

7b. Apical cell rounded, not wide ………………..………………………. 8

8a. End cell without thick outer cell wall ………………..***O. ornata*** var. ***crassa***

8b. End cell with slightly thick outer cell wall ……………… ***O. margeretifera***

9a. Filaments more than 15 µm wide ……………….…………….. ***O. jenensis***

9b. Filaments less than 15 µm wide ………..………………………………. 10

10a. Trichomes without sheath ……………….…………………………… 11
10b. Trichomes occasionally with sheaths ……………………….. ***O. rupicola***
11a. Cells discoid in shape ………………………………………………. 12
11b. Cells quadrate in shape ……………………………….……….. ***O. subsalsa***
12a. Trichomes blue-green in colour ………….……………… ***O. funiformis***
12b. Trichomes brownish green in colour ………...…………………….. 13
13a. Filaments short, apical cells rounded ……….……… ***O. tenuis*** var. ***levis***
13b. Filaments long, apical cells widely rounded …….…………… ***O. limosa***

1. ***Oscillatoria limosa*** Agardh ex Gomont

Thallus blackish blue green, olive green or brown, extended, thick, attached to a substrate, layered, sometimes free floating, tufts like, occasionally with other algal or cyanobacterial filaments; trichomes brown-violet, olive green, dark to bright blue green or brown in colour, 8-13 µm in width, very long, flexuous, straight, rarely curved, sheath not recorded, rarely develop under unfavourable conditions, cross walls granulated, not constricted, trichomes not attenuated towards the end; cells always shorter than wide, 8-13 µm wide, 1.5- 4.5 µm long, apical cell widely rounded, not capitate, without calyptra and thickened outer cell wall, convex; cell content mostly finely granular, not prominent; filaments motile, oscillating or gliding.

Recorded a temperature of 21.6°C during post-monsoon season and 29.9°C during summer season. pH recorded as 7.3 during post-monsoon season and 6.9 during summer season.

Habitat : Epilithic
Locality : Soochippara, Wayanad
Specimen number : CU No. 158515
Figure : 27 E & F

2. ***Oscillatoria lutea*** Agardh

Trichomes usually solitary or in small clusters, mostly among other algae or mosses, blue green, pale blue green or yellowish green colour, 6-8 µm wide, not constricted at the cross walls, cross walls also granulated, whole filament with the same width, not tapering towards the ends, cells usually very shorter than wide, 6-8 µm wide and 0.5-1.5 µm long, apical cells flattened, or widely round, without calyptra or thickened outer cell wall, not capitate; sheath absent; granules present, brownish or greenish colour, not prominent.

Recorded a temperature of 21.8°C during post-monsoon season. pH recorded as 7.0 during post-monsoon season.

Habitat : Planktic and epactiphytic

Locality : Bonacaud, Thiruvananthapuram

Specimen number : CU No. 153148

Figure : 27 G & H

3. ***Oscillatoria nitida*** Schkorbatov (Skorbatov)

Trichomes free floating, solitary, cylindrical, not constricted at the cross walls, rarely with very fine sheath or absent, blue green or bright green colour, 5-8.5 µm in width, terminal part of trichomes straight, not attenuated, not tapering towards the end; cells always shorter than wide, 5-8.5 µm wide, 1.8-3.3 µm long, rarely up to 4.5 µm long, cells quadrate or barrel shaped, bright green in colour, occasionally blue green; cellular content homogenous, without granulation in the cross walls; apical cells rounded, without calyptra and thickened outer cell wall, not capitate; aerotopes absent.

Recorded a temperature of 23.1°C during post-monsoon season and 30.3°C during summer season. pH recorded as 7.1 during post-monsoon season and 6.5 during summer season.

Habitat : Epactiphytic

Locality : Peruvannamuzhi, Kozhikode

Specimen number : CU No. 158535

Figure : 28 A & B

4. ***Oscillatoria ornata*** var. ***crassa*** Rao

Thallus blackish green or brownish colour, forming clusters or mats; trichomes dark blue green or brownish, usually straight, sometimes slightly irregularly wavy, 14-19 µm wide, constricted at the cross walls, towards the tip slightly coiled; cells always shorter than wide, 14-19 µm wide, 2-4.5 µm long, finely granulated, granules not prominent, usually with distinct granules at the cross walls; apical cells rounded, without calyptra or thickened outer cell wall, not capitate, sheaths absent; aerotopes absent.

Recorded a temperature of 23.4°C during post-monsoon season and 31.8°C during summer season. pH recorded as 7.5 during post-monsoon season and 6.9during summer season.

Habitat	: Edaphic
Locality	: Peechi, Thrissur
Specimen number	: CU No. 153135
Figure	: 28 C & D

5. ***Oscillatoria princeps*** Vaucher ex Gomont

Thallus dark blue green, blackish blue green or blackish green colour, expanded or thin, attached to a substrate, later free, developing into mats, rarely solitary, forming small clusters of filaments; trichome olive green, dark blue green or brownish green colour, 12.5-16.8 µm wide, usually straight, occasionally slightly curved, long, motile with gliding or oscillation, rotation usually anti clockwise, not constricted at the cross walls, cross walls usually ungranulated, very slightly attenuated towards the tip or not attenuated, without sheath; cells discoid or quadrate, rarely compressed, always shorter than wide, 12.5-16.8 µm wide, 2.9-8 µm long; cell content mostly finely granular; apical cells rounded, sometimes compressed hemispherical, with a slightly thickened outer cell wall, calyptra absent; granules not prominent.

Recorded a temperature of 21.5°C during post-monsoon season and 28.7°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.2 during summer season.

Habitat : Epilithic and edaphic

Locality : Meenmutti, Wayanad

Specimen number : CU No. 158530

Figure : 28 E & F

6. Oscillatoria refringens Gardner

Trichomes flexuous, sometimes rigid, bright blue green or blue green colour, 9-12 µm wide, not constricted at the cross walls, slightly attenuated towards the end; cells always shorter than wide, 9-12 µm wide, 1.5-3 µm long, sometimes compressed, bright blue green or blue green colour; apical cells rounded or widely rounded, rarely enlarged, with, thickened outer cell wall, without calyptra; sheath absent; granules present, not prominent; tip region of the filaments slightly bended; straight or highly flexuous.

Recorded a temperature of 23.4°C during post-monsoon season and 31.8°C during summer season. pH recorded as 7.5 during post-monsoon season and 6.9 during summer season.

Habitat : Epilithic

Locality : Peechi, Thrissur

Specimen number : CU No. 153136

Figure : 28 G & H; 29 A-C

7. Oscillatoria subsalsa (Agardh)

Thallus dark blue green or brownish green colour, gelatinous or mucous; trichomes 8-13 µm wide, straight, sometimes flexuous, irregularly wavy in rare occasions, not constricted or slightly constricted at the cross walls, slightly attenuated towards the tip or not attenuated; cells always shorter than wide, 8-13 µm wide, 2-4.5 µm long, pale blue green or pale green colour; apical cells rounded, slightly narrowed, without calyptra and thickened outer cell wall, not capitate; sheaths absent; granules present, not prominent.

Recorded a temperature of 23.9°C during post-monsoon season. pH recorded as 7.2 during post-monsoon season.

Habitat : Epactiphytic and planktic

Locality : Meenmutty, Thiruvananthapuram

Specimen number : CU No. 158529

Figure : 29 D & E

8. Oscillatoria tenuis var. ***levis*** Gardner

Thallus usually flat, clusters or mats in form, blue green or olive green colour, mucilaginous, thin, trichomes straight, very rarely irregularly curved, not constricted at the cross walls, granulation at the cross walls also absent, blue green, dull green or brownish green colour, 11-16.5 µm wide, cylindrical not attenuated towards the end, but very rarely a slight narrowed appearance on the tip region; cells always shorter than wide, 11-16.5 µm wide, 2-6 µm long; apical cells rounded, not capitate, without calyptra, sometimes outer cell wall thickened or not, blue green, pale blue green, dull green or brownish green colour; with scattered solitary granules, not prominent; sheath absent, or rarely found, hyaline and very thin.

Recorded a temperature of 21.6°C during post-monsoon season and 29.9°C during summer season. pH recorded as 7.3 during post-monsoon season and 6.9 during summer season.

Habitat : Epilithic

Locality : Soochippara, Wayanad

Specimen number : CU No. 158516

Figure : 29 F-H

9. *Oscillatoria sancta* Kutzing ex Gomont

Thallus dark blue green, steel blue to blackish blue, thin, shining, gelatinous, mucilaginous; trichomes bright blue green or dark blue green colour, rarely greyish violet, 15-20 µm wide, 1.8-4 µm long, usually straight, occasionally slightly curved, constricted at the cross walls, not attenuated towards the end, motile with clock wise rotation; cells discoid, always shorter than wide, 15-20 µm wide, 3.5-8 µm long; apical cells hemispherical or flatty rounded, capitate to wart like, yellowish or brownish thickened outer cell wall present; sheath usually absent; granules present, not prominent.

Recorded a temperature of 22.1°C during post-monsoon season and 30.6°C during summer season. pH recorded as 7.4 during post-monsoon season and 6.7 during summer season.

Habitat : Benthophytic and epactiphytic
Locality : Ilaveezhapoonchira, Kottayam
Specimen number : CU No. 158562
Figure : 30 A & B

10. *Oscillatoria rupicola* (Hansgirg) Hansgirg ex Forti

Thallus is small clusters, mats like, sometimes solitary, free living or among other algae or bryophytes, trichomes up to 12.5 µm wide, not constricted at the cross walls, olive green, blue green or dull green colour, occasionally with very fine, hyaline, unlamellated sheath; trichomes usually straight or slightly curved, not attenuated towards the end; cells always shorter than wide, 7-12.5 µm wide, 1.5-3.2 µm long; apical cells widely rounded, without calyptra and thickened outer cell wall, not capitate; granules present, not prominent.

Recorded a temperature of 24.2°C during post-monsoon season and 31.6°C during summer season. pH recorded as 6.8 during post-monsoon season and 6.1 during summer season.

Habitat : Epilithic

Locality : Vazhani, Thrissur

Specimen number : CU No. 158541

Figure : 30 C & D

11. Oscillatoria curviceps Agardh ex Gomont

Thallus mat like in appearance, bright blue green, blue green or dark blue green colour; trichomes blue green or pale blue green colour, 12-18 µm wide, straight, sometimes irregularly wavy, motile with left handed rotation, not constricted or rarely slightly constricted at the cross walls, usually not attenuated, rarely a slight narrowing towards the tip; cells always shorter than wide, 12-18 µm wide, 2-6 µm long; apical cell broadly rounded, without calyptra and thickened outer cell wall; granules highly present, not prominent or rarely prominent; sheaths usually absent.

Recorded a temperature of 22.1°C during post-monsoon season and 30.6°C during summer season. pH recorded as 7.4 during post-monsoon season and 6.7 during summer season.

Habitat : Benthophytic and epactiphytic

Locality : Ilaveezhapoonchira, Kottayam

Specimen number : CU No. 158559

Figure : 30 E-H

12. Oscillatoria jenensis Schmid

Thallus forming mats, dark brown or dirty blue green or brownish green colour; trichomes without sheath, sheaths only develop under unfavourable conditions, olive-green, blue green or dull green colour, 16-22 µm wide; motile with anticlockwise direction, not or slightly constricted at the cross walls, shortly attenuated towards the end and a hook like bent is seen, 10-13.5 µm wide towards the end; cells shorter than wide, 16-22 µm wide, 2.5-6 µm long, terminal cells possess colour variation, widely rounded, conical rounded, usually a little asymmetrical, without calyptra and thicker cell wall, indistinctly curved on tip; granules present, not prominent.

Recorded a temperature of 22.1°C during post-monsoon season and 30.6°C during summer season. pH recorded as 7.4 during post-monsoon season and 6.7 during summer season.

Habitat : Benthophytic and epactiphytic

Locality : Ilaveezhapoonchira, Kottayam

Specimen number : CU No. 158560

Figure : 31 A-C

13. Oscillatoria funiformis (Vouk) Komarek

Trichomes usually solitary or among other algae or cyanoprokaryotes, sometimes in small clusters, pale steel blue, blue green or pale green colour, occasionally olive green or violet colour, 9-15 µm wide, loosely elongated, straight or flexuous, sometimes screw like coiled, contorted, not constricted, or slightly constricted at the cross walls, not attenuated towards the end; cells short, discoid, 2.5-3.5 µm long, 9-15 µm wide; apical cells broadly rounded, sometimes very convex, without thickened outer cell wall and calyptra; sheath absent; granular content fine, not prominent.

Recorded a temperature of 23.0°C during post-monsoon season and 28.9°C during summer season. pH recorded as 7.5 during post-monsoon season and 7.1 during summer season.

Habitat : Benthophytic and epactiphytic

Locality : Chethalayam, Wayanad

Specimen number : CU No. 158564

Figure : 31 D & E

14. *Oscillatoria margaritifera* Kutzing ex Gomont

Thallus blackish brown colour, expanded, sometimes dark red, thin, mucilaginous, sometimes in clusters, otherwise solitary with other cyanoprokaryotes and algae; trichome brownish green or brownish red colour, 12-20 µm wide, usually straight, rarely flexuous or wavy, gradually attenuated towards the ends or not, distinctly constricted at the cross walls; cells usually shorter than wide, 12-20 µm wide, 2.3-4.5 µm long; cell content usually with large green granules, prominent; sheath absent; apical cell rounded, occasionally capitate, with or without calyptra.

Recorded a temperature of 21.1°C during post-monsoon season and 29.7°C during summer season. pH recorded as 7.4 during post-monsoon season and 7.2 during summer season.

Habitat	: Edaphic and epilithic
Locality	: Minnampara, Palakkad
Specimen number	: CU No. 158561
Figure	: 31 F-H

ii. Lyngbya C. Agardh ex Gomont 1892

Filaments straight or slightly waved, sometimes irregularly curved and in several species finely screw like coiled. Rarely found as solitary. Usually forming thin or thick compact large layered, leathery prostrate mats on substrate, free floating or attached. Very rarely produce pseudobranches. Sheaths usually present, thick or thin, lamellated or unlamellated. Certain species do not have sheath or gradually disappears. Sheath hyaline to coloured, light green to yellow to yellow brown to violet or reddish in colour. Very rarely bluish in appearance. Trichomes cylindrical, constricted or unconstricted at the cross walls, occasionally motile cells short, discoid, usually shorter than wide, quadrate, barrel shaped or rarely cylindrical shapes also observed. Sometimes isodiametric. Aerotopes usually absent, but some aquatic or planktic species possess aerotopes. Apical cells with or without calyptra. Thickened outer cell walls may or may not present. Granular contents usually fine, occasionally prominent. Heterocysts absent. Reproduction by trichome disintegration into short motile hormogonia by the help of necridia.

Key to the species

1a. Filaments more than 22 µm wide ……………..……………………… 2

1b. Filaments less than 22 µm wide ……………….…………………….... 4

2a. Filaments 22-30 µm wide ……………..……………………………. 3

2b. Filaments more than 30 µm wide …….…………………..... ***L. majuscula***

3a. Sheath thick, lamellate ………..……………………… ***L. scytonematoides***

3b. Sheath thin, unlamellate ……………………...……………….. ***L. birgei***

4a. Trichomes constricted ……………………….………………………….. 5

4b. Trichomes unconstricted ……………………….……………………….. 6

5a. Filaments 8-12 µm wide ……………………………..…….. ***L. agardhii***

5b. Filaments 17-22 µm wide …………………….…………….. ***L. splendens***

6a. Sheath thick, outside rough ……………………….……… ***L. martensiana***

6b. Sheath thin, outside smooth ……………………….……………………. 7

7a. Apical cell wall thick, sheath not coloured …………….……….. ***L. aestuarii***

7b. Apical cell wall thin, sheath coloured …………..………. ***L. connectens***

1. Lyngbya aestuarii Liebman ex Gomont

Thallus expanded, initially thin, later becoming thick, cluster like formation, leathery and layered, greenish brown, dark blue green to blackish colour, usually attached with a substrate, sometimes floating, rarely in solitary and free floating filaments; filaments long, cylindrical, straight or curved, densely arranged, entangled; trichomes blue-green or greenish black colour, 10-16 µm wide, not constricted at the cross walls, not attenuated or narrowed towards the end; cells short, discoid or quadrate, 10-16 µm wide, 3.5-6 µm long; apical cells truncate, rounded with thickened outer cell wall, without calyptra;

sheaths usually thin, smooth, unlamellate or sparsely lamellate, hyaline, sometimes outside uneven, rarely coloured; aerotopes present; granules prominent, greenish.

Recorded a temperature of 14.8°C during post-monsoon. pH recorded as 7.3 during post-monsoon.

Habitat	: Epactiphytic
Locality	: Meesapulimala, Idukki
Specimen number	: CU No. 158552
Figure	: 32 A

2. Lyngbya agardhii Gomont

Thallus mat like or in tufts, reddish violet or brownish violet colour, thick; filaments rigid, entangled, long; trichomes greenish violet, or brownish violet, sometimes pinkish, constricted at the cross walls, cylindrical, not attenuated towards the ends, 8-12 µm wide, cells quadrate or barrel, usually shorter than wide, rarely longer than wide, 8-12 µm wide, 5-9 µm long, occasionally isodiametric; apical cells widely rounded, without calyptra and thickened outer cell wall; sheaths thin, firm, usually unlamellate, rarely lamellate, hyaline, smooth; granules present, not prominent; cells brownish green with pink patches.

Recorded a temperature of 21.6°C during post-monsoon season and 29.9°C during summer season. pH recorded as 7.3 during post-monsoon season and 6.9 during summer season.

Habitat	: Epilithic
Locality	: Soochippara, Wayanad
Specimen number	: CU No. 158523
Figure	: 32 B & C

3. *Lyngbya birgei* G.M. Smith

Thallus tuft like, dark blue-green or brown colour; filaments straight or flexuous, sometimes irregularly curved, solitary or in groups, free floating, 22-28 µm wide; trichomes cylindrical, 20-26 µm wide, unconstricted or slightly constricted at the cross walls, not attenuated towards the end; cells always shorter than wide, 20-26 µm wide, 1.5-3.2 µm long, blue-green or brownish green colour; apical cells widely rounded, not capitate, without calyptra, occasionally with thickened outer cell wall or absent; sheath firm, thin, hyaline, outer surface uneven or rough, unlamellated or distinctly lamellated; granules present, not prominent; occasionally with aerotopes.

Recorded a temperature of 21.7°C during post-monsoon season and 29.4°C during summer season. pH recorded as 7.1 during post-monsoon season and 6.6 during summer season.

Habitat : Epilithic and corticolous

Locality : Kanthanpara, Wayanad

Specimen number : CU No. 158506

Figure : 32 D & E

4. *Lyngbya connectens* Bruhl et Biswas

Thallus expanded, mat like or tuft like, dark blue-green colour; filaments straight, flexuous or irregularly curved, not constricted at the cross walls, not attenuated towards the end; trichomes blue-green, pale green or olive green colour, cylindrical, unconstricted, or very slightly constricted; cells isodiametric, sometimes longer or shorter than wide, 11-15 µm wide, 3-5 µm long in older part, 7-12 µm long in the younger filaments; pale green or blue-green colour, rarely olive green; apical cell rounded, broadly rounded or slightly narrowed, longer than other vegetative cells; sheath thin, firm, coloured, colour changed occasionally from green to brown, unlamellate, smooth; granules present, fine, occasionally prominent.

Recorded a temperature of 21.6°C during post-monsoon season and 29.9°C during summer season. pH recorded as 7.3 during post-monsoon season and 6.9 during summer season.

Habitat : Corticolous and epiphytic

Locality : Soochippara, Wayanad

Specimen number : CU No. 158520

Figure : 32 F-H

5. Lyngbya majuscula Harvey ex Gomont

Thallus widely expanded up to several millimetres in size; dark blue-green, brownish green or yellowish brown in colour; tuft like; filaments long, straight or irregularly curved, sometimes wavy in nature, 30-35 µm wide; rarely slightly coiled in the tip region; trichomes cylindrical, dark blue-green or green in colour, up to 25 µm wide, not or slightly constricted at the cross walls, not attenuated towards the end; cells short, discoid or quadrate, 20-25 µm wide, 5-8 µm long, blue-green in colour; apical cells round, longer than other vegetative cells, up to 13 µm long, not capitates, without calyptra or thickened outer cell wall; sheath thick, firm or slightly detached like in appearance, hyaline, initially unlamellated, later become highly lamellated, outside rough, usually up to 7 µm thickness, occasionally up to 15 µm thick; granules fine, not prominent.

Recorded a temperature of 21.6°C during post-monsoon season and 29.9°C during summer season. pH recorded as 7.3 during post-monsoon season and 6.9 during summer season.

Habitat : Epilithic and edaphic

Locality : Soochippara, Wayanad

Specimen number : CU No. 158523

Figure : 33 A-D

6. *Lyngbya martensiana* Meneghini ex Gomont

Thallus feathered like, solitary or free floating, blue-green colour; filaments densely entangled, long, flexuous, variously curved, occasionally straight, 8-14 µm width; trichomes cylindrical, blue-green or pale blue-green colour, 6-12 µm width, not constricted at the cross walls, trichomes with uniform width, not attenuated towards the tip; cells always shorter than wide, 6-12 µm wide, 3-5 µm long, rarely isodiametric, cell content homogenous; apical cells widely rounded, hemispherical or compressed barrel, not capitate, without calyptra or thickened outer cell wall; granules fine, not prominent; sheath hyaline, colourless, initially thin, later thick, up to 3 µm thick, outside rough, occasionally distinctly lamellated.

Recorded a temperature of 20.5°C during post-monsoon season and 29.9°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.2 during summer season.

Habitat : Epilithic
Locality : Anakkayam, Thrissur
Specimen number : CU No. 153124
Figure : 33 E & F

7. *Lyngbya splendens* Gardner

Thallus thin, sometimes cespitose, yellowish brown colour; filaments long, 17-22 µm wide, not attenuated, solitary or in clusters; trichomes cylindrical, brownish green or blue-green in colour, 15-20 µm wide, not attenuated towards the tip, not constricted or very slightly constricted at the cross walls; cells brownish green, always shorter than wide, 15-20 µm wide and 4-9 µm long, cells discoid or compressed; apical cells slightly longer than wide, up to 13 µm long, acutely rounded to obtuse conical, not capitate, without calyptra or thickened outer cell walls; sheaths thin, unlamellate or sparsely lamellate, hyaline to light yellow or green colour, extending; granules present, prominent.

Recorded a temperature of 21.6°C during post-monsoon season and 29.9°C during summer season. pH recorded as 7.3 during post-monsoon season and 6.9 during summer season.

Habitat : Epiphytic and corticolous

Locality : Soochippara, Wayanad

Specimen number : CU No. 158521

Figure : 33 G & H

8. Lyngbya scytonematoides Gardner

Filaments tortuous, up to 25 µm wide; not forming a definite thallus, or sometimes forming a mucilaginous mass; trichomes solitary or in clusters, straight, occasionally flexuous, not or slightly attenuated towards the ends, not constricted at the cross walls, cylindrical, cells usually shorter than wide, occasionally longer than wide or isodiametric, blue green colour, apical cells rounded without calyptra or thickened outer cell wall, not capitate, sheaths thick, colourless, highly lamellated, extending, up to 6 µm thick; cells 9-15 µm wide; 5-7.5 µm long; cellular content fine, granules not prominent; aerotopes usually absent.

Recorded a temperature of 20.2°C during post-monsoon. pH recorded as 6.8 during post-monsoon season.

Habitat : Edaphic and epactiphytic

Locality : Agasthyamala, Thiruvananthapuram

Specimen number : CU No. 153146

Figure : 34 A-D

HETEROCYSTOUS CYANOBACTERIA

Family **Scytonemataceae** Rabenhorst ex Bornet et Flahault 1887

Uniseriate filamentous cyanobacteria with obligate false branching, heterocystous. Thallus usually prostrate, in the form of woolly mats or flat, less frequently forming erect fascicles; sometimes solitary filaments among other cyanoprokaryotes and algae. Filaments branching starts usually in trichomes between vegetative cells between two slightly distant heterocytes. Trichomes usually monoseriate, cylindrical, narrowed or widened at both ends, rarely forming hairs, usually with distinct meristematic zones. Sheaths commonly thick, firm or gelatinous, sometimes funnel-like widened at the ends, often lamellated, colourless or coloured with sheath pigments. Heterocysts occasionally basal, intercalary, usually bipored, mostly single. Typical akinetes absent. Reproduction by disintegration of the thallus or by hormogonia, less frequently with hormocytes.

Key to the genera

1a. Sheath thick, ends often funnel like ………………………….……… **Petalonema**

1b. Sheath thin or thick, ends not funnel like ………………..…… **Scytonema**

i. Scytonema Agardh ex Bornet et Flahault 1887

Filaments free or colonial in form, rarely forming layers. Attached to a substrate, irregularly coiled or in fascicles, creeping or erect. Filaments isopolar in nature, growing terminally and also from intercalary regions. Branches are false branch type, commonly arises between vegetative cells, slightly distant from heterocysts. Usual branching pattern is geminate, occasionally or less frequently single branches are seen. Branches usually erect, same as mother filament or slightly narrower than the mother filament. Filaments are enclosed or covered within a firm sheath. Sheath may be coloured or colourless, layered and rarely diffluent. Layers of the sheath have parallel lamina or are slightly divergent towards ends. Trichome solitary, inside sheath, uniseriate, usually cylindrical along the whole length including the terminal parts. Apical regions showing more meristematic activities. Trichomes constricted or unconstricted at the cross walls, cells usually shorter than wide, or isodiametric, rarely slightly longer than wide. Apical cells usually round, rarely conical or tapering towards the end. Heterocysts intercalary, solitary in usual, very rarely in pairs, spherical, quadrangular, cylindrical or sub spherical. Reproduction is by unsheathed hormogonia, liberate from the ends of branches; reproduction also carried out by disintegration of stratum. Granules may present or absent.

Key to the species

1a. Filaments more than 20 µm wide ……………………………………….. 2

1b. Filaments less than 20 µm wide ………………………………………… 7

2a. Filaments 20-25 µm wide …………………..………………………….. 3

2b. Filaments more than 25 µm wide …………..………………………... 4

3a. Sheath thin, coloured, not hyaline ………………………….. ***S. javanicum***

3b. Sheath thin, not coloured, hyaline ………………..………. ***S. stuposum***

4a. Branches same as mother filament ……………..…………………….. 5

4b. Branches narrower than mother filament ……….……………………. 6

5a. Heterocyst 17-20 µm wide ……………………..…………….. ***S. millei***

5b. Heterocysts 9-14 µm wide ………………………………… ***S. myochrous***

6a. Cells 6.5-10 µm long …………………………..……………… ***S. cryspum***

6b. Cells 2-4.5 µm long ………………………………….………***S. torulosum***

7a. Sheath thick …………………………..………………………… 8

7b. Sheath thin ……………………………………..…………………… 10

8a. Branches smaller than main filament …………..…… ***S. pseudoguyanense***

8b. Branches same as main filament ……………..……………………… 9

9a. Heterocysts 8-11 µm long ……………….………… ***S. coactile*** var**. *minor***

9b. Heterocysts 12-20 µm long …………………………….……… ***S. caldarium***

10a. Sheath thin, lamellate ……………….……………… ***S. pseudohofmanii***

10b. Sheath thin, unlamellate ……………………..………….. ***S. schmidtii***

1. Scytonema coactile var. ***minor*** Wille

Thallus woolly, brush like, occasionally in spherical colonies, forming clusters, radially expanded in irregular fascicles, filaments irregularly organised, brownish green or blue-green colour; filaments 12-16 µm wide, long, false branching, usually geminate, branches erect, morphologically similar to mother filaments, clearly divaricated from mother filaments; trichomes cylindrical along the whole length, slightly constricted at the cross walls, highly constricted towards the end, some parts remains unconstructed, brown, green or blue-green colour; cells isodiametric or sometimes longer or shorter than wide, terminal cells rotund; cells 6-8 µm diameter, quadrate or barrel shaped, blue-green or brownish green colour; heterocysts solitary, intercalary, cylindrical or barrel, longer than wide, rarely shorter than wide, 10-15 µm long, 8-11 µm wide; sheaths firm, thick, lamellated, sometimes hyaline towards the periphery, brownish towards the inner side, up to 4.5 µm wide; granules present, not prominent.

Recorded a temperature of 24.2^{o}C during post-monsoon season and 28.6^{o}C during summer season. pH recorded as 7.6 during post-monsoon season and 7.2 during summer season.

Habitat : Epilithic

Locality : Kakkayam, Kozhikode

Specimen number : CU No. 153019

Figure : 34 E-H

2. Scytonema crispum Bornet ex De Toni

Thallus caespitose, cluster like or fasciculated, among other algae, cyanobacteria or water plants, woolly, green, bright green, blue-green or brownish green colour; filaments entangled, sometimes coiled, solitary or in groups, up to 27 µm wide, cylindrical, false branches geminate or solitary;

trichomes cylindrical, 19-26 µm wide, indistinctly constricted at the cross walls, not tapering towards the end, branches morphologically similar to the main filament; cells shorter than wide, blue-green or dark green colour,16-26 µm wide and 6.5-10 µm long, old parts of trichome may isodiametric; heterocysts isodiametric, or slightly shorter or longer than wide, solitary or a few in rows, cylindrical, ellipsoidal or rounded in shape, 15-28 µm wide, 6-13 µm long; sheath firm, thin, mostly unlamellated, hyaline, rarely brownish colour; granules present, not prominent.

Recorded a temperature of 25.8°C during post-monsoon season and 32.7°C during summer season. pH recorded as 6.5 during post-monsoon season and 6.1 during summer season.

Habitat : Epilithic and corticolous

Locality : Pazhassi dam, Kannur

Specimen number : CU No. 191266

Figure : 35 A & B

3. ***Scytonema javanicum*** Bornet ex Bornet et Flahault

Thallus thin, prostrate, irregular, cushion shaped, bright blue-green or blue-green colour, rarely greenish violet; filaments straight or coiled, initially creeping then become erect, less frequently in vertical fascicles, up to 20 µm wide, false branches frequent, flexuous, long usually geminate, joined in the lower portion, same morphology of main filament, rarely showing narrower characteristic than main filament; trichomes cylindrical, not constricted at the cross walls, not tapering towards the end, up to 14.5 µm wide, olive green or blue-green colour, rarely showing violet patches; cells cylindrical, quadrate, shorter than wide,12-14.5 µm wide, 5.5-10 µm long, end cells shorter, up to 8 µm, terminal cells rotund; heterocysts quadrate or cylindrical, yellowish or olive green, rarely hemispherical, 12.5-15 µm diameter, sometimes longer or shorter than wide; sheath firm, usually thin, yellowish or hyaline, usually unlamellated, older parts showing lamellation; granular content present, not prominent.

Recorded a temperature of 21.2°C during post-monsoon season and 28.4°C during summer season. pH recorded as 7.2 during post-monsoon season and 6.9 during summer season.

Habitat : Corticolous

Locality : Muthanga, Wayanad

Specimen number : CU No. 191273

Figure : 35 C & D

4. Scytonema millei Bornet ex Bornet et Flahault

Thallus cushion like, woolly, expanded, widely prostrate, dark green to greenish brown in colour; filament blue-green or brownish, up to 25 µm wide, branches geminate, rarely solitary, smaller as compared with mother filament, or same as mother filament, flexuous, entangled, false branches divaricate and erect; trichomes cylindrical, constricted at the cross walls, 14-20 µm wide; blue-green colour; cells shorter than wide, 14-20 µm wide, 5-9 µm long, blue-green or green colour, constricted at the cross walls, shortly barrel shaped or cylindrical, cells in oldest parts are isodiametric, or shorter; heterocysts quadrate with soft edges or barrel shaped, 17-20 µm wide and 9-14 µm long, olive green or brownish yellow colour, solitary, intercalary, slightly longer and wider than vegetative cells; sheath firm thin to thick, lamellated parallelly, brown colour in older parts, initially hyaline; granules present, not prominent; aerotopes occasionally seen.

Recorded a temperature of 21.2°C during post-monsoon season. pH recorded as 7.2 during post-monsoon season.

Habitat : Epilithic

Locality : Peppara WLS, Thiruvananthapuram

Specimen number : CU No. 158564

Figure : 35 E-H

_5._ ***Scytonema myochrous*** C. Agardh ex Bornet et Flahault

Thallus flat, hemispherical, leathery, blackish or brownish black colour, attached to rocky substrates; filaments entangled, with usually common false branching, branching may geminate or solitary, up to 25 µm wide, branches wide similar or slightly narrower than mother filament; trichomes cylindrical, rarely showing slight wide ends, not constricted or slightly constricted at the cross walls, yellowish, yellow-green or brownish green colour; cells cylindrical or barrel shaped, sometimes compressed and irregular quadratic or slightly shorter or longer than wide, yellow, yellow-green or pale blue-green colour, 7-15 µm wide and 5-11 µm long, towards the tip more shortened cells, end cell rotund; heterocysts quadrate, barrel shaped or cylindrical, 9-14 µm wide and 9-16 µm long; sheath thick, firm, dark yellow or yellow-brown colour, rarely pale yellow, layers showing distinct diverges, highly lamellated; granules present, not prominent.

Recorded a temperature of 20.3^{o}C during post-monsoon season and 27.5^{o}C during summer season. pH recorded as 7.7 during post-monsoon season and 7.1 during summer season.

Habitat : Epilithic

Locality : Eravikulam NP, Idukki

Specimen number : CU No. 145510

Figure : 36 A & B

_6._ ***Scytonema pseudoguyanense*** Bharadwaja

Thallus cushion like, thick with long erect threads, brown, brownish green or dark blue-green colour; filaments densely entangled, irregularly curved, 13-18 µm in width, false branches frequently seen, slightly narrower than the main filament, developing secondary branches in the earlier stages; usually geminate, occasionally solitary, sometimes young branches arising in characteristic loops; trichomes cylindrical in shape, slightly constricted at the cross walls, 7.6-10.5 µm in width, 3.3-6.5 µm long, old parts of trichome become narrower; cells almost quadrate, shorter than wide, cells in older parts are cylindrical, longer than broad, up to 12 µm long, end cells short and flattened, rarely rotund, blue-green or dark blue-green in the initial stages, then become dark, brownish yellow or brown colour; heterocysts quadrate, cylindrical or ellipsoidal, rarely longer than wide, 9-14 µm broad, 7-12.5 µm long; sheaths firm, coloured, parallel lamellation, up to 2.5 µm thick, sheaths in young branches hyaline and thin, later it become thick and yellowish brown colour; granules present, not prominent.

Recorded a temperature of 20.7°C during post-monsoon season and 30.1°C during summer season. pH recorded as 7.2 during post-monsoon season and 6.6 during summer season.

Habitat : Epilithic and edaphic

Locality : Karappuzha, Wayanad

Specimen number : CU No. 191219

Figure : 36 C-E

7. Scytonema pseudohofmanii Bharadwaja

Thallus brownish green or yellowish brown colour, tuft like short growth; filaments densely entangled, irregularly curved, often straight, up to 16 µm width, false branches geminate or solitary, divaricate, less frequent, morphologically similar to the mother filament; trichomes cylindrical, usually constricted at the cross walls, sometimes unconstricted at the cross walls, 5-7.5 µm width, often slightly narrowed in the central portion of older filaments; cells usually cylindrical or barrel shaped, sometimes quadrate, slightly shorter than wide, rarely longer than wide. 5-7.5 µm wide, 3-5.5 µm long, dull green or brownish green in colour; heterocysts single, occasionally in pairs, larger than vegetative cells, quadrate or ellipsoidal, 7-12 µm wide and 6-9 µm long; sheaths firm, coloured, yellowish brown, with parallel lamellation; granules present, not prominent.

Recorded a temperature of 21.5°C during post-monsoon season and 29.2°C during summer season. pH recorded as 7.0 during post-monsoon season and 6.7 during summer season.

Habitat : Epilithic

Locality : Chelachuvad, Idukki

Specimen number : CU No. 153091

Figure : 36 F-H

8. Scytonema stuposum Bornet ex Bornet et Flahault

Thallus tomentose, widely expanded, woolly, prostrate, cushion shaped, dull green or dirty blue-green colour; filaments entangled, sometimes coiled, up to 23 µm wide, with common false branches, geminate or rarely solitary, branches express the same morphology as main filament; trichomes cylindrical distinctly constricted at the cross walls, olive green or dull green colour, occasionally blue-green, very slightly attenuated towards the end, 12-14 µm wide; cells shortly barrel shaped, quadrate or cylindrical, always shorter than wide, rarely isodiametric in older filaments, terminal cells rounded, cells 12-14 µm wide, 4.5-8 µm long; heterocysts solitary, usually with same width of vegetative cells, 12-15 µm wide, 12-19 µm long, olive green or yellowish colour, quadrate, cylindrical or barrel shaped, shorter or longer than wide; sheath firm, thin, hyaline, rarely light green coloured, not lamellated or rarely lamellated; granules present, not prominent.

Recorded a temperature of 19.3°C during post-monsoon season and 28.3°C during summer season. pH recorded as 7.3 during post-monsoon season and 6.9 during summer season.

Habitat : Corticolous

Locality : Siruvani, Palakkad

Specimen number : CU No. 191227

Figure : 37 D-F

9. *Scytonema caldarium* Setchell

Thallus expanded, tuft like, dark brown or yellowish brown colour, filaments straight or irregularly curved, in the basal part prostrate and entangled, up to 17.5 µm wide, false branches usually geminate, rarely in solitary, usually free, occasionally joined at the base; trichome cylindrical and narrow with long cells, not constricted at the cross walls, slightly expanded towards the end, olive green, yellowish or yellowish brown colour; cells usually longer than wide, 6-8 µm wide, 6.5-16.5 µm long, cell margin serrated occasionally, terminal cells rotund; heterocysts barrel shaped, cylindrical or elongated, slightly larger than vegetative cells, shorter or longer than wide, 12-18 µm wide 12-20 µm long, yellow coloured; sheaths firm, thin or thick, yellow brown or golden yellow colour, parallel lamellation seen; granules present.

Recorded a temperature of 20.7°C during post-monsoon season and 30.1°C during summer season. pH recorded as 7.2 during post-monsoon season and 6.6 during summer season.

Habitat	: Epilithic and edaphic
Locality	: Karappuzha, Wayanad
Specimen number	: CU No. 191219
Figure	: 37 G-H

10. *Scytonema torulosum* Jao

Thallus thin, dark green or brownish green colour, brush like; filaments densely entangled, commonly false branched, up to 27 µm wide, branches geminate or single; morphologically similar or slightly narrower than mother filament; trichomes cylindrical, wavy, constricted at the cross walls, not attenuated or widened towards the end, blue-green colour; cells barrel shaped, cylindrical or quadrate, blue-green, shorter than wide, rarely longer than wide, 4-7 µm wide and 2-4.5 µm long, rarely up to 8 µm long; heterocysts intercalary, spherical or hemispherical, yellowish brown colour, 5-9 µm wide, 2.5-6 µm long, sometimes 5-9 µm in diameter; sheath thick, firm, yellow brown, distinctly lamellated; granules present, not prominent.

Recorded a temperature of 23.6°C during post-monsoon season and 31.5°C during summer season. pH recorded as 6.9 during post-monsoon season and 6.5 during summer season.

Habitat : Epilithic and epactiphytic

Locality : Kanjirappuzha, Palakkad

Specimen number : CU No. 191259

Figure : 38 A-H

11. Scytonema schmidtii Gomont

Thallus extensive, blackish brown or yellowish brown, crusty or woolly, thick; filaments long, densely entangled, up to 16 µm wide (certain conditions help to improve their growth and they become wider up to 25 µm), richly and repeatedly false branched, branches usually geminate, occasionally solitary, divaricated; trichomes brownish yellow, brownish green or bluish green colour, cylindrical, constricted at the cross walls, 9-14 µm wide (up to 20 µm); cells always shorter than wide, barrel shaped or sometimes quadratic with smooth ends, 9-14 µm wide, 3-7.5 µm long; heterocyst quadrate or barrel shaped, rarely rounded, longer than vegetative cells, 6-13 µm wide, 5.5-9 µm long; sheaths thin or thick, unlamellate or slightly lamellate, yellowish brown or greenish brown colour; granules usually fine, not prominent.

Recorded a temperature of 21.8°C during post-monsoon season. pH recorded as 7.0 during post-monsoon season.

Habitat : Epilithic

Locality : Bonacaud, Thiruvananthapuram

Specimen number : CU No. 153148

Figure : 37 A-C

ii. **Petalonema** Berkeley ex correns 1889

Filaments free, in clusters or mats, irregularly coiled, sometimes creeping or erect, at first heteropolar with apical growth, subapical meristematic zones are also seen. Falsely branched with single or branches in pairs. Later becoming isopolar. Trichomes usually uniseriate, cylindrical, sometimes widened at the ends and narrowed in the middle parts. Constricted or unconstricted at the cross walls. Sheaths prominent, firm, delimited, extremely wide, mostly highly lamellated and funnel like divergent at the ends. Usually coloured, yellow, yellowish brown in colour; cells cylindrical, barrel shaped or spherical in shape. Heterocysts intercalary, sometimes at the bases of branches; usually branches arise between two heterocysts; spherical, oval, barrel shaped up to cylindrical. Usually found as solitary, rarely in pairs. Akinetes unknown. Reproduction by hormogonia and disintegration of filaments.

Key to the species

1a. Filaments up to 70 µm wide ……………………………………………..… 2

2a. Filaments below 35 µm wide …………………………………………… 3

2a. Cells blue-green, 7-16 µm long ………………………………… ***P. alatum***

2b. Cells dark green, 6-9 µm long ……………………..…….. ***P. pulchrum***

3a. Cells usually short barrel shaped ………………..……….. ***P. velutinum***

3b. Cells usually isodiametric …………………………………… ***P. involvens***

1. Petalonema involvens (Rabenhorst ex Bornet et Flahault) Migula

Thallus shrub like, spongy, dark blue-green to brown colour; filaments densely entangled, 20-35 µm wide, false branches solitary or geminate, erect, initially narrower than main filament, later morphologically similar; trichomes cylindrical, constricted or unconstricted at the cross walls, not much widened towards the end; cells 6-10 µm wide, 4-8 µm long, usually isodiametric, sometimes slightly longer or shorter than wide, cylindrical or barrel shaped, blue-green, greenish brown or olive green colour; heterocysts almost spherical, sometimes oval or slightly elongated, intercalary, 7-13 µm wide, 4-10 µm long; sheaths thick, inner layers yellowish brown to dark brown colour, outer layers yellowish or hyaline, sometimes yellowish brown, finely and obliquely striated, highly lamellated, uneven on outside; granules present, not prominent.

Recorded a temperature of 20.8°C during post-monsoon season and 28.6°C during summer season. pH recorded as 7.2 during post-monsoon season and 6.8 during summer season.

Habitat	: Corticolous
Locality	: Vagamon, Idukki
Specimen number	: CU No. 145256
Figure	: 39 A & B

2. ***Petalonema alatum*** (Borzi ex Bornet et Flahault) Correns

Filaments forming fasciculate clusters or solitary, usually found along with other algae or cyanophycean members, slightly erected or creeping, occasionally forming tufted layers, 30-75 µm wide, false branching rare, usually in pairs, rarely with solitary branches and very rarely with three branches; trichomes cylindrical, distinctly constricted at the cross walls, widened towards the end, elder parts are more narrowed and cylindrical in shape; cells 6-14 µm wide, 7-16 µm long, slightly longer than wide, sometimes narrower than wide, greenish brown colour; ; heterocysts intercalary, spherical or compressed spherical in shape, rarely cylindrical, 8-17 µm diameter; sheaths very thick, distinctly lamellated, arranged parallel to the trichome in inner parts, end portion is funnel like divergent, yellowish brown colour; granules present, occasionally prominent.

Recorded a temperature of 24.2°C during post-monsoon season and 28.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.2 during summer season.

Habitat : Epilithic

Locality : Kakkayam, Kozhikode

Specimen number : CU No. 153014

Figure : 39 C-E

3. Petalonema pulchrum (Fremy) Geitler

Filaments usually found along with other algae or cyanophycean members, irregularly flexuous, densely entangled, up to 70 µm wide, false branches usually germinate, occasionally solitary, morphologically similar to the main filament, divergent; trichomes cylindrical, constricted at the cross walls, dull blue-green colour, 10-15 µm wide; cells shortly barrel shaped or compressed spherical, sometimes compressed oval, dull blue-green or green in colour, 6-9 µm long, 10-15 µm wide; heterocysts intercalary, spherical or compressed, yellow colour, 10-17 µm diameter; sheath thick, highly lamellated, widened towards the tip, up to 20 µm thick, parallel fan like layers, yellow, yellowish brown or brown colour; granules present, rarely prominent.

Recorded a temperature of 22.1^{o}C during post-monsoon season. pH recorded as 7.4 during post-monsoon season.

Habitat : Edaphic

Locality : Soolamudi, Ernakulam

Specimen number : CU No. 150049

Figure : 39 F-H

4. Petalonema velutinum Migula

Thallus widened, cushion like, brownish or blackish; filaments 25-35 µm wide, occasionally wider, false branches usually germinate, sometimes solitary, very rarely clustered; trichomes cylindrical to moniliform, constricted at the cross walls, slightly widened towards the end, greenish brown or light blue-green colour; cells 7-13 µm wide, usually shorter than wide, 5-10 µm long, barrel shape to compressed spherical, rarely isodiametric; heterocysts shortly barrel shaped, or compressed spherical, intercalary, yellowish brown colour, 10-15 µm wide, 5-10 µm long; sheaths thick, highly striated, gelatinous, yellowish brown in colour, uneven from outside, lamellation parallel to the trichome; granules present, not prominent.

Recorded a temperature of 22.4°C during post-monsoon season. pH recorded as 7.4 during post-monsoon season.

Habitat : Edaphic and epactiphytic

Locality : Variyamkuthu, Ernakulam

Specimen number : CU No. 150045

Figure : 40 A & B

Family **Rivulariaceae** Kutzing ex Bornet et Flahault 1886

Filamentous cyanobacteria, in which the apical part is usually ends in terminal hairs, heterocystous, uniseriate. Thallus flat, bushy or gelatinous, prostrate, spherical, rarely in solitary filaments, often macroscopic, very rarely free floating, usually attached to the stony or plant substrate. Filaments generally with basal heterocytes and apical, often narrowed or widened ends. Filaments enveloped by gelatinous sheaths, which can be in several genera wide, stratified, funnel like widened. Branches generally grow in direction of main filaments, false branching. Branching in various genera almost absent, in others it is rich, obligate and genus specific. Trichomes always uniseriate, often with wider basal parts and narrowed towards end, attached up to the variously long, thin hair like formation, constricted or unconstructed at the cross walls, in several parts or along the whole length of the trichome. Cells barrel shaped or cylindrical, in terminal hairs elongated, cylindrical and narrowed. Heterocytes present, obligately basal, sometimes also intercalary, single or a few in a row. Akinetes present in various genera, generally arising above the basal heterocytes, solitary or a few in series, usually separated by other heterocytes or necridic cells one from another. Reproduction by disintegration of thallus, by repeated branching and particularly by hormogonia.

Key to the genera

1a. Thallus spherical or hemispherical …………………………………..…. 2

1b. Thallus not in a definite shape ……………..…..…..………… **Calothrix**

2a. Sheath not wider than filament ……………..……..…………. **Dichothrix**

2b. Sheaths sometimes expanding towards the ends ………...…… **Rivularia**

i. **Calothrix** Agardh ex Bornet et Flahault 1886

Thallus mat like, rough or soft, sometimes mucilaginous, usually attached with a rock like substrate. Filaments heteropolar with morphologically distinct base. Creeping or firmly attached by base to the substrate. Usually possess a basal heterocyst. Sheath present, firm or wide, which may be short or continually narrowed towards the apex. Rarely with widened sheath ends. Filaments solitary or sometimes in groups, long or short, erect, flexuous or creeping. Less frequently forming continuous layers. Do not develop distinct morphological colonies. Rarely showing false branching patterns, the branches separate from main filament and then grow separate. Sheaths present, firm or wide, colourless or coloured, homogenous or wide and stratified, occasionally lamellated. Trichomes different length and width, continually narrowing towards the end, cylindrical and shortly narrowed at the apex. Constricted or unconstricted at the cross walls. Ending by differently long cellular hairs. Cells of different length and width, long or very short. Heterocysts commonly found as basal, sometimes few numbers in a row or solitary. Rarely found as intercalary. Intercalary heterocysts formed before branching. Reproduction by fragmentation of trichomes.

Key to the species

1a. Filaments with thick sheath ……………..……………………………. 2

1b. Filaments with thin sheath ………..…..……………………………. 3

2a. Sheath lamellated …………………………….……………………. ***C. fusca***

2b. Sheath unlamellated ……………………………...……….. ***C. parietina***

3a. Cells 3-6 µm long, heterocysts 7-10 µm long …………..…. ***C. capitularis***

3b. Cells 3-6 µm long, heterocysts 7-10 µm long ………………... ***C. vivipara***

1. Calothrix capitularis Uher

Thallus micro or macroscopic, fasciculated, olive green or brownish green in colour, mucilaginous, forming mats, attached to a substrate in usual; filaments solitary or in small groups, sometimes parallely arranged, olive green or dull blue green in colour, long, at the base elliptically widened or swollen, gradually narrowed towards the end, basal portion up to 20 µm wide; trichomes heteropolar, constricted at the cross walls, ending in a long, curved or, flexuous hair; cells short barrel shaped in the basal portion, towards the end longer than wide and cylindrical or rod shaped, 10-17 µm wide at the basal portion, 3-6 µm long; heterocysts basal, hemispherical, 7-10 µm in diameter; sheath thin, firm, unlamellate, sometimes diffluent, hyaline, without colour; granular content fine, occasionally contents fine, occasionally prominent, dull green in colour.

Recorded a temperature of 22.4°C during post-monsoon season. pH recorded as 7.1 during post-monsoon season.

