ECOLOGY AND DIVERSITY OF MANGROVE-ASSOCIATED CYANOBACTERIA OF SOUTHERN KERALA, INDIA

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IN

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by

ARUN T. RAM

Under the guidance of

Prof. (Dr.) Tessy Paul P.

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My beloved Research Supervisor,

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My Family .....

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I, **Arun T. Ram**, hereby declare that the thesis entitled **"Ecology and Diversity of Mangrove-Associated Cyanobacteria of Southern Kerala, India"** being submitted in partial fulfilment of requirements for the degree of **Doctor of Philosophy in Botany** of the University of Calicut embodies the results of a bonafide research work done by me under the guidance of **Prof.** (**Dr.) Tessy Paul P.,** Dean of Science, Professor & Head, Department of Botany, Christ College (Autonomous), Irinjalakuda, and Research Guide of Research & Post Graduate Department of Botany, MES Asmabi College, Kodungallur, Kerala, India. No part of this thesis has formed the basis for the award of any degree, diploma, associateship, fellowship, title or recognition.

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This is to certify that the research work presented in the thesis entitled ***"Ecology and diversity of mangrove-associated cyanobacteria of southern Kerala, India"*** has been carried out as part of fulfilment of requirements for the degree of Doctor of Philosophy in Botany of University of Calicut by **Mr. ARUN T. RAM** under my supervision and guidance and no part of the work embodied in this thesis has been submitted earlier for the award of any degree.

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Research Guide

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ABSTRACT

The present study focuses on the diversity, taxonomy and ecology of mangrove-associated cyanobacteria in the southern Kerala, India. The species composition, richness and spatial and temporal distribution of cyanobacteria with respect to physico-chemical parameters of water and soil were investigated in the selected mangrove environments. During the present investigation, a total of 89 cyanobacterial species were identified under 5 orders, 15 families and 28 genera and were recorded. Out of these 44 new records or new additions to India and 29 species were new records to Kerala. Seasonal variation in physico-chemical parameters such as pH, temperature, salinity, dissolved oxygen, electrical conductivity, total dissolved solids, total alkalinity, total phosphorus, total nitrogen, potassium, calcium, magnesium and sodium of the water samples from ten stations were estimated and their relationship with the cyanobacterial diversity was discussed based on multivariate statistical analysis. Seasonal variations of soil physico-chemical parameters such as pH, salinity, electrical conductivity, organic carbon, total nitrogen, total phosphorus, potassium, sodium, calcium and magnesium were estimated and analysed with the cyanobacterial diversity based on multivariate statistical techniques.

Key words:

Mangrove-associated cyanobacteria, diversity, physico-chemical parameters, multivariate statistical analysis

PREFACE

Cyanobacteria are gram-negative, oxygenic phototrophic bacteria that date back to 3.5 billion years ago. They are considered the architects of the earth because their oxygen forming property led to the formation of an oxygen atmosphere on this planet. They are ubiquitous in freshwater and marine habitats and are considered important biomass producers, maintaining the trophic energy dynamics of both aquatic and terrestrial ecosystems. The biodiversity of cyanobacteria in mangrove environments is enormous and represented an almost untapped resource. This research was designed since there has been no previous research conducted on the diversity and distribution of cyanobacteria in the mangrove environments of Kerala, which are scanty and meagre. This research covers a wide range of topics, namely taxonomy, diversity and ecology of cyanobacteria in mangrove environments of southern Kerala, India. The study also explains the spatiotemporal variations in the mangrove ecosystem which influence the cyanobacterial diversity.

The thesis is presented in six chapters;

Chapter 1: Provides the general introduction to mangroves, the importance of cyanobacteria in mangrove environments, the significance of research works and the objective of the present study.

Chapter 2: Deals with the review of related literature on the distribution of mangroves in a global scenario, Indian distribution, and with special reference to Kerala. This chapter also provides the literature on the historical analysis of the taxonomy of cyanobacteria, the taxonomy and diversity of cyanobacteria in mangrove environments, and the environmental factors that influence cyanobacterial growth, which include the physical and chemical characteristics of water and soil.

Chapter 3: Explains the materials and methods adopted for the study. It deals with the geographical distribution of the study area, sampling techniques of cyanobacteria, isolation and identification of cyanobacteria, and the methods for the physico-chemical analysis of water and soil.

Chapter 4: Explains the result and discussion. This chapter discusses the cyanobacterial species found in mangrove environments, including their taxonomy, key preparation, distribution pattern, and habitat, as well as the alpha and beta diversity. This chapter evaluates the physico-chemical parameters of water and soil that influence cyanobacterial diversity by using recent trends in multivariate statistical analysis.

Chapter 5: This chapter briefly explains the summary and conclusion of the present investigation.

Chapter 6: Provides the recommendations for further research envisaged from the present study.

These chapters are followed by the list of works consulted and cited as references.

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ABBREVIATIONS / ACRONYMS

TVM	:	Thiruvananthapuram
KLM	:	Kollam
KTM	:	Kottayam
ALP	:	Alappuzha
EKM	:	Ernakulam
S1	:	Kadinamkulam
S2	:	(Edava) Kureekkadavu-Kappil
S3	:	Ayiramthengu
S4	:	Sakthikulangara (Vincent Island)
S5	:	Kumarakom
S6	:	Mekkara (near Vaikom)
S7	:	Ezhupunna
S8	:	Pathiramanal
S9	:	Kumbalam
S10	:	Vypin
BE	:	Benthic
EP	:	Epiphytic
EC	:	Epipsammic/Epipelic
PL	:	Planktic
CL	:	Corticolous
MS	:	Monsoon season
PRS	:	Pre-Monsoon season
POS	:	Post-Monsoon season
BG-11 medium	:	Blue-Green 11 medium
Temp	:	Temperature
DO	:	Dissolved oxygen
EC	:	Electrical conductivity
TDS	:	Total dissolved solids
TA	:	Total alkalinity
TP	:	Total phosphorus
TN	:	Total nitrogen
K	:	Potassium

Ca	:	Calcium
Mg	:	Magnesium
Na	:	Sodium
OC	:	Organic carbon
NMDS	:	Non-metric multidimensional scaling
PCoA	:	Principal coordinates analysis
CCA	:	Canonical correspondence analysis
PCA	:	Principal component analysis
PAST	:	Paleontological statistics
JASP	:	Jeffreys's amazing statistics program.
SD	:	Standard deviation
ANOVA	:	Analysis of variance
Fig.	:	Figure
ha	:	Hectares
μm	:	Micrometres
sp.	:	Species
ppt	:	parts per thousand
^{o}C	:	Degree Celsius
mg/L	:	Milligram per litre
Mg/Kg	:	Milligram per kilogram
dS/m	:	deciSiemens per metre

Chapter 1
INTRODUCTION

Mangroves are a type of low-lying coastal vegetation, which stimulates their adaptation to other flora and fauna. Mangroves act as a guard or buffer agent, which prevents soil and water erosion in the coastal lands that help to monitor the balance of ecoclimatic factors. The term 'Mangrove' has been described in literature differently and its origin can be traced back to 114 million years ago (Sujanapal & Sasidharan, 2014). The origin of the word 'mangrove' is formed from two words, 'mangue' and 'grove' in Portuguese and English respectively. The word 'mangue' is used for individual mangrove habitat species and 'grove' of mangrove with trees and shrubs. Macnae (1968) coined a new term 'mangal' for mangrove communities and retained the term 'mangrove' for an individual plant or tidal forest or both as 'Mangrove plants' and 'Mangrove ecosystem'. Chapman (1976) used the word 'mangrove' for inter-tidal plants and described plant communities as 'mangal' mangrove habitats. Many researchers have expressed their opinion that plants growing between the highest and lowest tidal limits can be regarded as 'mangroves' (Aubreville, 1964; Blasco, 1975, 1977; Clough, 1982; Davis, 1940; Grzimek et al., 1976; Naskar & GuhaBakshi, 1987; Tomlinson, 1986).

The mangroves are rightly described as 'sea lungs'. Mangroves are shrubs or trees that typically grow between the high tide of spring and the mean sea level. They also form dense forests occupying muddy intertidal shores, consisting of virtually monospecific patches or bands. Mangroves have several dominant features. They have been considered ecologically as an important component of the coastal watersheds in the tropical ecosystem and have also been continuously exploited for aquaculture, agriculture, urban growth and other economic activities.

Mangroves can survive and thrive in a wide range of salinity, tidal amplitudes, winds, temperatures and muddy anaerobic environments. Due to their dynamic environments, mangrove forests are extremely rich in biodiversity,

supporting a wide variety of plant and animal groups, including many rare, endangered and vulnerable species. Mangroves have become the most important biodiversity component of coastal areas due to their adaptive features in their root systems, stems, leaves and canopy development, which greatly contribute to the coastal region's resilience. Generally, mangroves offer a wide range of valuable forest products that preserve estuarine water quality and play a vital role in many fish and shellfish life cycles. Mangroves also have instructive and recreational qualities and are perfect spots for environmental education. Biologically, mangroves always carry a wide range of potential advantages but much remains to be learned about their system's structure, operation and dynamism.

Some mangroves have special cells in the leaves, resulting in salt crystals appearing on the leaf surfaces, which eventually drop back into the sea. The salt tolerance mechanism in mangroves is now a mystery and understanding this mechanism in depth will help to obtain new salt-resistant plant strains appropriate for salt soils. Mangrove leaves are also specially adapted to avoid the harsh mid-day sun by changing their orientation. They shield them and limit water levels through evaporation. The seed germination of mangrove species is quite interesting. When the seeds germinate even as they hang from the trees. When the taproot system reaches 15-45 cm, they drop down into the water like pointed arrows. From there they grow as new plants, such plants are called viviparous. These hydrochory adaptations help the mangroves to propagate rapidly and expand the forests. Detritus and other protein-rich food from the mangroves sustain millions of crabs, prawns, fishes and other life forms.

Mangroves stabilize the soil and establish an environment that is used by a host of other organisms; they form the basis of a complex and productive ecosystem as photosynthetic primary producers. Mangrove ecosystem residents are accustomed to their uncompromising environment and can cope with regular tidal immersion and exposure, fluctuating salinity, low water oxygen concentrations and high temperatures. Considering mangrove status as an ecotone between soil and water ecosystems, they along with other wetlands often act as 'nature's kidneys' by holding and decomposing or mineralising many dangerous pollutants draining from the land through land run-off before reaching the aquatic environment.

Mangrove plants and habitats play a very diverse and important role in both the tropical and subtropical areas of the world's estuarine mouths. Despite their significance in saving the biodiversity of flora and fauna of deltaic biological systems and the security of the coastline from normal catastrophes, these mangrove environments are for the most part disregarded. Indiscriminate habitat destruction and depletion have occurred by clearing and turning these forests into agricultural lands, brackish water plantations, saltpans and harbours. The mangrove biological system is associated with the ocean and structures the deltaic lands. These are exceptional factors corresponding to the soil characteristics, water assets, wind speed, precipitation design, temperature variance, farming methods and in conclusion however not least their average vegetation.

Coastal and marine resources are dwindling at an alarming rate. Despite the ecological importance, mangroves are nowadays facing threatful environments. In many parts of the world, mangroves are still being destroyed and degraded at a disturbing rate. Over the last decades, the global areas of mangroves are shrinking. It is mostly due to deforestation, degradation, freshwater diversion and conservation of other land users like intensive shrimp farming and agriculture. Added to this, human populations along the coastlines have increased (Ong, 1995; Macintosh, 1996). Huge areas of mangrove forests have been cleared to make way for residential areas, coastal industries and roads.

As the forest disappears, communities have to penetrate deeper into the forest to get the firewood, agricultural runoff, organic and inorganic pollution caused by chemicals and heavy siltation have killed many species of flora and fauna. In our ignorance, we may have destroyed the most powerful and abandoned natural resource, threatening not only our food security but even jeopardizing the lives of three million people on the planet. Therefore, an urgent need is for a collective and collaborative effort on mangrove restoration and protection to help restore the balance between man and nature. The collaborative efforts of government organizations, global agencies like IUCN and mangroves for future initiatives will help mangroves to recover and regain this equilibrium, thus ensuring a sustainable and secure future for millions of people as well as the silent guardians and protectors of coastlines.

Mangroves are unique in the way that they succour rich flora and fauna when compared to many other ecosystems. The water-logged or drowned portions of mangrove roots, stems and branches function as shelter islands that can host rich epifloral and faunal populations including bacteria, fungi, macroalgae, microorganisms and invertebrates. Pneumatophores and prop roots greatly increase the available surface area and provide a strong substrate, in comparison to the surrounding water while mangrove primary production provides many species with an energy source. The hard substrate provided by mangrove pneumatophores, prop roots, aerial roots, trunks and soil also provide a surface on which photosynthetic organisms such as unicellular diatoms and photosynthetic cyanobacteria can grow on nearly any surface available (Hogarth, 2015). According to Desikachary (1959), in India, out of saline circumstances, 85 species of cyanobacteria are known, including 50 marines which occur in the intertidal and supratidal regions, while a few are planktonic and it was concluded that salinity plays an important role as a single factor in the vegetation of the saline series of habitats.

Most of the earth's initial atmospheric oxygen was originally produced by species somewhat close to modern cyanobacteria (KnolI, 1985), which are still responsible for a large proportion of photosynthetic oxygen production in the oceans. Cyanobacteria are a group of photosynthetic prokaryotes that are an integral part of the microbiota, the source of nitrogen in all mangrove ecosystems, from single-cell colonies to filamentous heterocytous (Kathiresan & Bingham, 2001). In general, unicellular cyanobacteria have higher evolution rates than filamentous ones and the lowest recorded average development time for single-celled cyanobacterium was 41°C, 2.1 hours (Carr & Wyman, 1986) while the minimum average generation time of filamentous cyanobacteria is 3.6 hours at 42°C (Kratz & Myers, 1955). It is also unclear, however, whether unicellular forms tend to grow faster in nature than filamentous forms.

In several intertidal areas, cyanobacteria prevail (Whitton & Potts, 1982) and are often part of complex populations, sometimes grouped under the term ‘mat’ (Cohen, 1989). These are particularly well-developed communities where local conditions lead to hypersalinity. Microbial mats grow in a wide range of environments such as hypersaline ponds, alkaline lakes and intertidal coastal

sediments like mangrove ecosystems (Cohen et al., 1984; Cohen & Rosenberg, 1989). Because of the prevalence of cyanobacterial species and in recognition of their function in the formation of laminated sedimentary structures, microbial mats have been called algal mats, cyanobacterial mats and potential stromatolites (Krumbein, 1983, 1994). Cyanobacteria commonly form complex associations in structures called cyanobacterial mats with bacteria and green algae (Stal, 1995). The terminology used to classify cyanobacterial mats is very complex and typically differentiates between metaphyton (floating mats), epiphyton (periphytic algae) and epipelon (bottom mats) (Stevenson, 1996). Metaphyton derives from epiphyton and epipelon by sloughing off the submerged substrates and becoming a floating mat on the surface of the water. Such features make cyanobacteria especially suitable for mat formation; sheaths and mucilage contribute to matrix building, which supports other microbial colonizers and protozoans (Rejmankova et al., 2004). In addition to the structural support, a physiological link exists where N_2 fixed by heterocytous cyanobacteria is used directly by associated non-fixing bacteria (Paerl et al., 1996). One of the most important steps to understanding was realizing that a heterocyte is a place of nitrogen fixation (Fay et al., 1968) and that some non-heterocytous species also bind nitrogen (Wyatt & Silvey, 1969), which is known as picoplankton cyanobacteria are a major component of oceanic phytoplankton (Johnson & Sieburth, 1979; Waterbury et al., 1979).

The cyanobacterial mat is often covered with a thin layer of sand and cyanobacteria generally initiate the development of a microbial mat on sandy intertidal sediments. Instead, intertidal sediments are inundated and exposed to the atmosphere, causing changes in water quality, salinity and temperature. In the higher parts of the intertidal flats, where microbial mats develop particularly well, fluctuations in environmental conditions are more extreme (Stal et al., 1985; Pierson et al., 1987). Non-durable sandy silt is regularly possessed by filamentous cyanobacteria which structure a thick system of entrapped trichomes in which sand particles are trapped.

Cyanobacteria-dominated mat populations can thrive in harsh environments due to a variety of structural and functional adaptations (fixing capabilities of N_2; oxygenic vs. anoxygenic photosynthesis) that allow them to be sites of severe

biochemical and ecological interactions (Cohen & Rosenberg, 1989; Villbrandt et al., 1991; Stal, 1995; Steppe et al., 1996; Fenchel, 1998). These types of interaction studies have been conducted on marine intertidal sediments as well (Bebout et al., 1987; Paerl et al., 1989; Stal, 2001). Resistance to drought and water stress is widespread (Whitton, 1987b) and cyanobacteria are one of the most effective organisms in highly saline environments (Bauld, 1981; Borowitzka, 1986).

The causes of cyanobacterial mortality are poorly understood, despite the importance of oceanic cyanobacteria in global primary production and of heterotrophic bacteria in the consumption of marine organic matter (Procter & Fuhrman, 1990). Studies on cyanobacteria associated with mangroves are very important not only because of their abundance but also because of their high nitrogen fixation ability, which makes them potential candidates for possible reforestation and the rehabilitation of destroyed mangroves (Bashan et al., 1998). This is one of the groups that have been neglected, with only a few studies being conducted (Rejmankova et al., 2004; Sundararaman et al., 2007).

Biodiversity in mangrove ecosystems is prevalent (Mooney et al., 1995). Worldwide, ecosystems are increasingly losing taxonomic, phylogenetic, genetic and functional diversity due to human exploitation of natural resources, habitats and climate change and the spread of pathogenic, exotic and domestic plants and animals (Naeem et al., 2012). In mangrove habitats, high fixation levels of N_2 were correlated with the cyanobacterial mat that covers the sediment surface (Toledo et al., 1995a). Studies on cyanobacteria in the mangrove aquatic system are relatively small compared to information on angiosperms in mangroves. In aquatic systems, cyanobacteria that occur as plankton, benthic and epiphytes play a major role as primary producers, as a source of nutrients and also as animal feed (Krishnamurthy & Jeyaseelan, 1981).

Studies on the association of cyanobacteria with mangroves are important because most cyanobacterial members have heterocytes that contribute significantly to the fixation of nitrogen. But their identification and taxonomy are still troublesome considering their biological value and environmental issues. Cyanobacteria are an incredibly challenging category to identify. Cyanobacterial

taxonomy, their classification and knowledge of cyanobacterial diversity, therefore, belong to the major and fundamental problems of cyanobacterial research. Modern taxonomic classification is a system of identifying and documenting the diversity of species (both in nature and in cultures), based on evolutionary (genetic) and ecological relationships and phenotypic variability. The method of modern cyanobacterial diversity classification that respects all of these characteristics is generally called the 'polyphasic approach', which would be the standard for the current re-classification of cyanobacterial diversity (Komarek, 2011).

In addition to being photoautotrophic, many cyanobacteria are capable of heterotrophy, allowing them to occupy symbiotic structures such as the roots of plants that receive little or no light, where photosynthetic hosts can provide them with fixed carbon (Adams, 2012). Cyanobacteria are common epiphytes of mangrove pneumatophores (Steinke et al., 2003). There is a complete lack of information about the cyanobacterial flora in the mangrove forests of Kerala. Concerning the taxonomy of Cyanobacteria, Kerala has not conducted any research on estuarine mangrove habitats. Since cyanobacteria play an important role in mangrove ecosystem growth and sustenance due to their role in aquatic food chains, it was proposed to investigate the mangrove-associated cyanobacterial flora.

1.1. Objectives of the study

1) To survey the cyanobacteria in selected mangrove vegetation of southern Kerala.
2) A comprehensive taxonomic study and identification of the mangrove-associated cyanobacterial diversity of southern Kerala.
3) To provide a taxonomic key to the mangrove-associated cyanobacteria of southern Kerala.
4) To provide microphotographs and descriptions of the mangrove-associated cyanobacteria of southern Kerala.
5) To study the influence of physico-chemical parameters of water and soil on the distribution of cyanobacteria in mangrove ecosystems.

Chapter 2

REVIEW OF LITERATURE

Mangrove communities include a group of biological components that are highly adapted to intertidal environmental conditions, including plants, animals and microorganisms. Without the actual mangrove plants, however, none of these can be identified as a community in a mangrove ecosystem, implying that the true mangrove vegetation is the major constituent of the ecosystem. Mangrove vegetation describes the landscape and actively or indirectly participates in the biological processes taking place in this environment (Lugo & Snedaker, 1974; Hamilton & Snedaker, 1984; Tomlinson, 1986). The knowledge of the composition of certain species of mangrove plants in any country is a fundamental prerequisite for understanding all aspects of the composition and function of mangroves, as well as their ecological similarities, their conservation and management.

Naskar (1983) classified mangroves based on their habits, habitats and distribution in different saline zones such as 'true mangroves', 'mangrove associates' and 'obligatory mangroves'. Li and Lee (1997) coined two terms, 'true mangroves' and 'semi mangroves'. Mepham and Mepham (1984) and Naskar (1993) used the term 'mangrove associate' for the non-arborescent, herbaceous, sub-woody and climber species of flora found to grow mostly in areas bordering the tidal periphery of mangrove habitats.

2.1. Distribution of mangroves: Global Scenario

Mangroves are globally distributed and occupy 1,50,000 km^2, occur in over 123 countries and are made up of more than 73 species and hybrids (Bunt et al., 1992; Spalding, 1997; Spalding et al., 2010). It is estimated that there are around 15.2 million hectares of mangroves worldwide in 2005, down from 18.8 million hectares in 1980 (FAO, 2007). As per the satellite data, the total area of the world's mangrove forest is 1,37,760 km^2 (mangrove vegetation only and not including water bodies and barren land), which is roughly 12% lower than the FAO's most recent

estimate, distributed over 118 countries in the world's tropical and subtropical regions (Giri et al., 2011).

In Asia, the largest mangrove area is found, followed by Africa and North and Central America. Five countries (Indonesia, Australia, Brazil, Nigeria and Mexico) together account for 48% of the total global area (FAO, 2007). Around 75% of mangroves in the world are concentrated in just 15 countries (Giri et al., 2011). The remaining 25% is spread over approximately 100 countries and areas, of which 60 each have less than 10,000 ha of mangroves.

According to the most recent FAO report, 'Global Forest Resource Assessment 2020', 113 countries have 14.79 Mha of mangrove forests. The report further shows that Asia possesses the largest area of mangroves (5.55 Mha), followed by Africa (3.24 Mha), North and Central America (2.57 Mha), and South America (2.13 Mha). The smallest area of mangroves has been reported in Oceania (1.30 Mha). Indonesia (19%), Brazil (9%), Nigeria (7%) and Mexico (6%) together possess more than 40% of the global area covered by mangroves. Around 75% of the world's mangroves occur in 15 countries, of which merely 6.9% are protected under the existing protected areas network (Giri et al., 2011). Globally, India is one of the 15 countries with high mangrove prominence, with a total mangrove cover of about 3% in South Asia (FSI, 2019).

2.2. Mangroves in India

Mangroves occur along both the west and east coasts of India. India is one of the 15 most mangrove-rich countries having 2.7% of the global total area of mangroves (Giri et al., 2011). The distribution status of mangroves by Hamilton and Casey (2016) showed that mangroves are found in 105 nations possess about 52%. A higher percentage of global mangrove cover was noted in Indonesia (26-29%) and the Sundarbans National Park in India and Sundarbans Mangrove Forest in Bangladesh have been known to possess the world's largest united stretch of mangrove forest.

The mangrove cover assessment carried out by the Forest Survey of India (FSI 2019) is a part of the country-wide forest cover mapping and shows that the mangrove cover in the country is 4,975 km^2, which is 0.15% of the country's total

geographic area. The area covered by very dense mangroves (all lands with a tree canopy density of 70% and above) is 1,476 km^2 (29.66%), moderately dense mangroves (all lands with a tree canopy density of 40% and more but less than 70%) is 1,479 km^2 (29.73%), and open mangroves (all lands with a tree canopy density of 10% and more but less than 40%) is 2,020 km^2 (40.61%). There has been a net increase of 54 km^2 in the mangrove vegetation of the country when compared with the Forest Survey of India (FSI) 2017 assessment. India comes in third place globally in terms of mangrove variety, after Indonesia and Australia (FAO, 2020). Around 80% of Indian mangroves are found along the east coast and the largest areas are the Indian part of the Sundarbans and the Andaman and Nicobar Islands. There are 46 true mangrove species in India, classified into 14 families and 22 genera. The east coast of India has 40 mangrove species, whereas the west coast has 27 genera (Nandy et al., 2021).

2.3. Mangroves in Kerala

In Kerala, mangroves are extremely scattered and largely restricted to the estuaries along the coastal belt of major rivers, lagoons, backwaters, and creeks. Bourdillon (1908) recorded *Brugueira gymnorhiza* and *Rhizophora* sp. from Kollam. Rao and Sastry (1974) and Thomas (1962) recorded 5 mangrove species, *Acanthus ilicifolius* L., *Avicennia officinalis* L., *Bruguiera gymnorhiza* (L.) Lam., *Rhizophora apiculata* Blume and *Rhizophora mucronata* Lam. under 4 genera and 3 families from Veli backwaters of Trivandrum. Blasco (1975) reported *Acanthus ilicifolius* L. from Kollam. According to Basha (1991), Kerala had a total mangrove area of 700 km^2 which has declined to 16.71 km^2. The total mangrove vegetation of the state has been distributed among Trivandrum (23 ha), Kollam (58 ha), Alappuzha (90 ha), Kottayam (80 ha), Ernakulam (260 ha), Thrissur (21 ha), Malappuram (12 ha), Kozhikode (293 ha), Kannur (755 ha) and Kasaragod (79 ha).

Kurien et al. (1994) reported that the mangrove forest area of the state is only 1,095 ha. Suma (2005) recorded that the major patches of mangroves in Kerala are distributed in places like Veli, Asramam, Ashtamudi, Keeriyad Island, Chetwai, Vypeen Island, Mallikkad, Kumarakom, Pathiramanal, Edakkad, Pappinissery, Kunhimangalam and Chittarai and numerous other small patches across the state.

Mohanan (1997) reported that the total extent of Kerala's mangroves was spread along the upper reaches of estuaries, lagoons, backwaters and creeks, reaching 4200 ha. Sunil (2000) reported the most important mangrove species of the Alappuzha district come under 9 genera and 7 families. Anupama and Sivadasan (2004) published a detailed description of the mangroves of Kerala. The study reported that 15 true mangroves belong to 9 genera and 7 families. and 49 mangrove associates along the Kerala coast.

Radhakrishnan et al. (2006) reported the occurrence of 7 species of mangroves in the Kozhikode district. Sreeja and Khaleel (2010) studied the status of mangroves on Thekkumbad island in Kannur district. A total of 11 true mangroves and 6 associates have been reported and recorded *Rhizophora mucronata* Lam., *Bruguiera cylindrica* (L.) Blume, *Sonneratia alba* Sm. and *Excoecaria agallocha* L. as the most dominant species.

The floristic diversity of mangroves in Kannur is very high compared to other districts. Vidyasagaran et al. (2011) recorded 12 species of mangroves under 9 genera, belonging to 7 families from the Kannur district and the most important family reported was Rhizophoraceae with four species. Saritha and Tessy (2011) studied the diversity, distribution and abundance of mangroves in the Poyya backwaters of the Thrissur district and reported a total of 9 species; of which 4 were true mangroves and the remaining 5 were associates. Ram and Shaji (2013) reported a total of 17 species including 7 true mangroves, 2 semi mangroves and 8 mangrove associates have been reported from Kumbalam Island in Ernakulam district. Vidyasagaran and Madhusoodanan (2014) reported that the extent of mangroves in Kerala is 2,502 ha, out of which, 1,189 ha belongs to the state and 1,313 ha are under private ownership. Kannur district occupies the maximum extent of mangroves (1,100 ha), followed by Ernakulam (600 ha) and Kasaragod (315 ha) and the minimum was represented by three districts, Thrissur (30 ha), Thiruvanthapuram (28 ha) and Malappuram (26 ha). A total of 15 pure mangrove species and about 33 semi mangrove species were reported from the state.

Rahees et al. (2014) conducted a study at Kadalundi-Vallikkunnu community reserve in Malappuram- Kozhikode districts, exposing the occurrence of 7 species of

mangroves under 5 families. A total of 11 true mangrove species and 6 associated mangroves have been recorded from the Ashtamudi estuary, Kollam district (Sumesh et al., 2014). Sujanapal and Sasidharan (2014) reported that 18 true mangroves and 54 mangrove-associated species of Kerala were identified. Mohandas et al. (2014) identified a total of 24 species of mangroves belonging to 15 genera and 9 families along the 10 coastal districts of Kerala and the report highlighted the significance and resources of the environment as a whole and showed the urgent need to protect them concerning major forestry practices.

Vijayan et al. (2015) studied the diversity and phytosociological characteristics of mangroves from six locations in the Kollam district. The study reported 12 species of mangroves belonging to 8 genera and 6 families in which Rhizophoraceae and Avicenniaceae were the most predominant families. Vaiga and Joseph (2016) reported the diversity and distribution of mangroves from the Kannur district between 2015 and 2016. The study reported 7 species of true mangroves, 4 species of semi mangroves and 7 species of mangrove associates from Vellikkeel, and 10 species of true mangroves, 3 semi mangroves and 7 mangrove associates from the Ezhome area. Ratheesh et al. (2017) conducted a study on the diversity of mangroves in Asramam in the Kollam district and reported a total of 6 true mangroves and 16 mangrove associates. Sahadevan et al. (2017) identified 11 species of true mangroves and 32 species of mangrove associates from Puthuvype in Ernakulam district.

According to the reports of Pillai and Harilal (2018), 15 true mangrove species are classified into 9 genera and 6 families. The present study assessed the total extent of mangroves in Kerala to be 19.531 Km^2. Out of 10 districts studied, Kannur occupied the highest mangrove cover (38.22%), followed by Ernakulam (31.5%), Kozhikode (6.18%), Kasaragod (5.65%), Alappuzha (5.32%), Kottayam (5.04%), Kollam (2.71%), Thrissur (2.08%), Malappuram (1.88%) and Thiruvananthapuram (1.41%).

2.4. Taxonomy of Cyanobacteria

Cyanobacteria are the most widely distributed class of photosynthetic prokaryotes on Earth and one of the most important steps in evolution was their

origin in the Early Precambrian (Schopf, 1974a, 1974b, 1993, 1996) and Schopf and Walter (1982) termed the Proterozoic era from 2.5 to 0.54 billion years ago, the atmosphere turned from anoxic to oxygenated due to oxygenated photosynthesis - "the age of Cyanobacteria". Cyanobacteria descriptions started to appear in the botanical literature from the late eighteenth century onwards. This heterogeneous group has different nomenclatures too, such as Myxophyceae (Stitzenberger, 1860), Cyanophyceae (Sachs, 1874), Cyanophyta (Smith, 1938; Desikachary, 1959), blue-green algae (Bourrelly, 1970; Golubic, 1979; Anand, 1981), Cyanochloronta (Bold & Wynne, 1978) and Cyanoprokaryotes (Komarek & Anagnostidis, 1998).

In botanical tradition, blue-green algae are distinguished based on phenotypical properties. The first comprehensive taxonomic monographs for blue-greens were published by Thuret (1875), Bornet and Flahault (1887, 1888 a,b) and Gomont (1892), recognized by phycologists as a later starting point in taxonomic referencing.

Geitler (1925) first suggested Chroococcales, Entophysalidales, Pleurocapsales, Dermocarpales, Siphononematales, Nostocales and Stigonematales. Geitler (1932) provided an updated manual for taxonomic review and determination that recognized 1,300 species which were classified into 145 genera, 20 families, and 3 orders. Geitler's research depended on the morphology of field-collected specimens and his classification system marks the starting point of the modern era of cyanobacterial systematics, recognized by phycologists and microbiologists. Since then, it has formed the basis for numerous revised systems, including those suggested by Elenkin (1938-1949), Desikachary (1959), Fritsch (1959), Starmach (1966), Kondrateva (1968), Bourelly (1970), and Golubic (1976). Such systems share the view that cyanophyte systematics should be based on conventional botanical standards, sometimes referred to as the 'Geitlerian approach' or sometimes referred to as 'classical taxonomy'. Geitler (1932) suggested two unicellular orders, Chroococcales and Chamaesiphonales and one order of filamentous cyanobacteria, the Hormogonales.

Desikachary (1959) primarily studied the Stigonematales and assisted other researchers in uniting the non-branching filamentous taxa into one order. Prescott

(1962) adopted Frémy's (1929) system and Bourrelly (1970) used Desikachary's higher classification system. Rippka et al. (1979) recommended five sections (according to the reproduction). Section I: reproduction by binary fission or by budding; Section II: reproduction by multiple fission giving rise to small daughter cells or by both multiple fission and binary fission; Section III: division in only one plane and trichome always composed only of vegetative cells; Section IV: intercalary cell division always occurs in a plane at right angles to the long axis of the trichome which is consequently uniseriate and unbranched; Section V: retain filamentous structure throughout growth and division occurs in more than one plane. Later, Komarek and Anagnostidis (1998) divided the cyanobacterial classification into 14 families by the presence or absence of false branching, true branching and heterocytes, for discussion, they used ‘heterocytes’ and ‘hormogonia’ instead of ‘heterocysts’ and ‘hormogones’, as per the recommendation of the International Association for Cyanophyte Research (IAC) (Mollenhauer et al., 1994).

In both botanical and bacteriological literature, the systematics of cyanobacteria is viewed differently. In the botanical approach, which dates from Linnaeus (1753), identification at the binominal level (genus and species) is traditionally based mainly on morphological observations by light microscopy of natural samples. The nomenclature of ‘blue-green algae’ or ‘Cyanophyceae’ assumes the rules of the International Code of Nomenclature for algae, fungi, and plants (ICN) (Melbourne Code) (formerly referred to as the International Code of Botanical Nomenclature- ICBN or “Botanical Code”) (McNeill et al., 2012).

Traditionally, 'Cyanophytes' have been known as 'blue-green algae' in terms of their morphological diversity and size corresponding to other microalgae and their role in natural biotopes. Therefore, they were treated as microscopic plant organisms for a long time in the field of interest of botanists (phycologists) and ecologists. Detailed cytological and biochemical analysis of axenic culture strains conducted by bacteriologists led to the proposal to amend the common name of 'Cyanophyceae' into 'Cyanobacteria'.

Stanier et al. (1978) introduced the nomenclature of blue-green algae as ‘cyanobacteria’ under the International Code of Nomenclature of Prokaryotes

(ICNP) (formerly the International Code of Nomenclature of Bacteria- ICNB or "Bacteriological Code"). Oren (2004) and Oren and Garrity (2014) incorporated the cyanobacterial taxa under the 'Bacteriological Code' but those 'bacteriological classifications' were not accepted by botanists (phycologists) and they proposed that the blue-green algae be kept under 'algae' (Bourrelly, 1970; Golubic, 1979 a,b; Anand, 1981). But now they are included in Bergey's Manual of Systematic Bacteriology under the photosynthetic bacteria (Staley et al., 1989; Holt et al., 1994; Boone & Castenholz, 2001; Castenholz & Waterbury, 1989; Castenholz, 2001).

Revisions to the classification of cyanobacteria were originated by Anagnostidis and Komarek (1985, 1988 & 1990) and Komarek and Anagnostidis (1986, 1989) and they proposed the term 'Cyanoprokaryotes'. Komarek and Anagnostidis (1998, 2005) have developed a formal system in which bacteriological and botanical approaches are compromised. Its nomenclature is based on taxonomic botanical criteria, but also bacteriological and molecular data. The authors combined botanical and bacteriological approaches, incorporating traditional cyanobacterial morphology, physiology, and ecology into a synthesis of total evidence. They recognized four orders: Chroococcales (non-filamentous), Oscillatoriales (filamentous, lacking specialized cells), Nostocales (filamentous, facultative specialized cells), and Stigonematales (filamentous, obligatory specialized cells, and cell division into multiple planes).

Most recent taxonomic revisions and descriptions use a combination of morphological, ecological, and genetic observations, called the 'polyphasic approach' (Castenholz, 1992; Castenholz & Norris, 2005; Komarek, 2003, 2010; Komarek et al., 2014). Hoffmann et al. (2005 a, b) introduced a new system of classification where members of the Chroococcales and Oscillatoriales formed two subclasses, the Synechococcophycideae and the Oscillariophycidae. The Nostocales and Stigonematales were members of a separate monophyletic subclass, Nostochophycideae. Komarek and Golubic (2005) merged the bacteriological and botanical rules and suggested nomenclature for cyanobacteria. However, their concept has not yet been approved and either a combination of rules from both the codes is currently being applied or a conventional taxonomic classification is being followed by the Botanical Code. Komarek and Anagnostidis (1998, 2005) compiled

two volumes of monographic series of Cyanoprokaryota in which Part 1 consists of the order Chroococcales and Part 2 consists of the order Oscillatoriales respectively. Komarek (2013) published a manual of Cyanoparokaryota as Part 3, which consists of 'Heterocytous Genera'. Komarek et al. (2014) revised and introduced a new system of classification of Cyanoprokaryotes/Cyanobacteria based on the polyphasic approach, in which the whole cyanobacterial genera are included under 8 orders and 46 families and it is considered the most recent taxonomic classification by Cyanobacteriologists.

Komarek (2006) reviewed the problems and prospects of the combination of conventional and molecular approaches in modern cyanobacterial taxonomy. He suggested that even though molecular data provide basic criteria for the taxonomy of cyanobacteria, a valid phylogenetic system cannot be established without combining genetic data with information in the field of cyanobacterial diversity from the previous 150 years of research.

Palinska et al. (2006) attempted a study on the diversity and taxonomy of cyanobacteria and decided to start molecular research, also based on historical and dried environmental samples of cyanobacteria. Palinska and Surosz (2014) attempted a consensus approach to integrating herbarium collections for intensive phylogenetic studies and can thus contribute to discussions on traditional and newly emerging concepts of species and speciation in prokaryotes.

A scientific letter by Hentschke and Sant'Anna (2015), discussed the common problems arising in assessing the taxonomy of cyanobacteria. Advanced phylogenetic analysis has led to a more accurate knowledge of the relationships between taxa, but also, the authors disregarded the morphological data of environmental samples, describing organisms that grow only under culture conditions. The authors suggested that environmental studies could certainly contribute to the existing clades by providing more morphological support and clarification of cyanobacterial taxonomy.

Komarek (2016) strongly proposed that new molecular, cytomorphological and ecological methods should be adopted and combined in the traditional taxonomy of cyanobacteria, and should be recognized as the only approach for establishing

their current systematics. The combination of different approaches should be focused on molecular sequencing as the fundamental approach to which other parameters (morphological, ecological) must be applied if they are available and which are distinct and recognizable in cyanobacterial populations.

Walter et al. (2017) proposed a first attempt to combine taxonomy and eco-genomics with a convincing new perspective for the exploration of cyanobacterial studies. Firstly, a suitable phylogenomic framework was established using a set of genomic taxonomy signatures (including a tree based on preserved gene sequences, genome-to-genome distance, and average amino acid identity) to analyse 99 publicly available cyanobacterial genomes. Secondly, the relative abundances of these genomes in various global marine and freshwater ecosystems were determined using metagenomic data sets. The whole-genome-based taxonomy of the 99 genomes enabled us to identify 57 (of which 28 are new genera) and 87 (of which 32 are new species) different genera and species of cyanobacteria respectively. The eco-genomic analysis made it possible to distinguish three major ecological groups of cyanobacteria (a. Low Temperature; b. Low-Temperature Copiotroph; c. High-Temperature Oligotroph) consistently associated with genomic taxonomy. In light of genomic taxonomy and eco-genomic approaches, this work establishes a new taxonomic framework for cyanobacteria. But Komarek (2020) opined that all these 'new taxa' proposed by Walter et al. (2017) are not defined by nomenclatural rules, and are concerned only with single strains. Even though Walter et al. (2017) strongly recommended that modern cyanobacterial taxonomy should be based on whole-genome sequencing, a researcher could never identify a cyanobacterial population from nature itself or a newly isolated strain according to this scheme.

Komarek (2020) suggested that molecular sequencing and assessment will certainly form the basis of modern and future taxonomic classification, but the application of a polyphasic approach to the concept of single taxa and the orientation and subsequent identification of all taxonomic units defined is necessary and unavoidable. Komarek et al. (2020) clarified and revised the classification system and articulated the next step in the taxonomic characterization and classification of *Syncechococcus*-like cyanobacteria with the addition of the new family Thermosynechococcaceae under the order Pseudanabaenales.

Even though the quantity of biodiversity considered is expanding, the all-out number of species in various scientific categorizations remains dubious. Various studies estimated that the number of described Cyanobacterial species ranged from 2,000 to 8,000 (Sant'Anna et al., 2006; Guiry, 2012). Nabout et al. (2013) stated that there are currently 2,698 described species of Cyanobacteria and that more than half of the Cyanobacteria species remain to be described.

Researchers around the world have created various databases containing the genomic, proteomic, and metabolomic data of fully sequenced cyanobacterial genomes. Cyanobacteria databases such as CyanoDB 2.0, CyanoType, AlgaeBase and CyanoOmicsDB provide updated information on the taxonomy, phylogeny and genomic data of cyanobacteria.

CyanoDB 2.0 (http://www.cyanodb.cz) represents newly described cyanobacterial information, comprehensive literature availability, taxonomic information and a huge amount of molecular data. The primary objective of CyanoDB 2.0 is to be a research resource for taxonomists and other people interested in the taxonomy and diversity of cyanobacteria and to provide descriptions and updates on primary explanations of taxa and molecular research data. The database worked on the principle of revised taxonomical classification by Komarek et al. (2014). The CyanoDB 2.0 database now (as of 27/05/2022) consists of 2196 taxa, ranging from the level of phylum/class to species, including 439 genera (420 of which are valid under ICN and/or ICNP) and 1681 species (along with 1612 valid) (Hauer & Komarek, 2022).

CyanoType (http://lege.ciimar.up.pt/cyanotype) is a manually curated online database of relevant cyanobacterial strains for modern taxonomy, phylogenetic, and phylogenomic purposes, with related information collected through published literature. The first edition (CyanoType v.1) of the database aggregates data from 371 strains. Data for each strain includes strain synonymy and/or co-identity, strain category, habitat, molecular data accession numbers, taxonomy and nomenclature according to three separate classification schemes, including automatic hierarchical classification, phylogenetic positioning according to a set of relevant studies and relevant bibliographic references. The database is updated periodically by adding

new strains meeting the criteria and by adding updated metadata for strains already included in the list. The database is regularly modified by introducing new strains that meet the requirements and by inserting modified metadata for strains that are already on the list. A global 16S rDNA-based phylogeny is given to help users select the strains that match their studies (Ramos et al., 2017).

AlgaeBase (https://www.algaebase.org/) is an online database that provides taxonomic and distribution information for all algae including Cyanobacteria. AlgaeBase aims to provide taxonomic information that links to the identification of cyanobacterial genera, which allows taxonomists to make informed decisions. This database is considered the extensive media for checking the validity of a species. Information on the number of species and other taxa in AlgaeBase and estimates of the number of taxa still to be included are given in Guiry (2012), along with approximate numbers of undescribed species (Guiry et al., 2014).

CyanoOmicsDB (http://www.cyanoomics.cn/): The goal of this database is to provide detailed functional information for each cyanobacterial gene. CyanoOmicsDB has 8335261 cyanobacterial gene entries from 928 genomes. For each gene entry, it provides multiple gene identifiers, a visualised genomic location, and DNA sequences. CyanoOmicsDB can provide predicted gene function, amino acid sequences, homologs, protein-domain super-families, and accession numbers for public protein function databases for protein-encoding genes. Under various environmental culture conditions and genetic backgrounds, CyanoOmicsDB integrates both transcriptional and translational profiles of *Synechocystis* sp. PCC 6803. Furthermore, CyanoOmicsDB contains 23689 gene transcriptional start sites, 94644 identified peptides, and 16778 post-translation modification sites derived from transcriptomes or proteomes of a variety of model cyanobacteria. CyanoOmicsDB contains more datasets and functional information than other cyanobacterial databases currently available. Researchers in this field will benefit from CyanoOmicsDB's easy access to functional information on cyanobacterial genes (Zhou et al., 2021).

Recently, many web-based applications and databases have emerged for standardising the taxonomy of cyanobacteria. This is all about discussing the issues

and problems in cyanobacterial taxonomy and their solutions. The most important of these are the Cydrasil 3 web app and the GTDB database (Genome Taxonomy Database).

Cydrasil 3 (https://www.cydrasil.org) is a curated 16S rRNA gene reference package, database, and web application developed by Roush et al. (2021) to provide a complete phylogenetic perspective for cyanobacterial systematics and routine identification. Over 1300 manually curated sequences longer than 1100 base pairs are included in Cydrasil 3, which can be utilised for phylogenetic placement or as a reference sequence set for de novo phylogenetic reconstructions. Thousands of sequences can be placed into the reference tree using the web application (which uses PaPaRA and EPA-ng) and thorough instructions on how to analyse the findings are included. While the Cydrasil web application does not provide taxonomic assignments, it does offer phylogenetic placement, a searchable database with curation notes and metadata, and a mechanism for community feedback.

The Genome Taxonomy Database (GTDB) has proposed harmonising cyanobacteria nomenclature with that of other bacteria, as part of an endeavour to standardise microbial taxonomy based on genome phylogeny, to improve overall microbiota phylogenetic resolution. Dextro et al. (2021) described how cyanobacterial genomes from public databases fit into several taxonomic classifications. It also identifies some steps toward enhancing our attempts to develop a more cohesive and inclusive classification system, which can be substantially aided by large-scale sequencing and metagenomic approaches.

2.5. Cyanobacteria in mangrove ecosystems: Diversity and Taxonomy

Several studies have been conducted on the cyanobacterial diversity in mangroves across the world. However, a relatively limited amount of research work on this subject has been conducted. These surveys have identified a large number of cyanobacterial species in mangroves, providing an overview of the most common cyanobacteria in various mangrove habitats.

Moebius (1889) reported the occurrence of *Microcoleus chthonoplastes* Thuret ex Gomont 1892 in the mangroves of Joinville, Brazil. Joly (1951) recorded *Lyngbya confervoides* C. Ag. ex Gom. *Dermocarpa* sp., *Sirocoleum* sp. and

Stigonema sp., in Paraná State mangroves. Joly (1957) identified the species *Sirocoleum guyanense* Kütz. ex Gom distributed in Santos and surrounding mangroves.

Millard and Broekhuysen (1970) recorded certain cyanobacterial species from the South African estuaries of St. Lucia. Burkholder and Almodovar (1973) studied the mangrove algal communities in Puerto Rico and reported *Microcoleus lyngbyaceus*. Dor (1975) recorded the vertical zonation of *Scytonema* sp. from the Sinai mangal. Potts and Whitton (1977) recorded seven species of cyanobacteria from the intertidal sediments of the lagoon of Aldabra. Potts (1979) observed epiphytic cyanobacterial growth on *Avicennia* pneumatophores in mangrove forests of the Sinai estuary.

Potts (1980) reported the zonation of cyanobacteria on the pneumatophores of mangrove plants. According to Potts and Whitton (1980), the most abundant cyanobacterial species occurred in the mangrove areas. Beanland and Woelkerling (1983) identified *Rivularia atra* and *R. polyotis* from the mangrove environment of Spencer Gulf, South Australia. Sant'Anna et al. (1983) studied the Nostocophyceae from the State Park of Cardoso Island, State of Sao Paulo, Brazil. Dor (1984) studied the vertical zonation and morphological adaptations of epiphytic cyanobacteria found in the Sinai estuary. Oliveira (1984) identified certain cyanobacterial species in the Brazilian mangroves.

Carmo (1987) identified *Microcoleus* sp. from the mangroves located in the North of Baia de Vitoria, Espirito Santo State, Brazil. Ramachandran and Venugopalan (1987) identified and isolated four species of cyanobacteria. Sant'Anna (1988) studied the family Scytonemataceae (Cyanophyceae) from the Ilha do Cardoso mangroves. Santra et al. (1988) reported on the cyanobacterial species from the pneumatophores of mangrove plants. Coppejans and Gallin (1989) studied the macroalgae associated with the mangrove vegetation of Gazy bay, Kenya. Lambert et al. (1989) recorded 27 taxa of cyanobacteria from the mangrove-associated estuaries of South Africa.

Mahasneh et al. (1990) isolated a strain of *Calothrix* from the surface of mangrove roots that showed marked morphological and physiological responses to

the salinity of the medium. Rodriguez and Stoner (1990) reported certain cyanobacterial species as the epiphytic community of cyanobacteria associated with mangrove plants. Steinke and Naidoo (1990) conducted a study on the biomass of algae epiphytic on the pneumatophores of the mangrove *Avicennia marina* in the St. Lucia estuary.

Moura (1991) reported 29 cyanophycean members in a qualitative-quantitative study of the algae of the estuaries of the Paripe and Igarassu, Itamaracá in Pernambuco State, Brazil. Branco (1991) studied the benthic cyanophycean communities of the mangrove islands of Ilha do Cardoso, Cananeia, Brazil. Sant'Anna et al. (1991) studied the cyanophycean members of the Sao Paulo mangrove environment of Brazil. Sheridan (1991) reported six species of cyanobacterial growth on mangrove plants. Silva (1991) studied the cyanobacteria associated with mangrove trees on Inhaca Island, Mozambique.

As per the reports of Kannan and Vasantha (1992) and Mani (1992), only three species of cyanobacteria occurred from Pichavaram mangals. Neves and Tribuzi (1992) studied mangrove cyanobacteria from Ponta do Pai Vitorio, Cabo Frio, Rio de Janeiro State, Brazil. Rao (1992) conducted a detailed study on cyanobacteria from the mangroves and estuary. Hussain and Khoja (1993) conducted a survey on intertidal and subtidal cyanobacterial diversity among mangrove areas of Saudi Arabia.

Mann and Steinke (1993) verified the dominance of cyanobacteria in the pneumatophores of *Avicennia marina*. Branco et al. (1994) reported a new species *Stichosiphon mangle* from Inhaca Island Mozambique growing on *Gelidium* sp. and *Murrayella* sp. and on Cardoso Island, Brazil on *Bostrychia* spp. Dhargalkar (1994) recorded 16 species of cyanobacteria found associated with mangroves. Phillips et al. (1994) observed cyanobacteria on the pneumatophores of *Avicennia.*

Saifullah and Taj (1995) recorded three species of cyanobacteria that were found on the pneumatophores of *Avicennia marina*. Toledo et al. (1995 a) described vertical zonation of cyanobacterial colonization on the aerial roots of black mangroves in north-western Mexico. Toledo et al. (1995 b) isolated a filamentous cyanobacterium obtained from *Avicennia* and inoculated it onto young mangrove

seedlings to evaluate the nitrogen fixation and root colonization capacities of the bacterium under in vitro conditions in closed system experiments.

Branco et al. (1996) studied the Chroococcales order of cyanophyte flora from Cardoso Island mangroves, Sao Paulo. Brazil. According to Faust and Gulledge (1996), 3-25% of cyanobacteria were present in floating detritus at the mangrove island of Twin Cays in Belize. Phillips et al. (1996) worked on the vertical zonation of epiphytic algae associated with *Avicennia marina* pneumatophores.

Branco et al. (1997) studied the order Oscillatoriales of cyanophyte flora from Cardoso Island mangroves, Sao Paulo. Brazil. Saifullah et al. (1997) recorded 10 species of cyanobacteria that occurred from the pneumatophores of *Avicennia marina*. Bashan et al. (1998) worked on the isolation of diazotrophic filamentous cyanobacterium obtained from the pneumatophores of *Avicennia germinans* which was inoculated onto young mangrove seedlings to evaluate nitrogen transfer from the bacterium to the plants under in vitro conditions in closed system experiments.

Gab-Alla (2000) studied the biodiversity and distribution of epiphytes associated with the pneumatophores of *Avicennia marina* along the Egyptian Red Sea coast. Zaib-Un-Nisa et al. (2000) recorded 20 species of cyanobacteria growing on the pneumatophores of *Avicennia marina* and the adjacent surface of sediments in mangrove swamps at the Sandspit backwaters of Karachi.

Nogueira and Ferreira-Correia (2001) identified 15 taxa of cyanobacteria from the red mangrove forest in the estuaries of Sao Luis, State of Maranhão, Brazil. Banerjee and Santra (2001) reported eight cyanobacterial taxa from the Indian Sundarbans mangrove estuary. Lugomela et al. (2001) recorded cyanobacterial diversity in mangroves from Zanzibar, Tanzania. Selvakumar and Sundararaman (2001) identified a total of 17 species of cyanobacteria from the mangrove vegetation of the Muthupet estuary.

Branco et al. (2003) identified 16 species of cyanobacteria from the mangrove area of Pernambuco State, Brazil. Kyaruzi et al. (2003) recorded 10 cyanobacterial species from the mangrove ecosystem adjacent to Zanzibar town. Sen and Naskar (2003) reported that 50 species of cyanobacteria belong to 5 orders.

Steinke et al. (2003) recorded the distribution of cyanobacteria on the pneumatophores of *Avicennia marina*. Sudha (2005) identified 63 species of cyanobacteria from Muthupet mangrove environment of Tamilnadu.

Bano and Siddiqui (2007) identified 92 cyanobacterial species from the mangrove environments of the Karachi coast. In a study by Sudha et al. (2007), seasonal variation of cyanobacterial diversity was enumerated in the Muthupet mangrove environment. Essien et al. (2008) identified certain cyanobacterial species from the epipelic habitat of the Qua Ilobe mangrove estuary in Nigeria. Nedumaran et al. (2008) described 23 cyanophycean members in association with mangrove plants. An extensive study by Pena-Salamanca (2008) reported 4 cyanobacterial species. Rajkumar et al. (2009) studied the phytoplankton diversity of the Pichavaram mangrove ecosystem.

Boopathi (2011) conducted an extensive study on the epiphytic cyanobacterial diversity of the mangrove ecosystems of Muthupet and Pichavaram. Leon-Tejera et al. (2011) conducted a study on the biodiversity and temporal distribution of cyanoprokaryota of an arid mangrove in the Zacatecas estuary, Baja California Sur, Mexico. Pramanik et al. (2011) conducted a study on the isolation and characterization of cyanobacteria having antimicrobial activity in the Sundarban mangrove forest. Eight obligatory halophilic euryhaline cyanobacteria from intertidal soil showed a distinct clade consisting of four strains related to the *Lyngbya-Phormidium-Plectonema* group B.

Engene et al. (2012) discovered two new species of cyanobacteria *Moorea*, whose members in the mangrove ecosystem were probably misidentified due to morphological resemblances. Harith and Bojo (2012) identified five benthic cyanobacterial genera from the Asajaya mangrove, Kota Samarahan, Sarawak. Perez-Estrada et al. (2012) studied the cyanobacterial species diversity in an arid mangrove environment of Baja California, Mexico. Larkum et al. (2012) discovered a new chlorophyll D containing cyanobacterium *Acaryochloris* with the red alga *Gelidium caulacantheum* colonizing *Avicennia marina* pneumatophores. Rigonato et al. (2012 a) have done interesting research on the cyanobacterial diversity in the phyllosphere of the mangrove forest. Rigonato et al. (2012 b) examined the

community structure and ecological drivers that influence the cyanobacterial community harboured in mangrove soils inhabiting the genera Prochlorococcus and Synechococcus. Silambarasan et al. (2012) isolated marine cyanobacteria from rhizosphere soil samples of the three mangrove areas. Sakthivel and Kathiresan (2013) studied the cyanobacterial diversity in three different mangrove ecosystems of Pichavaram, Porto Novo and Mudasal Odai.