Habitat : Epilithic

Locality : Palaruvi, Kollam

Specimen number : CU No. 153196

Figure : 40 C & D

2. Calothrix fusca Bornet et Flahault

Filaments solitary or in irregular groups, unbranched, exceptionally will a branch be formed and associated with mother filament, straight, sometimes variously curved, 13-15.5 µm wide on basal portion; trichomes narrowing towards the end, usually 6.5-9 µm wide in the middle, greenish brown or dull green colour, not constricted at the cross walls, rarely showing slight constrictions; cells shorter than wide, quadrate in shape, 6-9.5 µm broad. 2.5-4.3 µm long, dull green or greenish brown colour; heterocyst basal, hemispherical in common, rarely rounded or shortened, olive green or yellow colour, 6.3-9.8 µm broad and 3.5-5.9 µm long; sheath thick, hyaline, lamellate or barely lamellate, at the ends sometimes widened; granules present, not prominent.

Recorded a temperature of 25.9°C during post-monsoon season and 33.0°C during summer season. pH recorded as 6.7 during post-monsoon season and 6.2 during summer season.

Habitat : Epactiphytic

Locality : Poomala, Thrissur

Specimen number : CU No. 153197

Figure : 40 E & F

3. ***Calothrix parietina*** Thuret ex Bornet et Flahault

Filaments in groups, rarely solitary, green colour, branches will form and associated with mother filament, variously curved or sparsely coiled, basal portion is not or slightly onion like widened, with sheath 9-18 µm broad, more or less tapering towards the end; cells blue green colour, barrel shaped in common, compressed or spherical were also seen, 6-11 µm broad, 6-8.5 µm long; sheath thick, hyaline, not lamellate, up to 4 µm thick; heterocyst basal, rarely intercalary, hemispherical or compressed, wider than the vegetative cells, 6-13 µm broad, 2-4.5 µm long, yellow colour.

Recorded a temperature of 24.9°C during post-monsoon season and 30.1°C during summer season. pH recorded as 6.9 during post-monsoon season and 6.5 during summer season.

Habitat : Edaphic and epactiphytic

Locality : Nadukani Ghat, Malappuram

Specimen number : CU No. 153198

Figure : 40 G & H

4. Calothrix vivipara Harvey ex Bornet et Flahault

Filaments solitary or groups, mixed with other algae or cyanobacteria, widely prostrate, intricated near the basal portion, 14-19.5 µm wide, tapering towards the end, false branches are seen; cells dull green or greenish brown in colour, quadrate, slightly constricted, 14-19.5 µm wide, 8-13.4 µm long, end cell conical; sheath firm, thin, unlamellate, hyaline; heterocyst terminal and intercalary, terminal heterocyst hemispherical in shape, 11.5-17.6 µm broad, 10-15.5 µm long, intercalary heterocyst barrel shaped or spherical, 15-19 µm in diameter, olive green colour; granules prominent, vacuoles occasionally present.

Recorded a temperature of 25.9^{o}C during post-monsoon season and 33.0^{o}C during summer season. pH recorded as 6.7 during post-monsoon season and 6.2 during summer season.

Habitat : Corticolous

Locality : Poomala, Thrissur

Specimen number : CU No. 153199

Figure : 41 A-C

ii. Rivularia (Roth) C. Agardh ex Borner et Flahault 1886

Many filaments aggregated to form a colony; Colonies usually aquatic or semiaquatic, attached to a firm substrate. Hemispherical, spherical or irregular; Later multiplies colonies aggregate together to form a mat or pillow like macroscopic expanded layers, with densely radially and parallels arranged filaments. Sometimes several species show impregnated intensely to calcareous precipitate features. Olive green, brownish, blackish, reddish, dark blackish or yellowish brown in colour. Bases of the filament originated from centre of the colonies, later substrate. Colonies usually firm, and delimited. Some colonies possess a small hole on the centre. Filaments bipolar, composed of trichomes and thick or thin coloured sheaths. Sheaths sometimes gelatinize and become confluent. Trichomes develop their own sheath and which are enclosed in the mother sheaths. Trichomes heteropolar with basal heterocysts; tapering towards the end, sometimes forming variously long hair, simple, later falsely branched. Branches grow parallely to mother trichomes. Later it become separated. Cells of different size along the trichome length, usually wide and short in subterminal meristematic zones, cylindrical at the bases, then become elongated towards the end. Barrel shaped, quadrate, elongate or nod shaped cells are also seen. Heterocysts basal in common. Intercalary heterocysts also found. Solitary, rarely in pairs, spherical, hemispherical or elongate. Reproduction by hormogonia and fragmentation of filaments.

Key to the species

1a. Filaments with thick sheath ………………...………………………….. 2

1b. Filaments with thin sheath ………………………...…………………. 4

2a. Sheaths funnel like widened ……………………………… ***R. beccariana***

2b. Sheaths widened, not funnel like ……………………………………… 3

3a. Cells more than 5 µm in length ……………………..………. ***R. nitida***

3b. Cells less than 5 µm in length ……………………….……… ***R. manginii***

4a. Cells shorter than wide, 2-4.5 µm long ……………………..…. ***R. bullata***

4b. Cells isodiametric or longer than wide, 7-15 µm long …………... ***R. atra***

1. ***Rivularia atra*** Roth ex Bornet et Flahault

Colonies spherical or hemispherical, pillow like, later confluent, blackish green or black colour, hard; Filaments radially and densely arranged, compact, repeatedly false branched, tapering towards the end. Trichomes pale green, brownish green or blue green colour, constricted at the cross walls, highly constricted in the lower parts and less constricted towards the tip; Cells slightly longer than wide except meristematic portion, 7-12 µm width and 7-15 µm length, cylindrical or barrel shaped; heterocysts basal, solitary, spherical or hemi spherical, intercalary heterocysts not observed, 6-10 µm diameter; sheath thin, firm, usually hyaline, occasionally yellowish or brownish colour, unlamellated, rarely layered; granules present, not prominent.

Recorded a temperature of 17.6°C during post-monsoon season and 28.5°C during summer season. pH recorded as 7.4 during post-monsoon season and 6.7 during summer season.

Habitat : Epilithic
Locality : Ponmudi, Thiruvananthapuram
Specimen number : CU No. 145508
Figure : 41 D-F

2. Rivularia beccariana Bornet et Flahault

Colonies usually hemispherical or irregularly spherical, hard, occasionally confluent together, without precipitation but stratified, olive green or brownish green colour; filaments hardly separable one from another, 7-9 µm wide, false branches parallel, filaments flexuous or wavy, irregularly curved; trichomes 5-8 µm wide near the basal portion, gradually narrowed towards the end, not constricted at the cross walls, elongated, long irregularly flexuous hair, hair overlaps sheaths; cells cylindrical to barrel shaped, usually longer than wide, occasionally shorter than wide, elongated into hairs, yellowish brown or brown in colour; heterocysts basal, solitary, hemispherical, spherical or oval; 5-9 µm diameter, colour same as the vegetative cells; sheaths relatively thin, indistinctly lamellated, initially hyaline, later become yellow-brown coloured, funnel like widened characteristics seen towards the ends, up to 7 µm widened in each side, granular content brownish, not prominent.

Recorded a temperature of 23.9°C during post-monsoon season and 30.0°C during summer season. pH recorded as 7.1 during post-monsoon season and 6.4 during summer season.

Habitat : Epilithic

Locality : Koodaranji, Kozhikode

Specimen number : CU No. 158563

Figure : 41 G & H

3. *Rivularia manginii* Fremy

Colonies usually spherical, sometimes subspherical, not confluent, occasionally agglomerated, olive green or brownish black colour, gelatinous, not hollow with smooth surface, not encrusted, firm; filaments radially arranged, coiled or irregularly curved, falsely branched, branches parallel; trichomes very slightly widened at the base, 2.7-5 µm wide, narrowed gradually towards the end, long, flexuous, hairy, hairs hyaline; cells usually isodiametric up to longer or shorter than wide, 2.7-5 µm wide, 2-4.5 µm long, brownish yellow or yellowish green colour; heterocysts basal, intercalary heterocysts not observed, solitary, spherical, hemispherical or oval, 3.5- 6 µm in diameter, brownish green colour; Sheaths wide, thick, lamellated or striated, particularly in the tip region, sometimes funnel like widened, hyaline to golden- brown, rarely yellow brown colour; granules present, brownish in content, not prominent.

Recorded a temperature of 20.7°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.1 during summer season.

Habitat : Epilithic and epiphytic

Locality : Nelliyampathy, Palakkad

Specimen number : CU No. 191212

Figure : 42 A-D

4. *Rivularia nitida* Agardh ex Bornet et Flahault

Colonies spherical in young, flat, later irregularly pillow like, variable in outline, widened, soft, later become large, dark olive green colour;

filaments aggregated, densely elongated together, parallely arranged, flexuous, irregularly curved; trichomes 5-9 µm wide in the basal portion, tapering towards the end, elongated, long, slightly constricted at the cross walls; cells longer or shorter than wide, barrel shaped or cylindrical, 7-8.3 µm wide 3.5-5 µm long, olive green, golden yellow or yellowish brown colour; heterocysts basal, usually spherical, sometimes hemispherical or oval, 8-10.5 µmdiameter, single; Sheaths thick, gelatinous, hyaline to yellowish, towards the end widened and dilated, distinctly lamellated; granular content blue green or yellowish colour, occasionally prominent.

Recorded a temperature of 20.7°C during post-monsoon season and 29.8°C during summer season. pH recorded as 7.2 during post-monsoon season and 6.8 during summer season.

Habitat	: Benthophytic
Locality	: Athirappilly, Thrissur
Specimen number	: CU No. 153096
Figure	: 42 E-H

5. Rivularia bullata Berkeley ex Bornet et Flahault

Colonies microscopic, later macroscopic, slimy, firm, less frequently slightly irregular, lobate, later hollow, dull green, olive green, green or brownish green in colour, attached to rocky substrates; filaments densely arranged, enlarged or parallel, radially situated, up to 8.5 µm wide in the basal portion, tapering towards the end; trichomes persist after false branching, 5-7.8 µm wide near basal region, slightly constricted or not constricted at the cross walls, narrowed, sometimes up to thin hair like; cells barrel shaped or cylindrical, shorter or larger than wide, rarely isodiametric, dull green or brownish green in colour, 5-7.8 µm wide, 5-10 µm long; heterocysts hemispherical, spherical, slightly conical or oval in shape, 9-13 µm in diameter, terminal, rarely intercalary, sometimes equal size of vegetative cells; Sheaths thin, firm, hyaline, unlamellated or sparsely lamellated, very less frequently yellowish, not widened, attached to the trichomes, sometimes end regions showing slight widened character; granules present, brownish in colour, not prominent.

Recorded a temperature of 24.2°C during post-monsoon season and 32.3°C during summer season. pH recorded as 6.8 during post-monsoon season and 6.4 during summer season.

Habitat : Epilithic

Locality : Parappa, Kannur

Specimen number : CU No. 145509

Figure : 43 A-D

iii. Dichothrix Zanardine ex Bornet et Flahault 1886

Colonies usually attached to a substrate, slimy, composed from sub dichotomic, falsely branched fasciculated filaments which are caespitose, penicillate, shrub like. Initially as solitary, then become macroscopic to form cushion like or feathery tufts. Sometimes more than one filament in the basal portion. Filaments heteropolar, bases sometimes widened. Ending with distinct hair like or funnel like widened apical portion. Enveloped by distinct sheaths. Filaments are clearly and usually false branched repeatedly. Branches in the same sheath during initial stages, then emerge in their own sheath. Sheaths thin, firm, close to trichomes. Rarely wide. Lamellated and funnel like widened towards the end. Trichomes heteropolar, with basal heterocysts. Intercalary heterocysts may or may not present. Trichomes constricted or not constricted at the cross walls. Elongated in a long narrow hair like apex. Cells usually quadrate, long or shorter than wide, long and cylindrical in the end portion. Heterocysts usually basal, rarely intercalary, spherical, hemispherical or conical in shape. Intercalary heterocysts cylindrical or barrel shaped. Reproduction by hormogonia and also by disintegration of filaments.

Key to the species

1a. Trichomes 6-9 µm wide …………………………………….. ***D. orsiniana***

1. Dichothrix orsiniana Bornet et Flahault

Colonies forming mats on stony substrates, slimy greenish brown colour; filaments flexuous, irregularly curved, 9.5-13 µm wide, repeatedly false branched, branches usually attached the main filament by their basal parts; trichomes cylindrical, tapering towards the end, elongated into long thin hair, not constricted at the cross walls or slightly constricted, 6-9 µm wide, at the basal portion cells always shorter than wide, olive green or greenish brown colour, at the end hairs elongated and cylindrical in appearance, 6-9 µm wide, 2-5 µm long; heterocysts basal, spherical or hemispherical, 5-8 µm in diameter; sheaths thin, firm, indistinctly lamellated, yellow brown; granules present, not prominent.

Recorded a temperature of 22.5°C during post-monsoon season. pH recorded as 6.8 during post-monsoon season.

Habitat : Epilithic and epiphytic
Locality : Pooyamkutti, Ernakulam
Specimen number : CU No. 150040
Figure : 43 E-H

Family **Microchaetaceae** Lemmermann 1910

Heterocystous, filamentous, able to produce simple false branching. False branching generally initiated intercalary heterocytes, rare or common and resulting in richly divaricated specimens. Filaments often sessile, attached by basal parts to the substrate, generally morphologically modified in basal and terminal parts, cylindrical or slightly narrowed or widened towards the end, enveloped by a thick or thin sheaths. Thallus in the form of solitary filaments or groups of filaments. Occasionally creeping on the substrates, sessile, less frequently gathered in mats. Trichomes usually with basal heterocysts, uniseriate, never terminated by a thin long hair. Cells commonly barrel shaped or cylindrical, terminal cells usually widely rounded, less frequently conical. Akinetes present in few genera. Heterocytes present in all genera, solitary or in short rows, obligately basal, occasionally also intercalary. Reproduction by hormogonia or by disintegration of thallus.

Key to the genera

1a. Branches usually single ……………………..………………… **Hassallia**

1b. Branches geminate or solitary ………………...…………….. **Tolypothrix**

i. Tolypothrix Kutzing ex Bornet et Flahault 1887

Filaments usually aquatic or aerophytic in habitat. Attached or floating, solitary or many together, in clusters or in fascicles, rarely creeping, mostly erect; polarised, heteropolar in initial conditions. Flexuous, false branches present frequently, branches appeared to be bush like (dendroid). Usually branches are single, less frequently Scytonema like two branches are seen. Branches usually arise below intercalary heterocysts. Sheath present, firm, thin or slightly thickened, variable, less frequently gelatinized and lamellated, always with only one trichome inside a sheath. Trichomes monoseriate, showing terminal growth. Trichomes not constricted at the cross walls, cylindrical, certain species showing narrowed or widened shape towards ends. Cells usually cylindrical in shape, variable, barrel, quadrate or elongated shape also found. Colour usually blue-green. Olive green, yellowish green, green, brownish green, dull colour variants also found. Terminal cells round, usually larger than other vegetative cells. Heterocyst basal in common, intercalary heterocyst also present. Commonly develop on the basal region of false branches. Solitary, rarely in rows. Spherical, cylindrical or barrel shaped. Granules usually present. May or may not be prominent.

Key to the species

1a. Cells less than 8 µm wide ……………………………………………….. 2

1b. Cells more than 8 µm wide ……………………...………………… 3

2a. Heterocysts 6-10.5 µm wide ……………………………… ***T. teodorescui***

2b. Heterocysts 3-6 µm wide ……………………..………………. ***T. tenuis***

3a. Sheath lamellated ……………………..…………………………… 4

3b. Sheath unlamellated ……………………………………………….. 5

4a. Sheath thick, widening towards the end ……………….……. ***T. rechingeri***

4b. Sheath thin, tapering towards the end …………….…………… ***T. saviczii***

5a. Trichomes tapering towards the end ……….………….. ***T. conglutinata***

5b. Trichomes with same width towards the end ………………. ***T. penicillata***

1. Tolypothrix conglutinata Borzi ex Bornet et Flahault

Filaments flexuous, densely elongated, mucilaginous, forming blue-green or brownish slimy crustaceous thallus, with sheath 13-17 µm wider, not constricted at the cross walls; cells 8-10.5 µm wide, 3- 4.5 µm long, shorter in length, blue- green, green or brownish green colour, barrel shaped or quadrate, end cells larger than vegetative cells, tapering towards the end; heterocysts single, terminal heterocysts spherical or hemispherical, intercalary heterocysts spherical to barrel shaped, olive green or bright green colour, 6- 14 µm diameter; granules present, brownish content, not prominent; Sheath firm, rarely diffluent, hyaline, unlamellate, up to 2 µm thickness, widened towards the end.

Recorded a temperature of 20.7°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.1 during summer season.

Habitat	: Epilithic
Locality	: Nelliyampathy, Palakkad
Specimen number	: CU No. 191213
Figure	: 44 A-C

2. ***Tolypothrix saviczii*** Kossinskaja

Colonies dendroid (bush like), olive brown or yellowish brown colour; filaments straight or slightly bent, organised radially from the basal part, 16-19 µm wide with sheath, terminal parts slightly narrower and 12-14.5 µm width, trichomes cylindrical; not constricted at the cross walls in usual, rarely showing a slight constriction; cells cylindrical, quadrate or barrel shaped spheroidal at the ends, shorter than wide or isodiametric, pale olive green to yellowish brown colour, terminal cells are larger than vegetative cells, 11-16 µm wide, 7-12 µm long; heterocysts are terminal and intercalary, usually solitary, spherical or hemispherical in shape, 13-17 µm in diameter; Sheath firm, thin or occasionally thick, hyaline, slightly lamellated; granules present not prominent; vacuoles often seen.

Recorded a temperature of 20.3°C during post-monsoon season and 28.6°C during summer season. pH recorded as 7.5 during post-monsoon season and 7.1 during summer season.

Habitat : Epilithic
Locality : Attappadi Ghat, Palakkad
Specimen number : CU No. 145511
Figure : 44 B & E

3. ***Tolypothrix tenuis*** Kutzing ex Bornet et Flahault

Colonies forming cluster like appearance, olive green or green colour, occasionally brownish, attached to a substrate, later free floating; filaments long, straight or slightly coiled, up to 14 µm width with sheath, false branches very frequently arise, diverge obliquely from mother filament, usually single, rarely scytonemoid type branching; trichomes cylindrical or elongate, slightly constricted at the cross walls; cells cylindrical, elongate or isodiametric, usually longer than wide, rarely shorter than width, in older parts cells narrower, long and more cylindrical, blue-green colour, rarely olive green or yellowish green, 2-7.5 µm wide, 4-10 µm long, rarely up to 14 µm long older parts; heterocysts solitary, rarely in rows, spherical, hemispherical or barrel shaped, with rounded ends, 3-6 µm long, 2-4.5 µm wide, green, yellow or brown colour; sheath firm, thick, unlamellate or distinctly lamellate, colourless to light green colour, up to 4 µm thick in older parts, thin in primary stage; granules present, not prominent.

Recorded a temperature of 20.7°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.1 during summer season.

Habitat : Epilithic
Locality : Nelliyampathy, Palakkad
Specimen number : CU No. 191207
Figure : 44 F-H

4. *Tolypothrix teodorescui* Tarnavschi et Mitroiu

Filaments many together, rarely solitary, entangled, straight, false branches single or in two rows (scytonemoide type), with sheath 10-24 µm wide; trichome cylindrical, not constricted at the cross walls; cells isodiametric, barrel shaped, quadrate or cylindrical, brownish green or brownish yellow colour, long and more cylindrical in older parts, 4-7.5 µm wide, 4-10.3 µm long; heterocyst terminal or intercalary, usually single, barrel shaped, quadrate or spherical, 7-10 µm wide and 6-10.5 µm long, brown or olive green colour; sheath firm, thick, brown coloured or colourless, distinctly lamellate, widened in the plane of branching; granules present, not prominent.

Recorded a temperature of 21.5°C during post-monsoon season and 29.2°C during summer season. pH recorded as 7.0 during post-monsoon season and 6.7 during summer season.

Habitat : Epilithic and edaphic
Locality : Chelachuvad, Idukki

Specimen number : CU No. 153091

Figure : 45 A & B

5. Tolypothrix penicillata Thuret ex Bornet et Flahault

Colonies fasciculate, soft, occasionally form cushion like formations, blue-green or olive green colour, rarely brown, filaments highly false branched, 10-13 µm wide; trichomes cylindrical, slightly or not constricted at the cross walls, not widened or attenuated towards the ends; cells isodiametric or slightly longer than wide, cylindrical, quadrate or slightly barrel shaped, blue-green or olive green in colour, 10-13 µm wide, 7.5-18 µm long, end cells usually more elongated; heterocysts intercalary, spherical, cylindrical or barrel shaped, 12-14 µm wide, 15-20 µm long, solitary or up to four in a row; sheath thin, firm, attached to trichome, hyaline, sometimes older sheath become yellowish brown; granules present, not prominent.

Recorded a temperature of 24.0°C during post-monsoon season and 28.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.2 during summer season.

Habitat : Epilithic and epactiphytic

Locality : Ambalappara, Kozhikode

Specimen number : CU No. 153048

Figure : 45 C-F

6. Tolypothrix rechingeri (Wille) Geitler

Colonies soft, thallus cushion like, brownish or olive green colour; filaments usually erect, 12.5-18 µm wide, with irregular single false branching; trichomes cylindrical, not constricted or occasionally slightly constricted at the cross walls, greenish brown or brown colour; cells usually isodiametric, or slightly longer or shorter than wide, blue-green or brownish green colour, 12.5-18 µm wide and 12-20 µm long; heterocysts spherical, quadrate, hemispherical in shape, 14-20 µm wide, 12-16 µm long, yellowish brown colour, sheaths firm, thin to thick, not widened towards the end, outer layers hyaline, inner layers yellow-brown or brownish colour, lamellated; cell content is finely granular, not prominent.

Recorded a temperature of 20.7°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.1 during summer season.

Habitat	: Epilithic
Locality	: Nelliyampathy Ghat, Palakkad
Specimen number	: CU No. 191213
Figure	: 45 G & H

ii. **Hassallia** Berkeley ex Bornet & Flahault 1886

Filament occur usually subaerophytically, solitary or in clusters. Irregularly tufty or occasionally as crustaceous mats. False branched, often fragmented. Branches solitary, usually shorter, commonly bend to one side. Usually with basal heterocysts, very rarely developing without heterocysts. Sheaths usually firm, thin to thick, often lamellated, close to the trichome or slightly widened, colourless or yellowish in colour. Trichomes cylindrical, usually constricted at the cross walls. Cells always short, distinctly shorter than wide. Heterocysts mainly basal, solitary, hemispherical, spherical rarely oval in shape. Akinetes not observed. Reproduction by hormogonia and fragmentation of filaments.

Key to the species

1a. Filaments 5-7.5 µm wide ……………………………………..….. ***H. bouteillei***

1. ***Hassallia bouteillei*** Bornet et Flahault

Filaments 5-7.5 µm wide, spherical, blackish brown colour, mat like structure, bent or arcuated false branches; trichomes cylindrical, constricted at the cross walls, not attenuated towards the periphery; cells barrel shaped, short, 4-5 µm wide; apical cells rotund; heterocyst solitary, basal on trichomes or branches; granules present, sometimes prominent; aerotopes occasionally found.

Recorded a temperature of 23.8°C during post-monsoon season and 31.2°C during summer season. pH recorded as 7.4 during post-monsoon season and 6.7 during summer season.

Habitat	: Epactiphytic and epilithic
Locality	: Pottachira, Thrissur
Specimen number	: CU No. 145514
Figure	: 46 A-D

Family **Chlorogloeopsidaceae** Mitra & Pandey 1967

Heterocysts present, generally placed irregularly or apically in colonies, single, intercalary and terminal. Cells in colonies organized or irregularly, sometimes only in few celled groups. Thallus in the form of multidimensional, packet like clusters of irregular trichomes and cells, sometimes forming irregular short filaments. Trichomes sometimes in pleurocapsoid stages, cylindrical up to monoliform, uniseriate up to multiseriate without distinct branches. Dormant stages in form of akinete like cells with thickened cell walls. Binary fission of cells in more planes. Reproduction by akinetes, hormogonia, also by baeocytes.

Key to the genus

The family consists up to now only one genus

i. **Chlorogloeopsis** Mitra & Pandey 1967

Thallus in the form of a compact stratum, composed from rounded cells or irregular packet like formations with agglomerations of cells. Sometimes irregular short filaments or rows of cells with lengthwise or up to 3 dimensional cell division. Cells spherical or irregularly spherical, sometimes irregularly hemispherical or barrel shaped. Heterocysts terminal in packet like groups or occasionally intercalary, irregularly disposed. Typical types of akinetes not observed. But arthrospores (akinete like cells with thickened cell walls) arise after division. Reproduction mostly by disintegration of trichomes or thallus. Sometimes also by hormogonia and baeocytes.

1. ***Chlorogloeopsis fritschii*** (A.K. Mitra) Mitra et Pandey

Thallus forms an amorphous mat, composed of irregular, rounded cells packets, typical trichomes are not formed, uniseriate filaments, 5-20 cells in a row; cells rounded or spheroidal, pale blue-green colour, 4.2-8.5 µm diameter; sheath hyaline, firm, not lamellate; granules present, not prominent; vacuoles not common; heterocyst terminal or intercalary, spherical or elongated, 2.5-4.5 µm long and 2-5 µm broad.

Recorded a temperature of 22.6°C during post-monsoon season. pH recorded as 7.4 during post-monsoon season.

Habitat	: Edaphic and epactiphytic
Locality	: Gavi, Pathanamthitta
Specimen number	: CU No. 153081
Figure	: 46 E-H

Family **Hapalosiphonaceae** Elenkin 1916

Thallus in the form of true branched, clustered filaments, which are comprised from sheaths and trichomes; all filaments and branches are morphologically similar. Branches cylindrical, or narrowed towards ends, rarely up to hair like attenuated. Trichomes uniseriate, often constricted at the cross walls, divaricated, but morphologically not divided into main trichomes and branches, moniliform, but commonly cylindrical, true branched, with T, V and Y branching. Cells cylindrical, barrel shaped or rarely rounded irregular; terminal cells generally rounded. Heterocytes usually barrel shaped or spheroidal, intercalary, sometimes missing. Akinete like dormant cells missing. Reproduction by hormogonia, hormocytes, arthrospores, rarely by baeocytes.

Key to the genus

1a. Trichomes usually with cylindrical shaped cells ………… **Chondrogloea**

1b. Trichomes usually with barrel shaped cells …………..………………… 2

2a. Branching strictly T-type ……………………..…………… **Hapalosiphon**

2b. Branching T-type or Y-type ……………….……………. **Mastigocladus**

i. **Chondrogloea** Schmidle 1901

Thallus composed of many true branched filaments. Filaments free, flexuous, entangled and long. Cylindrical in shape, some parts almost torulous with wider and narrower portions. Branches arising laterally, one sided, occasionally cylindrical at their bases. Upper parts usually torulous and again narrowed and cylindrical near the ends. Growing only from trichome parts with cylindrical cells. Sheaths thin, closely attached to trichomes, indistinct, usually colourless to pale yellow in colour, unlamellated. Trichomes uniseriate, slightly constricted at the cross walls, but unconstricted in the younger branches, especially in the terminal parts. Cells usually polymorphic in different parts of trichome. Long and cylindrical in common, occasionally barrel shaped or shortly barrel shaped. Heterocysts intercalary, rod shaped, barrel shaped, elongate or oval. Akinetes unknown. Reproduction probably by hormogonia and disintegration of thallus.

Key to the species

1a. Filaments 10 µm wide ……………………….……..…… ***C. flagelliformis***

1. ***Chondrogloea flagelliformis*** (Schmidle) Schmidle

Thallus small, dark in colour; filaments true branched, up to 10 µm wide, branches usually one sided, tapering towards the end, mother filament distinctly constricted at the cross walls; cells barrel shaped or spherical, slightly longer or shorter than wide 6-8 µm wide, 5-9 µm long; heterocyst intercalary, size almost same as vegetative cells, cylindrical or elongated; sheath present, very thin, firm, colourless.

Recorded a temperature of 23.4°C during post-monsoon season and 31.8°C during summer season. pH recorded as 7.5 during post-monsoon season and 6.9 during summer season.

Habitat : Epiphytic

Locality : Peechi, Thrissur

Specimen number : CU No. 153200

Figure : 47 A

ii. Hapalosiphon Nageli in Kutzing ex Borney et Flahault 1887.

Thallus aquatic, thin, floccose or caespitose, composed with free filaments which entangled together; Filaments free floating, flexuous, irregularly curved or straight. Commonly T- like true branches are seen, sometimes only unilateral and erect from primary prostrate filaments, very rarely possess scytonematoid type branches. Branches irregular, usually divaricated. Branches are morphologically similar to the mother filament. Sheaths thin, firm, very close, rarely widened. Lamellation may or may not observe. Trichomes uniseriate. Two cells beside one another was seen only during branch production. Cylindrical, old parts become torulous. Branches also cylindrical in nature. Cells barrel shaped in usual, cylindrical, spherical, quadrate and oblong cells are also found. Terminal cells cylindrical or rounded. Heterocysts always intercalary, very rarely lateral, usually solitary. Reproduction by the disintegration of thallus. Hormogonia develop in the lateral branches also helps in the reproduction.

Key to the species

1a. Cells barrel shaped ……………………………….…………………. 2

1b. Cells almost spherical ……….……….……………………… ***H. welwitschii***

2a. Heterocysts spherical …………………………..………… ***H. luteolus***

2b. Heterocysts cylindrical or barrel shaped …………….……. ***H. intricatus***

1. Hapalosiphon luteolus West et G.S. West

Thallus dark blue-green, microscopic; main filaments densely entangled, looks like small tufts; filaments cylindrical, branches lateral, morphologically similar to mother filaments, almost same width along the whole filaments, 9-13 µm wide, branches of different length, usually flexuous or variously curved; trichomes cylindrical, constricted at the cross walls, blue-green colour; cells barrel shaped or cylindrical, 5.5-8.5 µm wide, 5.5-8 µm long, sometimes isodiametric, green, blue-green, olive green or yellowish green colour; heterocysts cylindrical to barrel shaped, longer or shorter than wide, sometimes spherical, 7-10 µm diameter, olive green colour; sheath firm, occasionally thick, usually thin, unlamellated, hyaline; granules present, not prominent.

Recorded a temperature of 23.4°C during post-monsoon season and 31.8°C during summer season. pH recorded as 7.5 during post-monsoon season and 6.9 during summer season.

Habitat : Benthophytic

Locality : Peechi, Thrissur

Specimen number : CU No. 158551

Figure : 47 B & C

2. Hapalosiphon welwitschii West et G.S. West

Filaments usually found among other algae or cyanobacteria, sometimes free, irregularly curved, flexuous or coiled, up to 9 µm wide, laterally branched, short or long, slightly narrower than main filament, also slightly tapering towards the end. Trichome cylindrical, constricted at the cross walls, while remains unconstricted or slightly constricted at branches; dull blue-green colour, cells or main filament barrel shaped or cylindrical, rarely rounded or quadrate, 5-8.5 µm diameter; heterocysts rare, spherical, hemispherical or barrel shaped, olive green colour, same size of vegetative cells or slightly larger 5-9.5 µm diameter; sheaths very thin, firm, sometimes only slightly visible, unlamellated, usually colourless; granules present, sometimes prominent.

Recorded a temperature of 22.6°C during post-monsoon season. pH recorded as 7.4 during post-monsoon season.

Habitat	: Epilithic
Locality	: Gavi, Pathanamthitta
Specimen number	: CU No. 153073
Figure	: 47 D

3. Hapalosiphon intricatus West et G.S. West

Thallus blue green or dark green colour; filaments as densely entangled clusters, blue green colour, up to 8 µm wide, scarcely and irregularly branched, branches with same morphology of main filaments; sheaths thin, sometimes indistinct or diffluent, colourless, hyaline, unlamellated; trichomes usually uniseriate, constricted at the cross walls, slightly narrowed towards the ends of branches, 6-8 µm wide; cells barrel shaped, spherical or cylindrical, rarely isodiametric, in branches longer than shorter, 5.6-6.5 µm wide, 6-9 µm long, blue green or dull blue green colour; heterocysts intercalary, barrel shaped or cylindrical, yellowish colour, 4.5-7 µm wide and 5-10 µm long; granular contents high, blue green colour, prominent.

Recorded a temperature of 22.5°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.4 during post-monsoon season and 7.1 during summer season.

Habitat : Epactiphytic and benthophytic

Locality : Poringalkuthu, Thrissur

Specimen number : CU No. 191249

Figure : 47 E & F

iii. Mastigocladus Cohn ex Kirchner 1898

Thallus in the form of prostrate colonies, irregular, firm, spongy. Sometimes impregnated by sand particles, sometimes layered. Blue- green or olive green in colour. Solitary filaments or mixed with other algae or cyanobacteria. Filaments true branched, T- type or V- type branching, rarely Y- type branching. Creeping with long, usually continually attenuated branches. Trichomes uniseriate, older parts highly constricted, branches also showing constriction. Branches sometimes cylindrical, narrowed towards the end. Cells barrel shaped in common, rarely cylindrical. Cells in branches cylindrical or barrel shaped, terminal cells narrowed, elongated. Heterocysts intercalary, barrel shaped or quadrate with soft edges. Akinetes unknown. Sheaths thin, firm, gelatinised. Attached to trichome, hyaline, unlamellated. Reproduction by disintegration of filaments and also by hormogonia.

Key to the species

1a. True branched, 4.5-7 µm wide ……………………….……. ***M. laminosus***

1. Mastigocladus laminosus Cohn ex Kirchner

Thallus membraneous, sometimes leathery, firm, spongy, dirty blue-green or olive green in colour, sometimes impregnated by several particles; filaments densely elongated, 4.5-7 µm wide, irregularly flexuous, true branched, T-type or V-type branches, rarely Y-type branched; branches usually narrower than the main filament; trichomes divaricated in right angles, constricted more in older parts, cylindrical and sometimes unconstricted in branches; cells barrel shaped, rarely cylindrical, shorter or longer than wide , often in irregular length, 4-12.5 µm long, 3-6 µm broad, branches with cylindrical shaped cells, sometimes barrel shaped or quadrate cells are also found, 2-5 µm broad, 3-8 µm long, dull blue- green or olive green colour, apical cell with rounded ends, sometimes cylindrical; heterocysts intercalary, barrel shaped, spherical, cylindrical or elongated, 3.5- 7 µm wide, 4-9 µm long, usually solitary, rarely in pairs; sheaths thin, firm, later diffluent, unlamellate, hyaline; granules present, occasionally prominent.

Recorded a temperature of 19.4°C during post-monsoon season and 29.7°C during summer season. pH recorded as 7.5 during post-monsoon season and 7.2 during summer season.

Habitat	: Epiphytic
Locality	: Sholayar dam, Thrissur
Specimen number	: CU No. 153129
Figure	: 47 G & H

Family **Fischerellaceae** Anagnostidis & Komarek 1990

Thallus often comprised of morphologically distinct main filaments, usually forming a creeping part, from which grow erect. Heterocystous, filamentous cyanobacteria with obligately true branched trichomes and facultatively and secondarily false branched filaments. The combination of true and false branching is characteristic for a majority of the genera. The main trichomes monoseriate or multiseriate, usually more torulous or moniliform, thicker; the branches morphologically different, generally more cylindrical, narrower and only uniseriate, erect. Filaments less frequently different in bases and apical parts. Occasionally chroococcoid stages occur. Sheaths always present, homogeneous or lamellated, thin or thick, colourless or yellowish to brown. Cells irregularly rounded or barrel shaped, less frequently cylindrical, dividing length wise or cross wise. Heterocytes intercalary. Akinetes only in a few genera. Reproduction by hormogonia, hormocytes, monocytes, or by disintegration of thallus.

Key to the genera

1a. Filaments with widened, lamellated sheath ……………… **Fischerellopsis**

1b. Filaments with thin, unlamellated sheath ………………..… **Westiellopsis**

i. Fischerellopsis Fritsch 1932

Filaments in parallel arranged fascicles within a common gelatinous, later different envelope. Single or creeping type. Branches true and lateral, T-type branches, slightly narrowed towards end or uniform like main filament. Filaments flexuous, ends are club shaped. Club shaped ends later change into hormogonia. Sometimes club shaped hormogonia arise from both ends of the main filaments. Trichome usually uniseriate, rarely with biseriate cells. Prominently constricted at the cross walls, constriction also found in branches. Cells cylindrical or barrel shaped, normally shorter than wide, occasionally larger than wide. Heterocysts single. Found both in main filament and branches. Rounded or cylindrical, rarely compressed. Akinetes not reported from main filaments. Sheath thin or thick. Irregular from outside, lamellated, lamellation parallel or vertical. Showing a funnel like divergence in the terminal parts of branches and hormogonia. Reproduction is by club shaped hormogonia, liberated from sheath.

Key to the species

1a. Cells 5-9 µm wide, sheath broad …………..………..…. ***F. moniliformis***

1. Fischerellopsis moniliformis (Fermy) Fritsch

Filaments single, within a mucilaginous envelope, 14-22 µm wide, up to 27 µm branches in the tip portion, the branches are of T- type, rarely Y-type branches found, false branches very rare, lateral branches similar, 13-20 µm in width; pseudobranches short; trichomes uniseriate, clearly constricted at the cross walls; cells short, barrel shaped, 5-9 µm wide, 3-7 µm long, shorter than wide, branches almost have the same characteristic features as main filament, dull green or greenish brown colour; hormogonia arise from the pseudobranches; sheath thin at main filament, widened in branches mainly towards the tip region, divergent, highly lamellated, hyaline or brownish green colour; granules present, not prominent.

Recorded a temperature of 19.4°C during post-monsoon season and 29.7°C during summer season. pH recorded as 7.5 during post-monsoon season and 7.2 during summer season.

Habitat : Epilithic

Locality : Sholayar lower dam, Thrissur

Specimen number : CU No. 153127

Figure : 48 A-D

ii. Westiellopsis Janet 1941

Thallus filamentous, true branched filaments, main filaments thicker than branches, creeping composed of uniseriate or biseriate cells, rarely multiseriate branches are found. Branches torulous, trichomes irregular and firm. Sheath present, hyaline, not lamellated. Branches common, arising from main filaments, lateral, T-type branching, sometimes aggregated, thinner than main filaments. Erect, composed usually from uniseriate trichomes and thin sheaths. Cells in main trichome spherical-rounded, oval up to barrel shaped, often different in shape (also in one trichome) cells may longer or shorter than wide, chroococcoid parts almost spherical. Cells more uniform in branches. At the basal part of branch, cells showing similarities with the main branch cells. Upper part more elongated, cylindrical. Heterocysts intercalary in common, very rarely laterally. Spherical, oblong, oval, quadrate or cylindrical in shape. Akinetes are like enlarged cells with thicker cell walls. Reproduction is by uniseriate hormogonia (rarely more seriate), monocytes (Solitary reproduction cells) sometimes escape from filaments and form chroococcoid stages.

Key to the species

1a. Cells 3.5-6.8 µm in width ………………………………………. ***W. indica***

1b. Cells 6-11 µm in width …………………………..………….. ***W. prolifica***

1. Westiellopsis prolifica Janet

Main filament torulous, with mono to biseriate trichomes. Trichomes distinctly constricted at the cross walls; Branches common, true, T-type. Usually thinner than main filament, branches showing constrictions only in the basal parts; later cylindrical and not constricted, blue-green colour. 7-14 µm long and 6-11 µm wide; cells in branches, narrower, elongated quadrated or cylindrical in shape; blue-green colour, 7.5-15 µm long and 4.5-6 µm wide; heterocysts quadrate, oblong or cylindrical, 11-20 µm long, 6-10 µm broad, yellow or olive green colour, sheath present, thin, hyaline not lamellate; granules present, not prominent.

Recorded a temperature of 22.5°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.4 during post-monsoon season and 7.1 during summer season.

Habitat : Epactiphytic and benthophytic

Locality : Poringalkuthu, Thrissur

Specimen number : CU No. 191249

Figure : 48 E & F

2. Westiellopsis indica Bourrelly

Thallus forming dark green, green or yellowish green mats; filaments entangles, many together, highly branching, branches sometimes fasciculated; main filament usually monoseriate, occasionally biseriate in condition, richly branched; constricted at the cross walls; filaments towards the tip, slightly narrower; cells barrel, cylindrical, elongated or spherical, 4-8 µm wide, length up to 13 µm, cells in the branches are narrower and elongated than the cells in main filaments, up to 16 µm long and 3.5-6.8 µm broad; heterocysts cylindrical, barrel or spherical in shape, sometimes elongate or oblong heterocysts are also noticed, 8-16 µm long, 5-8 µm broad; sheath present, delimited, hyaline, unlamellate, thin, sometimes indistinct; granules present, not prominent.

Recorded a temperature of 25.8°C during post-monsoon season and 31.7°C during summer season. pH recorded as 6.8 during post-monsoon season and 7.1 during summer season.

Habitat	: Epactiphytic and benthophytic
Locality	: Poringalkuthu, Thrissur
Specimen number	: CU No. 191249
Figure	: 48 G & H

Family **Stigonemataceae** Borzi 1892

Filaments with branches of the same size and form as the main parts, but occasionally continually narrowed towards the ends. The whole thallus represents usually one organism with diversified parts and shows true branching. Filaments mainly moniliform or torulous, with colour, lamellated and firm sheaths. Trichomes monoseriate to polyseriate, consisted often from irregular rounded or spheroidal cells. Heterocytes lateral or intercalary, in young filaments and hormogonia occasionally terminal. Akinetes present in various species. Reproduction by disintegration of thallus and hormogonia, also by monocytes or hormocytes.

Key to the genera

1a. Thallus composed only with monoseriate filaments ………… **Doliocatella**

1b. Thallus composed with multiseriate filaments ………………… **Stigonema**

i. **Doliocatella** Geitler 1933

Colonies bush like, sometimes grass like, erect, caespitose, composed from filaments. Attached to a substrate. Filaments do not develop a basal prostrate thallus, near the basis thick and torulous. Usually uniseriate. Rarely cells dividing longitudinally and producing filaments side by side in a filament. In younger parts, thin and more or less cylindrical, uniseriate, T- like branched. Branches usually short, straight or slightly curved. Cells spherical or cylindrical, rounded, heterocysts not observed. Sheath thin, firm, unlamellated, coloured or hyaline. Reproduction is by fragmentation or by hormogonia.

Key to the species

1a. Filaments up to 27 µm wide …………………………….…… ***D. formosa***

1. Doliocatella formosa Geitler

Colonies brown or brownish green colour, main filaments up to 27 µm wide, young branches up to 20 µm wide; trichome composed of individual envelopes, branches are smaller than the main filament, brownish colour; cells barrel shaped or irregularly spherical, isodiametric or occasionally longer or shorter than wide, 4.5-10 µm diameter, pale brownish green colour, branches more elongated, rounded or cylindrical, true braches, branches shorter than main filaments; sheath not lamellated , brown or brownish green in usual, occasionally colourless; granules present, not prominent.

Recorded a temperature of 25.0°C during post-monsoon season and 32.3°C during summer season. pH recorded as 7.2 during post-monsoon season and 6.7 during summer season.

Habitat	: Corticolous
Locality	: Paithalmala, Kannur
Specimen number	: CU No. 158549
Figure	: 49 A-D

ii. Stigonema Agardh ex Bornet et Flahault 1886

Thallus composed of multiseriate cells, rarely uniseriate, or biseriate arrangements are seen. Irregularly waved filaments with creeping or erected nature. Mucilage sheath firm, thin to thick, widened particularly in older filaments. Sheaths homogenous, lamellated or absent. Mostly hyaline, rarely coloured. Filaments solitary, forming cushion like tufty patches. Found attached with any substrates and commonly among other algae. Rarely free-floating. Filaments repeatedly branched, branching may be irregularly and rapidly. At the basis of filaments sometimes irregular clusters of chroococcoid stages. Filaments growing usually apical with definite apical cells, segmentation cells. Branches showing resemblances with main filaments. Occasionally narrower than the main filament, rarely tapering towards the end. Cells globose, depressed globose, ovate or irregularly rounded. In older parts cells become quadrate with soft edges. Sometimes with diffluent, hyaline sometimes concentrically lamellated envelopes are also found. Heterocyst basal or intercalary in position, shape varies spherical, hemispherical, cylindrical or oblong. Reproduction is by fragmentation of the thallus. Granules present, rarely prominent.

Key to the species

1a. Filaments more than 25 µm, sheath thick …………………… ***S. turfaceum***

1b. Filaments less than 25 µm, sheath thin ……………………………… 2

2a. Cells less than 8 µm in diameter ………………..…… ***S. minutissimum***

2b. Cells more than 8 µm in diameter ……………………………………… 3

3a. Filaments 1-2 seriate …………………………………… ***S. tomentosum***

3b. Filaments 1-4 seriate ……………..……………………….. ***S. minutum***

1. Stigonema minutissimum Borzi

Colonies thin, blackish or brownish, crystal, filaments with creeping nature at initial stage, densely entangled, later becoming erected; filaments up to 25 µm wide, uniseriate in initial, then become 3- many seriate, sometimes cluster like arrangement (irregular) of cells also found, branches very rich, repeatedly and irregularly branched, branches short, few celled, monoseriate rarely multiseriate, basal portion always multiseriate; cells irregularly spherical or quadrate, usually gathered one to another, size showing variations 4-8 µm diameter; heterocysts intercalary or lateral, smaller than vegetative cells, 3-6 µm diameter, irregularly spherical; hormogonia short, 2-few celled, ellipsoidal; sheath thin, brownish green or brown colour; granules rare, not prominent.

Recorded a temperature of 20.2°C during post-monsoon season. pH recorded as 6.9 during post-monsoon season.

Habitat : Epilithic

Locality : Pongalappara, Thiruvananthapuram

Specimen number : CU No. 153138

Figure : 49 E & H

2. Stigonema tomentosum Hieronymus

Thallus brown or blackish brown colour, tufty; main filaments creeping type, 16-26 µm broad, mostly uniseriate, occasionally some parts showing biseriate cells; erect branches arise from main filament, width of branches and main filaments are almost same, commonly arranged in dense fascicles, usually uniseriate, rarely with paired cells; cells barrel shaped, elongate or spherical 8-14 µm wide, brownish green or brown colour, connected with cylindrical terminal trichome; heterocysts intercalary, barrel, spherical or elongate, 10-13 µm long; sheath thin, rarely thick, brown or brownish yellow colour, distinctly lamellated; granules absent or rare.

Recorded a temperature of 19.9°C during post-monsoon season and 30.7°C during summer season. pH recorded as 6.9 during post-monsoon season and 6.4 during summer season.

Habitat : Epactiphytic

Locality : Ambalavayal, Wayanad

Specimen number : CU No. 158531

Figure : 50 A & B

3. ***Stigonema turfaceum*** Cooke ex Bornet et Flahault

Colonies look like a pillow, black or dark brown, filaments entangled, creeping in lower parts, later erect, 25-40 µm wide, richly branched with erect branches, branches growing in the same direction of main filament, branches showing similar features of main filament, only the end portions showing slight narrower or wider features; trichomes biseriate to multiseriate, branches also showing the same features; cells spherical or irregularly spherical, 6-10 µm diameter, brownish green, yellowish brown or brown colour; heterocysts spherical or irregular, usually lateral, compressed more, rarely intercalary; sheath thick, lamellated, brown or yellow-brown colour; granules present, not prominent.

Recorded a temperature of 22.4°C during post-monsoon season. pH recorded as 7.4 during post-monsoon season.

Habitat : Epilithic

Locality : Variyamkuthu, Ernakulam

Specimen number : CU No. 150043

Figure : 50 C-E

4. ***Stigonema minutum*** Hassall ex Bornet et Flahault

Thallus thin, brown to black colour, pillow like or crusty, usually attached to a substrate; filaments entangled, creeping, branched, 11-25 µm wide, blue green colour, 1-4 seriate, branches usually short, branches slightly narrower than main filaments; trichomes with 1-4 cells aside, branches 1-2 seriate; cells blue green colour, spherical, hemispherical or perpendicularly oval in shape, 9-18 µm wide and 6-13 µm long; heterocysts intercalary or lateral, hemispherical, spherical or oval shape, 8-14 µm diameter; sheath thin, firm, lamellated, brownish yellow colour; granular content fine, not prominent.

Recorded a temperature of 22.5°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.4 during post-monsoon season and 7.1 during summer season.

Habitat	: Epilithic and edaphic
Locality	: Poringalkuthu, Thrissur
Specimen number	: CU No. 191271
Figure	: 50 G & H

Family **Nostocaceae** C.A. Agardh ex Kirchner 1898

Heterocystous, filamentous cyanobacteria with free localized uniseriate trichomes, enveloped by firm or fine mucilaginous sheaths; filaments flexuous, straight, contorted or screw like coiled, without true or false branching. Several genera occur in benthos, plankton, in metaphyton, periphyton, on soil, numerous species are endophytic in algae, ferns or spermatophytes. They grow in solitary filaments or form microscopic to macroscopic colonies, mucilaginous mats, in some benthophytic or aerophytic genera enveloped by a firm periderm. Trichomes moniliform or cylindrical, constricted or not constricted at the cross walls, sometimes narrowed towards both ends, usually without meristematic zones, with all vegetative cells capable of division. Cells spherical, barrel shaped to cylindrical, end cells rounded, conical, acutely pointed or cylindrical and bluntly rounded. Heterocytes present, or only terminally on both trichome ends, or intercalary and causing the several types of symmetric, sub-symmetric or metameric trichomes. The cytomorphological type of akinetes is characteristic for *Nostoc*. Akinetes present, occasionally several times larger than vegetative cells, with taxon specific morphology and size for different genera and species, with morphologically distinct cell walls. They are formed from one vegetative cells or after fusion of several vegetative cells and develop regularly proximal or distant from heterocytes. Cell division by binary fission. Reproduction by motile or immotile hormogonia, by akinetes, and by fragmentation of thallus and filaments.

Key to the genera

1a. Heterocysts intercalary or terminal ……………….…………………… 2
1b. Heterocysts terminal on both sides ……………………. **Cylindrospermum**
2a. Trichomes usually within a sheath ……………….………………….. 3
2b. Trichomes usually without sheath ……………………………………… 6
3a. Trichomes always within a sheath ……………...…………………….. 4
3b. Trichomes occasionally within a sheath …………..……………………. 5
4a. Cells always shorter than wide …………….…………………. **Nodularia**
4b. Cells longer or shorter than wide ………………..……………. **Aulosira**
5a. Trichomes long, cells usually isodiametric ……………………….. **Nostoc**
5b. Trichome short, cells with different size ………………………… **Mojavia**
6a. Akinetes distinct …………………...…………………………………. 7
6b. Akinetes may or may not see ……………...………………………… 8
7a. Akinetes present in both sides of heterocyst …..…… **Sphaerospermopsis**
7b. Akinete present in all positions ………………..……………… **Anabaena**
8a. Presence of chrococcoid stages ……………...……………………….. 9
8b. Chroococcoid stages not present ……………………..……….. **Aliinostoc**
9a. Heterocysts always intercalary …………..………………….. **Trichormus**
9b. Heterocysts terminal or intercalary ………………………... **Desmonostoc**

i. Sphaerospermopsis Zapomelova et al. 2010

Filaments or trichomes solitary or in small groups, free floating, usually planktic, with different length, straight or flexuous, sometimes coiled. More or less constricted at the cross walls. Usually without mucilaginous sheath, occasionally present. Vegetative cells normally possess aerotopes or gas vesicles. Spherical, cylindrical or barrel in shape, length variability is high. During division cells become compressed. Terminal cells usually tapered and slightly elongated, acutely conical or conical rounded in shape. Heterocysts only found as intercalary, solitary, spherical or slightly elongated. Akinetes always spherical or widely oval, developing from both sides of heterocysts, 2-4 times larger than vegetative cells. Reproduction disintegration of trichomes.

Key to the species

1a. Cells barrel shaped, 2.5-12.5 µm long …………….. ***S. aphanizomenoides***

1. Sphaerospermopsis aphanizomenoides (Forti) Zapomelova et al

Trichomes free floating, solitary or in small groups, straight or flexuous, long or short, without mucilaginous envelopes, slightly to distinctly constricted at the cross walls, tapering towards the end; cells barrel shaped to almost spherical, isodiametric or shorter than wide, 2.5-12.5 µm long, blue green or dark blue green colour; terminal cells slightly narrowed, conical rounded, large or small than other cells; heterocysts intercalary, solitary almost spherical to slightly ellipsoidal, 4.5-8 µm diameter, yellowish colour; akinetes large, cylindrical or barrel shaped, 10-17 µm long, 8-13 µm wide, blue green; granular contents blue green colour, slightly prominent.

Recorded a temperature of 22.5°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.4 during post-monsoon season and 7.1 during summer season.

Habitat : Epiphytic
Locality : Poringalkuthu, Thrissur
Specimen number : CU No. 191251
Figure : 51 A & B

ii. Anabaena Bory ex Bornet et Flahault 1888

Colonies mucilaginous, thin to thick, forming slimy mass, usually macroscopic. Filaments normally composed with trichomes enveloped within mucilaginous sheaths, amorphous, indistinct, diffluent or occasionally limited. Rarely as solitary, usually joined in colonies and microscopic and macroscopic gelatinous mats. Trichomes irregularly entangled, flexuous, less frequently coiled, always constricted at the cross walls, cylindrical or narrowing over a few terminal cells. Cells usually spherical, cylindrical or barrel shaped, gas vesicles and aerotopes are absent. Heterocysts intercalary, very rarely as terminal, usually solitary, spherical, oval, elongated or cylindrical. Akinetes rarely spherical in few species, usually oval upto long cylindrical, intercalary, solitary or few in a row. Exospore smooth or sculptured, colourless to brownish. Reproduction by fragmentation of colonies, trichomes and by akinetes.

Key to the species

1a. Apical cells rounded ………………………………………………….. 2

1a. Apical cells conical …………………………………………………… 6

2a. Heterocysts more than 6 µm in size ………………..…………………. 3

2b. Heterocysts less than 6 µm in size ……………..………… ***A. schauderi***

3a. Cells isodiametric ……………………………..……….. ***A. sphaerica***

3b. Cells shorter or longer than wide ………….…………………………. 4

4a. Cells spherical with aerotopes ……………………...………………… 5

4b. Cells barrel shaped without aerotopes ……………….……… ***A. orientalis***

5a. Heterocysts always terminal ………………….……….. ***A. echinospora***

5b. Heterocysts intercalary, rarely terminal …………………….. ***A. constricta***

6a. Heterocysts barrel shaped …………………..…………………………. 7

6b. Heterocysts spherical ………………………… ***A. iyengarii*** var. ***unispora***

7a. Heterocysts 3.9-5.5 µm long …………………..…………….. ***A. sedovii***

7b. Heterocysts 6-9 µm long ……………………..………..…. ***A. hatueyi***

1. Anabaena hatueyi Komarek

Thallus mucilaginous, forming slimy mats; trichomes free floating, solitary comparatively short, straight, constricted at the cross walls, shortly and distinctly attenuated at the ends; cells barrel shaped to almost cylindrical, isodiametric or rarely longer or shorter than wide; aerotopes occasionally present, cells 3.5-5 µm diameter, terminal cells are slightly elongated, up to 8 µm long; apical cells usually conical, pointed or rounded conical; dark blue green, blue green colour; heterocysts intercalary, solitary or oval, sometimes slightly elongated, larger than vegetative cells, 5-8 µm wide, 6-9 µm long; sheath usually absent; cell content highly granular, blue green, prominent.

Recorded a temperature of 22.5°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.4 during post-monsoon season and 7.1 during summer season.

Habitat	: Edaphic and epiphytic
Locality	: Poringalkuthu, Thrissur
Specimen number	: CU No. 145501
Figure	: 51 C & D

2. ***Anabaena sphaerica*** Bornet et Flahault

Thallus mucilaginous, dark green, slimy; trichomes long, straight or flexuous, parallel or entangled together, usually as clusters, rarely solitary, blue green or bright blue green colour, constricted at the cross walls, not or slightly attenuated towards the end, cylindrical; cells barrel shaped or almost spherical, usually shorter than wide, sometimes isodiametric, blue green, 4.5-6.5 µm wide, 3-4.5 µm long; apical cells rounded; heterocysts spherical, mainly intercalary, rarely terminal, solitary, olive green colour, slightly larger than vegetative cells, 6-8 µm diameter; sheaths not visible, occasionally develop under unfavourable situations, thin, hyaline, diffluent; cellular content fine, granules more or less prominent, blue green in appearance.

Recorded a temperature of 22.7°C during post-monsoon season. pH recorded as 7.1 during post-monsoon season.

Habitat : Edaphic

Locality : Chembra, Wayanad

Specimen number : CU No. 153189

Figure : 51 F-H

3. ***Anabaena constricta*** (Szafer) Geitler

Filaments in a colourless mucilaginous mass, many entangled together, blue green in colour; trichome long, irregularly curved, no separate sheath for trichome; cells spherical or slightly barrel shaped, isodiametric, green, blue green or pale blue green colour, 4.5-7 µm diameter; granules prominent; heterocyst intercalary or terminal, up to 7.5 µm diameter, spherical or hemispherical, bright yellow to olive green colour, slightly bigger than vegetative cells.

Recorded a temperature of 21.6°C during post-monsoon season and 29.9°C during summer season. pH recorded as 7.3 during post-monsoon season and 6.9 during summer season.

Habitat : Epiphytic

Locality : Soochippara, Wayanad

Specimen number : CU No. 158522

Figure : 52 A & B

4. ***Anabaena echinospora*** Skuja

Filaments loosely arranged, in a colourless mucilage, bright green or blue green colour; trichome long, curved or rarely straight, sheath absent; cells spherical or shorter than wide, 4.7-6.8 µm long, 7.4-9 µm broad, bright green colour; heterocyst terminal, rarely intercalary, spherical, 7-8 µm diameter, yellow or olive green colour, equal or smaller than vegetative cells; granules highly prominent, vacuoles present.

Recorded a temperature of 22.5°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.4 during post-monsoon season and 7.1 during summer season.

Habitat	: Epactiphytic
Locality	: Poringalkuthu, Thrissur
Specimen number	: CU No. 145502
Figure	: 52 E-H

5. Anabaena iyengarii var. ***unispora***

Colony mucilaginous, many filaments together, straight or rarely curved, blue green or dark green colour; trichome solitary, slightly attenuated towards the end, without specialised sheath; vegetative cells barrel shaped, rarely spherical, almost equal in width and length, 3.5-7 µm long, 4.7-5.2 µm wide, dark blue colour; heterocyst spherical, 6-7.5 µm diameter, olive green colour, bigger than vegetative cells, mostly in intercalary position; akinetes ellipsoidal, 11-13 µm long and 7-8 µm wide, attached with heterocyst, mostly single or up to 3 in a row, sometimes seen in both sides of heterocyst, dark green colour; granules prominent.

Recorded a temperature of 23.4°C during post-monsoon season and 31.8°C during summer season. pH recorded as 7.5 during post-monsoon season and 6.9 during summer season.

Habitat	: Corticolous and epiphytic
Locality	: Peechi, Thrissur
Specimen number	: CU No. 191236
Figure	: 53 A & B

6. Anabaena orientalis S.C. Dixit

Many trichomes aggregate together to form a mat like appearance, thallus dark green or blue green; filaments straight, rarely form spiral appearance, closely arranged, individual sheath absent; cells spherical or quadrate, longer than width, 4.8-7 µm long, 4.5- 6.2 µm wide, bright green in colour, sometimes blue green or dark green in colour, constricted at the cross walls, granules present; heterocyst intercalary and terminal, spherical or ellipsoidal, 6.5-10 µm long, 7-8.3 µm broad, olive green or yellow colour, end cell conical without sharp end.

Recorded a temperature of 22.5°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.4 during post-monsoon season and 7.1 during summer season.

Habitat : Epactiphytic
Locality : Poringalkuthu, Thrissur
Specimen number : CU No. 191271
Figure : 53 E & F

7. Anabaena schauderi H. Welsh

Filaments long, mucilaginous, coiled or straight, many together, green or dull green in appearance; cells barrel shaped or quadrate, longer than wide, 4-5.3 µm long, 2.8-3.5 µm wide, blue green, green or dull green in colour; heterocyst spherical, hemispherical on tip region, barrel shaped or quadrate in intercalary position, 4-6 µm in length and 3.5-5.5 µm in breadth, colourless or dull yellow colour; granules prominent; vacuoles occurred rarely.

Recorded a temperature of 24.3°C during post-monsoon season and 30.7°C during summer season. pH recorded as 7.2 during post-monsoon season and 6.4 during summer season.

Habitat : Epilithic
Locality : Neriyamangalam, Ernakulam
Specimen number : CU No. 153093
Figure : 53 G & H

8. *Anabaena sedovii* Kosinskaya

Mucilaginous, many filaments attached together, look like a mat, blue green colour; filaments long, straight, constricted, bright green colour; cells barrel shaped or cylindrical, 4-6.3 µm long, 4.3-5 µm wide, bright green or yellow green colour; heterocyst terminal or intercalary, yellow, olive green or bright yellow colour, spherical, hemispherical or compressed, 4-5.9 µm long, 3.9-5.5 µm broad; granules prominent.

Recorded a temperature of 21.8°C during post-monsoon season and 28.5°C during summer season. pH recorded as 7.4 during post-monsoon season and 6.8 during summer season.

Habitat : Edaphic and epactiphytic

Locality : Thamarassery Ghat

Specimen number : CU No. 145233

Figure : 54 A & B

iii. Aulosira Kirchner ex Bornet et Flahault 1888

Thallus thick or thin, mat like or net like, mucilaginous green to brown in colour, filaments solitary or loosely clustered in small fascicles. Trichomes cylindrical and are in individual sheaths. Uniseriate, constricted or unconstricted. Straight or flexuous, rarely wavy. Sheaths firm, distinct, not widened, or rarely slightly widened. Usually unlamellate, but occasionally slightly lamellated. Cells usually cylindrical or barrel shaped, sometimes isodiametric, or slightly longer or shorter than wide. Heterocysts solitary, intercalary, spherical, quadrate, oval, hemispherical or barrel shaped. Occasionally found as compressed forms of these. Aerotopes normally absent. Akinetes develop apoheterocytically, in rows. Necridic cells may or may not present. Reproduction by hormogonia and by germination of akinetes.

Key to the species

1a. Cells 3-6 µm wide ………………………………………………… ***A. prolifica***

1b. Cells 6.8-9.5 µm wide …………………………………………… ***A. implexa***

1. ***Aulosira prolifica*** Bharadwaja

Thallus brownish green or yellowish brown colour, mucilaginous mat like; filaments long, straight or flexuous; trichomes arranged in a parallel manner, straight or slightly flexuous, usually constricted at the cross walls, not attenuated towards the end; cells barrel shaped, long, occasionally short, sometimes up to cylindrical in shape, brownish green or yellowish green colour, normally longer than wide, 3-6 µm wide, 5-14 µm long; apical cells rounded or conical rounded; heterocysts intercalary, occasionally terminal, wider than vegetative cells, oval, ellipsoidal, long or rarely spherical, sometimes barrel shaped, 4-9.5 µm wide, 7-16 µm long, olive green colour; sheaths thin, firm, later become diffluent, colourless, hyaline, sometimes outer layer showing rough nature, unlamellate; granular content fine, not prominent.

Recorded a temperature of 23.1°C during post-monsoon season and 30.3°C during summer season. pH recorded as 7.1 during post-monsoon season and 6.5 during summer season.

Habitat	: Epipelic
Locality	: Peruvannamuzhi, Kozhikode
Specimen number	: CU No. 158537
Figure	: 54 C & D

2. ***Aulosira implexa*** Bornet et Flahault

Thallus dark green colour; filaments mucilaginous, many together, blue green or dark green colour, 12 to 14 µm breadth; trichome long, variously curved; sheath thick, up to 2.5 µm, hyaline, not lamellate; cells barrel to cylindrical, compressed in older parts, dark green or blue green in colour, 6.8-9.5 µm broad and 10.5-19 µm long; heterocyst intercalary, quadrate or barrel shaped, 12-13.5 µm long, 12.5-14 µm broad, yellow to bright yellow colour; apical cell round; granules present, not prominent; vacuoles seen occasionally.

Recorded a temperature of 23.5°C during post-monsoon season and 33.4°C during summer season. pH recorded as 6.8 during post-monsoon season and 6.3 during summer season.

Habitat	: Benthophytic and planktic
Locality	: Pothundi, Palakkad
Specimen number	: CU No. 191208
Figure	: 54 E & F

iv. Cylindrospermum Kutzing ex Bornet et Flahault 1888

Filaments in amorphous, mucilaginous dark blue-green or brownish thallus. Trichomes situated irregularly in mucilage. Cylindrical in shape, unbranched, having same width throughout the whole length. Usually without sheaths. Both ends with cylindrical or conical cells, with rotund ends. From the terminal portion, heterocysts developed. Trichomes usually symmetric, with terminal heterocysts at both ends. Vegetative cells usually cylindrical, with rotund ends. Rarely barrel shaped. Isodiametric or elongated. Heterocyst only present in the terminal portion. Solitary, very rarely in pairs. Akinetes develop adjacent to the heterocysts. Solitary, very less frequently in rows up to 3. Reproduction by fragmentation of thallus and trichomes, or by germination of akinetes.

Key to the species

1a. Akinetes rhomboid in shape …………..………………………………… 2

1b. Akinetes oval ………………………………..…………... ***C. muscicola***

2a. Cells 4.5-6.8 µm wide, blue-green ………….……………… ***C. licheniforme***

2b. Cells 4.9-7.3 µm wide, pale green ……..…. ***C. licheniforme*** var. ***tumidum***

1. Cylindrospermum licheniforme Kutzing ex Bornet et Flahault

Many filaments aggregated to form mat like appearance, mats macroscopic, mucilaginous, blue-green or blackish colour; trichomes constricted at the cross walls, sinuous; cells blue-green colour, isodiametric, barrel or cylindrical, 4.5-6.8 µm long, 3-4.5 µm broad; heterocysts elongated, conical or cyndrical with round ends, slightly wide and longer than the trichome, olive green or brownish yellow, 8-12.5 µm long, 4-7.5 µm broad, intercalary heterocysts absent; akinetes elongated, rhomboid or ellipsoidal with widened sides, rarely cylindrical, 20-40 µm long, 15-23 µm broad, blue-green colour; granules present, prominent; exospore brown green or greenish yellow colour.

Recorded a temperature of 22.1°C during post-monsoon season. pH recorded as 7.4 during post-monsoon season.

Habitat : Edaphic and epipelic

Locality : Soolamudi, Ernakulam

Specimen number : CU No. 150047

Figure : 54 G & H; 55 A & B

2. Cylindrospermum licheniforme var. ***tumidum***

Many filaments aggregated, mat like appearance, macroscopic, mucilaginous, blue-green or green colour; trichomes constricted at the cross walls, flexuous; cells bright blue-green or bright green colour, isodiametric, barrel or cylindrical in shape, 4.9-7.3 µm long, 3.3-4.8 µm broad; heterocysts elongated or conical with conical end, slightly wide and longer than the trichome, olive green or greenish yellow colour, 7-12 µm long, 3.8-6.2 µm broad, intercalary heterocysts absent; akinetes elongated, rhomboid or ellipsoidal with widened sides and little flattened ends, rarely cylindrical, 23-45 µm long, 14-25 µm broad, bright blue-green or blue green colour; granules present, prominent; exospore colourless or hyaline.

Recorded a temperature of 20.6°C during post-monsoon season and 30.1°C during summer season. pH recorded as 7.5 during post-monsoon season and 6.9 during summer season.

Habitat : Epilithic

Locality : Seetharkund, Palakkad

Specimen number : CU No. 153107

Figure : 55 C & D

3. ***Cylindrospermum muscicola*** Kutzing ex Bornet et Flahault

Thallus mucilaginous, expanded, dark green or pale green colour; trichomes sinuous, barrel shaped or cylindrical, constricted at cross walls; cells pale blue-green or green colour, isodiametric, barrel shaped or cylindrical, slightly shorter or broader than wide, 4-6.5 µm long, 3-5.3 µm broad; heterocysts terminal or intercalary, elongated or cylindrical, 6-10.8 µm long, 3.3-6 µm broad, pale yellow colour; akinetes solitary, oval, ovoid or broadly cylindrical, broadly rounded at the ends, 13-24 µm long, 8.5-14 µm broad, smooth exospore with brown colour; granules present, prominent.

Recorded a temperature of 23.3°C during post-monsoon season and 29.9° C during summer season. pH recorded as 7.5 during post-monsoon season and 7.1 during summer season.

Habitat : Epipelic

Locality : Janagikkadu, Kozhikode

Specimen number : CU No. 158536

Figure : 55 E & F

v. **Nodularia** (Martens in Jurgens) ex Bornet et Flahault 1888

Filaments solitary, free floating, often seen among other algae and cyanobacteria; also found as amorphous, formless, mucilaginous colonies or mats on various substrates. Unbranched, straight, rarely wavy in nature; Trichomes uniseriate, cylindrical and of the same width along the whole length, constricted at the cross walls, not attenuated towards the ends or very slightly attenuated in rare cases. Sheaths mucilaginous firm, fine and delimited. Unlamellated or occasionally lamellated. Usually open at both ends. Sheaths may gelatinous and become diffluent under certain conditions. Cells usually shorter than their width; barrel shaped elongate or quadrate with soft edges. Gas vesicles and aerotopes occasionally present. Granular contents present in most of the species. Heterocysts usually intercalary, or secondarily terminally. Solitary, rarely in pairs, normally shorter than wide. Sometimes isodiametric with vegetative cells, develop at certain distance in the trichome. Barrel shaped or quadrate. Heterocyst development are in principle metameric isopolar structures. Akinetes usually larger than vegetative cells. Shorter than wide, almost spherical with thick cell wall. Brownish in colour. Develop in rows, rarely solitary or two or few together. Distant from heterocyst. Reproduction by means of all cells. Normally by disintegration of trichomes or germination of akinetes.

Key to the species

1a. Cells 2.5-5 µm long ……………………………………….… ***N. moravica***

1b. Cells 6-15 µm long ………………………………….……… ***N. armorica***

1. Nodularia moravica Hindak, Smarda et Komarek

Filaments solitary, sometimes mucilaginous, microscopic or macroscopic, attached to a substrate. 8-15 µm wide, arranged in parallel, occasionally entangled; trichome cylindrical, clearly constricted at the cross walls, not attenuated towards the tip; cells barrel shaped, always shorter than wide, blue-green or green in colour, 2.5-5 µm long, 7-13 µm broad; heterocysts intercalary, quadrate or barrel shaped in regular distance, rarely on terminal position, solitary, shorter than wide, 2.7- 4.8 µm long, 7.5-13.8 µm broad, olive green colour; sheath thin, hyaline, occasionally diffluent, open at both ends; granules present, not prominent; gas vesicles and aerotopes absent.

Recorded a temperature of 23.8°C during post-monsoon season and 31.2°C during summer season. pH recorded as 7.4 during post-monsoon season and 6.7 during summer season.

Habitat : Epilithic

Locality : Pottachira, Thrissur

Specimen number : CU No. 153151

Figure : 55 G & H

2. *Nodularia armorica* Thuret ex Bornet et Flahault

Thallus thin to thick, brownish green or brown colour, mucilaginous, forming mat like slimy mass; filaments long, unbranched, flexuous or straight, 10-13 µm wide; trichomes cylindrical; cells 9-12 µm wide, 6-15 µm long, brownish green or yellowish brown colour, occasionally dark blue green; heterocysts intercalary, compressed or barrel shaped, olive green or bright green colour, as equal as vegetative cells, rarely slightly wider, 9-13 µm wide, 2.5-14 µm long; sheaths thin, firm, colourless, hyaline, unlamellated, smooth; granules present, brownish, not prominent; akinetes dark blue green colour, compressed, shorter than vegetative cells, solitary or in rows.

Recorded a temperature of 22.6^{o}C during post-monsoon season. pH recorded as 7.4 during post-monsoon season.

Habitat : Edaphic and epipelic

Locality : Gavi, Pathanamthitta

Specimen number : CU No. 153081

Figure : 56 A & B

vi. Trichormus (Ralfs ex Bornet et Flahault) Komarek et Anagnostidis 1989

Thallus thin or thick, forming mucilaginous mats or colonies on the substrate. Filaments usually without a firm sheath. Attached to a substrate, subaerophytic or submerged. Trichomes isopolar, uniseriate, without branches, usually not attenuated but occasionally slightly narrowed towards the end. Clearly constricted at the cross walls. Cells barrel shaped or cylindrical, rarely quadrate, sometimes isodiametric. Gas vesicles usually absent. Cytoplasm containing granules, occasionally prominent. Blue green or pale green in colour. Apical cells rounded or often conical rounded. Heterocysts intercalary, solitary, spherical, oval or cylindrical. Normally larger than vegetative cells. Akinetes develop apoheterocystically in rows. Oval or ellipsoidal in shape and are double the size of vegetative cells. Reproduction by hormogonia and germination of akinetes. Contain characters like apoheterocystic formation of akinetes indicates their relationship with *Nostoc*.

Key to the species

1a. Filaments straight or flexuous …………………………….……………….. 2

1b. Filaments spirally coiled …………………….……………. ***T. gelatinicola***

2a. Chroococcoide stages present ……………….………….. ***T. propinquus***

2b. Chroococcoide stages not observed …………………...………..……… 3

3a. Heterocysts 8-10 µm wide ……………….…… ***T. variabilis*** var. ***cylindracea***

3b. Heterocysts 5-7 µm wide ……………….…………………………………….. 4

4a. Heterocysts barrel shaped …………………..…………… ***T. naviculoides***

4b. Heterocysts spherical or hemispherical …………………….. ***T. subtropics***

1. Trichormus gelatinicola (Ghose) Komarek et Anagnostidis

Thallus like thick mats, mucilaginous, dark brown or pale brown colour; trichomes mostly solitary, spirally coiled in circular formations, rarely straight and flexuous, constricted at the cross walls, brownish colour; cells usually subspherical, shorter than wide, 5-7 µm wide, 3-5 µm long, brownish appearance; apical cells narrowed, sometimes pointed or rotund; heterocysts spherical or barrel shaped, larger than vegetative cells, 6-8 µm wide, 6-10 µm long; akinetes in rows, spherical or barrel shaped, 7-12 µm wide, 8-14 µm long; sheaths absent; cell content granular, not prominent.

Recorded a temperature of 21.0°C during post-monsoon season and 31.9°C during summer season. pH recorded as 7.4 during post-monsoon season and 6.7 during summer season.

Habitat	: Corticolous
Locality	: Pandimudi, Thrissur
Specimen number	: CU No. 145513
Figure	: 56 C & D

2. Trichormus naviculoides (Fritsch) Komarek et Anagnostidis

Forming a thin mucilaginous, flat, mat like structure. Trichomes long, many together, flexuous or coiled, blue-green or pale green, cylindrical, constricted at the cross walls; cells barrel shaped or cylindrical, longer or shorter than broad, isodiametric in certain cases, 3.3-4.9 µm wide, 3.5-5.8 µm long, pale green or dull green colour; apical cell conical; heterocysts intercalary, barrel shaped with soft edges, slightly larger than vegetative cells, single, isodiametric, 5-7 µm wide, 5.3-9 µm long; akinetes serially in rows, irregular, spherical, elongated or quadrate, larger than vegetative cells, 8-11 µm long, 6-7 µm broad; granules present, prominent.

Recorded a temperature of 24.4°C during post-monsoon season and 31.5°C during summer season. pH recorded as 6.6 during post-monsoon season and 6.2 during summer season.

Habitat	: Epilithic
Locality	: Pattathippara, Thrissur
Specimen number	: CU No. 153162
Figure	: 56 E-H

3. Trichormus propinquus (Setchell et Gardner) Komarek et Anagnostidis

Thin mat like mass, pale blue-green to brown colour, trichomes elongated, flexuous, constricted at the cross walls, without sheath; cells quadrate with soft edges or barrel shaped, longer than wide, normally 2-3.5 µm in width, 2.5-4 µm long in young stages, when mature up to 4.5 µm wide, 4-7.5 µm long, terminal cells conical-rounded; heterocysts spherical, quadrate or barrel shaped, rarely cylindrical, larger than vegetative cells, 5-8 µm long and 4-5 µm wide, olive green or yellowish green colour, akinetes spherical, barrel shaped or widely ellipsoidal, 7.5-9 µm long, 6-8 µm wide, arranged in rows, smooth cell wall, hyaline; granules present, not prominent; vacuoles occasionally present.

Recorded a temperature of 20.5°C during post-monsoon season and 28.4°C during summer season. pH recorded as 7.3 during post-monsoon season and 6.8 during summer season.

Habitat : Epiphytic

Locality : Pokalappara, Thrissur

Specimen number : CU No. 153178

Figure : 57 A-D

4. Trichormus subtropicus (Gardner) Komarek et Anagnostidis

Trichomes solitary or in small colonies, flexuous or straight, relatively shorter than other species, constricted at the cross walls, not attenuated or narrowed towards the end, pale green or dull blue-green colour; cells almost cylindrical or spherical, usually isodiametric, or slightly longer than wide. 3.5-4.5 µm wide, 3.2-5.2 µm long, pale blue-green mass, end cells cylindrical and rounded, rarely narrower than the vegetative cells; heterocysts spherical, hemispherical or cylindrical, intercalary or terminal, 5-7 µm diameter; akinetes spherical, elongate, or slightly longer or wider than vegetative cells, located distant from heterocysts, highly granulated, gas vacuoles present, up to 10 µm in diameter, cell walls smooth; granules present, rarely prominent.

Recorded a temperature of 22.7°C during post-monsoon season and 30.4°C during summer season. pH recorded as 7.3 during post-monsoon season and 6.8 during summer season.

Habitat : Epactiphytic and epipelic

Locality : Vellanippacha, Thrissur

Specimen number : CU No. 191234

Figure : 57 E & F

5. *Trichormus variabilis* var. *cylindracea*

Trichomes mucilaginous, mat like, dark blue-green or brownish green colour, filaments densely entangled, coiled or wavy nature, without sheath or special envelopes, constricted at the cross walls, not attenuated towards the end; cells barrel shaped, rarely spherical or elongated, blue –green, dull green or brownish green colour, 3.2-5 µm broad, 4.5-7 µm long, terminal cells conical or rounded; heterocysts intercalary, solitary, barrel shaped, rarely oblong, elongate or cylindrical, 8-10 µm long, 4-5 µm broad; akinetes in rows, larger than vegetative cells, dull blue-green colour, 8-11 µm long, 5-6.2 µm broad; granules present, not prominent.

Recorded a temperature of 24.4^{o}C during post-monsoon season. pH recorded as 7.1 during post-monsoon season.

Habitat	: Epilithic and epiphytic
Locality	: Palaruvi, Kollam
Specimen number	: CU No. 145516
Figure	: 57 G & H

vii. Nostoc Vaucher ex Bornet et Flahault 1888

Filaments aggregated and irregularly entangled in gelatinous colonies. Mostly macroscopic, spherical, lobate or irregular mass forming amorphous mucilaginous mat. Colonies are usually spherical in initial stages of vegetation period, with trichomes more concentrated on periphery. Later distributed irregularly in common slime. During the life cycle the shape of colonies and arrangement of filaments may vary. Mucilaginous envelopes are colourless to yellowish brown or yellowish green; rarely slight violet. Thallus may have appeared as balls, mats, mucilaginous mass and slimy mass. Trichomes uniseriate not branched, isopolar, flexuous, always constricted at the cross walls. Trichomes sometimes possess individual sheath, wide or thin. Occasionally coloured and lamellate. Cells barrel shaped to cylindrical, end cells usually not differentiated. Rounded to attenuated. Heterocysts terminal or intercalary, solitary or few in a rows, sometimes in apical position of initial colonies. Spherical to oval in shape, commonly arise from both ends of hormogonia. Akinetes arising apoheterocystically in rows. Sometimes all the cells in trichome changes into akinetes. Always larger than vegetative cells. Normally oval, ellipsoidal or spherical in shape. Reproduction by motile hormogonia, and also by disintegration of colonies. Less frequently reproduces by germination of akinetes.

Key to the species

1a. Sheath present ………………………..………………………….. 2
1b. Sheath absent …………………………...……………………….. 9
2a. Heterocysts spherical ……………………………………….………… 3
2b. Heterocysts not spherical ……………………………...……………… 8
3a. Sheaths always present ……………………………………..…………… 4
3b. Sheaths occasionally present ………………………….....…………….. 7
4a. Colonial envelope lamellate ………………….…………… ***N. pruniforme***
4b. Colonial envelope unlamellate …………….…………………………. 5
5a. Trichomes with individual sheath ……………..………. ***N. ellipsosporum***
5b. Trichomes without individual sheath …………………………………… 6
6a. Colony spherical ………………………...…………….…. ***N. minutum***
6b. Colony elongate or irregular ………………..……………… ***N. commune***
7a. Cells barrel shaped, longer than wide ……………….…….. ***N. paludosum***
7b. Cells spherical …………………………..…………… ***N. comminutum***
8a. Heterocysts 6-10 μm wide ………………..………… ***N. bicalyptratum***
8b. Heterocysts 4-6 μm wide …………………...…………… ***N. gelatinosum***
9a. Heterocysts spherical ……………………...……………………… 10
9b. Heterocysts elongate or oblong …….……..… ***N. spongiiforme*** var. ***tenue***
10a. Cells spherical ……………………..…………………………….. ***N. linckia***
10b. Cells not spherical …………………………………………………. 11

11a. Cells less than 4 µm wide ……………….…………………….. ***N. calcicola***

11b. Cells more than 4 µm wide …………………………………………… 12

12a. Heterocysts solitary ……………………..………………………..13

12b. Heterocysts 1-4 in a row ……………………………….. ***N. caeruleum***

13a. Heterocysts 7-10 µm in diameter ……………………..……. ***N. carneum***

13b. Heterocysts 5-7.5 µm in diameter ………………….……. ***N. spongiiforme***

1. ***Nostoc bicalyptratum*** Skuja

Colonies submersed, not attached, initially firm and spherical, later expanded and irregularly spherical, verrucose at the surface, mucilaginous inside, brownish or olivaceous colour; filaments densely entangled, irregularly arranged, sometimes freely entangled; cells usually spherical or barrel shaped, 2.5-4 µm wide, 3-5.5 µm long, blue green, pale blue green or olive green colour; heterocysts solitary, spherical, ellipsoidal or barrel shaped, pale yellow or yellow colour, terminal or intercalary, terminal heterocysts may hemispherical, 6-10 µm wide, 5-11 µm long; sheaths present, distinct at colonial periphery, wide, colourless to yellowish, unlamellate, hyaline; granules present, prominent; akinetes larger than vegetative cells, 8-13 µm diameter.

Recorded a temperature of 25.9°C during post-monsoon season and 33.0°C during summer season. pH recorded as 6.7 during post-monsoon season and 6.2 during summer season.

Habitat : Epiphytic

Locality : Poomala, Thrissur

Specimen number : CU No. 191247

Figure : 58 A & B

2. ***Nostoc caeruleum*** Lyngbye ex Bornet et Flahault

Colonies spherical, with smooth surface, firm periderm, blue green, brownish black or brownish colour; trichomes densely entangled, irregularly flexuous, long constricted at the cross walls; cells barrel shaped, rarely isodiametric, usually longer than wide; rarely shorter than wide, 4-6.5 µm wide, 5-8.5 µm long, brownish or greenish brown colour; heterocysts almost spherical, solitary or up to 4 numbers in row, 6-10 µm diameter, colourless to light green colour; sheaths almost absent, if present very thin, diffluent; granular content brownish, not prominent.

Recorded a temperature of 21.7°C during post-monsoon season and 29.4°C during summer season. pH recorded as 7.1 during post-monsoon season and 6.6 during summer season.

Habitat : Epilithic

Locality : Kanthanpara, Wayanad

Specimen number : CU No. 158501

Figure : 58 C-F

3. ***Nostoc calcicola*** Brebisson ex Bornet et Flahault

Colonies irregular, flat, gelatinous, dirt olive green to brownish green colour, rarely yellowish green; filaments loosely entangled, long, flexuous, irregularly curved, more distinct at colonial margins; cells barrel shaped, isodiametric or almost spherical, green, pale green or blue green colour, 2.5-4 µm wide, 2.5-4.5 µm long; heterocysts spherical, terminal or intercalary, slightly larger than vegetative cells, 4-6 µm diameter; sheath usually absent; granular content greenish, occasionally prominent.

Recorded a temperature of 20.7°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.1 during summer season.

Habitat : Epilithic

Locality : Nelliyampathy, Palakkad

Specimen number : CU No. 191207

Figure : 58 G & H

4. ***Nostoc carneum*** Agardh ex Bornet et Flahault

Colonies spherical in beginning stages, later vesicular, lobate or irregularly clustering, gelatinous, macroscopic, attached to substrates, sometimes submersed, later floating free, olive green, greyish blue green, or brownish colour; filaments long, flexuous, irregularly curved or spirally coiled, freely entangled; trichomes constricted at the cross walls; cells rarely or almost isodiametric, usually barrel shaped, rarely spherical or cylindrical, 5-6.5 µm wide, 6-8.5 µm long, brownish green colour; heterocysts barrel shaped, spherical or elongated, 7-10 µm diameter, yellowish colour; sheaths unclear, colourless; granules present, occasionally prominent.

Recorded a temperature of 24.1°C during post-monsoon season and 31.5°C during summer season. pH recorded as 7.4 during post-monsoon season and 6.8 during summer season.

Habitat	: Epilithic
Locality	: Marottichal, Thrissur
Specimen number	: CU No. 153112
Figure	: 59 A-D

5. ***Nostoc comminutum*** Kutzing

Colonies mucilaginous, irregular, forming gelatinous shiny mats, membranous, soft, green or blue green colour; trichomes long, flexuous, densely entangled, variously curved or irregularly coiled, blue green colour, constricted at the cross walls; cells spherical, isodiametric, 4-6.5 µm diameter, bright blue green or blue green colour; heterocysts spherical, rarely hemispherical on terminal, both intercalary and terminal heterocysts observed, slightly larger than vegetative cells, 5-8 µm diameter, olive green or light green colour; akinetes in rows, larger than vegetative cells, 7-12 µm diameter; sheaths occasionally present, hyaline and colourless; granular contents fine, not or rarely prominent.

Recorded a temperature of 22.7°C during post-monsoon season. pH recorded as 7.1 during post-monsoon season.

Habitat : Epilithic

Locality : Chembra, Wayanad

Specimen number : CU No. 153100

Figure : 59 E-H

6. ***Nostoc commune*** Vaucher ex Bornet et Flahault

Colonies macroscopic, gelatinous, spherical, later irregularly flattened, up to several centimetre in diameter, ball like structures, olive green, golden yellow, yellowish brown or dark brown colour, periderm firm; filaments flexuous, densely entangled, variously coloured; cells spherical or shortly barrel shaped, sometimes slightly longer or shorter than wide, pale green or olive green colour, 3-7 µm long, 4-6 µm wide; heterocysts almost spherical, terminal or intercalary, rarely few in rows, 5-9 µm diameter; sheath firm, surrounding a group or individual filaments, hyaline, colourless to yellowish brown colour, sometime slightly or highly lamellated, occasionally constricted; granular contents fine, sometimes prominent.

Recorded a temperature of 23.3°C during post-monsoon season. pH recorded as 7.3 during post-monsoon season.

Habitat : Edaphic and epactiphytic

Locality : Kakki dam, Pathanamthitta (also recorded from Athirappilly and Pottachira (Thrissur), Chethalayam (Wayanad), Kakkayam (Kozhikode) and Ranipuram (Kasargod))

Specimen number : CU No. 153062

Figure : 60 A-H

7. ***Nostoc ellipsosporum*** Rabenhorst ex Bornet et Flahault

Colonies gelatinous, flattened, irregular, granular, firm, olive green to brownish green colour; filaments long, flexuous, loosely entangled; trichomes brown colour, constricted at the cross walls, long, wavy, or irregularly curved; cells barrel shaped, cylindrical or rarely spherical, olive green or brownish green colour, 4-6 µm wide, 5.5-13.5 µm long; heterocysts almost spherical, sometimes slightly elongated, 6-14 µm diameter, olive green or yellowish colour; sheaths present, diffluent, thin or thick, colourless, hyaline, unlamellate; akinetes long oval, ellipsoidal or barrel shaped, larger than vegetative cells, rarely cylindrical, 6-8.5 µm wide, 13-20 µm long; granular content dull green or brownish, occasionally prominent.

Recorded a temperature of 24.8°C during post-monsoon season. pH recorded as 7.2 during post-monsoon season.

Habitat : Epiphytic and epilithic

Locality : Thenmala, Kollam

Specimen number : CU No. 158556

Figure : 61 A-C

8. ***Nostoc gelatinosum*** Schousboe ex Bornet et Flahault

Colonies irregular, flat, gelatinous, brownish or yellowish brown colour, forming slimy mucilaginous mass; trichomes long, flexuous, sheathed, yellowish brown colour, variously curved; cells long, cylindrical, sometimes barrel shaped, 3-5 µm wide, 4-10 µm long, yellowish or brownish yellow; heterocysts spherical, hemispherical or elongated, occasionally wider than vegetative cells, intercalary or terminal, 4-6 µm wide, 4-7.5 µm long; sheaths wide, yellow brown, constricted, lamellated or unlamellated, hyaline; granular content fine, brownish sometimes prominent.

Recorded a temperature of 22.5°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.4 during post-monsoon season and 7.1 during summer season.

Habitat : Epiphytic and epactiphytic

Locality : Poringalkuthu, Thrissur

Specimen number : CU No. 191267

Figure : 61 B-F

9. ***Nostoc linckia*** Bornet ex Bornet et Flahault

Colonies mucilaginous, fine, thin, submersed, attached to plants or rock substrates, later irregularly clustered, free floating, amorphous, usually brownish green or dirty olive green colour, disintegrating, gelatinous clusters; filaments flexuous, densely entangled, variously curved; cells almost spherical or shortly barrel shaped, isodiametric, pale blue green colour, 3-6 µm diameter; heterocysts spherical larger then vegetative cells, 4.5-7 µm diameter, olive green colour; sheaths may or may not present, colourless, visible occasionally in the marginal parts of the colonies; granular contents fine, not prominent.

Recorded a temperature of 20.5°C during post-monsoon season and 29.9°C during summer season. pH recorded as 7.3 during post-monsoon season and 6.8 during summer season.

Habitat : Epiphytic and epactiphytic

Locality : Vazhachal, Thrissur (also recorded from Paithalmala (Kannur) and Mangaladevi hills (idukki))

Specimen number : CU No. 153098

Figure : 61 G & H; 62 A & B

10. ***Nostoc minutum*** Desmazieres ex Bornet et Flahault

Colonies small, gelatinous, initially spherical, later irregular, longer in clusters, green or dark green colour; filaments densely entangled, flexuous, irregularly curved or wavy, rarely enveloped with individual sheaths; trichomes long, constricted at the cross walls; cells barrel shaped, isodiametric or occasionally spherical, sometimes slightly shorter or longer than spherical, 3-6.5 µm wide, 4-12 µm long, olive green or pale blue green colour; heterocysts spherical, larger than vegetative cells, bright green or olive green colour, 4-8 µm diameter, usually intercalary, rarely terminal; sheaths not distinct, occasionally present, diffluent; granular content high, blue green colour, sometimes prominent.

Recorded a temperature of 23.0^{o}C during post-monsoon season and 28.9^{o}C during summer season. pH recorded as 7.5 during post-monsoon season and 7.1 during summer season.

Habitat	: Epiphytic and corticolous
Locality	: Chethalayam, Wayanad (also recorded from Malakkappara (Thrissur))
Specimen number	: CU No. 158557
Figure	: 62 C-H

11. Nostoc paludosum Kutzing ex Bornet et Flahault

Colonies microscopic, later become macroscopic under favourable situations, flattened, irregular, mucilaginous mass, blue green or brownish green colour, long, densely entangled; cells spherical or barrel shaped, sometimes isodiametric, occasionally slightly longer or shorter than wide, in some parts of trichome cells become cylindrical, 4-6.5 µm wide, 5-8 µm long; apical cells cylindrical and rounded; heterocysts spherical or barrel shaped, sometimes slightly elongated, always slightly larger than vegetative cells, terminal and intercalary in position, 4-9 µm diameter; sheaths occasionally present, thin, hyaline, colourless, later become diffluent, unlamellate; granular contents fine, may or may not prominent; aerotopes sometimes present.

Recorded a temperature of 21.2^{o}C during post-monsoon season and 28.3^{o}C during summer season. pH recorded as 7.2 during post-monsoon season and 6.6 during summer season.

Habitat	: Epilithic and epactiphytic
Locality	: Churuli, Idukki
Specimen number	: CU No. 153094
Figure	: 63 A-C

12. ***Nostoc pruniforme*** Agardh ex Bornet et Flahault

Colonies spherical, oval or ovoid, with smooth periderm, inside mucilage is soft, olive green or brownish green colour; trichomes irregularly entangled in mucilaginous envelope, sometimes individual sheaths also present, long variously curved, aggregated, blue green colour; cells spherical or compressed barrel shaped, occasionally isodiametric, 4-6 µm wide, 4-7 µm long, blue green colour; heterocysts spherical, larger than vegetative cells, terminal or intercalary, 6-9.5 µm diameter; sheaths thin to thick, initially hyaline, then become coloured, brownish yellow colour, irregularly lamellated; granules present, not prominent.

Recorded a temperature of 23.3°C during post-monsoon season. pH recorded as 7.3 during post-monsoon season.

Habitat	: Epipelic and epilithic
Locality	: Kakki dam, Pathanamthitta
Specimen number	: CU No. 153063
Figure	: 63 D-F

13. ***Nostoc spongiiforme*** Agardh ex Bornet et Flahault

Colonies large, initially spherical, later irregular, gelatinous, inside mucilaginous, forms mat like structures, brownish green or yellowish brown colour; trichomes long, flexuous, loosely entangled, variously curved, constricted at the cross walls; cells barrel shaped or cylindrical, sometimes quadrate, usually longer than wide, occasionally shorter than wide, very rarely isodiametric; brownish green colour, 4-6 µm wide, 5-12.5 µm long; heterocysts oval or elongated, terminal and intercalary, larger than vegetative cells, olive green colour, 5-7.5 µm wide, 8-14 µm long; sheaths not observed; brownish granular content, sometimes prominent; aerotopes occasionally present; end cells rounded.

Recorded a temperature of 18.3°C during post-monsoon season and 28.4°C during summer season. pH recorded as 7.1 during post-monsoon season and 6.6 during summer season.

Habitat	: Epilithic and epiphytic
Locality	: Kumali, Idukki (also recorded from Meesapulimala (Idukki), Sholayar (Thrissur), Agasthyamala (Thiruvananthapuram) and Siruvani (Palakkad))
Specimen number	: CU No. 145517
Figure	: 63 G & H

14. Nostoc spongiiforme var. ***tenue*** Desikachary

Colonies mucilaginous, brownish green or yellowish green colour, thin; trichomes long, straight or sometimes flexuous, without individual sheath, free floating, solitary or in sparsely arranged in groups; cells barrel shaped, cylindrical or quadrate with soft edges, isodiametric or longer or shorter than wide, 4-6 µm wide, 7-11 µm long, brownish green colour, or dull green colour; heterocysts elongate or oblong, rarely spherical, usually intercalary, larger than vegetative cells, 5-8 µm wide, 7.5-11.8 µm long, brownish yellow colour; granular contents fine; aerotopes occasionally found.

Recorded a temperature of 18.9°C during post-monsoon season and 29.1°C during summer season. pH recorded as 7.2 during post-monsoon season and 6.7 during summer season.

Habitat	: Epilithic
Locality	: Kaduvakkuzhi, Wayanad
Specimen number	: CU No. 145517
Figure	: 64 A

viii. Desmonostoc Hrouzek et Ventura 2013

Filaments arranged in rounded macro-colonies, long, amorphous. The colour of the colonies dark green or brown in colour. Mucilaginous matter, diffuse inside, firm on the surface side. During the life cycle, long vegetative waved filaments forming intercalary and terminal heterocysts and akinetes for major period. Single filaments do not surround by firm slime forming compact micro-colonies. Cells are barrel shape in common. They also showing variation to quadrate, oval and elongate. 3.5 µm of minimum width was observed. Heterocysts are found on both terminal and intercalary. Terminal heterocysts are oval or hemispherical in common. Intercalary heterocysts spherical, elongate or cylindrical in shape. Akinetes occur in frequent, elliptic, highly granulated, well distinguishable from vegetative cells. Akinetes are formed in long chains. Reproduction is by fragmentation of the vegetative filaments and germination of hormogonia. Terminal cells of the hormogonia are oval in shape.

Key to the species

1. Cells 3-6 µm in length ……………………………….....……. ***D. muscorum***

1. Desmonostoc muscorum (Agardh ex Bornet et Flahault) Hrouzek et Ventura

Colonies hemispherical during young stages, later become irregular mucilaginous flattened mats like appearance, several centimeter in diameter, blue-green colour, later yellow-green to yellowish brown; filaments densely entangled, irregularly flexuous; cells shortly barrel shaped, rarely cylindrical, usually isodiametric, sometimes shorter than wide, rarely longer than wide, 3.4-5.7 µm long and 4-4.5 µm wide; sheath distinct towards the margin of colonies, yellow to brown colour; granules present, rarely prominent; vacuoles occasionally found.

Recorded a temperature of 18.3^{o}C during post-monsoon season and 27.4^{o}C during summer season. pH recorded as 7.6 during post-monsoon season and 7.1 during summer season.

Habitat	: Epactiphytic and corticolous
Locality	: Malakkappara, Thrissur (also recorded from Sholayar (Thrissur), Ilaveezhapoonchira (Kottayam) and Attappadi (Palakkad))
Specimen number	: CU No. 153126
Figure	: 64 B-D

ix. Mojavia Rehakova et Johansen 2007

Colonies microscopic, later macroscopic in certain conditions. Subspherical, ellipsoidal to irregular in nature. Surrounded by a firm mucilaginous envelope. Series of subcolonies create macroscopic pseudofilaments. Filaments developed from hormocytes, with specialized widened pairs of cells, which produce an acute bending of trichomes. Initial trichomes are short with terminal heterocysts in some cases. Trichomes uniseriate or strongly flexuous pleuroseriate colonies. Strongly constricted at the cross walls. Sometimes forming dense aggregations. Cells spherical, subspherical or barrel shaped. Blue green, dark green or bright green in colour. Heterocyst mainly terminal, or lateral in agglomerations. Intercalary heterocysts very rare. Young colonies only have terminal heterocysts. Akinetes unknown, reproduction is by colonial disintegration. Hormogonia germinate without heterocysts.

Key to the species

1a. Cells spherical, 5-11 µm in diameter ………………………….… ***M. pulchra***

1. Mojavia pulchra Rehakova et Johansen

Colonies microscopic, spherical in initial stages, then becoming erect, macroscopic colonies are dark green, yellowish and become brownish when old, microcolonies spherical, subspherical or irregular, arranged in irregular aggregations; cells spherical, subspherical or barrel shaped, 5-11 µm diameter; heterocysts terminal, subspherical or spherical, olive green colour, 4-8 µm diameter; sheath firm, thin, hyaline, brownish when getting older; hormogonia rare; granules present not prominent.

Recorded a temperature of 18.3°C during post-monsoon season and 27.4°C during summer season. pH recorded as 7.6 during post-monsoon season and 7.1 during summer season.

Habitat	: Edaphic and epipelic
Locality	: Malakkappara, Thrissur
Specimen number	: CU No. 153130
Figure	: 64 E-G

x. **Aliinostoc** Bagchi et Singh 2017

This genus widely spread in agricultural lands and waterbodies of India, Thailand and some saline-alkaline lakes of Brazil. All members of this genus showing close morphological resemblance with *Nostoc*, and almost no distinguishable differences being evident in *Allinostoc*. A diacritical feature is the presence of motile hormogonia with gas vesicles. Filaments loosely arranged, sometimes entangled together. Filaments showing a tendency for coiling or irregularly curved. This genus *Allinostoc* showing wide range of adaptability, so assign a specific habitat was possible. Some members have high adaptability towards alkaline and salt waters. Reproduction by disintegration of colonies and by means of akinetes. New discoveries showing representations from both Southern and Northern latitudes on both sides of equator. It indicates the possibility of biogeographical distribution around tropical regions.