Saifullah et al. (2014) identified 4 species of cyanobacteria from mangrove estuaries in Sarawak, Malaysia. Fatimahsari et al. (2014) recorded 9 genera of cyanobacteria belonging to 4 orders from the pneumatophores of *Avicennia marina*. Guidi-Rontani et al. (2014) described new filamentous toxic cyanobacteria belonging to the order Oscillatoriales colonizing the sulfidic periphyton mat in marine mangroves. According to Silva et al. (2014), 50 cyanobacterial strains were isolated from soil, water and periphytic samples collected from Brazilian mangroves using specific cyanobacterial culture media. The cultured cyanobacterial species represent five orders, seven families and eight genera.

Rao et al. (2015) reported 7 species of cyanophycean members from the mangrove habitats of the Visakhapatnam coast. Sivakamasundari and Rajendran (2015) recorded 13 cyanobacterial species from the natural mangrove vegetation of the Paravanar estuary at Poondiyankuppam. Alvarenga et al. (2015) compiled and discussed relatively few and scattered studies on cyanobacteria in mangrove environments, their diversity and ecological roles in these environments. Barman et al. (2015) reported 37 cyanobacterial species from different localities of Indian Sundarbans. Huisman et al. (2015) recorded 7 epiphytic cyanobacterial species from the mangrove forests of Western Australia. Mohamed and Al-Shehri (2015) reported 31 cyanobacterial species from the mangrove swamps of Saudi Arabia.

Ahmed et al. (2016) recorded six dominant filamentous cyanobacterial species from the mangrove environment of Sandspit, Pakistan. Joseph and Saramma (2016) identified numerous species of cyanobacteria from the mangrove area in the Cochin estuary rich in cyanobacterial flora. Bhuvaneshwari and Muruganandam (2016) isolated 35 species of marine cyanobacteria from the water samples of the Thondiyakadu coast and Valavanaru estuary. Alvarenga et al. (2016) discovered two

novel epiphytic cyanobacteria, *Phyllonema aviceniicola* and *Foliisarcina bertiogensis* inhabiting the phyllosphere of *Avicennia schaueriana*. Ramamurthy and Abhinand (2016) identified 30 species of cyanobacteria from the Manakudy mangrove environment water stream.

Ans and Mendez (2017) reported *Spirulina* sp. from the mangrove area of Ernakulam district. Kumar et al. (2017) identified 7 species of cyanobacteria from the Muthukuda mangrove ecosystem. Chakraborty et al. (2018) reported a new species, *Oxynema aestuarii* of the Microcoleaceae family which is isolated from the Indian mangrove forest of Sundarbans. Chakraborty et al. (2019) discovered two new species *Euryhalinema mangrovii* and *Leptoelongatus litoralis* from the Indian mangrove forest. Priya et al. (2019) reported 38 cyanobacterial species from the Kodiakkarai coast of Tamil Nadu.

2.6. Factors affecting cyanobacterial growth

2.6.1. Studies on the physico-chemical parameters of water

Water resources decide and regulate most behaviours and processes in every aquatic ecosystem. Estuarine hydrography is often difficult to study due to the dynamic nature of the estuary. The mangrove habitats are profoundly affected by the hydrographic features of the surrounding estuarine waters, which percolate continuously through the mangrove environment. The physico-chemical parameters of many of the mangrove ecosystems were studied in India.

Various studies on hydrography have been conducted in different estuarine habitats of the world (Day, 1951; Gibbs, 1972; Butler & Tibbitts, 1972; Liss, 1976; Foster et al., 1978; Burten, 1979; Kemp et al., 1982; Read, 1983; Wolaver et al., 1984; Begg, 1984; Bally & McQuaid, 1985; Emmerson, 1985; Taljaard et al., 1986; Emmerson & Erasmus, 1987; Cyrus, 1988a, 1988b; Perez et al., 1988; Emmerson, 1989; Admiraal et al., 1990; Harding, 1994; Slinger & Taljaard, 1994; Scharler et al., 1997; Harrison, 2004; Guinder et al., 2009; Pillay & Pillay, 2013; Izougarhane et al., 2014; Fatema et al., 2015; Morhit & Mouhir, 2014; Darif et al., 2018).

Blatter (1905) studied the mangroves of the Bombay presidency and their ecology. Cherian (1967) studied hydrological features in and around Cochin

harbour. Concerning environmental characteristics, the nutrients of the Cochin backwater have been studied by Sankaranarayanan and Quasim (1969). Wellershaus (1972) studied the hydrography of the Cochin backwaters. Joseph (1974) reported the nutrient distribution in Cochin harbour and its vicinity. Diel variations in hydrographical conditions during different seasons in the Cochin backwater have been studied by Balakrishnan and Shynamma (1976). Sundararaj (1979) studied the hydrographical aspects of mangroves and backwaters of the Porto-Novo region. The nature of the distribution of major inorganic nutrients in the Ashtamudi backwaters concerning environmental factors has been studied by Dharmaraj and Nair (1981). Banerjee (1987) reported ecological studies on the mangals of the Mahanadi estuarine delta. Selvam et al. (1992) studied diurnal variation in physico-chemical properties of hydrological variations in three interconnected biotopes including freshwater, marine and mangrove brackish water of the Kakinada coastal zone, Andhra Pradesh.

Ramanathan et al. (1998) studied the chemical composition of surface water in the Pichavaram mangrove environment. Bava and Seralathan (1999) studied the hydrochemistry of mangrove forests on the southwest coast of India. Lakshmi et al. (2000) analysed the environmental status of the mangrove ecosystem in Valapattanam. Tanaka and Choo (2000) examined the distribution of dissolved nutrients from the mangrove swamps in the Matang estuary of Malaysia. Muhibbullah et al. (2005) analysed the physico-chemical parameters of water of the Sundarban mangrove forest. Paramasivam and Kannan (2005) studied the physical and chemical parameters of the Muthupettai mangrove environment. Kumar et al. (2006) analysed the Physico-chemical characteristics of water in the Muthupettai mangrove environment.

Prabhu et al. (2008 a) studied seasonal variations in physico-chemical characteristics of Pichavaram mangroves, southeast coast of India. Prabhu et al. (2008 b) analysed the seasonal variations in Physico-chemical characteristics of the Uppanar mangrove environment of Cuddalore. Seasonal variations in the physico-chemical parameters of water in the arid zone of mangroves of Kachch have been studied by Saravanakumar et al. (2008).

Geetha et al. (2009) revealed a seasonal impact on hydrography and dissolved nutrients in mangrove ecosystems along the southwest coast of Kerala. Jalal et al. (2009) conducted studies on physico-chemical characteristics of the coastal waters in Pulau Tuba, Langkawi, Malaysia. Satheeshkumar and Khan (2009) examined seasonal variations in physico-chemical characteristics of water Pondicherry mangroves.

Mukherjee et al. (2010) carried out a water quality assessment in the Sundarbans mangrove ecosystem during different seasons. Sarkar and Bhattacharya (2010) conducted a water quality analysis of coastal regions of mangrove wetland by statistical methods.

Gandaseca et al. (2011) analysed the status of water quality based on the physico-chemical parameters of the Sibuti mangrove forest ecosystem. Kumara and Kumar (2011) evaluated the water quality of the Kundapura mangrove ecosystem. Lawson (2011) studied the physico-chemical parameters and heavy metal content of water from the mangrove swamps of Lagos Lagoon, Nigeria. Manivasagan et al. (2011) studied the water quality and physico-chemical properties of the Muthupettai mangrove ecosystem. Madhusudhanan and Jayesh (2011) conducted physico-chemical studies of the Mangalavanam mangrove environment at Ernakulam district. Certain studies have been considered to assess the physico-chemical characteristics of mangroves in the Poyya backwaters of the Thrissur district by Saritha and Tessy (2011).

Adame et al. (2012) investigated the effect of water quality on the exchange of dissolved organic carbon between the floodwater and mangrove forest. Aziz *et al*. (2012) analysed the water quality parameters at different sites of Sundarbans mangrove forest. Cuzzuol and Rocha (2012) conducted a study on the interaction of the water regime with nutrient relations in a mangrove area that was influenced by the hydric regime. Jitthaisong et al. (2012) studied the water quality of the mangrove environment of Phetchaburi province, Thailand. Manna et al. (2012) evaluated physical, chemical and biological components in the mangrove environments of Sundarbans. Manju et al. (2012) assessed the water quality parameters in mangrove ecosystems along the Kerala coast using statistical methods. Mohan et al. (2012)

analysed the ecological variations in the water quality of the Bhavanapadu mangrove environment of Andhra Pradesh. Ramamurthy et al. (2012) studied the physico-chemical analysis of water in the Vedaranyam mangrove environment of Tamilnadu. Satheeshkumar and Khan (2012) evaluated the variations in mangrove water quality of the Pondicherry mangroves using multivariate statistical techniques. For that, they tested pH, salinity and dissolved oxygen throughout all four seasons.

Briceno et al. (2013) investigated the relationship between salinity, nutrients and hydrologic variables in the mangrove ecotone. Inoue and Asano (2013) analysed the characteristics of water quality in Mekong delta mangroves. Keller et al. (2013) analysed the water quality in the mangrove environment in Victoria, Brazil. Navami and Jaya (2013) analysed the physico-chemical characteristics of mangrove species in Akkulam-Veli lake in Thiruvananthapuram. Rahman et al. (2013) investigated the physico-chemical parameters of the Passur of Sundarbans mangrove forest. Srinivasan et al. (2013) analysed the seasonal variability of coastal water quality from 12 sampling stations from Topputhurai to Muthupet in Vedaranyam. Srilatha et al. (2013) studied the physico-chemical parameters of water in different mangrove habitats at Muthupettai and Pointcalimere stations. Toriman et al. (2013) analysed mangrove water quality through the statistical method on Suppa coast, Indonesia.

Arumugam and Kumar (2014) evaluated the physico-chemical parameters and nutrients of the monthly samples of water in the Manakudy mangrove ecosystem on the southwest coast of India. Behera et al. (2014) studied the physico-chemical properties of water samples collected from the mangrove environment of Mahanadi Delta, Odisha, India. Billah et al. (2014) analysed Cu, Zn, Fe and Mn in the mangrove ecosystems of Sarawak. Chowdhury et al. (2014) conducted a case study on Indian Sundarbans regarding mangrove biomass and stored carbon concerning soil properties. Kumar and Kumara (2014) experimented on seasonal variations in physico-chemical parameters of the mangrove water of Kundapur. A seasonal variation in parameters such as dissolved oxygen, pH, electrical conductivity, BOD, calcium, magnesium, and sodium was observed throughout the study period and monthly comparisons were made as monsoon, pre-monsoon and post-monsoon. Phosphorus geochemistry in Brazilian mangrove soils has been investigated by Nobrega et al. (2014). Saifullah et al. (2014) analysed the physico-

chemical properties of water from the mangrove estuaries in Sarawak, Malaysia. Unimke et al. (2014) tested the surface and subsurface water and checked the influence of seasonal variation and physico-chemical parameters of the Imo Estuary of the Niger Delta Mangrove Ecosystem.

Arunprasath and Gomathinayagam (2015) conducted a comparative study on the water quality analysis of two mangrove forests in Tamilnadu. Fonge et al. (2015) discussed water quality and phytoplankton community structure in mangrove streams under different logging regimes. Kumar and Sheela (2015) assessed the seasonal flux of water quality around the mangrove ecosystem of Manakudy estuary by using statistical methods. Physico-chemical analysis of water from the Ayiramthengu mangrove ecosystem has been carried out by Praseetha and Rajani (2015). Ravichelvan et al. (2015) analysed the seasonal variations of water quality parameters in Adirampattinam and Mallipattinam coastal waters. Vilas and Ashwinova (2015) analysed the water quality of selected areas of the Sundarbans mangrove ecosystem. The study concluded that water quality parameters were administered by the flushing of rainfall, river water flow, seawater intrusion, runoff from agricultural fields and oil from the spill.

Atwell et al. (2016) experimented with a novel boat-mounted electromagnetic induction technique, the spatial and temporal distribution of salinity along with the mangrove riverine ecosystem. Alshawafi et al. (2016) analysed the physico-chemical parameters of water samples of the mangrove forests on the Island of Kamaran in Yemen. Billah et al. (2016) examined the seasonal variations in the water samples of Malaysian mangrove estuary. Rohit et al. (2016) documented the water quality parameters of the mangrove environment of Kachchh. In a study by Ramamurthy and Abhinand (2016), certain physico-chemical parameters like temperature, pH, dissolved oxygen, carbonate etc. exhibited considerable seasonal and spatial distribution of cyanobacteria. Shilna et al. (2016) assessed the water quality parameters in mangroves along with the coastal and inland aquatic environments of the Malappuram district. Trivedy et al. (2016) analysed the inter-annual variation of surface water salinity in three sectors (western, central and eastern) of Indian Sundarbans.

Ans and Mendez (2017) studied the seasonal variation in the physico-chemical characteristics of mangrove areas of Ernakulam district. Ayyadurai et al. (2017) studied physico-chemical parameters of water of Keezhathottam Mangrove, Tamil Nadu. Biswas et al. (2017) analysed the soil characteristics of Indian Sundarbans. Khalit et al. (2017) conducted a preliminary study on the marine water quality assessment at selected mangrove estuaries in east coast peninsular Malaysia. Kumar et al. (2017) analysed water samples from the Muthukuda mangrove ecosystem. They studied seasonal fluctuations in physico-chemical parameters of water concerning phytoplankton diversity. Sathyanarayana and Krishna (2017) conducted a water quality analysis of the east Godavari mangrove environment, Andhra Pradesh. In this study, a monthly analysis of water quality parameters was analysed. Lopez-Portillo et al. (2017) explored the spatial variability of physico-chemical parameters of water in contrasting seasons in four mangrove areas in the Gulf of Mexico.

A study on the assessment of physico-chemical characteristics of the mangrove environment in the Krishnapuram coastal region evaluated certain physico-chemical parameters by Dattatreya et al. (2018). Kaseng (2018) analysed nitrogen and carbon content in the soil of mangrove forests in Tongke-Tongke of East Sinaji. Das et al. (2019) studied physico-chemical characteristics of water from seven sites of mangroves in the southern Gulf of Kachchh. Assessment of water quality from the mangrove restoration area on the southern coast of Pangandaran, West Java, Indonesia has been studied by Pribadi et al. (2020).

2.6.2. Studies on the physico-chemical parameters of soil

Numerous studies have been conducted on mangrove soils, covering large areas. The results showed that soil properties are the main factors that limit plant growth and distribution in mangroves. (Gledhill, 1963; Giglioli & King, 1966; Clark & Hannon, 1967; Aksornkoae, 1975; Aksomkoae et al., 1985).

Hesse (1961) identified some differences between the soils of *Rhizophora* and *Avicennia* mangrove swamps in Sierra Leone. Frith et al. (1976) analysed the soil characteristics and mangrove vegetation of Phuket Island in Southern Thailand. Untawale and Parulekar (1976) observed the ecology of estuarine mangroves of Goa

and inferred that the organic matter in the mangrove ecosystem remains rich even during the large fluctuations in environmental factors. Aksomkoae et al. (1978) found that both physical and chemical characteristics of soils differed in different vegetation zones. Cintron et al. (1978) analysed the structure of the mangrove ecosystem and soil salinity along the south coast of Puerto Rico and Mona Island.

Naidoo and Raiman (1982) discussed some of the physical and chemical properties of mangrove soils from two sites in Sipingo and compared them to another mangrove soil from the Mgeni estuary and a non-mangrove soil. Venugopal et al. (1982) studied the trace metal levels in the sediments of the Cochin backwaters. Boto and Wellington (1984) analysed the soil characteristics and nutrient status in the north Australian mangrove ecosystem. Nair et al. (1984) studied the distribution of total phosphorus, total nitrogen and total potassium in the sediments of the Ashtamudi estuary. Singh and Mongia (1985) studied the soils of the Andaman and Nicobar Islands.

Joshi and Kumar (1986) studied the chemical characteristics of mangrove soil on the Gujarat coast. Matilal et al. (1986) investigated the soil and vegetation of Sundarban mangroves. Shanmukhappa et al. (1987) conducted an ecological and physical investigation into the sediment humic acids from two mangrove habitats and in the estuary. Sahoo et al. (1988) analysed the characteristics and nutrient status of mangrove soils of unstressed (Prentice and Lothian) and stressed (Sagar and Harinbari) Islands of Sundarbans. Upkong (1991) checked the performance and distribution of species along the mangrove swamps in Nigeria. In this study, direct gradient analysis procedures were employed to relate the performance and distribution of mangrove swamp species to salinity gradients.

In a study by Banerjee (1993), depending on the influence of small-scale variations in salinity conditions and different morphological adaptive characteristics of species, the inner riverine plant zonation has been classified into three distinct subtypes: the True mangrove zone, Semi-mangrove zone and Transitional mangrove zone. Dagar et al. (1993) studied the soil characteristics and vegetation of the Bay Islands in India. Khan et al. (1993) analysed the acid sulphate soil from the mangrove floodplain areas of Bangladesh. McKee (1993) studied the soil physico-

chemical properties and mangrove distribution. Mongia et al. (1993) studied the soils of mangrove habitats in the Andaman-Nicobar Islands. They analysed the soil profile, physico-chemical characteristics, organic matter and soluble salts and salinity. Nazrul-Islam (1993) evaluated the physico-chemical properties of Sundarban mangrove soils associated with each vegetation zone.

The soil physico-chemical properties of the mangrove forest of Apar Nature Reserve have been studied by Sukardjo (1994). Wakushima et al. (1994) analysed soil parameters of Japanese mangrove forests. Lacerda et al. (1995) did a comparative study between *Avicennia* and *Rhizophora* soils and found that organic carbon and nitrogen content were higher in *Avicennia* than in *Rhizophora* soils.

Kathiresan et al. (1996) analysed the influence of temperature, salinity, nitrogen, phosphorus and potassium on the growth of mangrove seedlings in the intertidal region of the Vellar estuary on the Southeast coast of India. Kaly et al. (1997) compared the soil conditions in mechanically damaged North Queensland mangrove forest with the undisturbed controls of selected physical, chemical and biological characteristics. The characteristics examined were soil compaction, grain size, pH, and percent by weight of total C, N, P, K, S, and Fe. Upkong (1997) examined mangrove vegetation-environment relationships such as soil nutrients and salinity.

Ball (1998) conducted a study on mangrove soil analysis in northern Australia. Sherman et al. (1998) examined soil chemical parameters and dynamics in the iron, phosphorus and sulphur contents in the mangrove soil. In a study by Tam and Wong (1998) variations in soil nutrient variation and organic matter content along the tidal gradients of a small mangrove environment were analysed. The study stated that site variations along tidal gradients were generally more prominent than temporal variations.

Chen and Twilley (1999) analysed the patterns of mangrove forest structure and soil nutrient dynamics. The study concluded that concentrations of nitrogen and phosphorus are more closely related to patterns of forest development with higher soil fertility at the mouth of the estuary, as indicated by higher concentrations of extractable ammonium, total soil P, and available P, along with higher ammonium

production rates. In the mangrove forest of Gazi Bay, Kenya, Matthijs et al. (1999) investigated the relationship between soil redox state, sulphide concentration, salinity and spatial patterns of mangrove species distribution. The results concluded that soil redox potential (Eh), sulphide concentration and salinity may contribute to the structure of mangroves through the distribution of dominant species, but only in combination with other environmental conditions and processes of vegetation dynamics.

Hseu and Chen (2000) studied the redox potential, pH and electrical conductivity of the Chuwei mangrove soils in northern Taiwan. Upkong (2000) studied the ecological classification to relate the structure of mangrove communities to soil nutrients. An analysis has been conducted by Joshi and Ghose (2003) in the Sundarbans mangroves to relate the community structure and distribution of species to soil salinity and pH gradients. McDonald et al. (2003) assessed the mangrove forest structure under varying environmental conditions.

Dinesh et al. (2004) conducted a comparative study on the biochemical properties of soils in undisturbed and disturbed mangrove forests of South Andaman. Lovelock et al. (2005) examined the soil characteristics of the mangrove forest of Panama. The study reported that there was a large variation in forest structure and edaphic characteristics like salinity, concentrations of available phosphorus, Eh and sulphide. Muhibbullah et al. (2005) analysed the soil physico-chemical parameters of the Sundarban mangrove forest.

Seasonal variations in the physico-chemical parameters of soil texture in the arid zone of mangroves of Kachch have been studied by Saravanakumar et al. (2008). Shazra et al. (2008) checked the soil fertility of the Maldives mangrove ecosystem. Chaudhuri et al. (2009) analysed the physico-chemical, biochemical and microbial characteristics of mangrove soils of the Andamans. The major aim was to determine whether the December 2004 tsunami had any effects on soil physico-chemical parameters such as pH, electrical conductivity, organic carbon, total nitrogen etc. Liao et al. (2009) carried out an analysis of mangrove soil in three different habitats within the mangrove ecosystem of China. Otero et al. (2009) studied the geochemistry of iron and manganese in soils and sediments of a

mangrove ecosystem on the Island of Pai Matos in Brazil. Sreeja et al. (2009) documented soil nutrients from mangrove rich wetlands of the Kannur district. In this study, they compared soil components in mangrove and non-mangrove areas. Xue et al. (2009) characterised the mangrove derived organic matter in wetland sediments and established the quantitative differentiation between mangrove derived organic matter and other organic matter sources in the Zhangjiang estuary mangrove wetland of southern China.

Ferreira et al. (2010) analysed the soil patterns for soil attributes and components in a mangrove environment in Sao Paulo, Brazil. Rambok et al. (2010) conducted a comparative analysis of soil chemical properties of two different mangrove forests in Sarawak. The study tried to find out the preliminary database of mangrove forest soil chemical properties and to compare the forest health of two different mangrove forest locations.

Moreno and Calderon (2011) conducted a study on the quantification of organic matter and physico-chemical parameters of mangrove soil at Hooker Bay of San Andres Island. Das et al. (2012) studied the depth-integrated physico-chemical parameters of mangrove soil of Sundarbans. Soil-vegetation interrelationships in a secondary forest in South-Southern Nigeria were studied using principal component analysis (PCA) and canonical correlation analysis (CCA) has been done by Eni et al. (2012). Hossain et al. (2012) analysed soil physico-chemical parameters of Sundarban mangrove forests. The spatial distribution of organic carbon density of Sundarbans mangrove soil has been investigated by Mitra et al. (2012). The study revealed that the bulk density of mangrove soil increased with depth while organic carbon and carbon density decreased with depth in all study areas. Physico-chemical analysis of soil characteristics of the Vedaranyam mangrove environment of Tamilnadu has been studied by Ramamurthy et al. (2012). Strauch et al. (2012) investigated the ecological effects of soil on the distribution of mangroves on Bahamas Island.

Iron and sulphur geochemistry in semi-arid mangrove soils concerning seasonal variations has been studied by Nobrega et al. (2013). Yang et al. (2013) studied the vegetation and sediment characteristics in an expanding mangrove forest

in New Zealand. Awal and Abdul (2014) analysed soil parameters in the Sundarbans mangrove ecosystem. The effect of mangrove zonation and the physico-chemical parameters of soil were documented by Dissanayake and Chandrasekara (2014). Kurlapkar and Shaikh (2014) investigated the physico-chemical conditions of mangrove soil from the habitats of Bhatey and Kalbadevi estuaries of Maharashtra. The present study analysed the physico-chemical parameters such as soil granulometry, temperature, pH and salinity of soil as well as water and vegetation from the study region. Rao and Rao (2014) tested the physico-chemical properties of mangrove soil in the Machilipatnam coastal region. Vaijayanthi and Vijayakumar (2014) analysed the physico-chemical characteristics of soil from the Muthupet mangrove ecosystem, Tamil Nādu.

Arunprasath and Gomathinayagam (2015) conducted a comparative study on the soil physico-chemical parameters of two mangrove forests of Tamil Nādu. Kiranmani et al. (2015) analysed the physico-chemical parameters of mangrove soils of the Visakhapatnam coast of the Bay of Bengal. Madi et al. (2015) analysed the distribution of Cu, Fe, Mn, and Zn in two mangroves of southern Brazil. Matsui et al. (2015) conducted a study on soil organic carbon content in mangrove ecosystems. Piquero et al. (2015) conducted a study on soil characteristics and nutrient composition of mangroves of Carmen, Cebu. Soil analysis of the Ayiramthengu mangrove region has been estimated by Praseetha and Rajani (2015). Saseeswari et al. (2015) studied the physico-chemical parameters of soil sediment in Karankadu mangrove forest of Tamil Nādu. Vilas and Ashwinova (2015) analysed the soil quality of selected areas of the Sundarbans mangrove ecosystem.

Alshawafi et al. (2016) analysed the soil physico-chemical parameters of mangrove forests on the Island of Kamaran in Yemen. Devi and Pathak (2016) conducted Physico-chemical studies of soil samples in the Gulf of Khambhat. Gomes et al. (2016) studied the characteristics and pedogenesis of mangrove soils from Ileus, Brazil. Madi et al. (2016) investigated soil analysis in two mangrove areas in southern Brazil.

Ayyadurai et al. (2017) studied some of the physico-chemical parameters of the soil of Keezhathottam Mangrove, Tamil Nadu. Ataullah et al. (2017) studied the

physico-chemical characteristics of soils in the Sundarbans mangrove ecosystems of Bangladesh. Chaikaew and Chavanich (2017) studied the spatial variability and relationship of mangrove soil organic matter to organic carbon. Sahoo et al. (2017) studied the physico-chemical properties of sediments from mangroves in Odisha. Sofawi et al. (2017) analysed the nutrient variability in mangrove soil. Premkumar and Santhanam (2017) analysed the physico-chemical properties of sediment samples collected from the mangrove ecosystems of the Palk Bay region on the Southeast coast of India.

Bomfim et al. (2018) conducted a case study on the morphology and physico-chemical characteristics of mangrove soil at Subae of Brazil. Dasgupta et al. (2018) conducted a comparative study on the properties of mangrove and non-mangrove soils of Sundarbans. de Andrade et al. (2018) evaluated the mangrove soil concerning the physical and chemical soil attributes of mangrove forests located in the Sao Francisco estuary. Huang et al. (2018) studied the distribution and influencing pattern for soil organic carbon in mangrove communities in China. Linh et al. (2018) studied the soil physico-chemical properties in Cua Tieu, Tien Giang province. Rajal et al. (2019) conducted a comprehensive study on the physico-chemical parameters of mangrove soil in the Gulf of Kachchh, Gujrat.

Chapter 3

MATERIALS AND METHODS

3. Study area

3.1. Sampling stations

Kerala State is located at the southwest tip of peninsular India between 8^0 18' and 12^0 48' N latitudes and 74^0 52' and 77^0 22' E longitudes. The present study was carried out in the selected mangrove area of Southern Kerala. The locations of study areas are prepared by using the software, ArcMap 10.7.1 (Fig. 3.1). The details of the sampling sites (Table 3.1. & Fig. 3.2-3.6) and true mangrove species are presented in Fig. 3.7-3.10.

Table 3.1

Details of the sampling stations

No.	Study areas			
	District	**Mangrove sites**	**Location (Latitude/Longitude)**	**Area (ha)**
1.	Thiruvananthapuram	Kadinamkulam	8^0 37'15.01" N 76^0 48' 43.81" E	0.5
		(Edava) Kureekkadavu-Kappil	8^0 46'11.14" N 76^0 42' 36.69" E	7.5
2.	Kollam	Ayiramthengu	9^0 07'33.93" N 76^0 28' 45.34" E	6
		Sakthikulangara (Vincent Island)	8^0 56'23.44" N 76^0 33' 09.88" E	15
3.	Kottayam	Kumarakom	9^0 36'59.46" N 76^0 25' 21.46" E	60
		Mekkara (near Vaikom)	9^0 48'54.31" N 76^0 21' 57.54" E	1.6
4.	Alappuzha	Ezhupunna	9^0 49' 24.43" N, 76^0 18' 39.54" E	2.5
		Pathiramanal	9^0 37' 09.78" N, 76^0 23' 06.43" E	19.6
5.	Ernakulam	Kumbalam	9^0 54' 41.96" N, 76^0 18' 32.36" E	7
		Vypin/Puthuvype	9^0 58' 26.46" N, 76^0 14' 38.14" E	6

3.1.1. Station 1: Thiruvananthapuram

Thiruvananthapuram district has the least occurrence of mangroves in which people are devastating mangrove forests due to the lack of awareness of the importance to the environment. The study was conducted at Kadinamkulam and Kureekkadavu-Kappil. Kadinamkulam, the lake linked to the sea through the Muthalapozhi estuary is the most neglected wetland of Thiruvananthapuram. The station covers 0.5 hectares of mangroves in which *Excoecaria agallocha* L. is the major mangrove found here. Subsequently, the station (Edava) Kureekkadavu-Kappil covers an area of 7.5 hectares of mangroves, which are having the critically endangered mangrove species *Shirakiopsis indica* (Willd.) Esser is grown here. This species is reported as 'Data deficient' in the IUCN Red List.

3.1.2. Station 2: Kollam

Kollam district bears South Kerala's most diverse area of mangroves. A vast area of mangroves has been depleted along with the government and private sectors. Through the development of the National Water Way, most of the mangrove ecosystems are devastated within the past two decades. In hiding the lake protection activities, a variety of mangroves have been depleted in the areas of Kayamkulam, Ashtamudi and Paravoor for the construction of coastal protection walls. The study was conducted at Ayiramthengu and Sakthikulangara. A 6-hectare spread of Ayiramthengu mangrove forest is a part of Kayamkulam estuary that was declared as an environmental hotspot after it was ravaged by a Tsunami that had happened in 2004 and threatened with extinction. This is considered as the long chain of mangrove forests along the Kerala coast, which is untouched by man. Ayiramthengu is the land of rare and threatened mangrove species such as *Lumnitzera racemosa* Willd, which was restricted to a few patches. *Avicennia officinalis* L., *Avicennia marina* (Forssk.) Vierh., *Rhizophora apiculata* Blume, *Rhizophora mucronata* Lam, *Sonneratia caseolaris* (L.) Engl., *Excoecaria agallocha* L., *Bruguiera cylindrica* (L.) Blume, *Lumnitzera racemosa* Willd and *Aegiceras corniculatum* (L.) Blanco is the major mangroves profusely grown here.

The station Sakthikulangara-Vincent Island has spread along to about 15 hectares to Neendakara estuaries that are owned as private property. The mangrove

species *Ceriops tagal* (Perr.) C.B.Rob. was considered extinct on the Kerala coast and was restricted to Sakthikulangara mangrove ecosystem. *Avicennia officinalis* L., *Avicennia marina* (Forssk.) Vierh., *Sonneratia caseolaris* (L.) Engl., *Sonneratia alba* Sm, *Ceriops tagal* (Perr.) C.B.Rob., *Bruguiera gymnorhiza* (L.) Lam., *Bruguiera cylindrica* (L.) Blume, *Excoecaria agallocha* L., *Rhizophora apiculata* Blume and *Aegiceras corniculatum* (L.) Blanco are the major mangrove species found here.

3.1.3. Station 3: Kottayam

Kumarakom panchayat harbours the widely distributed mangroves in Kottayam district, which is represented as a patchy assemblage of a few mangrove species having an area of 60 hectares. Mangroves are seen largely in areas of Kumarakom panchayat at Kottayam district. The diversity of mangroves here exists here around 100 years ago. As a part of different agriculture sectors like paddy, coconut and rubber and for buildings, roads and houses also the mangroves existed here were destroyed. KTDC (Kerala Tourism Development Corporation) compound situated along the east coast of Vembanad lake halts the famous bird sanctuary of Kumarakom is one of the famous mangrove communities at Kumarakom which is protected without any other disturbances. KTDC's several programmes for the protection of mangroves are now itself doing but as a part of eco-tourism. Several mangroves are under threat and kept under lesser areas. Different varieties of mangroves such as *Bruguiera cylindrica* (L.) Blume, *Sonneratia caseolaris* (L.) Engl., *Excoecaria agallocha* L. and *Avicennia officinalis* L. The station Mekkara, a place near Vaikom Taluk, has a mangrove area of 1.6 hectares. It is the land of a private place and occupies mangroves like *Avicennia officinalis* L., *Bruguiera cylindrica* (L.) Blume and *Excoecaria agallocha* L.

3.1.4. Station 4: Alappuzha

Alappuzha, famous for the vast mangrove ecosystem is now isolated only as for its namesake. There are no more places except one or two places that are abundant or rich in the mangrove ecosystem. In Ezhupunna, the mangrove ecosystem exists only for 2 hectares and going to be an end apart from the large ecosystem. *Bruguiera cylindrica* (L.) Blume, *Excoecaria agallocha* L., *Rhizophora*

mucronata Lam, *Avicennia officinalis* L., *Avicennia marina* (Forssk.) Vierh. and *Bruguiera gymnorhiza* (L.) Lam. are the major mangrove plants found here. Pathiramanal Island, the picturesque island in Vembanad Lake is considered the largest lake in Kerala State. Pathiramanal Island situated in Muhamma grama panchayat has been declared the first local biodiversity heritage site of Alappuzha. The place itself stays for an ecosystem including bird sanctuaries, marine cultivation, fish farming etc. around 19.6 hectares of this island is covered by mangroves. This island is now under threat because of the mangrove destruction in the name of development built by tourism. *Sonneratia caseolaris* (L.) Engl., *Excoecaria agallocha* L., *Rhizophora apiculata* Blume, *Avicennia officinalis* L. and *Bruguiera cylindrica* (L.) Blume are the major mangrove plants found here.

3.1.5. Station 5: Ernakulam

Ernakulam possesses the second-largest district with a rich diversity of mangroves. As it is the economic centre of the state, the conservation of mangroves is not done under developmental programmes. Most of them are being destroyed. The development of cities is increasing day by day and it is unconvincing that rural mangroves are being destroyed. The present study selected Puthuvype and Kumbalam as the study areas. Puthuvype is bounded by the Arabian Sea on the west, the Cochin Bay mouth on the south and the landman of Vypin on the other side. According to the Kerala Revenue Department Records 40-50 years back, this piece of land presently did not exist. One of the reasons for this remarkable land building activity in this region is the dredging going on in the Cochin Bay mouth for navigational purposes. These places, in particular, are biodiversity-rich varieties of mangroves, especially in the areas of the fire station compound and nearby places. Mangrove forests in Puthuvype considered one of the thickest in Ernakulam, have sustained relentless destruction with infrastructure projects gnawing away at the green cover. To prevent further depletion of mangroves, the Kerala state government has decided to approve the proposal of the Social Forestry Department to notify 50 hectares of the mangrove forests in Puthuvype as reserved forests. Considering the alarming rate of environmental degradation in Kochi, salvaging the mangroves could prove vital in providing the city with the much-needed green lungs. *Bruguiera cylindrica* (L.) Blume, *Bruguiera gymnorhiza* (L.) Lam, *Rhizophora mucronata*

Lam, *Avicennia officinalis* L., *Avicennia marina* (Forssk.) Vierh., *Excoecaria agallocha* L., and *Sonneratia caseolaris* (L.) Engl. are major mangroves found here. Kumbalam Island is a coastal region, more or less surrounded by Cochin backwaters and is extended up to Panangad. The Island is situated on the banks of Vembanad lakes, which meet the Arabian Sea in the west. The Island covers 7 ha of mangrove areas out of which 2 ha are seen as patches and 5 ha are seen besides Thirunettoor Railway lines. *Avicennia officinalis* L., *Bruguiera gymnorhiza* (L.) Lam, *Excoecaria agallocha* L., *Kandelia candel* (L.) Druce, *Rhizophora mucronata* Lam and *Sonneratia caseolaris* (L.) Engl. are the mangroves observed here.

Fig. 3.1

Map showing the location of study areas

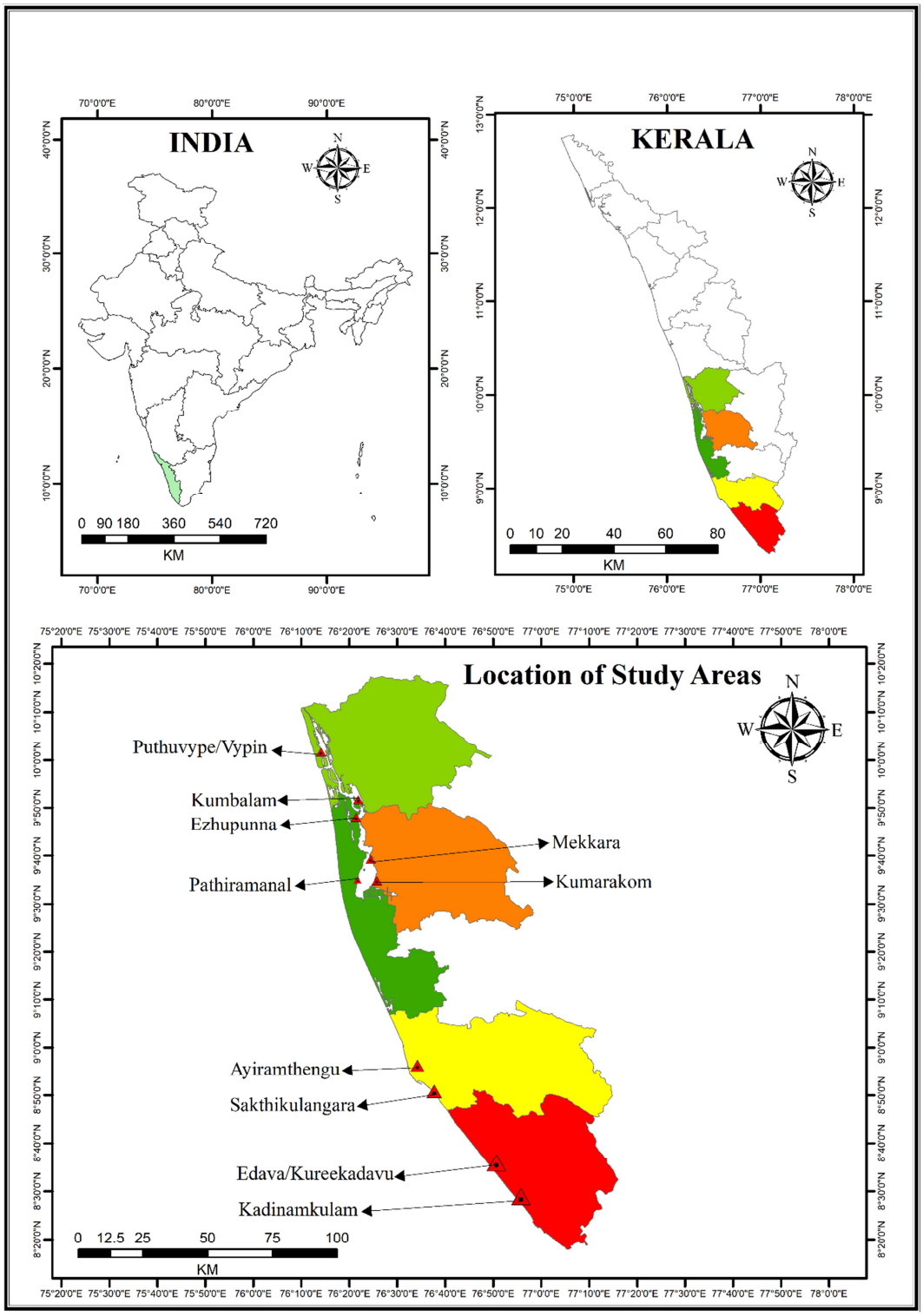


Fig. 3.2

Mangrove habitat of Thiruvananthapuram district



Fig A) Kadinamkulam**; B)** Edava (Kureekkadavu-Kappil).

Fig. 3.3

Mangrove habitat of Kollam district



Fig A) Ayiramthengu**; B)** Sakthikulangara

Fig. 3.4

Mangrove habitat of Kottayam district



Fig A) Kumarakom**; B)** Mekkara (near Vaikom)

Fig. 3.5

Mangrove habitat of Alappuzha district



Fig A) Pathiramanal**; B)** Ezhupunna

Fig. 3.6

Mangrove habitat of Ernakulam district



Fig A) Kumbalam**; B)** Vypin

Fig. 3.7

True mangrove species identified from the study area



Fig. A-C: *Aegiceras corniculatum* (L.) Blanco; **B-F:** *Avicennia officinalis* L.; **G-H:** *Avicennia marina* (Forssk.) Vierh.

Fig. 3.8

True mangrove species identified from the study area



Fig. A-B: *Bruguiera cylindrica* (L.) Blume; **C:** *Bruguiera gymnorhiza* (L.) Lam; **D:** *Excoecaria agallocha* L.; **E:** *Kandelia candel* (L.) Druce; **F:** *Lumnitzera racemose* Wild

Fig. 3.9

True mangrove species identified from the study area



Fig. A-B: *Rhizophora apiculata* Lam; **C-D:** *Rhizophora mucronata* Lam; **E-F:** *Shirakiopsis indica* (Wild) Esser

Fig. 3.10

True mangrove species identified from the study area



Fig. A-B: *Sonneratia alba* Sm; **C-F:** *Sonneratia caseolaris* (L.) Engl.

3.2. Cyanobacterial sampling

The samples for the study were collected from the selected mangrove areas presented in Table 3.1. Cyanobacterial samples were observed on the water bodies, soil, bark and pneumatophores of mangrove plants (Fig. 3.11-3.18) and were collected in plastic bottles using forceps. Planktic cyanobacteria were collected using the plankton net having a pore size of less than 10 µm. Epiphytic samples were collected from the stilt roots, prop roots, pneumatophores and bark of mangrove plants by repeated scraping or cutting with a sharpened blade. Benthic cyanobacteria were collected using forceps. The samples were scraped and transferred into sterile plastic bottles using sterile blades and forceps and transported to the Department of Botany, MES Asmabi College, Kodungallur, Kerala for taxonomic and culture studies.

Fig. 3.11

Habitat of cyanobacteria found attached to the pneumatophores (epiphytic)



Fig. 3.12

Habitat of cyanobacteria found attached to the pneumatophores (epiphytic)



Fig. 3.13

Habitat of cyanobacteria found attached to the aerial roots of mangroves (epiphytic)



Fig. 3.14

Habitat of cyanobacteria found attached to the aerial roots of mangroves (epiphytic)



Fig. 3.15

Habitat of planktic cyanobacteria in the mangrove environments

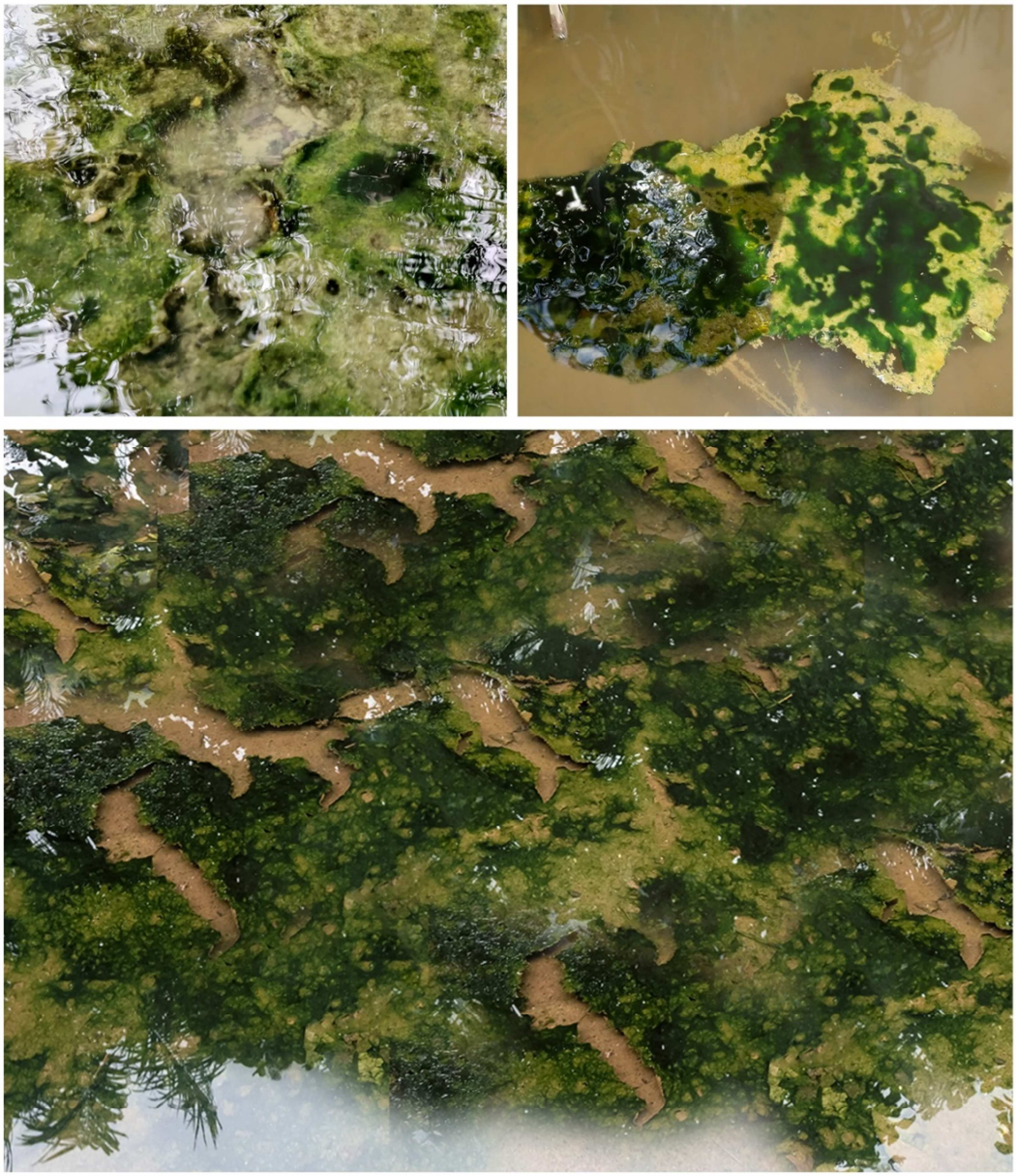


Fig. 3.16

Habitat of benthic (A-D) and planktic and epiphytic (E-F) cyanobacteria in the mangrove environments

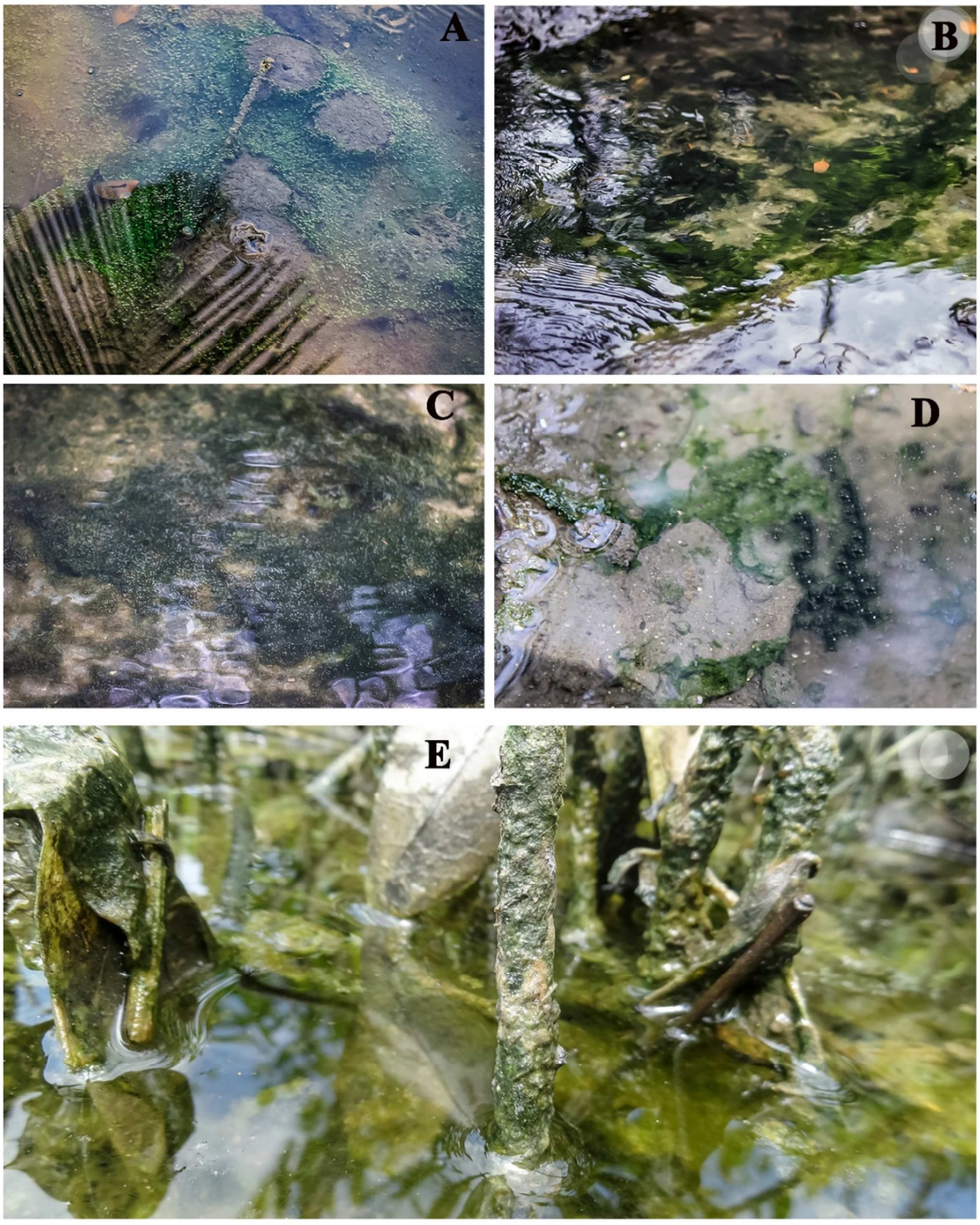


Fig. 3.17

Habitat of epipsammic/epipelic cyanobacteria in the mangrove environments

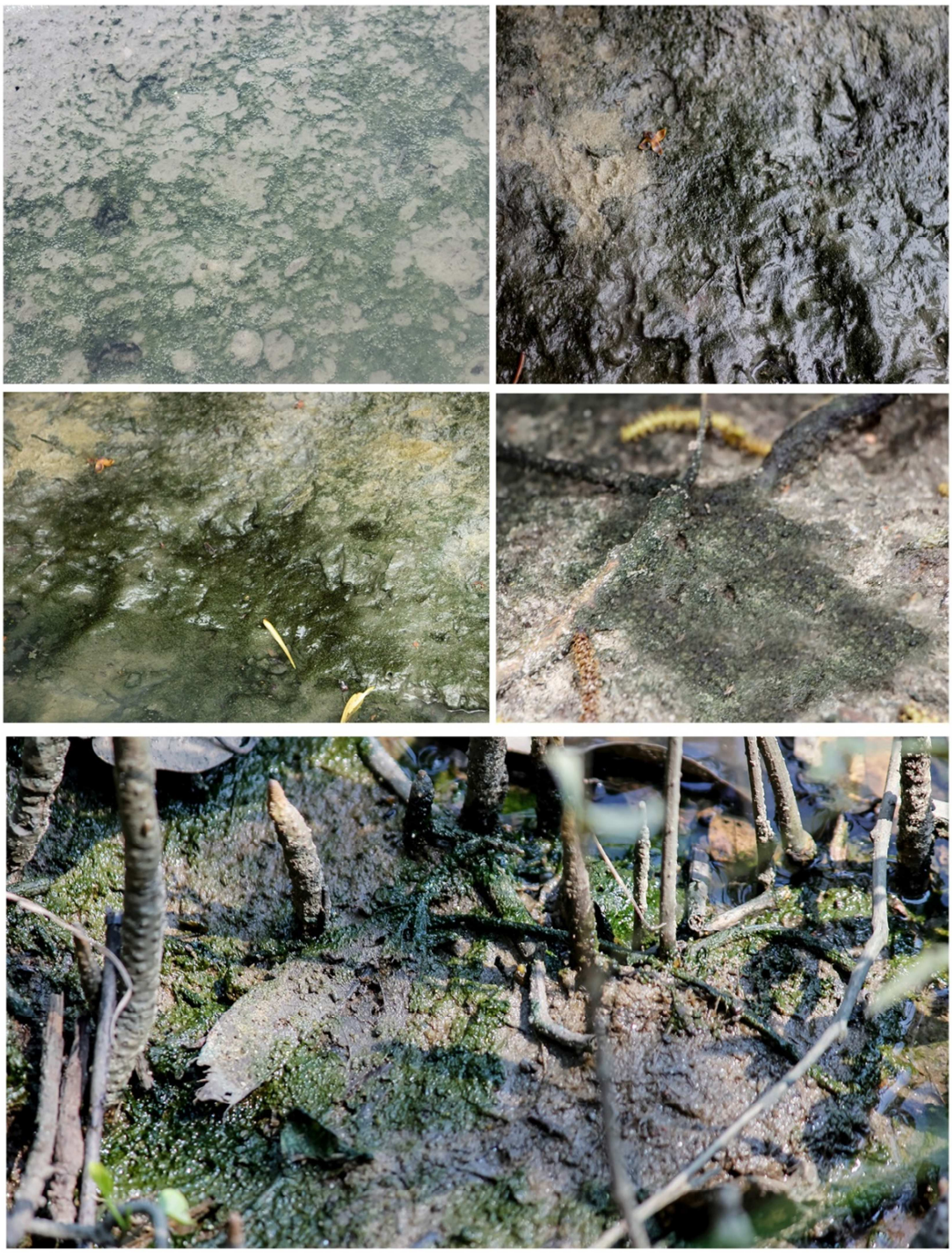


Fig. 3.18

Habitat of epipsammic/epipelic, epiphytic, benthic cyanobacteria in the mangrove environments



3.3. Isolation and identification of cyanobacteria

Cyanobacterial samples were collected in two sets. After collection, these samples were transported to the laboratory within 6-8 hours and then processed. One set of samples was preserved in a 4% formaldehyde solution. In the laboratory, samples were removed from their substrata and cleaned free of mud and other debris. The other set of live samples were analysed under a compound microscope and then transferred to a BG11 medium (Rippka et al., 1979).