Key to species

1a. Cells barrel shaped, heterocysts 7-8 μm long …...………... ***A. constrictum***

1. ***Aliinostoc constrictum*** Kabirnataj et al.

Colonies macroscopic, dark blue-green or dark greenish brown colour, mat like appearance in water, high presence of colourless slimy mucilaginous mass; trichomes coiled or straight, a thin delicate colourless mucilaginous sheath cover the trichome, many trichomes entangled together; cells blue-green or green colour, barrel shaped or quadrate with soft edges, rarely cylindrical, characteristically constricted, end cells conical shaped or widely attenuated, 4.5-6 µm wide, 5-7 µm long; heterocysts prominently visible, intercalary or rarely terminal, spherical or oblong, polar nodule very clear, 6.4-7.5 µm wide, 7-8 µm long, olive green or yellowish green colour; granules present, occasionally prominent; mats getting puffier when become older.

Recorded a temperature of 22.5°C during post-monsoon season and 29.6°C during summer season. pH recorded as 7.4 during post-monsoon season and 7.1 during summer season.

Habitat	: Epiphytic and edaphic
Locality	: Poringalkuthu, Thrissur
Specimen number	: CU No. 191251
Figure	: 64 H & I

Cyanobacteria, with adaptations to various environmental challenges are presumed to have the widest range of diversity of photosynthetic organisms in diverse growth habitats (Badger *et al.* 2006) and yet remains one of the most underexplored group of organisms. Diversity of these organisms, especially in the areas with minimal human interference is still only subject to speculations rather than explorations. As a major component of the soil microflora in agricultural fields and thus very valuable to agriculture, their scope in soil fertility enhancement has been studied extensively (Dhanya and Ray, 2015). The present work was aimed to provide a comprehensive taxonomic treatment of the cyanobacterial flora of the forests of Kerala. It opens us to the uncharted territories in the world of forest Cyanobacteria.

Studies on Cyanobacterial flora of Kerala were pioneered by Parukkutty (1940), who reported 51 forms of 'Myxophyceae' from the central and southern parts of the Travancore state. While most of the past and contemporary works focus on paddy field Cyanobacterial flora, this is one of the only few works outside of rice fields but yet does not provide much information on the forest flora. During the present study, carried out with extensive explorations of the forests of Kerala 204 species belonging to 50 genera were identified and described. Of the observed species heterocystous filamentous forms showed greater diversity with 84 members while unicellular forms were represented with 67 species and filamentous non-heterocystous forms showed the least diversity with 53 members.

Aiyer (1965) and Amma *et al.* (1966) focused their studies on the paddy fields in the state. Aiyer explored the agricultural fields of Kuttanadu and identified 19 species and observed ubiquitous distribution of *Aulosira fertilissima* throughout the acidic soils of Kuttanadu. Cyanobacterial flora of paddy fields from various Districts of Kerala were investigated by Anand and Hopper (1987) and a preliminary report of 30 cyanobacterial species were published. They later conducted a detailed study on the cyanobacteria of Kerala (Anand and Hopper, 1995) and described 158 cyanobacterial species coming under 33 genera, from various agricultural fields. A similar work was carried out by Shaji and Panicker (1994) who reported only 32 species coming under 3 genera. Dominic (1997) reported 92 cyanobacterial taxa from 31 genera and this work also was carried out in the paddy fields of Kerala.

Dhanya and Ray (2015) explored the paddy fields of Kuttanadu, Alappuzha and identified 64 cyanophycean members that coming under 22 genera and represented all 3 type cyanobacterial groups. Unicellular genera such as *Microcystis, Gloeocapsa, Gloeothece, Aphanothece, Aphanocapsa, Chroococcus, Synechocystis* and *Merismopedia* were observed. Among them *Chroococcus* showed the highest representation with four species. A total of

12 unicellular cyanobacterial members and 30 species of non-heterocystous filamentous cyanobacteria which comes under 7 genera were identified during this study. *Oscillatoria* showed maximum representation with 12 species. Five species were identified from both *Leptolyngbya* and *Phormidium*. *Spirulina*, *Arthrospira*, *Microcoleus* and *Lyngbya* were the other genera identified from non-heterocystous filamentous type. A total of 22 species were recorded from heterocystous cyanobacteria. Among them *Anabaena* dominated with nine species, followed by *Nostoc* with seven species. *Nodularia*, *Aulosira*, *Hapalosiphon*, *Scytonema* and *Westiellopsis* were also recorded during the study.

Most of the species observed by Dhanya and Ray (2015) from paddy fields of Kuttanadu are not observed from forest regions. Genera like *Spirulina*, *Arthrospira* and *Merismopedia* are not reported from forests during this study. Also, 27 genera reported during the present study were not observed from paddy fields of Kuttanadu, Alappuzha. 16 species from were common in both works. *Microcystis aeruginosa* is a toxin producing cyanobacteria observed from paddy fields of Kuttanadu as well as Pattathippara forests of Thrissur District.

Algal flora of Idukki District was explored by John (2008) and they reported 48 cyanobacterial species under 6 families. They found most representation by unicellular cyanobacteria from fresh water ecosystems of Idukki. The genera *Arthrospira*, *Merismopedia* and *spirulina* did not show any representation during the present study. Most of the genera recorded from forests showed less diversity in Idukki flora. Genera like *Leptolyngbya*, *Pseudanabaena*, *Gloeocapsopsis*, *Cyanosarcina* and *Doliocatella* were not observed in the Idukki flora of algae.

An investigation on filamentous microflora of Thodupuzha River was carried out by Sebastian and Joseph (2013). They reported nine cyanobacterial species under five genera. *Oscillatoria* dominated with five species while *Lyngbya*, *Nostoc*, *Phormidium* and *Scytonema* had a single species each. As compared to the current work, many filamentous cyanobacteria like *Stigonema*, *Hapalosiphon*, *Leptolyngbya*, *Pseudanabaena*, *Aulosira*, *Geitlerinema*, etc. were not reported from the river.

Cyanobacterial association with roots of orchids such as *Dendrobium crumenatum* was reported by Ram and Shamina (2015a). They identified six cyanobacterial species, of which five were heterocystous. Unicellular cyanobacterial members were not found during the study. Present work reported symbiotic association of cyanobacteria with bryophyte named *Philonotis hastata*. 12 species from both unicellular and filamentous cyanobacteria were recorded. This symbiotic association provides information about certain factors that favours symbiosis. Humidity, temperature and substratum for adherence of cyanobacteria were provided by roots of plants.

Ram and Shamina (2015b) identified 12 cyanobacterial taxa from mangrove forests of Kottayam District. Members of Oscillatoriaceae were found to be dominating over other families during this exploration. Shamina and Ram, (2014) reported *Oscillatoria ornata* var. *crassa* from marine habitats. We found the same species from forest region during the present work.

Cyanobacterial diversity from "kol" wetlands of Thrissur District were revealed by Tessy and Sreekumar (2010). Members of Oscillatoriaceae dominated over other families during the investigation. They also found that non-heterocystous filamentous cyanobacterial types overshadowed unicellular and heterocystous cyanobacteria. The current study showing similarities in generic level, but species in each genera were more or less different. This changes in species diversity may be because of the difference in ecosystem and habitat. Forest ecosystem with high diversity displays differences in species, but more diverse in the case of generic level.

Easa (2004) created a list including 190 species of identified cyanobacterial species of Kerala. Most of the species he listed out were either synonymised, merged or were transferred to a different genus. Of the 204 species reported during the study, 149 were new to Kerala (Table 2). Remarkable updates in cyanobacterial taxonomy was carried out during 2006-2015, so updated list of cyanobacteria from Kerala is not available. Present work used modern system of classification of cyanobacteria by Komarek and Anagnostidis (1998, 2005) and Komarek (2013), and this will resolve modernization problems

Chlorogloea novacekii, reported from Vazhikkadavu of Malappuram District is the only member of the family Entophysalidaceae. There is no information regarding the earlier report of this species, so this is the first report of *Chlorogloea* from Kerala. And also certain toxin producing cyanobacteria such as *Microcystis aeruginosa* and *Lyngbya majuscule* were also described from forests. *Microcrocis sabulicola* is a marine species which is now recorded from Pattathippara forests of Thrissur District for the first time from a freshwater ecosystem.

CHAPTER - V

SUMMARY AND CONCLUSION

Cyanobacteria are the photosynthetic nitrogen fixing organisms which come under the domain bacteria. These ubiquitous microorganisms are now known as Cyanoprokaryotes. More than 5000 cyanobacteria species have been recorded and reported from all over the world. In India, their studies are confined to agricultural fields and common riparian floras and hence only about 1500 species of cyanobacteria have been reported. India is well known for its rich biodiversity and the number of cyanobacterial taxa reported shows the lack of study on cyanobacterial diversity.

Cyanobacteria are one of the most useful microorganisms in the world. Every research on cyanobacteria undoubtedly revealed their potentials in different areas of daily life. They play a key role in the maintenance of soil fertility by fixing atmospheric nitrogen and phosphorous. Cyanoprokaryotes are also one of the major contributors of oxygen to the earth by the process of photosynthesis. They are also important for their rich content of proteins, lipids, pigments as well as vitamins. Some cyanobacterial species are also known for anti-microbial and anti-inflammatory activities. They are good source of natural pigments such as phycobiliproteins and chlorophyll.

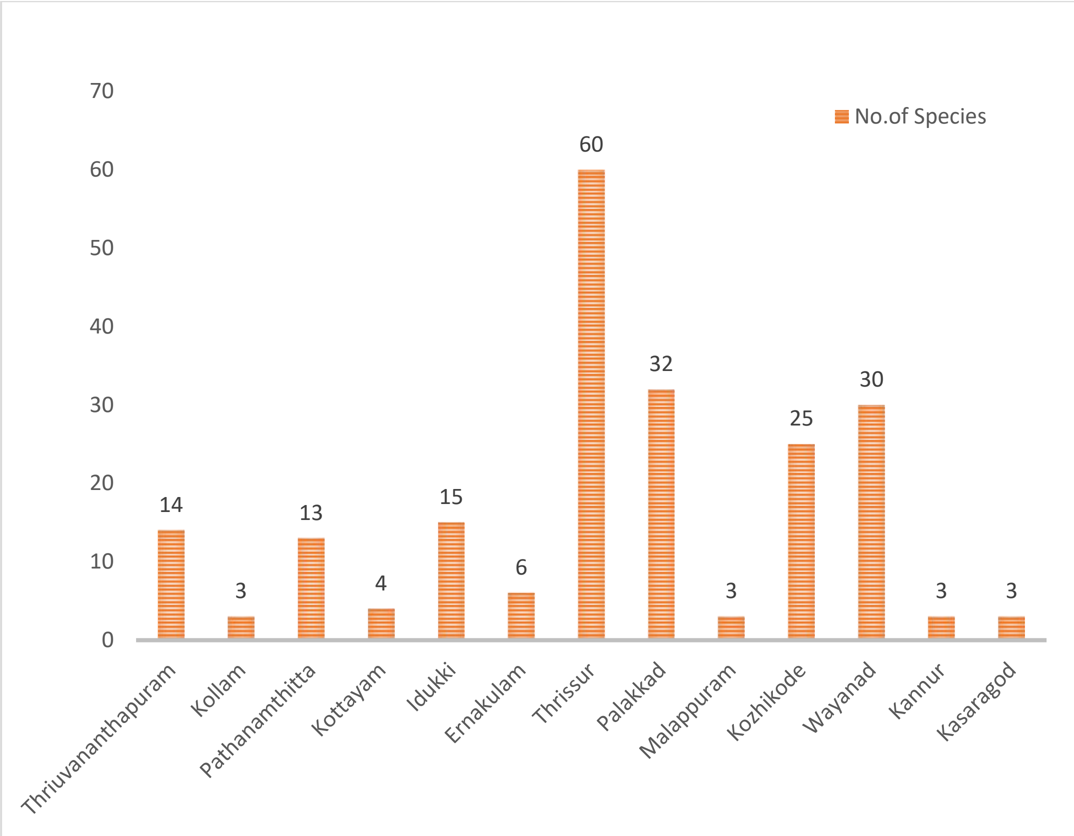
More than 97% of the Western Ghat region of Kerala comes under forest cover. These forests are very rich in biodiversity and hence many new species have been discovered from Kerala forests. Cyanobacterial studies from the forest regions of Kerala have not been carried out sufficiently. The percentage of cyanobacterial community as reported is very limited. Eventhough Kerala is known for monsoon seasons that provide essential circumstances for cyanobacterial growth and development, the rareness of reported cyanobacterial diversity from forests was the main reason behind the current work.

5.1. Distribution and ecology

In the present study, cyanobacteria were collected from various forest regions of Kerala, which come under the Western Ghats. Samples were collected during a time period of four years (2016-2020) from all the possible forest areas of Kerala State of India. Two major seasons were selected for collection; the primary collection was carried out during post-monsoon season, and the secondary collection during summer season. These two seasons show contrasting features in all environmental parameters. So, the variability in the diversity on the basis of climate has also been studied. The preliminary work resulted with the data that the diversity of cyanobacteria was four times greater in post monsoon season than that of summer season. Collection areas cover all forests that come under the regions of Western Ghats of Kerala and collection sites included rivers, reservoirs, small and large streams, water bodies, waterfalls, rocks, soils, plants and also excretions of animals. Specimens were collected from low altitude forests of 50 ft. (Mattampuram) and also from 8842 ft. (Anamudi), the highest peak of Western Ghats. More diversity was observed in humid regions with low temperature.

Cyanobacterial taxa were reported from the forests of 13 Districts coming under the Western Ghats, and only one District namely Alappuzha does not have any areas under the Western Ghats. Among the 13 Districts, Thrissur showed supreme representations with 60 species. Palakkad showed 32 cyanobacterial species from the forest regions and Wayanad also showed high diversity with 30 taxa. Kozhikode, Idukki, Thiruvananthapuram and Pathanamthitta had 25, 15, 14 and 13 species respectively while Ernakulam and Kottayam showed six and four species. The minimum representation was recorded from Kollam, Malappuram, Kannur and Kasaragod with only three species (Graph-1).

Graph-1: Distribution



The present study resulted in the identification of 204 cyanobacterial species. The identified cyanobacteria comes under 50 different genera of 16 families. Among these identified species, unicellular type Chroococcales showed a representation of 66 species from 15 genera. Five families such as Synechococcaceae, Merismopediaceae, Microcystaceae, Chroococcaceae and Entophysalidaceae showed 21, 9, 10, 25 and 1 species representation respectively from each family. Oscillatoriales provided 53 species coming under nine genera. Pseudanabaenaceae, Phormidiaceae and Oscillatoriaceae are the families with representation of 10, 21 and 22 species respectively. 84 species of heterocystous cyanobacteria were described under 25 genera of 8 families. Scytonemataceae, Rivulariaceae, Microchaetaceae, Chlorogloeopsidaceae, Hapalosiphonaceae, Fischerellaceae, Stigonemataceae and Nostocaceae were represented with 15, 10, 7, 1, 5, 3, 5 and 38 species respectively.

5.2. Habitat

Cyanobacterial specimens collected show different habitats such as epiphytic, epilithic, epactiphytic, epipelic, edaphic, corticolous, planktic and benthophytic (Fig. 65). Most of the collected strains showed epilithic habitat. Out of the 204 species, 70 were epilithic while 12 were epactiphytic. 11 edaphic, 10 planktic, eight corticolous, seven epipelic and six epiphytic strains were also observed. Only 2 cyanobacterial species are recognized as benthophytic taxa. Few species exhibited adaptability to multiple habitats. Seven species are seen as both epilithic and epactiphytic, similarly six taxa were found as both epactiphytic and benthophytic. 11 species were observed from both epilithic and epiphytic surroundings. Six cyanobacteria were recorded from both epiphytic and edaphic environments. Another 11 cyanobacterial strains observed from both epilithic and edaphic conditions, also 10 species showing adaptability to live in both epactiphytic and edaphic range (Table-1).

Epactiphytic and corticolous (1 species), epactiphytic and planktic (3 species), epiphytic and epipelic (2 species), epactiphytic and epiphytic (6 species), epilithic and epipelic (1 species), epilithic an corticolous (4 species), epiphytic and corticolous (5 species), epipelic and edaphic (4 species), planktic and benthophytic (2 species) were also described as combinations of habituation. Epilithic habitats was exhibited by most of the filamentous cyanobacteria with heterocysts and it indicates that the heterocystous cyanobacteria need a solid substratum for firm attachment and the diversity of habitats displays the adaptability and how diverse these cyanoprokaryotes are (Table 1).

Table.1: Cyanobacteria and habitats

Sl. No.	***Name***	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
1	*Cyanobium diatomicola*		+						+
2	*Cyanobacterium epiphyticum*		+						
3	*Cyanobacterium notatum*								+
4	*Cyanothece halobia*		+						
5	*Aphanothece pallida*		+						+
6	*Aphanothece stagnina*		+	+					
7	*Aphanothece bullosa*		+			+			
8	*Aphanothece elabens* var. *minor*		+						
9	*Aphanothece hegewaldii*			+					+
10	*Aphanothece castagnei*		+						+
11	*Aphanothece microscopica*		+						+
12	*Aphanothece smithii*			+					+
13	*Gloeothece incerta*				+				
14	*Gloeothece membranacea*		+						+
15	*Gloeothece tepidariorum*	+							+
16	*Gloeothece confluens*		+			+			
17	*Gloeothece palea*		+						
18	*Gloeothece rupestris*		+	+					
19	*Synechococcus subsalsus*	+							
20	*Synechococcus elongates*	+							+
21	*Synechococcus mundulus*	+							
22	*Synechocystis aquatilis*		+	+					
23	*Aphanocapsa holsatica*		+						
24	*Aphanocapsa fonticola*		+	+					
25	*Aphanocapsa delicatissima*						+		
26	*Aphanocapsa elachista*				+				

27	*Aphanocapsa grevillei*						+		
28	*Aphanocapsa nubilum*					+			
29	*Aphanocapsa orae*		+						
30	*Microcrocis sabulicola*		+						
31	*Coelosphaerium dubium*						+		
32	*Microcystis smithii*								+
33	*Microcystis aeruginosa*		+						
34	*Microcystis viridis*		+						
35	*Gloeocapsa atrata*			+					+
36	*Gloeocapsa conglomerata*								+
37	*Gloeocapsa decorticans*		+						
38	*Gloeocapsa fusco-lutea*		+						
39	*Gloeocapsa rupestris*		+						
40	*Gloeocapsa sanguinea*		+						
41	*Gloeocapsa compacta*		+						
42	*Gloeocapsopsis dvorakii*		+						
43	*Gloeocapsopsis pleurocapsoides*								+
44	*Gloeocapsopsis chroococcoides*								+
45	*Gloeocapsopsis magma*			+		+			
46	*Chroococcus cohaerens*						+		
47	*Chroococcus ercegovicii*		+	+					
48	*Chroococcus pallidus*						+		
49	*Chroococcus minutus*				+				
50	*Chroococcus minutus* var. *thermalis*		+						
51	*Chroococcus mipitanensis*		+						
52	*Chroococcus quaternarius*		+						
53	*Chroococcus subnudus*		+						
54	*Chroococcus turgidus*						+		

55	*Chroococcus turicensis*		+						
56	*Chroococcus indicus*		+						
57	*Chroococcus schizodermaticus*		+						
58	*Chroococcus varius*		+						
59	*Chroococcus prescottii*		+						
60	*Chroococcus tenax*		+						
61	*Chroococcus giganteus*						+		
62	*Chroococcus obliterates*		+						
63	*Cyanosarcina thalassia*						+		
64	*Cyanosarcina parthenonensis*	+	+						
65	*Cyanosarcina burmensis*	+	+						
66	*Cyanosarcina chroococcoides*	+	+						
67	*Chlorogloea novaceki*	+			+				
68	*Pseudanabaena biceps*	+		+					
69	*Pseudanabaena crassa*	+	+						
70	*Pseudanabaena franquetii*				+				
71	*Pseudanabaena galeata*	+							
72	*Pseudanabaena skujae*		+						
73	*Pseudanabaena thermalis*			+					+
74	*Jaaginema geminatum*						+	+	
75	*Geitlerinema amphibium*								+
76	*Leptolyngbya subtilis*						+		
77	*Leptolyngbya terebrans*		+						
78	*Planktothrix isothrix*	+					+		
79	*Planktothrix cryotovaginata*								+
80	*Planktothrix clathrata*		+						
81	*Planktothrix planktonica*		+	+					

82	*Phormidium aerugineo-caeruleum*								+
83	*Phormidium articulatum*		+						+
84	*Phormidium boryanum*			+					+
85	*Phormidium calcicola*		+						
86	*Phormidium crassior*					+			
87	*Phormidium favosum*	+							+
88	*Phormidium formosum*	+							+
89	*Phormidium hamelii*		+						
90	*Phormidium karakalpakense*	+							
91	*Phormidium targetinum*						+		
92	*Phormidium taylori*	+							
93	*Phormidium subsalsum*		+						
94	*Phormidium chlorinum*							+	
95	*Phormidium insigne*		+						
96	*Phormidium corium*	+							
97	*Microcoleus subtorulosus*		+						
98	*Microcoleus steanstrupii*		+						
99	*Oscillatoria limosa*		+						
100	*Oscillatoria lutea*	+					+		
101	*Oscillatoria nitida*	+							
102	*Oscillatoria ornata* var. *Crassa*								+
103	*Oscillatoria princeps*		+						+
104	*Oscillatoria refringens*		+						
105	*Oscillatoria subsalsa*	+					+		
106	*Oscillatoria tenuis var. levis*		+						
107	*Oscillatoria sancta*	+						+	
108	*Oscillatoria rupicola*		+						
109	*Oscillatoria curviceps*	+						+	
110	*Oscillatoria jenensis*	+						+	
111	*Oscillatoria funiformis*	+						+	

112	*Oscillatoria margaritifera*		+						+
113	*Lyngbya aestuarii*	+							
114	*Lyngbya agardhii*		+						
115	*Lyngbya birgei*		+			+			
116	*Lyngbya connectens*			+		+			
117	*Lyngbya majuscule*		+						+
118	*Lyngbya martensiana*		+						
119	*Lyngbya splendens*			+		+			
120	*Lyngbya scytonematoides*	+							+
121	*Scytonema coactile* var. *minor*		+						
122	*Scytonema crispum*		+			+			
123	*Scytonema javanicum*					+			
124	*Scytonema millei*		+						
125	*Scytonema myochrous*		+						
126	*Scytonema pseudoguyanense*		+						+
127	*Scytonema pseudohofmanii*		+						
128	*Scytonema stuposum*					+			
129	*Scytonema caldarium*		+						+
130	*Scytonema torulosum*	+	+						
131	*Scytonema schmidtii*		+						
132	*Petalonema involvens*					+			
133	*Petalonema alatum*		+						
134	*Petalonema pulchrum*								+
135	*Petalonema velutinum*	+							+
136	*Calothrix capitularis*		+						
137	*Calothrix fusca*	+							
138	*Calothrix parietina*	+							+
139	*Calothrix vivipara*					+			
140	*Rivularia atra*		+						
141	*Rivularia beccariana*		+						
142	*Rivularia manginii*		+	+					
143	*Rivularia nitida*							+	
144	*Rivularia bullata*		+						
145	*Dichothrix orsiniana*		+	+					

146	*Tolypothrix conglutinata*		+						
147	*Tolypothrix saviczii*		+						
148	*Tolypothrix tenuis*		+						
149	*Tolypothrix teodorescui*		+						+
150	*Tolypothrix penicillata*	+	+						
151	*Tolypothrix rechingeri*		+						
152	*Hassallia bouteillei*	+	+						
153	*Chlorogloeopsis fritschii*	+							+
154	*Chondrogloea flagelliformis*			+					
155	*Hapalosiphon luteolus*							+	
156	*Hapalosiphon welwitschii*		+						
157	*Hapalosiphon intricatus*	+						+	
158	*Mastigocladus laminosus*			+					
159	*Fischerellopsis moniliformis*		+						
160	*Westiellopsis prolifica*	+							+
161	*Westiellopsis indica*				+				
162	*Doliocatella formosa*					+			
163	*Stigonema minutissimum*		+						
164	*Stigonema tomentosum*	+							
165	*Stigonema turfaceum*		+						
166	*Stigonema minutum*		+						+
167	*Sphaerospermopsis aphanizomenoides*			+					
168	*Anabaena hatueyi*			+					+
169	*Anabaena sphaerica*								+
170	*Anabaena constricta*			+					
171	*Anabaena echinospora*	+							
172	*Anabaena iyengarii* var. *unispora*			+		+			
173	*Anabaena orientalis*	+							
174	*Anabaena schauderi*		+						
175	*Anabaena sedovii*	+							+

176	*Aulosira prolifica*				+				
177	*Aulosira implexa*						+	+	
178	*Cylindrospermum licheniforme*				+				+
179	*Cylindrospermum licheniforme* var. *tumidum*		+						
180	*Cylindrospermum musicola*				+				
181	*Nodularia moravica*		+						
182	*Nodularia armorica*				+				+
183	*Trichormus gelatinicola*					+			
184	*Trichormus naviculoides*		+						
185	*Trichormus propinquus*			+					
186	*Trichormus subtropicus*	+			+				
187	*Trichormus variabilis* var. *cylindracea*		+	+					
188	*Nostoc bicalyptratum*			+					
189	*Nostoc caeruleum*		+						
190	*Nostoc calcicola*		+						
191	*Nostoc carneum*		+						
192	*Nostoc comminutum*		+						
193	*Nostoc commune*	+							+
194	*Nostoc ellipsosporum*		+	+					
195	*Nostoc gelatinosum*	+		+					
196	*Nostoc linckia*	+		+					
197	*Nostoc minutum*			+		+			
198	*Nostoc paludosum*	+	+						
199	*Nostoc pruniforme*		+		+				
200	*Nostoc spongiaeforme*		+	+					
201	*Nostoc spongiaeforme* var. *tenue*		+						
202	*Desmonostoc muscorum*	+				+			
203	*Mojavia pulchra*				+				+
204	*Aliinostoc constrictum*			+					+

A-Epactiphytic, B-Epilithic, C-Epiphytic, D-Epipelic, E-Corticolous, F-Planktic, G-Benthophytic, H-Edaphic

5.3. Habit

All the major cyanobacterial types and groups were recorded during the study. They range from unicellular forms to branched filamentous forms. Chroococcales members are unicellular forms and some taxa are with solitary (*Cyanothece* and *Cyanobium*) cells. Some are in pairs of cells (*Cyanobacterium* and *Gloeothece*) and sometimes in colonial forms (*Aphanocapsa* and *Microcystis*). Filamentous cyanobacterial groups are further divided into Oscillatoriales and heterocystous cyanobacteria. Oscillatoriales are with solitary filaments (*Oscillatoria* and *Planktothrix*), filaments in a common sheath (*Microcoleus*), filaments with individual sheath (*Lyngbya* and *Phormidium*) and also pseudobranched (*Leptolyngbya*) cyanobacterial forms. Heterocystous cyanobacteria are again classified into branched and unbranched types. Unbranched types (*Nostoc* and *Anabaena*) are occasionally enveloped. Branched heterocystous cyanobacteria have false branched forms (*Scytonema* and *Tolypothrix*) as well as true branched types (*Hapalosiphon* and *Mastigocladus*).

5.3.1. Morphology

Most of the cyanobacterial species forming aggregations of colonies have become macroscopic. Usually they are mucilaginous and sometimes forming mat like appearance (*Scytonema*). Some cyanobacteria look like slimy gelatinous mass (*Chroococcus* and *Trichormus*) and some other cyanobacteria form gelatinous balls (*Nostoc* and *Desmonostoc*). Certain species of *Scytonema*, *Tolypothrix* and *Rivularia* become very thick forming a thread like structure which are firmly attached to a substratum. Colonies aggregate to form large slime or mucilage under favourable conditions. Most of the colonies are dark to pale brown in colour. Many of the Oscillatoriales members exhibit dark blue-green colour.

5.3.2. Trichomes and cells

Trichomes are usually cylindrical in majority of filamentous species, occasionally become rod shaped, elongated or spherical, with or without envelope and varying shape and size according to species. Cells are also with different size and shape. Spherical cell characters are exhibited by some *Anabaena* and *Aphanocapsa* members. A few *Cylindrospermum* and *Nostoc* members show barrel shaped cells. *Gloeothece* and *Cyanobacterium* have elongated, oval or rod shaped cells. Sheaths are either unlamellated (*Aulosira implexa*) or lamellated (*Scytonema torulosum*). Sheaths of some cyanobacterial species are widened and form wing like structure (*Petalonema*). Cells may or may not have granular contents. *Cylindrospermum musicola* was prominent with granular content, while *Aliinostoc constrictum* without prominent granules. (Fig. 66)

5.3.3. Heterocysts

Size of the heterocysts differs in accordance with change in genera and species. Shape of the heterocyst showed remarkable variations and shape may be spherical (*Desmonostoc*), oval or elongated (*Nostoc*), hemispherical (*Calothrix*), quadrate or compressed (*Nodularia*) and rod shaped (*Westiellopsis*). Position of heterocysts may be terminal (*Calothrix*) or intercalary (*Anabaena*, *Trichormus*). In some cases, as in multiseriate cyanobacteria such as *Stigonema* and *Westiellopsis*, heterocysts may appear in lateral position. Most of the heterocysts are olivaceous. Olive green, bright green or yellowish in colour, occasionally similar to the cell colour. (Fig. 67)

5.4. Temperature and pH

Temperature recorded from all the collection sites across Kerala showed variations between 2-10^{o}C. During summer season, temperature was maximum in Palakkad and Kannur Districts, and minimum in Idukki (Meesapulimala) and Thiruvananthapuram (Agasthyamala). Cyanobacterial diversity was found to be very less during this season. The temperature rise creates an adverse condition for cyanobacterial growth, so they become sporulated to survive the increased temperature. During the post-monsoon season, lowest temperature was recorded in Wayanad, Idukki, Thrissur and Thiruvananthapuram. Highest temperature was reported in Ernakulam and Kottayam. Cyanobacterial diversity shows exponential growth just after monsoon season. This season provides all the necessary requirements for cyanobacterial growth and establishment. The sporulated cyanobacterial cells germinate and vigorously grow during this season.

pH of collection site was recorded the lowest during summer season. Ernakulam and Palakkad had low pH value, and acidic in condition. Highest pH value was obtained from Thiruvananthapuram and Idukki during summer season. pH value decreased considerably and soil was comparatively more alkaline during monsoon season. Cyanobacteria prefer slight alkaline conditions for their optimum growth. During post monsoon season the soil and water become alkaline and therefore cyanobacteria showed maximum growth. Highest pH value obtained during post-monsoon season was from Gavi and Kozhikode. Lowest pH value was recorded from Thamarassesy Ghat and Neriyamangalam.

The current study revealed that the heterocystous cyanobacteria are the dominating category with 84 species out of 203 species reported, which is followed by unicellular Chroococcales with 66 species. Oscillatoriales members showed the lowest representation during the study with 53 species. Considering the genus level domination, *Chroococcus* was dominant over all other 48 genera by providing 17 species. *Phormidium* contributed 15 species and *Oscillatoria* and *Nostoc* provided 14 species from each.

By analysing the data, we can understand that the members with heterocysts were more diverse than others. But, the genus *Chroococcus* showed high adaptability and representation from most of the collection sites. Unbranched cyanobacterial taxa dominated over branched cyanobacterial taxa. Earlier it is believed that heterocystous genera are the only nitrogen fixators, but now it is proved that all the cyanoprokaryotes have the capability to fix atmospheric nitrogen and perform photosynthesis. 31 species of cyanobacteria identified during the study were new to Kerala. Among them eight are new to India. And also, species like *Microcrocis sabulicola* were reported first time from a non-saline habitat. All these data would help for the advanced studies on selected species. Documentation of a group of organisms is always important. Some toxic cyanobacterial strains (*Microcystis* and *Lyngbya*) were also reported during the study. By detecting their occurrence, it is easy to reduce their toxic impact on our daily life.

Throughout the study, many cyanobacterial specimens were collected and a few are still unidentified due to their morphological complexity with other cyanobacterial species and therefore detailed molecular study is needed to confirm their identity. We recommend those for detailed molecular characterisation to confirm their identity. For this purpose, the collected specimens are cultured and maintained in the germplasm collection of cyanobacteria in the Department of Botany, University of Calicut. It is critical to note that forests of Kerala are with thousands of unidentified cyanobacterial species. Researchers must focus on cyanoprokaryotes like organisms, because they are as important as higher plants. They are one of the largest producers of oxygen and are also used for many biotechnological, pharmaceutical and agricultural purposes. Scarcity of literature on cyanobacterial diversity in the forests of Kerala is perhaps the limiting factor for taking up extensive study on this unique group of organisms. This work provides evidences on richness of cyanobacterial diversity in Western Ghat regions of Kerala, and they showed optimum growth in natural habitats compared to agricultural fields.

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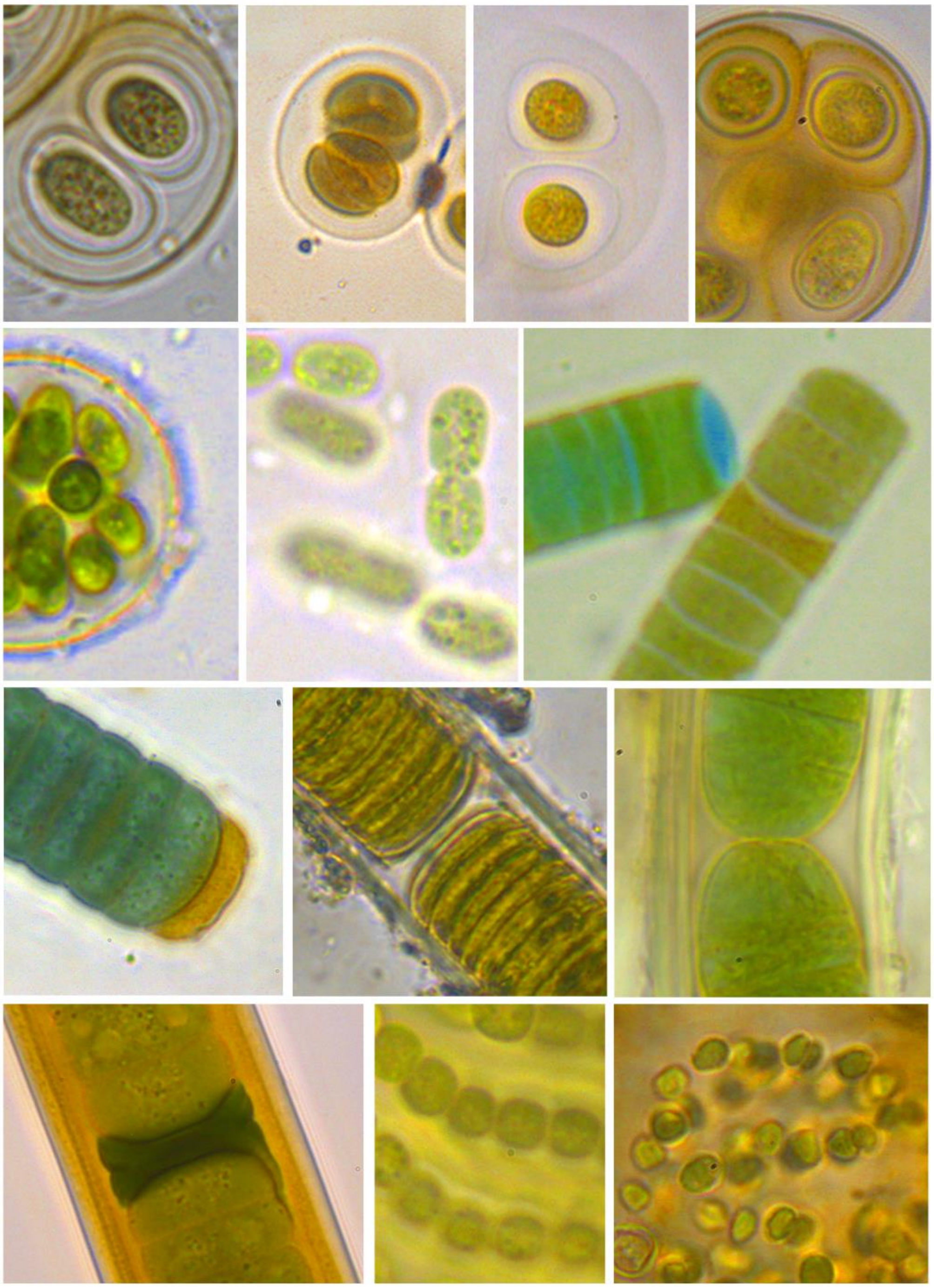

Fig. 66: Diversity of cyanobacterial trichome

Fig. 65: Habitat diversity of cyanobacteria

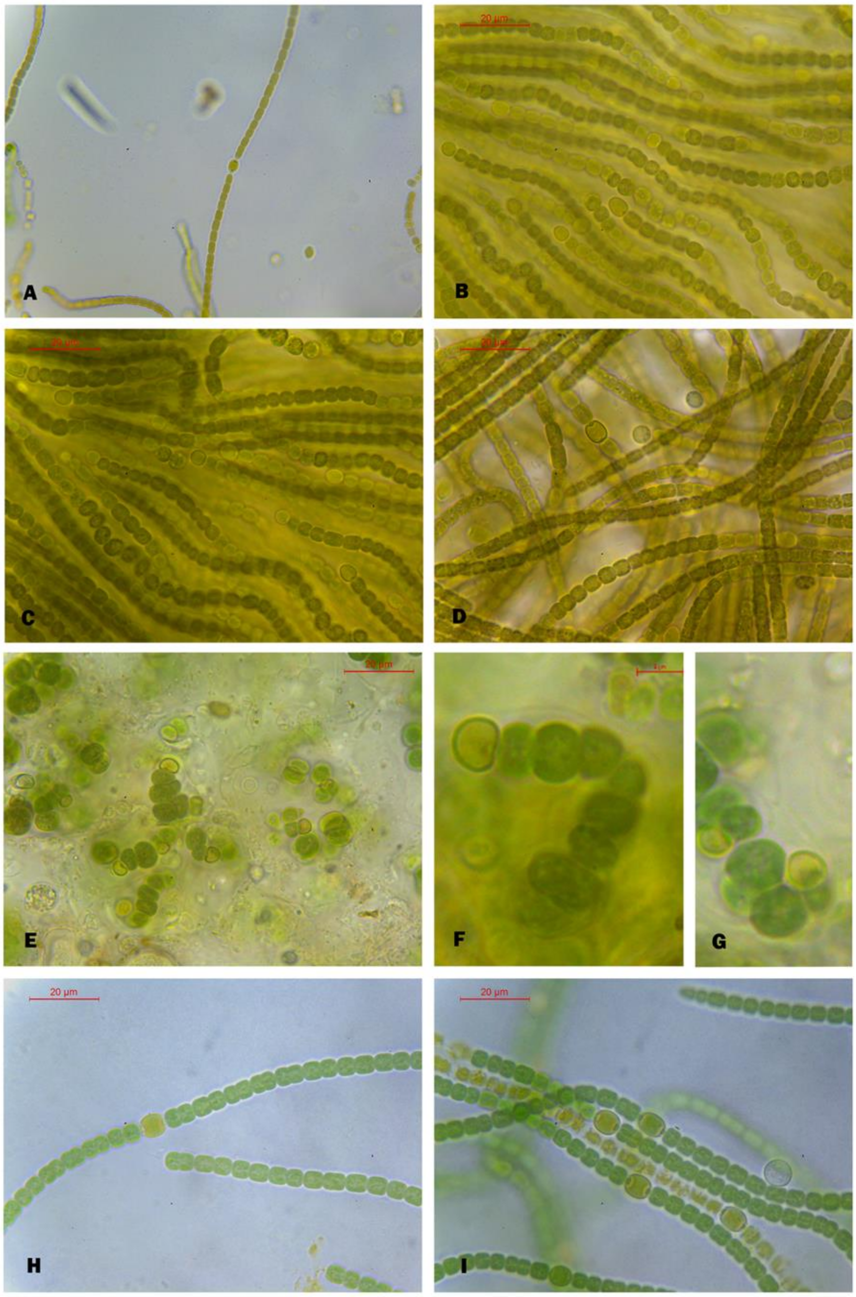

Fig. 64: A. *Nostoc spongiiforme* var. *tenue*, **B-D.** *Desmonostoc muscorum*, **E-G.** *Mojavia pulchra*, **H & I.** *Aliinostoc constrictum*

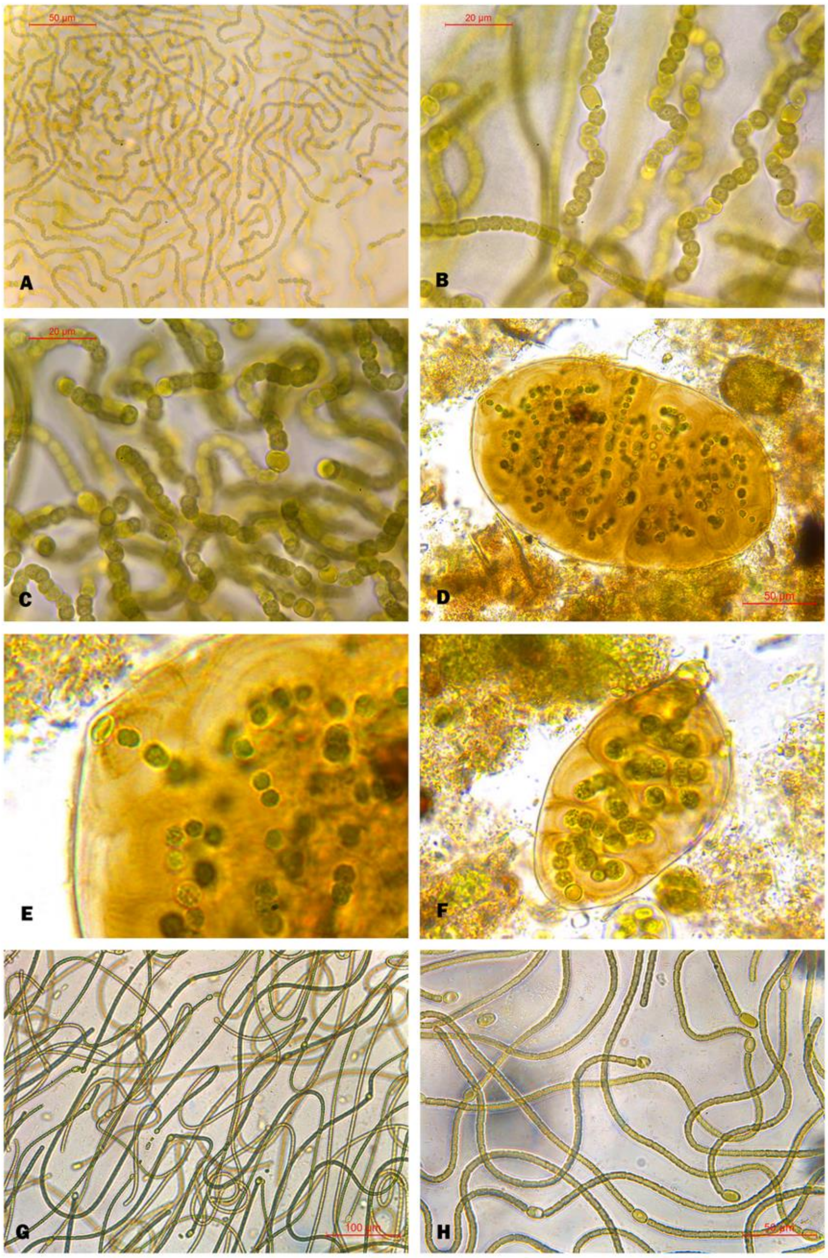

Fig. 63: **A-C.** *Nostoc paludosum,* **D-F.** *N. pruniforme,* **G & H.** *N. spongiiforme*

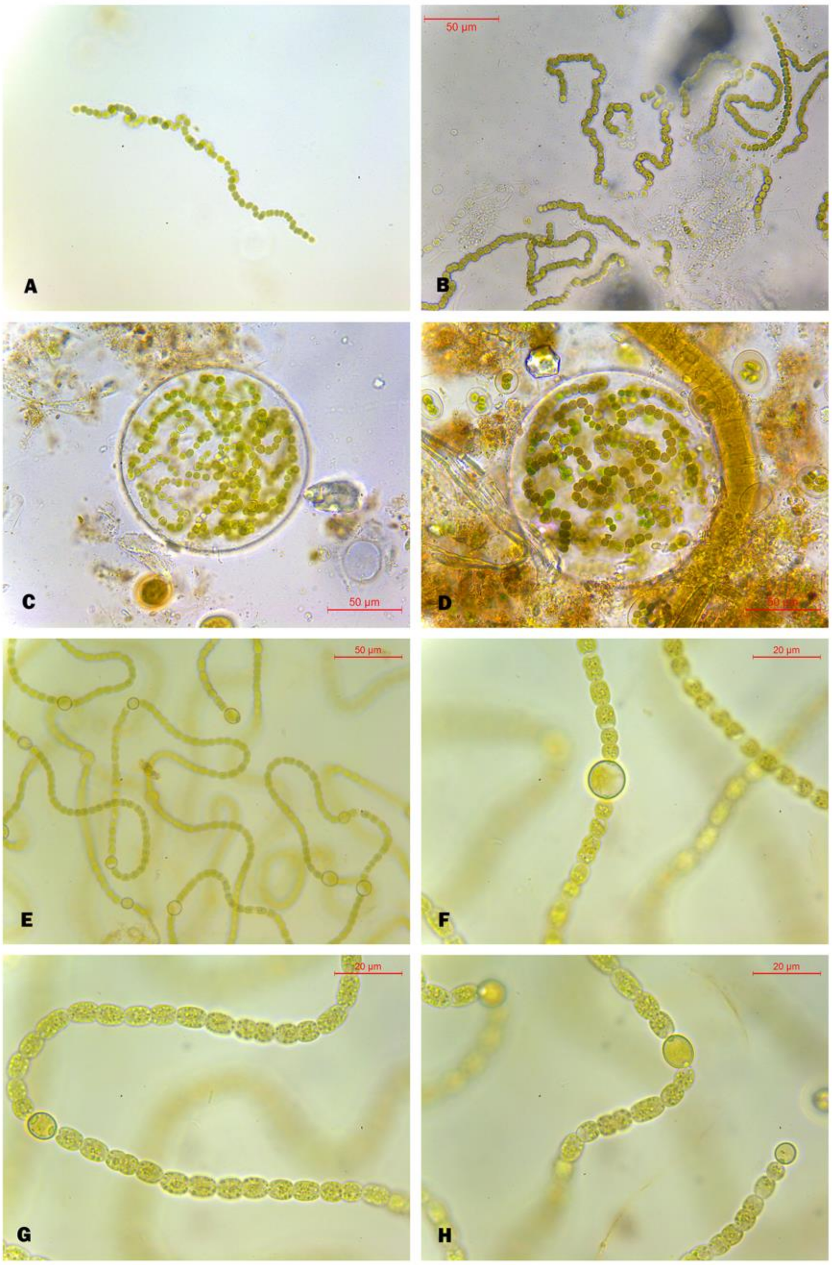

Fig. 62: **A & B.** *Nostoc linckia,* **C-H.** *N. minutum*

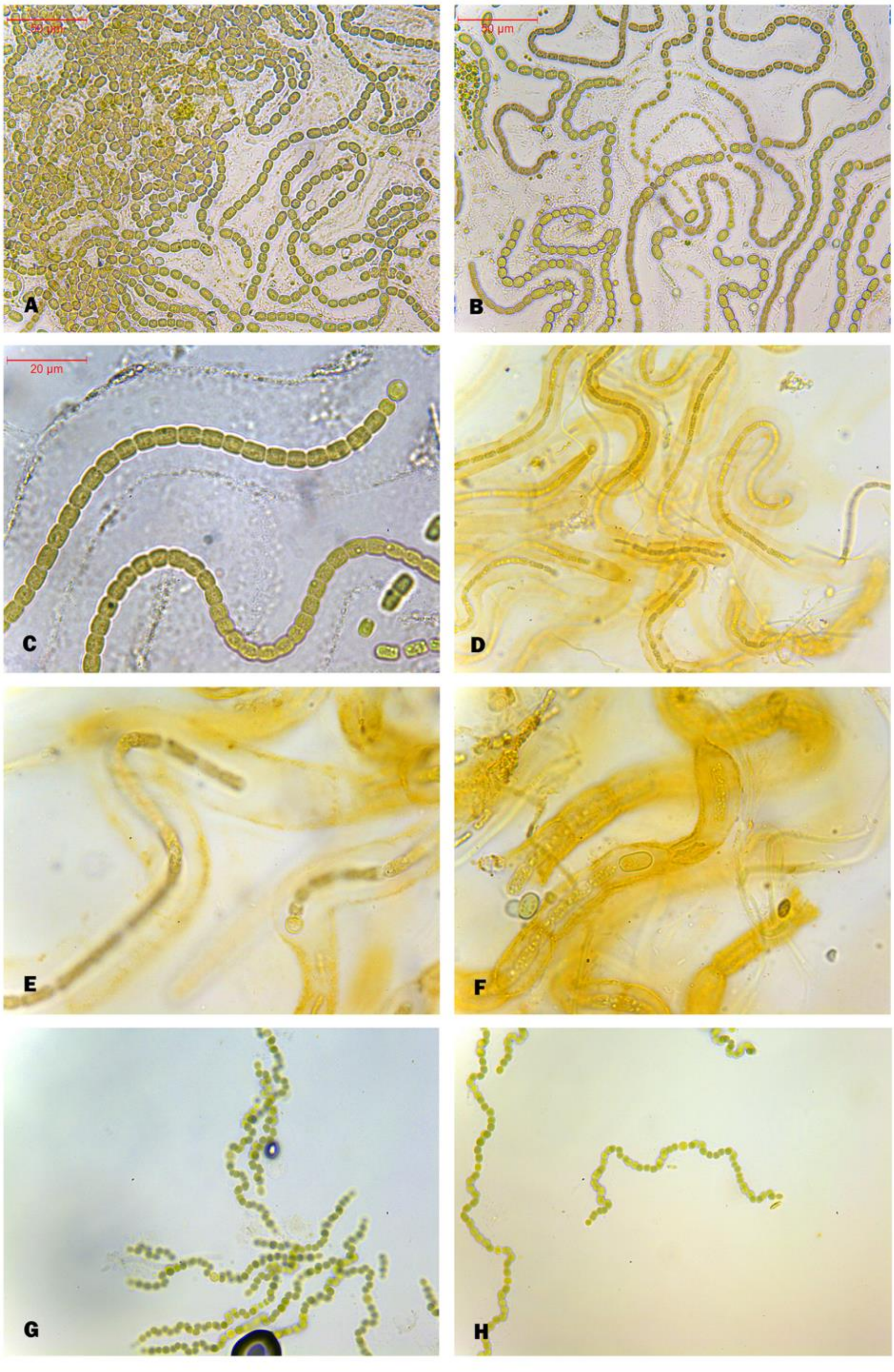

Fig. 61: **A-C.** *Nostoc ellipsosporum,* **D-F.** *N. gelatinosum*
G & H. *N. linckia*

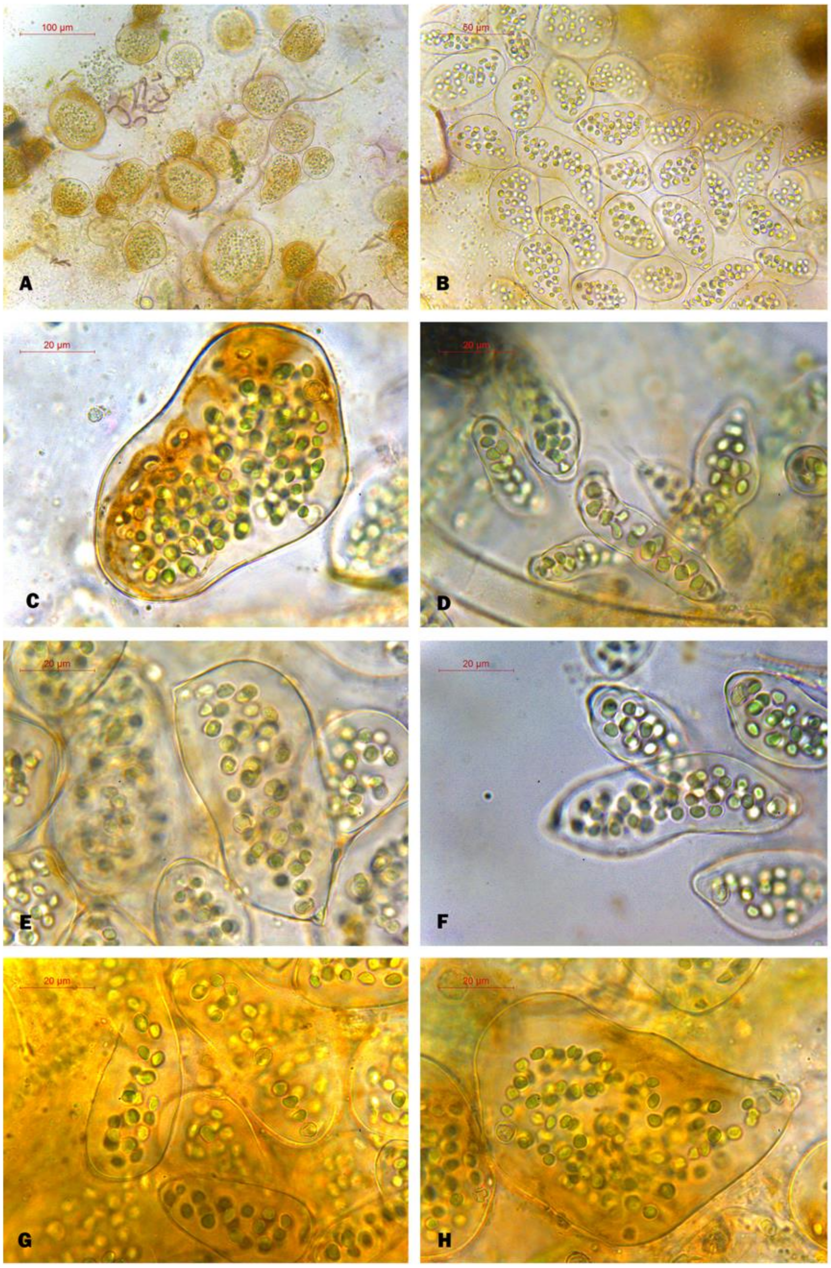

Fig. 60: **A-H.** *Nostoc commune*

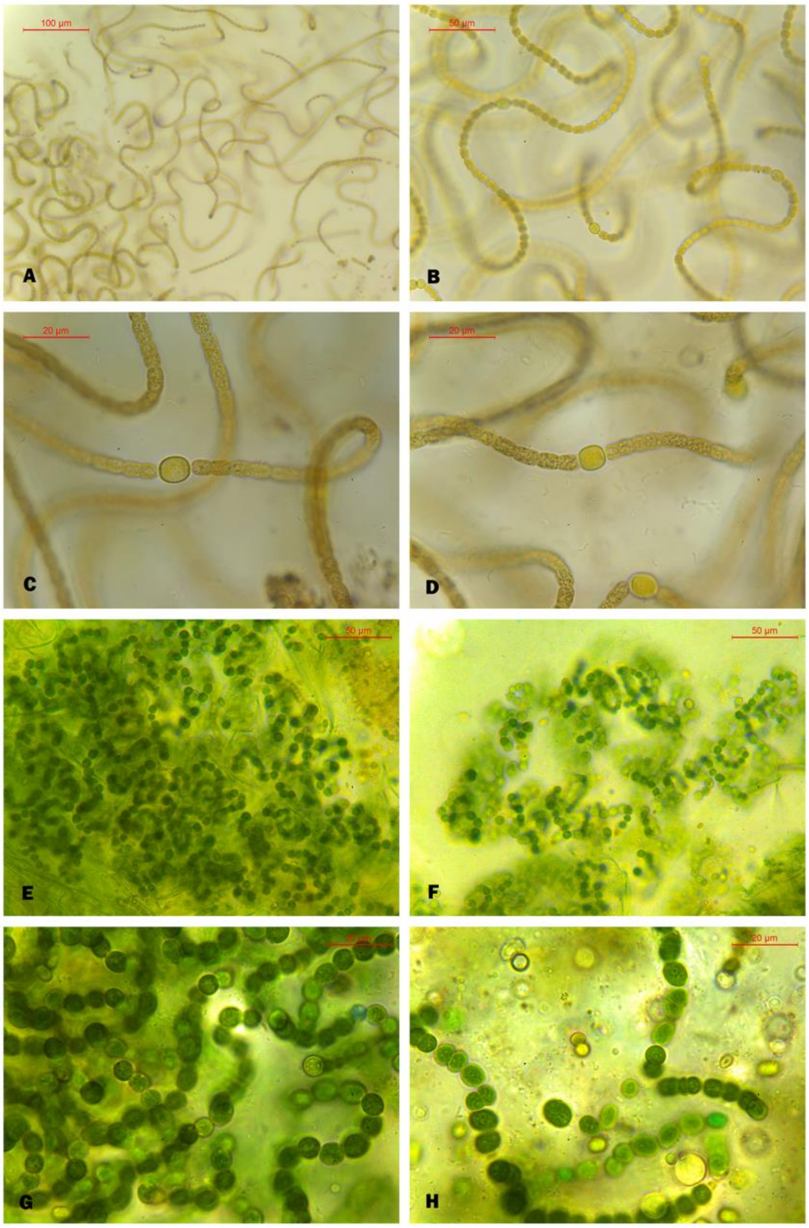

Fig. 59: **A-D.** *Nostoc carneum,* **E-H.** *N. comminutum*

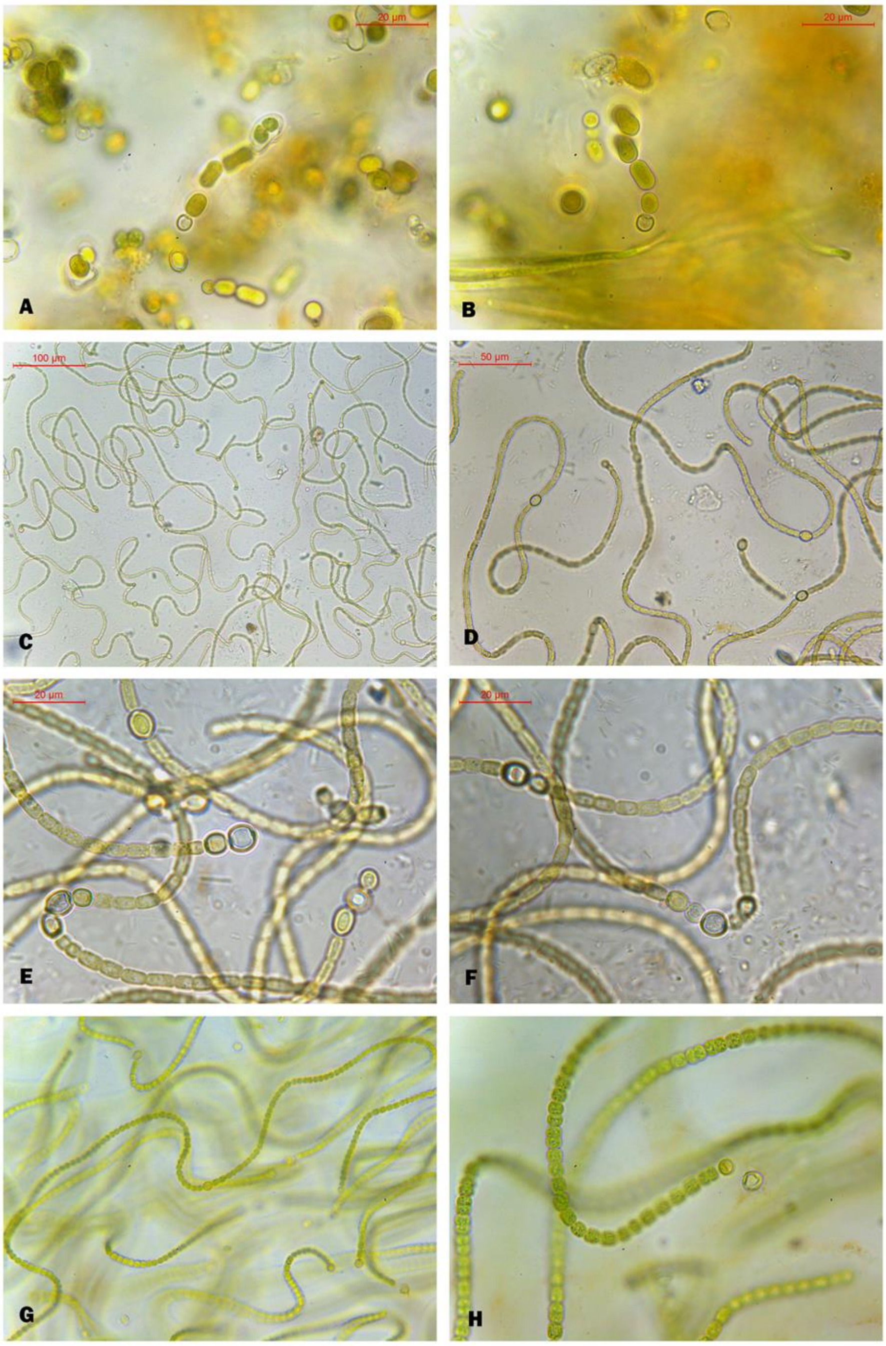

Fig. 58: **A & B.** *Nostoc bicalyptratum,* **C-F.** *N. caeruleum,* **G & H.** *N. calcicola*

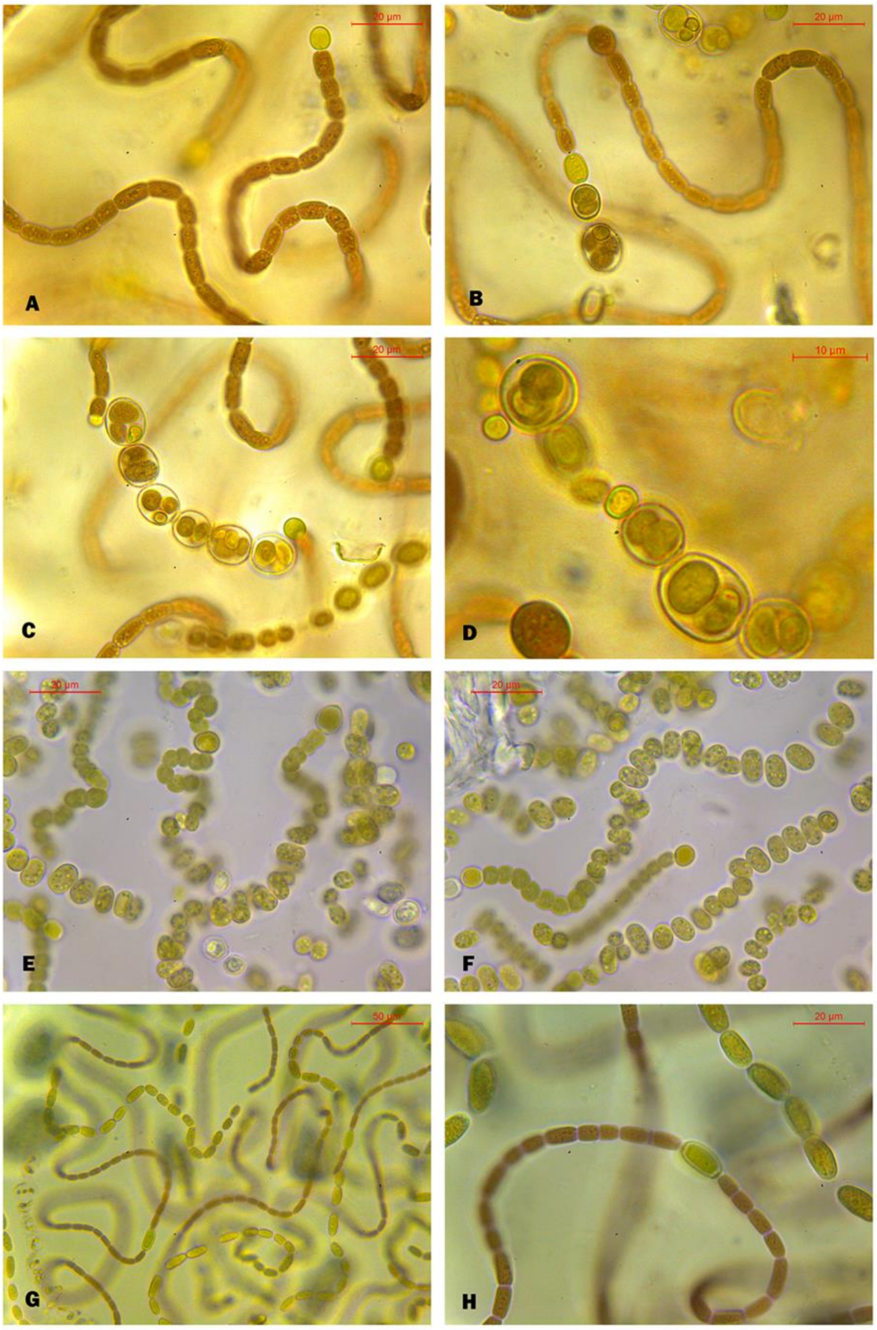

Fig. 57: **A-D.** *Trichormus propinquus,* **E & F.** *T. subtropicus,* **G & H.** *T. variabilis* var. *cylindracea*

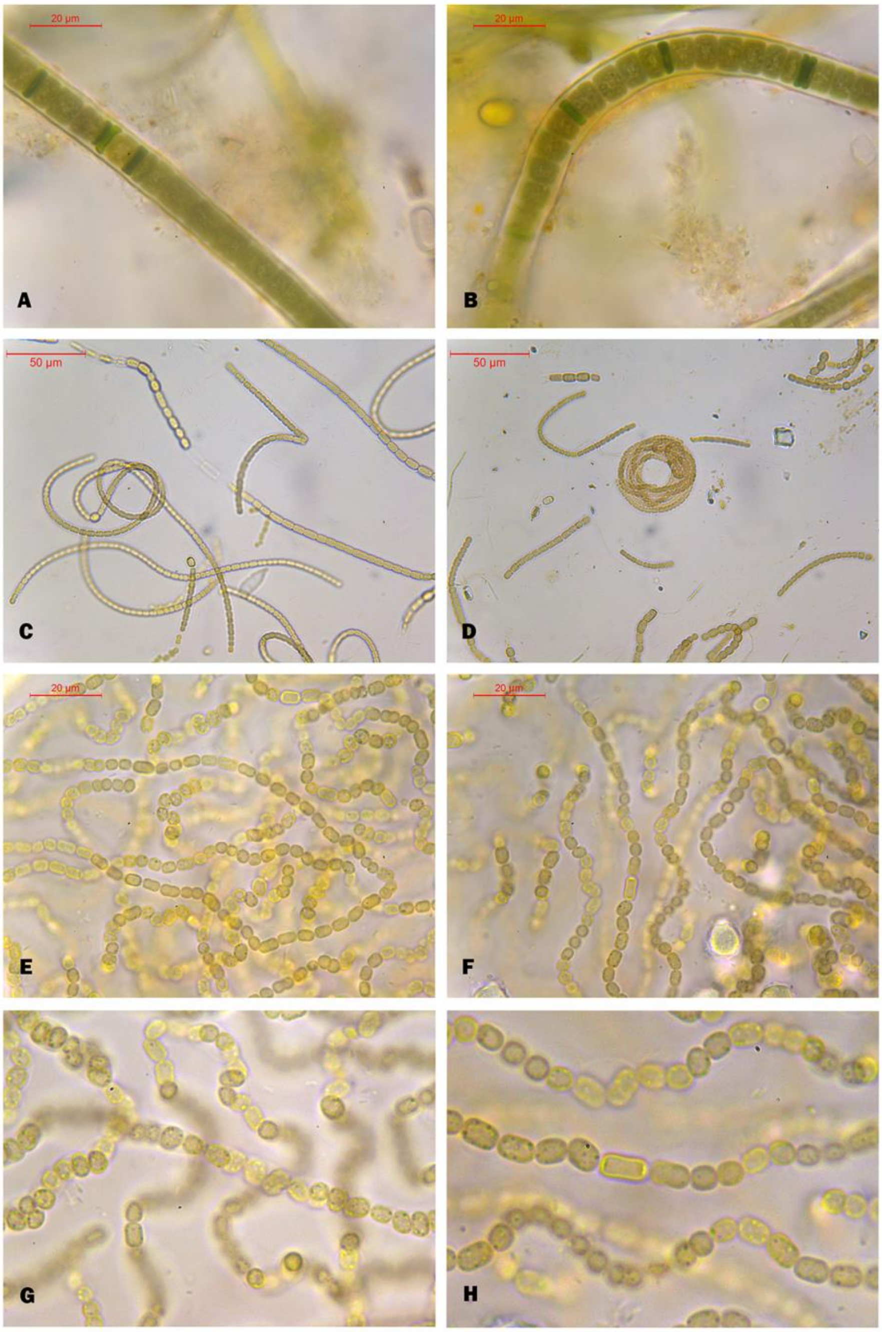

Fig. 56: A & B. *Nodularia armorica,* **C & D.** *Trichormus gelatinicola,* **E-H.** *T. naviculoides*

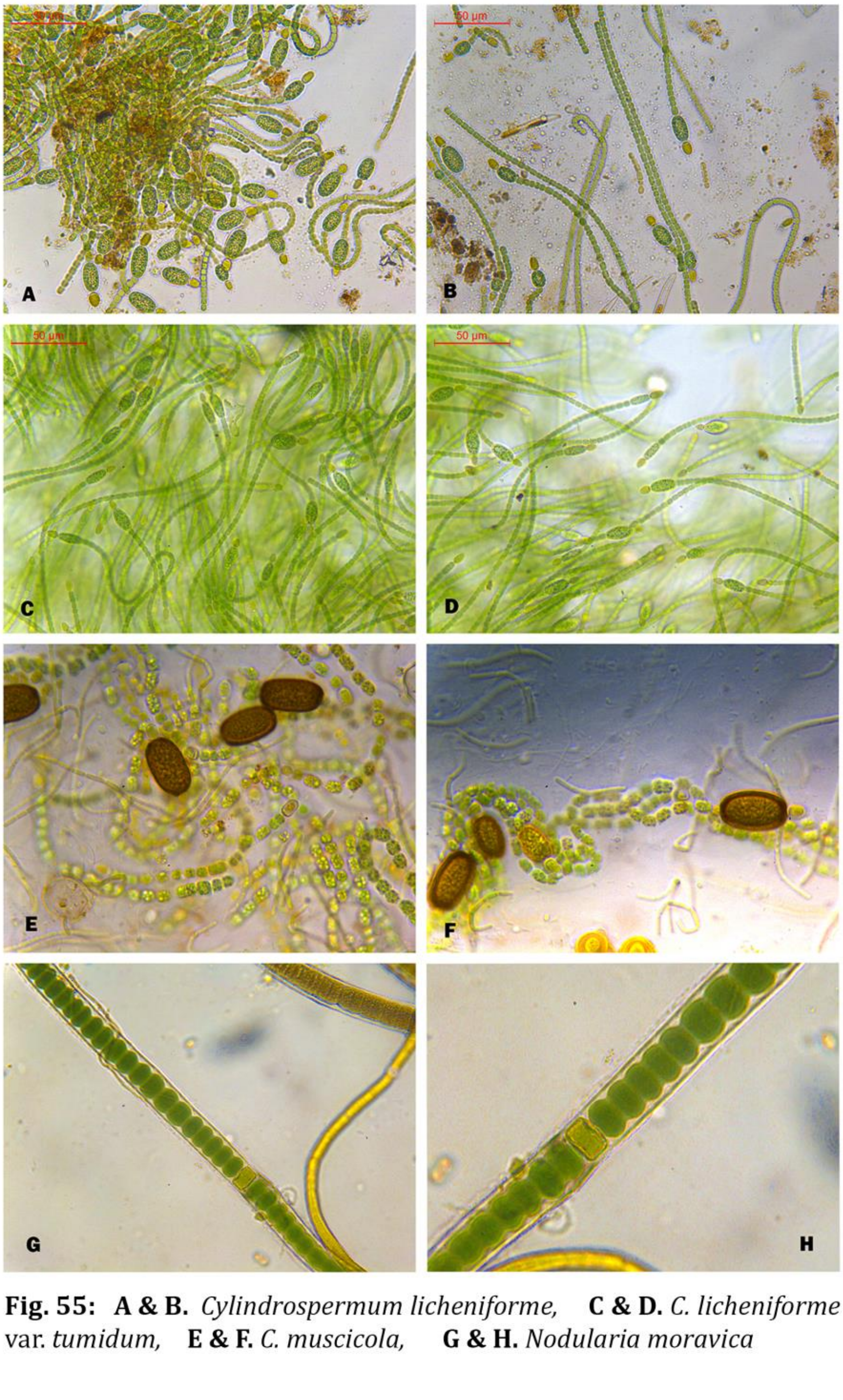

Fig. 55: A & B. *Cylindrospermum licheniforme,* **C & D.** *C. licheniforme* var. *tumidum,* **E & F.** *C. muscicola,* **G & H.** *Nodularia moravica*

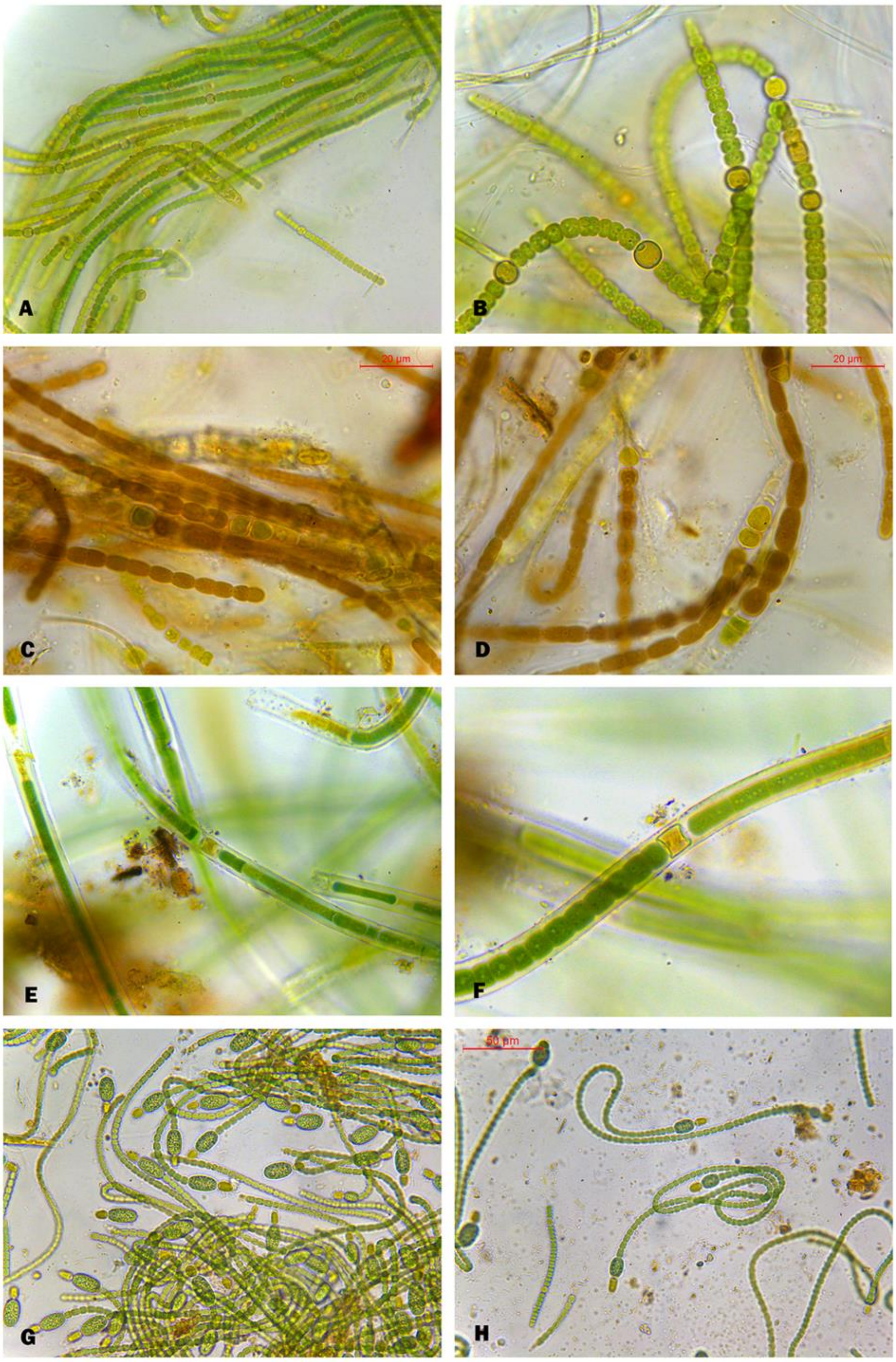

Fig. 54: **A & B.** *Anabaena sedovii,* **C & D.** *Aulosira prolifica,*
E & F. *A. implexa,* **G & H.** *Cylindrospermum licheniforme*

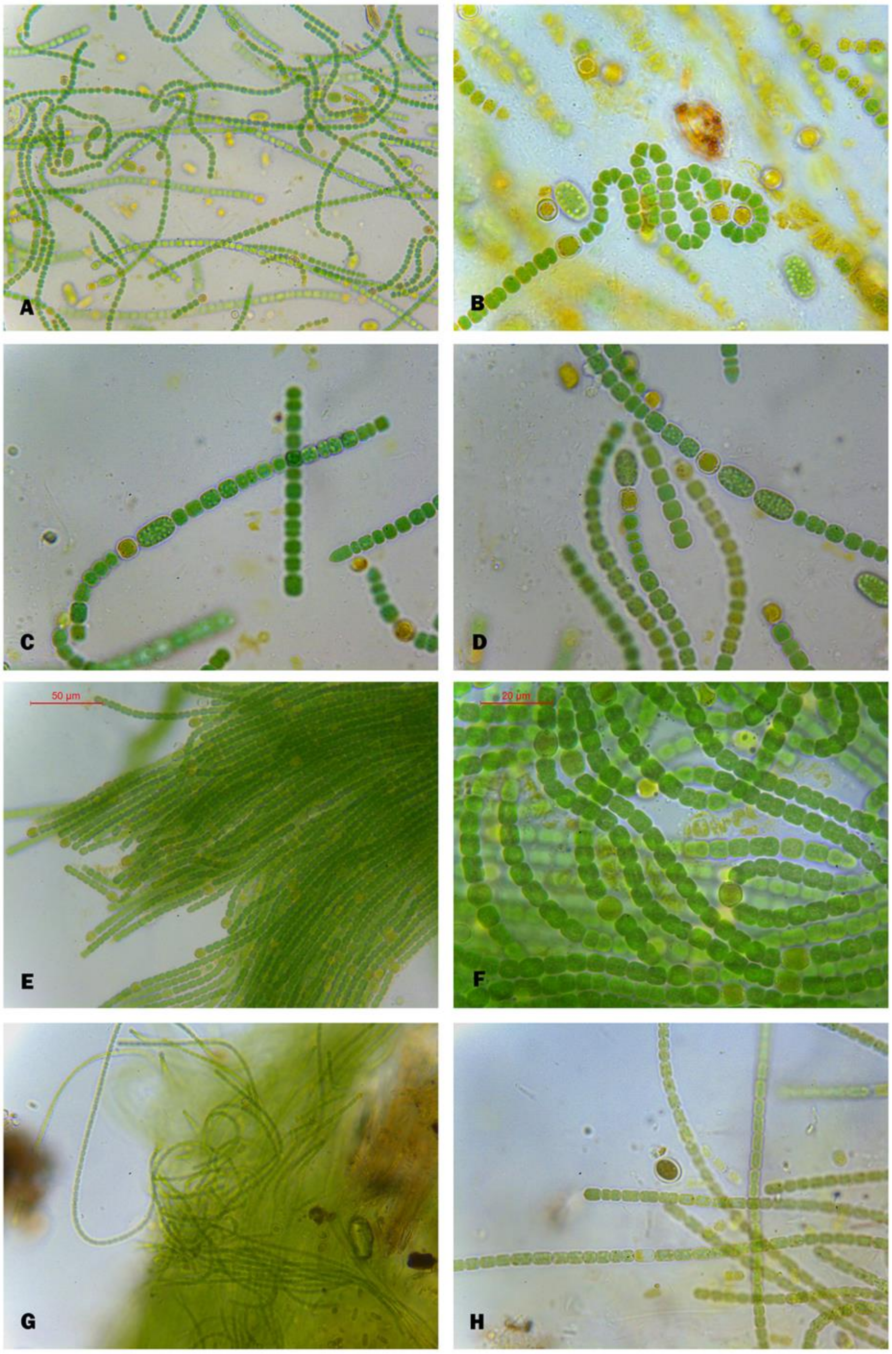

Fig. 53: A-D. *Anabaena iyyengarii* var. *unispora*, **E & F.** *A. orientalis* **G & H.** *A. schauderi*

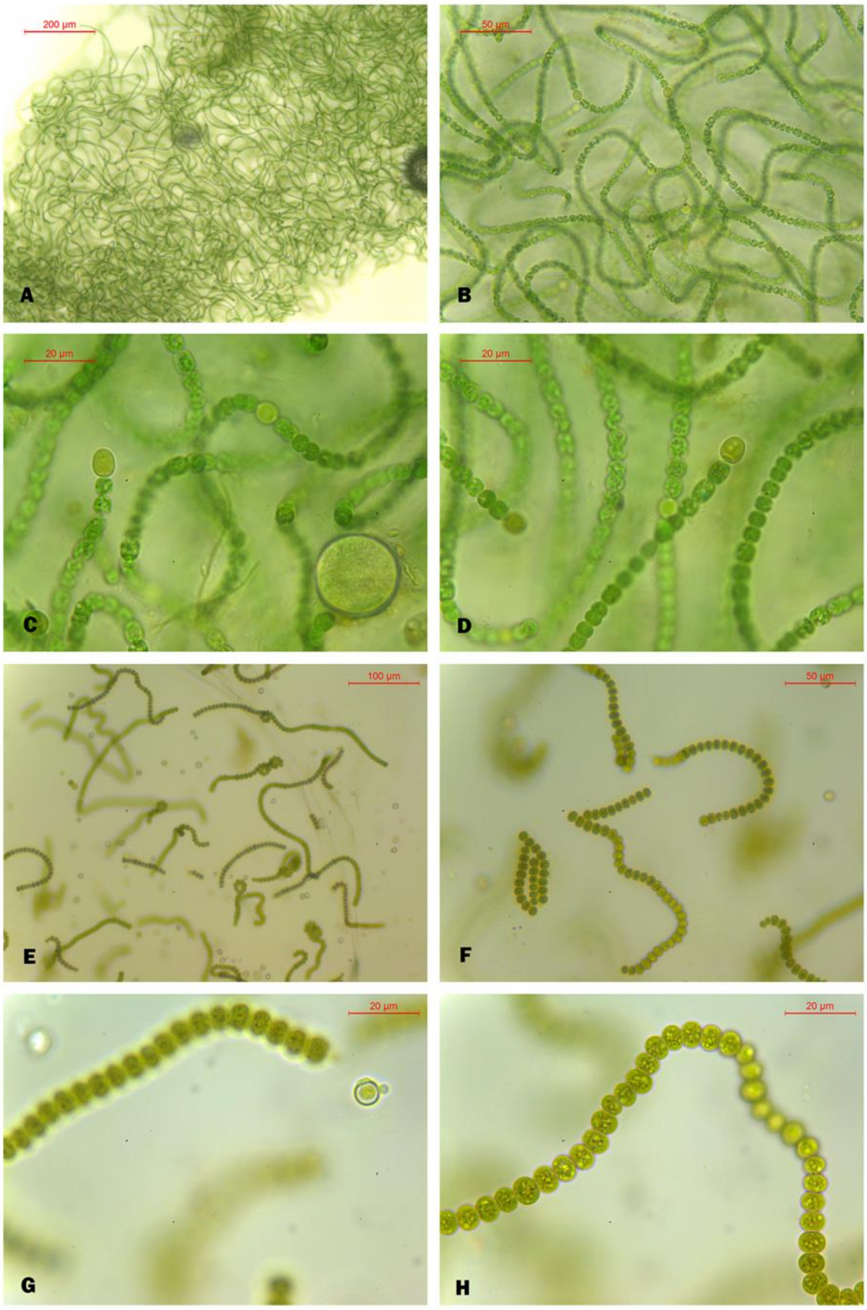

Fig. 52: A-D. *Anabaena constricta,* **E-H.** *A. echinospora*

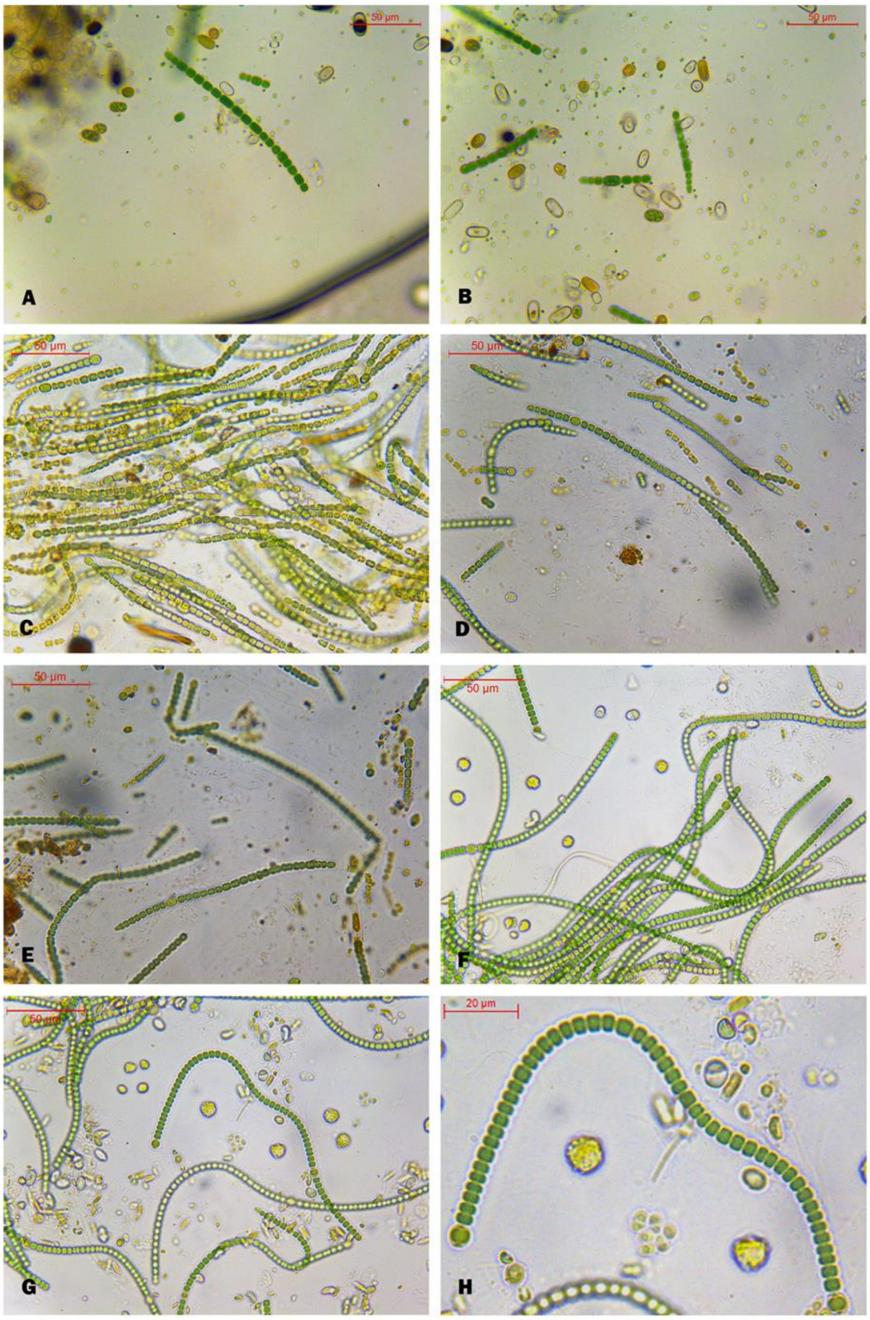

Fig. 51: A & B. *Sphaerospermospsis aphanizomenoides,*
C-D. *Anabaena hatueyi,* **F-H.** *A. sphaerica*

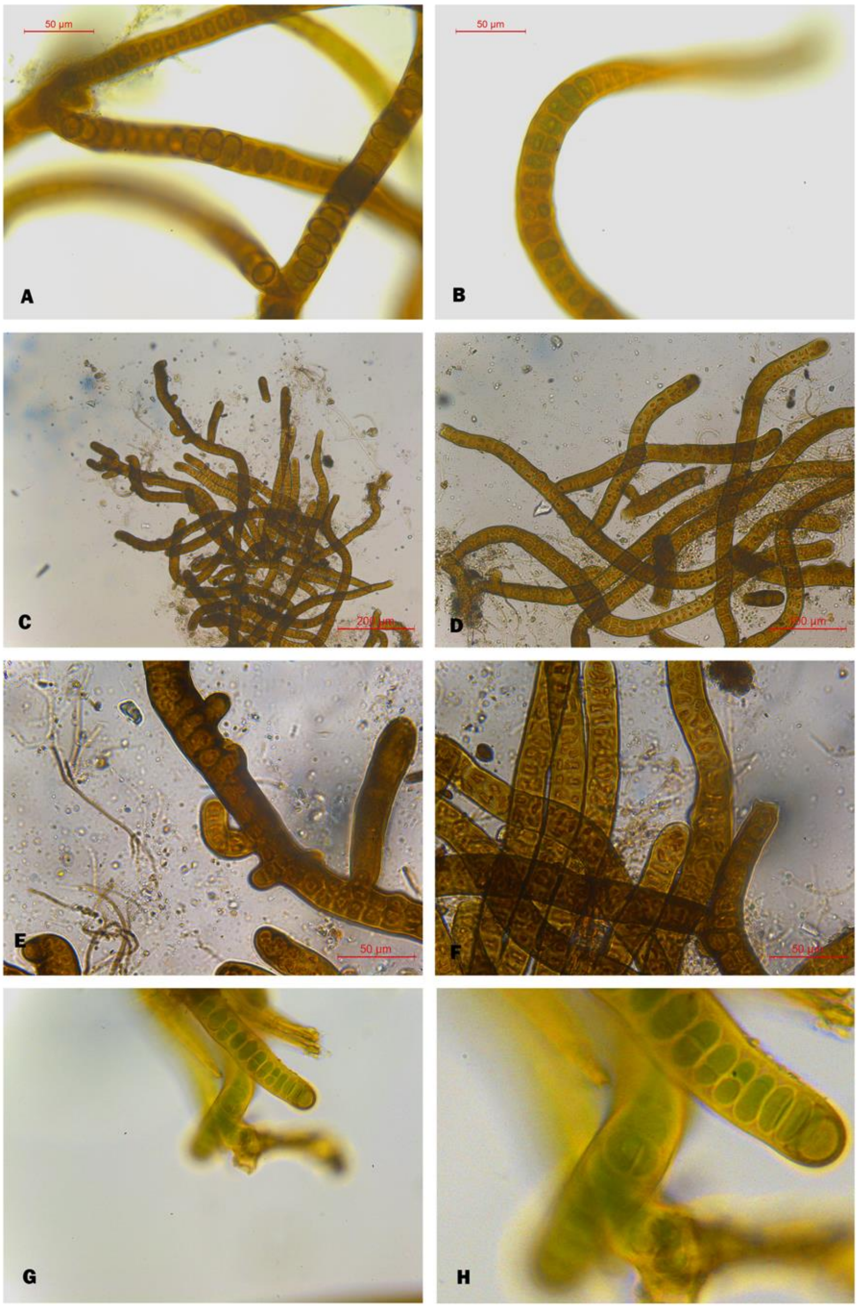

Fig. 50: A & B. *Stigonema tomentosum,* **C-E.** *S. turfaceum*
G & H. *S. minutum*

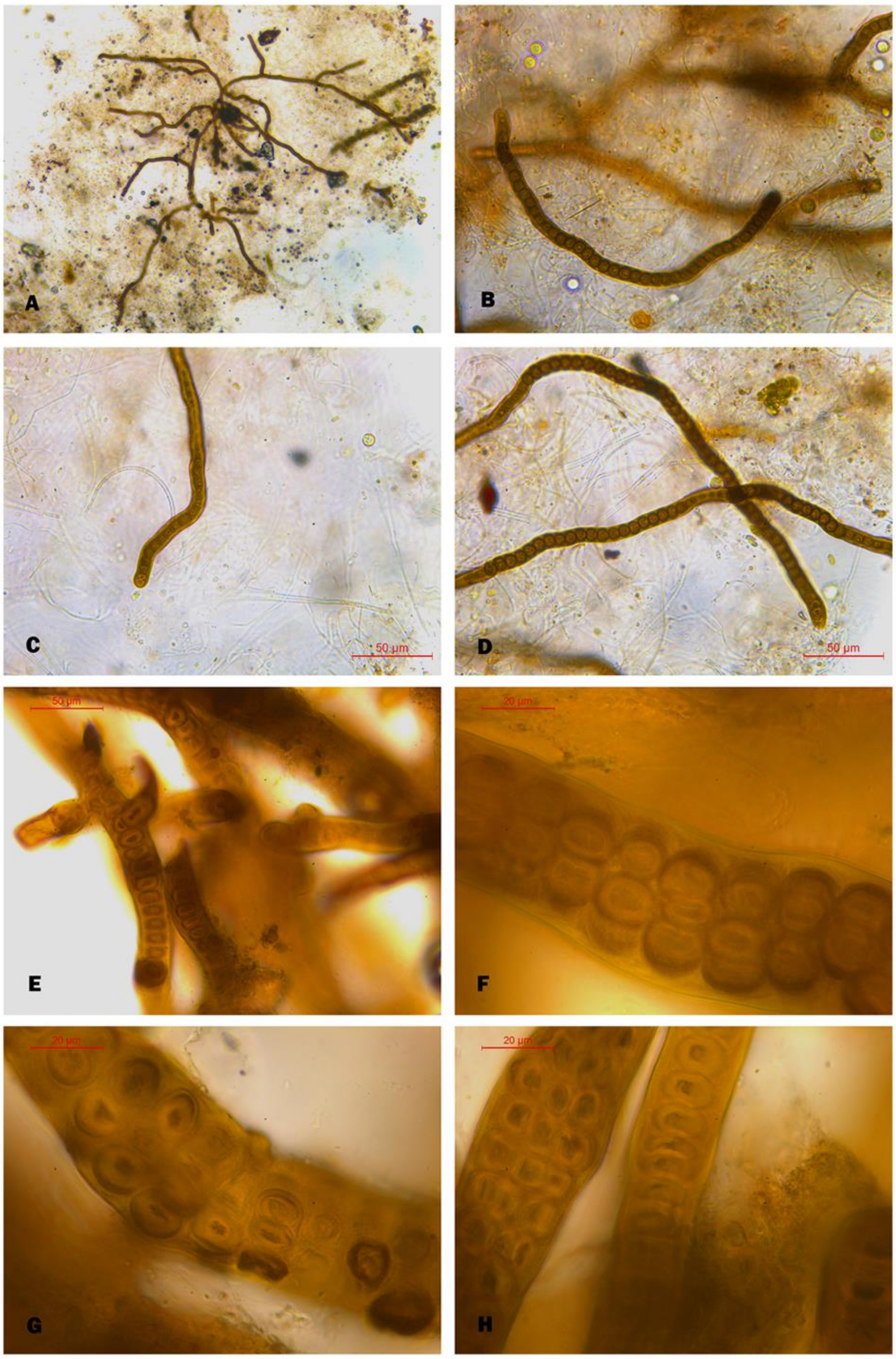

Fig. 49: A-D. *Doliocatella formosa,* **E & H.** *Stigonema minutissimum*

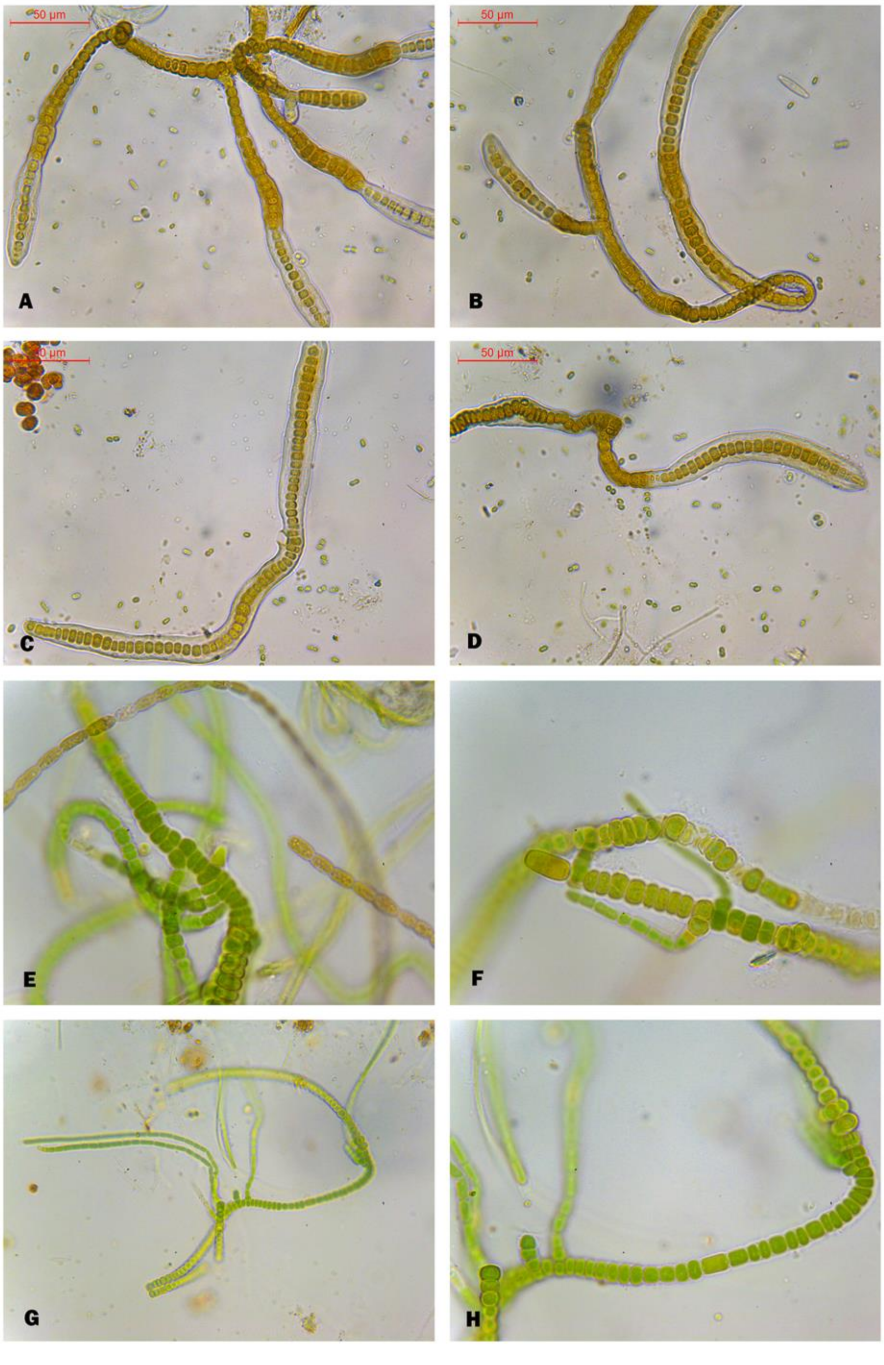

Fig. 48: A-D. *Fischerellopsis moniliformis,* **E & F.** *Westiellopsis prolifica,* **G & H.** *W. indica*