3.3.1. BG11 medium composition

Ingredients		**g/l**
$NaNO_3$	:	1.5
$K_2HPO_4.3H_2O$	:	0.04
$MgSO_4.7H_2O$	:	0.075
$CaCl_2.2H_2O$	:	0.036
Citric acid	:	0.006
Ferric ammonium citrate	:	0.006
EDTA	:	0.001
Na_2CO_3	:	0.02
Trace metal mix A5	:	1 ml
Distilled water	:	1000 ml
pH	:	7.4

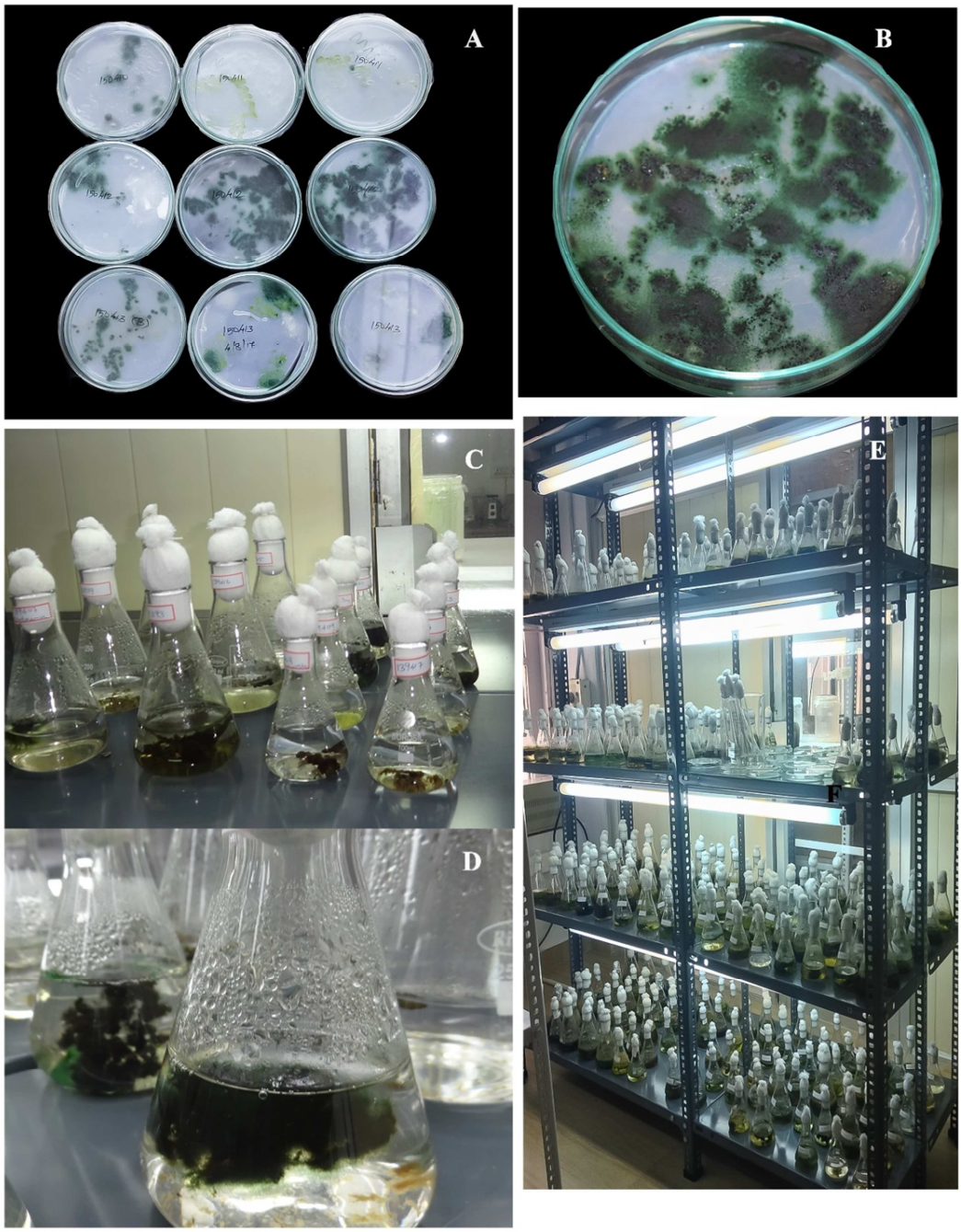
Trace metal mix A5

Ingredients		**g/l**
H_3BO_3	:	2.86
$MnCI_2.4H_2O$	:	1.81
$ZnSO_4.7H_2O$	:	0.222
$Na_2MoO_2.2H_2O$	:	0.390
$CuSO_4.5H_2O$	:	0.079
$Co\ (NO_3)_2.6H_2O$	:	0.0494

Cyanobacterial samples were isolated using BG11 medium by streak plate method (Fig. 3.19, A-B) and they were maintained in the culture room under a fluorescent lamp (±3000 lux), 14”10 L/day at ±25^{0}C. The collected samples were also subjected to culturing in a liquid medium (Fig. 3.19, C-E).

Fig. 3.19

Culturing and isolation of cyanobacteria in solid and liquid medium (BG11 medium)



Microscopic analysis was done in live conditions for the identification of cyanobacteria. Photomicrographs were taken using a Leica DM 1000 LED compound microscope. Cell measurements were made from the digital images using Leica Application Suite (LAS version 5.0.2). Cyanobacterial species were identified using the monographs and standard works of literature as follows: (Desikachary, 1959; Komarek &Anagnostidis, 1998, 2005; Komarek, 2012, 2013; Komarek & Komarkova-Legnerova, 2007; Komarek et al., 2011; McGregor, 2013, 2018). Using all available information, morpho-taxonomic identification was done up to the species level. The identified cyanobacterial species were classified based on the current classification system proposed by Komarek et al., 2014, Komarek et al., 2020 and Hauer and Komarek, 2022 (http://www.cyanodb.cz/). The entity of the taxonomically accepted species was verified according to Guiry and Guiry (2022) (https://www.algaebase.org/).

3.4. Sampling procedures and processing

To evaluate seasonal variation in species diversity and distribution, sample collection of water and soil was held bi-monthly from January 2015 to March 2019. Estimation of various physico-chemical parameters of water and soil were analysed by the standard protocols (APHA, 1998, Trivedy & Goel, 1986, Sarkar & Haldar, 2005).

3.4.1. Water Analysis

Water sampling procedure

The surface water samples were collected about 10 cm below water using plastic bottles of 500 ml. The water samples for physico-chemical analysis were brought to the laboratory for further analysis.

a) Temperature

The temperature was measured using a precision mercury thermometer with an accuracy of $\pm 0.01^{o}$ C.

b) pH

The pH of the collected water samples was measured electrometrically using a pH meter (Eutech PCS tester 35).

c) Salinity

The salinity was measured by using a salinity meter (Eutech multi parameter tester, PCS tester 35). The salinity was expressed in ppt.

d) Dissolved Oxygen (DO)

The dissoved oxygen was measured by using portable dissolved oxygen meter (Eutech). The results are expressed in mg/L.

e) Electrical Conductivity

Electrical Conductivity (EC) is the measure of the amount of electrical current a material can carry or its ability to carry a current. EC was measured using (Eutech multi-parameter tester, PCS tester 35). The results are depicted in milli Siemens (dS/m) per unit area.

f) Total Dissolved Solids (TDS)

Total dissolved solids (TDS) represent the total concentration of dissolved substances in water. TDS was measured by using (Eutech multi-parameter tester, PCS tester 35). The results are depicted in ppt.

g) Total alkalinity

Reagents:

1. 0.1N Hydrochloric acid

2. 0.1N Sodium Carbonate

3. Methyl orange indicator

Procedure:

100ml of water sample was taken in a conical flask and added 2-3 drops of methyl orange indicator. Mixed well and titrated the contents against 0.1N HCl taken in the burette. The endpoint was noted as a colour change from yellow to pink.

Total alkalinity as $CaCO_3$, mg/L = $\frac{(ml \times N) of\ HCl \times 1000 \times 50}{ml\ sample}$

h) Total Phosphorous

Phosphorous estimation generally includes two steps; (a) conversion of any form of phosphorous to dissolved orthophosphates and (b) spectrophotometric determination of the orthophosphate. The first step is accomplished through the persulphate oxidation technique and the second one through the stannous chloride method.

Reagents

1. Sulfuric acid solution- added 300 ml of concentrated sulfuric acid to about 600 ml of distilled water. Cooled and diluted to 1 litre with distilled water.
2. Ammonium molybdate solution - Dissolved 25 g of $(NH_4)6Mo_7O_{24}$. $4H_2O$ in 175 ml of distilled water. Added 280 ml of concentrated sulfuric acid slowly to 400 ml of distilled water. Cooled and added molybdate solution to the acid solution and diluted to 1 litre.
3. Stannous chloride solution: Dissolved 2.5 g of fresh $SnCl_2$-$2H_2O$ in 100 ml of glycerol. Heated in a water bath and stirred with a glass rod to hasten dissolution.
4. Potassium persulfate as the analytic reagent.

Procedure

1 ml of sulfuric acid solution and 0.4 g of potassium persulfate was added to 50 ml of sample and boiled gently for 30 minutes until a volume of 10 ml was reached. Diluted the sample to 50 ml with distilled water. 2 ml of ammonium molybdate solution and 3 drops of stannous chloride solution were added to the sample and mixed well. Kept the samples for another 10 – 12 minutes and measured the optical density at 690 nm. Compared the values with a calibration curve, using distilled water as blank. The concentration of phosphorous from the standard graph was calculated.

i) Total Nitrogen

Kjeldahl method (Kjeldahl, 1883) is the most common, reliable and economical method for analysing total nitrogen.

Reagents

1. Sulphuric acid- Salicylic acid (N- free): dissolve 1 g of salicylic acid in 30 ml concentrated sulphuric acid.
2. Sodium thiosulphate (N-free): 24 mesh dried powder.
3. Catalyst mixture: Mix potassium sulphate, ferrous sulphate or selenium powder and copper sulphate in a ratio of 20:2: I and grind the mixture to pass through a 40-mesh sieve.
4. Sodium hydroxide (45%): Dissolve 450 g NaOH in one litre of distilled water.
5. Boric acid-indicator solution: Dissolve 40 g of H_3BO_3 in about 900 ml of hot distilled water. Cool and add 20 ml of mixed indicator solution (prepared by dissolving 0.5 g of bromocresol green and 0.1 g of methyl red in 100 ml of g1a/o ethanol). Add 0.1 M NaOH solution dropwise until the colour becomes reddish-purple. Make complete one-litre volume by adding distilled water.
6. Standard 0.01 N H_2SO_4
7. Standard 0.01N NaOH

Procedure

Digestion phase:

1. Take 5 ml of water sample in an 800 ml Kjeldahl digestion flask.
2. Add 30 ml concentrated sulphuric-salicylic acid in it, shake the mixture for 2-3 minutes and then allow to react nitrate with salicylic acid in cold for 30 minutes to form nitro compound.
3. Now add 5 g sodium-thiosulphate and 50 ml distilled water and shake the mixture well and allow to stand for 5 min.
4. Start heating the mixture containing in Kjeldahl flask initially slowly and then heat is raised gradually until the acid reaches to boil.
5. The sample attained a green colour when it was fully digested. The samples were allowed to cool and diluted with distilled water for further analysis

Distillation phase:

1. After mixing thoroughly, transfer measured 100 ml of digest solution in 500 ml Erlenmeyer flask of steam chamber fitted to distillation rack.
2. To absorb the evolved ammonia of the digest mixture, 10 ml of 0.1 N H_2SO_4 was taken into the receiver flask.
3. The distillation flask is blocked with rubber cork having a double hole.
4. Pour excess of 40 % NaOH (40-50 ml) into the flask through this rubber tube and immediately close the mouth of the rubber tube with a pinchcock.
5. After making all connections airtight, start distillation initially at low flame and then gradually increase the flame up to boiling.
6. When distillate becomes ammonia-free (at about 40-50 ml distillate), disconnect the receiver flask and wash the end of the delivery tube with distilled water and then put off the burner to prevent back sucking.

Titration phase:

After trapping all ammonia present, the resultant solution was titrated against 0.1 N HCl for estimating the total nitrogen content.

Calculations

1 ml of 1 N HCl or H_2SO_4 = 0.014 g N

Per cent nitrogen in soil = $\frac{(T-B)\times 0.014\times N\times soil\ dilution\times 100}{S\times A}$

where, T = ml of standard HCl or H_2SO_4 used for titrating soil sample

B = ml of standard HCl or H_2SO_4 used for blank titration,

N = Normality of standard HCl or H_2SO_4 (0.1N) and

S = Water sample weight in ml

A = Aliquot taken for distillation in ml

j) Potassium

Reagents

1. Stock potassium solution (1000mg/L) - dissolved 1.907 g KCl in distilled water to make 1 litre of solution.
2. Intermediate sodium solution (100mg/L) – Diluted the stock solution 10 times.
3. Standard sodium solution (10 mg/L) - Diluted the intermediate solution further to 10 times.

Procedure

The concentration of potassium present in the sample was estimated using Flame Photometer. The instrument was calibrated with a higher and lower concentration of standard potassium stock solutions. All the samples were analyzed in the instrument and the results are reported in ppm concentration.

k) Calcium

Reagents

1. 0.01M EDTA solution
2. 1N Sodium hydroxide
3. Murexide indicator- Mixture of 0.2 g ammonium purpurate and 100g of NaCl.

Procedure

50 ml of sample was taken in a conical flask; added 2 ml sodium hydroxide solution and approximately 100 mg of Murexide indicator to it. The development of pink colour was observed. Titrated the solution against 0.01 M EDTA, until the colour changed to purple.

Calcium mg/L = $\frac{ml\ EDTA\ used \times 400.8}{ml\ sample}$

l) Magnesium

Reagents

1. 0.01M EDTA solution
2. Buffer solution- Mixture of Ammonium chloride, Ammonium hydroxide and disodium EDTA
3. Eriochrome Black T indicator
4. 1N Sodium hydroxide
5. Murexide indicator- Mixture 0.2 g ammonium purpurate and 100g of NaCl.

Procedure

Magnesium is determined as the difference between Ca + Mg titration and the titration alone for calcium. In the present study, titrated a constant volume of sample for calcium and also for total hardness, found out the volume of EDTA used for both the titrations separately.

$$\text{Magnesium mg/L} = \frac{(y-x)\times 400.8}{ml\ sample \times 1.645}$$

Where, x = EDTA used for calcium determination

y = EDTA used for total hardness (Ca + Mg).

m) Sodium

Reagents

1. Stock sodium solution (1000mg/L) - dissolved 2.542 g NaCl in distilled water to make 1 litre of solution.
2. Intermediate sodium solution (100mg/L) – Dilute the stock solution to 10 times.
3. Standard sodium solution (10 mg/L) - Dilute the intermediate solution further 10 times.

Procedure

The concentration of sodium present in the sample was estimated by using Flame Photometer. The instrument was calibrated with a higher and lower

concentration of standard sodium solution. All the samples were analysed in the instrument and the results are obtained in ppm concentration.

3.4.2. Soil sampling

Soil samples for analysing the physico-chemical parameters were collected from all the sampling locations simultaneously with the cyanobacterial collection. For the study, soil samples were collected from the study areas from a rooting depth of 10-15 cm in polythene bags immediately after the soil was withdrawn, the colour and texture were identified and documented and brought to the laboratory. Dry the collected sample under shade (at a temperature of about 25°C to 35°C). Soon after drying, stones and other similar subjects are picked up and the soil is ground in a mortar to break up aggregates or lumps, taking care not to break actual soil particles. The soil is then passed through a stainless steel 2 mm sieve and discarded plant residues, gravel and other foreign matter are retained in the sieve. If the gravel content is substantial, it has to be recorded. For certain types of analysis (eg. organic carbon) it is necessary to grind further to pass it through a 0.5 mm sieve (Trivedy & Goel, 1986).

Procedures for soil analysis

a) pH

The pH of the soil is the measure of acidity and alkalinity of soil-water suspension and provides a good identification of the soil's chemical nature. To determine the pH, a suspension was prepared in a 1:5 soil solution (1 soil: 5 water), take 20g of soil and add 100 ml of distilled water to it. Stir for about an hour at regular intervals and the pH was measured by using a pH meter (Eutech multi-parameter tester, PCS tester 35).

b) Salinity

To determine the salinity of the soil, 1:5 soil suspension was prepared as mentioned above and the salinity was measured by using a salinity meter (Eutech multi-parameter tester, PCS tester 35). The salinity was expressed in ppt.

c) Electrical Conductivity

To determine the electrical conductivity, 1:5 soil suspension was prepared as mentioned above and electrical conductivity was measured using a conductivity meter (Elico 180).

d) Organic Carbon

Organic carbon is the measure of total carbon present in the soil. In the present study, Walkley- Black wet digestion method (Walkley, 1947) is followed for determining the organic carbon content in the soil.

Reagents

i) Potassium dichromate ($K_2Cr_2O_7$)- 1N: dissolve 49.04 g of reagent grade $K_2Cr_2O_7$ (dried at 105 ^{0}C) in water and dilute the solution to a volume of 1 litre.

ii) Concentrated Sulphuric acid (H_2SO_4), not less than 96%.

iii) 0.5 N Ferrous ammonium sulphate: Dissolve 196 g of reagent grade [Fe $(NH_4)_2(SO_4)_2.6H_2O$] in about 400 ml distilled water, add 7.5 ml of concentrated sulphuric acid and make the final volume to 1 litre with distilled water.

iv) Sodium fluoride (NaF) or Phosphoric acid (85%).

v) Diphenylamine indicator: Dissolve 0.5 g of diphenylamine indicator in a mixture of 20 ml of distilled water and 100 ml concentrated (H_2SO_4).

Procedure

Grind sufficient soil to pass through a 0.5 mm sieve avoiding iron or steel mortars. Transfer a weighed sample, containing 10-25 mg of organic carbon (approximately 0.5 to 1 g soil), but not above 10 g soil, into a 500 ml Erlenmeyer flask. Add 10 ml of 1N $K_2Cr_2O_7$ and swirl the flask gently to disperse the soil in the solution. Then rapidly add 20 ml of concentrated H_2SO_4. Immediately swirl the flask gently until the soil and reagents are mixed, then more vigorously for a total of one minute. Allow the flask to stand for about 30 minutes for the reaction to complete. Then add 200 ml of distilled water to the flask to dilute the suspension. Add 10 ml

of Orthophosphoric acid or 0.5 g of NaF and shake vigorously to mix. Then add 1 ml of diphenylamine indicator. A deep violet colour will appear. Titrate it with 0.5 N Ferrous Ammonium Sulphate till the colour changes from violet to blue and finally bright green. Note the volume of Ferrous Ammonium Sulphate used in the titration. Carry out a blank titration (without soil) in the same way.

e) Calculation

Weight of the soil taken = W g

Volume of 0.5 N Fe $(NH_4)_2(SO_4)_2.6H_2O$ used for blank titration = X ml

Volume of 0.5 N Fe $(NH_4)_2(SO_4)_2.6H_2O$ used for sample titration = Y ml

Volume of 1 N $K_2Cr_2O_7$ used for oxidation of C = 0.5 (X-Y) ml

[1ml of 1N $K_2Cr_2O_7$ = 0.003 g Organic carbon]

Percentage of Organic carbon in the soil = $\frac{0.5\ (X-Y)\ ml \times 0.003 \times 100}{W}$

Organic carbon (%) in soil = Z

Organic carbon (%) in soil = Z x 1.3 = R

e) Total Nitrogen

Soil sample for total nitrogen analysis is air-dried, oven-dried, ground to pass through a 0.4 mm mesh sieve before analysis. Kjeldahl method (Kjeldahl, 1883) is the most common, reliable and economical method for analysing nitrogen.

Reagents

1. Sulphuric acid- Salicylic acid (N- free): dissolve 1 g of salicylic acid in 30 ml concentrated sulphuric acid.
2. Sodium thiosulphate (N-free): 24 mesh dried powder.
3. Catalyst mixture: Mix potassium sulphate, ferrous sulphate or selenium powder and copper sulphate in the ratio of 20:2:I and grind the mixture to pass through a 40 mesh sieve.
4. Sodium hydroxide (45%): Dissolve 450 g NaOH in one litre of distilled water.

5. Boric acid-indicator solution: Dissolve 40 g of H_3BO_3 in about 900 ml of hot distilled water. Cool and add 20 ml of mixed indicator solution (prepared by dissolving 0.5 g of bromocresol green and 0.1 g of methyl red in 100 ml of g1a/o ethanol). Add 0.1 M NaOH solution dropwise until the colour becomes reddish-purple. Make a complete one-litre volume by adding distilled water.
6. Standard 0.01 N H_2SO_4
7. Standard 0.01N NaOH

Procedure

Digestion phase:

1. Take 5 g of soil sample in 800 ml Kjeldahl digestion flask.
2. Add 30 ml concentrated sulphuric-salicylic acid in it, shake the mixture for 2-3 minutes and then allow to react nitrate with salicylic acid in cold for 30 minutes to form a nitro compound.
3. Now add 5 g sodium thiosulphate and 50 ml distilled water and shake the mixture well and allow to stand for 5 min.
4. Start heating the mixture containing in Kjeldahl flask initially slowly and then heat is raised gradually until the acid reaches to boil.
5. The sample attained a green colour when it was fully digested. The samples were allowed to cool and diluted with distilled water for further analysis

Distillation phase:

1. After mixing thoroughly, transfer measured 100 ml of digest solution in 500 ml Erlenmeyer flask of steam chamber fitted to distillation rack.
2. To absorb the evolved ammonia of the digest mixture, 10 ml of 0.1 N H_2SO_4 was taken into the receiver flask.
3. The distillation flask is blocked with a rubber cork having a double hole.
4. Pour excess of 40 % NaOH (40-50 ml) into the flask through this rubber tube and immediately close the mouth of the rubber tube with a pinchcock.

5. After making all connections airtight, start distillation initially at low flame and then gradually increase the flame up to boiling.
6. When distillate becomes ammonia-free (at about 40-50 ml distillate), disconnect the receiver flask and wash the end of the delivery tube with distilled water and then put off the burner to prevent back sucking.

Titration phase:

After trapping all ammonia present, the resultant solution was titrated against 0.1 N HCl for estimating the total nitrogen content.

Calculations

1 ml of 1 N HCI or H_2SO_4 = 0.014 g N

Per cent nitrogen in soil = $\frac{(T-B)\times 0.014\times N\times soil\ dilution\times 100}{S\times A}$

where T = ml of standard HCI or H_2SO_4 used for titrating soil sample

B = ml of standard HCI or H_2SO_4 used for blank titration,

N = Normality of standard HCI or H_2SO_4 (0.1N) and

S = Soil sample weight in g.,

A = Aliquot taken for distillation in ml

f) Total Phosphorous (Stannous chloride method)

The total phosphorus is estimated by colorimetric method employing ammonium molybdate and stannous chloride.

Reagents

1. Sulfuric acid solution- added 300 ml of concentrated sulfuric acid to about 600 ml of distilled water. Cooled and diluted to 1 litre with distilled water.
2. Ammonium molybdate solution - Dissolved 25 g of $(NH_4)6Mo_7O_{24}$. $4H_2O$ in 175 ml of distilled water. Added 280 ml of concentrated sulfuric acid slowly to 400 ml of distilled water. Cooled and added molybdate solution to the acid solution and diluted to 1 liter.

3. Stannous chloride solution: Dissolved 2.5 g of fresh $SnCl_2$-$2H_2O$ in 100 ml of glycerol. Heated in water bath and stirred with a glass rod to hasten dissolution.
4. Potassium persulfate as the analytic reagent

Procedure

1 ml of sulfuric acid solution and 0.4 g of potassium persulfate was added to 50 ml of sample and boiled gently for 30 minutes until a volume of 10 ml was reached. Diluted the sample to 50 ml with distilled water. 2 ml of ammonium molybdate solution and 3 drops of stannous chloride solution were added to the sample and mixed well. Kept the samples for another 10 - 12 minutes and measured the optical density at 690 nm.

Compared the values with a calibration curve, using distilled water as blank. The concentration of phosphorous from the standard graph was calculated.

g) Sodium and Potassium (Flame photometric method)

Reagents

1. Neutral1N ammonium acetate solution (CH_3COONH_4): Dissolve 77.08 g of ammonium acetate in distilled water and made up to 1L. Adjust the pH if necessary, to 7 with acetic acid or ammonium hydroxide.
2. Standard K solution: Dissolve 1.908 g of dried potassium chloride (KCl) AR grade in distilled water and made up to 1L to get 1000µg m/l solution.

5.3 Procedure

Extraction

Shake 5 g of soil with 25 ml of neutral normal ammonium acetate for 5 minutes and filter immediately through a dry Whatman No.42 filter paper. The first few ml of the filtrate may be discarded. Potassium concentration in the extract is determined using a flame photometer after the necessary setting and calibration of the instrument.

h) Calcium

Calcium is one of the most abundant elements imparting hardness to natural water. At high pH, much of the quantities may get precipitated as $CaCO_3$.

Reagents

1. 0.01M EDTA solution
2. 1N Sodium hydroxide
3. Murexide indicator- Mixture of 0.2 g ammonium purpurate and 100g of NaCl.

Procedure

50 ml of sample was taken in a conical flask; added 2 ml sodium hydroxide solution and approximately 100 mg of Murexide indicator to it. Development of pink colour was observed. Titrated the solution against 0.01 M EDTA, until the colour changed to purple.

$$\text{Calcium} = \frac{ml\ EDTA\ used \times 400.8}{ml\ sample}$$

i) Magnesium

Reagents

1. 0.01M EDTA solution
2. Buffer solution- Mixture of Ammonium chloride, Ammonium hydroxide and disodium EDTA
3. Eriochrome Black T indicator
4. 1N Sodium hydroxide
5. Murexide indicator- Mixture 0.2 g ammonium purpurate and 100g of NaCl.

Procedure

Magnesium is determined as the difference between Ca + Mg titration and the titration alone for calcium. In the present study, titrated a constant volume of sample for calcium and also for total hardness, found out the volume of EDTA used for both the titrations separately.

$$\text{Magnesium} = \frac{(y-x)\times 400.8}{ml\ sample\times 1.645}$$

Where, x=EDTA used for Calcium determination

y = EDTA used for total hardness (Ca+Mg).

3.5. Statistical analysis

Identification and enumeration of cyanobacteria were done by using a compound microscope (Leica DM 1000). Alpha (α) and Beta (β) diversity indices were analysed according to Magurran (1988). α-diversity measures and summarises the structure of the ecological community in terms of richness, evenness/uniformity or both. α-diversity indices of cyanobacteria were analysed by using PAST 4.03 statistical software (Hammar et al., 2001) which generates 11 diversity indices, i.e., Dominance index, Simpson index (Simpson, 1949), Shannon-Weiner index (Shannon & Weiner, 1949), Evenness index (Pielou, 1975), Brillouin index (Brillouin, 1956), Menhinick's index (Whittaker, 1977), Margalef index (Margalef, 1968), Equitability index, Fisher-Alpha index (Fisher et al., 1943), Berger-Parker index (Berger & Parker, 1970) and Chao-1 index (Chao, 1984). Individual and sample rarefaction (Sanders, 1968), SHE analysis (Buzas & Hayek, 1998) and diversity profile were also performed using PAST 4.03 statistical software.

β-diversity explains the variation of species composition and distribution from one environment to another (Whittaker, 1972). A low β-diversity index suggests a high level of similarity, whereas a high β-diversity index indicates a low level of similarity. It was analysed by using Hierarchical Cluster Analysis (HCA) based on Bray-Curtis, Jaccard and Sorenson-Dice similarity indices, Non-metric Multidimensional Scaling (NMDS) and Principal Coordinates Analysis (PCoA) based on Bray-Curtis index by using OriginPro 2022 (v.9.9.0.225) and PAST 4.03 software.

Spatiotemporal variations of physico-chemical parameters of water and soil were calculated based on descriptive and multivariate statistical analysis. In the present study, mean± standard deviation, ANOVA, Pearson correlation coefficient matrix, Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA) were used for analysis and interpretation. All the physico-chemical

parameters were estimated and corroborated with the cyanobacterial diversity by using the software, Microsoft Excel (Microsoft Office LTSC Professional Plus 2021), OriginPro 2022 (v.9.9.0.225) and PAST 4.03. JASP network analysis was also performed to find out the association between the environmental parameters and cyanobacterial diversity. It was performed by using the software, Jeffreys's Amazing Statistics Program (JASP, v. 0.16.2) initiated by the University of Amsterdam, Netherlands.

Chapter 4

RESULTS AND DISCUSSION

The classification of cyanobacteria developed under the botanical system, as traditionally they were recognized as "blue-green algae", and identified as such with the nomenclatural provisions of the International Code for Nomenclature for Algae, Fungi and Plants (ICN). However, Pinevich (2015) suggested a proposal to consistently apply the nomenclature rules under the provisions of the International Code of Nomenclature of Prokaryotes (ICNP) to the names of cyanobacteria, including those validly published under the International Code of Botanical Nomenclature (ICBN) or ICN. The current classification system of cyanobacteria is based on the polyphasic approaches that combine the traditional methods using morphological and ultrastructural analysis with the modern molecular, cytomorphological and ecological methods in the morpho-taxonomic identification of cyanobacteria and this polyphasic approach has become a widely accepted system for nomenclature to solve the problems of classification of cyanobacteria (Komarek & Anagnostidis, 1998, 2005; Komarek, 2013; Komarek et al., 2014; Komarek, 2016; Komarek et al., 2020; Hauer & Komarek, 2022).

The collected cyanobacterial samples were subjected to species-level identification and they were classified based on the current and revised classification system proposed by Komarek et al. (2014), Komarek et al. (2020) and Hauer and Komarek (2022) (http://www.cyanodb.cz/). The entity of the taxonomically accepted species was verified according to AlgaeBase (https://www.algaebase.org/) (Guiry & Guiry, 2022).

4.1. Systematic Account

Cyanobacteria Stanier 1973

Synonyms: Cyanophyceae, Cyanophyta, Cyanoprokaryota, Blue-Green Algae

Unicellular or multicellular without a true nucleus. cyanobacteria were identified based on morphological traits such as cell dimensions, shape, colour, type

of branching, sheath characteristics, and cell contents. Cyanobacteria may be unicellular, colonial, or filamentous. Filamentous cyanobacteria may exhibit both false and true branching.

According to Hauer and Komarek (2022), cyanobacteria is divided into 10 orders. Among these, the following orders of cyanobacteria were reported from the study areas.

Key to the Orders

1. Unicellular or colonial, never with trichome organization ..... **1. Chroococcales**
2. Coccoid, bacilloid unicellular, colonial and simple filamentous forms with peripherally arranged thylakoids..... **2. Synechococcales**
3. Trichomes regularly and usually tightly screw-like coiled..... **3. Spirulinales**
4. Filamentous without heterocytes and akinetes..... **4. Oscillatoriales**
5. Filamentous forms including both branched and unbranched, with heterocytes and akinetes..... **5. Nostocales**

1. Order: Chroococcales

The order is characterised by unicellular or colonial forms of definite or indefinite shapes, without trichomes, lacking heterocytes and akinetes, reproduction mainly by binary fission and colony fragmentation or disintegration, cell division is one, two or more perpendicular planes.

As far as 9 families known to occur in all biotopes including freshwater, marine, terrestrial and in extreme environmental conditions. 9 families representing 14 genera and 646 species are known. Among these 2 families including 3 genera and 7 species are reported from the study area.

Key to the family

1. Cells solitary or in mucilaginous colonies, usually irregularly arranged, cells almost spherical, oval, widely oval or rod-shaped ..... **1. Aphanothecaceae**
2. Cells unicellular or forming colonies, not forming filament-like growth…… .....**2. Chroococcaceae**

1. Aphanothecaceae

Cells solitary, or in mucilaginous colonies, usually irregularly arranged, cells are surrounded by their own, sometimes lamellate or coloured envelopes. Cells almost spherical, oval, widely oval or rod-shaped. Cell division by binary fission, only in one plane, cell divides into two isomorphic cells.

The family consists of 14 genera and over 170 species. The family representing the genus *Aphanothece* and its 3 species are known to occur in the mangrove ecosystem of southern Kerala and are presented in this chapter.

Key to the genera

1. Cells oval, without their own gelatinous envelopes..... **1. *Aphanothece***

1. *Aphanothece* Nageli 1849

Colonies micro-macroscopic, cells arranged irregularly, loosely or densely in common mucilage, gelatinous, spherical, greenish, blue-green, violet or brown. Cells in their own indistinct or distinct delimited envelop. Cells widely oval to cylindrical with rounded ends.

A cosmopolitan genus of 63 species from diverse habitats including freshwater, marine and in extreme environmental conditions. Here 3 species are described from soil and planktic form from the mangrove ecosystems of southern Kerala.

Key to the species

1a. Cells with rounded ends 2

1b. Cells oval, granulated, 4.6 – 5.2 µm wide, 7.4 - 12.5 µm long..... **2. *A. granulosa***

2a. Cells oval to elongate cylindrical, 2.5-4.5 µm wide..... **1. *A. bullosa***

2b. Cells oblong, more or less ovoid or widely cylindrical, 3.6 - 6.2 µm wide .....**3. *A. stagnina***

1. *Aphanothece bullosa* (Meneghini) Rabenhorst 1865

Rabenhorst, Fl. Eur. Alg. 2:65. 1865; Forti in De toni, Sylloge Algarum, 5: 84. 1907; Fremy, Myxo.d'Afr.equat. franc. 30. 1929; Geitler, Kryptogamenflora,

172. 1932; Rao, Proc. Nat. Acad. Sci. India. B, 6. 339–375. 1937; Rao, J.Ind. bot.soc. 17:81-96. 1938; Mitra, Indian J.agric. sci. 21:357-373. 1950; Gupta, Proc. Nat. Acad. Sci. India., 20(3): 109-115. 1950; Hirose et al. Illustrations of the Japanese fresh-water algae, 1-933. 1977; Alvarez-Cobelas & Gallardo, Acta Bot Malac., 13: 53-76. 1988; Aysel, Journal of Black Sea/Mediterranean Environment, 11: 1-124. 2005; Leghari et al. Int. J. Phycol. Phycochem. 1(2): 151-158.2005; Johansen et al., Southeastern Naturalist, 1: 99-134. 2007; Choudhary, Bangladesh J. Plant Taxon., 16(1): 57-63. 2009; Siddiqui et al. Encyclopaedia of flora and fauna of Bangladesh, 1-415. 2009; Smith, Int J Algae, 12(3): 230-256. 2010; Gadea et al., Thalassas, 29(1): 35-58. 2013; Maulood et al. Checklist of algal flora in Iraq, 1-94. 2013; Kumar et al. Asian Pac. J. Trop. Biomed. 3 (6): 458-463. 2013; Kumar et al. Cell. Mol. Biol. 60 (5): 76-83. 2014; Hindak & Hindakova, Zoznam nižších a vyssich rastlín Slovenska, 2016; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Torres-Arino et al. Cybella, 50 (1): 1-97. 2019; Taskin et al. Turkiye suyosunlari listei, 1-804. 2019.

Synonyms: *Microcystis bullosa* Meneghini 1837

References: Komarek & Anagnostidis (1998); Desikachary (1959).

Description: Colonies macroscopic, mucilaginous, more or less spherical. Cells oval to elongate cylindrical with rounded ends, with more or less homologous content, sometimes finely granular, pale blue-green, without individual envelops, 2.5-4.5 μm wide, 5.2-7.1 μm long.

Distribution: No distributional records were found along with the marine environment.

General Environment: Freshwater/terrestrial, subaerophytic, on rocks and stones, free-floating in warm water.

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Planktic form appeared as green in colour.

Specimen Examined: INDIA: Kerala; Ernakulam district, Vypin, 9^0 58’ 26.46” N, 76^0 14’ 38.14” E, 16.07.2015, MES 13761. Kottayam district, Mekkara, 9^0 48’54.31” N 76^0 21’ 57.54” E. 18.10.2016, MES 13786. **(Plate 1, Fig. A).**

2. *Aphanothece granulosa* (N.L.Gardner) Komárek & Komákova-Legnerova 2007 Komárek & Komakova-Legnerova, Nova Hedwigia, 84(1/2): 65-111. 2007; McGregor, Phytotaxa 133: 1-130. 2013; Tavera et al., Bot. Sci., 91(1): 27-52. 2013; Nava-Olvera et al., Revista de Biologia Marina y Oceanografia, 52(3): 429-439. 2017.

Synonyms: *Aphanothece microscopica* var. *granulosa* N.L.Gardner 1927

References: McGregor (2013); Komarek & Komarkova- Legnerova (2007).

Description: Colonies microscopic, cells loosely arranged, in older colonies densely agglomerated cells in fine, colourless mucilage, usually well-defined at the margin and overlapping the cells. Cells oval, granulated, 4.6-5.2 µm wide, 7.4-12.5 µm long.

Distribution: No distributional records were found along with the marine environment.

General Environment: Freshwater species

Comments: New record to the marine cyanobacterial flora of India.

Habitat: On mangrove soil, it appeared as a dark brownish/black coloured cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 24.09.2017, MES 13774; Kollam district, Ayiramthengu, 9^0 07'33.93" N 76^0 28' 45.34" E, 22.11.2018, MES 21534. **(Plate 1, Fig. B).**

3. *Aphanothece stagnina* (Sprengel) A. Braun in Rabenhort 1863

Rabenhorst, Algen Europa's, Fortsetzung der Algen Sachsens, Resp. Mittel-Europa's. 2: 57-58. 1863; Forti in De Toni, Sylloge Algarum, 5: 76. 1907; Boye-Peterson, Freshwater cyanophyceae of Iceland, Bot. of Iceland, 2. 1923; Crow, J. Bot.Lond., 61. 139. 1923; Fremy, Myxo.d'Afr.equat.franc. 26. 1929; Geitler, Kryptogamenflora, 164. 1932, Fremy, Cyano. Cotes d'Eur. 18. 1933; Rich, Trans. R. Soc. South Africa., 23 (2): 107-160. 1935; Banerji, J. Indian. Bot. Soc., 15. 297. 1936; Singh, Proc. Indian Acad. Sci. B, 9: 63-68. 1939; Parukutty, Indian Acad. Sci. B, 11: 3. 117-124. 1940; Fremy, Blumea, 21-40. 1942; Prescott, Algae of the

Western Great Lakes area, 1-977. 1962; Sheath & Steinman, Can J Bot., 60: 1964-1997. 1982; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Aboal, An. Jard. Bot. Madr., 45(1): 3-46. 1988; Alvarez-Cobelas & Gallardo, Acta Bot Malac., 13: 53-76. 1988; Chu, Flora algarum sinicarum aquae dulcis Tomus II Chroococcophyceae, 1-161. 1991; Fenchel et al., Ophelia, 43: 45-100. 1995; Poulin et al., Can. Field-Nat., 109: 27-110. 1995; Day et al., Flora of Australia, 4. 1-276. 1995; Silva et al., University of California Publications in Botany, 79: 1-1259. 1996; Calvo et al., Bot Mar., 42: 343-353. 1999; Vinogradova et al., Biodiversity of cyanoprocaryotes, algae and fungi of Israel, 32-141. 2000; Ling & Tyler, Bibliotheca Phycologica, 105:1-643. 2000; Vitenaite, Bot. Lith., 7(4): 343-364. 2001; Calvo & Bárbara, Nova Acta Científica Compostelana, 12: 5-34. 2002; Haroun et al., Lista de especies marinas de Canarias, 3-4. 2003; Whitton et al., A coded list of freshwater algae of the British Isles, 2003; Mauch & Schmedtje. Taxaliste der Gewässerorganismen Deutschlands zur Kodierung biologischer Befunde. 1-388. 2003; Lobban & Tsuda, Micronesica 35/36: 54-99. 2003; Hallfors, Baltic Sea Environment Proceedings, 95: 1-208. 2004; Bárbara et al., An. Jard. Bot. Madr., 62: 69-100. 2005; Leghari et al., Int. J. Phycol. Phycochem., 1(2): 151-158. 2005; Matula et al., Pol. Polar Res., 28(4): 283-315. 2007; Patova & Demina, Inland Water Biol., 1(1): 54-63. 2008; Choudhary, Bangladesh J. Plant Taxon., 16(1): 57-63. 2009; Barinova et al., Turk J Bot., 33: 353-372. 2009; Smith, Int J Algae., 12(3): 230-256. 2010; Rai et al., Our Nature, 8: 336-354. 2010; Moro et al., Listado preliminar de especies marinas de Canarias, 174. 2011; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Barinova et al., Turk J Bot., 35: 729-774. 2011; Tauscher, Verhandlungen des Botanischen Vereins von Berlin und Brandenburg, 144: 177-192. 2011; Alfinito, Biodiversity Journal, 2 (3): 121-144. 2011; Gadea et al., Thalassas, 29(1): 35-58. 2013; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Halder & Sinha, Indian Journal of Plant Sciences, 2(3): 58-65. 2013; Patova, J. Sib. Fed. Univ. Biol., 3: 282-290. 2014; Afonso-Carrillo, Lista actualizada de las algas marinas de las islas Canarias, 1-64. 2014; Barinova & Kukhaleishvili, The Journal of Biodiversity, 113: 305-338. 2014; Barinova et al., Plant Biosyst., 138: 245-259. 2014; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far East, 1-271. 2014; Veen et al., Rijkswaterstaat

Waterdienst, Informatiehuis, 2015; Gkelis et al., Biodivers. Data J., 4(e10084): 1-103. 2016; Gallardo et al., Algas Boletín Informativo de la Sociedad Española de Ficología, 51: 7-52. 2016; Tandon et al. International Journal of Current Research, 8(12): 43390-43392. 2016; Barinova & Kukhaleishvili, Elixir BioSciences 104: 45934-45947. 2017; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Gaysina et al., Cryptogam Algol., 39(2): 167-198. 2018; Patova & Novakovskaya, Novosti Sistematiki Nizshikh Rastenii, 52(2): 311–353. 2018; Zotov, Algologia, 28 (2): 208-232, 2018; Rosset et al., Phycologia, 59(6): 1-7. 2020;

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

References: Komarek & Anagnostidis (1998); Desikachary (1959).

Description: Thallus gelatinous, spherical, ellipsoidal, brownish or violet colour; cells oblong, more or less ovoid or widely cylindrical with rounded ends, 3.6 - 6.2 μm wide, 6.7 - 12.3 μm long, densely or sparsely arranged, without individual envelopes, homogeneous mucilage.

Distribution: The species was reported from the rock pool and coastal waters of mangrove areas of Karachi (Bano and Siddiqui, 2003), mangrove environment of Brazil (Nogueira and Ferreira-Correia, 2001); epilithic and epipsammic (Silva, 1991), planktic (Martins *et al.,* 2012).

General Environment: Freshwater and marine species

Habitat and Ecology: Dark blackish or brownish mat collected from the mangrove soil surface and planktic form.

Specimen Examined: INDIA: Kerala; Alappuzha district, Pathiramanal, 9^0 37’ 09.78” N, 76^0 23’ 06.43” E, 28.10.2016. MES 13716. Kottayam district, Mekkara, 9^0 48’54.31” N 76^0 21’ 57.54” E, 12.08.2016. MES 13752. **(Plate 1, Fig. C).**

2. Chroococcaceae

Cells in colonies, single or forming colonies, mainly irregularly joined together into packet-like mucilaginous, cells mostly spherical, ellipsoidal, cylindrical, membranes thick, mucilaginous, lamellated. Colony shapeless, spherical, ellipsoidal or hemispherical. Cells divide successively in three or more different planes, reaching the original shape before the next division, but not into spherical form.

The family consists of 38 genera and 237 species. The family representing the genera *Gloeothece* and *Chroococcus* and their respective species are known to occur in the study area.

Key to the genera

1. Cells spherical, with distinct individual envelopes.....**1. *Chroococcus***
2. Cells ellipsoidal to cylindrical, with their own mucilaginous envelope ....**2. *Gloeothece***

1. *Chroococcus* Nageli 1849

Cells or group of cells surrounded by mucilaginous envelopes, cells spherical or subspherical, rarely solitary (initial stages) or in small groups of 2-16 individuals, sheath of individual cell is distinct, firm, generally lamellated. Cell content grey, grey-green, blue-green, olive green, yellowish, orange, reddish or violet, granular.

The genus has 94 species from diverse habitats, including freshwater, marine and extreme environmental conditions. Here, two species were described from the soil and pneumatophores from the mangrove ecosystems of southern Kerala.

Key to the species

1a. Sheath unlamellated 2

2a. Cells without sheath 3.5-7.5 µm wide .....**1. *C. indicus***

2b. Cells without sheath 4.8-7.2 µm wide.....**2. *C. pallidus***

1. *Chroococcus indicus* Zeller 1873

Zeller, J. Asiat. Soc. Bengal., 42(2): 175-193. 1873; Chu, Flora algarum sinicarum aquae dulcis Tomus II Chroococcophyceae, 1-161. 1991; Hu & Wei, The freshwater algae of China, 1-1023. 2006; Nikam et al., Biorem. Biodiv. Bioavail., 7(1). 70-80. 2012; Singh & Balasingh, Indian Journal of Fundamental and Applied Life Sciences, 2(4). 134-140. 2012; Paul & Anu, Int J Adv Lif Sci., 9(3): 302-306. 2016; Ashraf et al., Int. J. Curr. Res. Biosci. Plant Biol. 4(1), 32-36. 2017; Caraus, tudii si Cercetari Biologie 7: 1-1002. 2017; Jaiswal & Gavit, Int. J. Life Sci.,13. 126-134. 2019; Philip & Radhakrishnan, Int. J. Adv. Res., 8(9): 817-820. 2020.

References: Komarek & Anagnostidis (1998); Desikachary (1959).

Description: Thallus gelatinous, thin, pale brownish; cells single, oblong to sub-spherical, 3.5 μm to 7.5 μm wide, 3.4 μm to 10.8 μm long, olive-green; sheath hyaline, conspicuous, contents granular.

Distribution: This species was reported as epiphytic, edaphic (Bano & Siddiqui, 2007), planktic form (Sahoo et al., 2020),

Habitat: Appeared as a dark brownish coloured cyanobacterial mass on the pneumatophores of *Avicennia officinalis* L. and planktic form.

Specimen Examined: INDIA: Kerala; Alappuzha district, Ezhupunna, 9^0 49’ 24.43” N, 76^0 18’ 39.54” E, 24.11.2019. MES 13707; Thiruvananthapuram district, Kadinamkulam, 8^0 37’15.01” N 76^0 48’ 43.81” E, 14.07.2016. MES 13751. **(Plate 1, Fig. D).**

2. *Chroococcus pallidus* Nageli 1849

Nageli, Neue Denkschriften der Allg. Schweizerischen Gesellschaft für die Gesammten Naturwissenschaften, 10(7): 1-139. 1849; Forti in De Toni, Sylloge Algarum, 5: 19. 1907; Adams, Proceedings of the Royal Irish Academy, 27B (2): 11-60. 1908; Fremy, Myxo.d’Afr.equat. franc., 45. 1929; Geitler, Kryptogamenflora, 238. 1932; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Hirose et al., Illustrations of the Japanese fresh-water algae. 1-933. 1977; Hirano, Mem. Natl. Inst. Polar Res., 11: 1-25. 1979; Sheath & Steinman, Can J Bot., 60: 1964-1997. 1982; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Alvarez-Cobelas & Gallardo,

Acta Bot anca Malac., 13: 53-76. 1988; Chu, Flora algarum sinicarum aquae dulcis Tomus II Chroococcophyceae, 1-161. 1991; Mehwish & Aliya, Int. J. Phycol. Phycochem. 1(2): 117-124. 2005; Leghari et al., Int. J. Phycol Phycochem., 1(2): 151-158. 2005; Ersanli & Gonulol, Cryptogam Algol., 27: 289-305, 2006; Soylu & Gonulol, Cryptogam Algol., 27: 85-101. 2006; Johansen et al., Southeast Nat., 1: 99-134. 2007; Singh et al., Acta Bot Malac., 33. 17-28. 2008; Soylu & Gonulol, Turkish J. Fish. Aquat. Sci., 10: 53-60. 2010; Smith, Int J Algae, 12(3): 230-256. 2010; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Davydov, Algol Stud /Archiv für Hydrobiologie, 142: 29-44. 2013; Gadea et al., Thalassas, 29(1): 35-58. 2013; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Davydov, Folia Cryptogam Est., 51: 13-23. 2014; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Jaiswal, Algae of north-west Khandesh, 1-448. 2017; Davydov, Botanica, 24(2): 185-201. 2018; Stutz et al., Beiträge zu den Algen Baden-Wurttembergs, 1-504. 2018; Joshi & Singh, World J. Pharm. Res., 8(2): 525-539. 2019; Taskin et al., Turkiye suyosunlari liste, 1 -804. 2019; Rosset et al., Phycologia, 59(6): 1-7. 2020; Philip & Radhakrishnan, Int. J. Adv. Res., 8(9): 817-820. 2020; Kadam, International Advanced Research Journal in Science, Engineering and Technology, 8(1): 61-63. 2021.

References: Komarek & Anagnostidis (1998); Desikachary (1959).

Description: Colonies usually microscopic, gelatinous, amorphous. Cells single or in 2-3, without sheath 4.82-7.22 μm wide, with sheath 9.64-13.92 μm wide, elliptic oblong colonies, cells arranged in a common sheath, common sheath more or less delimited, inside confluent, colourless, structureless. Around the cells special colourless, more or less rounded, not lamellate envelops present.

Distribution: This species was reported as epilithic (Bano & Siddiqui, 2007) from the mangrove environments of Pakistan.

General Environment: Freshwater, terrestrial, marine species, possibly cosmopolitan distribution.

Habitat: On the soil surface which is appeared as green coloured cyanobacterial mat

Specimen Examined: INDIA: Kerala; Thiruvananthapuram district, Kadinamkulam, 14.07.2016. MES 13750; Kottayam district, Kumarakom, 9^0 36'59.46" N 76^0 25' 21.46" E, 13.11.2018. MES 13793. **(Plate 1, Fig. E).**

2. *Gloeothece* Nageli 1849

Colonies usually small, composed of sheathed cells or group of cells (2 or more), cells enclosed within their own gelatinous envelopes and sometimes surrounded by common mucilage. Cells and groups of cells enclosed in hyaline or concentrically limited at the margin. Cells widely oval, rounded at the ends, pale blue-green, blue-green, olive green or violet.

The genus has 46 species from diverse habitats, including freshwater, marine and extreme environmental conditions. Here, 3 species are described as epipsammic, benthic and planktic forms from the mangrove ecosystems of southern Kerala.

Key to the species

1a. Cells up to 6 μm wide..... 2

1b. Cells ellipsoidal, rounded, 7.5-8.6 μm wide..... **3. *G. ustulata***

2a. Cells oval or short cylindrical ..... **1. *G. rupestris***

2b. Cells round or ellipsoidal ..... **2. *G. samoensis***

1. *Gloeothece rupestris* (Lyngbye) Bornet in Wittrock & Nordstedt 1880

Wittrock & Nordstedt, Algae aquae dulcis exsiccatae. Fasc. 7. 301-350. 1880; Alg.de Schousb., Mem. Soc. Sci. Nat. Math.de Cherbourg, 28: 117. 1892; Forti in De toni Sylloge Algarum, 5: 63. 1907; Adams, Proc. R. Ir. Acad., 27B(2): 11-60. 1908; Fremy, Myxo.d'Afr.equat. franc., 52. 1929; Geitler, Kryptogamenflora, 221. 1932; Fritsch & Rich, Trans. R. Soc. South Africa, 25(2): 153-228. 1937; Parukutty, Proce. Ind.Acad. Sci., B, 11(3): 117-124. 1940; Skuja, Nova Acta Regiae Societatis Scientiarum Upsaliensis, Series 4, 14(5): 1-188. 1949; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Sheath & Steinman, Can J Bot, 60: 1964-1997. 1982; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Aboal, An. Jard. Bot. Madr., 45(1): 3-46. 1988; Alvarez-Cobelasm& Gallardo, Acta Bot Malac., 13: 53-

76. 1988; Aboal, Limnética, 5: 1-11. 1989; Chu, Flora algarum sinicarum aquae dulcis Tomus II Chroococcophyceae., 1-161, 1991; Poulin et al., Can. Field-Nat., 109: 27-110. 1995; Vinogradova et al., Cyanoprocaryotes and algae of continental Israel, 32-141. 2000; Aysel, V. J. Black Sea/Mediterranean Environment, 11: 1-124. 2005; Hu & Wei, The freshwater algae of China, 1-1023. 2006; Johansen et al., Southeast. Nat., 1: 99-134. 2007; Hauer, Fottea, 8(2): 129–132. 2008; Singh et al., Acta Bot Malac., 33. 17-28. 2008; Wołowski & Kowalska, Fragmenta Floristica et Geobotanica Polonica, 16(1): 145-154, 2009; Choudhary, Bangladesh J. Plant Taxon., 16(1): 57-63. 2009; Nugari et al., Int. Biodeterior. Biodegradation, 63(6): 705-711. 2009; Smith, Int J Algae, 12(3): 230-256. 2010; Rai et al., Our Nature, 8: 336-354. 2010; Pham et al., A checklist of the algae of Singapore, 1-100. 2011; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Gadea et al., Thalassas, 29(1): 35-58. 2013; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Srivastava et al., Trop. Plant Res., 1(2): 11–16. 2014; Barinova et al., Turk J Bot., 39: 535-546. 2015; Gkelis et al., Biodivers Data J., 4(e10084): 1-103.2016; Caraus, Studii si Cercetari Biologie, 7: 1-1002, 2017; Patova & Novakovskaya, Novosti Sistematiki Nizshikh Rastenii 52(2): 311–353. 2018; Barinova & Niyatbekov, Biodivers. Int. J., 2(3): 236-263. 2018; Popkova & Mazina, Journal of Environmental Research, Engineering and Management, 75(3): 71-83, 2019; Taskin et al., Türkiye suyosunlari listei, 1-804. 2019; Joshi & Singh, World J. Pharm. Res., 8(2): 525-539. 2019.

Synonyms: *Palmella rupestris* Lyngbye 1819; *Microhaloa rupestris* (Lyngbye) Kützing 1843; *Micraloa rupestris* (Lyngbye) Trevisan 1848; *Gloeocystis rupestris* (Lyngbye) Rabenhorst 1863; *Anacystis rupestris* (Lyngbye) F.E.Drouet & W.A.Daily 1942; *Coccochloris stagnina* f. *rupestris* (Lyngbye) Drouet & Daily; *Gloeothece rupestris* var. *maxima* West 1892; *Gloeothece rupestris* f. *maxima* (West) Hollerbach 1938.

References: Komarek & Anagnostidis (1998); Desikachary (1959).

Description: Colonies small, enveloped by small sheaths, with solitary sheathed cells. Gelatinous envelops around the cell. Cells ellipsoidal to cylindrical, without

envelope 4.13-5.80 μm wide, 7.58- 8.74 μm long, contents pale blue-green, with sheath 8.76 μm wide, 10.75 μm long.

Distribution: This species was reported from the mangrove environment of Puthuvaippu (Joseph & Saramma, 2016); mangrove swamps and epiphytic (Bano & Siddiqui, 2007), pneumatophores (epiphytic) (Zaib-Un-Nisa et al., 2000, Branco et al., 1996).

General Environment: Freshwater, marine species, possibly cosmopolitan distribution.

Habitat: On the soil surface which is appeared as a green coloured cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Thiruvananthapuram district, Kadinamkulam, 9^0 49' 24.43" N, 76^0 18' 39.54" E, 14.10.2016. MES 13750. Kottayam district, Kumarakom, 9^0 36'59.46" N 76^0 25' 21.46" E, 13.11.2018. MES 13793. **(Plate 1, Fig. F).**

2. *Gloeothece samoensis* Wille 1913

Wille, Susswasseralg. Samosa-Ins., Hedwigia, 53:144. 1913; in Rchinger, Bot. and Zool. Ergebn. Samoa and Solomoninseln, 6. 1915; Geitler, Kryptogamenflora, 219. 1932; Asencio & Aboal, Anales Jard. Bot. Madrid, 55: 137-138. 1997; Vinogradova et al., yanoprocaryotes and algae of continental Israel., 2000; Werner, Catálogo de plantas e fungos do Brasil., 356-366. 2010; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Taskin et al., Turkiye suyosunlari listei, 1-804. 2019; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Chu, Flora algarum sinicarum aquae dulcis Tomus II Chroococcophyceae, 1-161. 1991; Azevedo et al., Hoehnea, 23(1): 1-38. 1996; Singh et al., Acta Bot Malac., 33. 17-28. 2008; Branco et al., Cryptogam Algol., 30(1): 135-152. 2009; Gama Jr et al., Phytotaxa 178(2): 61–97, 2014.

References: Komarek & Angnostidis (1998); Desikachary (1959); Gama Jr et al. (2014).

Description: Round, oblong to elliptical colonies, with sheath 9.85-20.43 μm diam., with 2 cells. Sheath firm to diffluent, hyaline, conspicuous, smooth. Cells oblong to

ellipsoid, 3.33-5.82 μm wide, 5.26–8.42 μm long. Cell content granulated, blue-green to olive green.

Distribution: This species was reported as epiphytic, epizoic from the mangrove environment of Pakistan (Bano & Siddiqui, 2007).

General Environment: Freshwater species

Comments: New record to the marine cyanobacterial flora of India

Habitat: On the soil surface which is appeared as green coloured cyanobacterial mat

Specimen Examined: INDIA: Kerala; Alappuzha district, Pathiramanal, 9^0 37' 09.78" N, 76^0 23' 06.43" E, 28.10.2016. MES 13775. Kottayam district, Kumarakom, 9^0 36'59.46" N 76^0 25' 21.46" E, 17.11.2018. MES 13792. **(Plate 2, Fig. A-B).**

3. *Gloeothece ustulata* Beck-Mannagetta 1929

Beck-Mannagetta, Archiv für Protistenkunde 66: 1-10. 1929; Jevtić, Croatian Journal of Fisheries: Ribarstvo, 44(6): 123-134. 1989; Kaštovský et al., Cyanobacteria on rock surfaces, 87-140. 2021.

References: Komarek &Anagnostidis (1998).

Description: Colonies yellowish, irregularly spherically elongate, envelopes around cells hyaline, not lamellated, colourless or slightly bluish coloured. Cells widely elliptical, with rounded, almost twice approaching or longer than wide, with homogeneous, slightly granulate content, 7.52 – 8.63 μm wide, 15.5 μm long.

Distribution: No distributional records were found along with the marine environment.

General Environment: Aerophytic species

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Appeared as dark brownish coloured benthic and planktic cyanobacterial mat

Specimen Examined: INDIA: Kerala; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 18.08.2016, MES 13764. 24.09.2017, MES 13776; Kumbalam, 9^0

54’ 41.96” N, 76^0 18’ 32.36” E, 28.08.2018, MES 21511; Kollam district, Ayiramthengu, 9^0 07’33.93” N 76^0 28’ 45.34” E, 22.11.2018, MES 21535. **(Plate 2, Fig. C).**

2. Order: Synechococcales

Key to the order

1. Coccoid, bacilloid unicellular, colonial and simple filamentous forms with peripherally arranged thylakoids ..... **Synechococcales**

Synechococcales

The order is characterised by coccoid and bacilloid, unicellular and colonial and simple filamentous forms with peripherally arranged thylakoids.

As many as 13 families, including 95 genera and 984 species, are known to occur in all biotopes. Among these, 3 families representing 3 genera and 3 species are reported from the study area.

Key to the family

1. Cells solitary or in colonies, cells spherical, oval or elongate to rod- shaped, in several species surrounded by individual gelatinous envelopes .... **1. Merismopediaceae**
2. Cells solitary without mucilage or forming mucilaginous colonies, cells widely oval, oval, short cylindrical or rod- shaped to elongate cylindrical .... **2. Synechococcaceae**
3. Trichomes uniseriate, usually not distinctly arrowed towards ends, without their own sheaths ..... **3. Trichocoleusaceae**

1. Merismopediaceae

Cells solitary or in colonies, spherical mucilaginous colonies, mucilage mainly colourless. Cells spherical, oval or elongate to rod-shaped, in several species surrounded by individual gelatinous envelopes. Cell division by binary fission in two planes perpendicular to each other. Reproduction by the disintegration of colonies, rarely by solitary cells.

The family consists of 10 genera and 170 species. The family representing the species *Aphanocapsa grevillei* is known to occur in the mangrove ecosystem of southern Kerala and is presented.

Key to the genera

1. Colonies mucilaginous, with irregularly arranged cells, cells spherical .... **1. *Aphanocapsa***

1. *Aphanocapsa* Nageli 1849

Colonies many-celled, irregular, usually amorphic, microscopic, gelatinous, with irregularly, loosely or densely distributed cells; mucilage colourless, fine, diffluent or yellowish, brownish or bluish, cells without own mucilaginous envelopes. Cells spherical, after division hemispherical, pale greyish blue or blue-green, rarely bright blue-green or olive-green, Reproduction by the dissociation of colonies, sometimes up to small groups of cells, and by solitary cells liberated from a colony.

There are 64 species are known to occur so far. Here only 1 species is described from the pneumatophores and benthic form from the mangrove ecosystems of southern Kerala.

Key to the species

1. Cells 3.72 – 4.75 μm diameter, bright blue-green..... **1. *A. grevillei***

1. *Aphanocapsa grevillei* (Berkeley) Rabenhorst 1865

Rabenhorst, Flora europaea algarum aquae dulcis et submarinae, 1-319. 1865; Hylander, Bulletin State of Connecticut State Geological and Naural History Survey, 42: 1-245. 1928; Skuja, Symbolae Botanicae Upsalienses 9(3): 1-39. 1948; Skuja, Nova Acta Regiae Societatis Scientiarum Upsaliensis Series IV, 16(3): 1-404. 1956; Adams, Proc. R. Ir. Acad., 27B (2): 11-60. 1908; Tell, Bibliotheca Phycologica, 70:1-283. 1985; Fenchel et al., Ophelia, 43: 45-100. 1995; Sheath & Steinman, Can J Bot., 60: 1964-1997. 1982; Poulin et al., Can. Field-Nat., 109: 27-110. 1995; Vitenaite, Bot. Lith., 7(4): 343-364. 2001; Hallfors, Balt. Sea Environ. Proc., 95: 1-208. 2004; Aysel, J Black Sea/Mediterranean Environment, 11: 1-124. 2005; Mehwish & Aliya, Int. J. Phycol. Phycochem. 1(2): 117-124. 2005; Hu &

Wei, The freshwater algae of China, 1-1023. 2006; Hasler et al., Fottea, 7(1): 49-68. 2007; Johansen et al., Southeast. Nat., 1: 99-134. 2007; Barinova et al., Turk J Bot., 33: 353-372. 2009; Gonzalez, Catalogo de las algas y cianoprocariotas dulciacuícolas de Cuba. 1-147. 2009; Barinova, J. Arid Environ., 74: 765–776. 2010; Bostock & Holland, Census of the Queensland Flora, 1-320. 2010; Rai et al., Our Nature 8: 336-354. 2010; Smith, Int J Algae, 12(3): 230-256. 2010; Patova & Demina, Inland Water Biol., 1(1): 54-63. 2008; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Barinova et al., Turk J Bot., 35: 729-774. 2011; Tauscher, Verhandlungen des Botanischen Vereins von Berlin und Brandenburg, 144: 177-192. 2011; Davydov, Algol Stud /Archiv für Hydrobiologie, 142: 29-44. 2013; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Varol & Sen, Journal of Fisheries Sciences, 8: 1-14. 2014; Figueroa-Torres e al., CienciaUAT, 9(2): 15-29. 2015; Gadea et al., Thalassas, 29(1): 35-58. 2013; Davydov, Folia Cryptogam. Est., 51: 13-23. 2014; Barinova & Kukhaleishvili, The Journal of Biodiversity, 113: 305-338. 2014; Tauscher, Archiv der Freunde der Naturgeschichte in Mecklenburg, 53: 107-122. 2014; Patova et al., Plants and fungi of the polar deserts in the northern hemisphere, 133-166. 2015; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Barinova & Kukhaleishvili, Elixir Bio Sciences, 104: 45934-45947. 2017; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Gainutdinov et al., Cave Karst Sci., 44(3): 119-126. 2017; Davydov, Botanica, 24(2): 185-201. 2018; Zotov, Algologia, 28(2): 208-232. 2018; Barinova & Niyatbekov, Biodivers Int J., 2(3): 236-263. 2018; Popkova & Mazina, Journal of Environmental Research, Engineering and Management, 75(3): 71-83. 2019; Kopyrina et al., International Journal of Oceanography and Hydrobiology, 49(2): 99-122. 2020.

Synonyms: *Coccochloris grevillei* (Berkeley) Hassall 1845; *Anacystis grevillei* (Berkeley) Kützing 1849; *Microcystis grevillei* (Berkeley) Elenkin 1938; *Gloeocystis grevillei* (Berkeley) Drouet & Dailey 1948.

References: Komarek & Anagnostidis (1998); Desikachary (1959).

Description: Thallus or colonies more or less spherical or hemispherical, greenish, mucilaginous, with irregularly and densely aggregated cells. Cells spherical or oval, 3.72 – 4.75 μm diameter, contents finely granular, individual envelops not distinct.

Distribution: This species was reported from the mangrove swamps and epilithic from Farasan Archipelago (Hussain & Khoja, 1993).

General Environment: Freshwater species.

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Found attached to the pneumatophores of *Avicennia officinalis* L. and as benthic form from the mangrove environment.

Specimen Examined: INDIA: Kerala; Kottayam district, Mekkara, 9^0 48'54.31" N 76^0 21' 57.54" E. 07.04.2015, MES 13770. 18.10.2016, MES 13787; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 14.08.2019, MES **(Plate 2, Fig. D-E).**

2. Synechococcaceae

Cells solitary, without mucilaginous colonies, mucilaginous envelopes lacking, colourless, diffluent at the margin. Cells widely oval, oval, short cylindrical, rod-shaped to elongate cylindrical. Cell division only in one direction, perpendicular to the long axis of the cell, symmetrically or asymmetrically.

The family consists of 19 genera and 130 species. The family representing the species *Anathece bacteriosa* is known to occur in the mangrove ecosystem of southern Kerala and is presented.

Key to the genera

1. Colonies microscopic, irregular, with colourless, homogenous, diffluent slime, cells without their own mucilaginous envelopes, (0.8)1-2(6) x 0.3–2 μm..... .....**1. *Anathece***

1. *Anathece* (Komarek & Anagnostidis) Komarek, Kastovsky & Jezberova, 2011

Colonies multicellular, gelatinous, with individual cells arranged irregularly, loosely or densely in a common mucilage, spherical or amorphous, greyish, green, blue-green or brown. Common mucilage distinct, delimited, irregular, colourless or

(rarely) yellowish, yellow brown (rarely reddish), with cells in marginal parts enveloped by their own distinct and/or lamellose, delimited sheaths. Cells rod shaped, widely oval to cylindrical with widely rounded ends, straight or slightly arcuate, mostly (2) 3–9 (12) x (1) 2.5–5 (8) mm. Cell division by binary fission in one plane in successive generations, perpendicular to the long axis.

7 species are known to occur. Here only 1 species is described as benthic form from the mangrove ecosystems of southern Kerala.

Key to the species

1. Cells shortly rod shaped, 1.32- 2.6 x 0.83-1.21 μm diameter……..**1. *A. bacteriosa***

1. *Anathece bacteriosa* (Komarek & Komarkova-Legnrova) Komarek, Kastovsky & Jezberova 2011.

Komarek et al., Eur. J. Phycol., 46(3): 315-326. 2011; Komárek, Hydrobiologia, 764(1): 259-270. 2016.

Synonyms: *Aphanothece bacteriosa* Komarek & Komarkova-Legnerova 2007

References: Komarek et al. (2011); Komarek & Komarkova-Legnerova (2007).

Description: Thallus gelatinous, colonies macroscopic, irregular, mucilaginous, diffluent or with delimited margin, olive green, with irregularly agglomerated cells. Cells shortly rod-like, 1.32- 2.6 x 0.83-1.21 μm diameter.

Distribution: No distributional records were found in the marine environment.

General Environment: Freshwater species

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Dark green coloured benthic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Kottayam district, Mekkara, 9^0 48’54.31” N 76^0 21’ 57.54” E. 14.03.2016, MES 13738. 14.11.2019, MES 13788. **(Plate 2, Fig. F).**

3. Trichocoleusaceae

Filaments containing few to numerous trichomes, situated parallel. Sheaths not lamellated, often diffluent, colourless, often distant from the fasciculated trichomes. Trichomes 0.5-2.5 (3) µm wide. Cell always longer than wide. Apical cell acute conical, obtuse or rounded, without calyptra or thickened outer cell wall. Reproduction by hormogonia which separate after disintegration from the terminal parts of trichomes.

The family consists of 1 genus and 19 species. The family representing the species *Trichocoleus delicatulus* is known to occur in the mangrove ecosystem of southern Kerala and is presented.

Key to the genera

1. Wide sheaths open at the ends, trichomes without own sheaths, usually tightly joined into fascicles or clusters, trichomes up to 3 µm wide, cells always longer than wide ……**1. *Trichocoleus***

1. *Trichocoleus* Anagnostidis, 2001

Filaments containing few to numerous trichomes situated parallel. Sheaths not lamellated, often diffluent, colourless, usually slightly or clearly distant from the fasciculated trichomes. Trichomes 0.5-2.5 (3) µm wide. Cells always longer than wide. Apical cells acute-conical, obtuse or rounded, without calyptra or thickened outer cell wall. Reproduction by hormogonia, which separate after disintegration from the terminal parts of trichomes.

19 species are known to occur. Only one planktic species were identified from the mangrove ecosystems of southern Kerala, which is described here.

Key to the Species

1. Trichomes 1.22-2.0 µm wide, apical cells cylindrical, rounded….**1. *T. delicatulus***

1. *Trichocoleus delicatulus* (West & G.S.West) Anagnostidis 2001

West & West, J. R. Microsc. Soc., 16: 149-165. 1896; Anagnostidis, Preslia, Praha, 73: 359-375. 2001; Flechtner et al., West. N. Am. Nat., 68(4): 405-436. 2008; Alwathnani & Johansen, Monographs of the Western North American Naturalist,

5(1), 71-89. 2011; Komárek & Kovacik, Polar Boi., 36(12): 1811-1822. 2013; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian, 1-271. 2014; Ulcay, Turk J Bot., 39(1), 173-188. 2015; Davydov, Czech Polar Rep., 6(1): 66-79. 2016; Davydov, Czech Polar Rep., 7(1): 94-108. 2017; Davydov, Botanica, 24(2): 185-201. 2018; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Davydov, Botanica, 24(2): 185-201. 2018.

Synonyms: *Microcoleus delicatulus* West & G.S.West 1896

Reference: Anagnostidis (2001).

Description: Filaments long, unbranched, nearly straight. Sheaths commonly completely diffluent, open, containing numerous parallel arranged trichomes. Trichome greenish, 1.22-2.0 µm wide. Cells somewhat longer than wide, 1.82- 2.65 µm long. Apical cells cylindrical and rounded.

Distribution: No distributional records were found along the marine environment.

General Environment: Freshwater species.

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Dark green coloured planktic form.

Specimen Examined: INDIA: Kerala; Thiruvananthapuram district, Kureekkadavu; 8^0 46'11.14" N 76^0 42' 36.69" E. 22.05.2017. MES 13755; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 14.11.2018, MES 21429. **(Plate 3, Fig. A-C).**

3. Order: Spirulinales

Key to the order

1. Trichomes regularly and usually tightly screw-like coiled .....**Spirulinales**

The order is characterised by typical, regularly screw-like coiled trichomes without sheaths. Only one family is known to occur in this order in almost all biotopes including freshwater, marine and terrestrial conditions, i.e., Spirulinaceae.

Key to the family

1. Trichome without sheaths, regularly and usually tightly screw-like coiled…... ……...……**1. Spirulinaceae**

1. Spirulinaceae

The family is characterised by the trichomes without sheaths, or enveloped by very thin, fine, colourless, homogenous, diffluent slime, regularly and tightly screw-like coiled, solitary or in colonies. Reproduction by motile hormogonia or by the disintegration of trichomes, without necridic cells.

The family consists of 3 genera and 55 species, which represents the genus *Spirulina* and its 3 species are known to occur from the diverse habitats of soil and planktic form in the study area.

Key to the genera

1. Tightly coiled (regularly spirally coiled) trichomes; coils touch one to another……..…**1. *Spirulina***

1. *Spirulina* Turpin ex Gomont 1892

Trichomes short to long, cylindrical, tightly or loosely coiled into a more or less regular spiral, blue-green, olive green, yellowish, brownish, violet or grey in colour. Sheath absent. Apical cell rounded, hemispherical, without calyptra or thickened outer cell wall.

A cosmopolitan genus with 51 species from diverse habitats, including freshwater, marine and extreme environmental conditions. 3 species are known to occur from the mangrove ecosystem and are presented in this chapter.

Key to the species

1a. Spirals distant ..... **2. *S. major***

1b. Spirals touch one another 2

2a. Spirals 1.7-2.8 µm wide..... **1. *S. labyrinthiformis***

2b. Spirals 5.3-6.4 µm wide.....**3. *S. spirulinoides***

1. *Spirulina labyrinthiformis* Gomont 1892

Gomont, Monogr. Oscillariees, 255. 1892; Forti in De toni, Sylloge Algarum, 5:215. 1907; Fremy, Myxo.d'Afr. equat.franc. 237. 1929; Geitler, Kryptogamenflora, 928. 1932; Fremy, Cyano, cote d'Eur., 134, 1933; Iyengar & Desikachary, J.Madras Univ. B., 16: 37-68. 1944; Skuja, H. Nova Acta Regiae Societatis Scientiarum Upsaliensis, 14(5). 1-188. 1949; Feldmann, Travaux Station Biologique de Roscoff, Nouvelle Série Suppl. 6: 1-152. 1954; Hirose et al. Illustrations of the Japanese fresh-water algae. 1-933. 1977; Tell, G. Bibliotheca Phycologica, 70:1-283. 1985; Lee & Kang, Korean Journal of Phycology, 1(1): 311-325. 1986; Vinogradova et al. Biodiversity of cyanoprocaryotes, algae and fungi of Israel. 32-141. 2000; Silva & Pienaar, Bot Mar., 43: 11-27. 2000; Whitton et al. A coded list of freshwater algae of the British Isles, 2003; Aysel, J Black Sea/Mediterranean Environment, 11: 1-124. 2005; Leghari et al. Int. J. Phycol. Phycochem., 1(2): 151-158. 2005; Ruiyu, Checklist of biota of Chinese seas. 1-1267. 2008; González. Catálogo de las algas y cianoprocariotas dulciacuícolas de Cuba. 1-147. 2009; Werner, Catalogo de plantas e fungos do Brasil. 356-366. 2010; Bostock & Holland, Census of the Queensland Flora, 1-320. 2010; Moro et al. istado preliminar de especies marinas de Canarias. 174. 2011; John et al. The freshwater algal flora of the British Isles, 2011; Widey & Merican, Zealand inventory of biodiversity, 50-69. 2012; Afonso-Carrillo, J. Lista actualizada de las algas marinas de las islas Canarias,1-64. 2014; Veen et al. Rijkswaterstaat Waterdienst, Informatiehuis Water. 2015; Barinova et al. Turk J Bot., 39: 535-546. 2015; Gkelis et al. Biodivers Data J., 4(e10084): 1-103. 2016; Gallardo et al. Algas Boletín Informativo de la Sociedad Española de Ficología, 51: 7-52. 2016; Caraus et al. Studii si Cercetari Biologie, 7: 1-1002. 2017; Bangmei, Flora algarum marinarum sinicarum Tomus I Cyanophyta., 1-176. 2017; Maulood et al. Checklist of algal flora in Iraq, 1-94. 2013; Barinova & Niyatbekov, Biodivers Int J., 2(3): 236-263. 2018; Taskin et al. Türkiye suyosunlari listei, 1-804. 2019.

Synonyms: *Oscillatoria labyrinthiformis* (Gomont) Bourrelly 1970; *Oscillatoria subsalsa* f. *minor* Compère 1967; *Oscillatoria pseudolabrinthiformis* Iltis 1970.

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Description: Thallus soft, thin, mucilaginous, blue-green to shining brilliant green. Trichomes bright blue-green, expanded, 1.3-2 μm wide, 3.1-4.2 μm long, regularly densely screw-like coiled, straight or variously curved. Coils dextral, regularly tightly joined to one another, 1.7-2.8 μm wide. Apices rounded.

Distribution: This species was reported from the mangrove environment of Pakistan (Ahmed et al., 2016) and Puthuvaippu, Kerala (Joseph & Saramma, 2016), Pichavaram, Porto Novo and Mudasal Odai (Sakthivel & Kathiresan, 2013), Muthupet (Sudha et al., 2007); benthic (Silva & Pienaar, 1999); epiphytic (Potts & Whitton, 1980); epiphytic, epizoic, epilithic, edaphic and rock pool water of mangrove ecosystem (Bano & Siddiqui, 2007); epilithic, edaphic and rock pool water of mangrove ecosystem (Bano & Siddiqui, 2003); microbial mat and mangrove swamps of Farasan Archipelago (Hussain & Khoja, 1993).

General Environment: Freshwater, marine or brackish water, attached to submerged stones and sand, probably distributed worldwide, cosmopolitan.

Habitat: Planktic and benthic forms appeared as green coloured cyanobacterial mass.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 12.08.2018, MES 13728, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E,13.01.2017, MES 21439; Kollam district, Ayiramthengu, 9^0 07'33.93" N 76^0 28' 45.34" E, 22.11.2018, MES 21430. **(Plate 3, Fig. D-F)**.

2. *Spirulina major* Kutzing ex Gomont 1892

Kutzing, Phyc.gen.,183. 1843; Gomont, Monographie des Oscillariées., 251. 1892; Batters, Journal of Botany, British and Foreign, 40. 1-107. 1902; Forti, in De Toni, Syllogue Algarum, 5, 210. 1907; Adams, Proc. R. Ir. Acad., 27 B (2): 11-60. 1908; Fremy, Myxo.d'Afr.equat. franc., 234. 1929; Geitler, Kryptogamenflora. 930. 1932; Reinhold, Annales de la Societe Geologique de Belgique, 61(1): 39-47. 1937; Skuja, Nova Acta Regiae Societatis Scientiarum Upsaliensis, Series 4, 14(5): 1-188. 1949; Feldmann, Travaux Station Biologique de Roscoff, Nouvelle Serie Suppl. 6: 1-152. 1954; Dawson, Pacific Science, 11: 92-132. 1957; Hirose et al., Illustrations of the Japanese fresh-water algae. 933.1977; Prescott, Algae of the Western Great

Lakes area, 1-977. 1962; Papenfuss, Israel Journal of Botany, 17: 1-118. 1968; Cobelas, Collectanea Botanica, 13: 709-722. 1982; Aboal & Llimona, Limnetica, 1: 141-147. 1984; Aboal & Llimona, Anales de Biologia, 2(2): 1-17. 1984; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Lee & Kang, Korean Journal of Phycology, 1(1): 311-325. 1986; Aboal, M. An. Jard. Bot. Madr., 45(1): 3-46. 1988; Alvarez-Cobelas & Gallardo, Acta Bot Malac., 13: 53-76. 1988; Aboal, Limnetica, 5: 1-11. 1989; Poulin et al. The Canadian Field-Naturalist 109: 27-110. 1995; Kristiansen & Lind, Nordic Journal of Botany, 15: 443-448. 1995; Day et al., Flora of Australia, 4:1-276. 1995; Cvijan & Blazencic, Flora algi Srbije. Tom 1. Cyanophyta. 1-290. 1996; Barbara & Cremades, Botanica Marina, 39: 371-388. 1996; Aboal et al., Hydrobiologia, 340: 101-107. 1996; Aboal, Arch. Hydrobiol. Algol Stud., 82: 117-131. 1996; Calvo et al., Bot Mar., 42: 343-353. 1999; Vinogradova et al. Cyanoprocaryotes and algae of continental Israel, 32-141. 2000; Ling & Tyler, Bibliotheca Phycologica, 105: 1-643. 2000; Vitenaite, Botanica Lithuanica, 7(4): 343-364. 2001; Calvo & Barbara, Nova Acta Cientifica Compostelana (Bioloxia) 12: 5-34. 2002; Pena & Barbara, Nova Acta Cientifica Compestelana (Bioloxia), 12: 35-66. 2002; Mauch & Schmedtje, Informationsberichte des Bayerischen Landsamtes für Wasserwirtschaft Heft, 01(03):1-388. 2003; Whitton et al., A coded list of freshwater algae of the British Isles. 2003; Afsharzadeh et al., Iranian Journal of Biology, 14: 32-45. 2003; Hällfors, Baltic Sea Environment Proceedings, 95: 1-208. 2004; Sherwood, Bishop Museum Occasional Papers. 80: 1-26. 2004; Barbara et al., An. Jard. Bot. Madr., 62: 69-100. 2005; Aysel, J Black Sea/Mediterranean Environment, 11. 1-124. 2005; Hu & Wei, The freshwater algae of China. 1-1023. 2006; Barinova et al. Flora Mediterranea, 16: 111-132. 2006; Ersanli & Gonulol, Cryptogamie Algologie, 27: 289-305. 2006; Gul et al., Int. J. Phycol. Phycochem., 3(1): 37-48. 2007; Chu et al. Flora algarum sinicarum aquae dulcis Tomus IX Cyanophyta Hormogonophyceae, 1-312. 2007; Perez et al., Acta Bot. Croat., 68: 11-27. 2009; Gonzalez, A. Catalogo de las algas y cianoprocariotas dulciacuicolas de Cuba, 1-147. 2009; Barinova et al. Turkish Journal of Botany, 33: 353-372. 2009; Siddiqui et al., Encyclopaedia of flora and fauna of Bangladesh, 1-415. 2009; Werner, Cyanophyceae. In: Catalogo de plantas e fungos do Brasil, 1:356-366. 2010; Rodriguez & Moliner, Bol. Cien. Nat.

RIDEA 51: 135-212. 2010; Bostock & Holland, Census of the Queensland Flora. 1-320. 2010; Alfinito, Biodiversity Journal, 2(3): 121-144. 2011; Tsuda & Fisher, Micronesica, 43(1): 14-50. 2012; Widey & Merican, New Zealand inventory of biodiversity, 50-69. 2012; Villeneuve et al., J of Phycol., 48(2): 275-284. 2012; Gadea et al., Thalassas, 29(1): 35-58. 2013; Tsuda & Walsh, Micronesica, 2:1-91. 2013; Rai et al., Our Nature, 8: 336-354. 2010; Maulood et al., Checklist of algal flora in Iraq. 1-94. 2013; Nguyen et al. Bot Mar., 56(3): 207-227. 2013; Barinova et al., The Journal of Biodiversity, 113: 305-338. 2014; Nassar et al., Annu. Res. Rev. Biol., 4(23): 3566-3585. 2014; Tauscher, Bestandssituation der Pflanzen und Tiere in Sachsen-Anhalt. 2014; Barinova et al. Plant Biosyst., 138: 245-259. 2014; Varol & Sen, Journal of Fisheries Sciences. 8: 1-14. 2014; Figueroa-Torres et al., CienciaUAT, 9(2): 15-29. 2015; Mohamed & Al-Shehri. Bot Mar., 58(1): 23-34. 2015; Rao & Gupta, Algae of India, 3: 1-93. 2015; Veen et al., Rijkswaterstaat Waterdienst, Informatiehuis Water, 2015; Barinova et al., Turk J Botany., 39, 535-546. 2015; Phang et al., Raffles Bulletin of Zoology Supplement 40: 13-59. 2016; Alamos, Acta Bot Malac., 41: 5-17. 2016; Tauscher, L. Pflanzen und Tiere in Sachsen-Anhalt Ein Kompendium der Biodiversitat. 63-112. 2016; Gallardo et al. Algas. Boletin Informativo de la Sociedad Espanola de Ficologia, 51: 7-52 2016; Gkelis, Biodivers Data J., 4(e10084): 1-103. 2016; Hindak & Hindakova. Algae. In: Zoznam nizsich a vyssich rastlin Slovenska, 2016; Al-Saboonchi & Al-Shawi, J. Int. Acad. Res. Multidiscip., 3(12): 71-86. 2016; Barinova & Kukhaleishvili, Elixir Bio Sciences, 104: 45934-45947. 2017; Caraus, Studii si Cercetari Biologie, 7:1-1002. 2017; Xia, Flora algarum marinarum sinicarum Tomus I Cyanophyta, 1-176. 2017; Jaiswal, Algae of north-west Khandesh, 1-448. 2017; Karlson et al., Nordic Microalgae, 2018; Zotov, Algologia, 28(2): 208-232. 2018; Stutz et al., Beitrage zu den Algen Baden-Wurttembergs. Band 1 Allgemeiner Teil, 1-504. 2018; Perez et al., Algas, 55: 25-35. 2019; Torres-Arino et al., Cybella, 50 (1): 1-97.2019; Barinova & Niyatbekov, Biodivers Int J., 2(3): 236-263. 2018; Taskin et al., Turkiye suyosunlari listei,1-804. 2019; Pellizzari et al., Scientia Marina, 84(3): 1-16. 2020; Kopyrina et al., International Journal of Oceanography and Hydrobiology, 49(2): 99-122, 2020.

Synonyms: *Arthrospira major* (Kutzing ex Gomont) W.B.Crow 1892; *Spirulina oscillariorides* Turpin 1827; *Spirulina major* f. *constans* Emoto & Hirose 1952; *Oscillatoria oscillariorides* Iltis 1970.

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Description: Thallus soft fragile, blue-green mats, Trichome pale to bright blue-green, 1.2-1.9 µm wide, regularly screw-like coiled, not constricted at the cross walls, 175.2- 487.3 µm long, coils left-handed, not joined one to another, 2.5-4.3 µm wide, distance with the spirals 2.6-3.9 µm long.

Distribution: This species was reported from the mangrove swamps and microbial mats of Farasan Archipelago (Hussain & Khoja 1993); mangrove backwaters of Pakistan (Ahmed et al., 2016); epiphytic, epizoic, epilithic, edaphic and coastal waters of mangrove ecosystems of Karachi coast (Bano & Siddiqui, 2007); epilithic, edaphic, coastal waters of Karachi coast (Bano & Siddiqui, 2003); planktonic form from Pichavaram (Nedumaran et al., 2008) and Sundarbans mangal (Sen & Naskar, 2003); Muputhupet mangrove estuary (Selvakumar & Sundararaman, 2001); mangrove sediments of Pichavaram and Porto Novo (Sakthivel & Kathiresan, 2013); mangrove area of Pernambuco, Brazil (Branco et al., 2003).

General Environment: Freshwater, marine and brackish shallow stagnant waters, distributed worldwide, possibly cosmopolitan.

Comments: New record to the mangrove cyanobacterial flora of Kerala.

Habitat: Green coloured mats from the soil (epipsammic).

Specimen Examined: INDIA: Kerala; Kollam district, Ayiramthengu, 9^0 07’ 33.93” N 76^0 28’ 45.34” E, 10.01.2018, MES 13722. **(Plate 3, Fig. G)**.

3. *Spirulina spirulinoides* (Ghose) Geitler 1925

Geitler, L. *Die Susswasser-Flora Deutschlands, Osterreichs und der Schweiz*. 12:1-450. 1925; Aysel. J Black Sea Mediterr Environ 11: 1-124. 2005; Torres-Arino et al. Cybella 50(1): 1-97, 2019; Taskin et al. Türkiye suyosunlari listei. 1-804 2019.

Reference: Komarek & Anagnostidis (2005).

Synonyms: *Arthrospira spirulinoides* Ghose 1924

Description: Trichomes blue-green, densely coiled with touching coils, regularly screw-like coiled, coils dextral, regularly tightly joined to one another with slightly visible cross walls. Cells 5.32-6.41 μm wide, 4.62-9.23 μm long.

Distribution: No distributional records were found along with the marine environment.

General Environment: This is a freshwater species.

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Planktic form appeared as a dark green coloured cyanobacterial mass.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 12.10.2018, MES 13729. **(Plate 4, Fig. A-B)**.

4. Order Oscillatoriales

Key to the order

1. Filamentous without heterocytes and akinetes ……**1. Oscillatoriales**

4. Order: Oscillatoriales

The order is characterised by the filamentous cyanobacteria without heterocytes and akinetes, with or without sheaths, appearance of the filament, false branching and the colour of cells have been used as the generic characters. The cell size, shape, constrictions at the cross walls, cellular granulations or vacuoles, apical cell shapes of trichomes have been the main taxonomic criteria at the species level.

The order consists of 10 families, including the above 121 genera and 1364 species. Of these, only 3 families and 38 species are reported from the study area.

Key to the family

1. Filamentous with radial or fasciculated thylakoid arrangement, not or constricted at the cross walls..... **1. Coleofasciculaceae**
2. Thallus gelatinous, usually with fasciculated trichomes within sheaths, trichomes cylindrical.....**2. Microcoleaceae**

3. Trichomes isopolar, with morphologically the same ends in full-grown trichomes .....**3. Oscillatoriaceae**

1. Coleofasciculaceae

Filamentous cyanobacteria with radial or fasciculated thylakoid arrangement, with or without constrictions at the cross-walls, with cell division completed before the next cell division begins.

The family consists of 10 genera and 30 species. The family representing two genera is known to occur in the mangrove ecosystem of southern Kerala and is presented.

Key to the genera

1. Trichomes cylindrical, absence of capitate apical cells .....**1. *Anagnostidinema***
2. Filaments with multiple trichomes per sheath, trichomes slightly constricted at the cross walls, end cells rounded to conically rounded, non-calyptrate, typically longer than wide .....**2. *Coleofasciculus***

1. *Anagnostidinema* Strunecky, Bohunicka, Johansen et Komarek, 2017

Colonies spreading, green to blue-green, mucilaginous. Sheaths absent. Trichomes thin, mostly bright blue-green, usually straight or slightly bent, unconstricted or only indistinctly constricted at cross walls. Trichomes cylindrical, straight, not capitate, motile with intense gliding in the direction of the longitudinal axis, sometimes accompanied by bending and distinctive rotation, 1–3 µm wide. Cells usually 2–4 longer than wide, 4–8 µm long, sometimes with evident carotenoid granules, without aerotopes. Apical cells in developed trichomes bent, narrowed and pointed–rounded, never calyptrate or capitate. Reproduction by disintegration of trichomes in hormogonia without necridic cells.

The genus has 11 species. Only one species, a benthic form from the mangrove ecosystems of southern Kerala, is described here.

Key to the species

1. Trichomes unconstricted at the cross walls, 1.6-2.2 µm wide .....

.....**1. *A. Pseudacutissimum***

1. *Anagnostidinema pseudacutissimum* (Geitler) Strunecky, Bohunicka, Johansen et Komarek, 2017.

Strunecky et al., Fottea, 17(1): 114-126. 2017; Yim et al., Korean J. Environ. Biol., 36(3): 291-298. 2018; Zaki et al., Harmful Algae, 93. 1-7. 2020.

Synonyms: *Oscillatoria pseudacutissima* Geitler; *Phormidium pseudacutissimum* (Geitler) Anagnostidis & Komarek 1988; *Geitlerinema pseudacutissimum* (Geitler) Anagnostidis 1989.

References: Strunecky et al. (2017); Zaki et al. (2020).

Description: Thallus green, mucilaginous. Filaments solitary, sheath absent. Trichome thin, motile, bright blue-green, without branching, usually straight or slightly bent, dispersed evenly and loosely without mat formation, unconstricted at the cross walls, 1.6-2.2 μm wide, small orange granules located near the cell walls. Cells cylindrical, homogenous in size, with orange granules at cross walls, 4.2-7.0 μm long. Apical cell cylindrical rounded and elongated, conical, never calyptrate or capitate.

Distribution: No distributional records were found along with the mangrove environment.

General Environment: Freshwater species.

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Benthic form

Specimen examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54’ 41.96” N, 76^0 18’ 32.36” E, 07.06.2018, MES 13777. **(Plate 4, Fig. C-F)**.

2. *Coleofasciculus* (Thuret ex Gomont) Siegesmund, Johansen et Friedl 2008

Filaments with multiple trichomes per sheath, sheath colourless, unlamellated. Trichomes slightly constricted at the cross walls, cells with radial or fasciculated thylakoid arrangement, end cells rounded to conically rounded, non-calyptrate, typically longer than wide.

The genus has only 1 species and is described as having planktic, benthic, epipsammic and epiphytic forms from the mangrove ecosystems of southern Kerala.

Key to the species

1. Cell isodiametric or longer than wide, constricted at cross walls, apical cells conical- pointed ……**1. *C. chthonoplastes***

1. *Coleofasciculus chthonoplastes* (Thuret ex Gomont) M.Siegesmund, J.R.Johansen et T.Friedl 2008

Siegesmund et al., J. Phycol., 44: 1572-1585. 2008; Barinova et al., Turkish Journal of Botany, 33: 353-372. 2009; Gadea et al., Thalassas, 29(1): 35-58. 2013; Nguyen et al., Botanica Marina 56(3): 207-227. 2013; Tsuda & Walsh, Micronesica, 2: 1-91. 2013; Afonso-Carrillo, Lista actualizada de las algas marinas de las islas Canarias, 1-64. 2014; Barinova & Kukhaleishvili, The Journal of Biodiversity (Photon), 113: 305-338. 2014; Tsuda, Phytotaxa, 167(1): 35-60. 2014; Figueroa-Torres et al., CienciaUAT, 9(2): 15-29. 2015; Smith et al., Taxonomic catalogue of algae from Ghana (Africa) and new additions, 1-101. 2015; Gkelis et al., Biodivers. Data J., 4(e10084): 1-103. 2016; Phang et al., Raffles Bull. Zool., 40: 13-59. 2016; Alamos, Acta Bot Malac., 41: 5-17. 2016; Gallardo et al., Algas Boletín Informativo de la Sociedad Española de Ficología, 51: 7-52. 2016; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Mendoza-Gonzalez et al., Biota Neotrop., 17(4): 1-14. 2017; Nava-Olvera et al., Revista de Biologia Marina y Oceanografia, 52(3): 429-439. 2017; Taskin et al., Türkiye suyosunlari listei, 1-804. 2019; Kopyrina et al., International Journal of Oceanography and Hydrobiology, 49(2): 99-122. 2020.

Synonyms: *Microcoleus chthonoplastes* Thuret ex Gomont 1892; *Oscillatoria chtonoplastes* Hofman-Bang ex Gomont 1892; *Microcoleus chthonoplastes* var. *Lyngbyei* (Kützing) Rabenhorst in Hansgirg 1893.

References: Siegesmund et al. (2008); Komarek & Anagnostidis (2005); Desikachary (1959).

Description: Thallus widely expanded, dense, thick, dark green. filaments densely aggregated, elongate, irregularly curved, approximately 142 μm wide. Sheath colourless, diffluent, having many closely grouped trichomes. Trichomes blue-green, constricted at the cross walls, cross-walls not granulated, straight, numerous within sheaths 2.3-5.8 μm wide. Cells nearly isodiametric, 2-3 times longer than

wide, 4.3-12.5 μm long. Apical cell bluntly rounded (after trichome breakage), elongated and long acute - conical, not capitate.

Distribution: This species was reported from the mangrove environment of Brazil (Moebius, 1889, Branco et al., 1997, Nogueira & Ferrieira-Correia, 2001, Branco et al., 2003), Africa (Millard & Broekhuysen, 1970), Kenya (Coppejans & Gallin, 1989), India (Dhargalkar, 1994, Sudha, 2005; Sudha et al., 2007, Sakthivel & Kathiresan, 2013, Barman et al., 2015, Ramamurthy & Abhinand, 2016), Saudi Arabia (Mohammed & Al-Shehri, 2015), epipsammic (Potts & Whitton, 1977, Potts & Whitton, 1980), epiphytic (Lambert et al., 1989, Steinke & Naidoo, 1990, Silva, 1991, Mann & Steinke, 1993, Phillips et al., 1994, Phillips et al., 1996, Saifullah et al., 1997, Bashan et al., 1998, Sen & Naskar, 2003, Steinke et al., 2003, Nedumaran et al., 2008, Boopathi, 2011, Huisman et al., 2015), mangrove swamps (Hussain & Khoja,1993).

General Environment: Marine species.

Habitat: Green coloured cyanobacterial mat collected as benthic, planktic, epipsammic and epiphytic on the pneumatophores of *Avicennia officinalis* L. and aerial roots of *Rhizophora mucronata* Lam.

Specimen examined: INDIA: Kerala; Ernakulam district, Vypin, 9^0 58’ 26.46” N, 76^0 14’ 38.14” E, 13.01.2017, MES 21440; Kumbalam, 9^0 54’ 41.96” N, 76^0 18’ 32.36” E; 22.07.2016, MES 13737; 07.06.2018, MES 13778; Kollam district, Pathiramanal, 9^0 37’ 09.78” N, 76^0 23’ 06.43” E,16.08.2017, MES 21459. **(Plate 5, Fig. A-D)**.

2. Microcoleaceae

The family is distinguished by filaments solitary or aggregated in irregular fascicles and forming mats. Trichomes uniseriate, isopolar, more or less cylindrical without sheaths or with simple sheaths, sometimes more trichomes enveloped by one common sheath, fasciculated with attenuate or cylindrical ends; apical cells are attenuated and rounded, often developing distinct calyptra. Cells isodiametrical or slightly shorter or longer as wide, with thylakoids located irregularly or radially. Reproduction by fragmentation of trichomes by help of necridic cells.

The family consists of 24 genera and over 260 species. The family represents four genera and eleven species are known to occur from the mangrove ecosystem of southern Kerala and are presented in this chapter.

Key to the genera

1. Trichomes simple, cylindrical along their whole length (up to the end), uniseriate, (2.5) 3–5 (5.3) μm wide, end cells rounded, bent and hooked without calyptra ..... **1. *Kamptonema***

2. Sheath hyaline, usually contains several to many densely and parallel arranged trichomes .....**2. *Microcoleus***

3. Trichomes solitary, straight, cylindrical, 3.5-10 um wide; with aerotopes through the whole cell volume, end cells widely rounded or slightly narrowed ..... **3. *Planktothrix***

4. Filaments always with sheaths, sheath firm, thick, joined to the trichomes or slightly distant, trichomes cylindrical, end cell widely rounded ..... **4. *Porphyrosiphon***

1. *Kamptonema* Strunecky, Komarek et Smarda 2014

Filaments solitary without sheaths, or with very fine, facultative and diffluent sheaths, sometimes with several to many trichomes associated more or less in parallel without common firm sheaths. Trichomes simple, cylindrical along their whole length (up to the end), uniseriate, slightly constricted or unconstricted at cross-walls, (2.5) 3-5 (5.3) μm wide. Cells isodiametric or slightly longer or shorter than wide. End cells rounded, bent and hooked without calyptra. Solitary granules of polyphosphate and cyanophycin are present in cells.

The genus has 11 species and only 3 species are known to occur from the mangrove environment of southern Kerala and is presented.

Key to the species

1a. Cells 3.6 μm to 3.9 μm wide, apical cells rounded..... **1. *K. chlorinum***

2a. Trichomes straight, 3.2-4.4 μm wide, end cell hooked, conical-rounded ..... **2. *K. jasorvense***

3a. Trichomes 4.2-5.3 µm wide, apical cells obtusely rounded-conical.... **3. *K. okenii***

1. *Kamptonema chlorinum* (Kutzing ex Gomont) Strunecky, Komarek et J.Smarda 2014

Gkelis et al., Biodivers. Data J., 4(e10084): 1-103. 2016; Stutz et al., Beitrage zu den Algen Baden-Württembergs. Band 1 Allgemeiner Teil. 1-504, 2018; Barinova & Niyatbekov, Biodivers. Int. J., 2(3): 236-263. 2018; Taskin et al., Turkiye suyosunlari listei, 1-804. 2019; Rosset et al., Phycologia, 59(6): 1-7. 2020.

Synonyms: *Oscillatoria chlorina* Kutzing ex Gomont 1892; *Phormidium chlorinum* (Kutzing ex Gomont) Umezaki & Watanabe 1994; *Lyngbya chlorina* Hansgirg 1885; *Lyngbya amoena* var. *chlorina* Hansgirg ex Forti 1907.

References: Strunecky et al. (2014).

Description: Thallus very thin, yellowish-green, often in solitary filaments. Sheaths absent. Trichome straight or curved, yellow-green, not constricted at the cross walls; cells 3.8-7.6 µm long, 3.6-3.9 µm wide, cross-walls not granulated. Apical cells rounded; calyptra absent.

Distribution: This species was reported from the mangrove environments (Mohammed & Al-Shehri, 2015), epilithic (Bano & Siddiqui, 2003, 2007), epiphytic (Lambert et al., 1989; Steinke et al., 2003), Sundarbans soils (Sen & Naskar, 2003), mangrove sediments (Sakthivel & Kathiresan, 2013).

General Environment: Freshwater and marine species.

Habitat: Dark greenish planktic form.

Specimen examined: INDIA: Kerala; Alappuzha district, Pathiramanal, 9^0 37' 09.78" N, 76^0 23' 06.43" E, 11.02.2016, MES 13711, 07.06.2017, MES 13758; Kottayam district, Mekkara, 9^0 48'54.31" N 76^0 21' 57.54" E, 11.10.2018, MES 13773; Thiruvananthapuram district, Kadinamkulam, 8^0 37'15.01" N 76^0 48' 43.81" E, 11.11.2018, MES 13780. **(Plate 5, Fig. E-F)**.

2. *Kamptonema jasorvense* (Vouk) Strunecky, Komarek et J.Smarda 2014

Strunecky et al., Preslia (Prague), 86: 193-207. 2014; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Barinova & Niyatbekov, Biodivers. Int. J., 2(3): 236-263. 2018; Taskin et al., Turkiye suyosunlari listei, 1-804. 2019.

Synonyms: *Oscillatoria jasorvensis* Vouk 1919; *Phormidium jasorvense* (Vouk) Anagnostidis & Komarek 1988; *Geitlerinema jasorvense* (Vouk) Anagnostidis 1989.

References: Strunecky et al. (2014).

Description: Thallus yellowish green, thin. Trichomes straight, 3.2-4.4 µm wide, pale blue green, not or slightly constricted at cross walls, not attenuated and often bend at the ends, hooked, not capitate or calyptrate. Cells isodiametric or little longer or shorter than wide, 2.3-4.5 µm long, cell content distinctly shows plenty of small granules. Apical cell conical-rounded.

Distribution: This species was reported from the mangrove environments of Cochin (Joseph & Saramma, 2016).

General Environment: Freshwater and marine species.

Habitat: Greenish planktic and benthic form.

Specimen examined: INDIA: Kerala; Thiruvananthapuram district, Kureekkadavu, 8^0 46'11.14" N 76^0 42' 36.69" E, 12.07.2016, MES 13723; Kollam district, Ayiramthengu, 9^0 07'33.93" N 76^0 28' 45.34" E, 14.08.2017. MES 13743. **(Plate 6, Fig. A-B)**.

3. *Kamptonema okenii* (Agardh ex Gomont) Strunecky, Komarek et J.Smarda 2014

Strunecky et al., Preslia (Prague), 86: 193-207. 2014; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Smith et al., Taxonomic catalogue of algae from Ghana (Africa) and new additions, 1-101. 2015; Barinova & Niyatbekov, Biodivers. Int. J., 2(3): 236-263. 2018; Stutz et al., Beitrage zu den Algen Baden-Wurttembergs, 1-504. 2018; Shiels et al., Biology, 8(59): 1-19. 2019; Taskin et al., Türkiye suyosunlari listei, 1-804 2019.

Synonyms: *Lyngbya okenii* (C.Agardh) Hansgirg 1884; *Oscillatoria okenii* C.Agardh ex Gomont 1892; *Phormidium okenii* (C.Agardh ex Gomont) Anagnostidis & Komarek 1988.

References: Strunecky et al. (2014).

Description: Thallus in the form of dark blue-green mats. Trichome long, straight, fragile, slightly to distinctly constricted at the cross walls, 4.2-5.3 µm wide, cross walls ungranulated, at the ends gradually attenuated, undulating and slightly hooked or bent, occasionally with thin, delicate, firm or diffluent indistinct colourless sheaths. Cells 2.5-5.2 µm long, at the ends, 5.5 -8.3 µm long, sometimes almost isodiametric in nature, cell content generally homogenous with minute granules. Apical cells obtusely rounded-conical, not capitate, without calyptra.

Distribution: This species was reported from the mangrove environments of Tamil Nadu (Bhuvaneshwari & Muruganandam, 2016; Priya et al., 2019).

General Environment: Freshwater and marine species.

Habitat: Greenish planktic, epiphytic on *Avicennia officinalis* L. and aerial roots of *Rhizophora mucronata* Lam.

Specimen examined: INDIA: Kerala; Thiruvananthapuram district, Kadinamkulam, 8^0 37'15.01" N 76^0 48' 43.81" E, 14.03.2015, MES 13739, Kureekkadavu, 8^0 46'11.14" N 76^0 42' 36.69" E, 14.08.2017; Kottayam district, Mekkara, 9^0 48'54.31" N 76^0 21' 57.54" E, 11.10.2018, MES 13772, Kumarakom, 9^0 36'59.46" N 76^0 25' 21.46" E, 01.07.2018, MES 13745; Alappuzha district, Ezhupunna, 9^0 49' 24.43" N, 76^0 18' 39.54" E, 06.04.2017, MES 13789, Pathiramanal, 9^0 37' 09.78" N, 76^0 23' 06.43" E, 06.04.2017, MES 13789; Kollam district, Ayiramthengu, 8^0 46'11.14" N 76^0 42' 36.69" E, 12.07.2016, MES 13723, 28.08.2017, MES 13726, Sakthikulangara, 8^0 56'23.44" N 76^0 33' 09.88" E, 10.08.2018, MES 13721; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 13.09.2018, MES 13730, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 16.07.2015, MES 13760. **(Plate 6, Fig. C-D)**.

2. *Microcoleus* Desmazieres ex Gomont, 1892

Filaments solitary or in flat mats, sheaths hyaline, widened, mostly colourless, tapering and usually open, containing numerous to many trichomes. Trichomes within the widened sheaths densely aggregated, nearly parallel arranged and tightly fasciculated, not or slightly constricted at cross walls, often rope-like contorted, straight, mostly attenuated at the ends. Cells cylindrical, isodiametric, apical cells mostly subconical to acute-conical. Reproduction by trichome disintegration and by hormogonia.

The genus has 56 species, of which 4 species are reported as planktic, corticolous, epipsammic and benthic from the mangrove environment of southern Kerala and are presented.

Key to the species

1a. Cells isodiametric or shorter than wide ..... **2.**

1b. Cells isodiametric or longer than wide ..... **3.**

2a. Trichomes 4.6-7.6 µm wide, apical cell rounded…..…… **1. *M. autumnalis***

2b. Filaments solitary or in flat mats, trichomes 3.1- 4.3 µm wide, apical cells conical rounded or obtuse-conical .....**2. *M. codii***

3a. Trichomes 3.5 – 5.6 µm wide, apical cells obtuse, acute conical ....**3. *M. lacustris***

3b. Trichomes 5.1-7.0 µm wide, not constricted at the cross walls ....**4. *M. paludosus***

4a. Trichomes 6.1-9.6 µm wide, apical cells cylindrical-rounded……. ..... **5. *M. subtorulosus***

1. *Microcoleus autumnalis* (Trevisan ex Gomont) Strunecky, Komarek et J.R.Johansen 2013

Strunecky et al., J.Phycol., 49(6):1167-1180. 2013; Davydov, Folia Cryptogamica Estonica, 51:13-23. 2014; Patova et al., Cyanoprokaryotes and algae, 133-166. 2015; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Barinova & Kukhaleishvili, Elixir Bio Sciences, 104: 45934-45947. 2017; Caraus, Studii si Cercetari Biologie, 7:1-1002. 2017; Nava-Olvera et al., Revista de Biologia Marina

y Oceanografia, 52(3):429-439. 2017; Barinova & Niyatbekov, Biodivers Int J., 2(3): 236-263. 2018; Davydov, Botanica, 24(2): 185-201. 2018; Dunck et al., Hoehnea, 45(4): 560-590. 2018; Gaysina et al., Cryptogam Algol., 39(2):167-198. 2018; Patova & Novakovskaya, Novosti Sistematiki Nizshikh Rastenii, 52(2): 311–353. 2018; Kelly et al., Toxins, 10(11): 1-15. 2018; Das et al., Phytotaxa, 435(4):255-279. 2020; Rosset et al., Phycologia, 59(6):571-577. 2020; McAllister et al., Can. J.Fish.Aquat.Sci., 77(2):1-41. 2020; Wood et al., N. Z. J. Mar. Freshw. Res., 54(3): 449-466. 2020; Davydov, Polar Biol., 1-12. 2021; Davydo & Redkina, Proceedings of the Karelian Scientific Centre of the Russian Academy of Sciences, 2021(1): 51-68. 2021; Puddick et al., Chemosphere, 263(127937). 2021.

Description: Thallus expanded, dark blue-green. filaments straight, not indented by cross walls, cross walls clearly visible, cells of some trichomes divided by an incomplete cell wall. Sheath thin, diffluent or sometimes lacking. Trichomes bright blue-green or dirty green, 4.62-7.66 µm wide, cells shorter than wide, 1.5-3.7 µm long, not constricted at cross walls, sometimes frequent granulations visible at cross-walls. Apical cell rounded somewhat elongated or truncated conical calyptra. In some trichomes large, irregular, olive granulations may be observed.

Synonyms: *Phormidium autumnale* Gomont 1892; *Lyngbya autumnalis* (Gomont) P.A.C.Senna 1983; *Oscillatoria autumnalis* C.Agardh 1812; *Oscillatoriella autumnalis* (C.Agardh) Gaillon 1833.

References: Komarek & Anagnostidis (2005); Strunecky et al. (2013).

Distribution: No distributional records were found along with the marine environment.

General Environment: Freshwater species

Comments: New record to the mangrove cyanobacterial flora of India.

Habitat: Appeared as green coloured benthic and corticolous on *Avicennia officinalis* L.

Specimen Examined: INDIA: Kerala; Thiruvananthapuram district, Kadinamkulam, 8^0 37’15.01” N 76^0 48’ 43.81” E, 14.03.2015, MES 13741;

Kottayam district, Kumarakom, 9^0 36'59.46" N 76^0 25' 21.46" E, 14.11.2017, MES 13781. **(Plate 6, Fig. E-F; Plate 7, Fig. A-B)**.