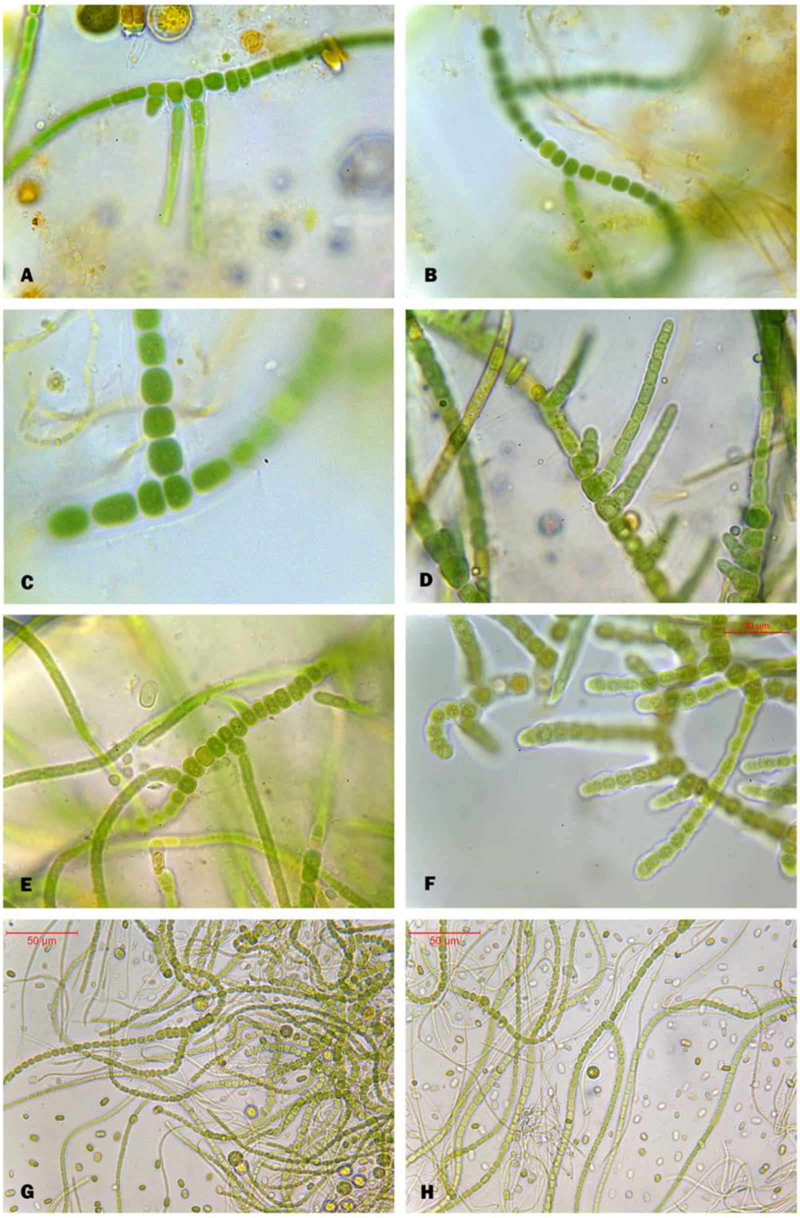

Fig. 47: A. *Chondrogloea flagelliformis,* **B & C.** *Hapalosiphon luteolus,* **D.** *H. welwitschii* **E & F.** *H. intricatus,* **G & H.** *Mastigocladus laminosus*

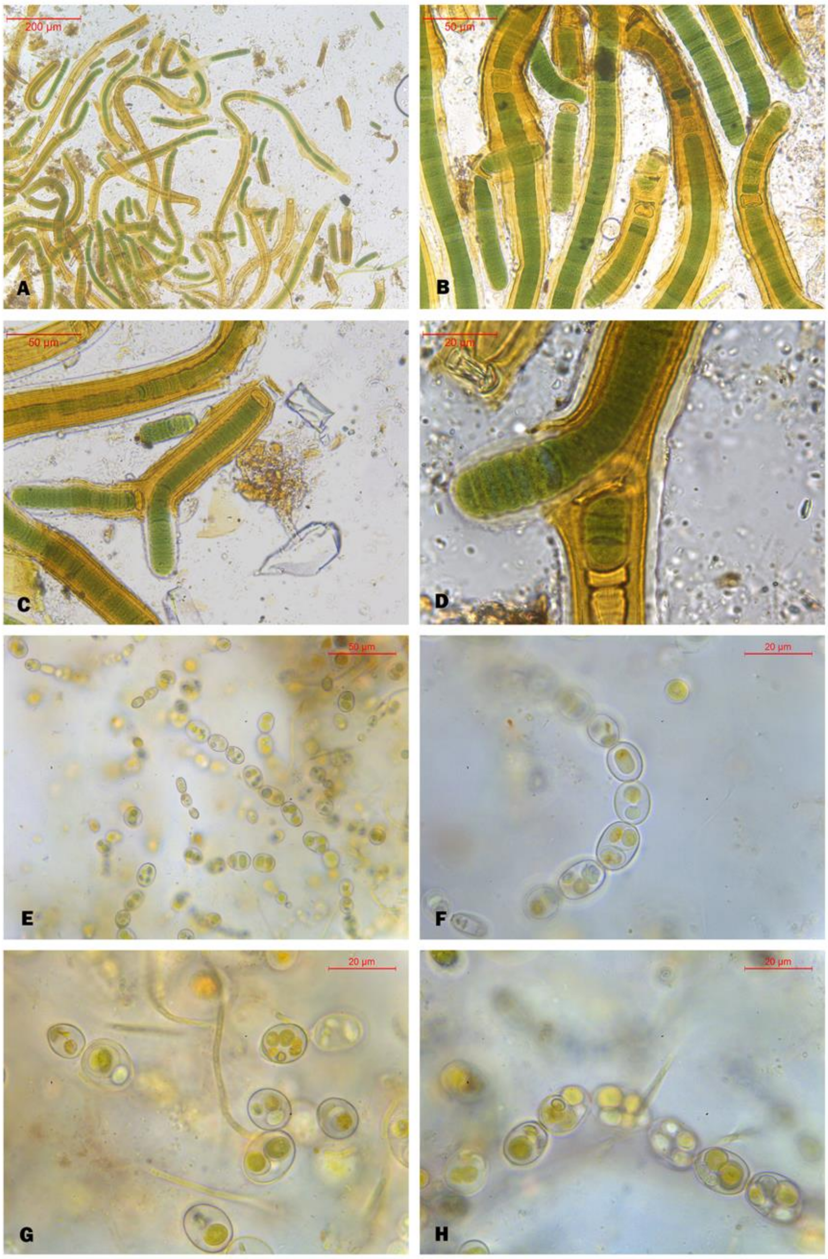

Fig. 46: **A-D.** *Hassallia bouteillei,* **E-H.** *Chlororgloeopsis fritschii*

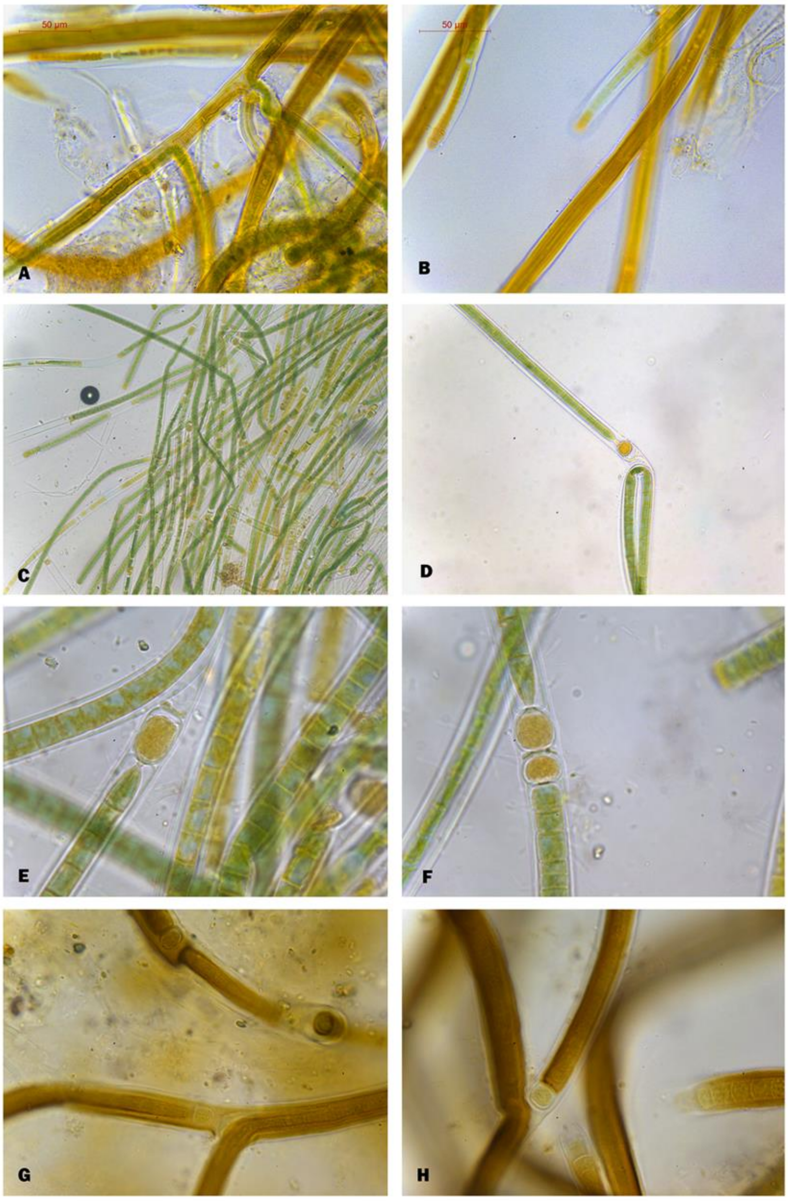

Fig. 45: **A & B.** *Tolypothrix teodorescui,* **C-F.** *T. penicillata,* **G & H.** *T. rechingeri*

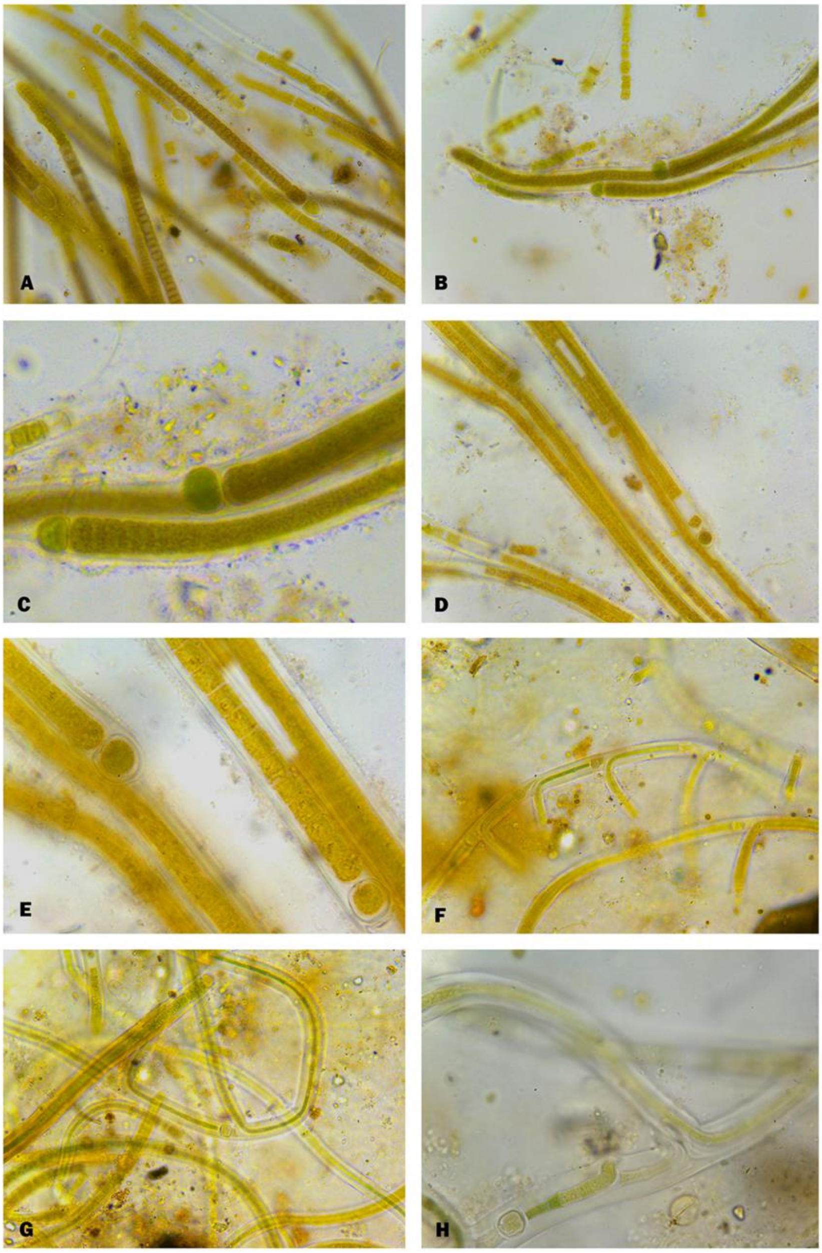

Fig. 44: **A-C.** *Tolypothrix conglutinata,* **D & E.** *T. saviczii,* **F-H.** *T. tenuis*

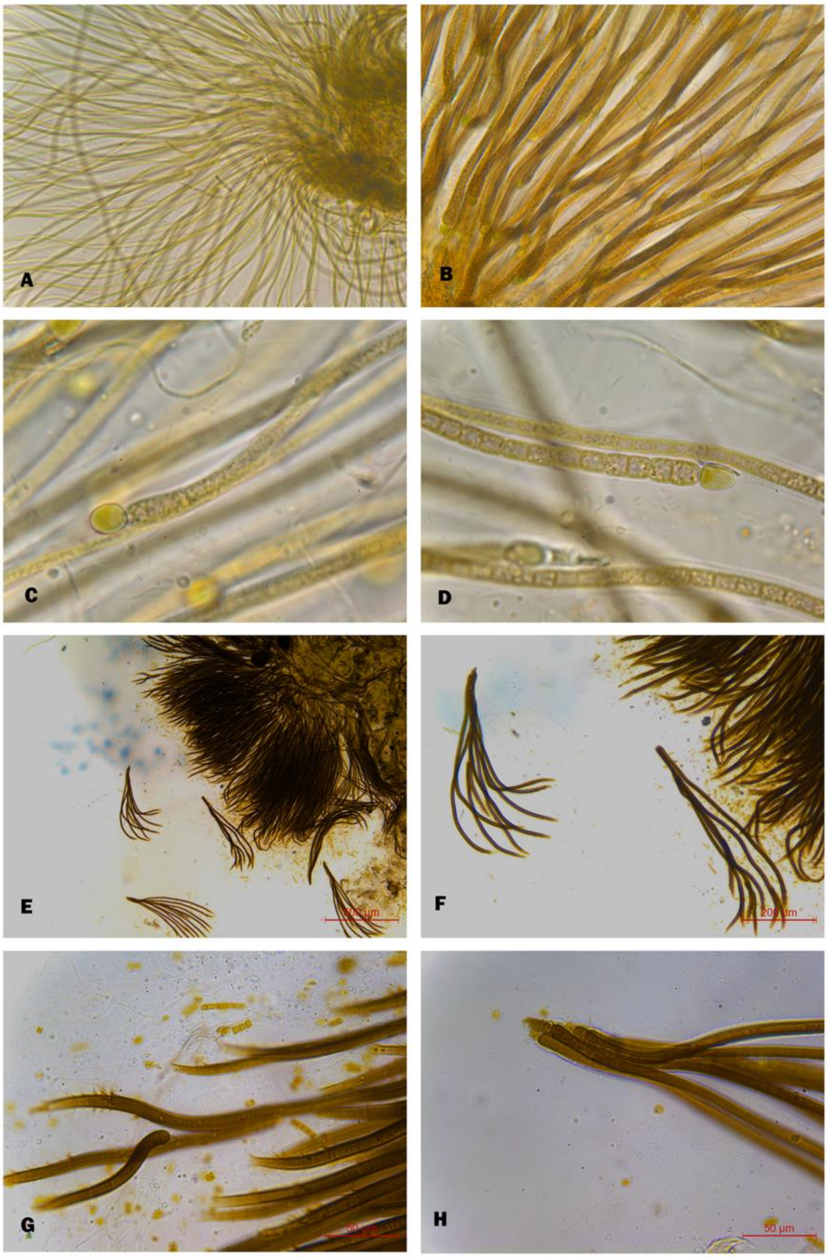

Fig. 43: **A-D.** *Rivularia bullata,* **E-H.** *Dichothrix orsiniana*

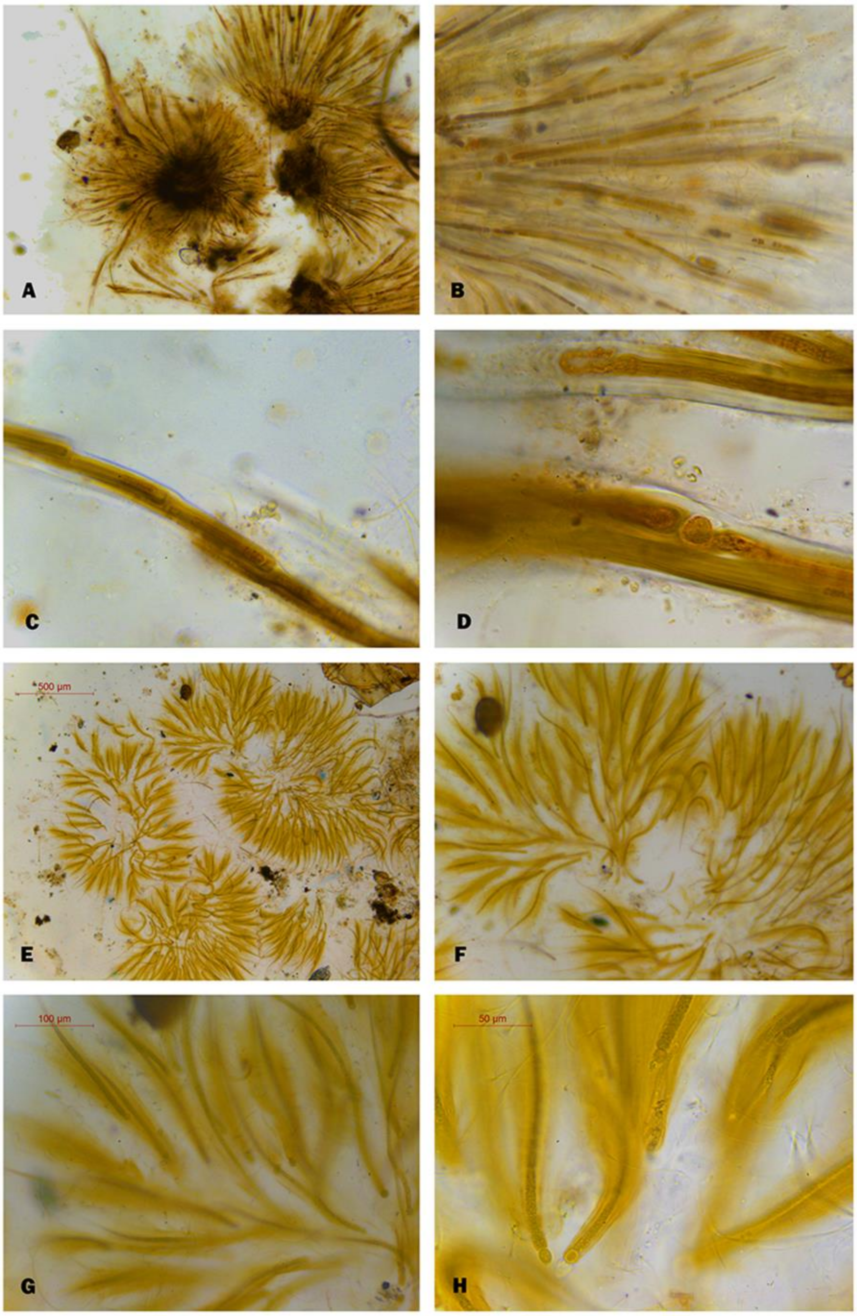

Fig. 42: **A-D.** *Rivularia manginii,* **E-H.** *R. nitida*

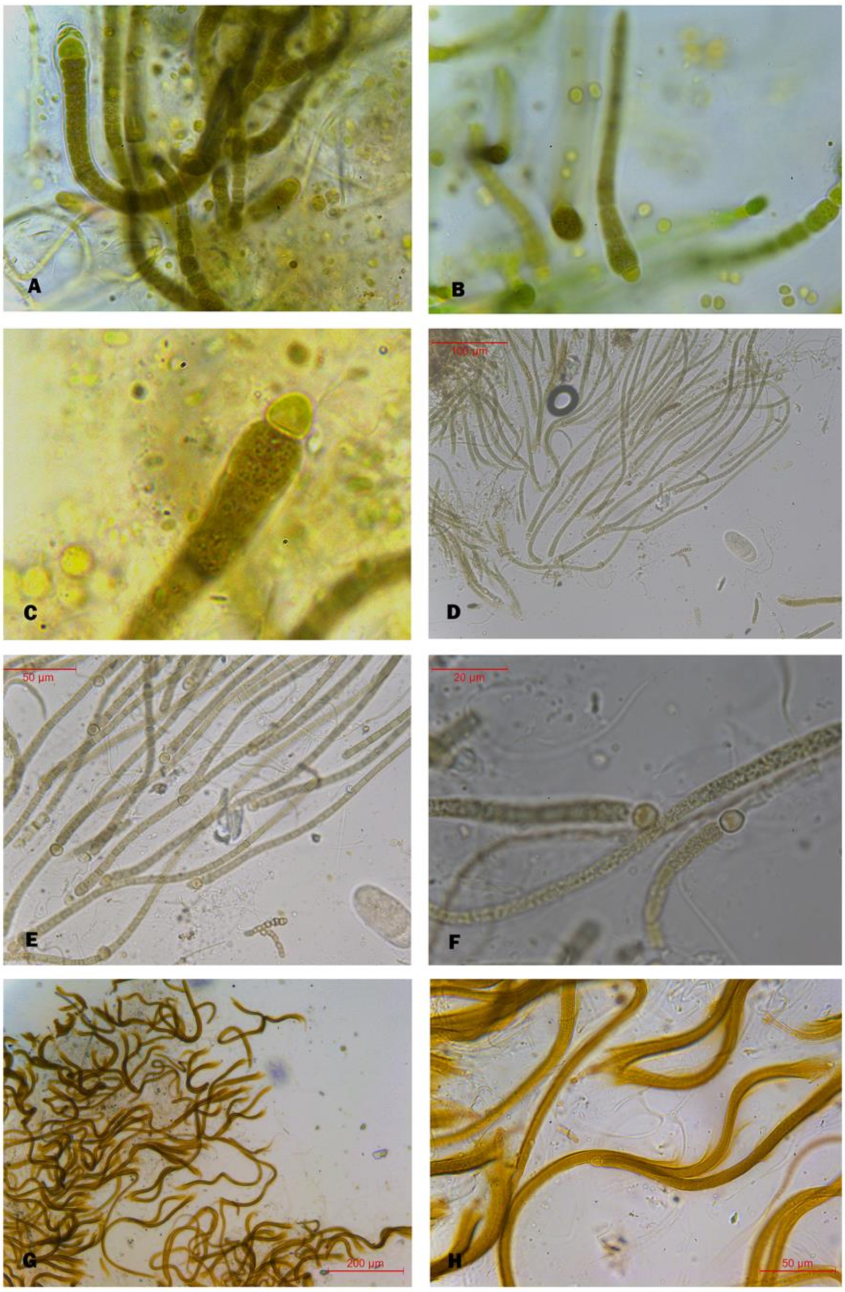

Fig. 41: **A-C.** *Calothrix vivipara,* **D-F.** *Rivularia atra,* **G & H**. *R. beccariana*

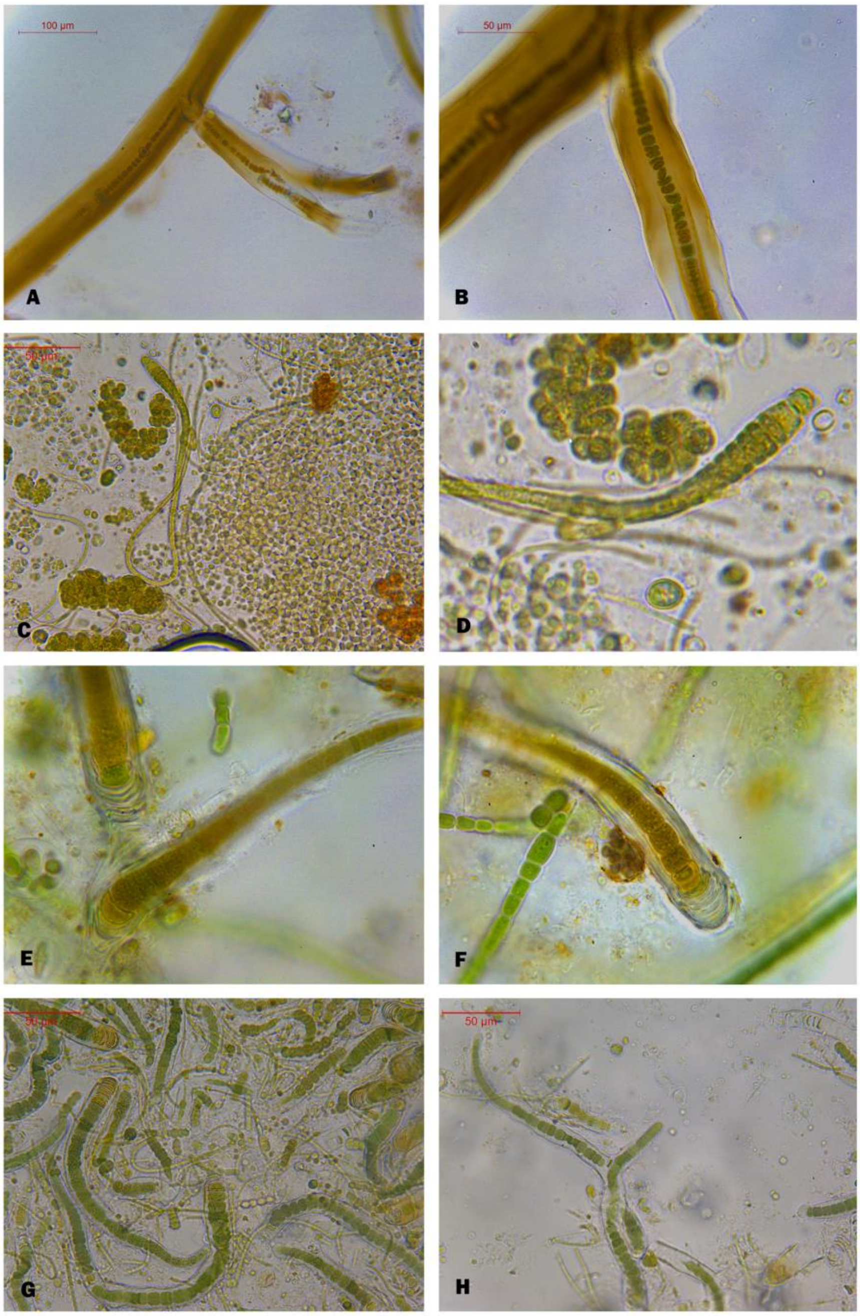

Fig. 40: **A & B.** *Petalonema velutinum*, **C & D.** *Calothrix capitularis*, **E & F.** *C. fusca*, **G & H**. *C. parietina*

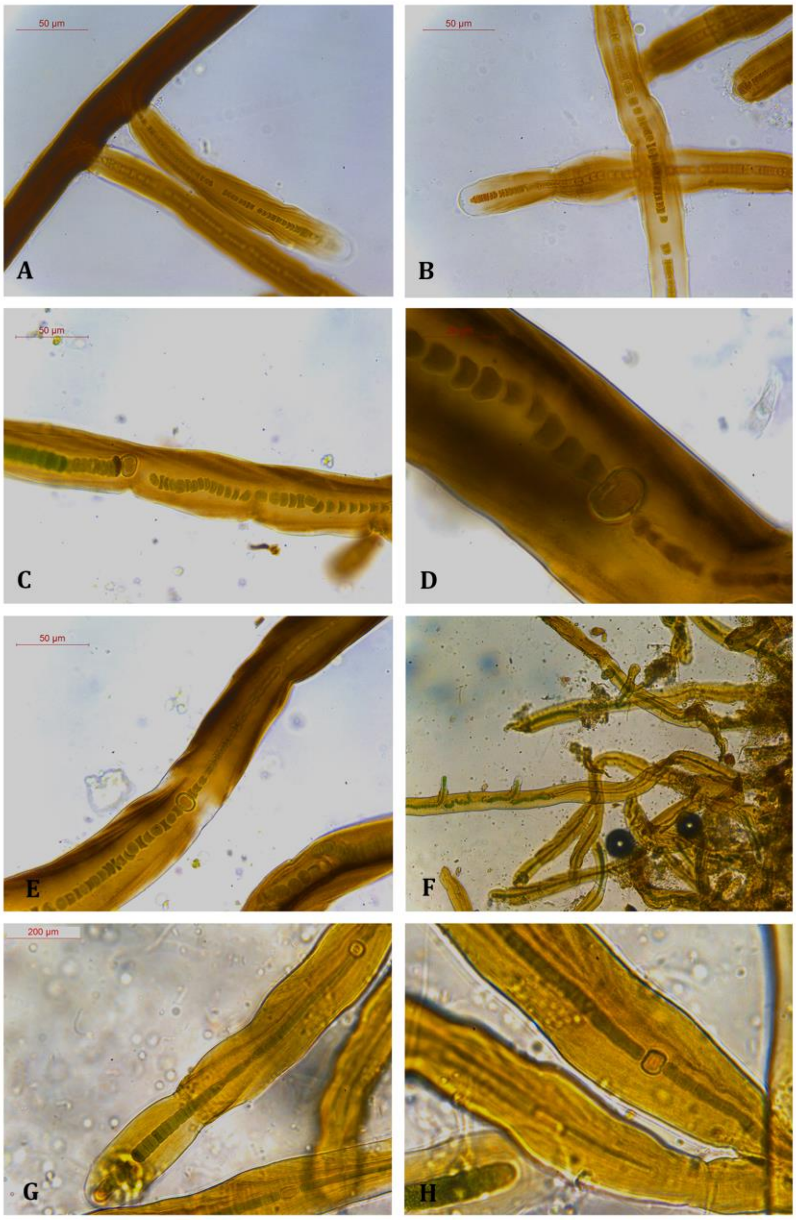

Fig. 39: A & B. *Petalonema involvens,* **C-E.** *P. alatum,* **F-H.** *P. pulchrum*

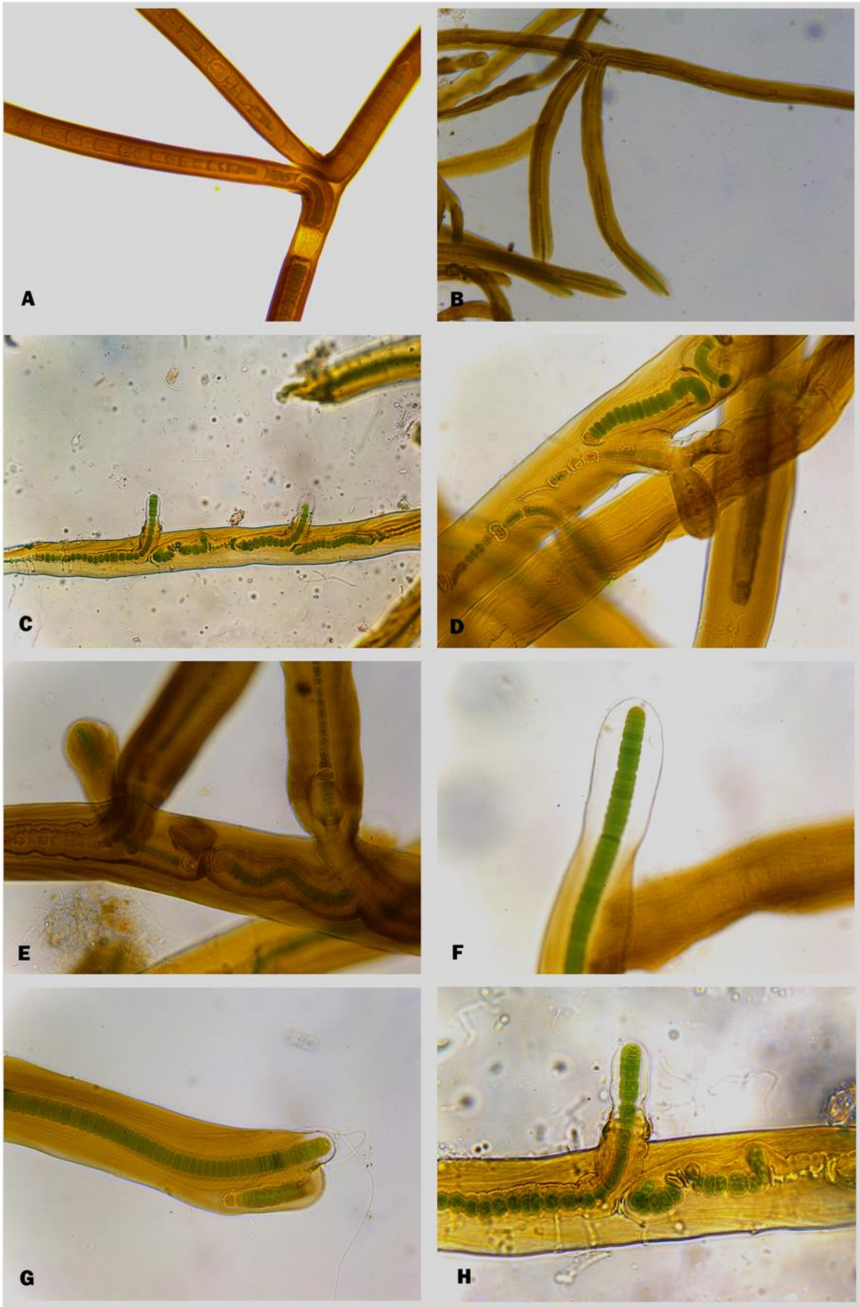

Fig. 38: **A-H.** *Scytonema torulosum*

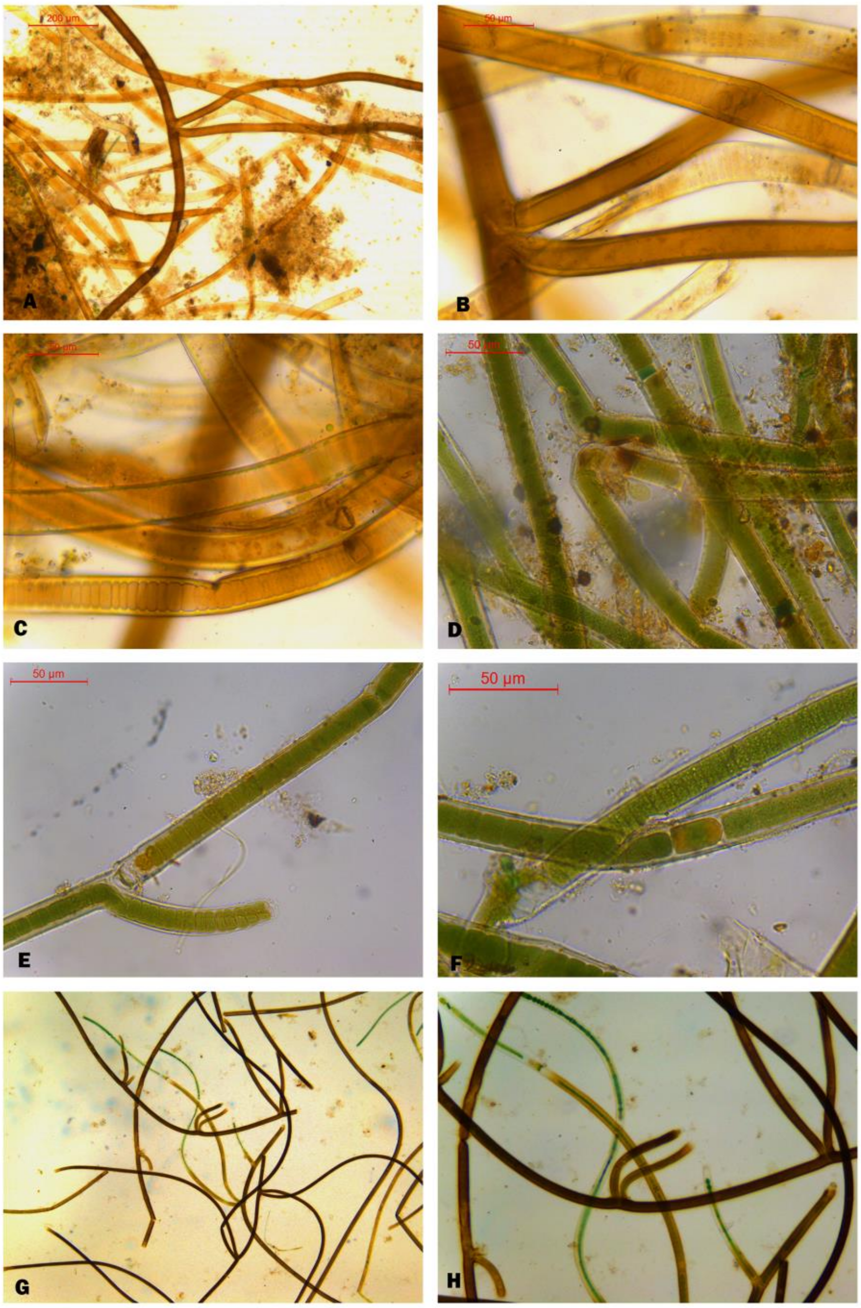

Fig. 37: **A-C.** *Scytonema schmidtii,* **D-F.** *S. stuposum,* **G-H.** *S. caldarium*

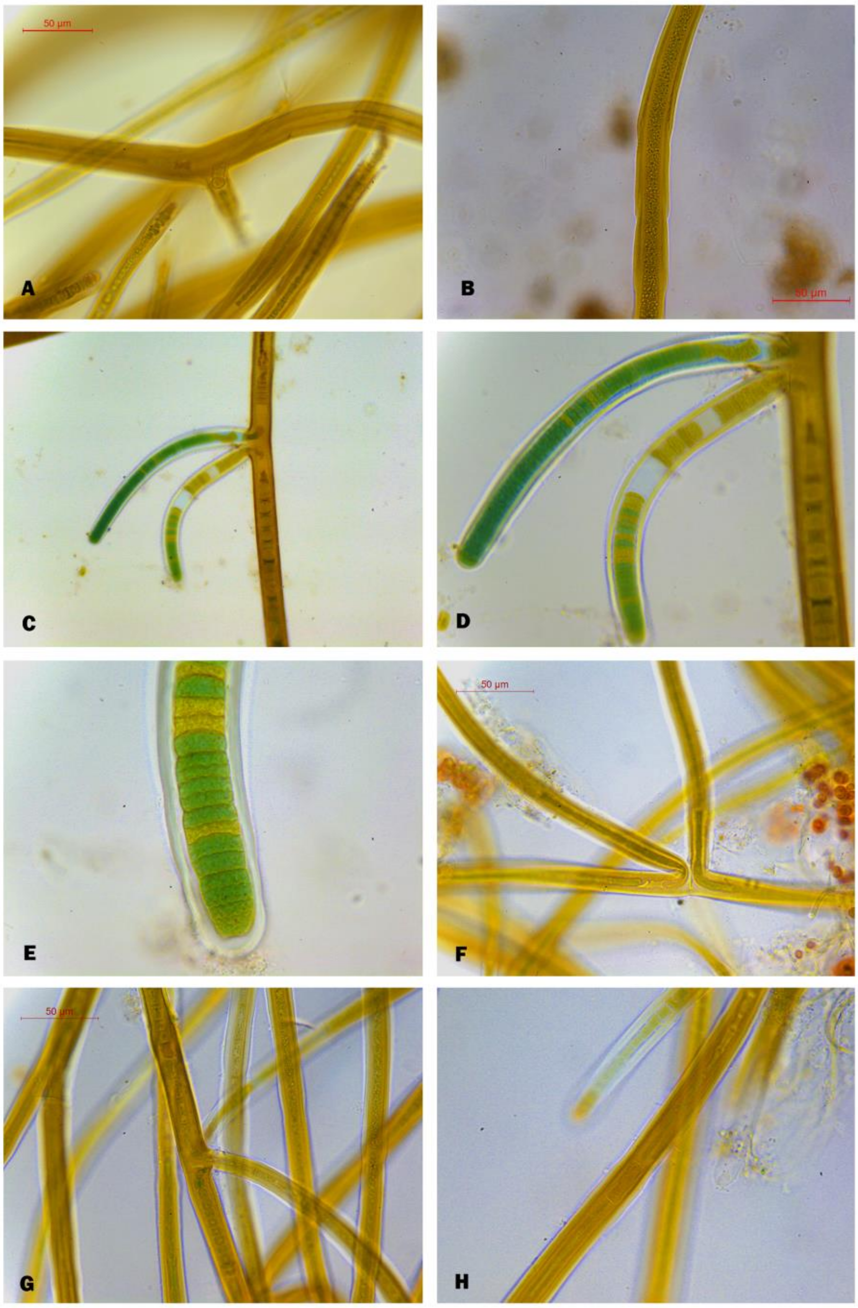

Fig. 36: **A & B.** *Scytonema myochrous,* **C-E.** *S. pseudoguyanense,* **F-H.** *S. pseudohofmanii*

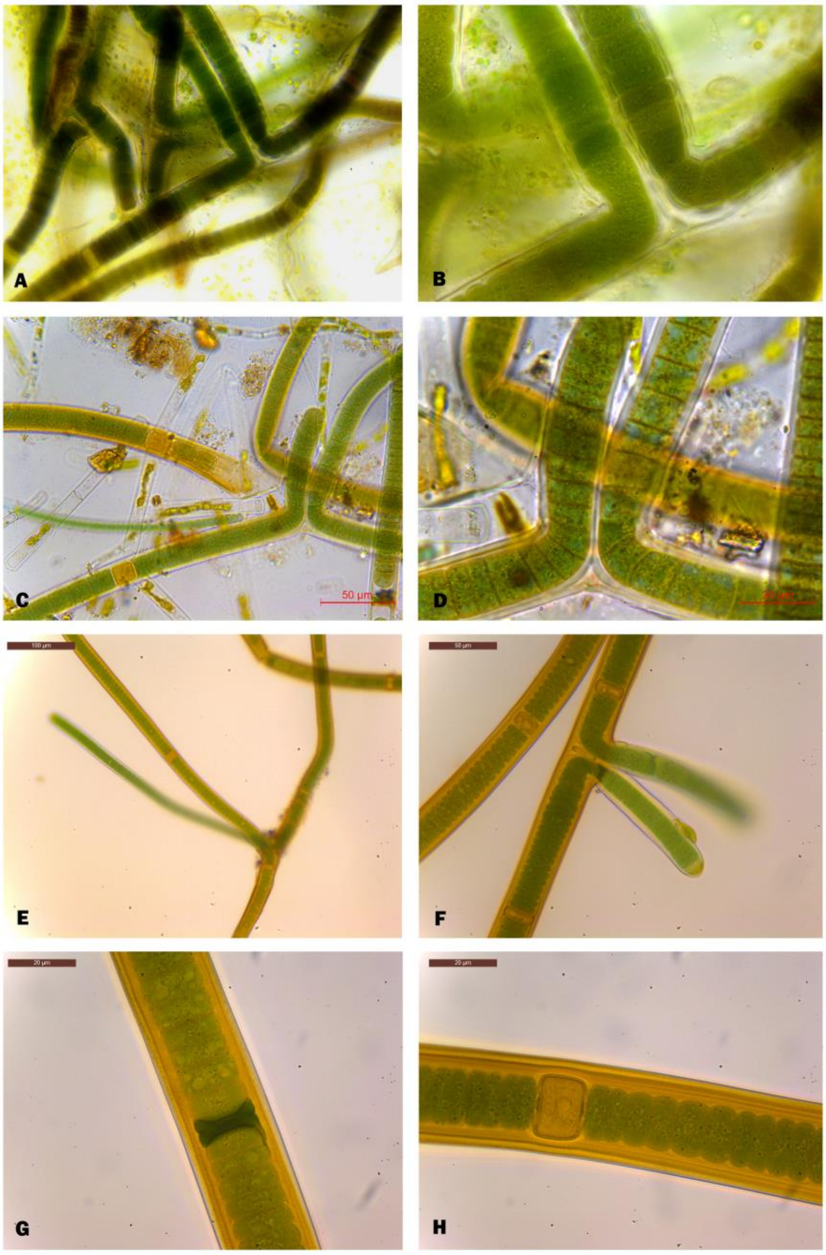

Fig. 35: **A & B.** *Scytonema crispum,* **C & D.** *S. javanicum,* **E-H.** *S. millei*

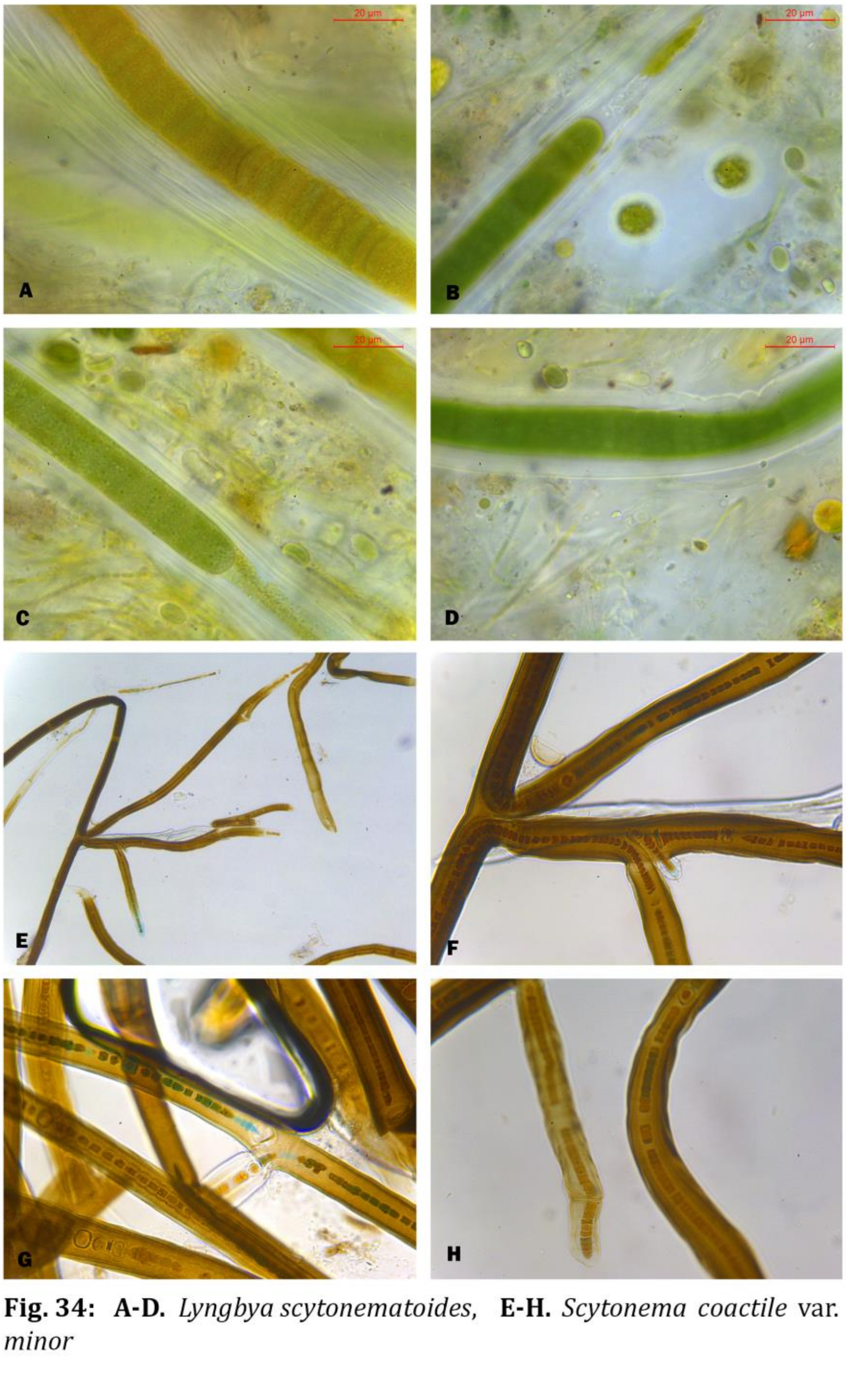

Fig. 34: A-D. *Lyngbya scytonematoides*, **E-H.** *Scytonema coactile* var. *minor*