2. *Microcoleus codii* Fremy 1932

Frémy, Compte Rendu Hebdomadaire des Séances de l''Académie des Sciences. Paris 195: 1413-1414. 1932; Barbara & Cremades, Botanica Marina, 39: 371-388. 1996; Haroun et al., Botanica Marina, 45: 139-169. 2002; Barbara et al., An. Jard. Bot. Madr., 62: 69-100. 2005; Taskin et al., The check-list of the marine algae of Turkey,1-87. 2008; Afonso-Carrillo, Lista actualizada de las algas marinas de las islas Canarias, 1-64. 2014; Gallardo et al., Boletin Informativo de la Sociedad Espanola de Ficologia, 51: 7-52. 2016; Taskin et al., Turkiye suyosunlari listei, 1-804. 2019.

References: Komarek & Anagnostidis (2005).

Description: Filaments solitary or in flat mats, nearly straight. Sheath open, totally diffluent, containing 4-8 trichomes parallel arranged. Trichomes pale blue green, 3.1- 4.3 µm wide, not constricted at cross walls. Cells isodiametric, usually shorter than wide, 3.1-4.0 µm long, cell contents finely granulated. Apical cells conical rounded or obtuse-conical, not capitate or calyptrate.

Distribution: No distributional records were found along with the marine environment.

General Environment: Marine species

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Planktic and epipsammic form appeared as dark green coloured cyanobacterial mass.

Specimen Examined: INDIA: Kerala; Thiruvananthapuram district, Kureekkadavu, 8^0 46'11.14" N 76^0 42' 36.69" E, 18.09.2017, MES 13749; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 14.02.2018, MES 21424. **(Plate 7, Fig. C-D)**.

3. *Microcoleus lacustris* Farlow ex Gomont 1892

Gomont, Annales des Sciences Naturelles, Botanique, Serie 7 (15): 263-368. 1892; Forti in De Toni, Syllogue Algarum, 5:376. 1907; Fremy, Myxo.d'Afr. equat.franc., 80, 1929; Geitler, Kryptogamenflora, 1142. 1932; Suryaprakasa, Proc Natl Acad Sci India B., 11(3): 125-131.1940; Strickland, Am J Bot., 27(8): 628-633. 1940; Nielsen & Madsen, Q. j. Fla. Acad. Sci., 11(4): 111-117. 1948; Skuja, Nova Acta Regiae Societatis Scientiarum Upsaliensis, 4, 14(5): 1-188. 1949; Durrell, American Midland Naturalist, 61(2): 322-328. 1959; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Aboal, An. Jard. Bot. Madr., 45(1): 3-46. 1988; Alvarez-Cobelas & Gallardo, Acta Bot Malacit., 13: 53-76. 1988; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Islam, Internationale Revue der gesamten Hydrobiologie und Hydrographie, 70(5): 755-766. 1985; Day et al., Flora of Australia, 4: 1-276. 1995; Poulin et al., The Canadian Field-Naturalist, 109: 27-110. 1995; Vinogradova et al., Cyanoprocaryotes and algae of continental Israel, 32-141. 2000; Issa et al., Soil Biology and Biochemistry, 33(10):1425-1428. 2001; Sherwood, Bishop Museum Occasional Papers, 80: 1-26. 2004; Leghari et al., Int. J. Phycol. Phycochem., 1(2): 151-158. 2005; Bostock & Holland, Census of the Queensland Flora, 1-320. 2010; Rai et al., Our Nature, 8: 336-354. 2010; Smith, Int J Algae, 12(3): 230-256. 2010; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Deka & Sarma, Int. J. Appl. Biol. Pharm., 2(4): 430-433. 2011; Siahbalaei et al., Rostaniha, 12(2): 95-100. 2012; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Gadea et al., Thalassas, 29(1): 35-58. 2013; Pentecost, Life, 4(4): 1026-1037 2014; Diana et al., Int J Curr Sci., 11: E 32-39. 2014; Alamos, Acta Bot Malacit., 41: 5-17. 2016; Gkelis et al., Biodivers. Data J., 4(e10084): 1-103. 2016; Gallardo et al., Boletin Informativo de la Sociedad Espanola de Ficologia, 51: 7-52. 2016; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Barinova & Niyatbekov, Biodivers. Int. J., 2(3): 236-263. 2018; Chaudhari, Bioinfolet, 17(1b), 208-211. 2020; Ozturk, Indian J Geo-Mar Sci., 49(10): 1661-1668. 2020; Smith, Int J Algae, 22(3): 245-268. 2020.

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Description: Thallus thin, blue-green. Filaments almost straight, contorted. Sheath thin, colourless, diffluent. Trichomes blue-green, 3.5-5.6 μm wide, contorted, parallel arranged, distinctly constricted at the cross walls, cross walls not granulated. Cells isodiametric, longer than wide, 6.1-12.3 μm long. Apical cells obtuse, acute conical, not capitate.

Distribution: This species was reported from the mangrove environments of Sundarbans (Barman et al., 2015).

General Environment: Freshwater species

Comments: New record to the cyanobacterial flora of Kerala.

Habitat: Appeared as dark green coloured benthic form.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 08.08.2017, MES 13757. 08.03.2018, MES 13765. **(Plate 7, Fig. E-F)**.

4. *Microcoleus paludosus* Gomont ex Gomont 1892

Gomont, Annales des Sciences Naturelles, Botanique, Serie 7, 15: 263-368. 1892; Forti in De Toni, Syllogue Algarum, 5:376. 1907; Fremy, Myxo.d'Afr. equat.franc., 80, 1929; Geitler, Kryptogamenflora, 1144. 1932; Chapman et al., Transactions of the Royal Society of New Zealand, 84: 695-747. 1957; Shields, Ecology, 38(4): 661-663. 1957; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933.1977; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Alvarez-Cobelas & Gallardo, Acta Bota Malac., 13: 53-76. 1988; Poulin et al., The Canadian Field-Naturalist, 109: 27-110. 1995; Day et al., Flora of Australia, 4: 1-276. 1995; Vinogradova et al., Cyanoprocaryotes and algae of continental Israel, 32-141. 2000; Tiwari et al., Biology and Fertility of Soils, 34(4): 291-295. 2001; Maya & Lopez-Cortes, Geomicrobiol. J., 19(5): 505-518. 2002; Aysel, J. Black Sea/Medit. Environ., 11: 1-124. 2005; Tell & Mataloni, Algol Stud/Archiv für Hydrobiologie, 71-77. 2005; Zhang, Sci. Bull., 50(2): 117-121. 2005; Rivera-Aguilar et al., J. Arid Environ., 67(2): 208-225. 2006; Rivera-Aguilar et al., J. Arid Environ., 73(11): 1023-1028. 2009; Pocs, Acta Botanica Hungarica, 51(1-2): 147-178. 2009; Lopez-Cortes et al.,

Revista mexicana de biodiversidad, 81(1): 1-7. 2010; Barinova et al., Turk J Botany, 35: 729-774. 2011; Gadea et al., Thalassas, 29(1): 35-58. 2013; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Lin et al., Bot. Stud., 54(1): 1-12. 2013; Datta & Keshri, Vegetos, 27:112-126. 2014; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far East, 1-271. 2014; Patova et al., Cyanoprokaryotes and algae, 133-166. 2015; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Vinoth et al., J. Life Sci., Bioinform., Pharmaceut. Chem. Sci., 3: 215-241. 2017; Ansary et al., Banats J Biotechnol., 8(15): 83. 2017; Davydov, Botanica, 24(2): 185-201. 2018; Patova & Novakovskaya, Novosti Sistematiki Nizshikh Rastenii, 52(2): 311–353. 2018; Barinova & Niyatbekov, Biodivers. Int. J., 2(3): 236-263. 2018; Taskin et al., Turkiye suyosunlari listei, 1-804. 2019.

Synonyms: *Chthonoblastus paludosus* Kutzing 1849

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Description: Thallus dark blue-green. Filaments with several trichomes, blue-green. sheaths colourless, open and diffluent at the ends, containing many straight, parallel arranged or rope-like twisted trichomes. Trichomes blue-green, not constricted at the cross walls, cross walls slightly granulated, not attenuated towards ends. Cells shorter than wide, isodiametric, or longer than wide, 5.1-7.0 µm wide, 4.5-12.6 µm long, apical cell not capitate or calyptrate, cylindrical rounded, conical and bluntly pointed.

Distribution: This species was reported from the mangrove environments of Sundarbans (Barman et al., 2015).

General Environment: Freshwater species

Comments: New record to the cyanobacterial flora of Kerala.

Habitat: Appeared as green coloured benthic and planktic form.

Specimen Examined: INDIA: Kerala; Thiruvananthapuram district, Kureekkadavu, 8^0 46’11.14” N 76^0 42’ 36.69” E, 18.11.2017, MES 13748. 16.04.2015, MES 13740; Kottayam district, Kumarakom, 9^0 36’59.46” N 76^0 25’ 21.46” E, 26.07.2018, MES 13733. **(Plate 8, Fig. A-F)**.

5. ***Microcoleus subtorulosus*** Gomont ex Gomont 1892

Gomont, Annales des Sciences Naturelles, Botanique, Serie 7, 15: 263-368. 1892; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Junior et al., Hydrobiologia, 213(3): 241-250. 1991; Patrick & Palavage, Proceedings of the Academy of Natural Sciences of Philadelphia, 55-92. 1994; Branco & Necchi, Hydrobiologia, 333(3):139-150. 1996; Necchi et al., Archiv Fur Hydrobiologie-Supplement, 118: 91-112. 1997; Muller, Eur. J. Phycol., 34(5): 487-496. 1999; Branco & Pereira, Archiv fur Hydrobiologie, 155(1): 147-161.2002; Mauch & Schmedtje, Taxaliste der Gewässerorganismen Deutschlands zur Kodierung biologischer Befunde, 1-388. 2003; Branco et al., Revista Brasil. Bot., 28(2): 267-275. 2005; Aysel, J. Black Sea/Medit. Environ., 11: 1-124. 2005; Borges & Junior, Braz J Bot., 29, 669-680. 2006; Peres et al., Acta Botanica Brasilica, 22(2): 333-344. 2008; Vitonyte & Kostkeviciene, Bot. Lith., 14(4): 223-231. 2008; Peres et al., Braz J Bot., 32(4): 625-633. 2009; Bostock & Holland, Census of the Queensland Flora, 1-320. 2010; Rai et al., Our Nature, 8: 336-354. 2010; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Martins et al., Revista Brasil. Bot., 35: 325-338. 2012; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Gadea et al., Thalassas, 29(1): 35-58. 2013; Lin et al., Bot. Stud., 54(1): 1-12. 2013; Asencio, Int J Environ Res., 8(3): 531-542. 2014; Nimbhore & Jadhav, Bioscience Discovery, 5(1): 42-44. 2014; Mahadik & Jadhav, Bioscience discovery, 5(1): 123-125. 2014; Monteagudo & Moreno, Ecol. Indic., 67: 693-702. 2016; Barinova & Niyatbekov, Biodivers Data J., 2(3): 236-263. 2018; Taskin et al., Turkiye suyosunlari listei, 1-804. 2019.

Synonyms: *Phormidium subtorulosum* Brebisson 1847; *Oscillaria subtorulosa* (Brebisson) Farlow 1881; *Lyngbya subtorulosa* (Brebisson) Kirchner ex Hansgirg 1892; *Lyngbya subtorulosa* (Brebisson) Hauck ex Hansgirg 1893; *Lyngbya subtorulosa* (Gomont ex Gomont) Hansgirg 1893; *Oscillatoria subtorulosa* (Brebisson) Farlow ex Forti 1907.

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Description: Thallus expanded, bluish. Filaments long, contorted. Sheath mucilaginous, containing several to many trichomes. Trichomes bluish, straight,

slightly constricted at the cross walls, gradually attenuated at the ends. Cells short barrel-shaped, nearly isodiametric, 6.1-9.6 μm wide, 5.6-9.3 μm long. Apical cells cylindrical-rounded, not capitate.

Distribution: No distributional records were found along with the marine environment.

General Environment: Freshwater species

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as green coloured benthic and epipsammic.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 08.11.2017, MES 13756; Kottayam district, Kumarakom, 9^0 36'59.46" N 76^0 25' 21.46" E, 17.09.2018, MES 13794. **(Plate 9, Fig. A-F)**.

3. *Planktothrix* K.Anagnostidis & J.Komarek, 1988

Trichomes solitary, straight or irregularly curved, usually growing without sheath. Trichomes with cylindrical cells, slightly constricted at the cross walls, sometimes slightly tapering to the ends, (2)3-12 (15) μm wide. Cells cylindrical, usually a little shorter than wide to isodiametric. Apical cells widely rounded or narrowed conical, sometimes with calyptra or with thickened outer cell wall. Reproduction by trichome disintegration into hormogonia, by help of necridic cells.

The genus has 16 species, of which 3 species are reported as epipsammic and planktic forms from the mangrove environments of southern Kerala and are presented.

Key to the species

1a. Trichomes 5-10 μm wide ..... 2.

1b. Trichomes 3.8- 4.3 μm wide, apical cell longer, nearly hemispherical ..... **3. *P. suspensa***

2a. Trichomes 6.4-9.2 μm wide, end cells roundly obtuse ..... **1. *P. geitleri***

2b. Trichomes 5.8-9.6 μm wide, end cells cylindrical and widely rounded ..... **2. *P. isothrix***

1. *Planktothrix geitleri* (Kisselev) Anangnostidis et Komarek 1998

Anagnostidis & Komarek, Archiv fur Hydrobiologie, Supplement, 80: 327-472. 1988; Komárek, Rapporti Istisan, (9): 6-43. 2002; Passarinho et al., Acta Limnologica Brasiliensia, 25(4): 361-374. 2013; Barinova et al., Turk J Bot., 39: 535-546. 2015.

Synonyms: *Oscillatoria geitleri* Kisselev 1927

References: Komarek & Anagnostidis (2005); Komárek & Komárková (2004).

Description: Thallus dark green, mucilaginous, expanded. Trichome solitary, 6.4-10.2 μm wide, straight, not constricted at the cross walls, gradually narrowed towards the ends, at the ends 3.5-4.2 μm wide, roundly obtuse. Cells 2.9-3.6 μm long, cells with aerotopes, not capitate.

Distribution: No distributional records were found along with the marine environment.

General Environment: Marine species

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as dark brown coloured epipsammic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 17.12.2018, MES 13766; Kollam district, Ayiramthengu, 9^0 07'33.93" N 76^0 28' 45.34" E, 16.11.2018, MES 21420. **(Plate 10, Fig. A-B)**.

2. *Planktothrix isothrix* (Skuja) Komarek & Komarkova 2004

Komarek & Komarkova, Czech Phycology, 4: 1-18. 2004; Hasler et al., Fottea, Olomouc, 7(1): 49-68. 2007; Gonzalez, Boletin de la Sociedad Espanola de Ficologia, 39: 21 - 29. 2008; Barinova et al., Turk J Bot., 33: 353-372. 2009; Gonzalez, Catalogo de las algas y cianoprocariotas dulciacuícolas de Cuba,1-147. 2009; Perez et al., Acta Botanica Croatica, 68: 11-27. 2009; Bostock & Holland, Census of the Queensland Flora, 1-320. 2010; John et al., The freshwater algal flora

of the British Isles. 1-878. 2011; Tauscher, Verhandlungen des Botanischen Vereins von Berlin und Brandenburg 144: 177-192. 2011; Silva-Benavides & Torzillo, J Appl Phycol., 24: 267–276. 2012; Gadea et al., Thalassas, 29(1): 35-58. 2013; Nguyen et al., Bot Mar., 56(3): 207-227. 2013; Bittencourt-Oliveira et al., An Acad Bras Cienc, 86(1): 297-309. 2014; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Phang et al., Raffles Bulletin of Zoology, 40: 13-59. 2016; Gonzalez et al., Algas, 53: 23-33. 2017; Perez et al., Algas, 55: 25-35. 2019; Rego et al., Braz. J. Biol., 80(1): 1-11. 2020.

Synonyms: *Oscillatoria agardhii* var. *isothrix* Skuja 1948; *Oscillatoria mougeotii* Bory ex Gom. 1892; *Planktothrix mougeotii* (Bory ex Gom.) Anagn. et Kom. 1988.

References: Komarek & Anagnostidis (2005); Komárek & Komárková (2004).

Description: Thallus blue green, straight or somewhat slightly curved, usually very long, 5.8 -9.6 μm wide, not constricted at the cross walls, presence of granules, not attenuated at the ends. Cells cylindrical, shorter than wide, nearly isodiametric, 5.5-7.3 μm long. Apical cell cylindrical and widely rounded or flatly rounded, not capitate, without calyptra or thickened outer cell wall.

Distribution: This species was recorded as epiphytic, epizoic, epilithic, edaphic and rock pool waters of mangrove environments of Pakistan (Bano & Siddiqui, 2007).

General Environment: Freshwater species

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as dark brown coloured epipsammic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Thiruvananthapuram district, Kadinamkulam, 8^0 37'15.01" N 76^0 48' 43.81" E, 27.06.2017, MES 13783. **(Plate 10, Fig. C-D)**.

3. *Planktothrix suspensa* (Pringsheim) Anagnostidis et Komarek 1988

Anagnostidis & Komarek, Archiv für Hydrobiologie, 80: 327-472.1988; Gadea et al., Thalassas, 29(1): 35-58. 1988; Wolowski et al., Acta Hydrobiologica, 32: 1-2. 1990; Jaworska & Zdanowski, Oceanol Hydrobiol Stud., 38: 27-39. 2009; D'Alelio & Salmaso, Phycologia, 50(4): 379-383. 2011; D'Alelio & Salmaso,

Phycologia, 50(4): 379-383. 2011; D'Alelio et al., J.Phycol., 49(6): 1107-1117. 2013; De la Rosa Alamos, Acta Bot. Malac., 41: 5-17. 2016; Gallardo et al., Boletin Informativo de la Sociedad Espanola de Ficologia, 51: 7-52. 2016; Boegehold et al., Freshwater Science, 37(3): 510-518. 2018; Munawar et al., Aquat Ecosyst Health Manag., 21(4): 447-457. 2018; Gonzalves et al., Gayana Bot., 76(2): 189-207. 2019; Uzunov et al., Toxins, 13(448): 1-15. 2021.

Synonyms: *Oscillatoria agardhii* var. *suspensa* Pringsheim 1965

References: Komarek & Anagnostidis (2005); Komárek & Komárková (2004).

Description: Filaments solitary, blue-green. Trichome straight, long, bright blue green, sometimes olive green, slightly constricted at the cross walls, 3.8- 4.3 μm wide, intensely motile, slightly or sometimes not constricted at the cross walls, cell walls finely granulated, slightly attenuated at the end and bent. Cells nearly quadrate, up to ½ as long as wide, 2.6 – 5.2 μm long. Septa sometimes granulated. Apical cell longer, 6.3 μm long, nearly hemispherical, calyptra absent, not capitate.

Distribution: No distributional records were found along with the marine environment.

General Environment: Freshwater species

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as a green coloured planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Vypin, 9^0 58’ 26.46” N, 76^0 14’ 38.14” E, 14.02.2018, MES 13797; Kottayam district, Kumarakom, 9^0 36’59.46” N 76^0 25’ 21.46” E, 18.11.2019, MES 21449. **(Plate 10, Fig. E-F)**.

4. *Porphyrosiphon* Kützing ex Gomont, 1892

Filamentous; filaments unbranched, usually slightly coiled, solitary or in microscopic to macroscopic clusters or compact mats, always with. Sheaths firm, thick, later always layered, tube-like, joined to the trichomes or slightly distant from them, colourless or coloured with yellow-brown or reddish sheath-pigments, open at the apex, containing one, very rarely two parallel trichomes; sheaths are often characteristically widened and coiled after hormogonia release. Trichomes isopolar,

6-20 µm wide, cylindrical, with or without constrictions at the cross walls, immotile. Cells isodiametric or slightly longer or shorter than wide, without aerotopes, sometimes with granular content or several prominent granules; end cells widely rounded, sometimes with thickened outer cell wall.

1. Filaments 12.7-19.3 µm wide, end cells rotund without calyptra...**1. *P. ceylanicus***

1. *Porphyrosiphon ceylanicus* (Wille) Anagnostidis & Komarek 1988

Anagnostidis & Komarek, Archiv für Hydrobiologie, 80: 327-472. 1988; Silva et al., University of California Publications in Botany, 79: 1-1259. 1996; Aysel, J.Black Sea/Mediterranean Environment, 11: 1-124. 2005; Saha et al., Indian J. Microbiol., 47(3), 219-232. 2007; Samad & Adhikary, Algae, 23(2): 91-114. 2008; Adhikary & Kovacik, J. Indian Bot. Soc., 89(1 & 2): 19-23. 2010; Mandal & Rath, Int. Biodeterior. Biodegradation, 84, 291-299. 2013; Adhikary et al., Algol Stud., 147: 67–93. 2015; Taskin et al., Türkiye suyosunlari listei, 1-804. 2019: Smith, Int J Algae, 22(3): 245-268. 2020.

Description: Thallus dark to olive green. Filaments 12.6-19.3 µm wide, straight, sheath 2.2-3.2 µm thick, sheath colourless. Trichomes blue green, unconstructed at the cross walls, not attenuated at the ends. cells 8.3-12.3 µm wide, 4.4-6.2 µm long. End cell rotund, without calyptra.

Synonyms: *Lyngbya ceylanica* Wille 1914

References: Komarek & Anagnostidis (2005).

Distribution: No distributional records were found along with the marine environment.

General Environment: Freshwater/terrestrial species

Comments: New record to the cyanobacterial flora of Kerala.

Habitat: Appeared as green coloured planktic and epiphytic on the pneumatophores of *Avicennia officinalis* L.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 17.12.2018, MES 13767; 07.01.2019, MES 21528;

Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 13.08.2017, MES 21532; Kollam district, Ayiramthengu, 17.10.2017, MES 21520. **(Plate 11, Fig. A-F)**.

3. Oscillatoriaceae

Filaments isopolar with morphologically identical ends, with or without sheaths. Sheaths are lacking, or facultative or obligatory, wide, gelatinous or thin and firm, cylindrical, open at the ends, rarely closed. Trichomes cylindrical, straight or slightly waved, not constricted or slightly constricted at the cross walls, facultatively motile (gliding, oscillation) or immotile without or within sheaths. Cells discoid always shorter than wide, with rapid cell division. Apical cells in full grown trichomes usually with thickened outer cell wall or with calyptra. Reproduction by disintegration of trichomes, dividing by the help of necridic cells.

The family consists of 43 genera and 883 species. The family representing four genera are known to occur from the mangrove ecosystem of southern Kerala and is presented.

Key to the genera

1. Filaments simple, with distinct firm sheaths, cells cylindrical, always wider than long.....**1. *Limnoraphis***
2. Sheaths thin, firm, sheaths contain only one trichome or trichomes without sheaths .....**2. *Lyngbya***
3. Trichomes without sheaths (in nature), trichomes in mats, rarely solitary .....**3. *Oscillatoria***
4. Cells ± isodiametric or shorter than wide, with or without sheath, calyptra present in short-celled types only..... **4. *Phormidium***

1. *Limnoraphis* Komárek, Zapomělová, Šmarda, Kopecký, Rejmánková, Woodhouse, Neilan et Komárková 2013

Filaments, simple, solitary, free–floating, 5–25 µm wide, or growing in small aggregations, straight or slightly curved, with distinct sheaths. Sheaths firm, colourless, hyaline, thin or slightly widened. Trichomes uniseriate, not or slightly constricted at the cross–walls, cylindrical, not narrowed towards ends, without clear

calyptra. Cells cylindrical, short, always wider than long, with facultative gas vesicles (and aerotopes), present in distinct segments of a trichome. Heterocytes and akinetes missing. Reproduction by intense hormogonia production.

The genus has 4 species. Here only 1 species is described as planktic form from the mangrove ecosystems of southern Kerala.

Key to the species

1. Filaments 12.3-14.6 μm wide, sheaths firm, apical cells widely rounded ..... **1. *L. hieronymusii***

1. *Limnoraphis hieronymusii* (Lemmermann) J.Komarek, E.Zapomelova, J.Smarda, J.Kopecky, E.Rejmankova, J.Woodhouse, B.A.Neilan & J.Komarkova 2013

Komárek et al., Fottea, 13(1): 39-52. 2013; Stoyanov et al., Journal of BioScience & Biotechnology, 5(1): 19-28. 2016; Salazar-Alcaraz et al., Revista Mexicana de Biodiversidad, 92(e923485):1-10. 2021.

Description: Filaments solitary, free-floating, straight or slightly curved, 12.3 - 14.6 μm wide. Distinct sheath, sheath firm, homogenous, colourless. Trichomes blue green, cylindrical, 11.3-13.5 μm wide, 2.3 - 4.2 μm long, not constricted at the cross walls, cross walls granulated, not attenuated at the ends. Apical cells widely rounded, without calyptra or thickened cell wall.

Synonyms: *Lyngbya hieronymusii* Lemmermann 1905

References: Komarek & Anagnostidis (2005).

Distribution: This species was recorded as planktic form from the mangrove environment of Indian Sundarbans (Sen & Naskar, 2003), mangrove environment of Manakudy, Tamil Nadu (Ramamurthy & Abhinand, 2016).

General Environment: Marine/Freshwater species

Comments: New record to the cyanobacterial flora of Kerala.

Habitat: Appeared as a dark green coloured planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 05.02.2016, MES 21501. **(Plate 12, Fig. A-C)**.

2. *Lyngbya* C. Agardh ex Gomont 1892

Filamentous; filaments thick, rarely solitary, usually connected into thick, layered, sometimes leathery strata (mats), rarely tangled into free clusters of coiled filaments, with firm sheaths, which are sometimes layered or stratified and brownish coloured, opened at the ends; very rarely without sheaths. Trichomes isopolar, straight or slightly waved, composed of shortly cylindrical or barrel-shaped discoid tells, unconstricted or constricted at the cross walls, not attenuated or attenuated to the ends. Cells very short, always shorter (usually several times) than long, without or (rarely) with facultative aerotopes, usually finely granulated, sometimes more at the cross walls; cell content blue-green, olive green, yellowish, brownish or pinkish; end cell with thickened outer cell wall or with prominent calyptra.

The genus has 225 species. Only three species are described here: planktic, epiphytic, epipsammic, and benthic forms from the mangrove environments of southern Kerala.

Key to the species

1. Trichomes unconstricted 2

2a. Trichomes 10.3-18.2 μm wide..... **1. *L. aestuarii***

2b. Trichomes 6.6-8.4 μm wide ..... **2. *L. lutea***

2c. Trichomes 13.6-16.4 μm wide.....**3. *L. truncicola***

1. *Lyngbya aestuarii* Liebman ex Gomont 1892

Liebmann, Kroyers Tidsskrift, 492. 1841; Gomont, Annales des Sciences Naturelles, Botanique, 7(16): 91-264. 1892; Forti in De Toni, Sylloge Algarum, 5: 262. 1907; Adams, Proc. R. Ir. Acad., 27B(2): 11-60. 1908; Cotton, Proc R Ir Acad B., 31B(15): 1-178. 1912; Ghose, J. Indian Bot Soc., 1(1): 8-13. 1919; Lyle, Journal of Botany, British and Foreign, 58: 1-53. 1920; Setchell & Gardner, Proc. Calif. Acad. Sci., 19: 109-215. 1930; Biswas, Mem Asiatic Soc., 11(5): 165-198. 1932; Biswas, Hedwigia, 72: 31-41. 1932; Dixit, Proc. Indian Acad Sci. B, 3:93-106. 1936; Reinhold, Annales de la Société Géologique de Belgique, 61(1): 39-47. 1937; Taylor, Allan Hancock Pacific Expeditions 12: 1-528. 1945; Gonzalves & Joshi, J.

Bombay Nat Hist Soc., 46(1):1946; Chacko, Proc. Indian Acad Sci. B, 31:162-174. 1950; Taylor, Plants of Bikini and other northern Marshall Islands, 1- 227. 1950; Feldmann, Travaux Station Biologique de Roscoff, 6: 1-152. 1954; Chapman, J. Linn. Soc., Bot., 55(360): 333-501. 1956; Skuja, Nova Acta Regiae Societatis Scientiarum Upsaliensis, 16(3): 1-404. 1956; Dawson, Pacific Science, 11: 92-132. 1957; Dixon, British Phycological Bulletin, 2: 71-80. 1961; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Oliveira Filho, Algas marinhas bentônicas do Brasil, 1-406. 1977; Hirano, Memoirs of the National Institute of Polar Research, 11: 1-2. 1979; Sammarco, Marine ecology progress series. Oldendorf, 13(1): 1-14. 1983; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Lee & Kang, Korean Journal of Phycology, 1(1): 311-325. 1986; Aboal, An. Jard. Bot. Madr., 45(1): 3-46. 1988; Alvarez-Cobelas & Gallardo, Acta Bot Malac., 13: 53-76. 1988; Zeybek et al., The marine algae of Turkey, 169-197. 1993; Day et al., Flora of Australia, 4: 1-276. 1995; Poulin et al., The Canadian Field-Naturalist, 109: 27-110. 1995; Zehr et al., Applied and Environmental Microbiology, 61(7): 2527-2532. 1995; Cvijan & Blazencic, Flora algi Srbije, 1-290. 1996; Silva et al., University of California Publications in Botany, 79: 1-1259. 1996; Pari & N'Yeurt, Australian Systematic Botany, 10: 867-910. 1997; Calvo, S., Bárbara & Cremades, Bot Mar., 42: 343-353. 1999; Hoffmann, Eur. J. Phycol., 34(4): 371-379. 1999; Vinogradova et al., Cyanoprocaryotes and algae of continental Israel, 32-141. 2000; Calvo & Bárbara, Nova Acta Científica Compostelana, 12: 5-34. 2002; Haroun et al., Bot Mar., 45: 139-169. 2002; Peña & Bárbara, Nova Acta Científica Compestelana, 12: 35-66. 2002; Phillips, Algae, 228-244. 2002; Díaz-Pulido & Díaz-Ruíz, Biota Colombiana, 4: 203-246. 2003; Lobban & Tsuda, Micronesica, 35/36: 54-99. 2003; Hallfors, Baltic Sea Environment Proceedings, 95: 1-208. 2004; Gorostiaga et al., An. Jard. Bot. Madr., 61: 155-180. 2004; Aysel, J Black Sea/Mediterranean Environment, 11: 1-124. 2005; Bárbara et al., An. Jard. Bot. Madr., 62: 69-100. 2005; Diaz-Tapia & Bárbara, Nova Acta Científica Compostelana, 14: 13-42. 2005; Barinova et al., Flora Mediterranea, 16: 111-132. 2006; Richert et al., European Journal of Phycology, 41(3): 259-279. 2006; Tsuda, Checklist and bibliography of the marine benthic algae within Chuuk, Pohnpei, and Kosrae States, Federated States of Micronesia, 1-43. 2006; Tsuda et al.,

Micronesica, 38: 207-219. 2006; Matula et al., Pol. Polar Res., 28(4): 283-315. 2007; Patova & Demina, Biodiversity of the Polar Ural ecosystems, 69-89. 2007; Stenina & Patova, Algae, 5-21. 2007; Woelfel et al., Estuar. Coast. Shelf Sci., 75(3): 296-307. 2007; Einav & Israel, Israel Journal of Plant Sciences, 56: 127-184. 2008; Hamed, Aust. J. Basic Appl. Sci., 2(1): 1-21. 2008; Komárek et al., Polar Biol., 31(7): 853-865. 2008; Liu, Checklist of biota of Chinese seas, 1-1267. 2008; Rath & Adhikary, Biodiversity assessment of algae in Chilika Lake, east coast of India, 22-33. 2008; Taskin et al., The check-list of the marine algae of Turkey, 1-87. 2008; Araújo et al., Bot Mar., 52: 24-46. 2009; Barinova et al., Turk J Bot., 33: 353-372. 2009; Bostock & Holland, Census of the Queensland Flora, 1-320. 2010; Smith, Int J Algae, 12(3): 230-256. 2010; Barinova et al., Turk JBot, 35: 729-774. 2011; Moro et al., Listado preliminar de especies marinas de Canarias, 1-174. 2011; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Widey & Merican, New Zealand inventory of biodiversity, 3: 50-69. 2012; Scholz & Liebezeit, Eur. J. Phycol., 47(2): 120-137. 2012; Tsuda & Walsh, Micronesica, 2: 1-91. 2013; Gadea et al., Thalassas, 29(1): 35-58. 2013; Lakkis, Biologie, Biodiversité, 1-510. 2013; Liao et al., Phytotaxa, 152(1): 1-17. 2013; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Nguyen et al., Bot Mar., 56(3): 207-227. 2013; Stanca et al., Transitional Waters Bull., 7(2): 133-144. 2013; Afonso-Carrillo, Lista actualizada de las algas marinas de las islas Canarias, 1-64. 2014; Barinova & Kukhaleishvili, The Journal of Biodiversity, 113: 305-338. 2014; Bagheri & Fallahi, Casp. J. Environ. Sci., 12(1): 81-97. 2014; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far East, 1-271. 2014; Varol & Sen, Journal of Fisheries Sciences, 8: 1-14. 2014; Tsuda, Phytotaxa 167(1): 35-60. 2014; Rath et al., Acta Physiol. Plant., 36(2): 409-419. 2014; Barinova et al., Turk J Bot, 39: 535-546. 2015; Mazur-Marzec et al., Eur. J. Phycol., 50(3): 343-360. 2015; Patova et al., Cyanoprokaryotes and algae, 133-166. 2015; Smith et al., Taxonomic catalogue of algae from Ghana (Africa) and new additions, 1-101. 2015; Rao & Gupta, Algae of India, 1-93. 2015; Gkelis et al., Biodivers. Data J., 4(e10084): 1-103. 2016; Phang et al., Raffles Bulletin of Zoology, 40: 13-59. 2016; Álamos, Acta Bot Malac., 41: 5-17. 2016; Gallardo et al., Algas Boletín Informativo de la Sociedad Española de Ficología, 51: 7-52. 2016; Solonenko, Int J Algae, 18(3). 247-

256. 2016; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Nava-Olvera et al., Revista de Biologia Marina y Oceanografia, 52(3): 429-439. 2017; Xia, Flora algarum marinarum sinicarum, 1-176. 2017; Barinova & Niyatbekov, Biodiversity International Journal, 2(3): 236-263. 2018; Zotov, Algologia, 28(2): 208-232. 2018; Medvedeva & Nikulina, Species diversity of Cyanobacteria and algae in the Bureya river basin Khabarovsk Territory, 8: 91-113. 2019; Taskin et al., Türkiye suyosunlari listei, 1-804. 2019; Chaudhari & Nandan, Bioinfolet, 17(1b): 135-139. 2020; Davydov, Polar Biol., 1-12. 2021.

Description: Filaments single, dull blue-green, straight, 15.2-26.8 μm wide. Sheaths initially thin, smooth, later thick, slightly lamellated. Cells 10.3-18.2 μm wide, 2.32-4.52 μm long, not constricted at the cross walls, cross walls slightly granulated, not or somewhat attenuated at the ends. Apical cells rounded, flat with thickened membrane, slightly attenuated.

References: Komarek &Anagnostidis (2005); Desikachary (1959).

Synonyms: *Conferva aestuarii* Mertens 1816; *Oscillatoria aestuarii* (Mertens) Lyngbye 1818; *Oscillatoria littoralis* Carmichael 1833; *Lyngbya littoralis* (Carmichael) Cooke 1884; *Lyngbya aerstuarii* f. *ferruginea* Gomont 1892; *Lyngbya aerstuarii* f. *natans* Gomont 1892; *Lyngbya aerstuarii* f. *limicola* Gomont 1892; *Lyngbya aerstuarii* f. *aeruginosa* Gomont 1892; *Lyngbya aerstuarii* f. *spectabilis* Gomont 1892; *Oscillatoria aestuarii* (Mertens) Lyngbye ex Gomont 1892; *Oscillatoria aestuarii* var. *atrovirens* Jürgens ex Gomont 1892; *Lyngbya littoralis* (Carmichael) Cooke ex Forti 1907.

Distribution: This species was reported from the microbial mat, mangrove swamps of Saudi Arabia (Hussain & Khoja, 1993), mangrove environments of Brazil (Nogueira & Ferrieira-Correia, 2001), Tamil Nadu (Sudha, 2005; Sudha et al., 2007, Sakthivel & Kathiresan, 2013), as Epiphytic, mangrove swamps of Pakistan (Bano & Siddiqui, 2007), planktic from Tamil Nadu (Nedumaran et al., 2008), epiphytic from Colombia (Pena-Salamanca, 2008), Epipsammic from Egypt (Potts, 1979).

General Environment: Ubiquitous species

Comments: New record to the marine cyanobacterial flora of Kerala.

Habitat: Appeared as green coloured planktic, epiphytic and epipsammic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 05.02.2018, MES 21502; Kottayam district, Kumarakom, 9^0 36'59.46" N 76^0 25' 21.46" E, 26.10.2018, MES 13734; Thiruvananthapurm district, Kadinamkulam, 8^0 37'15.01" N 76^0 48' 43.81" E, 04.08.2017, MES 21521. **(Plate 12, Fig. D-F)**.

2. *Lyngbya lutea* Gomont ex Gomont 1892

Gomont, Annales des Sciences Naturelles, Botanique, 7 (16): 91-264. 1892; Cotton, Proceedings of the Royal Irish Academy, 31B(15): 1-178. 1912; Setchell & Gardner, Proceedings of the California Academy of Science, 4(19): 109-215. 1930; Chapman, Journal of the Linnean Society of London, 55(360): 333-501. 1956; Koster, Blumea, 12(1): 45-56. 1963; Newhouse, Atoll Research Bulletin, 1-8. 1969; Little, British Phycological Journal, 8(1): 47-50. 1973; Ballantine & Humm, Florida Scientist, 150-162. 1975; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Hirano, Memoirs of the National Institute of Polar Research, 11: 1-25. 1979; Sheath & Steinman, Can J Bot., 60: 1964-1997. 1982; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Coutinho & Seeliger, Estuar. Coast. Shelf Sci., 23(6): 889-900. 1986; Lee & Kang, Korean Journal of Phycology, 1(1): 311-325. 1986; Otero-Schmitt & Sanjuan, Bot Mar., 35: 379-390. 1992; Silva, University of California Publications in Botany, 79:1-1259. 1996; Yoo et al., Algae, 11(3): 295-295. 1996; Pari & N'Yeurt, Australian Systematic Botany, 10: 867-910. 1997; Vinogradova et al., Cyanoprocaryotes and algae of continental Israel, 32-141. 2000; Phillips, Algae, 228-244. 2002; Nielsen & Gunnarsson, Seaweeds of the Faroe Islands, 49: 45-108. 2001; Haroun et al., Botanica Marina, 45: 139-169. 2002; Díaz-Pulido & Díaz-Ruíz, Biota Colombiana, 4: 203-246. 2003; Aldanondo-Aristizábal et al., Bol. Inst. Esp. Oceanogr., 19(1-4): 165-170. 2003; Herrera-López et al., Revista de la Academia Canaria de Ciencias, 15(3&4): 129-141. 2003; Hallfors, Baltic Sea Environment Proceedings 95: 1-208. 2004; Sherwood, Bishop Museum Occasional Papers, 80: 1-26. 2004; Hernández-González et al., Rev. Acad. Canar. Cienc., 16(4): 37-57. 2004; Domínguez-Alvarez et al., Vieraea 33: 79-92. 2005; Tsuda, Checklist

and bibliography of the marine benthic algae within Chuuk, Pohnpei, and Kosrae States, Federated States of Micronesia, 1-43. 2006; Taskin et al., The check-list of the marine algae of Turkey, 1-87. 2008; Debnath et al., Algae, 24(4): 185-193. 2009; Smith, Int J Algae, 12(3): 230-256. 2010; Moro et al., Listado preliminar de especies marinas de Canarias, 174. 2011; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Jeyachitra et al., Afr. J. Microbiol. Res., 7(25): 3240-3247. 2013; Lakkis, Biologie, Biodiversité, Biogéographie, 1-510. 2013; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Ramanathan et al., J Algal Biomass Utln, 4(3): 26-34. 2013; Stoyneva-Gärtner et al., Annuaire de l'Université de Sofia, 100: 1-55. 2015; Smith, Taxonomic catalogue of algae from Ghana (Africa) and new additions, 1-101. 2015; Gkelis et al., Biodiversity Data Journal, 4(e10084): 1-103. 2016; Yarovyi et al., Ukr. J. Ecol., 7(2): 91-95. 2017; Barinova & Niyatbekov, Biodivers. Int. J., 2(3): 236-263. 2018; Patova & Novakovskaya, Novosti Sistematiki Nizshikh Rastenii, 52(2): 311–353. 2018; Zotov, Algologia, 28(2): 208-232. 2018; Kopyrina et al., International Journal of Oceanography and Hydrobiology, 49(2): 99-122. 2020; Pandkar et al., Biosci. Biotechnol. Res. Asia, 17(2):235-245. 2020.

Description: Thallus blue green, thin, gelatinous. Trichomes solitary, straight, 6.6-8.3 μm wide, not constricted at the cross walls, cross walls not granulated, not tapering towards ends. Cells usually much shorter than wide, 3.3-5.2 μm long. Apical cells flattened rounded, with slightly thickened outer cell wall.

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Synonyms: *Oscillatoria lutea* Agardh ex Gomont 1824; *Porphyrosiphon luteus* (Gomont ex Gomont) Anagnostidis & Komárek 1988.

Distribution: This species was reported as epiphytic from the mangrove environment of Africa (Lambert et al., 1989), Puerto Rico (Rodriguez & Stoner, 1990), Microbial mat, Mangrove Swamps of Saudi Arabia (Hussain & Khoja,1993), mangrove environment of Brazil (Branco et al., 1997), (Nogueira & Ferrieira-Correia, 2001), as epipsammic from the mangrove environment of Indian Sundarbans (Sen & Naskar, 2003), Tamil Nadu (Sudha, 2005; Sudha et al., 2007).

General Environment: Freshwater species

Comments: New record to the cyanobacterial flora of Kerala.

Habitat: Appeared as olive green coloured benthic and epipsammic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Kottayam district, Mekkara, 9^0 48'54.31" N 76^0 21' 57.54" E, 10.07.2016, MES 21536; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 14.12.2018, MES 21576. **(Plate 13, Fig. A)**.

3. *Lyngbya truncicola* Ghose 1924

Ghose, Bot. J. Linn. Soc., 46: 333-346. 1924; Randhawa, Proc. Indian Acad. Sci. B, 4(1)36-44. 1936; Khan et al., World J. Microbiol. Biotechnol., 10(3): 296-298. 1994; Singh, Proc. Indian Acad. Sci. B, 49(1):66-73. 1959; Shevchenko, Int J Algae, 1(4): 68-85. 1999; Tiwari et al., Biol. Fertil. Soils, 34(4): 291-295. 2001; Smith & Olson, Int J Speleol., 36(2): 105-114. 2007; Naskar et al., Bangladesh J. Plant Taxon., 15(1):31-38. 2008; Siddiqui et al., Cyanobacteria, Bacteria and Fungi, 1-415. 2009; Bhakta et al., J. Indian Bot. Soc., 89(1 & 2): 169-184. 2010; Chakraborty et al., Indian Hydrobiology, 12(2): 204-224. 2010; Deka & Sarma, Int. J. Appl. Biol. Pharm., 2(4): 430-433. 2011; Lemes-da-Silva et al., Brazilian Journal of Botany, 35(2):169-179. 2012; Schmidle & Schmidle, Philipp J. Sci., 141(1): 57-66. 2012; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Madhumathi & Vijayakumar, J Algal Biomass Utln, 4(1):70-79. 2013; Tunca et al., Chin. J. Oceanol. Limnol., 32(4): 845-857. 2014; Isabella et al., Journal of Research in Ecology, 3(1): 1-20. 2015; Azam et al., Webbia, 71(1): 141-153. 2016; Caraus, Studii si Cercetari Biologie, 7:1-1002. 2017; Jaiswal, Algae of north-west Khandesh, 1-448. 2017; Unković et al., Zbornik Matice srpske za prirodne nauke, 132: 57-67. 2017; Galindo-Alcázar et al., Polibotánica 45: 131-146. 2018; Schinquel et al., Rev. Fac. Cs. Ex. Fis. Nat, 5: 59-67. 2018; Antsiferova et al., VSU Bulletin. Series: Geography. Geoecology, 4:53-60. 2020; Chaudhari & Nandan, Bioinfolet, 17(1b):135-139. 2020; Nikolaeva et al., Polar Sci., 24(100522): 1-9. 2020; Tharik et al., International Journal of Ecology and Environmental Sciences, 47(2):153-169. 2021.

Description: Thallus thin, expanded, blue-green. filaments straight, 13.6-16.3 μm wide. Sheaths at first hyaline and delicate, later firm and slightly yellowish,

unlamellated. Trichomes cylindrical, blue-green, 12.2-14.2 μm wide, not constricted at the cross walls, cell walls not granulated, not attenuated at the ends. Cells short, 2.8-4.1 μm long, cell contents granular, apical cell rounded, without calyptra.

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Distribution: No distributional records were found along with the mangrove environment.

General Environment: Freshwater/Aerophytic species

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Appeared as green coloured epiphytic on the pneumatophores of *Avicennia officinalis* L. cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 21.01.2017, MES 21527. **(Plate 13, Fig. B-C)**.

3. *Oscillatoria* Vaucher ex Gomont, 1892

Trichomes cylindrical, straight or slightly waved, motile with gliding, oscillation and left-handed or right-handed rotation, not constricted or constricted at the cross walls, usually without sheaths. Cells short, discoid always more than 2 times shorter than wide, cell contents homogenous or sometimes with large prominent granules. Apical cell widely rounded, sometimes capitate or with narrow calyptra. Cell division transversal to the trichome axis in a rapid sequence, cells dividing rapidly before reaching the original size. Reproduction by disintegration into short motile hormogonia, with help of necridic cells.

The genus has 306 species. Only 14 planktic, benthic, epipsammic, epiphytic, or corticolous species from the mangrove ecosystems of southern Kerala are described here.

Key to the species

1a. Apical cell without calyptra or thickened cell wall 2

1b. Apical cell with calyptra or thickened cell wall 11

2a. Trichomes up to 10.0 μm wide 3

2b. Trichomes over 10.0 µm wide 6

3a. Trichomes not constricted at cross walls 4

3b. Trichomes constricted at the cross walls 5

4a. Trichomes 5.6-8.3 µm wide ..... **2. *O. curviceps* var. *angusta***

4b. Trichomes 4.1- 6.8 µm wide ..... **3. *O. rupicola***

4c. Trichomes 7.4 -9.0 µm wide ..... **11. *O. simplicissima***

4d. Trichomes 5.3-5.9 µm wide ..... **12. *O. subbrevis***

5a. Trichomes 4.3- 8.2 µm wide ..... **13. *O. tenuis***

6a. Trichomes not constricted at the cross walls 7

6b. Trichomes constricted or slightly constricted at the cross walls 8

7a. Trichomes 7.0 -17.0 µm wide 9

7b. Trichomes over 17 µm wide 10

8a. Trichomes 4.3-8.2 µm wide ..... **13. *O. tenuis***

8b. Trichomes 12.9-13.8 µm wide ..... **6. *O. perornata***

9a. Cells 1.5-4.5 µm long 11

9b. Cells over 4.5 µm long 12

11a. Trichomes 8.2-11.1 µm wide, cells 1.5-2.2 µm long ..... **14. *O. vizagapatensis***

11b. Trichomes 7.1-13.1 µm wide, cells 2.4-4.3 µm long ..... **3. *O. limosa***

12a. Trichomes 13.9- 17.0 µm wide, cells 3.5-4.9 µm long ..... **1. *O. curviceps***

12b. Trichomes 12.8-16.2 µm wide, cells 3.2-5.3 µm long ..... **10. *O. sancta***

10a. Trichomes 18.0-21.1 µm wide ..... **4. *O. major***

10b. Trichomes 21.6-24.9 µm wide ..... **5. *O. obtusa***

11a. Trichomes 35.1-43.2 µm wide ..... **7. *O. princeps***

11b. Trichomes 30.8-36.5 µm wide ..... **8. *O. princeps* var. *pseudolimosa***

1. *Oscillatoria curviceps* C.Agardh ex Gomont 1892

Gomont, Annales des Sciences Naturelles, Botanique, 16: 91-264. 1892; Skuja, Nova Acta Regiae Societatis Scientiarum Upsaliensis, Series 4, 16(3): 1-404. 1956; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Hirano, Mem. Natl. Inst. Polar Res, 11: 1-25. 1979; Sheath & Steinman, Can J Bot., 60: 1964-1997. 1982; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Etheredge & Pridmore, Water & Soil Miscellaneous Publication, 111: 5-122. 1987; Alvarez-Cobelas & Gallardo, Acta Bot Malac., 13: 53-76. 1988; Day et al., Flora of Australia, 4: 1-276. 1995; Silva et al., University of California Publications in Botany, 79: 1-1259. 1996; Calvo et al., Bot Mar., 42: 343-353. 1999; Ling & Tyler, Bibliotheca Phycologica, 105: 1-643. 2000; Vitenaite, Botanica Lithuanica, 7(4): 343-364. 2001; Joseph & Joseph, Environ. Monit. Assess., 80(2): 175-185. 2002; Hällfors, Balt. Sea Environ. Proc., 95: 1-208. 2004; Aysel, J Black Sea/Mediterranean Environment 11: 1-124. 2005; Hamed, Acta Bot. Hung., 47(1-2): 117-136. 2005; Tiwari et al., Trop. Ecol., 46(2): 165–171. 2005; Dwivedi et al., Bull Environ Contam Toxicol., 77(3): 427-436. 2006; Muthukumar et al., Acta Bot Malac., 32: 17-25. 2007; Stenina & Patova, Algae, 5-21. 2007; Tiwari & Shukla, Nat. Environ. Pollut. Technol., 6(1): 85-90. 2007; Vijayakumar et al., Acta Bot Malac., 32: 27-34. 2007; Hamed, A. F. Aust. J. Basic & Appl. Sci., 2(1): 1-21. 2008; Naskar et al., Bangladesh J. Plant Taxon., 15(1): 31-38. 2008; Senthilkumar & Sivakumar, J. Environ. Biol., 29(5): 747-752. 2008; Taskin et al., The check-list of the marine algae of Turkey, 1-87. 2008; Škaloud, Fottea, 9(1): 65-80. 2009; Ajani, Journal of Biological Sciences, 2: 1-13. 2010; Bostock & Holland, Census of the Queensland Flora, 1-320. 2010; Chakraborty et al., Indian Hydrobiology, 12(2): 204-224. 2010; Rai et al., Our Nature, 8: 336-354. 2010; Suryavanshi et al., J. Indian Bot. Soc., 89(1 & 2): 189-196. 2010; Smith, Int J Algae, 12(3): 230-256. 2010; Cherian & Shahare, International Journal for Environmental Rehabilitation and Conservation, 2(2): 70-78. 2011; Dubey et al., Biotechnol. J. Int., 61-67. 2011; Pham et al., A checklist of the algae of Singapore, 1-100. 2011; Sarim et al., Pak. J. Pl. Sci., 16(2-1). 2011; Täuscher, Verhandlungen des Botanischen Vereins von Berlin und Brandenburg, 144: 177-192. 2011; Yakub et al., Int. J. Biol. Chem. Sci. 5(1): 150-163. 2011;

Widey & Merican, New Zealand inventory of biodiversity, 3: 50-69. 2012; Govindasamy & Viji, World Appl. Sci. J., 16(10): 1409-1415. 2012; Kshirsagar et al., Terrestrial and Aquatic environmental Toxicology, 6(2): 136-142. 2012; Martins et al., Rev. Bras. Bot., 35(4): 325-338. 2012; Patil et al., J. Algal Biomass Utiln, 3(2): 71-102. 2012; Park, Algal flora of Korea, 5(1):1-71. 2012; Samreen et al., Pak. J. Pl. Sci., 18(1): 25-34. 2012; Gadea et al., Thalassas, 29(1): 35-58. 2013; Lin et al., Botanical studies, 54(1): 1-12. 2013; Madhumathi & Vijayakumar, J Algal Biomass Utln, 4(1): 70-79. 2013; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Elayaraj & Selvaraju, Int. J. Biol. Res., 2(2): 90-95. 2014; Elayaraj & Selvaraju, Int. Lett. Nat. Sci., 11(2): 145-156. 2014; Kamble & Karande, J. Indian Bot. Soc., 93(1&2):120-125. 2014; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far East, 1-27. 2014; Nassar & Khairy, Annu. Res. Rev. Biol., 4(23): 3566-3585. 2014; Naz et al., Plant Environ. Dev., 3(I): 6-14, 2014; Singh et al., J Asia Pac Biodivers., 7(4): 462-470. 2014; Smirnova, Novosti Sistematiki Nizshikh Rastenii, 48: 89-103. 2014; Varol & Sen, Journal of Fisheries Sciences, 8: 1-14. 2014; Arman et al., Journal of Aquatic Ecology, 4(4): 79-71. 2015; Jain, J Exp Biol Agric Sci., 3(2): 131-137. 2015; Kesarwani et al., Phykos, 45(1): 18-29. 2015; Malammanavar, Advances in Plant Sciences and Biotechnology, 40-45. 2015; Miranda & Krishnakumar, Environ. Monit. Assess., 187(11): 1-25. 2015; Patova et al., Cyanoprokaryotes and algae, 133-166. 2015; Raghavendra et al., Int. J. Adv. Res., 3(6): 2400-2405. 2015; Rao & Gupta, Algae of India, 1-93. 2015; Smith et al., Taxonomic catalogue of algae from Ghana (Africa) and new additions, 1-101. 2015; Vijayan & Ray, Am. J. Plant Sci., 6(18): 2924-2938. 2015; Azam et al., Webbia, 71(1): 141-153. 2016; Ekhator & Alika, Ife Journal of Science, 18(1): 63-84. 2016; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Jadhav et al., Nat. Environ. Pollut. Technol., 15(4): 1363-1367. 2016; Kumar & Mohan, The Biobrio, 3(3&4): 218-220. 2016; Phang et al., Raffles bull. zool., 40: 13-59. 2016; Tagad, Int. J. Res. Biosci. Agric. Techn., 4(1): 27-33. 2016; Usmani et al., J. Indian Bot. Soc., 95(1 & 2): 28-36. 2016; Yaseen et al., Pure Appl. Biol., 5(4): 1-7. 2016; Ansary et al., Banats J Biotechnol., 8(15): 83-89. 2017; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Dasgupta et al., Cryptogam Biodiversity and Assessment, 2(2): 1-10. 2017; Dirborne & Ramanujam, Nelumbo, 59(2): 195-212. 2017; Halder,

Braz. J. Biol. Sci., 4(7), 89-101. 2017; Hokmolahi et al., Iran. J. Bot., 23(1): 60-71. 2017; Pandiammal et al., Journal of Academia and Industrial Research, 6(1): 7-12. 2017; Umarani et al., Indian J Sci Technol., 10(13): 1-7. 2017; Hajong & RamanujamJ. Algal Biomass Util., 9(2): 9-24. 2018; Ray et al., European Journal of Biomedical, 5(3): 335-342. 2018; Srinivas & Aruna, Int J Sci Res Sci & Technol., 4(10): 245-256. 2018; Stutz & Mattern, Beiträge zu den Algen Baden-Württembergs, 1-504. 2018; Barupal, J. Algal Biomass Utln, 10(1): 26-35. 2019; Bodkhe, Bioinfolet, 16(4): 206-210. 2019; Le, J. Viet. Env., 11(2): 83-90. 2019; Medvedeva & Nikulina, Species diversity of Cyanobacteria and algae in the Bureya river basin Khabarovsk Territory, 8: 91-113. 2019; Tandle & Mulani, Int. J. Res. Anal. Rev., 6(1): 942-945. 2019; Taskin et al., Türkiye suyosunlari listei, 1-804. 2019; Tucci et al., Atlas de cianobactérias e microalgas de águas continentais brasileiras,1-232. 2019; Dey & Chakraborty, Asian J Biol Life Sci., 9(3): 387-390. 2020; Jonah et al., Int. J. Fish. Aquat., 8(3): 532-536. 2020; Kopyrina et al., International Journal of Oceanography and Hydrobiology, 49(2): 99-122. 2020; Hajong et al., Int. J. Botany Stud., 6(2): 589-596. 2021; Tharik et al., Int. J. Ecol. Environ. Sci., 47(2): 153-169. 2021.

Description: Thallus blackish blue-green. Trichome blue-green, more or less straight, sometimes bent at the ends, 13.9-17 µm wide, not constricted at the cross walls, cross walls sometimes granulated. Cells 1/3- 1/6 as long as wide, 3.5-4.9 µm long. Apical cells flat rounded, not capitate, sometimes with slightly thickened cell walls.

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Distribution: This species was reported from the mangrove environments of Tamil Nadu (Sakthivel & Kathiresan, 2013), Saudi Arabia (Mohammed & Al-Shehri, 2015), Brazil (Branco et al., 1997), microbial mat, mangrove swamps of Saudi Arabia (Hussain & Khoja, 1993), as epiphytic (Selvakumar & Sundararaman, 2001), as planktic (Sen & Naskar, 2003).

General Environment: Freshwater species

Comments: New record to the marine cyanobacterial flora of Kerala.

Habitat: Appeared as a blackish green or green coloured planktic and benthic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Alappuzha district, Pathiramanal, 9^0 37' 09.78" N, 76^0 23' 06.43" E, 06.02.2017, MES 21517; Kottayam district, Mekkara, 9^0 48'54.31" N 76^0 21' 57.54" E, 17.07.2016. MES 21537; Kollam district, Ayiramthengu, 24.10.2019, MES 21555. **(Plate 13, Fig. D-F)**.

2. *Oscillatoria curviceps* var. *angusta* Ghose 1927

Ghose, Journal of the Burma Research Society, 17(3): 238-243. 1927; Alvarez & Bazan, Semiarida, 7(2): 49-62. 1994; Cherian & Matta, ESSENCE Int. J. Env. Rehab. Conser., 1(2): 81-87. 2010; Smith, Int J Algae, 12(3): 230-256. 2010; Hussain et al., J. Bio. & Env. Sci., 1(5): 66-74. 2011; Patil et al., J. Algal Biomass Utln., 3(2): 71-102.2012; Álvarez & Bazán, Semiárida, 7(2): 43-62. 2020.

Description: Thallus blue-green. Sheaths not observed. Trichomes straight, green, not attenuated, not constricted at the cross walls, cross walls granulated, 5.6 – 8.3 μm wide, shorter than wide, 2.30-3.11 μm long. Apical cell rounded to obtuse-conical.

References: Desikachary (1959).

Distribution: No distributional records were found along with the marine environment.

General Environment: Freshwater species

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as a blue-green or olive-green coloured planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Kottayam district, Kumarakom, 9^0 36'59.46" N 76^0 25' 21.46" E, 10.07.2016, MES 21540; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 14.12.2018, MES 21577. **(Plate 14, Fig. A)**.

3. *Oscillatoria limosa* Agardh ex Gomont 1892

Gomont, Annales des Sciences Naturelles, Botanique, 16: 91-264. 1892; Forti in De Toni, Sylloge Algarum, 5: 154. 1907; Adams, Proc. R. Ir. Acad., 27B(2):

11-60. 1908; Lyle, Journal of Botany, British and Foreign, 58: 1-53. 1920; Fremy, Myxo. d'Afr. Equat, franc., 212. 1929; Geitler, Kryptogamenflora, 944. 1932; Fremy, Cyano.cotes d'Eur., 117. 1933; Reinhold, Annales de la Société Géologique de Belgique, 61(1): 39-47. 1937; Ganapathi, Proc. Nat. inst. Sci., 6: 237-300. 1940; Skuja, Symbolae Botanicae Upsalienses, 9(3): 1-399. 1948; Skuja, Nova Acta Regiae Societatis Scientiarum Upsaliensis, 14(5): 1-18. 1949; Skuja, Nova Acta Regiae Societatis Scientiarum Upsaliensis, 16(3): 1-404. 1956; Chapman et al., Trans. Roy. Soc. New Zealand, 84: 695-747. 1957; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Bicudo & Martau, Iheringia Serie Botanica, 19: 31-40. 1974; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Pfiester et al., Southwest Nat., 149-164. 1979; Sheath & Steinman, Can J Bot., 60: 1964-1997. 1982; Tell, Bibliotheca Phycologica, 70:1-283. 1985; Shaji & Panikkar, Phykos, 33(1&2): 105–112. 1994; Alvarez-Cobelas & Gallardo, Acta Botanica Malacitana 13: 53-76. 1988; Day et al., Flora of Australia, 4: 1-276. 1995; Kristiansen & Lind, Nord. J. Bot., 15: 443-448. 1995; Poulin et al., Can. Field-Nat., 109: 27-110. 1995; Zehr et al., Appl. Environ. Microbiol., 61(7): 2527-2532. 1995; Cvijan & Blazencic, Flora algi Srbije, 1-290. 1996; De-Lamonica-Freire & Heckman, Internationale Revue der gesamten Hydrobiologie 81(2): 253-280. 1996; Skulberg, Terrestrial and limnic algae and cyanobacteria, 383-395. 1996; Silva et al., Univ. Calif. Publ. Bot., 79: 1-1259. 1996; Pari & N'Yeurt, Aust. Syst. Bot., 10: 867-910. 1997; Calvo et al., Bot Mar., 42: 343-353. 1999; Ling & Tyler, Bibliotheca Phycologica, 105:1-643. 2000; Vinogradova et al., Cyanoprocaryotes and algae of continental Israel, 32-141. 2000; Brattegard & Holthe, Distribution of marine, benthic macro-organisms in Norway, 1-394. 2001; Vitenaite, Bot Lith., 7(4): 343-364. 2001; Bárbara et al., Anales Jard. Bot. Madr., 59(2): 292-297. 2002; Calvo & Bárbara, Nova Acta Científica Compostelana, 12: 5-34. 2002; Phillips, Algae, 228-244. 2002; Mauch & Schmedtje, Informationsberichte des Bayerischen Landsamtes für Wasserwirtschaft Heft, 1(3): 1-388. 2003; Hällfors, Balt. Sea Environ. Proc., 95: 1-208. 2004; Hamisi et al., West. Indian Ocean J. Mar. Sci., 3(2): 113-122. 2004; Aysel, J Black Sea/Mediterranean Environment, 11: 1-124. 2005; Bárbara et al., An. Jard. Bot. Madr., 62: 69-100. 2005; Jungblut et al., Environ. Microbiol., 7(4), 519-529. 2005; Hamed, Acta Bot. Hung., 47(1-2): 117-136. 2005; Leghari et al., Int. J.

Phycol. Phycochem., 1(2): 151-158. 2005; Leghari et al., Int. J. Phycol. Phycochem., 1(2): 167-172. 2005; Sahin, Turk. J. Biol., 28(2-4): 103-109. 2005; Vilalta & Sabater, Phycologia, 44: 678-684. 2005; Soylu & Gönülol, Cryptogam Algol., 27: 85-101. 2006; Tiwari & Chauhan, J. Environ. Biol., 27(1): 35-38. 2006; Chattopadhyay & Banerjee. Turk J Bot., 31(4): 287-296. 2007; Hasler et al., Fottea, 7(1): 49-68. 2007; Johansen et al., Southeast. Nat., 1: 99-134. 2007; McGregor, Flora of Australia, 1-123. 2007; Stenina & Patova, Algae, 5-21. 2007; Tiwari & Shukla, Nat Environ Pollut Technol., 6(1), 85-90. 2007; Bhatnagar et al., J. Arid Environ., 72(2): 73-83. 2008; Jena et al., Indian Hydrobiology, 11(1): 9-24. 2008; Taskin et al., The check-list of the marine algae of Turkey, 1-87. 2008; Barinova et al., Turk J Bot., 33: 353-372. 2009; Büdel et al., Microb. Ecol., 57(2): 229-247. 2009; González, Catálogo de las algas y cianoprocariotas dulciacuícolas de Cuba, 1-147. 2009; Al-Obaidi et al., BioRisk, 3, 111-126. 2009; Wołowski & Kowalska, Fragmenta Floristica et Geobotanica Polonica, 16(1): 145-154. 2009; Barinova et al., J. Arid Environ., 74: 765–776. 2010; Bostock & Holland, Census of the Queensland Flora, 1-320. 2010; Chakraborty et al., Indian Hydrobiology, 12(2): 204-224. 2010; González & González, Algas Boletín de la Sociedad Española de Ficología, 43: 6-10. 2010; Gupta, Nelumbo, 52: 53-62. 2010; Makandar & Bhatnagar, J. Algal Biomass Util., 1(3): 54-69. 2010; Rai et al., Our Nature, 8: 336-354. 2010; Smith, Int J Algae, 12(3): 230-256. 2010; Suryavanshi et al., J. Indian Bot. Soc., 89(1&2):189-196. 2010; Dash et al., E-planet, 9(1), 1-14. 2011; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Kumar et al., Botanica Orientalis, 8: 77-89. 2011; Täuscher, Verhandlungen des Botanischen Vereins von Berlin und Brandenburg, 144: 177-192. 2011; Tao, Procedia Environmental Sciences, 10, 2336-2341. 2011; Bhakta & Adhikary, The Ecoscan, 1: 1-4. 2012; Widey & Merican, New Zealand inventory of biodiversity, 3: 50-69. 2012; Kshirsagar et al., Terrestrial and Aquatic environmental Toxicology, 6(2):136-142. 2012; Lone et al., Egypt. Acad. J. Biol. Sci., 4(2), 19-26. 2013; Mohanty & Adhikary, Journal of Water Resource and Protection, 5(6): 611-623. 2013; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Merino-Virgilio et al., Check List, 9(4): 771-779. 2013; Nguyen et., Bot Mar., 56(3): 207-227. 2013; Gadea et al., Thalassas, 29(1): 35-58. 2013; Thakur et al., Environ. Monit. Assess., 185(10):

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48(1): 36-45. 2018; Stutz & Mattern, Beiträge zu den Algen Baden-Württembergs, 1-504. 2018; Saber et al., Cryptogam Algol., 39(2): 215-226. 2018; Ozer et al., Turkish J. Fish. Aquat. Sci., 18(10): 1187-1194. 2018; Zotov, Algologia, 28(2): 208-232. 2018; Barupal, J. Algal Biomass Utln, 10(1): 26-35. 2019; Berezovskaya, Algologia, 29(1): 59-76. 2019; Belokda et al., Saudi J. Biol. Sci., 26(3), 431-438. 2019; Bigham et al., Phycological R., 3(1): 275-286. 2019; Hameed et al., World News of Natural Sciences, 24: 251-268. 2019; Koziychuk, Hydrobiol. J., 55(5): 44-56. 2019; Le et al., J. Vietnam. Environ., 11(2): 83-90. 2019; Maurya & Paliwal, Plant Archives, 19(2): 3307-3312. 2019; Taş et al., Desalination and water treatment, 155: 402-415. 2019; Tandle & Mulani, Int. J. Res. Anal. Rev., 6(1): 942-945. 2019; Taskin et al., Türkiye suyosunlari listei, 1-804. 2019; Torres-Ariño et al., Cybella, 50(1): 1-97. 2019; Bharati et al., Crypt. Biodivers. Assess, 4(2): 1-6. 2020; Dey & Chakraborty, Asian J Biol Life Sci., 9(3): 387-390. 2020; Dochin, Annual of Sofia University, 104: 58-74. 2020; Rosset et al., Phycologia, 59(6): 571-577. 2020; Das et al., Phytotaxa, 435(4): 255-279. 2020; Pandkar et al., Biosci. Biotechnol. Res. Asia, 17(2), 235-245. 2020; Arguelles, Philipp J. Sci., 150(1): 123-137. 2021; Piranti et al., J. Ecol. Eng., 22(3): 135–142. 2021; Davydov, Polar Biol., 1-12. 2021; Tarasova et al., IOP Conf. Ser. Earth Environ. Sci., 818(1): 1-7. 2021.

Description: Thallus dark green, brown, extended, thick trichome more or less straight, not attenuated at the apices, 7.1-13.1 µm wide, usually very long, straight, colourless sheaths, not constricted at the cross walls, cross walls frequently granulated, not attenuated at the ends, not capitate, slowly gliding and oscillating. Cells rectangular, 1/3-1/6 as long as wide, 2.468-4.348 µm long, cell content mostly fine granular. Apical cells flat-rounded, mostly with slightly thickened outer cell wall.

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Synonyms: *Oscillatoria tenuis* var. *limosa* (Dillwyn) Kirchner ex Forti 1907; *Phormidium limosum* (Dillwyn) P.C.Silva 1996

Distribution: This species was reported as planktic from the mangrove environments of Visakhapatnam (Rao et al., 2015), as epiphytic from South Africa (Lambert et al., 1989; Mann & Steinke, 1993; Steinke et al., 2003), as periphytic

(Sen & Naskar, 2003); mangrove environment of Pakistan (Ahmed et al., 2016), Tamil Nadu (Bhuvaneshwari & Muruganandam, 2016; Priya et al., 2019; Dhargalkar, 1994).

General Environment: Freshwater species

Comments: New record to the mangrove cyanobacterial flora of Kerala.

Habitat: Appeared as dark brown coloured epipsammic and planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Alappuzha district, Pathiramanal, 9^0 37' 09.78" N, 76^0 23' 06.43" E, 06.02.2017, MES 21518; 02.12.2016, MES 13719; Thiruvananthapuram district, Kadinamkulam, 8^0 37'15.01" N 76^0 48' 43.81" E, 19.04.2018, MES 21515. **(Plate 14, Fig. B-F)**.

4. *Oscillatoria major* Vaucher ex Forti 1907

Forti, Sylloge Myxophycearum, 5. 1-761. 1907; Reinhold, Annales de la Société Géologique de Belgique, 61(1): 39-47. 1937; Cvijan & Blazencic, Flora algi Srbije, 1-290. 1996; Samylina et al., Int J algae, 12(2): 142-158. 2010; Gadea et al., Thalassas, 29(1): 35-58. 2013; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Barinova & Niyatbekov, Biodivers Int J., 2(3): 236-263. 2018.

Description: Thallus mucilaginous, blue-green. Trichome 18-21.1 µm wide, blue-green, straight, not constricted at the cross walls, cross walls granulated. Cells shorter than wide, 4.6-6 µm long. Apical cells obtusely rounded, without calyptra or thickened cell walls.

References: Komarek & Anagnostidis (2005).

Synonyms: *Lyngbya major* Hansgirg 1893

Distribution: No distributional records were found along with the marine environment.

General Environment: Freshwater species

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as a dark green coloured planktic and benthic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Kollam district, Ayiramthengu, 9^0 07'33.93" N 76^0 28' 45.34" E, 11.11.2016, MES 21522; 14.08.2017, MES 13742; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 14.09.2017, MES 201406. **(Plate 15, Fig. A-C)**.

5. *Oscillatoria obtusa* N.L.Gardner 1927

Gardner, Mem. N. Y. Bot. Gard., 7: 1-144. 1927; Nagarkar, Bot Mar., 45(3): 274-283. 2002; Chu et al., Flora algarum sinicarum aquae dulcis Tomus IX Cyanophyta Hormogonophyceae, 1-312. 2007; Polge et al., Turkish J. Fish. Aquat. Sci., 10(1): 39-45. 2010; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Kesarwani et al., Phykos, 45(1): 18-29. 2015; Raghavendra et al., Int. J. Adv. Res., 3(6): 2400-2405. 2015; Rajyalaxmi & Aruna, Int J Sci Res Sci & Technol., 6(1): 227-234. 2019; Taskin et al., Türkiye suyosunlari listei,1-804. 2019; Tharik et al., Int. J. Ecol. Environ. Sci., 47(2): 153-169. 2021.

Description: Thallus blue-green, mucilaginous. Trichome straight, bright blue-green to olive green, 21.6-24.9 µm wide, 2.7-4.3 µm long, not constricted at the cross walls, apical cell flattened rounded with slightly thickened outer cell wall.

References: Komarek & Anagnostidis (2005).

Distribution: No distributional records were found along with the marine environment.

General Environment: Freshwater species

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as a green or olive green coloured benthic and planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 11.10.2018, MES 21412; Thiruvananthapuram district, Kureekkadavu, 8^0 46'11.14" N 76^0 42' 36.69" E, 24.03.2016, MES 21455;

Kottayam district, Kumarakom, 9^0 36'59.46" N 76^0 25' 21.46" E, 18.02.2017, MES 21471. **(Plate 15, Fig. D-F)**.

6. ***Oscillatoria perornata*** Skuja 1949

Skuja, Nova Acta Regiae Societatis Scientiarum Upsaliensis, 14(5): 1-188. 1949; Richardson, Florida Scientist, 205-208. 1973; Begum et al., Phykos, 32 (1&2): 109-114. 1993; Aysel, J Black Sea/Mediterranean Environment 11: 1-124. 2005; Schrader et al., N. Am. J. Aquac., 67(2): 138-147. 2005; Nguyen et al., Nova Hedwigia, 85(1-2): 1-34. 2007; Schrader et al., N. Am. J. Aquac., 69(4): 360-366. 2007; Bostock & Holland, Census of the Queensland Flora, 1-320. 2010; Gupta, Nelumbo, 52: 53-62. 2010; Patil, Flora and Fauna, 16(1): 41-44. 2010; Santos et al., Acta Bot. Bras., 24, 924-934. 2010; Sarim et al., Pakistan Journal of Plant Sciences, 16(2-1): 2011; George et al., Egypt. J. Aquat. Res., 38(3): 157-170. 2012; Patil et al., J. Algal Biomass Utiln, 3(2): 71-102. 2012; Sun et al., J. Appl. Phycol., 24(5): 1003-1013. 2012; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Mohanty & Adhikary, Water Resour. Prot., 5(6): 611-623. 2013; Soni & Thomas, Int. J. Environ., 2(1): 115-126. 2013; Al-Hassany & Hassan, Mesop. Environ. J., 1(2): 96-108. 2015; Narmada, Appl Ecol Environ Res., 13(1):115-131. 2015; Kesarwani et al., Phykos, 45(1): 18-29. 2015; Álamos, Acta Botanica Malacitana 41: 5-17. 2016; Ambika & Krishnamurthy, J. Indian Bot. Soc., 95(1&2): 78-91. 2016; Gallardo et al., Algas Boletín Informativo de la Sociedad Española de Ficología, 51: 7-52. 2016; Das & Keshri, Phykos, 47(1): 31-51. 2017; Gupta, Int. J. Plant Env., 3(1): 53-63. 2017; Gupta, Trop. Plant Res., 4(3): 421-432. 2017; Vinoth et al., J. Life Sci., Bioinform., Pharmaceut. Chem. Sci., 3: 215-241. 2017; Dunck et al., Hoehnea, 45(4): 560-590. 2018; Davari et al., Phycological Res., 2(2): 237-253. 2018; Le et al., J. Vietnam. Environ.,11(2): 83-90. 2019; Tucci et al., Núcleo de Pesquisa em Ficologia, 1-232. 2019; Van Tu et al., Vietnam J Sci Technol., 20(2):189-197. 2020; Piranti et al., J. Ecol. Eng.., 22(3): 135-142. 2021; Tiwari et al., J Pure Appl Microbiol, 15(2): 851-864. 2021.

Description: Thallus dark blue-green, mucilaginous. Trichomes erect, flexuous, solitary, straight or bent, distinctly constricted at the cross walls, 12.9-13.8 μm wide.

Cells 2.9-5.3 μm long, septa more or less granulated. Apical cell rounded- conical, without thickened outer cell walls or without calyptra.

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Synonyms: *Planktothrix perornata* (Skuja) Anagnostidis & Komarek 1988

Distribution: This species was reported as epizoic, rockpool water, coastal waters of mangrove environment of Pakistan (Bano & Siddiqui, 2007), mangrove environment of Tamil Nadu (Bhuvaneshwari & Muruganandam, 2016; Priya et al., 2019).

General Environment: Freshwater species

Comments: New record to the mangrove cyanobacterial flora of Kerala.

Habitat: Appeared as a dark brown coloured planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 11.08.2018, MES 21413; 17.01.2017, MES 21526; Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 14.09.2017, MES 21407; Kollam district, Ayiramthengu, 9^0 07'33.93" N 76^0 28' 45.34" E, 16.09.2018, MES 21419; Kottayam district, Mekkara, 9^0 48'54.31" N 76^0 21' 57.54" E, 16.07.2019, MES 21490. **(Plate 16, Fig. A-B)**.

7. *Oscillatoria princeps* Vaucher ex Gomont 1892

Gomont, Annales des Sciences Naturelles, Botanique, 16: 91-264. 1892; Forti in De Toni, Sylloge Algarum, 5: 150. 1907; Adams, Proc. R. Ir. Acad., 27B(2): 11-60. 1908; Geitler, Kryptogamenflora, 947. 1932; Reinhold, Annales de la Société Géologique de Belgique, 61(1): 39-47. 1937; Prescott, Trans Am Microsc Soc., 61(2): 109-119. 1942; Skuja, Nova Acta Regiae Soc. Sci. Upsal., 14(5): 1-188. 1949; Shinke & Ueda, Memoirs of the College of Science, University of Kyoto. Series B, 23(1): 101-104. 1956; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Halfen & Halfen, J. Phycol., 14(4): 437-439. 1978; Sagarra & Romero, Collect. Bot., 13(2): 723-765. 1982; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Sheath & Steinman, Can J Bot., 60: 1964-1997. 1982; Anand & Hopper, Hydrobiologia, 144(3): 223-232. 1987; Aboal, An. Jard. Bot. Madr, 45(1): 3-46. 1988; Alvarez-Cobelas & Gallardo, Acta Bot Malac., 13: 53-76. 1988; Balakrishnan

et al., Seaweed Res. Utiln., 15(1&2): 63-68. 1992; Day et al., Flora of Australia, 4:1-276. 1995; Poulin et al., Can. Field-Nat., 109: 27-110. 1995; Aboal, Algol Stud., 82: 117-131. 1996; Azevedo et al., Hoehnea, 23(1): 1-38. 1996; Cvijan & Blazencic, Flora algi Srbije, 1-290. 1996; De-Lamonica-Freire & Heckman, Int. Rev. Gesamten Hydrobiol., 81(2): 253-280. 1996; Silva et al., Univ. Calif. Publ. Bot., 79: 1-1259. 1996; Pari & N'Yeurt, Aust. Syst. Bot., 10: 867-910. 1997; Branco & Necchi, Archiv fur Hydrobiologie, 142: 241-256. 1998; Underwood et al., Eur. J. Phycol., 33(2): 173-183. 1998; Ling & Tyler, Bibliotheca Phycologica, 105: 1-643. 2000; Silva & Pienaar, Bot Mar., 43: 11-27. 2000; Vinogradova et al., Cyanoprocaryotes and algae of continental Israel, 32-141. 2000; Vitenaite, Bot Lith., 7(4): 343-364. 2001; Suda et al., Int. J. Syst. Evol. Microbiol., 52: 1577-1595. 2002; Mauch & Schmedtje, Informationsberichte des Bayerischen Landsamtes für Wasserwirtschaft Heft, 1(3): 1-388. 2003; Hällfors, Balt. Sea Environ. Proc., 95: 1-208. 2004; Hamed, Acta Bot. Hung., 47(1-2): 117-136. 2005; Leghari et al., Int. J. Phycol. Phycochem., 1(2): 167-172. 2005; Hu & Wei, The freshwater algae of China, 1-1023. 2006; Aftab & Shameel, Int.J. Phycol. Phycochem., 3(2):159-168.2007; McGregor, Freshwater Cyanoprokaryota of North-Eastern Australia 1: Oscillatoriales, 24: 1-123. 2007; Nguyen et al., Nova Hedwigia, 85(1-2): 1-34. 2007; Gafur & Parvin, Bangladesh J. Bot., 37(1): 49-53. 2008; Barinova et al., Turk J Bot., 33: 353-372. 2009; González, Catálogo de las algas y cianoprocariotas dulciacuícolas de Cuba, 1-147. 2009; Bostock & Holland, Census of the Queensland Flora, 1-320. 2010; Khalid et al., Int. J. Phycol. Phycochem., 6(2): 73-80. 2010; Rai et al., Our Nature, 8: 336-354. 2010; Smith, Int J Algae, 12(3): 230-256. 2010; Alfinito, Biodivers J., 2(3): 121-144. 2011; Barinova et al., Turk J Bot., 35: 729-774. 2011; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Seu-Anoï et al., Afr. J. Aquat. Sci., 36(3), 321-330. 2011; Täuscher, Verhandlungen des Botanischen Vereins von Berlin und Brandenburg, 144: 177-192. 2011; Widey & Merican, New Zealand inventory of biodiversity, 3: 50-69. 2012; Park, Algal flora of Korea, 5(1):1-71. 2012; Gadea et al., Thalassas, 29(1): 35-58. 2013; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Nguyen et al., Botanica Marina, 56(3): 207-227. 2013; Won Hong et al., Polar Res., 32(1): 1-7. 2013; Barinova & Kukhaleishvili, The Journal of Biodiversity, 113: 305-338. 2014; Barinova et al., Plant Biosystems, 138: 245-259.

2014; Dey et al., Poll Res, 33: 807-11. 2014; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far East, 1-271. 2014; Singh et al., J Asia Pac Biodivers., 7(4): 462-470. 2014; Barinova et al., Turk J Bot., 39: 535-546. 2015; Barinova & Romanov, Natural Resources and Conservation, 3(2): 19-30. 2015; Figueroa-Torres et al., CienciaUAT, 9(2): 15-29. 2015; Kesarwani et al., Phykos, 45(1): 18-29. 2015; Kouassi et al., J. Biodivers. Environ. Sci., 7(5): 136-149. 2015; Rao & Gupta, Algae of India, 3: 1-93. 2015; Roy et al., Algol Stud., 147: 29-44. 2015; Smith et al., Taxonomic catalogue of algae from Ghana (Africa) and new additions, 1-101. 2015; Gallardo et al., Algas Boletín Informativo de la Sociedad Española de Ficología, 51: 7-52. 2016; Phang et al., Raffles Bull. Zool., 40: 13-59. 2016; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Rani et al., Indian J. Edu. Inf. Manage., 5(1): 1-5. 2016; Täuscher, Pflanzen und Tiere in Sachsen-Anhalt Ein Kompendium der Biodiversität, 63-112. 2016; Vijayarani et al., Int. J. Botany Stud., 1(6): 8-12. 2016; Barinova & Kukhaleishvili, Elixir Bio Sciences, 104: 45934-45947. 2017; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Gupta, Int. J. Plant Env., 3(1): 53-63. 2017; Halder, Braz. J. Biol. Sci., 4(7): 89-101. 2017; Jaiswal, Algae of north-west Khandesh, 1-448. 2017; Salem et al., Egypt. J. Basic Appl. Sci., 4(3): 219-226. 2017; Sarmah & Rout, J Algal Biomass Utln, 8(4): 135-144. 2017; Shrestha & Rai, Our nature, 15(1-2): 44-54. 2017; Barinova & Niyatbekov, Biodivers. Int. J., 2(3): 236-263. 2018; Dunck et al., Hoehnea, 45(4): 560-590. 2018; Mühlsteinová et al., Preslia, 90: 151-169. 2018; Zotov, Algologia, 28(2): 208-232. 2018; Ghadage & Karande, J. Threat. Taxa, 11(14): 14862-14869. 2019; Tucci et al., Núcleo de Pesquisa em Ficologia, 1-232. 2019; Rosset et al., Phycologia, 59(6): 571-577. 2020; Thu et al., Phycological Res., 68(3): 216-226. 2020.

Description: Thallus dark blue-green to black-green, straight. Trichomes dark blue-green, brown-green to brownish, 35.1-43.2 μm wide, mostly straight or sometimes curved, rigid, very long, motile with oscillation, not constricted at the cross walls, slightly attenuated at the ends and bent. Cells 5.8-7.2 μm long, cell content finely granular. End cell flatly rounded, capitate, with slightly thickened membrane.

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Synonyms: *Lyngbya princeps* (Vaucher ex Gomont) Hansgirg 1893; *Oscillatoriella princeps* (Vaucher) Gaillon 1833; *Lyngbya princeps* (Vaucher ex Gomont) Hansgirg 1893.

Distribution: This species was reported from the mangrove environments of Saudi Arabia (Hussain & Khoja,1993), India (Dhargalkar, 1994), Brazil (Branco et al., 1997), Tamil Nadu (Sakthivel & Kathiresan, 2013), as planktic from Sundarbans (Sen & Naskar, 2003, Barman et al., 2015), Pakistan (Ahmed et al., 2016), as epiphytic from Pakistan (Bano & Siddiqui, 2007).

General Environment: Ubiquitous species

Comments: New record to the mangrove cyanobacterial flora of Kerala.

Habitat: Appeared as dark brown or blackish green coloured planktic and epiphytic on *Avicennia officinalis* L. cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 07.05.2016, MES 21525; Thiruvananthapuram district, Kureekkadavu, 8^0 46'11.14" N 76^0 42' 36.69" E, 18.09.2017, 13747; Kollam district, Ayiramthengu, 9^0 07'33.93" N 76^0 28' 45.34" E, 11.08.2018, MES 21414. **(Plate 16, Fig. C-F)**.

8. *Oscillatoria princeps* var. *pseudolimosa* Ghose 1924

Ghose, Bot. J. Linn., 46: 333-346. 1924; Sahito et al., Pak J Bot., 18(2):355-357. 1986; Anand & Hopper, Hydrobiologia, 144(3): 223-232. 1987; Silva et al., Univ. Calif. Publ. Bot., 79: 1-1259. 1996; Rao & Gupta, Algae of India, 3: 1-93. 2015; Jaiswal, Algae of north-west Khandesh, 1-448. 2017; Reddy & Chaturvedi, Phykos, 48(1):36-45. 2018; Jaisawal & Gavit, Int. J. Life Sci., 13: 126-134. 2019; Taskin et al., Türkiye suyosunlari listei,1-804. 2019; Bardhan, J. Emerg. Technol. Innov. Res., 8(5):897-900. 2021.

Description: Thallus blue-green, trichome straight, rigid, fragile, not constricted sometimes slightly constricted at the cross walls, cross walls not granulated, 30.8-36.5 μm wide. Cells cylindrical, 4.9-8.8 μm long, cell contents granular, apices straight, apical cell slightly convex, capitate.

References: Desikachary (1959).

Distribution: No distributional records were found along with the marine environment.

General Environment: Freshwater species

Comments: New record to the marine cyanobacterial flora of Kerala.

Habitat: Appeared as green coloured corticolous on *Avicennia officinalis* L. and planktic form.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 22.12.2016, MES 21409; Kottayam district, Mekkara, 9^0 48'54.31" N 76^0 21' 57.54" E, 07.01.2017, MES 21552. **(Plate 17, Fig. A-C)**.

9. *Oscillatoria rupicola* (Hansgirg) Hansgirg ex Forti 1907

Forti in De Toni, Sylloge Myxophycearum, 5: 1-761. 1907; Geitler, Kryptogamen-Flora von Deutschland, 14: 673-1196. 1932; Vinogradova et al., Cyanoprocaryotes and algae of continental Israel, 32-141. 2000; Johansen et al., Southeast. Nat., 1: 99-134. 2007; Gadea et al., Thalassas, 29(1): 35-58. 2013; Kesarwani et al., Phykos, 45(1): 18-29. 2015; Álamos, Acta Bot Malac., 41: 5-17. 2016; Gallardo et al., Algas Boletín Informativo de la Sociedad Española de Ficología, 51: 7-52. 2016; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Miscoe et al., Bibliotheca Phycologica, 123: 75-152. 2016; Gainutdinov et al., Cave Karst Sci., 44(3): 119-126. 2017; Gainutdinov et al., Barinova & Niyatbekov, Biodivers Int J., 2(3): 236-263. 2018; Dunck et al., Hoehnea, 45(4): 560-590. 2018; Barupal, J. Algal Biomass Utln, 10(1): 26-35. 2019; Popkova et al., Ecologica Montenegrina, 28: 8-19. 2019; Popkova & Mazina, Environ. Res. Eng. Manag., 75(3): 71-83. 2019; Shernazarov & Tashpulatov, Scientific Bulletin of Namangan State University, 1(2): 124-132. 2019; Kopyrina et al., International Journal of Oceanography and Hydrobiology, 49(2): 99-122. 2020; Davydov, Polar Biol.,1-12. 2021.

Description: Thallus olive green, mucilaginous. Trichomes 4.1-6.8 μm wide, not constricted at the cross walls, olive green, with fine sheaths. Trichome straight or slightly curved, not attenuated at the ends. Cells isodiametric, 2.2-3.2 μm wide, apical cells rounded without calyptra, with slightly thickened outer cell wall.

References: Komarek & Anagnostidis (2005).

Synonyms: *Lyngbya rupicola* Hansgirg 1893*; Phormidium rupicola* (Hansgirg ex Gomont) Anagnostidis & Komarek 1988

Distribution: No distributional records were found along with the marine environment.

General Environment: Freshwater/Terrestrial species

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as olive green coloured epipsammic and planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 07.07.2016, MES 21416; Kottayam district, Kumarakom, 9^0 36'59.46" N 76^0 25' 21.46" E, 27.11.2018, MES 21529. **(Plate 17, Fig. D-F)**.

10. *Oscillatoria sancta* Kutzing ex Gomont 1892

Gomont, Annales des Sciences Naturelles, Botanique, 16: 91-264. 1892; Skuja, Symbolae Botanicae Upsalienses, 9(3): 1-399. 1948; Skuja, Nova Acta Regiae Societatis Scientiarum Upsaliensis, 14(5): 1-188. 1949; Skuja, Nova Acta Regiae Societatis Scientiarum Upsaliensis, 16(3): 1-404. 1956; Chapman et al., Trans. Roy. Soc. New Zealand, 84: 695-747. 1957; Dodd, Trans Am Microsc Soc., 79(4): 480-485. 1960; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Sheath & Steinman, Can J Bot., 60: 1964-1997. 1982; Aboal & Llimona, Anales de Biología, 2(2): 1-17. 1984; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Anand & Hopper, Hydrobiologia, 144(3): 223-232. 1987; Aboal, Anales Jard. Bot. Madrid, 45(1): 3-46. 1988; Alvarez-Cobelas & Gallardo, Acta Bot Malac., 13: 53-76. 1988; Aboal, Limnética 5: 1-11. 1989; Widey & Kibblewhite, Antarct Sci., 3(1): 35-45. 1991; Day et al., Flora of Australia, 4: 1-276. 1995; Poulin et al., Can. Field-Nat., 109: 27-110. 1995; Aboal, Ecología Acuática y Sociedad,117-128. 1996; Cvijan & Blazencic, Flora algi Srbije. Tom 1. Cyanophyta, 1-290. 1996; Silva et al., Univ. Calif. Publ. Bot., 79: 1-1259. 1996; Pari & N'Yeurt, Aust. Syst. Bot., 10: 867-910.

1997; Ling & Tyler, Bibliotheca Phycologica, 105: 1-643. 2000; Vinogradova et al., Cyanoprocaryotes and algae of continental Israel, 32-141. 2000; Vitenaite, Bot Lith., 7(4): 343-364. 2001; Nagarkar, Bot Mar., 45: 274-283. 2002; Mauch & Schmedtje, Informationsberichte des Bayerischen Landsamtes für Wasserwirtschaft Heft, 1(3): 1-388. 2003; Hällfors, Baltic Sea Environment Proceedings, 95: 1-208. 2004; Sherwood, Bishop Museum Occasional Papers, 80: 1-26. 2004; Aysel, J Black Sea/Mediterranean Environment, 11: 1-124. 2005; Shahnaz & Shameel, Int. J. Phycol. Phycochem. 1(2): 193-198. 2005; Rodriguez et al., Cryptogam Algol., 27: 63-83. 2006; Matula et al., Pol. Polar Res., 28(4): 283-315. 2007; Comas González, Algas Boletín de la Sociedad Española de Ficología, 39: 21 - 29. 2008; Liu, Checklist of biota of Chinese seas, 1-1267. 2008; Senthilkumar & Sivakumar, J. Environ. Biol., 29(5): 747-752. 2008; Comas González, Catálogo de las algas y cianoprocariotas dulciacuícolas de Cuba, 1-147. 2009; Barinova et al., J. Arid Environ., 74: 765–776. 2010; Bostock & Holland, Census of the Queensland Flora, 1-320. 2010; Comas González & Moreira González, Algas Boletín de la Sociedad Española de Ficología, 43: 6-10. 2010; Rai et al., Our Nature, 8: 336-354. 2010; Smith, Int J Algae, 12(3): 230-256. 2010; Widey & Merican, New Zealand inventory of biodiversity, 3: 50-69. 2012; Gadea et al., Thalassas, 29(1): 35-58. 2013; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Barinova & Kukhaleishvili, The Journal of Biodiversity, 113: 305-338. 2014; Davydov, Folia Cryptogam. Estonica, 51: 13-23. 2014; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far East, 1-271. 2014; Täuscher, Checkliste der Algen Cyanobacteria et Phycophyta,1-44. 2014; Varol & Sen, Journal of Fisheries Sciences, 8: 1-14. 2014; Barinova et al., Tajikistan. Turk J Bot., 39: 535-546. 2015; Kesarwani et al., Phykos, 45(1): 18-29. 2015; Patova et al., Cyanoprokaryotes and algae, 133-166. 2015; Rao & Gupta, Algae of India: A checklist of Indian marine algae, 3: 1-93. 2015; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Harris et al., J Environ Sci., 47: 211-218. 2016; Phang et al., Raffles Bull. Zool., 40: 13-59. 2016; Täuscher, Cyanobacteria et Phycophyta, 63-112. 2016; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Shrestha & Rai, Our nature, 15(1-2): 44-54. 2017; Barinova & Niyatbekov, Biodivers. Int. J., 2(3): 236-263. 2018; Davydov, Botanica, 24(2): 185-201. 2018; Dunck et al., Hoehnea,

45(4): 560-590. 2018; Taskin et al., Türkiye suyosunlari listei, 1-804. 2019; Rosset et al., Phycologia, 59(6): 571-577. 2020; Stoyneva-Gärtner & Descy, Checklist of cyanoprokaryotes and algae in the large tropical River Congo, 104: 18-57. 2020; Davydov, Polar Biol., 1-12. 2021;

Description: Thallus blue-green, mucilaginous. Trichomes blue-green to olive green, very long, straight or slightly curved, sometimes within sheaths, not or slightly constricted at the cross walls, cross walls granulated, not attenuated at the ends. Cells cylindrical or discoid, 12.8-16.2 μm wide, 3.2-5.3 μm long. Apical cell hemispherical or flattened, capitate, with a thickened membrane.

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Synonyms: *Lyngbya sancta* (Gomont ex Gomont) Hansgirg 1893.

Distribution: This species was reported from the mangrove environments of Tamil Nadu (Sakthivel & Kathiresan, 2013), Saudi Arabia (Mohammed & Al-Shehri, 2015), edaphic, rockpool waters in the mangrove environment of Pakistan (Bano & Siddiqui, 2007).

General Environment: Freshwater species

Comments: New record to the mangrove cyanobacterial flora of Kerala.

Habitat: Appeared as a green coloured or olive green coloured benthic and planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Thiruvananthapuram district, Kadinamkulam, 8^0 37'15.01" N 76^0 48' 43.81" E, 19.12.2015, MES 21546; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 10.01.2017, MES 21444; Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 21.12.2018, MES 21472. **(Plate 18, Fig. A)**.

11. *Oscillatoria simplicissima* Gomont 1892

Gomont, Annales des Sciences Naturelles, Botanique, 16: 91-264. 1892; Adams, Proc. R. Ir. Acad., 27B(2): 11-60. 1908; Reinhold, Annales de la Société Géologique de Belgique, 61(1): 39-47. 1937; Bicudo & Ventrice, Anais da Sociedade Botanica do Brasil XIX Congresso Nacional de Botânica, Fortaleza: 3-42.

1968; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Tell, Bibliotheca Phycologica, 70:1-283. 1985; Alvarez-Cobelas & Gallardo, Acta Bot Malac., 13: 53-76. 1988; Azevedo et al., Hoehnea, 23(1): 1-38. 1996; Cvijan & Blazencic,Flora algi Srbije, 1-290. 1996; Dogadina et al., Int J Algae, 1(4): 86-91. 1999; Vinogradova et al., Cyanoprocaryotes and algae of continental Israel, 32-141. 2000; Kruskopf & Du Plessis, Hydrobiologia, 556(1): 357-362. 2006; Nassar, Egypt. J. Aquat. Res., 33(2):133-151. 2007; Altunöz et al., Biyolojik Çeşitlilik ve Koruma, 9(1): 116-127. 2008; Monoran et al., Aquac Aquar Conserv Legis., 1(2): 123-136. 2008; Smith, Arkansas Acad. Sci., 62(1): 97-102. 2008; Ungureanu, Oltenia-studii si comunicari stiintele naturii, 4: 7-12. 2008; Chakraborty et al., Indian Hydrobiology, 12(2): 204-224. 2010; El-Sherif et al., Egypt. J. Aquat. Res., 36(4): 609-621. 2010; El-Sheekh et al., Pak. J. Bot, 42(4), 2621-2633. 2010; Samylina et al., Int J Algae, 12(2): 193-210. 2010; Smith, Int J Algae, 12(3): 230-256. 2010; Suryavanshi et al., J. Indian Bot. Soc., 89(1&2): 189-196. 2010; Devi, & Tiwari, J. Indian Bot. Soc., 90(1&2): 33-44. 2011; Harith & Hassan, Proceedings of the Seminar on Lanjak Entimau Scientific Expedition, 375-382. 2011; Widey & Merican, New Zealand inventory of biodiversity, 3: 50-69. 2012; Sharma et al., Int. J. Pharm. Bio. Sci., 3(3): 890-899. 2012; Das & Keshri, NeBIO, 4(6): 61-69. 2013; Deep et al., Aquat. Biosyst., 9(1): 1-12. 2013; Gadea et al., Thalassas, 29(1): 35-58. 2013; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Mohanty & Adhikary, Water Resour. Prot., 5: 611-623. 2013; Van Nguyen et al., Bot Mar., 56(3): 207-227. 2013; Davydov, Folia Cryptogam. Est., 51: 13-23. 2014; Nassar & Khairy, Annu. Res. Rev. Biol., 4(23): 3566-3585. 2014; Sikdar & Keshri, Int. J. Curr. Res. Rev., 6(21): 47. 2014; Kesarwani et al., Phykos, 45(1): 18-29. 2015; Rao & Gupta, Algae of India, 3: 1-93. 2015; Vijayan & Ray, Am. J. Plant Sci., 6(18): 2924-2938. 2015; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Janse van Vuuren & Taylor, Afr. J. Aquat. Sci., 41(4): 369-375. 2016; Tagad, Int. J. Res. Biosci. Agric. Technol., 4(1): 81-83. 2016; Jaiswal, Algae of north-west Khandesh, 1-448. 2017; Barinova & Niyatbekov, Biodivers. Int. J., 2(3): 236-263. 2018; Dunck et al., Hoehnea, 45(4): 560-590. 2018; Ray et al., European J. Biomed. Pharm., 5(3): 335-342. 2018; Kadim et al., AACL Bioflux, 11(3): 833-845. 2018; Stutz & Mattern, Beiträge zu den Algen Baden-Württembergs, 1-504. 2018; Maharana et al.,

Environ. Ecol., 37: 737-746. 2019; Mohan & Kumar, Biotechnol Appl Biochem, 5(1): 15-32. 2019; Taskin et al., Türkiye suyosunlari listei, 1-80. 2019; Kopyrina et al., International Journal of Oceanography and Hydrobiology, 49(2): 99-122. 2020; Kopyrina et al., Oceanol Hydrobiol Stud., 49(2): 99-122. 2020; Pshennikova & Kopyrina, Int J Algae, 22(1): 33-46. 2020; Rashad & El-Chaghaby, Egypt. J. Aquat. Biol. Fish., 24(5): 147-160. 2020; Stoyneva-Gärtner & Descy, Annual of Sofia University, 104: 18-57. 2020; Davydov, Polar Biol., 1-12. 2021; Elkomy & Ismail, Iran. J. Microbiol., 13(4): 553–559. 2021; Ignatenko et al., Biosyst. Divers., 29(1):59-66. 2021.

Description: Thallus blackish blue-green, flat mats. Trichome straight, flexuous, not constricted at the cross walls, 7.4-9 µm wide, trichome ends straight, not attenuated. Cells 1/3 -1/2 as long as wide, 2.2-4.7 µm long, finely homogenously granulated, without prominent granulation at cross walls. Terminal cells rounded or hemispherical, without thickened cell wall or calyptra.

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Synonyms: *Phormidium simplicissimum* (Gomont) Anagnostidis & Komarek 1988

Distribution: This species was recorded from the mangrove environments of Brazil (Branco et al., 1997).

General Environment: Freshwater species

Comments: New record to the mangrove-associated cyanobacterial flora of India.

Habitat: Appeared as dark brown coloured benthic and epiphytic on the pneumatophores of *Avicennia officinalis* L.

Specimen Examined: INDIA: Kerala; Kollam district, Ayiramthengu, 9^0 07’33.93” N 76^0 28’ 45.34” E, 17.10.2016, MES 21523; Kottayam district, Kumarakom, 9^0 36’59.46” N 76^0 25’ 21.46” E, 01.07.2018, MES 13746. **(Plate 18, Fig. B-D)**.

12. *Oscillatoria subbrevis* Schmidle 1901

Engler’s Bot. Jahrb., 30: 243. 1901; Reinhold, Annales de la Société Géologique de Belgique, 61(1): 39-47. 1937; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Bicudo & Senna, Arch. Hydrobiol. / Suppl. 51. Algol

Stud., 18: 25-32. 1977; Jenkerson & Hickman, Internationale Revue der gesamten Hydrobiologie und Hydrographie, 68(4): 453-471. 1983; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Pridmore & EtheredgeN. Z. J. Mar. Freshwater Res., 21(3): 491-502. 1987; Alvarez-Cobelas & Gallardo, Acta Bot Malac., 13: 53-76. 1988; Thajuddin & Subramanian, Bot Mar., 35: 305-314. 1992; Poulin et al., Can. Field-Nat., 109: 27-110. 1995; Silva et al., University of California Publications in Botany, 79: 1-1259. 1996; Nagarkar, Bot Mar., 41: 527-542. 1998; Afsharzadeh et al., Iranian Journal of Biology, 14: 32-45. 2003; Aysel, J Black Sea/Mediterranean Environment, 11: 1-124. 2005; El-Awamri & Hamed, Egypt. J. Phycol., 6(1): 169-182. 2005; Hamed, Acta Bot. Hung., 47(1-2): 117-136. 2005; Leghari, et al., Int. J. Phycol. Phycochem. 1(2): 151-158. 2005; Mehwish & Aliya, J. Phycol. Phycochem., 1(2): 117-124. 2005; Hu & Wei, The freshwater algae of China, 1-1023. 2006; Rodriguez et al., Cryptogamie Algologie, 27: 63-83. 2006; Gul et al., Int. J. Phycol. Phycochem., 3(1): 37-48. 2007; Johansen et al., Southeast. Nat., 1: 99-134. 2007; El-Gamal et al., Egypt. J. Phycol., 9(1): 1-23. 2008; Hamed, Aust. J. Basic & Appl. Sci., 2(1): 1-21. 2008; Liu, Checklist of biota of Chinese seas, 1-1267. 2008; Zhang et al., Biol. Fertil. Soils, 45(5): 539-547. 2009; Bostock & Holland, Census of the Queensland Flora, 1-320. 2010; Ceschin et al., Cryptogam Algol., 31(2): 273. 2010; Dey et al., Ecoprint, 17: 77-85. 2010; Smith, Int J Algae, 12(3): 230-256. 2010; Alfinito, Biodivers. J., 2(3): 121-144. 2011; Jemi & Balasingh, Int. J. Basic Appl. Biol., 5(1&2): 94-99. 2011; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Pham et al., A checklist of the algae of Singapore, 1-100. 2011; Zhang et al., Arid. Land Res. Manag., 25(3): 275-293. 2011; Widey & Merican, New Zealand inventory of biodiversity, 3: 50-69. 2012; Ghimire et al., Indian Hydrobiology, 15(2): 223-226. 2012; George et al., Egypt. J. Aquat. Res., 38(3): 157-170. 2012; Manickam et al., Int. J. Pharma Bio Sci., 3(3): 289-300. 2012; Park, Algal flora of Korea, 5(1): 1-101. 2012; Choudhary & Singh, J. Algal Biomass Util., 4(2), 53-58. 2013; Divya et al., Int. J. Innov. Res. Sci. Eng. Technol., 2(7): 2736-2747. 2013; Heidari et al., Iran. J. Bot., 19(2): 161-172. 2013; Jeyachitra et al., Afr. J. Microbiol. Res., 7(25): 3240-3247. 2013; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Ramanathan et al., J Algal Biomass Utln., 4(3): 26-34. 2013; Soni & Thomas, Int. J. Environ., 2(1):115-126. 2013;

Bazán et al., Biol. Acuat., 30: 47-57. 2014; Dey et al., Poll Res, 33: 807-11. 2014; Elayaraj & Selvaraju, Int. J. Biol. Res., 2(2), 90-95. 2014; Sikdar & Keshri, Int. J. Curr. Res. Rev., 6(21): 47. 2014; Varol & Sen, Journal of Fisheries Sciences, 8: 1-14. 2014; Kesarwani et al., Phykos, 45(1): 18-29. 2015; Rao & Gupta, Algae of India, 3: 1-93. 2015; Al-Saboonchi & Al-Shawi, Journal of International Academic Research for Multidisciplinary, 3(12): 71-86. 2016; Arguelles, IAMURE International Journal of Ecology and Conservation, 17: 22-39. 2016; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Paul & Rout, Int. J. of Pharm Bio Sci., 7(3): 1274-1280. 2016; Phang et al., Raffles Bull. Zool., 40: 13-59. 2016; Yaseen et al., Pure Appl. Biol., 5(4): 927-933. 2016; Caraus, Studii si Cercetari Biologie 7: 1-1002. 2017; Gupta, Int. J. Plant Env., 3(1): 53-63. 2017; Jaiswal, Algae of north-west Khandesh, 1-448. 2017; Sarmah & Rout, J Algal Biomass Utln., 8(4): 135-144. 2017; Vinoth et al., J. Life Sci., Bioinform., Pharmaceut. Chem. Sci., 3, 215-241. 2017; Dunck et al., Hoehnea, 45(4): 560-590. 2018; Ahlesaadat et al., Rostaniha, 18(2): 107-121. 2018; Jeevanantham et al., J. pharmacogn. phytochem., 8(2): 635-640. 2019; Kowthaman et al., Ecol. Environ., 37(4): 1230-1239. 2019; Taskin et al., Türkiye suyosunlari listei, 1-804. 2019; Torres-Ariño et al., Cybella, 50(1): 1-97. 2019; Arguelles, Philipp J. Sci., 149(3): 589-602. 2020; Bharati et al., Crypt. Biodivers. Assess., 4(2): 1-6. 2020; Jonah et al., Int. J. Fish. Aquat., 8(3): 532-536. 2020; Manickam et al., Acta Ecol. Sin., 40(1): 81-89. 2020; Shamina, International Journal on Algae, 22(4): 347-358. 2020; Mukhtar et al., Microsc. Res. Tech., 1-7. 2021; Geethu & Shamina, Bangladesh J Plant Taxon., 28(1): 83-95. 2021; Rajasekaran & Raja, Res J Agric Anim Sci., 36(2):1-3. 2021.

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

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Distribution: This species was reported as epiphytic from the mangrove environments of Tamil Nadu (Boopathy, 2011), South Africa (Lambert et al., 1989, Phillips et al., 1994, Phillips et al., 1996), Puerto Rico (Steinke & Naidoo, 1990);

Planktic (Kannan & Vasantha, 1992); mangrove environments of Sundarbans (Barman et al., 2015, Sen & Naskar, 2003), Tamil Nadu (Bhuvaneshwari & Muruganandam, 2016, Priya et al., 2019), Brazil (Branco et al., 1997).

General Environment: Ubiquitous species

Comments: New record to the cyanobacterial flora of Kerala.

Habitat: Appeared as a green or dark green coloured planktic and benthic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 14.07.2016, MES 21417; 23.09.2016, MES 21426; Kottayam district, Mekkara, 9^0 48'54.31" N 76^0 21' 57.54" E, 28.01.2017, MES 21436; Alappuzha district, Pathiramanal, 9^0 37' 09.78" N, 76^0 23' 06.43" E, 24.03.2018, MES 21558. **(Plate 18, Fig. E-F; Plate 19, Fig. A-B)**.

13. *Oscillatoria tenuis* C.Agardh ex Gomont 1892

Gomont, Annales des Sciences Naturelles, Botanique, 7(16): 91-264. 1892; Adams, Proc. R. Ir. Acad., 27B(2): 11-60. 1908; Skuja, Symbolae Botanicae Upsalienses, 9(3): 1-399. 1948; Skuja, Nova Acta Regiae Societatis Scientiarum Upsaliensis, 16(3): 1-404. 1956; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Álvarez, Collectanea Botanica, 13: 709-722. 1982; Aboal & Llimona, Anales de Biología, 2(2): 1-17. 1984; Aboal, An. Jard. Bot. Madr., 45(1): 3-46. 1988; Alvarez-Cobelas & Gallardo, Acta Bot Malac., 13: 53-76. 1988; Cvijan & Blazencic, Flora algi Srbije, 1-290. 1996; Cremades et al., An. Jard. Bot. Madr., 55(2): 433-440. 1997; Veiga et al., Boletim do Museu Municipal do Funchal, 5: 481-493. 1998; Rajchel et al., Geol. Q., 46(2): 189-198. 2002; Mauch & Schmedtje, Informationsberichte des Bayerischen Landsamtes für Wasserwirtschaft Heft, 1(3):1-388. 2003; Matula et al., Pol. Polar Res., 28(4): 283-315. 2007; Hasler et al., Fottea, 7(1): 49-68. 2007; Smith, Int J Algae, 12(3): 230-256. 2010; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Gadea et al., Thalassas, 29(1): 35-58. 2013; Barinova & Kukhaleishvili, The Journal of Biodiversity, 113: 305-338. 2014; Davydov, Folia Cryptogam. Est., 51: 13-23. 2014; Di Pippo et al., Eur. J. Phycol., 49(3): 384-394. 2014; Patova, J. Sib. Fed. Univ. Biol., 3: 282-290.