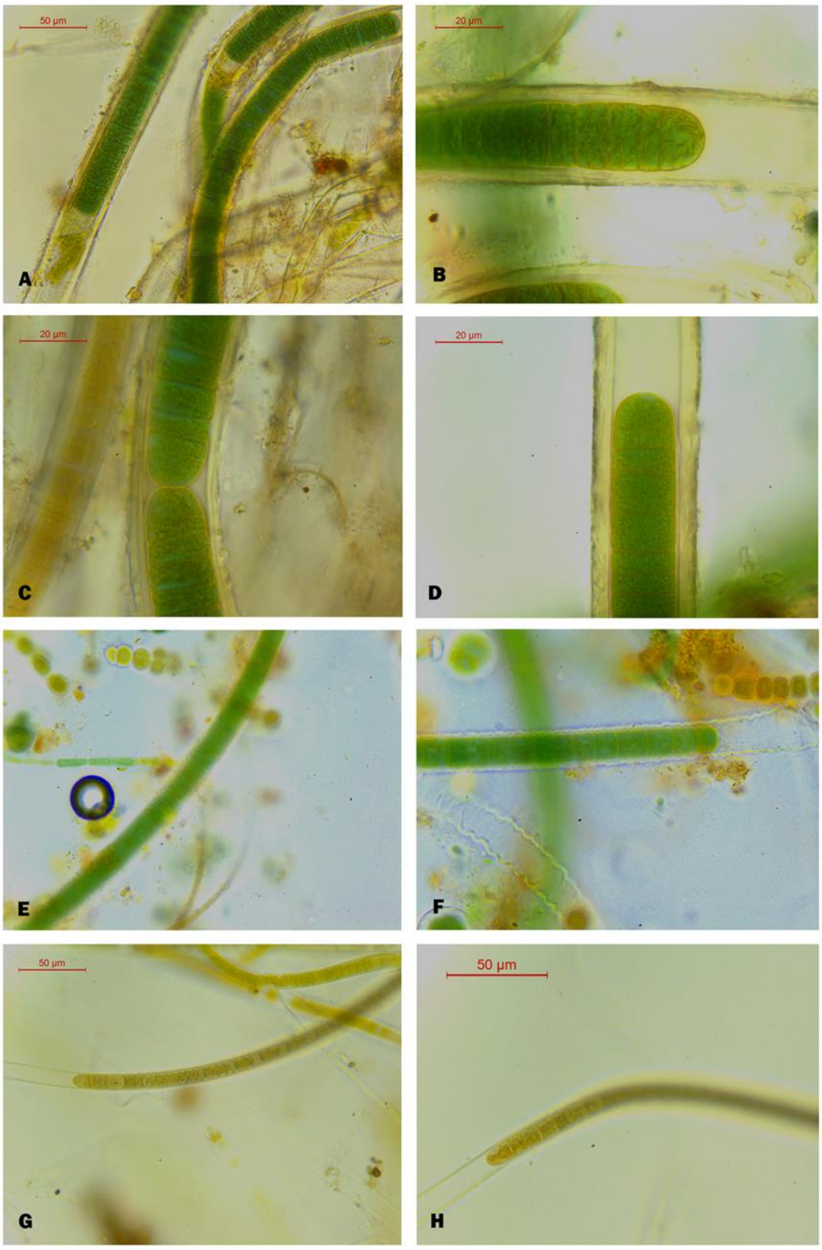

Fig. 33: A-D. *Lyngbya majuscula,* **E & F.** *L. martensiana,* **G & H.** *L. splendens*

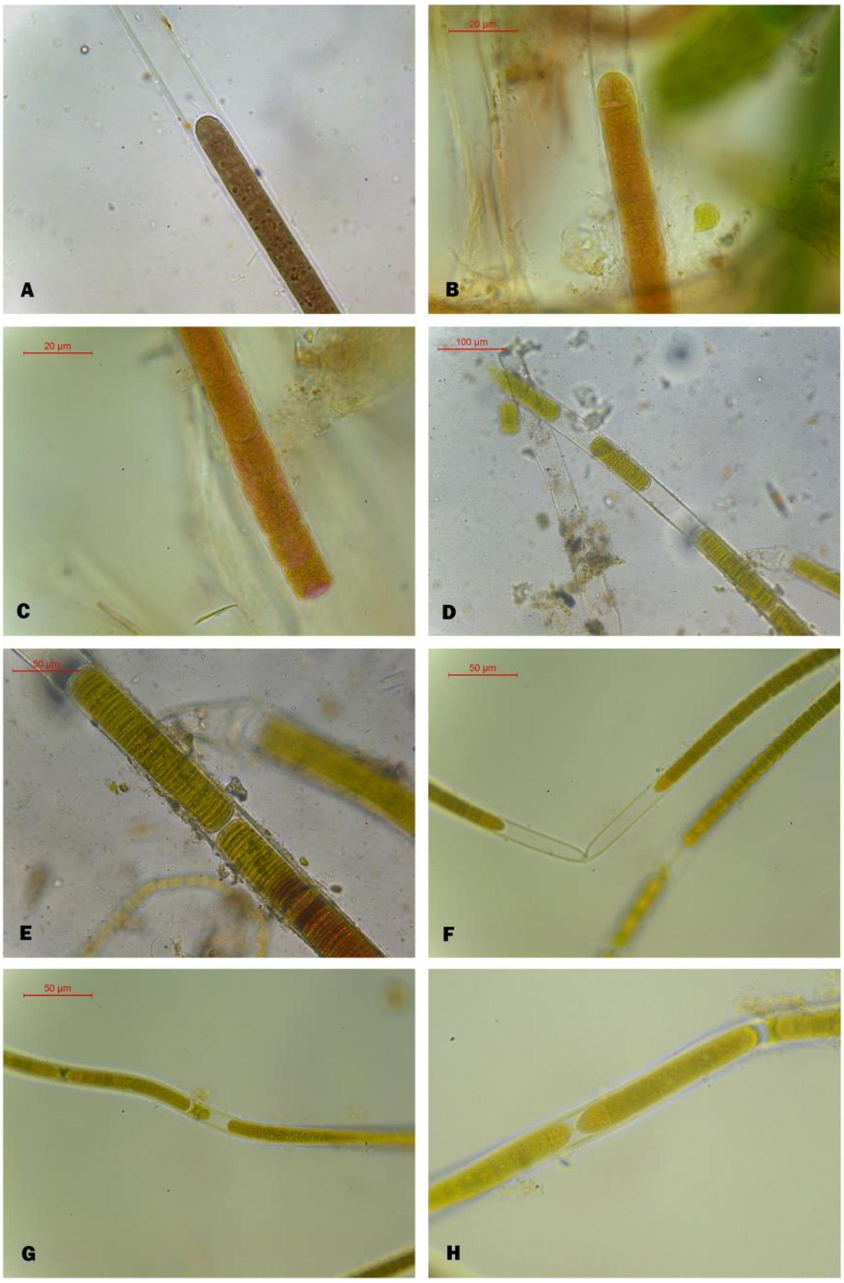

Fig. 32: A. *Lyngbya aestuarii,* **B & C.** *L. agardhii,* **D & E.** *L. birgei* **F-H.** *L. connectens*

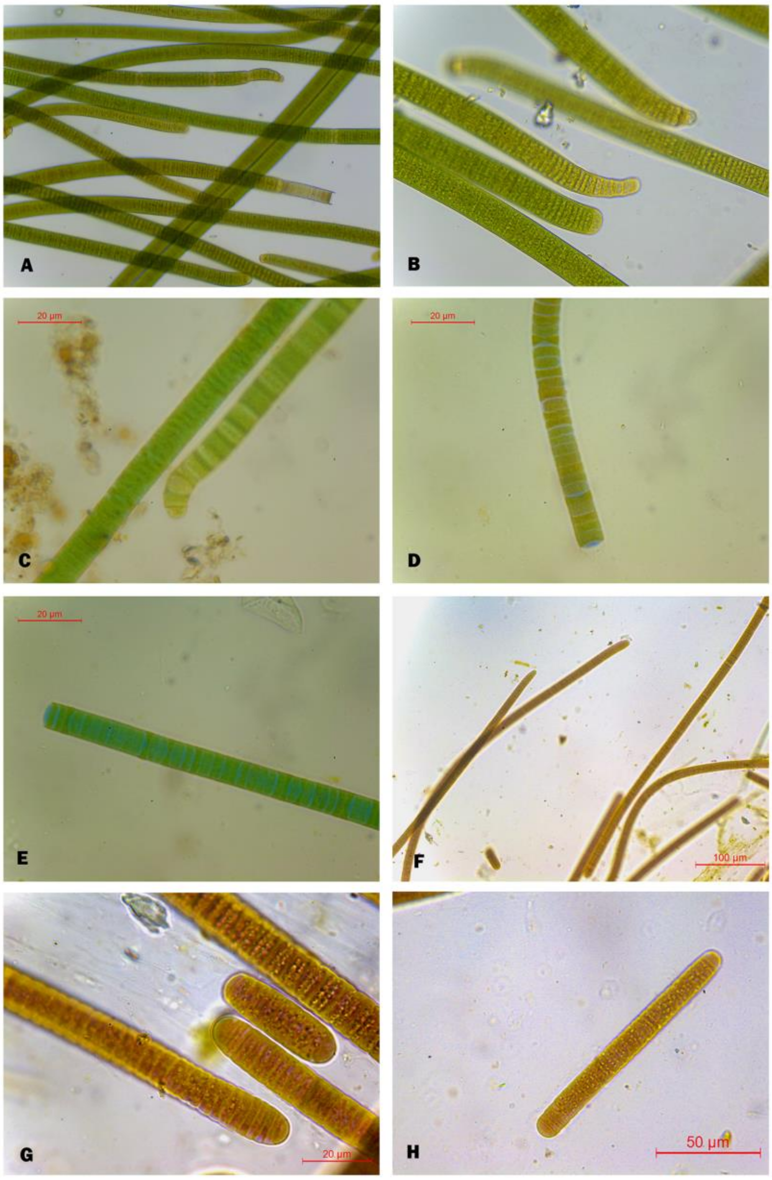

Fig. 31: **A-C.** *Oscillatoria jenensis*, **D & E.** *O. funiformis*, **F-H.** *O. margaritifera*

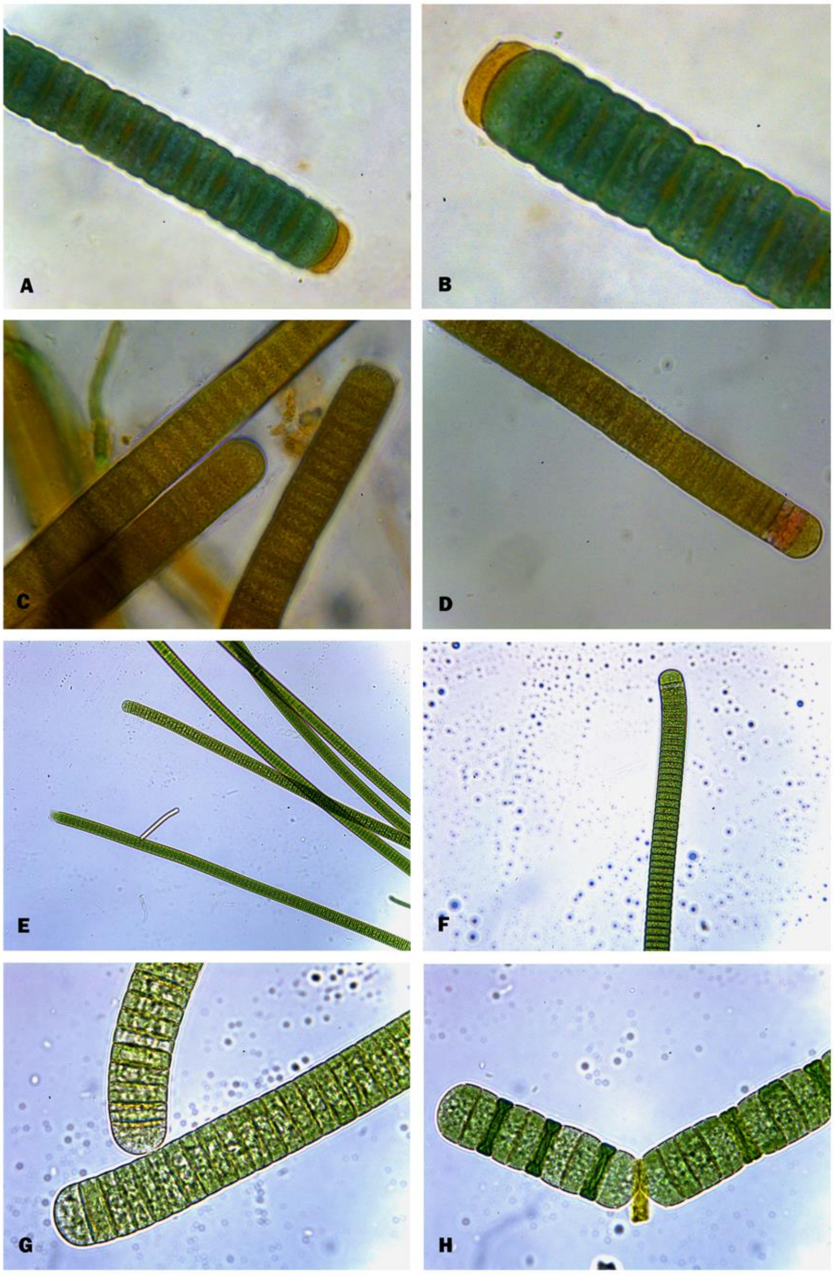

Fig. 30: A & B. *Oscillatoria sancta,* **C & D.** *O. rupicola,* **E-H.** *O. curviceps*

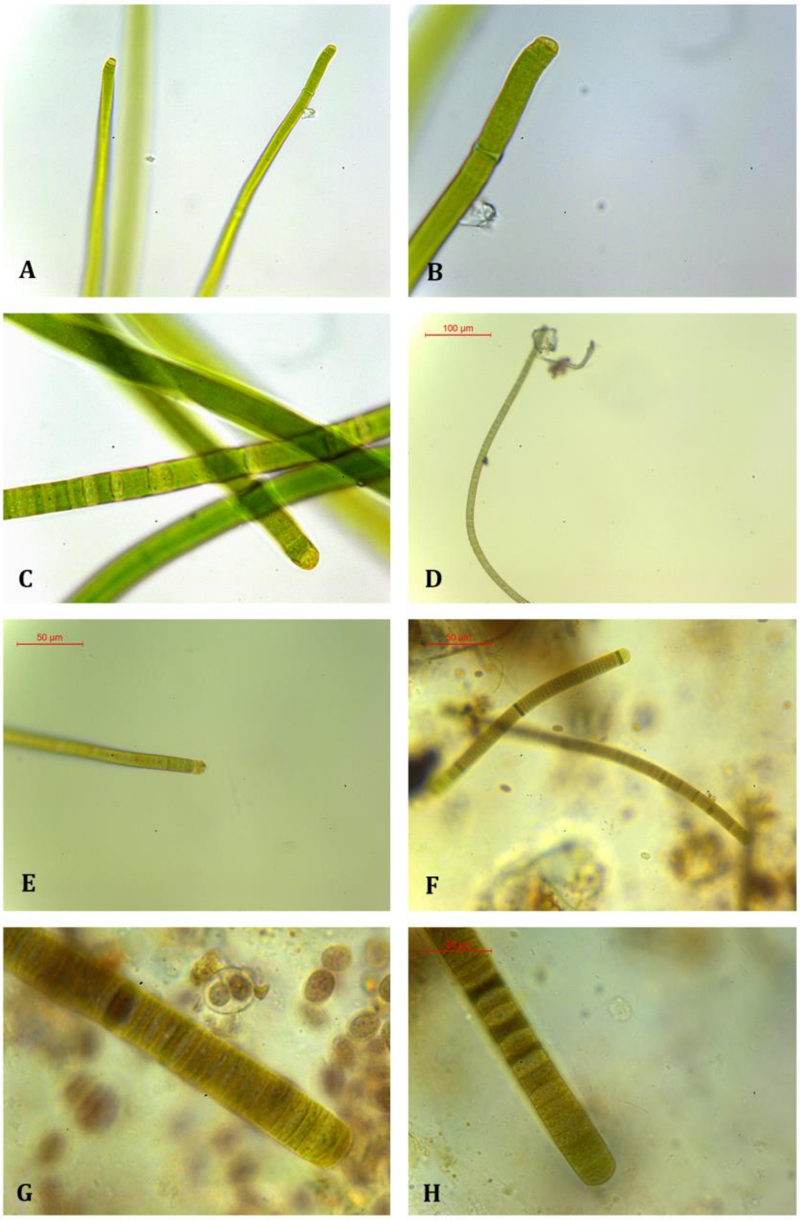

Fig. 29: A-C. *Oscillatoria refrigens*, **D & E.** *O. subsalsa*, **F-H.** *O. tenuis* var. *levis*

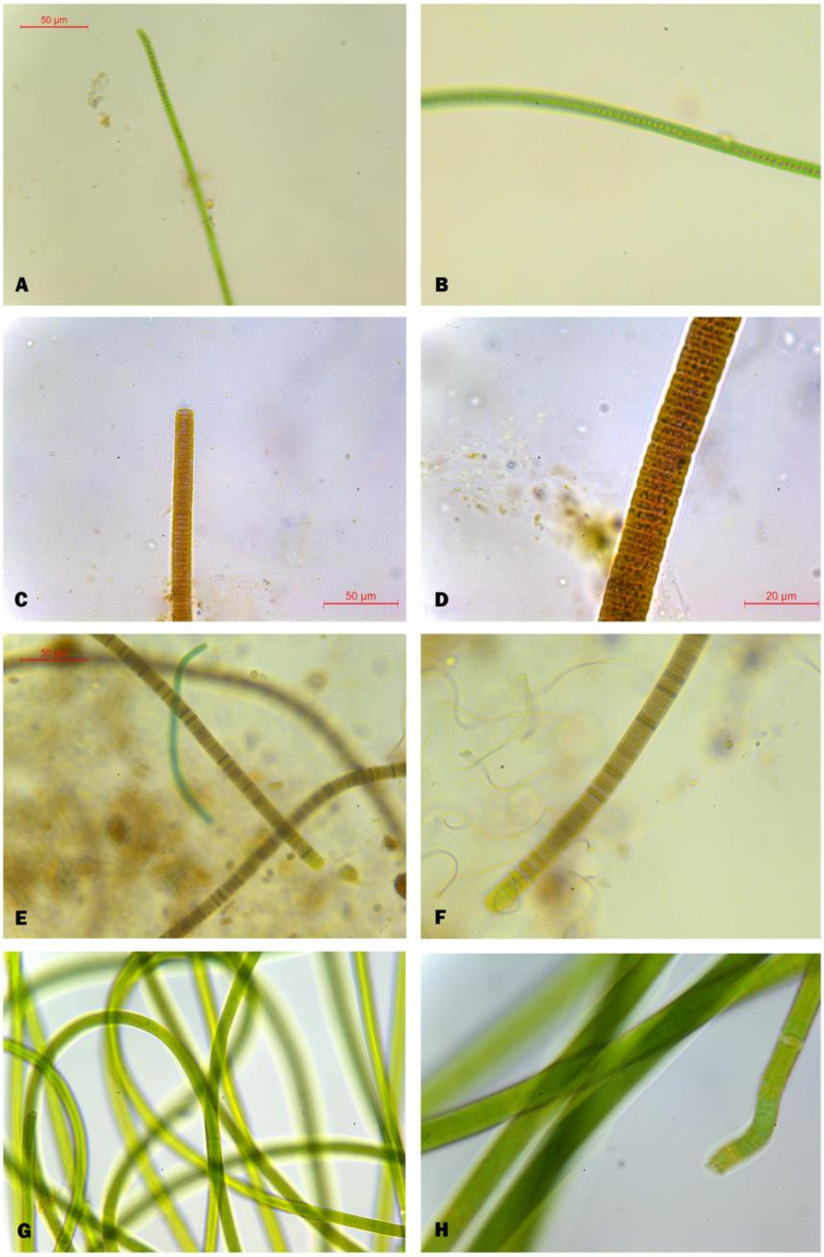

Fig. 28: A & B. *Oscillatoria nitida,* **C & D.** *O. ornata* var. *crassa,* **E & F.** *O. princeps* **G & H.** *O. refrigens*

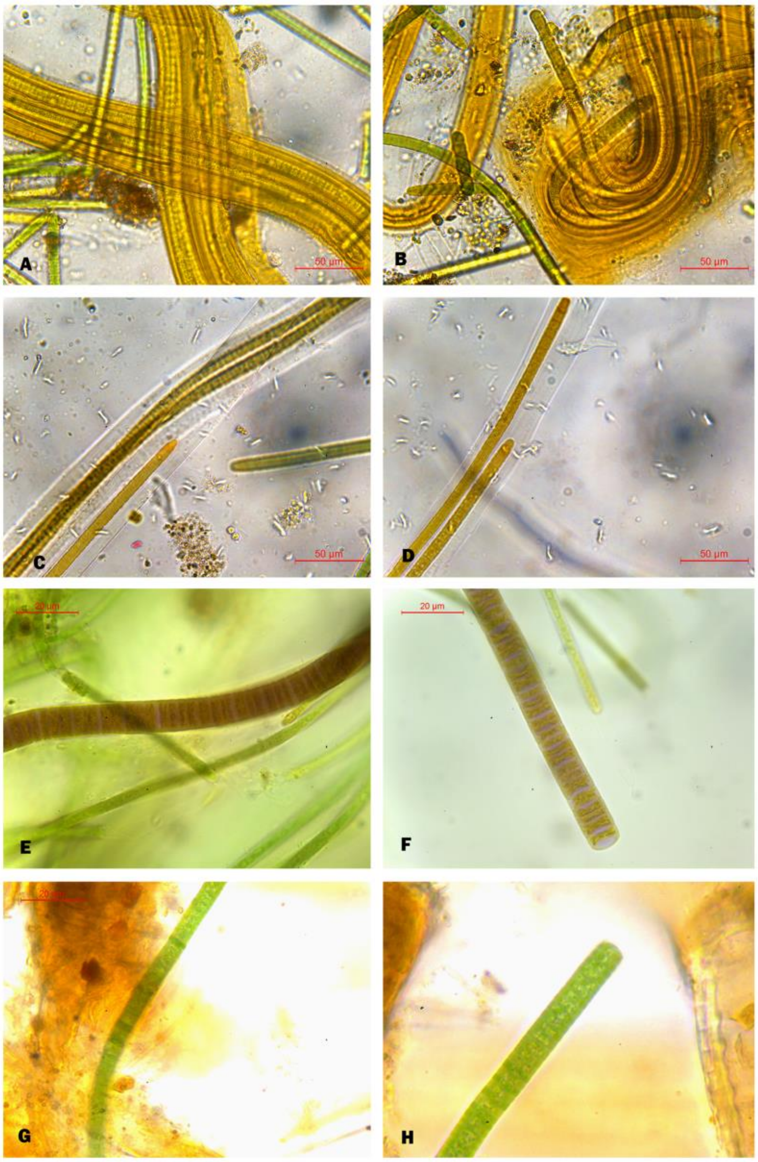

Fig. 27: A-D. *Microcoleus steenstrupii,* **E & F.** *Oscillatoria limosa,* **G & H.** *O. lutea*

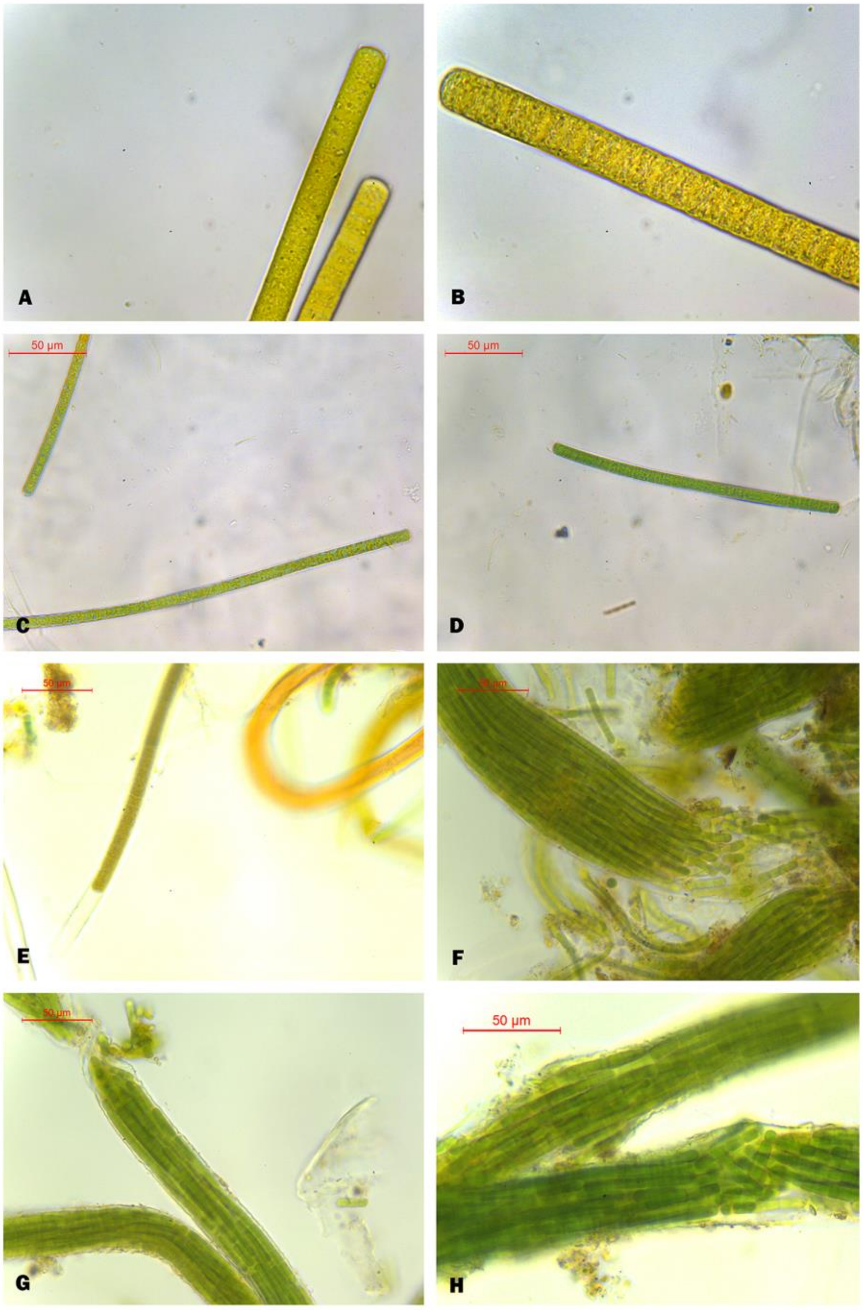

Fig. 26: A & B. *Phormidium chlorinum*, **C & D.** *P. insigne*, **E.** *P. corium*, **F-H.** *Microcoleus subtorulosus*

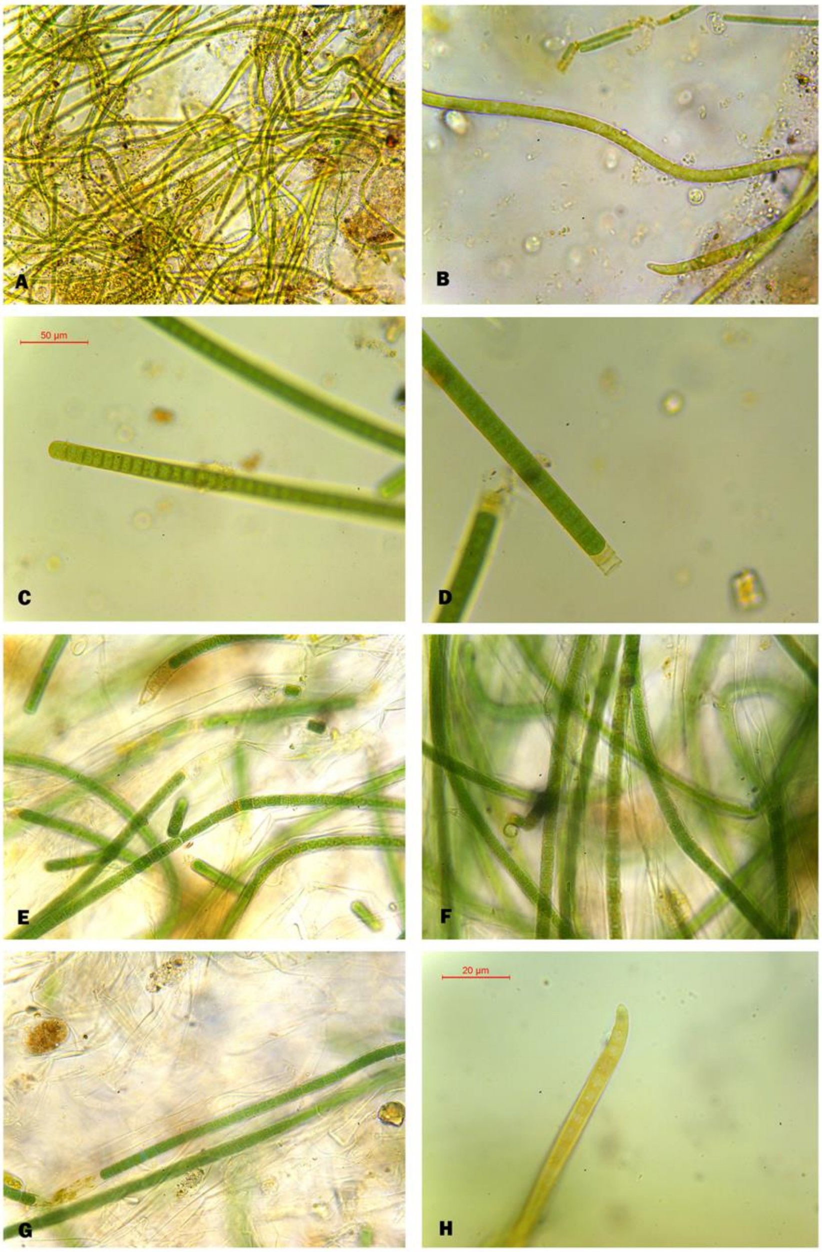

Fig. 25: A & B. *Phormidium karakalpakense*, **C & D.** *P. tergestinum*
E-G. *P. taylorii*, **H.** *P. subsalsum*

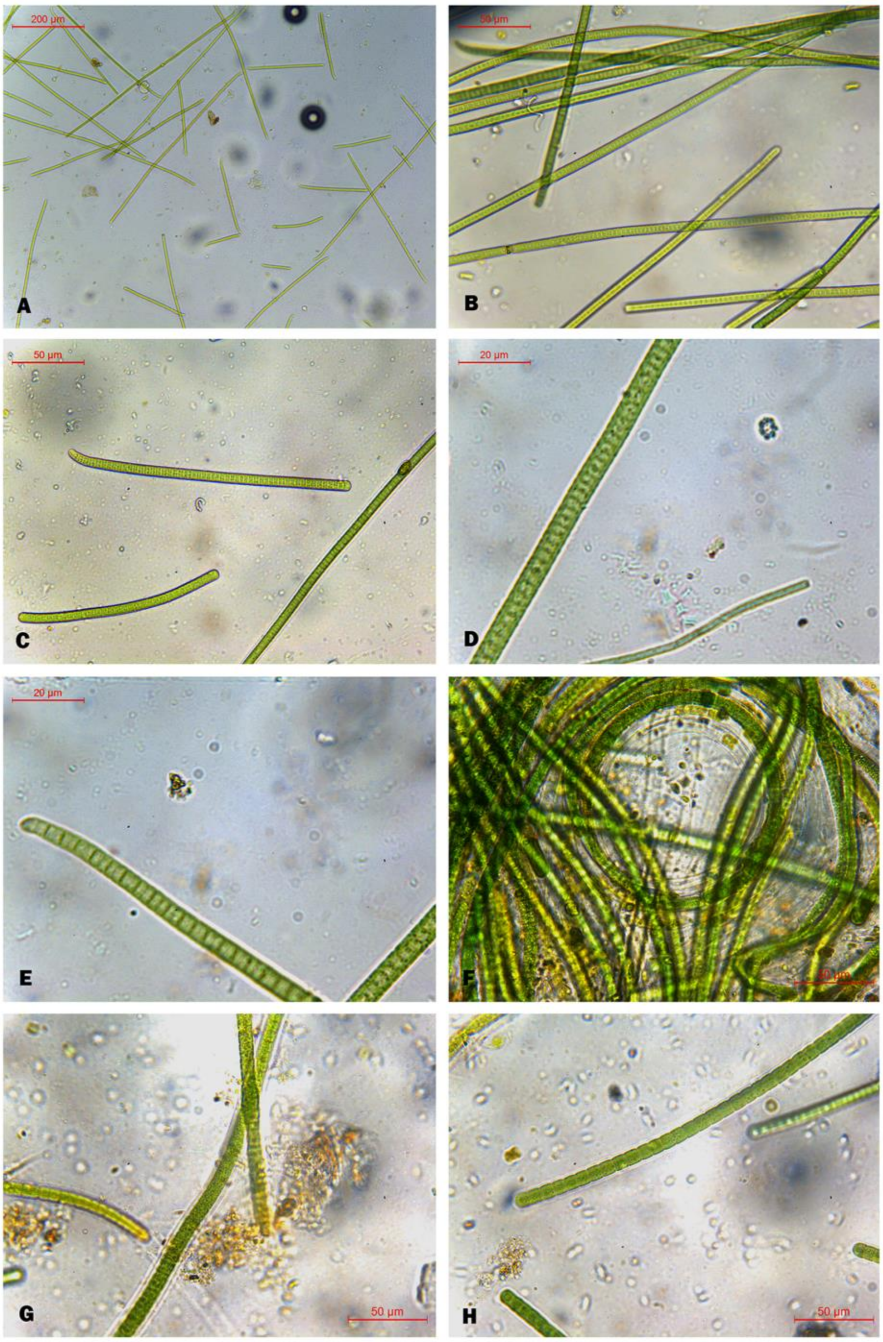

Fig. 24: **A-E.** *Phormidium formosum*, **F-H.** *P. hamelii*

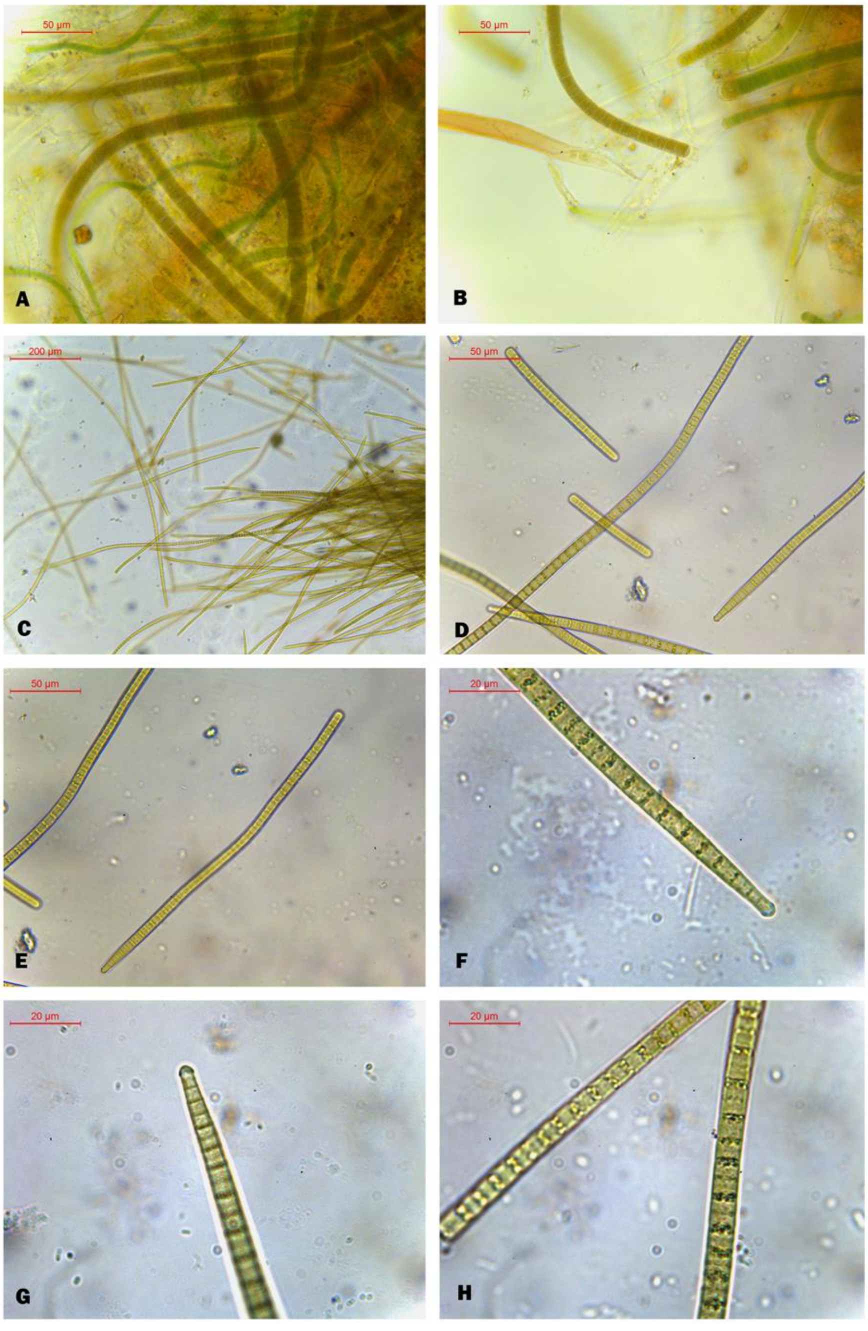

Fig. 23: **A & B.** *Phormidium crassior,* **C-H.** *P. favosum*

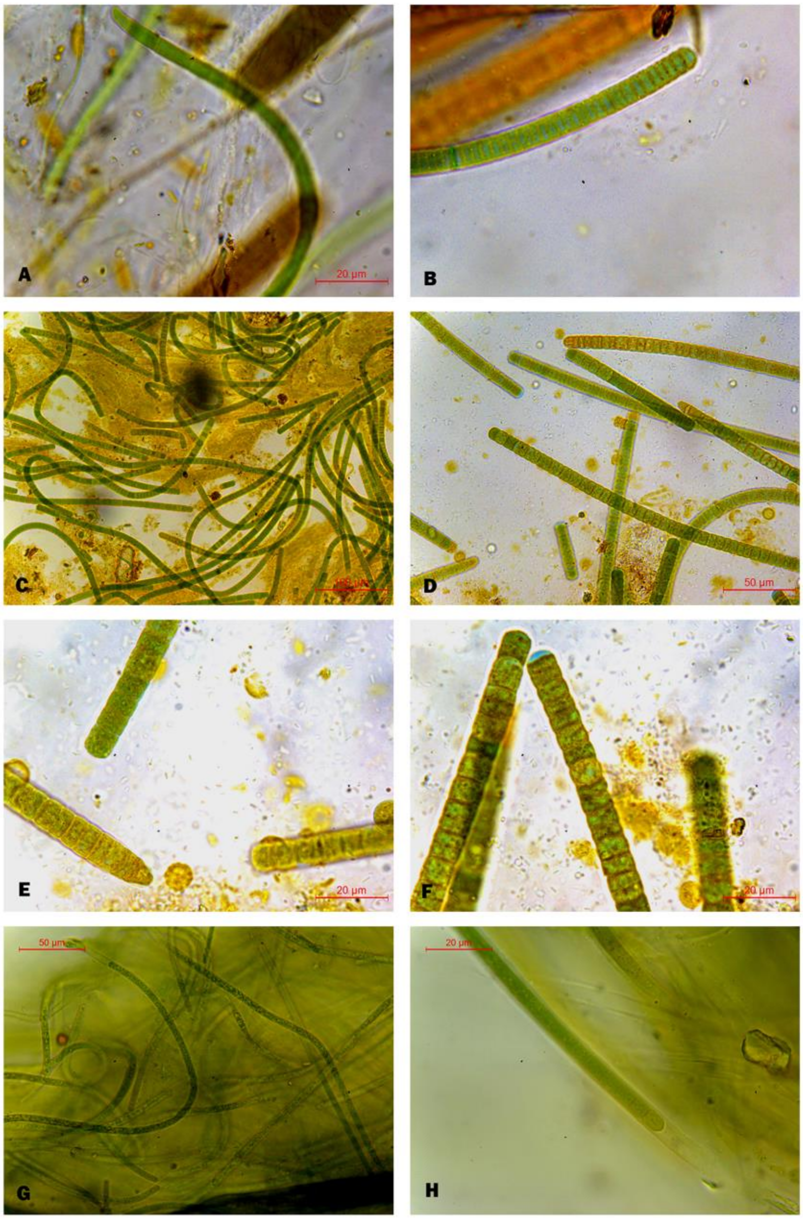

Fig. 22: **A & B.** *Phormidium articulatum,* **C-F.** *P. boryanum,* **G & H.** *P. calcicola*

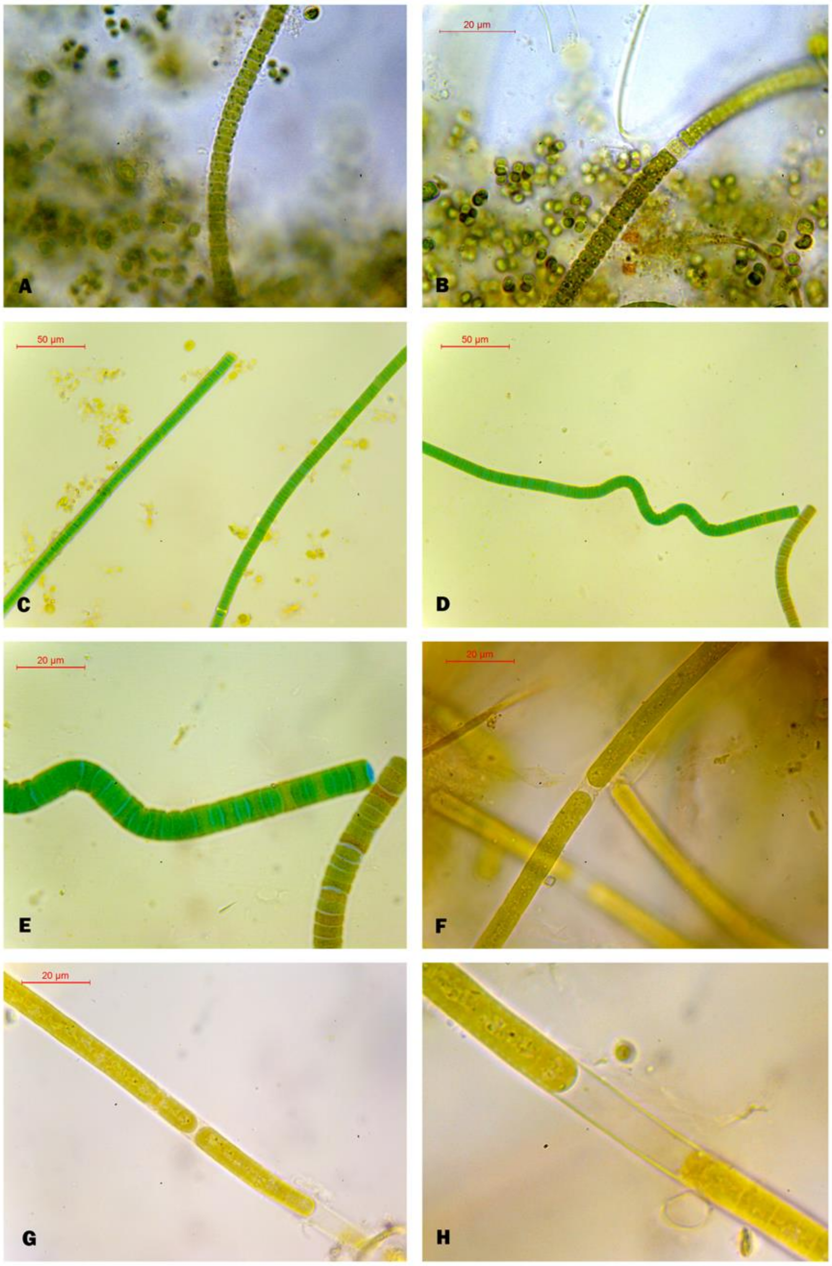

Fig. 21: **A & B.** *Planktothrix clathrata,* **C-E.** *P. planktonica,* **F-H.** *Phormidium aerugineo-caeruleum*

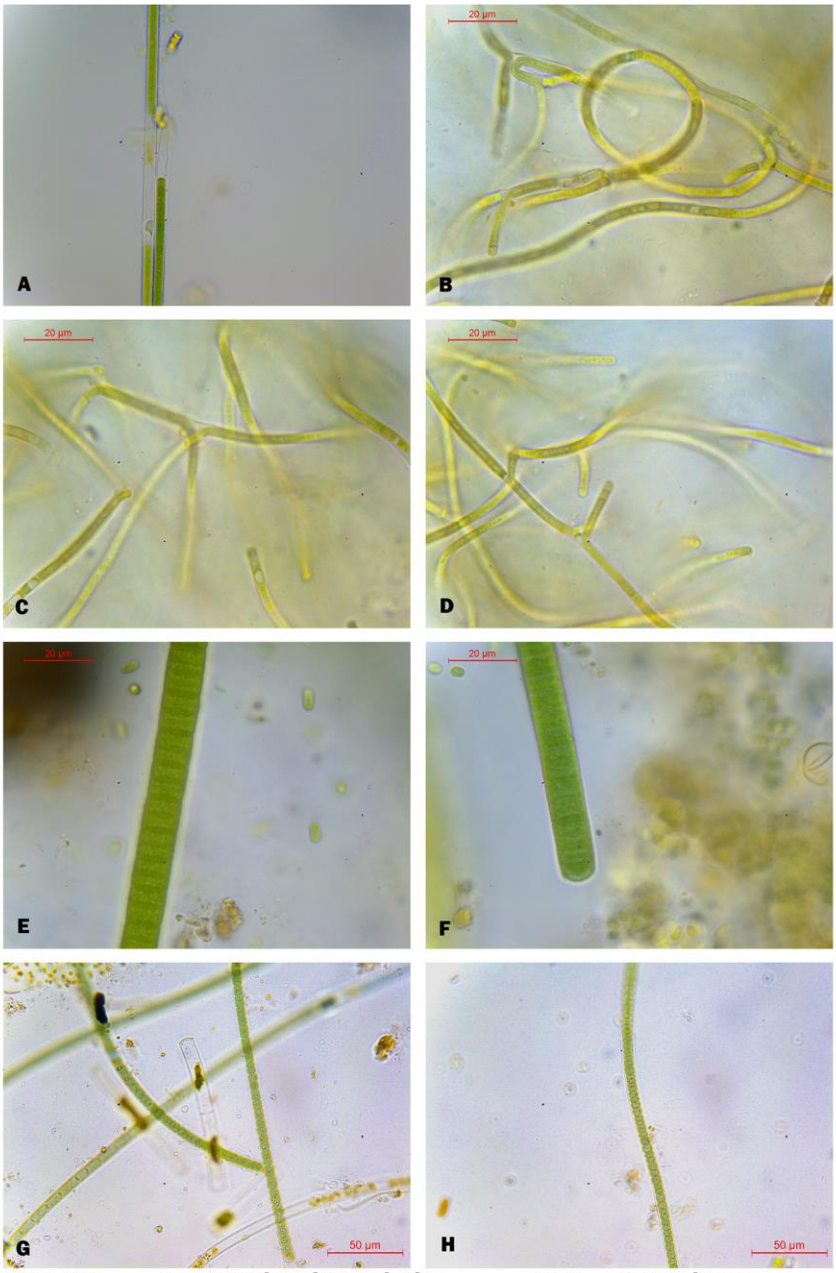

Fig. 20: **A .** *Leptolyngbya subtilis,* **B-D.** *L. terebrans,* **E & F.** *Planktothrix isothrix,* **G & H.** *P. cryptovaginata*

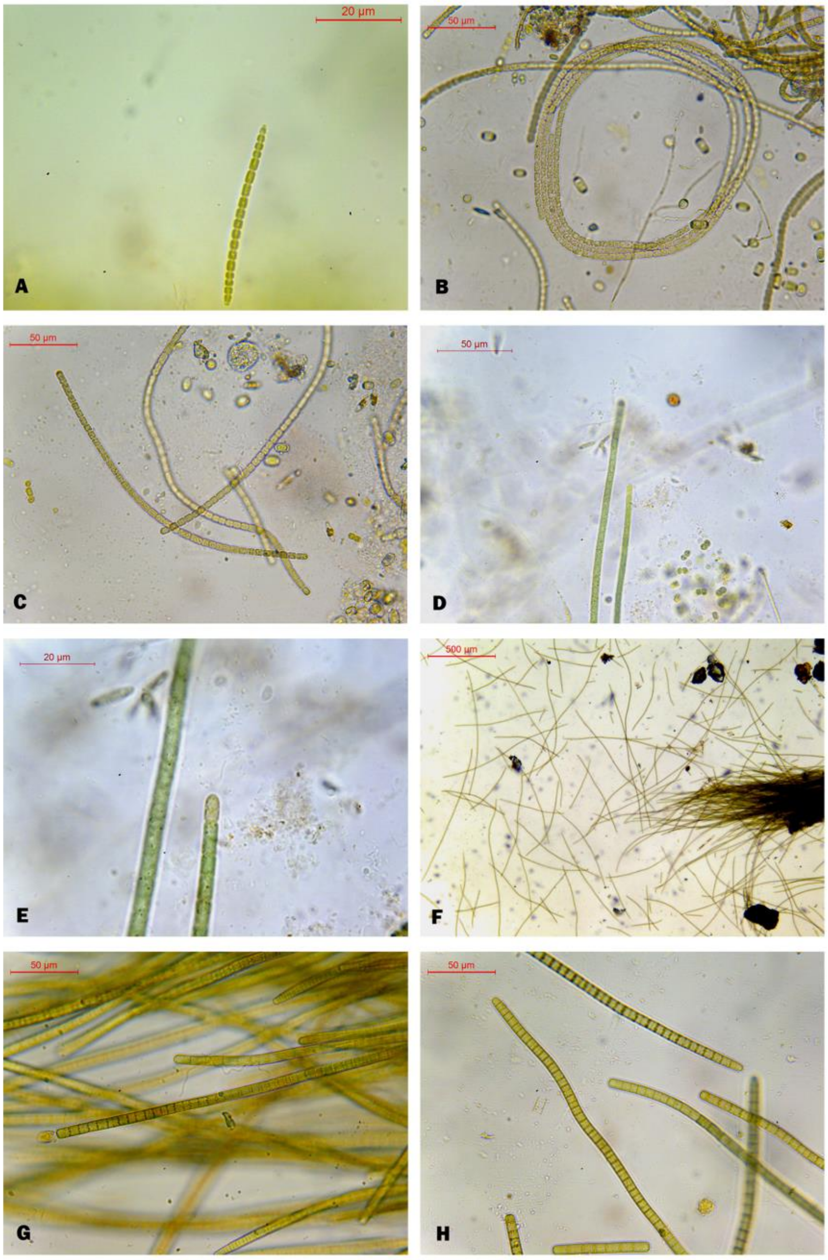

Fig. 19: **A .** *Pseudanabaena skujae,* **B & C.** *P. thermalis,*
D & E. *Jaaginema geminatum,* **F-H.** *Geitlerinema amphibium*