2014; Täuscher, Pflanzen und Tiere in Sachsen-Anhalt Ein Kompendium der Biodiversität, 63-112. 2016; Gkelis et al., Biodivers Data J, 4(e10084): 1-103. 2016; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Malakhov et al., Pol. Bot. J., 62(1): 61-76. 2017; Davydov, Botanica, 24(2): 185-201. 2018; Stutz & Mattern, Beiträge zu den Algen Baden-Württembergs, 1-504. 2018; Patova & Novakovskaya, Novosti Sistematiki Nizshikh Rastenii, 52(2): 311–353. 2018; Komulaynen, Nat. Conserv. Res., 3(3): 46-60. 2018; Berezovskaya, Algologia, 29(1): 59-76. 2019; Davydov, Polar Biol., 1-12. 2021.

Description: Thallus thin, mucilaginous, olive-green, trichome straight or very slightly curved, fragile, slightly constricted at the cross walls, 4.3 µm - 8.2 µm wide, not attenuated at the apices, cells as long as wide, 3 µm - 4.8 µm long, septa granulated, end cell more or less hemispherical with thickened outer membrane.

Synonyms: *Phormidium neotenue* G.Hallfors 2004

References: Komarek & Anagnotidis (2005); Desikachary (1959).

Distribution: This species was recorded in the mangrove environment of Tamil Nadu (Ramamurthy & Abhinand, 2016, Sudha, 2005; Sudha et al., 2007, Silambarasan et al., 2012, Sakthivel & Kathiresan, 2013), Saudi Arabia (Mohamed & Al-Shehri, 2015), Kerala (Joseph & Saramma, 2016); as epiphytic from Tamil Nadu (Selvakumar & Sundararaman, 2001), Pakistan (Bano & Siddiqui, 2007); as Epipsammic from Sundarbans (Sen & Naskar, 2003).

General Environment: Freshwater species

Habitat: Appeared as green or olive green coloured planktic and corticolous on *Excoecaria agallocha* L.

Specimen Examined: INDIA: Kerala; Thiruvananthapuram district, Kadinamkulam, 8^0 37’15.01” N 76^0 48’ 43.81” E, 13.12.2017, MES 21404; Kollam district, Ayiramthengu, 9^0 07’33.93” N 76^0 28’ 45.34” E, 11.08.2018, MES 21415; Ernakulam district, Vypin, 9^0 58’ 26.46” N, 76^0 14’ 38.14” E, 16.07.2019, MES 21484. **(Plate 19, Fig. C)**.

14. *Oscillatoria vizagapatensis* C.B.Rao 1938

Rao, Proc. Indian Acad. Sci. B, 8: 157-170. 1938; Sahito et al., Pak. J. Bot., 20(2): 305-309. 1988; Day et al., Bibliographic check-list of non-marine algae in Australia, 4:1-276. 1995; Tiwari, Hydrobiologia, 39(3): 335-350. 1972; Bicudo & Senna, Algol Stud, 51(1): 25-32. 1977; Prasad & Khanna, J. Indian Bot. Soc., 66: 253-260. 1987; Mahajan & Patel, Indian Bot. Reptr, 8(1), 5-11. 1989; Nagarkar, Bot Mar., 41:527-542. 1998; Lopez-Cortes, Bulletin-Institut Oceanographique Monaco, 87-94. 1999; Nagarkar & Willlams, Phycologia, 38(5): 385-393. 1999; Ling & Tyler, Bibliotheca Phycologica, 105:1-643. 2000; Tiwari et al., Biol. Fertil. Soils, 34(4): 291-295. 2001; Leghari et al., Int. J. Phycol. Phycochem.,1(2): 167-172. 2005; Islam & Irfanullah, Bangladesh J. Plant Taxon., 12(1): 33-52. 2005; Gul et al., Int. J. Phycol. Phycochem., 3(1): 37-48. 2007; McGregor, Freshwater Cyanoprokaryota of North-Eastern Australia 1: Oscillatoriales, 24, 1-123. 2007; Bostock & Holland, Census of the Queensland Flora,1-320. 2010; Suryavanshi et al., J. Indian Bot. Soc., 89(1&2): 189-196. 2010; Widey & Merican, New Zealand inventory of biodiversity, 3: 50-69. 2012; Maulood et al., Checklist of algal flora in Iraq,1-94. 2013; Kesarwani et al., J. Indian Bot. Soc., 94(1&2): 40-51. 2015; Kesarwani et al., Phykos 45(1): 18-29. 2015; Jaiswal, Algae of north-west Khandesh, 1-448. 2017; Sarmah & Rout, J Algal Biomass Utln., 8(4):135-144. 2017; Pandkar et al., Biosci. Biotechnol. Res. Asia, 17(2): 235-245. 2020; Rahman et al., Poll Res., 39(4): 1148-1153. 2020; Zaheri et al., Iran. J. Fish. Sci., 20(2): 572-589. 2021.

Description: Thallus dark brown or olive green. Trichomes straight, or bent, uniformly wide except at the extreme apex, 8.2-11.1 μm wide, not constricted at the cross walls, cross walls granulated. Cells shorter than wide, 1.5-2.2 μm long, cell contents granular. Apical cells widely rounded with slightly thickened outer cell wall.

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Distribution: This species was reported as epiphytic from the mangrove environments of Pakistan (Bano & Siddiqui, 2007), Tamil Nadu (Selvakumar & Sundararaman, 2001).

General Environment: Terrestrial species

Comments: New record to the mangrove cyanobacterial flora of Kerala.

Habitat: Appeared as a dark brown or blackish green coloured benthic and planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 19.12.2016, MES 13798; Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 14.01.2018, MES 21423. **(Plate 19, Fig. D-F)**.

4. *Phormidium* Kützing ex Gomont, 1892

Filamentous; filaments usually entangled, rarely solitary, usually in fine, smooth, layered up to leathery strata (mats). Sheaths occur facultatively or obligatorily, firm or thin, colourless, joined to the trichomes, opened at the ends, containing always a single trichome. Trichomes cylindrical, long, more or less straight, coiled or waved, usually 2-12(15) μm wide, uniserial, never branched, composed of cylindrical up to slightly barrel-shaped cells, more or less isodiametrical or slightly shorter or longer than wide, unconstricted or slightly to distinctly constricted at the cross walls, not attenuated and bent or screw-like twisted towards the ends, motile (waving, creeping, oscillations) within and out of sheaths. Apical cell pointed, narrowed or rounded with or without calyptra. Reproduction by the disintegration of trichomes into long or short. Motile hormogonia.

Among 420 species (infraspecific) reported up to date, 207 species are currently accepted as taxonomically valid taxa (Guiry & Guiry, 2022). Only six planktic species from the mangrove ecosystems of southern Kerala are described here.

Key to the species

1a. Apical cells narrowed, hooked 2

1b. Apical cells nearly capitate 3

2a. Trichomes 4.2-5.6 μm wide ..... **1. *P. acula***

2b. Trichomes 7.9- 10.8 μm wide ..... **2. *P. chalybeum***

3a. Trichomes slightly constricted at cross walls..... **4. *P. nigro-viride***

3b. Trichomes not constricted at cross walls..... **6. *P. irriguum***

4a. Apical cells rounded 5

5a. Trichomes 5.4-7.5 µm wide ..... **3. *P. crassior***

6a. Trichomes 8.5-9.3 µm wide, apical cell pointed and truncated ..... **5. *P. nigrum***

1. *Phormidium acula* (Bruhl & Biswas) Anagnostidis & Komárek 1988

Anagnostidis & Komárek, Archiv für Hydrobiologie, 80: 327-472. 1988; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017.

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

Synonyms: *Oscillatoria acula* Bruhl & Biswas 1922

References: Komarek & Anagnostidis (2005): Desikachary (1959)**.**

Distribution: This species was reported from the mangrove environment of Sundarbans (Barman et al., 2015), Kerala (Joseph & Saramma, 2016).

General Environment: Freshwater/Terrestrial species

Habitat: Appeared as dark green coloured planktic, corticolous on the bark of *Rhizophora mucronata* Lam. and benthic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Alappuzha district, Pathiramanal, 9^0 37' 09.78" N, 76^0 23' 06.43" E, 07.11.2016, MES 21434, 12.10.2017, MES 13718; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 20.05.2016, MES 21405; Kottayam district, Mekkara, 9^0 48'54.31" N 76^0 21' 57.54" E, 07.12.2017, MES 21553; Thiruvananthapuram district, Kadinamkulam, 8^0 37'15.01" N 76^0 48' 43.81" E, 30.09.2018, MES 21591. **(Plate 20, Fig. A-B)**.

2. *Phormidium chalybeum* (Mertens ex Gomont) Anagnostidis et Komarek 1988

Anagnostidis & Komárek, Archiv für Hydrobiologie, 80: 327-472. 1988; Silva et al., Univ. Calif. Publ. Bot., 79:1-1259. 1996; Brattegard & Holthe,

Distribution of marine, benthic macro-organisms in Norway, 1: 1-394. 2001; Vitenaite, Bot Lith., 7(4): 343-364. 2001; Lobban & Tsuda, Micronesica, 35/36: 54-99. 2003; Hällfors, Baltic Sea Environment Proceedings, 95: 1-208. 2004; Aysel, J Black Sea/Mediterranean Environment, 11: 1-124. 2005; Gul et al., Int. j. phycol. Phycochem., 3(1): 37-48. 2007; Johansen et al., Southeast. Nat., 1: 99-134. 2007; McGregor, Freshwater Cyanoprokaryota of North-Eastern Australia 1: Oscillatoriales, 1-123. 2007; Stenina & Patova, Systematic lists of species of flora and fauna state natural reserve Nenetzkij, 5-21. 2007; Liu, Checklist of biota of Chinese seas, 1-1267. 2008; Taskin et al., The check-list of the marine algae of Turkey, 1-87. 2008; Bostock & Holland, Census of the Queensland Flora, 1-320. 2010; Smith, Int J Algae, 12(3): 230-256. 2010; Victoria & Gómez, Sci. Total Environ., 408(13): 2696-2705. 2010; Barinova et al., Turk J Bot., 35: 729-774. 2011; Lopes & Vasconcelos, Marine drugs, 9(5): 790-802. 2011; Täuscher, Verhandlungen des Botanischen Vereins von Berlin und Brandenburg, 144: 177-192. 2011; Widey & Merican, New Zealand inventory of biodiversity, 3: 50-69. 2012; Park, Algal flora of Korea, 5(1): 1-71. 2012; Ch & Rajashekhar, African Journal of Microbiology Research, 7(17): 1757-1765. 2013; Gadea et al., Thalassas, 29(1): 35-58. 2013; Umanskaya & Gorbunov, Natura Montenegrina, 12(3-4): 813-824. 2013; Bagheri & Fallahi, Casp. J. Environ. Sci., 12(1): 81-97. 2014; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far East, 1-271. 2014; Tsuda, Phytotaxa, 167(1): 35-60. 2014; Varol & Sen, Journal of Fisheries Sciences, 8: 1-14. 2014; Barinova et al., Turk J Bot., 39: 535-546. 2015; Rao & Gupta, Algae of India A checklist of Indian marine algae, 3: 1-93. 2015; Smith et al., Taxonomic catalogue of algae from Ghana (Africa) and new additions, 1-101. 2015; Gallardo et al., Algas Boletín Informativo de la Sociedad Española de Ficología, 51: 7-52. 2016; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Phang et al., Raffles Bull. Zool., 40: 13-59. 2016; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Barinova & Niyatbekov, Biodivers. Int. J., 2(3): 236-263. 2018; Stutz & Mattern, Beiträge zu den Algen Baden-Württembergs, 1-504. 2018; Zotov, Algologia, 28(2): 208-232. 2018; Pérez et al., Algas, 55: 25-35. 2019; Taskin et al., Türkiye suyosunlari listei, 1-804. 2019; Kopyrina et al.,

International Journal of Oceanography and Hydrobiology, 49(2): 99-122. 2020; Rosset et al., Phycologia, 59(6): 571-577. 2020;

Description: Thallus dark blue-green, soft, fragile, expanded. Trichome straight to curved, dark blue-green to olive green, 7.9-10.7 µm wide, motile, very slightly constricted at the cross walls, attenuated at the ends and somewhat bent. Cells 1/2-1/3 times as long as wide, 2.7-5.9 µm long, cell content finely granulated. Apical cell obtuse, hooked, not capitate, without calyptra.

Synonyms: *Oscillatoria chalybea* (Mertens) Gomont 1892; *Lyngbya chalybea* Hansgirg 1893

References: Komarek & Anagnostidis (2005).

Distribution: This species was recorded from the mangrove environments of Kollam, Kerala (Benny et al., 2021), Tamil Nadu (Sakthivel & Kathiresan, 2013), Pakistan (Bano & Siddiqui, 2007).

General Environment: Marine/Freshwater species

Habitat: Appeared as a green coloured planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Alappuzha district, Pathiramanal, 9^0 37' 09.78" N, 76^0 23' 06.43" E, 11.10.2017, MES 13713, 16.08.2018, MES 21418; Kollam district, Ayiramthengu, 9^0 07'33.93" N 76^0 28' 45.34" E, 17.08.2017, MES 21491; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 16.07.2019, MES 21485. **(Plate 20, Fig. C-F)**.

3. *Phormidium crassior* (Behre) Anagnostidis 2001

Anagnostidis, Preslia, 73: 359-375. 2001; Kaštovský et al., Fottea, 10(2): 245-249. 2010; Fernandez-Carazo et al., FEMS Microbiol. Ecol., 77(3): 503-517. 2011; Gavio et al., Bol. Investig. Mar. Costeras, 44(1):117-126. 2015; Álamos, Acta Bot Malac., 41: 5-17. 2016; Gallardo et al., Algas Boletín Informativo de la Sociedad Española de Ficología, 51: 7-52. 2016.

Description: Thallus mat like densely entangled, blue-green tufts in appearance. Filaments straight, coiled. Sheaths very thin, hyaline, colourless, in some filaments sheath not extending. Trichomes straight, not attenuated at the ends, bright blue, 5.4-

7.5 µm wide, not or feebly constricted at the distinct cross walls. Cells 3.2-9.2 µm long, cell contents finely granular. Apical cell rounded, without calyptra or thickened outer cell wall.

References: Komarek & Anagnostidis (2005).

Synonyms: *Lyngbya allorgei* f. *crassior* Behre 1956

Distribution: No distributional records were found along with the marine environment.

General Environment: Freshwater species

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as a bluish-green coloured planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Thiruvananthapuram district, Kureekkadavu, 8^0 46'11.14" N 76^0 42' 36.69" E, 27.06.2017, MES 13784. **(Plate 21, Fig. A-B)**.

4. *Phormidium nigro-viride* (Thwaites ex Gomont) Anagnostidis & Komarek 1988

Anagnostidis & Komárek, Archiv für Hydrobiologie, 80: 327-472. 1988; Silva et al., Univ. Calif. Publ. Bot., 79:1-1259. 1996; Haroun et al., Bot Mar., 45: 139-169. 2002; Lobban & Tsuda, Micronesica, 35/36: 54-99. 2003; Gorostiaga et al., An. Jard. Bot. Madr., 61: 155-180. 2004; Bárbara et al., An. Jard. Bot. Madr., 62: 69-100. 2005; Liu, Checklist of biota of Chinese seas, 1-1267. 2008; Taskin et al., The check-list of the marine algae of Turkey, 1-87. 2008; Araújo et al., Bot Mar., 52: 24-46. 2009; Barinova et al., Turk J Bot., 35: 729-774. 2011; Widey & Merican, Zealand inventory of biodiversity, 3: 50-69. 2012; Nguyen et al., Bot Mar., 56(3): 207-227. 2013; Tsuda & Walsh, Micronesica, 2: 1-91. 2013; Afonso-Carrillo, Lista actualizada de las algas marinas de las islas Canarias, 1-64. 2014; Rao & Gupta, Algae of India A checklist of Indian marine algae, 3:1-93. 2015; Phang et al., Raffles Bull. Zool., 40: 13-59. 2016; Gallardo et al., Algas Boletín Informativo de la Sociedad Española de Ficología, 51: 7-52. 2016; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Balycleva & Ryabushko, Nat. Conserv. Res., 2(2): 9-18. 2017; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Zotov, Algologia, 28(2): 208-232. 2018; Taskin et al., Türkiye suyosunlari listei, 1-804. 2019; Pellizzari

et al., Sci. Mar., 84(3): 1-16. 2020; Ryabushko et al., Inland Water Biol., 13(3): 399-407. 2020; Yüce & Altundağ, J. Chem. Metrol., 14(2): 1-8. 2020.

Description: Thallus expanded, olive green. sheath absent. Trichome straight, olive green, 7.8-11.2 µm wide, slightly constricted at cross walls, contents homogenous, cross walls granulated. Cells shorter than wide, 3.23-6.11 µm long. Apical cells nearly capitate with slightly thickened outer cell wall.

Synonyms: *Oscillatoria nigroviridis* Thwaites ex Gomont 1892

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Distribution: This species was reported as epiphytic and mangrove swamps of Pakistan (Bano & Siddiqui, 2007); as epiphytic from South Africa (Lambert et al., 1989, Phillips et al., 1994, Phillips et al., 1996), Puerto Rico (Steinke & Naidoo, 1990); Epipsammic from Nigeria (Essien et al., 2008), mangrove environments of Tamil Nadu (Sakthivel & Kathiresan, 2013, Dhargalkar, 1994), Saudi Arabia (Mohammed & Al-Shehri, 2015), Brazil (Branco et al., 2003); as planktic from Sundarbans (Sen & Naskar, 2003), Tamil Nadu (Sudha, 2005; Sudha et al., 2007).

General Environment: Marine/Terrestrial species

Comments: New record to the mangrove cyanobacterial flora of Kerala.

Habitat: Appeared as green coloured planktic and epiphytic on the pneumatophores of *Sonneratia caseolaris* (L.) Engl.,

Specimen Examined: INDIA: Kerala; Thiruvananthapuram district, Kadinamkulam, 8^0 37'15.01" N 76^0 48' 43.81" E, 18.02.2016, MES 21432; Kollam district, Sakthikulangara, 8^0 56'23.44" N 76^0 33' 09.88" E, 18.11.2017, MES 21468; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 16.07.2019, MES 21486. **(Plate 21, Fig. C-F)**.

5. *Phormidium nigrum* (Vaucher ex Gomont) Anagnostidis & Komarek 1988

Nagnostidis & Komárek, Archiv für Hydrobiologie, 80: 327-472. 1988; Vitenaite, Botanica Lithuanica, 7(4): 343-364. 2001; Aysel, J Black Sea/Mediterranean Environment, 11: 1-124. 2005; Widey & Merican, New Zealand inventory of biodiversity, 3: 50-69. 2012; Park, Algal flora of Korea, 5(2): 1-108.

2012; Gadea et al., Thalassas, 29(1): 35-58. 2013; Nguyen et al., Bot Mar., 56(3): 207-227. 2013; Di Pippo et al., Eur. J. Phycol., 49(3): 384-394. 2014; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far East, 1-271. 2014; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Phang et al., Raffles Bull. Zool., 40: 13-59. 2016; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Hokmolahi et al., Iran J Bot., 23(1): 60-71. 2017; Barinova & Niyatbekov, Biodivers Int J., 2(3): 236-263. 2018; Stutz & Mattern, Beiträge zu den Algen Baden-Württembergs, 1-504. 2018; Alimjanova & Soatov, Int J Algae, 21(2): 149-162. 2019; Taskin et al., Türkiye suyosunlari listei, 1-804. 2019.

Description: Filaments straight, dark green to olive green, 8.5-9.3 μm wide, somewhat indistinctly constricted at the cross walls, cross walls granulated. Sheath thin, colourless. Cells quadratic, as long as wide, 8.5-9.5 μm long, finely granular. Apical cell pointed and truncated or widened conical, sometimes with thickened outer cell wall.

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Synonyms: *Oscillatoria nigra* Vaucher ex Gomont 1892; *Lyngbya nigra* Hangirg 1893.

Distribution: This species was reported as epiphytic from the mangrove environments of South Africa (Silva, 1991).

General Environment: Freshwater species

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Appeared as olive green coloured benthic, planktic and epipsammic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Kottayam district, Mekkara, 9^0 48'54.31" N 76^0 21' 57.54" E, 12.08.2016, MES 13753; Kollam district, Sakthikulangara, 8^0 56'23.44" N 76^0 33' 09.88" E, 14.08.2018, MES 21427; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 18.11.2019, MES 21487. **(Plate 22, Fig. A)**.

6. *Phormidium irriguum* (Kutzing ex Gomont) Anangnostidis et Komarek 1988

Anagnostidis & Komárek, Archiv für Hydrobiologie, 80: 327-472. 1988; Vitenaite, Botanica Lithuanica, 7(4): 343-364. 2001; Hällfors, Baltic Sea Environment Proceedings, 95: 1-208. 2004; Aysel, J Black Sea/Mediterranean Environment, 11: 1-124. 2005; Johansen et al., Southeast. Nat., 1: 99-134. 2007; Matula et al., Pol. Polar Res., 28(4): 283-315. 2007; Stenina & Patova, Systematic lists of species of flora and fauna state natural reserve Nenetzkij, 5-21. 2007; González, Algas Boletín de la Sociedad Española de Ficología, 39: 21 - 29. 2008; González, Catálogo de las algas y cianoprocariotas dulciacuícolas de Cuba, 1-147. 2009; Bostock & Holland, Census of the Queensland Flora, 1-320. 2010; González & González, Algas Boletín de la Sociedad Española de Ficología, 43: 6-10. 2010; Täuscher, Verhandlungen des Botanischen Vereins von Berlin und Brandenburg, 144: 177-192. 2011; Gadea et al., Thalassas, 29(1): 35-58. 2013; Barinova & Kukhaleishvili, The Journal of Biodiversity, 113: 305-338. 2014; Smirnova, Novosti Sistematiki Nizshikh Rastenii, 48: 89-103. 2014; Varol & Sen, Journal of Fisheries Sciences, 8: 1-14. 2014; Barinova et al., Turkish Journal of Botany 39: 535-546. 2015; Kumar et al., Curr. Sci., 110(10): 1999-2004. 2016; Barinova & Kukhaleishvili, Elixir Bio Sciences, 104: 45934-45947. 2017; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Gainutdinov et al., Cave Karst Sci., 44(3): 119-126. 2017; Stutz & Mattern, Beiträge zu den Algen Baden-Württembergs, 1-504. 2018; Dunck et al., Hoehnea, 45(4): 560-590. 2018; Popkova et al., Ecol. Montenegrina, 28: 8-19. 2019; Taskin et al., Türkiye suyosunlari listei, 1-804. 2019; Conklin et al., Harmful algae, 93(101767): 1-11. 2020; Kopyrina et al., International Journal of Oceanography and Hydrobiology, 49(2): 99-122. 2020; Stoyneva-Gärtner & Descy, Checklist of cyanoprokaryotes and algae in the large tropical River Congo, 104: 18-57. 2020; Yang et al., Environ. Sci. Pollut. Res., 27(5): 4814-4829. 2020; Davydov, Polar Biol., 1-12. 2021.

Description: Thallus dark blue-green. Trichome straight, flexible, 8.6-11.2 μm wide, attenuated, not constricted at the cross walls, cell walls granulated. Cells cylindrical, short, 3.8-8.2 μm long, apical cells convex, slightly capitate, with thickened cell walls.

Synonyms: *Oscillatoria irrigua* Kutzing ex Gomont 1892; *Microcoleus irriguus* (Kutzing ex Drouet) F.E.Drouet 1968

References: Komarek & Anagnostidis (2005); Desikachary (1959).

Distribution: This species was reported from the mangrove environments of Kerala (Benny et al., 2021).

General Environment: Freshwater species

Habitat: Appeared as dark brown or black coloured epipsammic, planktic and benthic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 04.12.2017, MES 21503; 18.03.2019, MES 21509; Kollam district, Ayiramthengu, 9^0 07'33.93" N 76^0 28' 45.34" E, 19.11.2019, MES 21574; Sakthikulangara, 8^0 56'23.44" N 76^0 33' 09.88" E, 14.11.2018, MES 21551. **(Plate 22, Fig. B-D)**.

5. Order: Nostocales

The order is characterised by the filamentous forms including both branched and unbranched forms. The branching is of two types, false branching and true branching.

The order consists of 19 families, including more than 132 genera and more than 1500 species. Among these, only 6 families, 11 genera, and 37 species are reported from the study area.

Key to the family

1. False branching absent or rare with basal heterocytes ..... **1. Calotrichaceae**
2. Thallus composed of true branched filaments of trichomes and sheaths, true branching with T, V or Y-type branching, heterocytes intercalary ..... **2. Hapalosiphonaceae**
3. Filamentous, heterocytous, uniseriate trichomes enveloped by fine or firm mucilaginous sheaths, heterocytes basal on both ends or intercalary ..... **3. Nostocaceae**

4. Thallus usually attached to a substratum, bushy or gelatinous, filaments uniseriate, always heteropolar, apical parts typically ending in terminal hair like cells, terminal cells often elongated, heterocytes basal .....**4. Rivulariaceae**
5. Filamentous with obligatory false branching, uniseriate trichomes, sheaths usually thick, firm, heterocytes intercalary, solitary ..... **5. Scytonemataceae**
6. Filamentous, solitary or forming cushion-like, with true branching, trichomes bi- or multiseriate, uniseriate in young trichomes and at the end of the branches, sheath thin or thick, heterocytes intercalary, solitary ..... **6. Stigonemataceae**

1. Calotrichaceae

Filaments heteropolar with distinct base, usually with basal heterocytes, gelatinous. Filaments solitary, erect, false branching absent or rare. Trichomes of different length, continually narrowed towards ends. Reproduction by fragmentation of trichomes, commonly by hormogonia and by separation of secondary branches.

The family consists of 2 genera and 144 species. The family represents 1 genus and 4 species and is known to occur in the mangrove ecosystem of southern Kerala and is presented.

Key to the genera

1. Trichomes single in a sheath, without false branching ……**1. *Calothrix***

1. *Calothrix* Agardh ex Bornet et Flahault, 1886.

Filaments heteropolar, clearly differentiated into basal and apical parts, filaments continuously narrowed towards apex, simple, solitary or in small groups, separated one from another, rarely with single, lateral false branches, branches soon separate from the main filaments and attach individually to the substrate. Trichomes of different length, continually narrowed towards ends, always with basal, more or less spherical or hemispherical heterocytes. Trichomes sometimes with widened basal part, constricted or unconstricted at the cross walls, ending by the hair-like apical part composed of narrow, long, hyaline cells. Sheaths always present, usually firm, sometimes lamellated and yellow-brownish coloured, or funnel-like widened at the ends. Vegetative cells cylindrical or barrel-shaped.

Among 222 species (infraspecific) reported up to date, 141 species are currently accepted as taxonomically valid taxa (Guiry & Guiry, 2022). Only one species, a benthic form from the mangrove ecosystems of southern Kerala, is described here.

Key to the species

1a. Cells in trichomes mostly shorter or slightly shorter than wide..... 2

1b. Cells as long as or longer than wide 3

2a. Trichomes slightly constricted at the base and not constricted in upper parts ..... **4. *C. nidulans***

2b. Trichomes not constricted at the cross walls..... **1. *C. braunii***

3a. Trichomes distinctly constricted at the cross walls, end cell conical, bluntly pointed..... **2. *C. marchica***

3b. Trichomes slightly constricted at the cross walls .....**3. *C. marchica* var. *intermedia***

1. *Calothrix braunii* Bornet et Flahault 1886

Bornet & Flahault, Annales des Sciences Naturelles, Botanique, 3: 323-381. 1886; Reinhold, Annales de la Societe Geologique de Belgique, 61(1): 39-47. 1937; Drouet, Am. J. Bot., 25(9): 657-666. 1938; Singh, Proc. Indian Acad. Sci., B, 49(1): 66-73. 1959; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Kidd & Wade, Southwest. Nat., 227-233. 1965; Kawecka, Polskie Archiwum Hydrobiologii, 21(1): 211-228. 1974; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Whitton et al., Atoll Res. Bull., 1-10. 1977; Sheath & Steinman, Can J Bot., 60: 1964-1997. 1982; Charlton & Hickman, Internationale Revue der gesamten Hydrobiologie und Hydrographie, 69(3): 297-332. 1984; Alvarez-Cobelas & Gallardo, Acta Bot. Malacit., 13: 53-76. 1988; Aboal, An. Jard. Bot. Madr., 45(1): 3-46. 1988; Day et al., Flora of Australia, 4: 1-276. 1995; Fenchel et al., Ophelia, 43: 45-100. 1995; Poulin et al., Can. Field-Nat., 109: 27-110. 1995; Fumanti et al., Hydrobiologia, 316(2): 81-90. 1995; Aboal, Ecologia Acuatica y Sociedad, 117-128. 1996; Vinogradova, Isr. J. Plant Sci., 46(3): 229-238. 1998; Vinogradova et al., Cyanoprocaryotes and algae of continental Israel, 32-141. 2000; Aboal et al.,

Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen, 27(1): 555-559. 2000; Cavacini, Soil algae from northern Victoria land Antarctica, 45-60. 2001; Mauch & Schmedtje, Informationsberichte des Bayerischen Landsamtes für Wasserwirtschaft Heft, 1(3): 1-388. 2003; Smith & Piccin, The Southwestern Naturalist, 49(3): 395-406. 2004; Wheeler, Southwest. Nat., 49(3): 406-408. 2004; Mishra et al., Indian J. Plant Physiol., 10(4): 404-407. 2005; Hu & Wei, The freshwater algae of China, 1-1023. 2006; Patova & Demina, Biodiversity of the Polar Ural ecosystems, 69-89. 2007; Johansen et al., Southeast. Nat., 1: 99-134. 2007; Uher, Fottea, 7(1): 33–38.2007; Dwivedi et al., Ecoprint, 15: 29-36. 2008; Patova & Demina, Inland Water Biology, 1(1): 54-63. 2008; Karosiene & Kasperoviciene, Botanica Lithuanica, 15(2): 79-91. 2009; Barinova et al., Journal of Arid Environments, 74: 765–776. 2010; Smith, Int J Algae, 12(3): 230-256. 2010; Barinova et al., Turk J Bot., 35: 729-774. 2011; Dash et al., E-planet, 9(1): 1-14. 2011; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Kumar et al., Botanica Orientalis: Journal of Plant Science, 8: 77-89. 2011; Widey & Merican, New Zealand inventory of biodiversity, 3: 50-69. 2012; Suresh et al., Pak. J. Biol. Sci., 15(19), 919-928. 2012; Dey & Bastia, J Algal Biomass Utln., 3(4): 1-4. 2012; Gadea et al., Thalassas, 29(1): 35-58. 2013; Maulood, Checklist of algal flora in Iraq, 1-94. 2013; Barinova & Kukhaleishvili, The Journal of Biodiversity, 113: 305-338. 2014; Patova, Journal of Siberian Federal University, Biology, 3: 282-290. 2014; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far East, 1-271. 2014; Rinkel & Manoylov, P Acad Nat Sci Phila., 163(1): 43-59. 2014; Roy et al., Phykos, 44, 1-8. 2014; Kamble & Karande, J. Indian Bot. Soc., 93(1 &2): 120-125. 2014; Tauscher, Pflanzen und Tiere in Sachsen-Anhalt Ein Kompendium der Biodiversität, 63-112. 2016; Gkelis et al., Biodiversity Data Journal, 4(e10084): 1-103. 2016; Adam et al., European Journal of Ecology, 3(2): 92-106. 2017; Barinova & Kukhaleishvili, Elixir Bio Sciences, 104: 45934-45947. 2017; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Patova & Novakovskaya, Novosti Sistematiki Nizshikh Rastenii, 52(2): 311–353. 2018; Barinova & Niyatbekov, Biodivers. Int. J., 2(3): 236-263. 2018; Stutz & Mattern, Beitrage zu den Algen Baden-Wurttembergs, 1-504. 2018; Kumar et al., Nelumbo, 60(2): 154-160. 2018.

Description: Thallus blue-green. Filaments straight, 9.8-11.5 μm wide, in the middle 4.7-8.3 μm wide, solitary. Sheaths thin, colourless, not lamellated. Trichomes not constricted at the cross walls, green, 6.3-8.9 μm wide at the base, in the middle 3.2-5.2 μm wide. Cells usually slightly shorter than wide up to isodiametric in nature, cylindrical to barrel-shaped. Heterocytes basal, solitary, hemispherical to spherical, 6.8 μm wide, 5.4 μm long.

References: Komarek (2013); Desikachary (1959).

Distribution: No distributional record was found along with the mangrove environment.

General Environment: Freshwater/terrestrial species.

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Appeared as green coloured epipsammic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Kollam district, Sakthikulangara, 8^0 56'23.44" N 76^0 33' 09.88" E, 23.11.2017, MES 21544. **(Plate 22, Fig. E-F)**.

2. *Calothrix marchica* Lemmerman 1914

Lemmermann, Abhandlungen herausgegeben vom Naturwissenschaftlichen Vereine zu Bremen, 23: 247-248. 1914; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Alvarez-Cobelas & Gallardo, Acta Bot Malacit., 13: 53-76. 1988; Day et al., Flora of Australia, 4: 1-276. 1995; Silva et al., University of California Publications in Botany, 79: 1-1259. 1996; Prosperi et al., Ecological aspects of Cyanobacteria from the rice fields of Corrientes, 141-146. 1996; Vinogradova et al., Cyanoprocaryotes and algae of continental Israel, 32-141. 2000; Lopez-Cortes et al., Int. Microbiol., 4(4): 227-236. 2001; Castiglioni et al., Appl. Environ. Microbiol., 70(12): 7161-7172. 2004; Mikter & Shukla, Bulletin of Arunachal Forest Research, 22(1): 1-8. 2006; Berrendero et al., Int J Syst Evol Microbiol., 58(2): 447-460. 2008; Korai et al., Turkish J. Fish. Aquat. Sci., 8(2): 259-268. 2008; Siddiqui et al., Cyanobacteria, Bacteria and Fungi, 2:1-415. 2009; Veenus et al., Advances in Plant Sciences, 22(1): 27-30. 2009; Deepa Devi et al., Assam University Journal of Science and Technology, 5(1): 6-13. 2010; Ghadai et al., Int. J. Agric. Sci., 2(2), 28. 2010; Oinam et al., J. Indian Bot. Soc., 90(1 & 2):

45-59. 2011; Shariatmadari & Riahi, Rostaniha, 11(2): 113-119. 2011; Singh et al., Microbiology, 80(3): 411-419. 2011; Das & Adhikary, Phykos, 44(2): 29-43. 2012; Nikam et al., Bioremediation, Biodiversity and Bioavailability, 7(1): 70-80. 2012; Dey & Bastia, J Algal Biomass Utln, 3(4), 1-4. 2012; Patil et al., J. Algal Biomass Utiln, 3(2): 71-102. 2012; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Aslani et al., Iran. J. Bot., 20(2), 257-264. 2014; Keshari & Adhikary, Int. Biodeterior. Biodegrad., 90, 45-51. 2014; Indrama et al., J. Indian Bot. Soc., 94(1 & 2): 52-63. 2015; Oinam et al., J. Appl. Biol. Biotechnol., 3(06): 1-8. 2015; Tiwari et al., Int J Curr Microbiol App Sci., 4: 666-680. 2015; Ambika & Krishnamurthy, J. Indian Bot. Soc., 95(1 & 2): 78-91. 2016; Kumar et al., Curr. Sci., 1999-2004. 2016; Bora et al., Algal Wealth of Northeast India, 215-228. 2016; Gkelis et al., Biodivers. Data J., 4(e10084): 1-103. 2016; Srinivas & Aruna, Int. J. Sci., 5(5), 27-30. 2016; Jaiswal, Algae of north-west Khandesh, 1-448. 2017; Rai et al., Algal Res., 35: 142-151. 2018; Bodkhe, Bioinfolet, 16(4): 206-210. 2019; Jeevanantham et al., J. pharmacogn. phytochem., 8(2): 635-640. 2019; Dash et al., Ecol. Environ., 38(4), 852-858. 2020; Mukherjee, Indian J. Ecol., 48(3): 859-865. 2021.

References: Komarek (2013); Desikachary (1959).

Description: Filaments straight or slightly bent, 4.9-6 μm wide. Sheath thin, narrow, colourless. Trichome straight, continually narrowed towards end, distinctly constricted at the cross walls, 4.2-5.6 μm wide at the very slightly widened base. Cell quadratic or shortened, nearly as long as wide. End cell conical, bluntly pointed. Heterocytes basal, single, nearly spherical or subspherical, 3.8-5.6 μm wide, 6.2 μm long.

Distribution: No distributional records were found along with the marine environment.

General Environment: Freshwater species

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as green or olive green coloured epiphytic on the pneumatophores of *Sonneratia caseolaris* (L.) Engl.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 19.12.2016, MES 13799. **(Plate 23, Fig. A)**.

3. *Calothrix marchica* var. *intermedia* C.B.Rao 1937

Rao, Proc. Indian Acad. Sci., B 6(6): 339-375. 1937; Singh & Saxena, Hydrobiologia, 34(3): 503-512. 1969; Tiwari, Hydrobiologia, 39(3): 335-350. 1972; Adhikary, J. Basic Microbiol., 27(9): 475-481. 1987; Anand & Hopper, Hydrobiologia, 144(3): 223-232. 1987; Day et al., Flora of Australia, 4: 1-276. 1995; Azevedo et al., Hoehnea, 23(1): 1-38. 1996; Jena et al., Indian Hydrobiology, 9(1): 103-113. 2006; Bhattacharya & Ray, West Bengal distribution of species in relation to soil parameters, 1-8. 2013; Das & Maurya, Nelumbo, 57: 124-134. 2015; Sikdar & Keshri, Vegetos, 28(2): 25-35. 2015.

Description: Filaments solitary, 6.5-8.6 μm wide at the base, in the middle 4.1-5.2 μm wide, without a terminal hair. Sheath firm, hyaline, slightly lamellated, yellow-brown, widened. Trichomes at the base 5.7-7.8 μm, slightly widened, in the middle 3.4-6.2 μm wide, slightly constricted at the cross walls. Cells longer than wide. Heterocytes basal, single, spherical or hemispherical (onion-like), 8.2 μm wide, 10.5 μm long.

References: Komarek (2013); Desikachary (1959).

Distribution: No distributional record was found along with the mangrove environment.

General Environment: Freshwater species.

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Appeared as dark brown coloured planktic, epipsammic and epiphytic on the pneumatophores of *Sonneratia caseolaris* (L.) Engl.

Specimen Examined: INDIA: Kerala; Kollam district, Sakthikulangara, 8^0 56'23.44" N 76^0 33' 09.88" E, 26.09.2018, MES 21548; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 25.11.2017, MES 21530; Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 07.12.2016, MES 21539. **(Plate 23, Fig. B-D)**.

4. *Calothrix nidulans* Setchell & N.L.Gardner 1924

Setchell & Gardner, Proc. Calif. Acad. Sci., 12(29): 695-949. 1924; Lakkis, Biologie, Biodiversité, Biogéographie, 1-510. 2013; Nguyen et al., Bot. Mar., 56(3): 207-227. 2013; Phang et al., Raffles Bull. Zool., 40: 13-59. 2016; Gerasimiuk, Int J Algae, 21(2): 137-148. 2019.

Description: Filaments short, not branched, up to 60-68 μm long, distinctly widened at the base, 9.8-12.3 μm wide and intensely narrowed towards ends. Sheath fine, colourless, homogenous, widened. Trichomes pale blue-green, 9.2-10.6 μm wide at the base, slightly constricted at the base and not constricted in upper parts. Cells shorter than wide, 2.6-5 μm long. Heterocytes hemispherical, solitary, basal, narrower than vegetative cells, 4.3 μm wide, 3.7 μm long.

References: Komarek (2013).

Distribution: No distributional record was found along with the mangrove environment.

General Environment: Marine species.

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Appeared as green coloured epiphytic on the aerial roots of *Rhizophora apiculata* Blume.

Specimen Examined: INDIA: Kerala; Kollam district, Sakthikulangara, 8^0 56'23.44" N 76^0 33' 09.88" E, 07.10.2016, MES 21477. **(Plate 23, Fig. E-F)**.

2. Hapalosiphonaceae

Thallus in form of true branched, clustered filaments, all filaments and branches are morphologically similar. Trichomes uniseriate, often constricted at cross walls, true branched, with T, V or Y branching. Branches cylindrical or narrowed towards ends. Cells cylindrical, barrel shaped, apical cells usually rounded. Heterocytes intercalary, usually barrel shaped or spheroidal. Reproduction by hormogonia.

The family consists of 27 genera and 102 species. The family represents 3 genera and 4 species, which are known to occur in the mangrove ecosystem of southern Kerala and are presented.

Key to the genera

1. Cells in main trichomes and branches isomorphic, more or less cylindrical or barrel-shaped ..... **1. *Hapalosiphon***
2. Cells of different shapes in same thallus, short or elongated barrel-shaped or cylindrical cells ..... **2. *Mastigocladus***
3. Creeping filaments represent a main part of the thallus during the whole vegetative period ..... **3. *Westiellopsis***

1. *Hapalosiphon* Nägeli in Kützing ex Bornet et Flahault 1887

Filamentous thallose; thallus from free, coiled filamentous clusters. Filaments irregularly arcuated, with uniseriate trichomes (only rarely with some cells length-wise divided), laterally (usually unilaterally) true-branched (T-type) and morphologically not differentiated in main and lateral trichomes, only rarely are branches slightly narrower. Sheaths thin, colourless, rarely indistinctly layered. Heterocytes intercalary, cylindrical, exceptionally lateral, usually solitary. Cells cylindrical, only rarely indistinctly constricted at cross-walls or barrel-shaped, sometimes with finely and sparsely granular content. Reproduction by disintegration of thallus by hormogonia separating from trichomes at the ends of lateral branches through necridic cells.

Among the 43 species (infraspecific) reported up to date, 28 species are currently accepted as taxonomically valid taxa (Guiry & Guiry, 2022). Only one species, a planktic form from the mangrove ecosystems of southern Kerala, is described here.

Key to the species

1. Filaments flexuous, 5.5 μm to 7.2 μm wide ..... **1. *H. welwitschii***

1. *Hapalosiphon welwitschii* West & G.S.West 1897

West & West, Journal of Botany, British and Foreign, 35: 242. 1897; Forti in De Toni, Sylloge Algarum, 5: 572. 1907; Fremy, Myxo. d'Afr. equat. frac., 420. 1929; Geitler, Kryptogamenflora, 531. 1932; Gonzalves & Gangla, Ibid, 16: 51-59. 1949; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Bicudo & Picelli-Vicentim, Revista Brasileira de Biologia, 48(1): 15-28. 1988; Day et al., Flora of Australia, 4: 1-276. 1995; Saha et al., Indian J. Microbiol., 47(3): 219–232. 2007; Arulmurugan et al., J. ecobiotechnol., 3(10): 19-29. 2011; Rai et al., Our Nature, 8: 336-354. 2010; Widey & Merican, New Zealand inventory of biodiversity, 3: 50-69. 2012; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Pradhan et al., Phykos, 48(1): 58-66. 2018; Basumatary et al., Journal of Global Biosciences, 9(12): 8178-8187. 2020; Chaudhari, Bioinfolet, 17(4b): 654-656. 2020; Arguelles Philippine Journal of Science, 150(4): 829-844. 2021;

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

References: McGregor (2018); Komarek (2013); Desikachary (1959).

Distribution: This species was reported from the mangrove environment of Tamil Nadu (Sudha, 2005; Sudha et al., 2007, Ramamurthy & Abhinand, 2016).

General Environment: Freshwater species.

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Appeared as green coloured planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Alappuzha district, Pathiramanal, 9^0 37' 09.78" N, 76^0 23' 06.43" E, 05.08.2015, MES 13708. **(Plate 24, Fig. A)**.

2. *Mastigocladus* Cohn ex Kirchner 1898

Thallous soft, spongy mats, smooth or gelatinous at the surface, up to compact, occasionally layered, dirty blue-green or olive green, composed from more or less densely tangled filaments. Trichomes uniserial, irregularly coiled, with thin, distinct, colourless sheaths, which diffluent in old stages; true branching of T, V or Y- type, often unilateral, in some stages the branching is rare or almost absent; branches usually continually tapering to the ends. False branching also facultatively present, but not common. Cells irregularly barrel-shaped, in branches up to cylindrical, terminal cells narrowed, elongate and rounded. Heterocytes intercalary, solitary or (rarely) in pairs.

Among the 5 species (infraspecific) reported up to date, 3 species are currently accepted as taxonomically valid taxa (Guiry & Guiry, 2022). Only one species, an epipsammic form from the mangrove ecosystems of southern Kerala, is described here.

Key to the species

1. Trichomes 4.5-7.3 µm wide, cells often of different size in the same trichome ..... **1. *M. laminosus***

1. *Mastigocladus laminosus* Cohn ex Kirchner 1898

Kirchner, Die natürlichen Pflanzenfamilien nebst ihren Gattungen und wichtigeren Artn insbesondere den Nutzpflanzen unter Mitwirkung zahlreicher hervorragender Fachgelehrten I. Teil, 45-92. 1898; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Jha, Internationale Revue der gesamten Hydrobiologie und Hydrographie, 77(3): 435-443. 1992; Day et al., Flora of Australia, 4: 1-276. 1995; Cvijan & Blazencic, Flora algi Srbije. Tom 1. Cyanophyta, 1-290. 1996; Vinogradova et al., Cyanoprocaryotes and algae of continental Israel, 32-141. 2000; Phillips, Algae, 228-244. 2002; Aysel, J. Black Sea/Mediterranean Environment, 11: 1-124. 2005; Sompong et al., Chiang Mai Journal Science, 33: 363-370. 2006; Kastovsky & Johansen, Phycologia, 47: 307-320. 2008; Bhatnagar et al., J. Arid Environ., 72(2): 73-83. 2008; Miller et al., Appl. Environ. Microbiol., 75(3), 729-734. 2009; Ionescu et al., Algol Stud., 130(1): 109-

124. 2009; Bostock & Holland, Census of the Queensland Flora, 1-320. 2010; Smith, Int J Algae, 12(3): 230-256. 2010; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Soe et al., Phycol. Res., 59(3), 135-142. 2011; Siangbood & Ramanujam, Int J Algae, 13(2): 178-185. 2011; Singh et al., J. Indian Bot. Soc., 90(3&4): 200-206. 2011; Widey & Merican, New Zealand inventory of biodiversity, 3: 50-69. 2012; Gadea et al., Thalassas, 29(1): 35-58. 2013; Bauersachs et al., Org. Geochem., 56: 19-24. 2013; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far East, 1-271. 2014; Stoyneva-Gartner et al., Red list of Bulgarian algae. II. Microalgae, 100: 1-55. 2015; Bhakta et al., Nelumbo, 58: 157-173. 2016; Gkelis et al., Biodivers. Data J., 4(e10084): 1-103. 2016; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Minj et al., Indian J. Biotechnol., 16: 586-593. 2017; Boutarfa et al., Algas, 55: 39. 2019; Taskin et al., Turkiye suyosunlari listei, 1-804. 2019.

Description: Thallus membranous, blue green. Filaments densely entangled, usually uniseriate or with biseriate organisation of cells, short, distinctly constricted at the cross walls, 4.5-7.3 µm wide, curved, with distinct sheath, when older torulose, indistinct, side branches 2.4 µm wide, erect. Cells barrel-shaped to short cylindrical, often of different sizes in one and the same trichome, 3.2-6.2 µm wide, 3-7.9 µm long. Heterocytes intercalary, spherical or ellipsoidal, 5.8 µm wide, 6 µm long.

References: Komarek (2013); Desikachary (1959).

Synonyms: *Fischerella laminosa* (Hansgirg ex Bornet & Flahault) Castenholz; *Hapalosiphon laminosus* Hansgirg ex Bornet & Flahault 1886

Distribution: No distributional record was found along with the mangrove environment.

General Environment: Freshwater species.

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Appeared as dark green coloured epipsammic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 06.11.2019, MES 21566. **(Plate 24, Fig. B)**.

3. *Westiellopsis* Janet 1941.

Thallus filamentous, containing true branched filaments. Main filaments creeping, thicker than branches, composed of uni-bi seriate, torulous, irregular trichomes with indistinct colourless sheaths. Branches arising laterally from the main filaments with T-type of branching, generally distinctly thinner than main filaments, often erect, composed usually from monoseriate trichomes. Cells in main trichomes sphercal-rounded, oval upto barrel shaped, irregular, often different in shape, longer or shorter than wide. Heterocytes intercalary. Akinetes described in *Westiellopsis akinetica* Mishra et P. Singh 2020.

7 species are currently accepted as taxonomically valid taxa (Guiry & Guiry, 2022). Here, only two species are described as planktic and epiphytic forms from the mangrove ecosystems of southern Kerala.

Key to the species

1a. Cells barrel-shaped, 2.7- 7.7 μm length, 3.3- 6.7 μm width ..... **1. *W. interrupta***

1b. Cells barrel-shaped to irregular-rounded, ± 8-12 μm in diameter or slightly longer, 6.6-16.2 x 8-12.3 μm.....**2. *W. prolifica***

1. *Westiellopsis interrupta* Kanthamma 1972

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

Reference: Komarek (2013); Jeeji-Bai (1972).

Description: Main filaments torulose, irregularly coiled, mono-seriate, from which grow perpendicularly (unidirectional T-shaped) branches, which are thinner, constricted at the cross walls. Cells in main filaments barrel-shaped, 2.7-7.7 μm long, 3.3-6.7 μm wide, in branches elongate, oval or long oval up to cylindrical cells, 3.3-10.8 μm long, 2.4-4.2 μm wide; intercalary cells divide in clusters of wide, short and rounded cells. Heterocytes intercalary, quadrate to oblong cylindrical, 4.2-12.3 μm long, 3.4-5.2 μm wide.

Distribution: No distributional record was found along with the mangrove environment.

General Environment: Freshwater/Terrestrial species.

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Appeared as a green coloured planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Alappuzha district, Ezhupunna, 9^0 49' 24.43" N, 76^0 18' 39.54" E, 14.07.2019, MES 13706. **(Plate 24, Fig. C-F)**.

2. *Westiellopsis prolifica* Janet 1941

Janet, Ann. Bot., 5(1): 167-170. 1941; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Das, Phykos, 41(1&2): 71-76. 2002; Tirkey & Adhikary, Curr. Sci., 89(3): 515-521. 2005; Tiwari et al., Trop. Ecol., 46(2): 165-171. 2005; Jena et al., Indian Hydrobiology, 9(1): 103-113. 2006; Singh & Samdariya, Adv. Ecol., 191-197. 2006; Tirkey & Adhikary, Feddes Repert., 117(3□4): 280-306. 2006; Singh et al., Punjab Academy of Sciences, 4: 1-2. 2007; Samad et al., Nelumbo, 50(1-4): 51-56. 2008; Samad & Adhikary, Algae, 23(2), 91-114. 2008; Siddiqui et al., Cyanobacteria, Bacteria and Fungi, 2: 1-415. 2009; Pathmanapan et al., Recent res. sci. technol., 2(6): 58-71. 2010; Dash et al., E-planet, 9(1): 1-14. 2011; Selvam et al., Journal of Research in Biology, 1(3): 153-162. 2011; Singh et al., J. Indian Bot. Soc., 90(3&4): 200-206. 2011; Nikam et al., Biorem. Biodiv. Bioavail., 7(1): 70-80. 2012; Bharadwaj & Baruah, J. Algal Biomass Util., 4: 23-33. 2013; Keshari & Adhikary, Biofouling, 29(5): 525-536. 2013; Abed et al., Int. J. Adv. Res., 2, 895-900. 2014; Kamble & Karande, J. Indian Bot. Soc., 93(1&2), 120-125. 2014; Priyadarshani et al., Int. J. Appl. Biol. Pharm., 5(3): 239-246. 2014; Keshari & Adhikary, Int. Biodeterior. Biodegradation, 90, 45-51. 2014; Adhikari & Baruah, J. Algal Biomass Util., 6, 12-16. 2015; Shaaban et al., Egyptian J. of Phycol., 16(1): 47-74. 2015; Vijayan & Ray, Am. J. Plant Sci., 6(18): 2924-2934. 2015; Yasmin et al., Int. J. Curr. Microbiol. Appl. Sci, 4(12): 297-302. 2015; Bhakta et al., Nelumbo, 58, 157-173. 2016; Thajamanbi et al., Int. J. Life Sci. Pharma Res., 6(4): 23-32. 2016; Bala & Sinha, Academic Voices, 7; 14-19. 2017; Saber et al., Phycologia, 56(6): 697-709. 2017; Shaaban et al., Egypt. J. Bot., 57(3): 517-524. 2017; Kumar et al., Nelumbo, 60(2): 154-160. 2018; Chaudhari, Bioinfolet,17(4b): 654-656. 2020; Basumatary et al., Journal of Global Biosciences, 9(12): 8178-8187. 2020; Bagul et al., Rhizospheric diversity of cyanobacteria and

their Significance in Tropical Ecosystem, 39-50. 2021; Brenes-Guillen et al., J. Phycol., 57(1): 183-198. 2021.

Description: Main filaments torulose, flexuous, with short barrel-shaped cells, monoseriate trichomes, which are distinctly constricted at the cross walls, cells in main trichomes barrel-shaped to irregular rounded which are as long as wide, 7.8 - 11.7 μm wide, or slightly longer, 8.6 - 14.1 μm long. Branched filaments thinner than main filaments, which are arising from the horizontal system and not constricted at the cross walls, with elongate cylindrical cells, 7.5 -13.1 μm long, 5.5 - 6 μm wide. Heterocytes intercalary, either quadrate or oblong- cylindrical, 5.5 - 6.2 μm wide, 10.5 - 21.6 μm long.

Synonyms: *Parthasarathiella prolifica* Suba Raju 1962

Distribution: No distributional record was found along with the mangrove environment.

General Environment: Freshwater/Terrestrial species.

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Appeared as green coloured planktic and epiphytic on the pneumatophores of *Avicennia officinalis* L.

Specimen Examined: INDIA: Kerala; Alappuzha district, Ezhupunna, 9^0 49’ 24.43” N, 76^0 18’ 39.54” E, 14.07.2018, MES 13705; Ernakulam district, Vypin, 9^0 58’ 26.46” N, 76^0 14’ 38.14” E, 12.09.2016, MES 21585; Kumbalam, 9^0 54’ 41.96” N, 76^0 18’ 32.36” E, 23.11.2017, MES 21531. **(Plate 25, Fig. A-D)**.

3. Nostocaceae

Filamentous, heterocytous, isopolar, with uniseriate trichomes, enveloped by fine or firm mucilaginous envelopes or sheaths, filaments straight, without false or true branching. Trichomes isopolar, cylindrical or moniliform, constricted or not constricted at cross walls, sometimes narrowed towards both ends. Cells spherical, barrel-shaped to cylindrical, end cell rounded, conical, acutely pointed or cylindrical or bluntly pointed. Heterocytes present, terminally on both trichome ends or intercalary. Akinetes present, several type larger than vegetative cells.

The family consists of 35 genera and 466 species. The family represents 4 genera and 20 species and is known to occur in the mangrove ecosystem of southern Kerala.