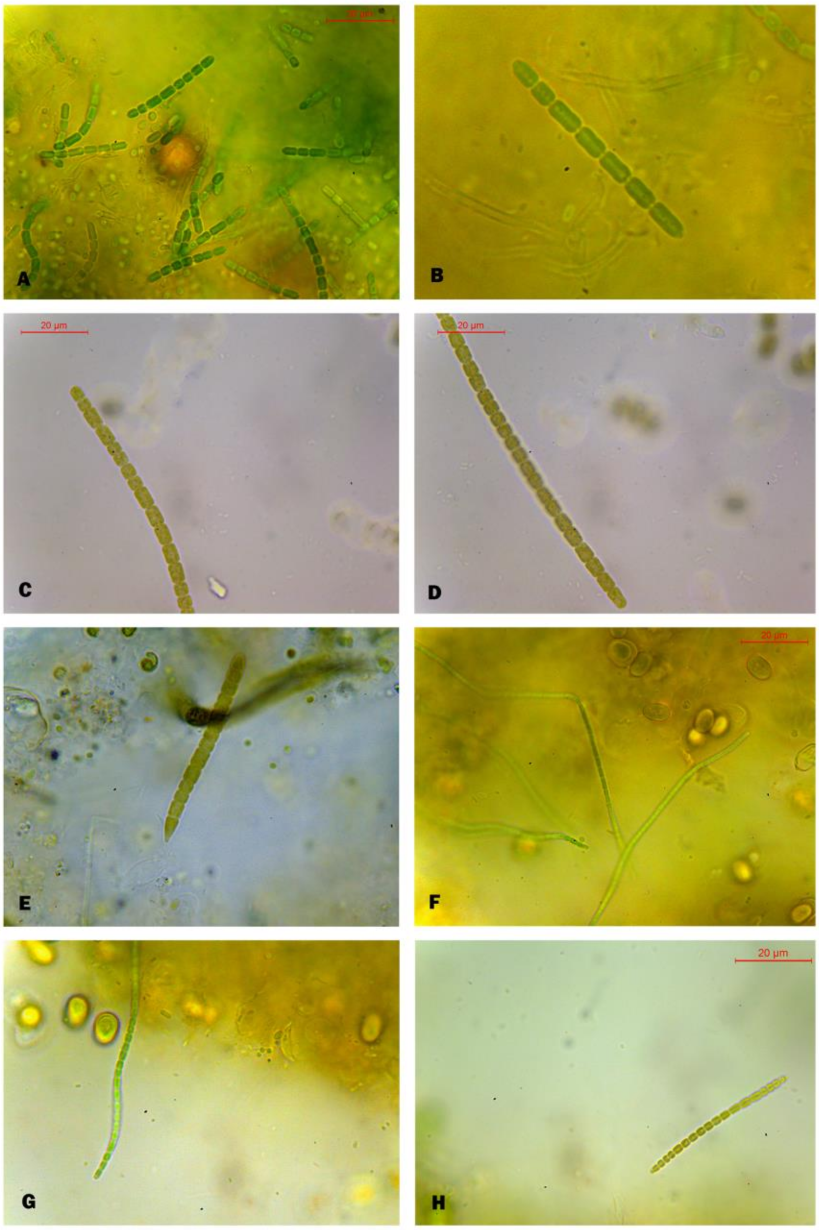

Fig. 18: **A & B.** *Pseudanabaena biceps,* **C & D.** *P. crasaa,* **E.** *P. franquetii,* **F & G.** *P. galeata* **H.** *P. skujae*

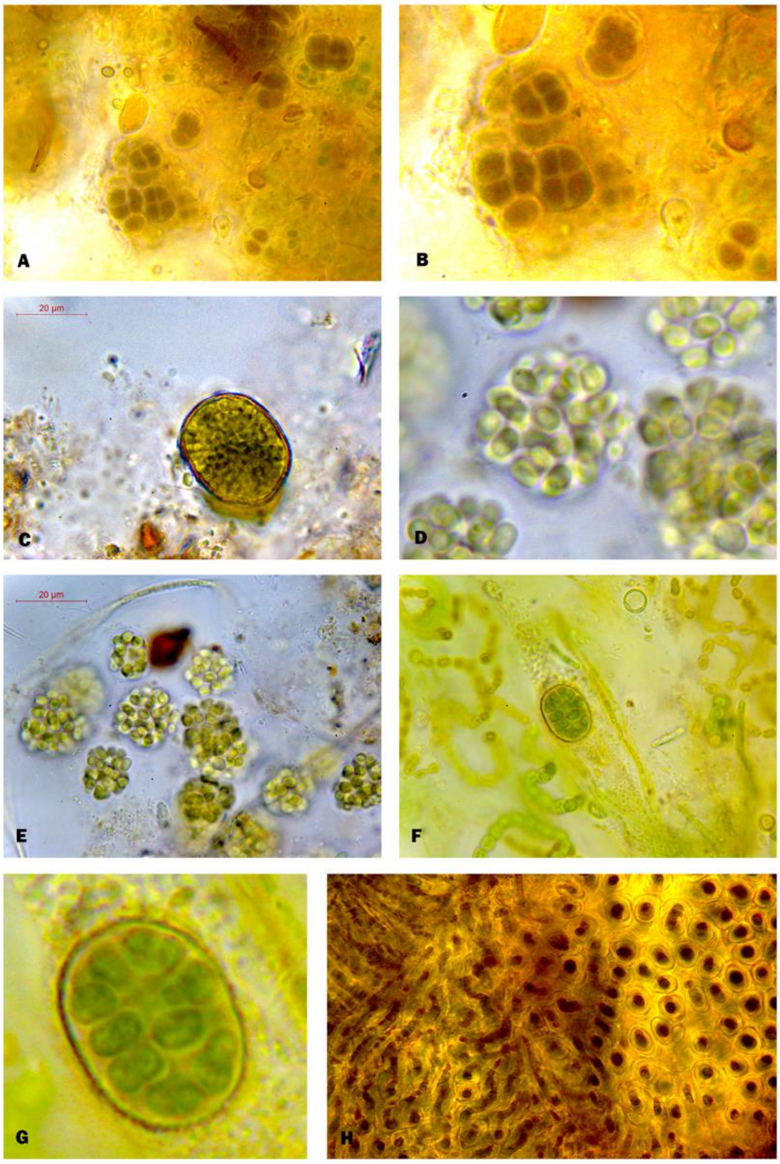

Fig. 17: **A & B.** *Cyanosarcina thalassia*, **C.** *C. parthenonensis*, **D & E.** *C. burmensis*, **F & G.** *C. chroococcoides* **H.** *Chlorogloea novacekii*

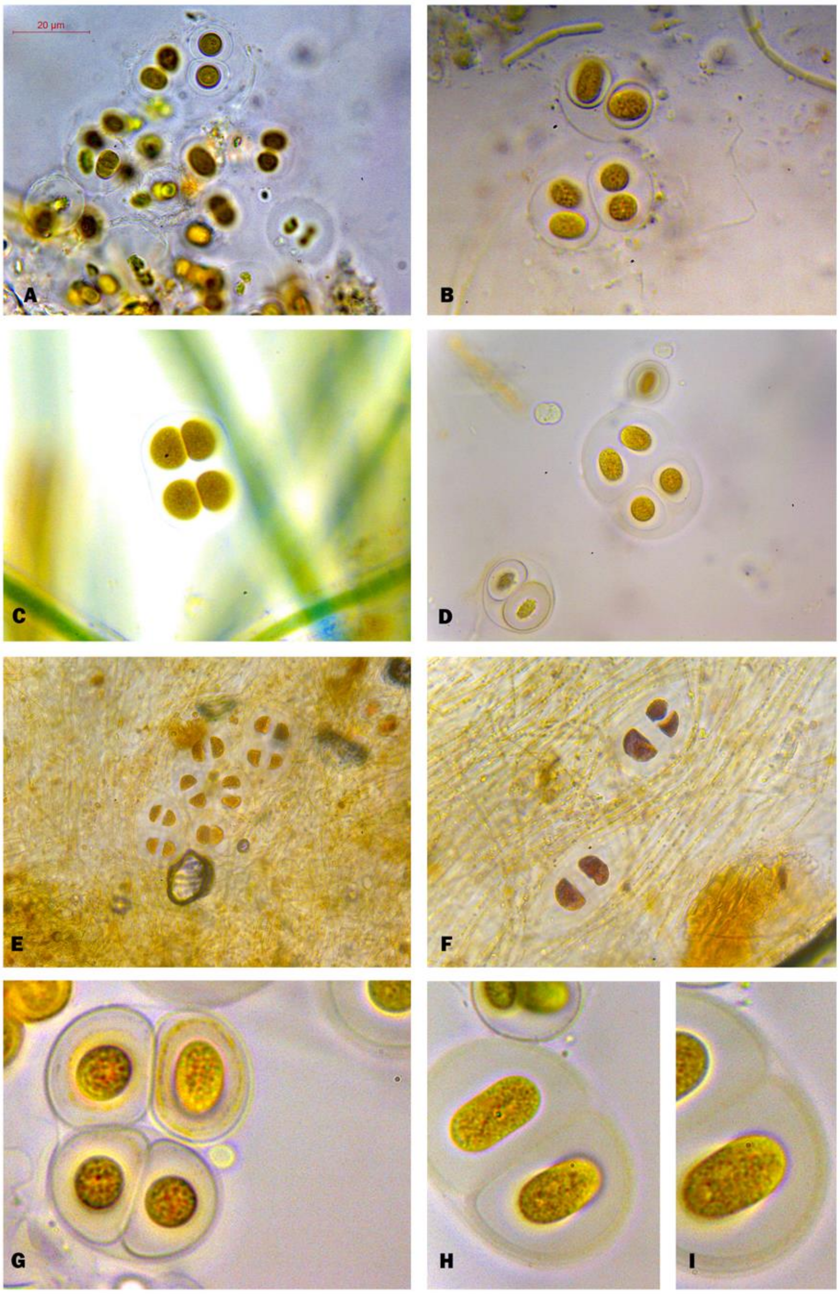

Fig. 16: **A & B.** *Chroococcus prescotii,* **C & D.** *C. giganteus,* **E & F.** *C. obliteratus,* **G-I.** *C. tenax*

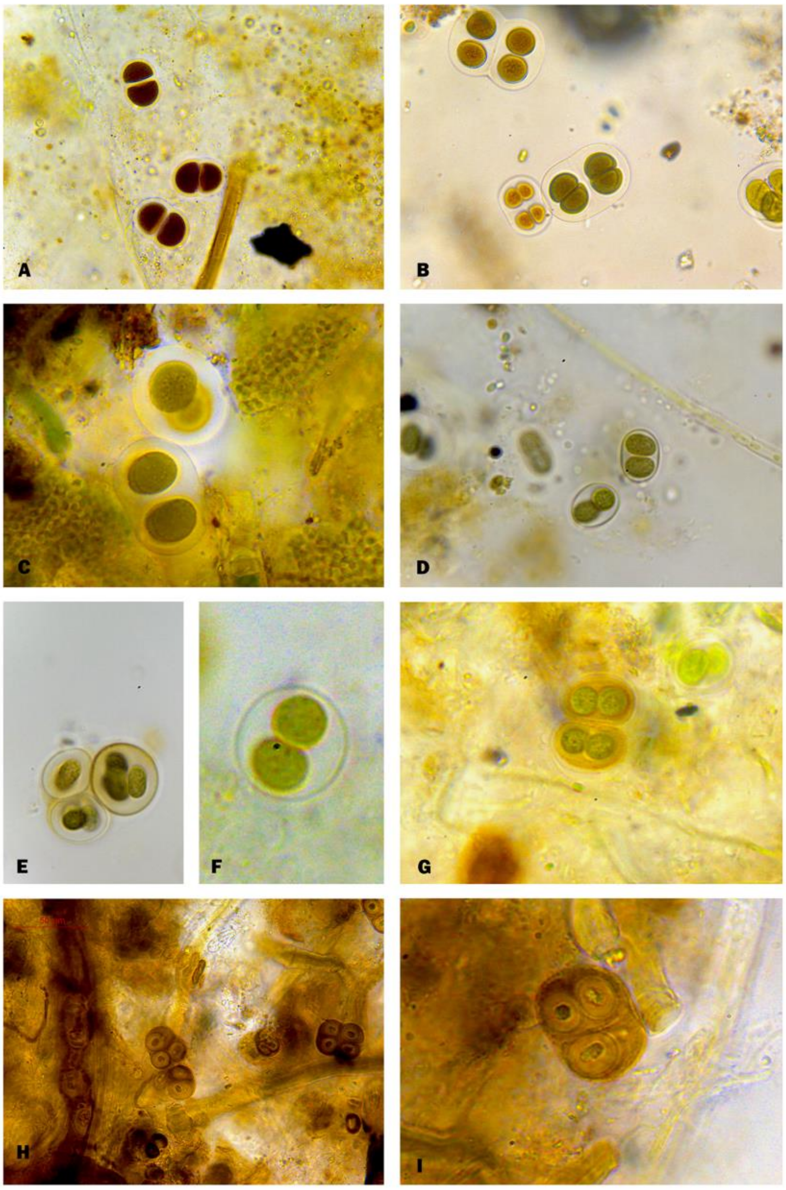

Fig. 15: **A.** *Chroococcus subnudus*, **B.** *C. turgidus*, **C.** *C. turicensis*, **D-F.** *C. indicus*, **G.** *C. schizodermaticus*, **H & I.** *C. varius*

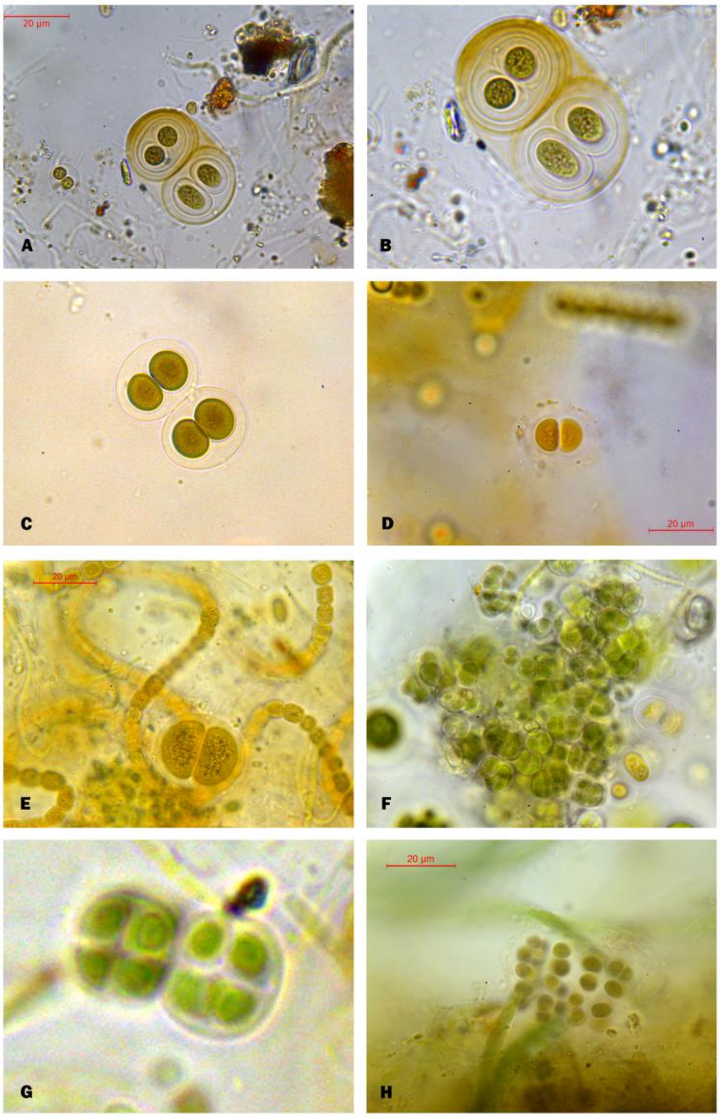

Fig. 14: **A & B.** *Chroococcus ercegovicii*, **C.** *C. pallidus*, **D.** *C. minutus*, **E.** *C. minutus* var. *thermalis*, **F & G.** *C. mipitanensis*, **H.** *C. quaternarius*

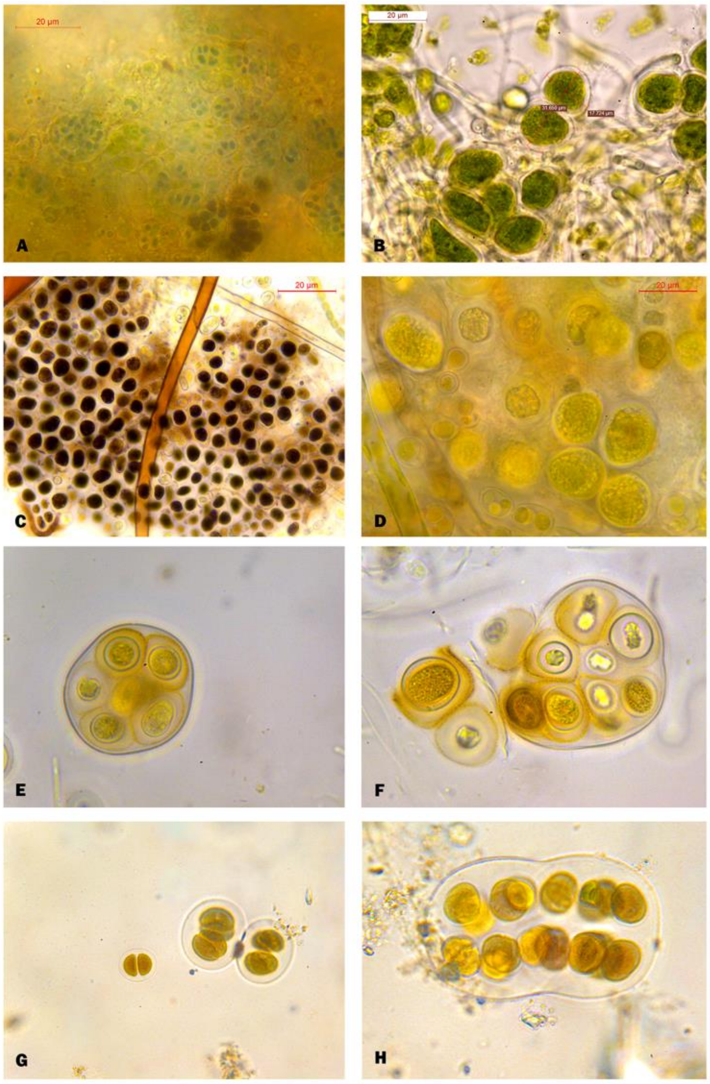

Fig. 13: **A.** *Gloeocapsa compacta*, **B.** *Gloeocapsopsis dvorakii*. **C.** *G. pleurocapsoides*, **D.** *G. chroococcoides*, **E & F.** *G. magma*, **G & H.** *Chroococcus cohaerens*

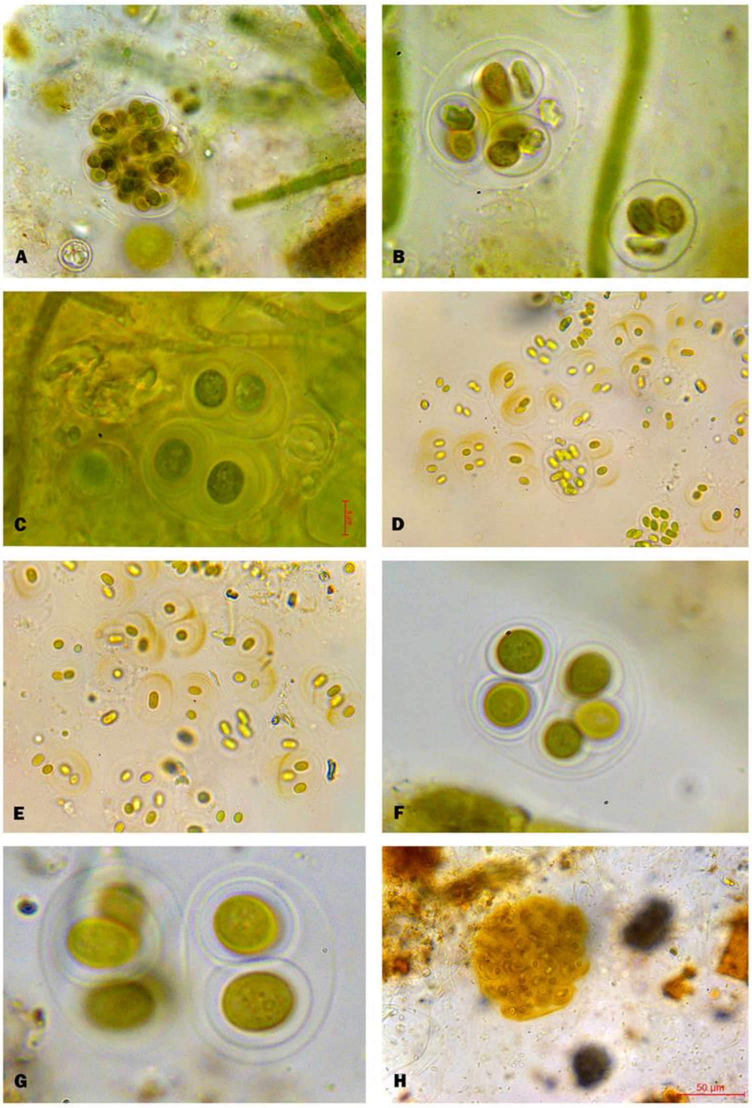

Fig. 12: A & B. *Gloeocapsa conglomerata*, **C.** *G. decorticans.* **D & E.** *G. fuscolutea*, **F & G.** *G. ruprstris*, **H.** *G. sanguinea*

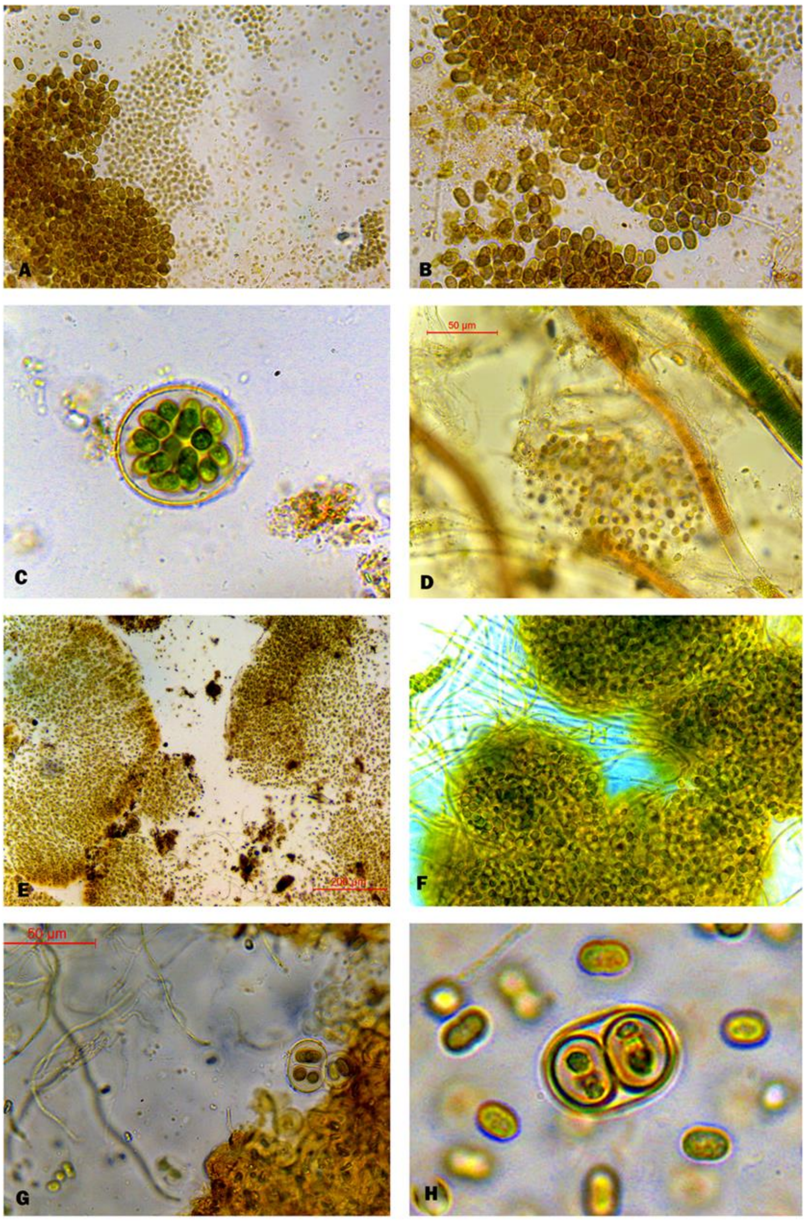

Fig. 11: **A & B.** *Microcrocis sabulicola,* **C.** *Coelospaerium dubium* **D.** *Microcystis smithii*, **E.** *M. aeruginosa,* **F.** *M. viridis* **G.** *Gloeocapsa atrata*

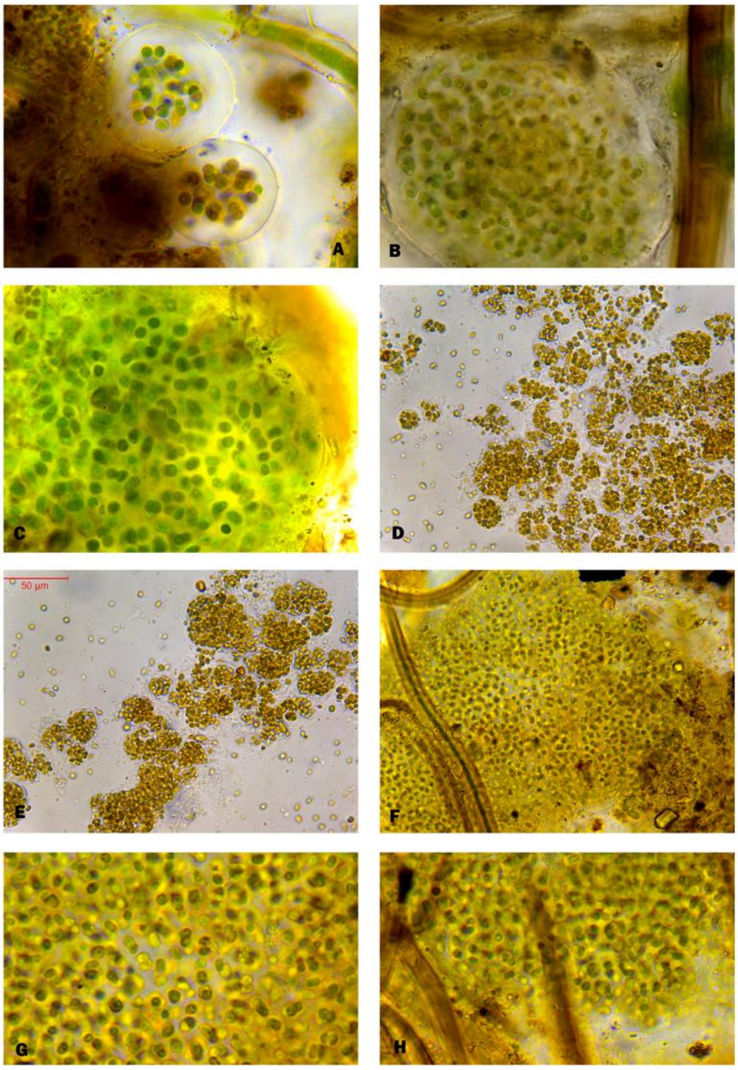

Fig. 10: **A.** *Aphanocapsa delicatissima*, **B.** *A. elachista* **C .** *A. grevillei*, **D & E.** *A. nubila*, **F-H.** *A. orae*

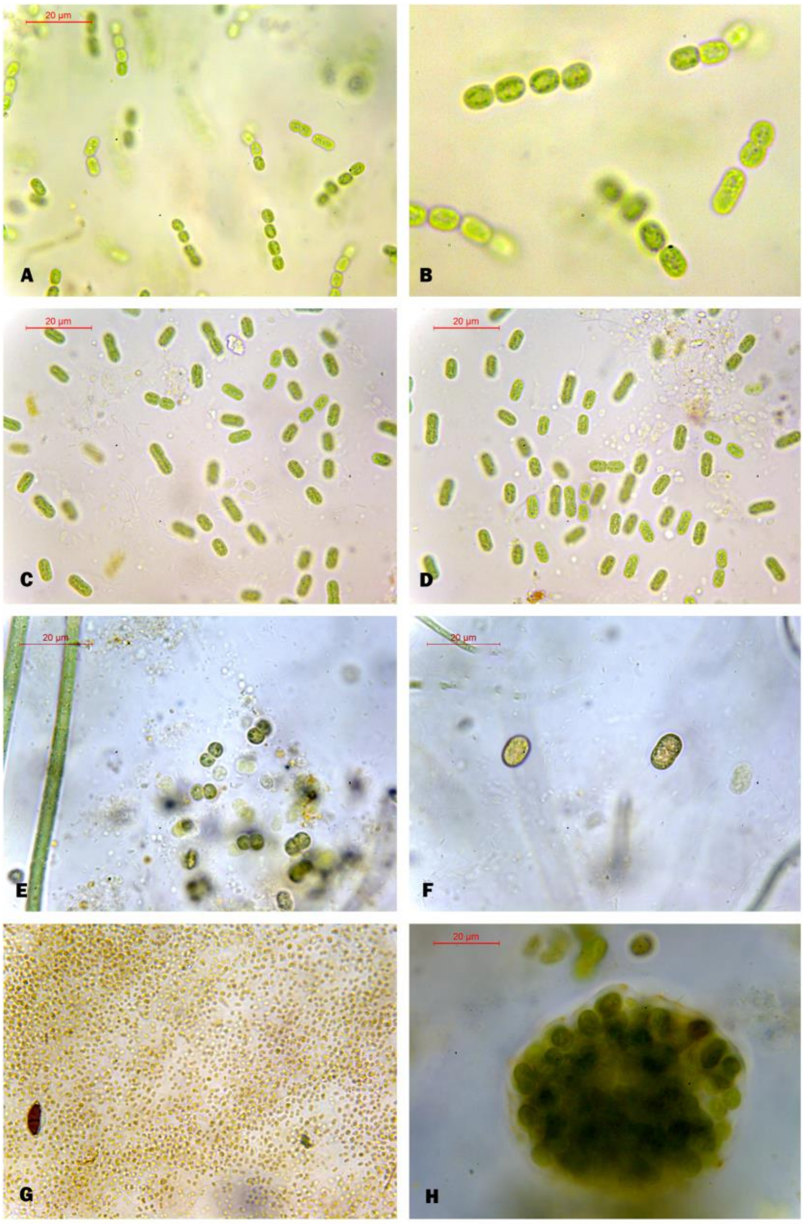

Fig. 9: **A & B.** *Synechococcus elongatus*, **C & D.** *S. mundulus*, **E & F.** *Synechocystis aquatilis*, **G.** *Aphanocapsa holsatica*, **H.** *A. fonticola*

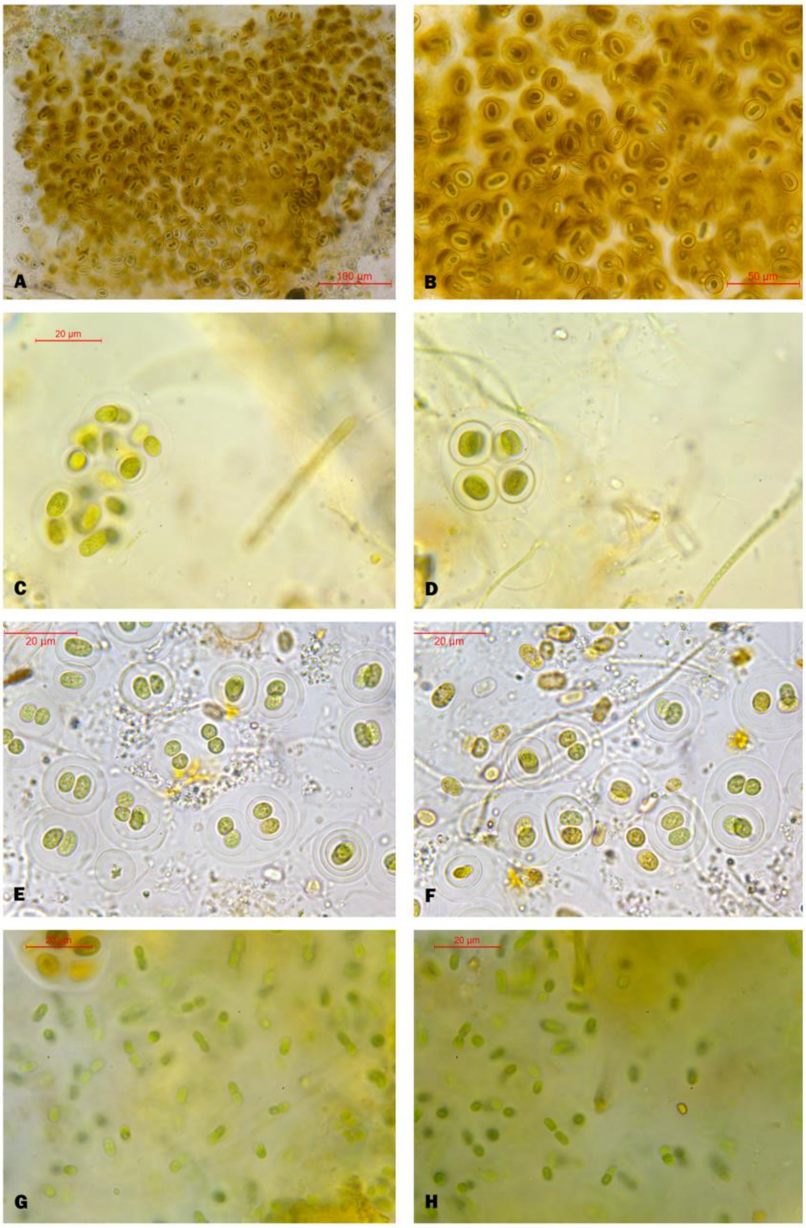

Fig. 8: A & B. *Gloeothece confluens*, **C & D.** *G. palea*, **E & F.** *G. rupestris*, **G & H.** *Synechococcus subsalsus*

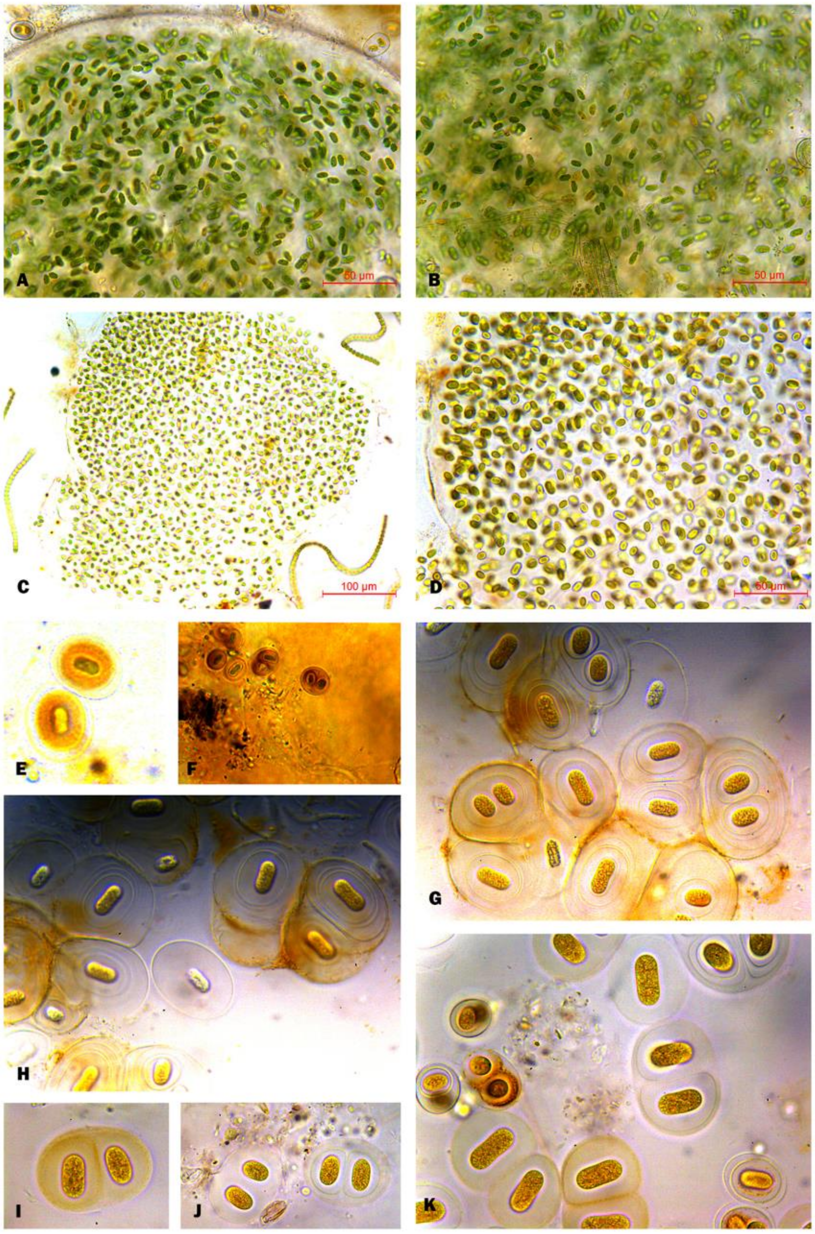

Fig. 7: **A & B.** *Aphanothece microscopica*, **C & D.** *A. smithii*, **E & F.** *Gloeothece incerta*, **G & H.** *G. membranaceae*, **I-K.** *G. tepidariorum*

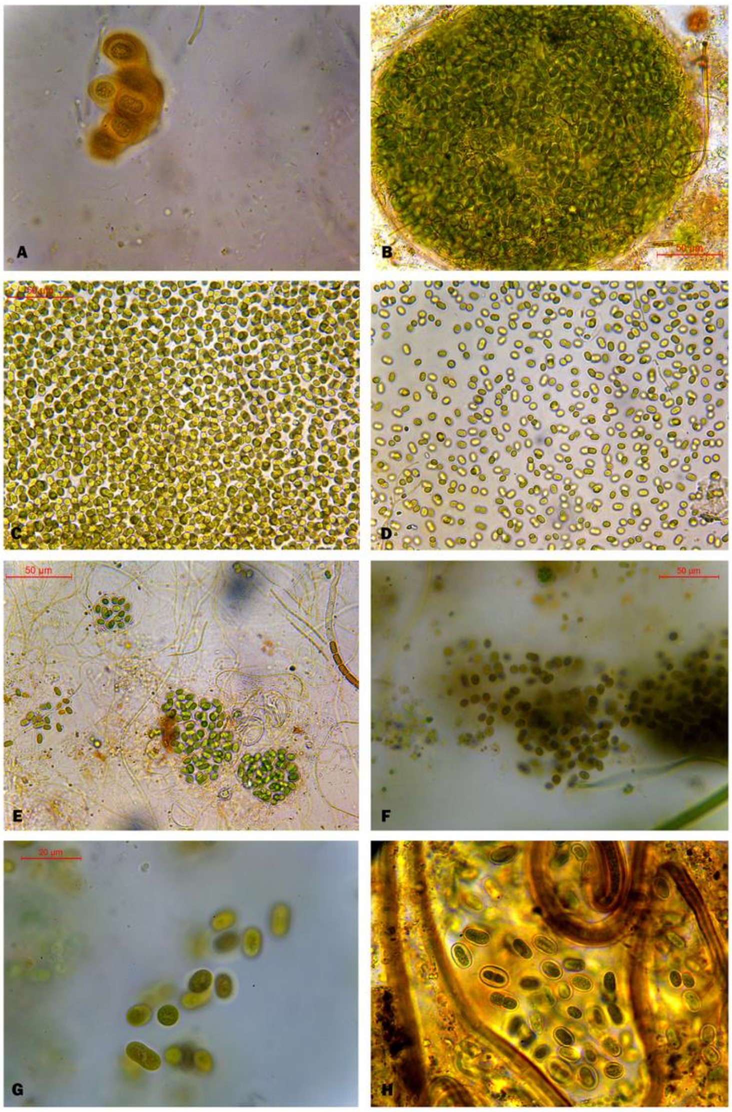

Fig. 6: A. *Aphanothece pallida*, **B.** *A. stagnina*, **C & D.** *A. bullosa*, **E.** *A. elabens* var. *minor*, **F & G.** *A. hegewaldii*, **H.** *A. castagnei*

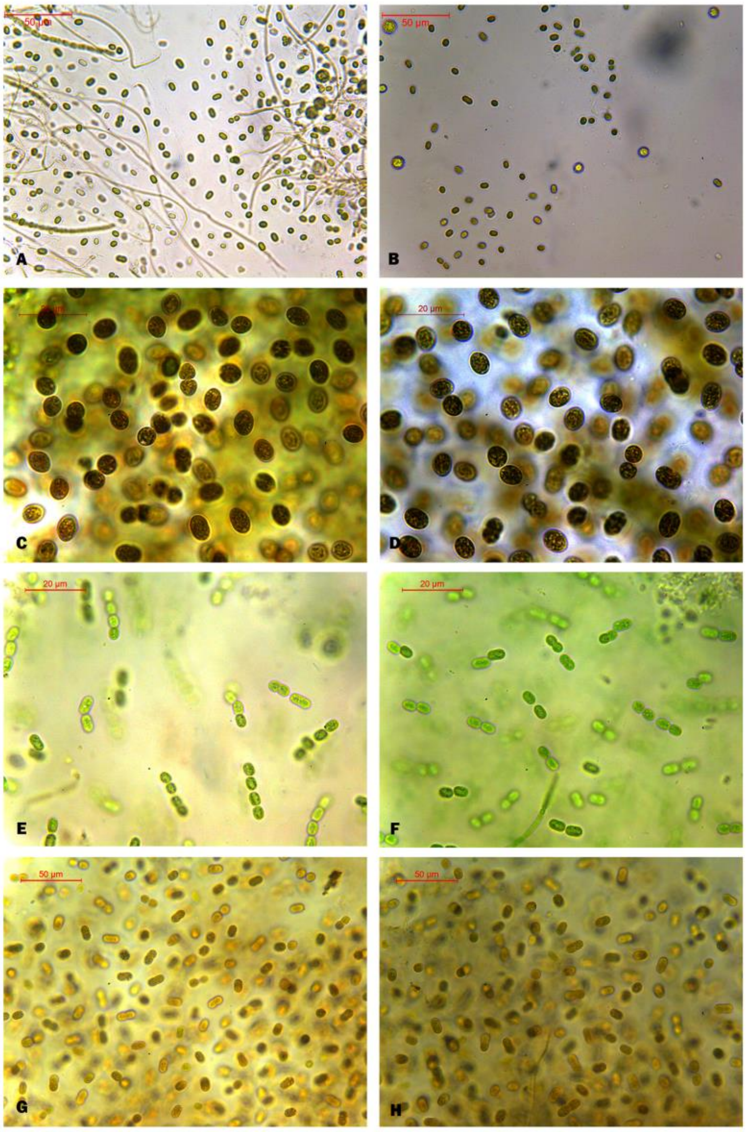

Fig. 5: **A & B.** *Cyanobium diatomicola*, **C & D**. *Cyanobacterium epiphyticum*, **E & F**. *C. notatum*, **G & H.** *Cyanothece halobia*

Fig. 4 : Collection and culturing

Fig. 3 : Western Ghat regions of Kerala

Fig. 2: Western Ghat regions of Kerala

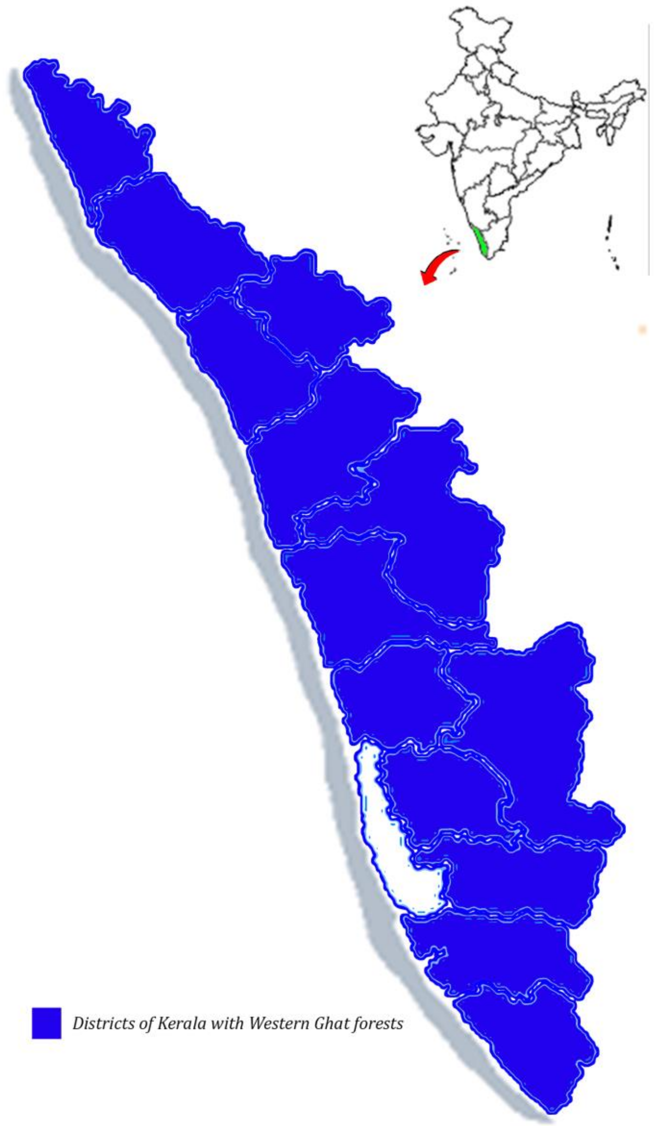

Fig. 1: Study area

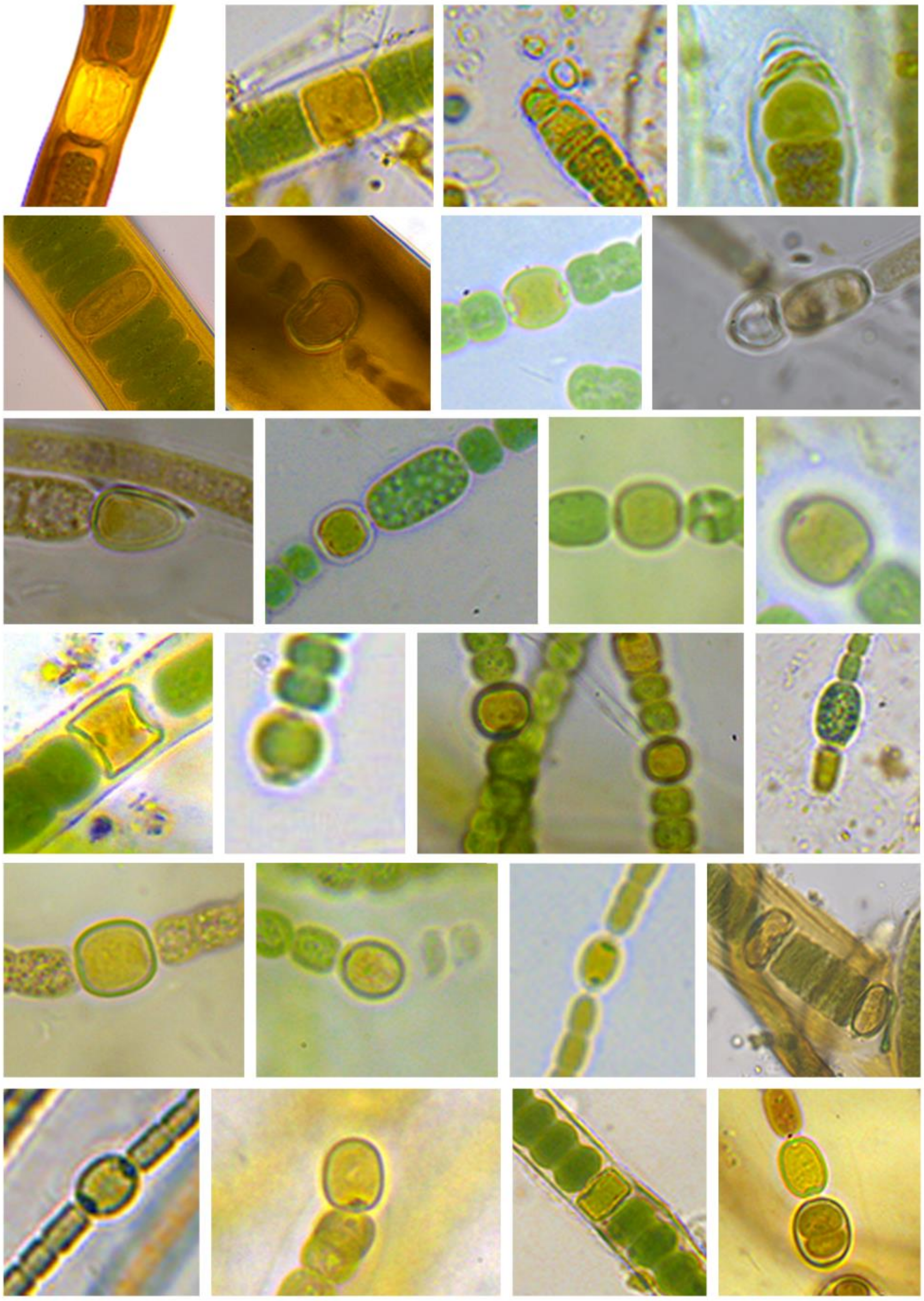

Fig. 67 : Different types of heterocysts observed