Key to the genera

1. Akinetes adjacent to heterocytes or distant, 1-2 in a row, mature akinetes several times larger than vegetative cells ..... **1. *Anabaena***

2. Filaments in colonies, or in layers of homogenous matter, heterocytes intercalary or terminal, mostly without firm colonies ..... **2. *Desmonostoc***

3. Trichomes mainly moniliform, unified into firm, slimy colonies (often macroscopic) with a distinct, defined margin .....**3. *Nostoc***

4. Filaments enveloped by homogeneous mucilage, heterocytes only intercalary, trichomes more or less cylindrical, without prominent sheaths, with constrictions at the cell walls .....**4. *Trichormus***

1. *Anabaena* Bory ex Bornet et Flahault 1888

Filaments usually composed of trichomes enveloped within mucilaginous envelops which are amorphous, indistinct, diffluent. Trichomes isopolar, usually flexuous or coiled, always constricted at cross walls, cylindrical. Vegetative cells cylindrical, barrel shaped or spherical. Heterocytes intercalary, solitary, spherical, oval or cylindrical. Akinetes usually oval to long cylindrical, intercalary, solitary or sometimes up to 4. Reproduction by fragmentation of colonies, trichomes and by akinetes.

Among 339 species (infraspecific) are reported up to date, and 150 species are currently accepted as taxonomically valid taxa (Guiry & Guiry, 2022). Here only 5 species are described as planktic, benthic, epiphytic and epipsammic forms from the mangrove ecosystems of southern Kerala.

Key to the species

1a. Cells slightly shorter or longer than wide 2

1b. Cells longer than wide 3

2a. Cells 4.3-5.0 μm wide, heterocytes ovoid or elliptical..... **5. *A. torulosa***

2b. Cells 3.7-5.6 μm wide, heterocytes spherical to cylindrical .....**3. *A. laxa***

3a. Heterocytes almost spherical to slightly elongated with rounded flattened ends, basal..... **1. *A. bispora***

3b. Heterocysts intercalary, spherical, oval or elongated cylindrical ..**2. *A. inaequalis***

4a. Cells spherical, 3.2- 4.6 μm wide..... **4. *A. sedovii***

1. *Anabaena bispora* Gayral & Mazancourt 1958

Gayral & Mazancourt, Bulletin de la Société Botanique de France, 105:7-8, 344-350. 1958; Gayral & de Mazancourt, Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen, 14(1), 475-480. 1961.

Description: Thallus gelatinous, membranous, blue-green to olive green. Filaments mats. Trichomes slightly flexuous, constricted at the cross walls, slightly narrowed towards the ends. Cells isodiametric, slightly longer than wide, 3.9-4.2 μm wide, 3.5- 6.6 μm long, terminal cells conical, slightly elongated. Heterocytes almost spherical to slightly elongated with rounded flattened ends, basal, 4.5- 5.5 μm wide, 5.4 – 6.8 μm long.

References: Komarek (2013).

Distribution: No distributional record was found along with the mangrove environment.

General Environment: Freshwater/Marine species.

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as dark green coloured planktic and epipsammic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Vypin, 9^0 58’ 26.46” N, 76^0 14’ 38.14” E, 18.02.2016, MES 21557; Kollam district, Ayiramthengu, 9^0 07’33.93” N 76^0 28’ 45.34” E, 24.10.2019, MES. 21554. **(Plate 25, Fig. E-F)**.

2. *Anabaena inaequalis* Bornet et Flahault 1886

Bornet & Flahault, Annales des Sciences Naturelles, 7: 177-262. 1886; Rich, Transactions of the Royal Society of South Africa, 23 (2): 107-160. 1935; Reinhold,

Annales de la Société Géologique de Belgique, 61(1): 39-47. 1937; Chapman et al., Trans. Roy. Soc. New Zealand, 84: 695-747. 1957; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Sheath & Steinman, Canada. Can J Bot., 60: 1964-1997. 1982; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Alvarez-Cobelas & Gallardo, Acta Bot Malac., 13: 53-76. 1988; Day et al., Flora of Australia, 4: 1-276. 1995; Poulin et al., The Canadian Field-Naturalist, 109: 27-110. 1995; Ling & Tyler, Bibliotheca Phycologica, 105: 1-643. 2000; Vitenaite, Botanica Lithuanica, 7(4): 343-364. 2001; Mauch & Schmedtje. Taxaliste der Gewasserorganismen Deutschlands zur Kodierung biologischer Befunde, 1(3):1-388. 2003; Hallfors, Baltic Sea Environment Proceedings, 95: 1-208. 2004; Aysel, J. Black Sea/Mediterranean Environment 11: 1-124. 2005; Hu & Wei, The freshwater algae of China, 1-1023. 2006; Stenina & Patova, Algae, 5-21. 2007; Bostock & Holland, Census of the Queensland Flora, 1-320. 2010; Smith, Int J Algae, 12(3): 230-256. 2010; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Widey & Merican, New Zealand inventory of biodiversity, 3:50-69. 2012; Gadea et al., Thalassas, 29(1): 35-58. 2013; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Davydov, Folia Cryptogamica Estonica, 51: 13-23. 2014; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far East, 1-271. 2014; Smith et al., Taxonomic catalogue of algae from Ghana (Africa) and new additions, 1-101. 2015; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; McGregor, Phytotaxa, 359(1): 1-166. 2018; Taskin et al., Turkiye suyosunlari listei, 1-804. 2019; Davydov, Polar Biol., 1-12. 2021.

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

Synonyms: *Anabaena californica* O.Borge 1909; *Anabaena laxa* f. *californica* (O.Borge) Canabaeus 1929.

References: McGregor (2018); Komarek (2013).

Distribution: No distributional record was found along with the mangrove environment.

General Environment: Freshwater species.

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as dark greenish coloured planktic and benthic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Alappuzha district, Pathiramanal, 9^0 37' 09.78" N, 76^0 23' 06.43" E, 13.12.2017, MES 13714; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 06.11.2019, MES 21567. **(Plate 26, Fig. A-F)**.

3. *Anabaena laxa* A.Braun 1886

Braun in Bornet & Flahault, Annales des Sciences Naturelles, 7: 177-262. 1886; Day et al., Flora of Australia, 1-276. 1995; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Rai et al., Our Nature, 8: 336-354. 2010; Barinova et al., Turk J Bot., 35: 729-774. 2011; Tauscher, Verhandlungen des Botanischen Vereins von Berlin und Brandenburg, 144: 177-192. 2011; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far East, 1-271. 2014; Barinova et al., Turk J Bot., 39: 535-546. 2015; Bidyarani et al., J. Basic Microbiol., 55(4), 407-419. 2015; Patova et al., Cyanoprokaryotes and algae, 133-166. 2015; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Barinova & Kukhaleishvili, Elixir Bio Sciences, 104: 45934-45947. 2017; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Lenartowicz et al., J. Clust. Sci., 28(5): 3035-3055. 2017; Barinova & Niyatbekov, Biodivers. Int. J., 2(3): 236-263. 2018; Davydov, Botanica, 24(2): 185-201. 2018.

Description: Thallus floccose, dark green; trichomes straight or slightly flexuous, constricted at the cross walls, cells 3.7-5.6 μm wide, 3.8 μm long, cells barrel-shaped, isodiametric or shorter or longer than wide, apices hardly attenuated or conical; heterocytes spherical to cylindrical, intercalary, solitary, 4.4-5.1 μm wide, 5.5-7.6 μm long; akinete cylindrical, single or binary, 4.6-6.7 μm wide, 11.6-19.3 μm long.

References: McGregor (2018); Komarek (2013).

Distribution: No distributional record was found along with the mangrove environment.

General Environment: Freshwater species.

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Appeared as dark greenish coloured planktic and epiphytic on the pneumatophores of *Avicennia officinalis* L.

Specimen Examined: INDIA: Kerala; Alappuzha district, Ezhupunna, 9^0 49' 24.43" N, 76^0 18' 39.54" E, 27.08.2017, MES 13701; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 06.11.2019, MES 21568. **(Plate 27, Fig. A-B)**.

4. *Anabaena sedovii* Kossinskaja 1933

Kossinskaja, Act. Inst. Bot. Ac. Sci. URSS ser. II, 1. 1933; Kukk, Florist. Märkmed, 1: 115-117. 1961; Aysel, J. Black Sea/Mediterranean Environment, 11: 1-124. 2005; Patova, Lower Plant Taxonomy News, 39: 1-12. 2005; Bondarenko & Schure, Int J Algae, 9(2): 187-204. 2007; Patova & Demina, Algae of other divisions, 69-89. 2007; Gerasimiuk, Int J Algae, 10(1): 1-13. 2008; Sterligova & Patova, Botanical Journal, 93(7): 1011-1029. 2008; Kozhevnikov & Kozhevnikova, Fottea, 9(1): 49-51. 2009; Kozhevnikov & Kozhevnikova, Inland Water Biology, 4(2), 143-152. 2011; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far East, 1-271. 2014; Barinova & Kukhaleishvili, Elixir Bio Sciences, 104: 45934-45947. 2017; Davydov, Botanica, 24(2): 185-201. 2018.

Description: Filaments solitary, blue green, constricted at the cross walls. Cells shortly barrel shaped to spherical, blue green, 3.2-4.6 μm wide, 4-6.1 μm long, end cell rounded. Heterocytes solitary, intercalary, spherical, 3.6-4.9 μm in diameter.

References: Komarek (2013).

Distribution: No distributional record was found along with the mangrove environment.

General Environment: Freshwater species.

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Appeared as green coloured epipsammic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 16.10.2018, MES 21447. **(Plate 27, Fig. C)**.

5. ***Anabaena torulosa*** (Carmichael) Lagerheim ex Bornet et Flahault 1886

Bornet & Flahault, Annales des Sciences Naturelles, 7: 177-262. 1886; Adams, Proc. R. Ir. Acad., 27B(2): 11-60. 1908; Cotton, Proc. R. Ir. Acad., 31B(15): 1-178. 1912; Lyle, Journal of Botany, British and Foreign, 58: 1-53. 1920; Miranda, Trabajos Museo Nacional Ciencias Naturales. Serie Botánica, 25: 1-106. 1931; Reinhold, Annales de la Société Géologique de Belgique, 61(1): 39-47. 1937; Skuja, Nova Acta Regiae Societatis Scientiarum Upsaliensis, Series 4 14(5): 1-188. 1949; Feldmann, Travaux Station Biologique de Roscoff, 6: 1-152. 1954; Chapman, J. Linn. Soc., Bot., 55(360): 333-501. 1956; Dixon, British Phycological Bulletin, 2: 71-80. 1961; Papenfuss, Iran. J. Bot., 17: 1-118. 1968; Cullinane, Irish Naturalists' Journal, 17: 6-8. 1971; Pankow, Algenflora der Ostsee II. Plankton einschliesslich benthischer Kieselalgen, 1-493. 1976; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Guiry, A consensus and bibliography of Irish Seaweeds, 1-287. 1978; Day et al., Flora of Australia, 4:1-276. 1995; Poulin et al., The Canadian Field-Naturalist, 109: 27-110. 1995; Cvijan & Blazencic, Flora algi Srbije, 1-290. 1996; Payri & N'Yeurt, Aust. Syst. Bot., 10: 867-910. 1997; Payri et al., Algues de Polynésie française, 320. 2000; Ling & Tyler, Bibliotheca Phycologica, 105: 1-643. 2000; Brattegard & Holthe, Distribution of marine, benthic macro-organisms in Norway, 1-394. 2001; Calvo & Barbara, Nova Acta Científica Compostelana, 12: 5-34. 2002; Haroun et al., Bot. Mar., 45: 139-169. 2002; Haroun et al., Lista de especies marinas de Canarias (algas, hongos, plantas y animals, 3-4. 2003; Hallfors, Baltic Sea Environment Proceedings, 95: 1-208. 2004; Aysel, J. Black Sea/Mediterranean Environment, 11: 1-124. 2005; Barbara et al., Anales del Jardín Botánico de Madrid, 62: 69-100. 2005; Miranda, Boletín de Ciencias del Real Instituto de Estudios Asturianos 49: 77-89. 2005; Taskin et al., The check-list of the marine algae of Turkey, 1-87. 2008; Hamed, Aust. J. Basic & Appl. Sci., 2(1), 1-21. 2008; Bostock & Holland, Census of the Queensland Flora, 1-320. 2010; Choudhary

& Bimal, Nord. J. Bot., 28(1): 100-103. 2010; Rodriguez & Moliner, Bol. Cien. Nat. RIDEA, 51: 135-212. 2010; Alfinito, Biodiversity Journal, 2(3): 121-144. 2011; Moro et al., Listado preliminar de especies marinas de Canarias, 174. 2011; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Pham et al., A checklist of the algae of Singapore, 1-100. 2011; Widey & Merican, New Zealand inventory of biodiversity, 3: 50-69. 2012; Scholz & Liebezeit, Eur. J. Phycol., 47(2): 120-137. 2012; Gadea et al., Thalassas, 29(1): 35-58. 2013; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Tsuda & Walsh, Micronesica, 2: 1-91. 2013; Afonso-Carrillo, Lista actualizada de las algas marinas de las islas Canarias, 1-64. 2014; Aslani et al., Iran. J. Bot., 20(2), 257-264. 2014; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far East, 1-271. 2014; Shariatmadari et al., Iran. J. Bot., 20(1): 119-129. 2014; Srivastava et al., Tropical Plant Research, 1(2): 11-16. 2014; Vijayan & Ray, American Journal of plant sciences, 6(18): 2924-2938. 2015; Gallardo et al., Algas Boletín Informativo de la Sociedad Española de Ficología, 51: 7-52. 2016; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Das & Keshri, Phykos, 47(2): 47-65. 2017; Taskin et al., Turkiye suyosunlari listei, 1-804. 2019; Maharana et al., Environ. Ecol., 37, 737-746. 2019; Zubia et al., Hydrobiologia, 843(1): 61-78. 2019.

References: McGregor (2018); Komarek (2013); Desikachary (1959).

Description: Thallus mucilaginous, thin, blue-green. Trichome flexuous, joined and entangled in the blue green mats, to the ends slightly narrowed. Cell barrel-shaped, isodiametric or slightly shorter or longer than wide, blue-green, 4.3-5 μm wide, terminal cell conical. Heterocytes ovoid or ellipsoidal shape, 5.3-6.4 μm wide, 6.3 μm long.

Synonyms: *Anabaena oscillarioides* f. *torulosa* (Lagerheim) Elenkin 1938

Distribution: This species was reported from the mangrove environments of Tamil Nadu (Silambarasan et al., 2012).

General Environment: Freshwater/Marine species.

Comments: New record to the marine cyanobacterial flora of Kerala.

Habitat: Appeared as green coloured epipsammic and epiphytic on the pneumatophores of *Avicennia officinalis* L.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 23.09.2016, MES 21525; Kollam district, Ayiramthengu, 9^0 07'33.93" N 76^0 28' 45.34" E, 19.11.2019, MES 21573. **(Plate 27, Fig. D-F)**.

2. *Desmonostoc* Hrouzek et Ventura, 2013

Colonies in nature usually pale to dark green to brown, with diffluent mucilage within a firmer surface layer. Filaments long, aggregated into rounded macrocolonies, firm mucilage or formation of compact microcolonies can be observed rarely and only in primordial state or stress conditions. Cells barrel-shaped to oval. Heterocytes terminal and intercalary, solitary. Akinetes frequently occurring, variable in shape but mostly elliptical in the population, easily distinguished from vegetative cells, up to 10 µm long, up to 6 µm wide (average size exceeds 4.8 µm long and 4.2 µm wide). Reproduction both by akinetes and by motile hormogonia which are formed by fragmentation of the vegetative filaments.

8 species are currently accepted as taxonomically valid taxa (Guiry & Guiry, 2022). Only one species, a planktic form from the mangrove ecosystems of southern Kerala, is described here.

Key to the species

1. Cells barrel shaped to cylindrical, heterocytes almost spherical or compressed-globose ..... **1. *D. muscorum***

1. *Desmonostoc muscorum* (C.Agardh ex Bornet & Flahault) Hrouzek et Ventura 2013

Hrouzek et al., Fottea 13(2): 201-213. 2013; Smith et al., Taxonomic catalogue of algae from Ghana (Africa) and new additions, 1-101. 2015; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Gaysina et al., Cryptogam Algol., 39(2): 167-198. 2018; Dunck et al., Hoehnea, 45(4): 560-590. 2018; Patova & Novakovskaya, Novosti Sistematiki Nizshikh Rastenii, 52(2): 311–353. 2018; Taskin et al., Türkiye suyosunlari listei, 1-804. 2019; Kopyrina et al., International

Journal of Oceanography and Hydrobiology, 49(2): 99-122. 2020; Novakovskaya et al., Phycologia, 59(4): 320-329. 2020; Davydov & Redkina, Proceedings of the Karelian Scientific Center of the Russian Academy of Sciences, 2021(1): 51-68. 2021; Davydov, Polar Biol., 1-12. 2021; Geethu & Shamina, Bangladesh J. Plant Taxon., 28(1): 83–95, 2021.

Description: Thallus dark blue-green, mucilaginous, with densely entangled filaments, filaments irregularly flexuous. Sheaths around trichomes lacking or indistinct. Cells variable in shape, shortly barrel-shaped to cylindrical, isodiametric or shorter or little longer than wide, 3.2-5.6 μm wide, 4.2-6.2 μm long. Heterocytes almost spherical or compressed-globose, 4.5-6.2 μm wide, 4.8-7 μm long.

References: Komarek (2013); Desikachary (1959).

Synonyms: *Nostoc muscorum* C.Agardh ex Bornet & Flahault 1888

Distribution: This species was recorded from the mangrove environment of Tamil Nadu (Ramamurthy & Abhinand, 2016).

General Environment: Terrestrial species.

Comments: New record to the marine cyanobacterial flora of Kerala.

Habitat: Appeared as a green coloured planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Alappuzha district, Ezhupunna, 9^0 49’ 24.43” N, 76^0 18’ 39.54” E, 08.09.2017, MES 21435; Kottayam district, Kumarakom, 9^0 36’59.46” N 76^0 25’ 21.46” E. 11.12.2016, MES 21547 **(Plate 28, Fig. A-D)**.

3. *Nostoc* Vaucher ex Bornet et Flahault 1888

Thallose; thallus micro- or macroscopic gelatinous, amorphous or spherical, later irregularly spherical, filamentous or forming flat gelatinous, usually with distinct periderm on the colonial surface. Filaments within colony irregularly coiled and loosely or densely agglomerated, sheaths around trichomes present, but visible usually only in the periphery of colony or in young colonies, wide, fine mucilaginous, confluent with colonial mucilage, sometimes yellowish-brown. Trichomes isopolar, of the same width along the whole length, apical cells morphologically not different from other cells; cells cylindrical, barrel-shaped up to

almost spherical (forming moniliform trichomes; variability of cell size and shape sometimes distinct in the same species). Heterocytes solitary, develop in trichomes terminally or intercalary, sometimes in apical position of initial colonies spherical to oval. Akinetes arise apoheterocytic, oval, little larger than cells; almost all cells between heterocytes change successively in akinetes towards heterocytes.

Among 228 species (infraspecific) reported up to date, 108 species are currently accepted as taxonomically valid taxa (Guiry & Guiry, 2022). Only nine species of planktic, epiphytic, epipsammic, benthic forms from southern Kerala mangrove ecosystems are described here.

Key to the species

1a. Cells barrel-shaped, 3.5-4.7 µm wide ..... **6. *N. linckia***

1b. Cells cylindrical 2

2a. Heterocytes 4.1-5.2 µm wide ..... **3. *N. carneum***

2b. Heterocytes 6.4-8.3 µm wide ..... **5. *N. ellipsosporum***

3a. Cells shorter or longer than wide 4

3b. Cells longer than wide ..... **2. *N. calcicola***

4a. Cells 3.2-5 µm wide ..... **1. *N. bornetii***

4b. Cells 3.67-5.52 µm wide ..... **4. *N. commune***

5a. Heterocytes spherical or subspherical 6

5b. Heterocytes barrel-shaped or cylindrical ..... **8. *N. spongiaeforme* var. *varians***

6a. Heterocytes 4.2 µm wide, 4.6 µm long ..... **7. *N. sphaericum***

6b. Heterocytes 4.9-6.2 µm wide, 5.8-6.2 µm long ..... **9. *N. undulatum***

1. *Nostoc bornetii* Gain 1911

Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Hirano, Mem. Natl. Inst. Polar Res., 11: 1-25. 1979; Flechtner et al., West. N. Am. Nat., 68(4): 405-436. 2008.

Description: Filaments entangled, blue-green. Sheaths not visible. Trichomes blue-green, flexuous, slightly constricted at cross walls. Cells cylindrical, barrel-shaped, 3.2-4.9 µm wide, isodiametric, shorter or longer than wide, 3.2-7.6 µm long, cell contents finely granulated. Heterocytes solitary, terminal, spherical or ellipsoidal, 3.6- 5.3 µm wide, 3.2-7.4 µm long.

References: Komarek (2013).

Distribution: No distributional record was found along with the mangrove environment.

General Environment: Terrestrial species.

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as a dark green coloured benthic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Thiruvananthapuram district, Kureekkadavu, 8^0 46'11.14" N 76^0 42' 36.69" E, 21.06.2016, MES 21506. **(Plate 28, Fig. E-F)**.

2. *Nostoc calcicola* Brebisson ex Bornet et Flahault 1886

Bornet & Flahault, Annales des Sciences Naturelles, Botanique, 7: 177-262. 1886; Reinhold, Annales de la Societe Geologique de Belgique, 61(1): 39-47. 1937; Alvarez-Cobelas & Gallardo, Acta Bot. Malac., 13: 53-76. 1988; Day et al., Flora of Australia, 4: 1-276. 1995; Dodds et al., J. Phycol., 31(1): 2-18. 1995; Kumar et al., J. Plant Physiol., 148(1-2): 86-91. 1996; Aysel, J.Black Sea/Mediterranean Environment, 11: 1-124. 2005; Hu & Wei, The freshwater algae of China, 1-1023. 2006; Matula et al., Pol. Polar Res., 28(4): 283-315. 2007; Ramachandran et al., Silicon, 1(4): 215-223. 2009; Rai et al., Our Nature, 8: 336-354. 2010; Smith, Int J Algae, 12(3): 230-256. 2010; Barinova et al., Turk J Bot., 35: 729-774. 2011; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Gupta, Algae of India, 1-160. 2012; Tsuda & Walsh, Micronesica, 2: 1-91. 2013; Gadea et al., Thalassas, 29(1): 35-58. 2013; Keshari et al., Eur. J. Phycol., 50(4): 395-399. 2015; Alamos, Acta Bot. Malac., 41: 5-17. 2016; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Jaiswal, Algae of north-west Khandesh, 1-448. 2017; Gaysina et al., Cryptogam Algol., 39(2): 167-198. 2018; Patova et al., Novosti Sistematiki Nizshikh Rastenii, 52(2): 311–353. 2018; Taskin et al., Turkiye

suyosunlari listei, 1-804. 2019; Kant et al., J. Indian Bot. Soc., 100(1/2): 16-29. 2020; Davydov, Polar Biol., 1-12. 2021.

Description: Thallus mucilaginous, slightly diffluent, olive. Filaments loosely entangled. Filaments freely entangled, sheath indistinct, yellowish. Trichomes barrel-shaped, subspherical, 2.5-3.2 μm wide, somewhat longer than wide, 4.6 μm long. Heterocytes spherical or subspherical, 4.3 μm wide.

References: Komarek (2013.); Desikachary (1959).

Distribution: No distributional record was found along with the mangrove environment.

General Environment: Terrestrial species.

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as a dark green coloured planktic and epiphytic on the pneumatophores of *Avicennia officinalis* L.

Specimen Examined: INDIA: Kerala; Thiruvananthapuram district, Kureekkadavu, 8^0 46'11.14" N 76^0 42' 36.69" E, 21.06.2016, MES 21507; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 24.07.2018, MES 21504; Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 13.10.2017, MES 21533. **(Plate 29, Fig. A-B)**.

3. *Nostoc carneum* (Lyngbye) Agardh ex Bornet et Flahault 1886

Bornet & Flahault, Annales des Sciences Naturelles, Botanique, 7: 177-262. 1886; Adams, Proceedings of the Royal Irish Academy 27B(2): 11-60. 1908; Chapman et al., Transactions of the Royal Society of New Zealand, 84: 695-747. 1957; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Tell, Bibliotheca Phycologica, 70:1-283. 1985; Alvarez-Cobelas & Gallardo, Acta Bot. Malac., 13: 53-76. 1988; Day et al., Flora of Australia, 4: 1-276. 1995; Aysel, J. Black Sea/Mediterranean Environment, 11: 1-124. 2005; Hu & Wei, The freshwater algae of China, 1-1023. 2006; Pohl, & Schimmack, J. Appl. Phycol., 18(2), 135-143. 2006; Kostkeviciene, & Spakaite, Bot. Lith., 15(1): 31-40. 2009; Smith, Int J Algae, 12(3): 230-256. 2010; Bhattacharyya et al., Chemosphere, 84(1), 131-135. 2011; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Widey & Merican, New Zealand inventory of biodiversity, 3:50-69. 2012; Gadea et al.,

Thalassas, 29(1): 35-58. 2013; Loza et al., J. Phycol., 49(2): 282-297. 2013; Maulood et al., Checklist of algal flora in Iraq,1-94. 2013; Loza et al., Journal of Phycology, 49(2): 282-297. 2013; Stoyneva-Gartner et al., Annuaire de l'Université de Sofia Botanique, 100: 1-55. 2015; Smith et al., Taxonomic catalogue of algae from Ghana (Africa) and new additions, 1-101. 2015; Silvia et al., International Journal of Advanced Research, 3(10): 1752-1761. 2015; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Jaiswal, Algae of north-west Khandesh, 1-448. 2017; Saha et al., J Microbiol Exp, 6(1): 23-26. 2018; Gupta, Anusandhaan-Vigyaan Shodh Patrika, 6(1): 40-46. 2018; Farghl et al., Fresenius Environ. Bull., 28(7): 5481-5490. 2019; Sarmah & Rout, Energy, Ecology and Environment, 4(5), 240-252. 2019; Taskin et al., Turkiye suyosunlari listei, 1-804. 2019.

Description: Thallus floating free, gelatinous, reddish-violet, flesh-coloured; filaments flexuous, usually freely entangled; sheaths unclear, colourless or yellowish; cells long, usually barrel-shaped up to cylindrical, 4-6.7 μm long, 3.1-3.7 μm wide. Heterocysts oblong, 5.1-7.6 μm long, 4.1-5.2 μm wide.

References: Komarek (2013); Desikachary (1959).

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

Distribution: This species was reported from the mangrove environment of Indian Sundarbans (Barman et al., 2015).

General Environment: Freshwater species.

Comments: New record to the cyanobacterial flora of Kerala.

Habitat: Appeared as blackish green coloured planktic, epipsammic and epiphytic on the pneumatophores of *Avicennia officinalis* L.

Specimen Examined: INDIA: Kerala; Alappuzha district, Pathiramanal, 9^0 37' 09.78" N, 76^0 23' 06.43" E, 26.11.2019, MES 21467, 13.12.2017, MES 13715; Kollam district, Ayiramthengu, 9^0 07'33.93" N 76^0 28' 45.34" E, 27.08.2018, MES 21570. **(Plate 29, Fig. C-D)**.

4. ***Nostoc commune*** Vaucher ex Bornet et Flahault 1888

Bornet & Flahault, Annales des Sciences Naturelles, Botanique, 7: 177-262. 1886; Adams, Proc. R. Ir. Acad., 27B(2): 11-60. 1908; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Croasdale, National Museum of Canada Publications in Botany 3: 1-131. 1973; Sagarra & Martinengo, Collectanea Botanica (Barcelona), 13(2): 723-765. 1982; Vidal et al., Collectanea Botanica, 13(2): 997-1008. 1982; Sheath & Steinman, Can J Bot., 60: 1964-1997. 1982; Davey & Marchant, Phycologia, 22(4):377-385. 1983; Aboal & Llimona, Anales de Biologia, 2(2): 1-17. 1984; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Alvarez-Cobelas & Gallardo, Acta Bot. Malacit., 13: 53-76. 1988; Saunders, Proceedings of the Washington Academy of Sciences, 3: 391-486. 1901; Poulin et al., The Canadian Field-Naturalist, 109: 27-110. 1995; Skulberg, Terrestrial and limnic algae and cyanobacteria, 383-395. 1996; Calvo et al., Bot. Mar., 42: 343-353. 1999; Jaki et al., J. Nat. Prod., 62(3): 502–503. 1999; Brüll et al., J. Phycol., 36(5): 871-881. 2000; Jaki et al., J. Nat. Prod., 63(9): 1283–1285. 2000; Vinogradova et al., Cyanoprocaryotes and algae of continental Israel, 32-141. 2000; Vitenaite, Bot. Lith., 7(4): 343-364. 2001; Calvo & Barbara, Nova Acta Científica Compostelana, 12: 5-34. 2002; Rindi & Guiry, Cryptogam Algol., 24: 245-267. 2003; Furnari et al., Biol. Mar. Mediterr., 10(1): 1-482. 2003; Tamaru et al., Appl. Environ. Microbiol., 71(11): 7327-7333. 2005; Barbara et al., An. Jard. Bot. Madr., 62: 69-100. 2005; Aysel, J.Black Sea/Mediterranean Environment, 11: 1-124. 2005; O'Brien et al., Eur. J. Phycol., 40: 363-378. 2006; Matula et al., Pol. Polar Res., 28(4): 283-315. 2007; Patova & Demina, Algae of other divisions, 69-89. 2007; Stenina & Patova, Algae, 5-21. 2007; Rehakova et al., Phycologia, 46: 481-502. 2007; Johansen et al., Southeastern Naturalist, 1: 99-134. 2007; Novis et al., Glob Chang Biol., 13(6): 1224-1237. 2007; Smith, Int J Algae, 12(3): 230-256. 2010; Barinova et al., Turk J Bot, 35: 729-774. 2011; Czerwik-Marcinkowska & Mrozinska, Pol. Bot. J., 56(2): 203-243. 2011; Tauscher, Verh. Bot. Ver. Berlin Brandenburg, 144: 177-192. 2011; Arima et al., FEMS Microbiol Ecol., 79(1): 34-45. 2012; Davydov, Algol Stud/Archiv für Hydrobiologie, 142: 29-44. 2013; Gadea et al., Thalassas, 29(1): 35-58. 2013; Barinova & Kukhaleishvili, The Journal of Biodiversity, 113: 305-338. 2014; Davydov, Folia Cryptog. Estonica, 51: 13-23. 2014; Moller et al., Freshwater

Biology, 59(10): 2183-2193. 2014; Patova et al., Cyanoprokaryotes and algae, 133-166. 2015; Smith et al., Taxonomic catalogue of algae from Ghana (Africa) and new additions, 1-101. 2015; Gallardo et al., Algas Boletín Informativo de la Sociedad Espanola de Ficología, 51: 7-52. 2016; Gkelis et al., Biodiversity Data Journal, 4(e10084): 1-103. 2016; Barinova & Kukhaleishvili, Elixir Bio Sciences, 104: 45934-45947. 2017; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Davydov, Botanica, 24(2): 185-201. 2018; Dunck et al., Hoehnea 45(4): 560-590. 2018; Gaysina et al., Cryptogam Algol., 39(2): 167-198. 2018; Komulaynen, Nature Conservation Research, 3(3): 46-60. 2018; Patova & Novakovskaya, Novosti Sistematiki Nizshikh Rastenii, 52(2): 311–353. 2018; Taskin et al., Turkiye suyosunlari listei, 1-804. 2019; Dvorak, Eur J Phycol., 55(1): 30-38. 2019; Torres-Arino et al., Cybella, 50(1): 1-97. 2019; Roncero-Ramos et al., J. Appl. Phycol., 31(4): 2217-2230. 2019; Torres-Maza et al., Sci. Agropecu., 11(4): 583-589. 2020; Pellizzari et al., Sci. Mar., 84(3): 1-16. 2020; Davydov, Polar Biol., 1-12. 2021.

Description: Thallus macroscopic, gelatinous, blue-green. filaments densely entangled. Trichomes blue-green, constricted at the cross walls, cross walls not granulated. Cells shortly barrel-shaped or almost spherical, a little shorter or longer than wide, 3.6-5.5 µm wide, 3.2-5.7 µm long. Heterocytes almost spherical or elongated, both terminal and intercalary, 5.3-6.5 µm wide, 5.8-7.3 µm long.

References: Komarek (2013); Desikachary (1959).

Distribution: This species was recorded from the mangrove environment of Indian Sundarbans (Barman et al., 2015).

General Environment: Freshwater/ terrestrial species.

Comments: New record to the cyanobacterial flora of Kerala.

Habitat: Appeared as a dark green coloured epiphytic on the pneumatophores of *Avicennia officinalis* L.

Specimen Examined: INDIA: Kerala; Ernakulam district, Vypin, 9^0 58’ 26.46” N, 76^0 14’ 38.14” E, 17.12.2018, MES 13766; Alappuzha district, Pathiramanal, 11.10.2017, MES 21496. **(Plate 29, Fig. E-F)**.

5. *Nostoc ellipsosporum* (Demazieres) Rabenhort ex Bornet et Flahault 1886

Bornet & Flahault, Annales des Sciences Naturelles, Botanique, 7: 177-262. 1886; Cameron, Trans Am Microsc Soc., 81(4): 379-384. 1962; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Alvarez-Cobelas & Gallardo, Acta Bot Malac., 13: 53-76. 1988; Chapman et al., Trans. Roy. Soc. New Zealand, 84: 695-747. 1957; Leganés et al., Mol. Microbiol., 12(4): 679-684. 1994; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Pari & N'Yeurt, Aust. Syst. Bot., 10: 867-910. 1997; Aysel, J. Black Sea/Mediterranean Environment 11: 1-124. 2005; Nowruzi & Ahmadimoghadam, Journ. Bot, 11(2), 170-173. 2006; Papaefthimiou et al., Int. J. Syst.Evol. Microbiol., 58(3): 553-564. 2008; Rai et al., Our Nature, 8: 336-354. 2010; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Widey & Merican, New Zealand inventory of biodiversity, 3: 50-69. 2012; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Gadea et al., Thalassas, 29(1): 35-58. 2013; Gaysina et al., Cryptogam Algol., 39(2): 167-198. 2018; Taskin et al., Turkiye suyosunlari listei, 1-804. 2019; Kant et al., J. Indian Bot. Soc., 100(1/2): 16-29. 2020.

Description: Thallus gelatinous, expanded, firm, blue green to olive green. Filaments flexuous, loosely entangled. Cells cylindrical, constricted at the cross walls, 3.4-4.2 μm wide, 6.2-9.3 μm long. Heterocytes almost spherical or elongated, up to cylindrical, basal, intercalary, 6.4-8.3 μm wide, 6.8-7.3 μm long.

References: Komarek (2013); Desikachary (1959).

Distribution: This species was reported from the mangrove environment of Indian Sundarbans (Barman et al., 2015).

General Environment: Terrestrial species.

Comments: New record to the cyanobacterial flora of Kerala.

Habitat: Appeared as a dark green coloured planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Vypin, 9^0 58’ 26.46” N, 76^0 14’ 38.14” E, 13.03.2017, MES 21445. **(Plate 30, Fig. A-B)**.

6. *Nostoc linckia* (Roth) Bornet et Flahault 1886

Bornet & Flahault, Annales des Sciences Naturelles, Botanique, 7: 177-262. 1886; Adams, Proc. R. Ir. Acad., 27B(2): 11-60. 1908; Lyle, Journal of Botany, British and Foreign, 58: 1-53. 1920; Alvarez-Cobelas & Gallardo, Acta Bot Malac., 13: 53-76. 1988; Fenchel et al., Ophelia, 43: 45-100. 1995; Cvijan & Blazencic, Flora algi Srbije, 1-290. 1996; Skulberg, Terrestrial and limnic algae and cyanobacteria, 383-395. 1996; Stenina & Patova, Algae, 5-21. 2007; Patova & Demina, Biodiversity of the Polar Ural ecosystems, 69-89. 2007; Patova & Demina, Inland Water Biology, 1(1): 54-63. 2008; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Barinova et al., Turk J Bot., 35: 729-774. 2011; Gadea et al., Thalassas, 29(1): 35-58. 2013; Barinova & Kukhaleishvili, The Journal of Biodiversity, 113: 305-338. 2014; Patova et al., Cyanoprokaryotes and algae, 133-166. 2015; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Barinova & Kukhaleishvili, Elixir Bio Sciences, 104: 45934-45947. 2017; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Gainutdinov et al., Cave Karst Sci., 44(3): 119-126. 2017; Davydov, Botanica, 24(2): 185-201. 2018; Patova & Novakovskaya, Novosti Sistematiki Nizshikh Rastenii, 52(2): 311–353. 2018; Mikhailyuk et al., Eur. J. Phycol., 54(3): 263-290. 2019; Davydov, Polar Biol., 1-12. 2021.

References: Komarek (2013); Desikachary (1959).

Description: Thallus blue-green. Trichomes loosely entangled. Sheath diffluent. Cells subspherical, barrel-shaped, 3.5-4.7 μm wide, shorter or longer than wide, 3.3-6.8 μm long, blue-green to olive green. Heterocytes intercalary or basal, almost spherical or subspherical, 6.5 μm wide, 7.5 μm long.

Distribution: This species was reported as epiphytic form from the Indian Sundarbans (Sen & Naskar, 2003); from the mangrove environment of Tamil Nadu (Priya et al., 2019, Bhuvaneshwari & Muruganandam, 2016)

General Environment: Freshwater species.

Comments: New record to the cyanobacterial flora of Kerala.

Habitat: Appeared as a dark green coloured epiphytic on the pneumatophores of *Avicennia officinalis* L. and planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Kollam district, Sakthikulangara, 8^0 56'23.44" N 76^0 33' 09.88" E, 07.11.2019, MES 21561; Kottayam district, Kumarakom, 12.01.2018, MES 21463. **(Plate 30, Fig. C-D)**.

7. *Nostoc sphaericum* Vaucher ex Bornet et Flahault 1886

Bornet & Flahault, Annales des Sciences Naturelles, Botanique, 7: 177-262. 1886; Adams, Proc. R. Ir. Acad., 27B(2): 11-60. 1908; Reinhold, Annales de la Société Géologique de Belgique, 61(1): 39-47. 1937; Chapman, J. Linn. Soc., Bot., 55(360): 333-501. 1956; Chapman et al., Trans. Roy. Soc. New Zealand, 84: 695-747. 1957; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Brown & Bisalputra, Phycologia, 8(2): 119-126. 1969; Duckett et al. New Phytol., 79(2): 349-362. 1977; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Hirano, Memoirs of the National Institute of Polar Research, 11: 1-25. 1979; Sheath & Steinman, Can J Bot., 60: 1964-1997. 1982; Tell, Bibliotheca Phycologica, 70:1-283. 1985; Aboal, An. Jard. Bot. Madr., 45(1): 3-46. 1988; Alvarez-Cobelas, & Gallardo, Acta Bot. Malac., 13: 53-76. 1988; Day et al., Flora of Australia, 4: 1-276. 1995; Poulin et al., Can. Field-Nat., 109: 27-110. 1995; Aboal, Arch. Hydrobiol. Algol Stud, 82: 117-131. 1996; Asencio, & Aboal,Algol Stud., 83: 55-72. 1996; Cvijan & Blazencic, Flora algi Srbije, 1-290. 1996; Calvo et al., Bot Mar., 42: 343-353. 1999; Calvo, & Barbara, Nova Acta Científica Compostelana, 12: 5-34. 2002; Phillips, Algae, 228-244. 2002; Uher et al., Cryptogam Algol., 26: 275-308. 2005; Aysel, J. Black Sea/Mediterranean Environment, 11: 1-124. 2005; Johansen et al., Southeast. Nat., 1: 99-134. 2007; Flechtner et al., West. N. Am. Nat., 68(4): 405-436. 2008; Becerra-Absalon, & Tavera, Nova Hedwigia, 88(1-2): 117-128. 2009; Bostock, & Holland, Census of the Queensland Flora,1-320. 2010; Smith, Int J Algae 12(3): 230-256. 2010; Rai et al., Our Nature, 8: 336-354. 2010; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Widey & Merican, New Zealand inventory of biodiversity, 3: 50-69. 2012; Gadea et al., Thalassas, 29(1): 35-58. 2013; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Ramos et al., Acta Bot Brasilica, 28(1): 8-16. 2014; Gallardo et al., Algas Boletín Informativo de la Sociedad Espanola de Ficología, 51: 7-52. 2016; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Stutz & Mattern, Beitrage zu den Algen Baden-Württembergs, 1-504. 2018; Taskin et al.,

Turkiye suyosunlari listei, 1-804. 2019; Torres-Maza et al., Sci. Agropecu., 11(4): 583-589. 2020;

Description: Thallus free, olive-green to yellow. Filaments flexuous, densely entangled trichomes. Sheath absent around the trichomes. Trichomes 3.7-4.8 μm wide, cells barrel-shaped or spherical, isodiametric or slightly shorter or longer than wide. Heterocytes subspherical, 4.2 μm wide, 4.6 μm long.

References: Komarek (2013); Desikachary (1959).

Synonyms: *Nostocella sphaerica* (Vaucher) Gaillon; *Nostoc sphaericum* var. *majus* C.-C.Jao 1939

Distribution: No distributional record was found along with the mangrove environment.

General Environment: Freshwater/Terrestrial species.

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as an olive green or green coloured benthic and planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Kollam district, Sakthikulangara, 8^0 56'23.44" N 76^0 33' 09.88" E, 29.09.2019, MES 21479; Kottayam district, Mekkara, 9^0 48'54.31" N 76^0 21' 57.54" E, 09.11.2018, MES 21448. **(Plate 30, Fig. E-F)**.

8. *Nostoc spongiaeforme* var. *varians* C.B.Rao 1937

Rao, Proc.Indian Acad. Sci. B, 6: 359. 1937; Ram & Shamina, 1(12): 1-3. Int. J. chem. biol. sci., 2015; Bhakta et al., Nelumbo, 58: 157-173. 2016.

Description: Thallus gelatinous, leathery, irregularly expanded, violet coloured. Filaments flexuous, usually freely entangled. Sheaths unclear or diffluent. Cells barrel-shaped to cylindrical with rounded or flat ends, 3.6 μm wide, 3.2 μm long. Heterocytes barrel-shaped or cylindrical with rounded ends, slightly elongated, 7.1 μm wide, 8.3 μm long.

References: Komarek (2013); Desikachary (1959)

Distribution: No distributional record was found along with the mangrove environment.

General Environment: Freshwater/Terrestrial species.

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Appeared as dark violet or black coloured epiphytic on the aerial roots of *Rhizophora apiculata* Blume

Specimen Examined: INDIA: Kerala; Kollam district, Sakthikulangara, 8^0 56'23.44" N 76^0 33' 09.88" E, 22.09.2016, MES 13762. **(Plate 31, Fig. A-D)**.

9. *Nostoc undulatum* Archibald 1967

Archibald, Nova Hedwigia, 13(3-4): 388-398. 1967.

Description: Thallus blue-green, mucilaginous. Trichome coiled, constricted at the cross walls, cross walls not granulated, 3.3-5.4 μm wide. Cells subspherical to barrel-shaped, isodiametric, shorter or longer than wide, 3.2-6.7 μm long, cell contents granulated. Heterocytes terminal, intercalary, sometimes 2 heterocytes in a row located intercalary, spherical, 4.9-6.2 μm wide, 5.8-6.2 μm long.

References: Komarek (2013).

Distribution: No distributional record was found along with the mangrove environment.

General Environment: Freshwater species.

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as dark green coloured cyanobacterial mat growing epiphytically on the aerial roots of *Rhizophora apiculata* Blume.

Specimen Examined: INDIA: Kerala; Kollam district, Ayiramthengu, 9^0 07'33.93" N 76^0 28' 45.34" E, 19.11.2019, MES 21575, 28.12.2017, MES 21465. **(Plate 31, Fig. E-F)**.

4. *Trichormus* (Ralfs ex Bornet et Flahault) Komárek et Anagnostidis 1989

Filaments usually without firm sheaths, in mucilaginous mats. Trichomes isopolar, uniseriate, not branched, not or sometimes narrowed towards ends, with

intercalary heteocytes, constricted at cross walls. Cells barrel-shaped, rarely up to cylindrical, mainly blue-green or pale green, apical cells rounded or frequently conical-rounded. Heterocytes solitary and intercalary, spherical, oval to cylindrical. Akinetes usually oval or ellipsoidal. Reproduction by hormogonia and by germination of akinetes.

Among the 44 species (infraspecific) reported up to date, 36 species are currently accepted as taxonomically valid taxa (Guiry & Guiry, 2022). Here, only five species are described as epiphytic, planktic and epipsammic forms from the mangrove ecosystems of southern Kerala.

Key to the species

1a. Heterocytes more than 9 µm long 2

1b. Heterocytes oval, 7.1 µm long ..... **1. *T. ellipsosporus***

2a. Heterocytes spherical and elongated ..... **3. *T. Pseudovariabilis***

2b. Heterocytes cylindrical ..... **2. *T. kashiensis***

3a. Cells slightly longer than wide ..... **4. *T. rotundosporus***

3b. Cells slightly shorter or longer than wide ..... **5. *T. variabilis***

1. *Trichormus ellipsosporus* (Fritsch) Komarek et Anagnostidis 1989

Komarek & Anagnostidis, Algol Stud., 56: 247-345. 1989; Johansen et al., Southeast. Nat., 1: 99-134. 2007.

Description: Thallus mucilaginous, thin, blue-green; trichome flexuous, solitary, cylindrical, distinctly constricted at the cross walls; cells barrel-shaped, isodiametric, slightly shorter or longer than wide, 4-5 µm long, 4.2-4.8 µm wide, apical cell conical, up to 5.0 µm long. Heterocytes solitary, intercalary, spherical to ovate, 7.1 µm long, 6.2 µm wide. Akinetes solitary, widely cylindrical, ellipsoidal, sometimes seems slightly concave at the middle of sides, flatly rounded at the ends, 11.6-17.6 µm long, 4.6-9 µm wide.

Synonyms: *Anabaena ellipsospora* (F.E.Fritsch) Obuchova 1959; *Anabaena variabilis var. ellipsospora* F.E.Fritsch 1949

Distribution: This species was reported from the mangrove environment of Tamil Nadu (Silambarasan et al., 2012).

General Environment: Freshwater/terrestrial species

Comments: New record to the mangrove cyanobacterial flora of Kerala.

Habitat: Appeared as a dark green coloured epiphytic on the pneumatophores of *Avicennia officinalis* L.

Specimen Examined: INDIA: Kerala; Alappuzha district, Ezhupunna, 9^0 49' 24.43" N, 76^0 18' 39.54" E, 12.11.2017, MES 13702; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 14.08.2019, MES 21560. **(Plate 32, Fig. A-E)**.

2. *Trichormus kashiensis* (Bharadwaja) Komarek 2012

Komarek, Fottea, 12(1): 141-148. 2012.

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

Synonyms: *Anabaena kashiensis* Bharadwaja 1935; *Anabaena variabilis* var. *kashiensis* (Bharadwaja) F.E.Fritsch 1949.

References: Komarek (2013).

Distribution: No distributional records were found along with the marine environment.

General Environment: Freshwater species

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as dark green coloured epipsammic and planktic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Alappuzha district, Ezhupunna, 9^0 49' 24.43" N, 76^0 18' 39.54" E, 27.12.2016, MES 13704; Kollam district, Ayiramthengu, 9^0 07'33.93" N 76^0 28' 45.34" E,12.07.2018, MES 21437. **(Plate 32, Fig. F)**.

3. *Trichormus pseudovariabilis* (Woronichin) Komarek et Anagnostidis 1989

Komarek & Anagnostidis, Algological Studies, 56: 247-345. 1989; Iarovyi, Chornomors'k bot. z., 9(2): 238-256. 2013; Arabadzhy-Tipenko et al., Int J Algae, 21(4): 299–310. 2019; Makeeva & Osipova, Problems of Botany of Southern Siberia and Mongolia, 95-99. 2020.

Description: Thallus dense, soft, mucilaginous, dark green. Trichomes straight or slightly bent, constricted at the cross walls, attenuated towards ends, without mucilaginous sheaths. Cells quadratic rounded, cylindrical to barrel-shaped, up to twice as long as wide, 5.4-6.2 μm wide, 4.8- 8.2 μm long, terminal cells conical with sharp or rounded apex. Heterocytes solitary, basal or intercalary, spherical or elongated, larger than vegetative cells, 4.3-5.4 μm wide, 8.2-10.6 μm long.

References: Komarek (2013).

Synonyms: *Anabaena pseudovariabilis* Woronichin [Voronichin] 1929

Distribution: No distributional records were found along with the marine environment.

General Environment: Brackish species

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as green or dark green coloured planktic and epiphytic on the aerial roots of *Rhizophora apiculata* Blume.

Specimen Examined: INDIA: Kerala; Kollam district, Sakthikulangara, 8^0 56'23.44" N 76^0 33' 09.88" E, 17.01.2019, MES 21457; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 14.12.2018, MES 21578. **(Plate 33, Fig. A-C)**.

4. *Trichormus rotundosporus* (Hollerbach) Komarek & Anagnostidis 1989

Komarek & Anagnostidis, Algological Studies, 56: 247-345. 1989; Barinova et al., Plant Biosystems, 138(3): 245-259. 2014; Barinova et al., Turk J Bot, 39: 535-

546. 2015; Sudakova et al., Problems of Botanics of South Siberia and Mongolia, 19(1):185-190. 2020.

Description: Thallus blue-green, mucilaginous, with irregularly entangled trichomes without sheaths. Trichomes cylindrical, not attenuated towards ends, constricted at cross walls, sometimes coiled. Cells barrel-shaped, isodiametric or slightly longer than wide, 3.4-4.4 μm wide, 3.9- 6.6 μm long. Apical cell conical-rounded. Heterocytes terminal, spherical or oval or slightly longer than wide, 5.8-6.5 μm wide, 6.2- 8.3 μm long.

References: Komarek (2013).

Synonyms: *Anabaena variabilis* f. *rotundospora* Hollerbach 1935

Distribution: No distributional records were found along with the marine environment.

General Environment: Terrestrial species

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as dark blue-green coloured planktic and epipsammic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 18.01.2018, MES 21543; Kollam district, Sakthikulangara, 8^0 56'23.44" N 76^0 33' 09.88" E, 07.11.2019, MES 21562. **(Plate 33, Fig. D-F)**.

5. ***Trichormus variabilis*** (Kutzing ex Bornet et Flahault) Koamarek et Anagnostidis 1989

Komarek & Anagnostidis, Algological Studies, 56: 247-345. 1989; Silva et al., University of California Publications in Botany, 79: 1-1259. 1996; Vitenaite, Bot. Lith., 7(4): 343-364. 2001; Calvo & Barbara, Nova Acta Científica Compostelana, 12: 5-34. 2002; Haroun, Botanica Marina, 45: 139-169. 2002; Mauch & Schmedtje, Taxaliste der Gewässerorganismen Deutschlands zur Kodierung biologischer Befunde, 1(3): 1-388. 2003; Hallfors, Baltic Sea Environment Proceedings, 95: 1-208. 2004; Aysel, J.Black Sea/Mediterranean Environment, 11: 1-124. 2005; Barbara et al., Anales del Jardín Botánico de Madrid, 62(1): 69-100.

2005; Willame et al., J Phycol., 42: 1312-1332. 2006; Matula et al., Pol. Polar Res., 28(4): 283-315. 2007; Patova & Demina, Biodiversity of the Polar Ural ecosystems, 69-89. 2007; Johansen et al., Southeastern Naturalist, 1: 99-134. 2007; Taskin et al., The check-list of the marine algae of Turkey, 1-87. 2008; Smith, Int J Algae, 12(3): 230-256. 2010; Barinova et al., Turk J Bot, 35: 729-774. 2011; Moro et al., Listado preliminar de especies marinas de Canarias, 174. 2011; Widey & Merican, Phylum Cyanobacteria: blue-green bacteria, blue-green algae, 50-69. 2012; Scholz & Liebezeit, Eur. J. Phycol., 47(2): 120-137. 2012; Gadea et al., Thalassas, 29(1): 35-58. 2013; Afonso-Carrillo, Lista actualizada de las algas marinas de las islas Canarias, 1-64. 2014; Ramos et al., Acta Botanica Brasilica 28(1): 8-16. 2014; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far East, 1-271. 2014; Barinova et al.Turk J Bot, 39: 535-546. 2015; Mazur-Marzec et al., Eur. J. Phycol., 50(3): 343-360. 2015; Phang et al., Raffles Bulletin of Zoology Supplement, 40: 13-59. 2016; Gallardo et al., Algas Boletín Informativo de la Sociedad Española de Ficología, 51: 7-52. 2016; Gkelis et al., Biodiversity Data Journal, 4(e10084): 1-103. 2016; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Gainutdinov et al., Cave and Karst Science Transactions of the British Cave Research Association, 44(3): 119-126. 2017; Barinova & Niyatbekov, Biodivers. Int. J., 2(3): 236-263. 2018; Bellini et al., Mar. Drugs, 16(298): 1-21. 2018; Gaysina et al., Cryptogam Algol., 39(2): 167-198. 2018; Stutz & Mattern, Beitrage zu den Algen Baden-Wurttembergs, 1-504. 2018; Patova & Novakovskaya, Novosti Sistematiki Nizshikh Rastenii, 52(2): 311–353. 2018; Zotov, Algologia, 28(2): 208-232. 2018; Abedi et al., Sci Rep., 9(2511): 1-10. 2019; Abedi et al., Biofuels, Bioprod. Bioref., 13(5): 1-18. 2019; Berezovskaya, Algologia, 29(1): 59-76. 2019; Popkova et al., Ecol. Montenegrina, 28: 8-19. 2019; Medvedeva & Nikulina, Levanidov's Biennial Memorial Meetings, 8: 91-113. 2019; Taskin et al., Türkiye suyosunlari listei, 1-804. 2019; Kopyrina et al., International Journal of Oceanography and Hydrobiology, 49(2): 99-122. 2020; Rosset et al., Phycologia, 59(6): [1-7] 571-577. 2020; Davydov, Pol Biol., 1-12. 2021; Park et al., Cryobiology, 98: 87-95. 2021.

Description: Thallus gelatinous, dark green, with irregularly and usually densely arranged filaments. Filaments without sheaths. Trichomes cylindrical, constricted at

the cross walls, not attenuated or slightly narrowed at the ends. Cells barrel-shaped or subspherical, isodiametric or slightly shorter or longer than wide, 3.5-5.8 µm wide, 2.5 -6.3 µm long, terminal cells conical-rounded. Heterocytes basal or intercalary, solitary, spherical or slightly elongated and oval, 5.8-6.2 µm wide, 7.3-8.3 µm long.

References: Komarek (2013); Desikachary (1959).

Synonyms: *Anabaena variabilis* Kutzing ex Bornet & Flahault 1886

Distribution: This species was reported as planktic from the mangrove environment of Tamil Nadu (Nedumaran et al., 2008), mangrove environment of Indian Sundarbans (Barman et al., 2015), mangrove swamps of Saudi Arabia (Hussain & Khoja, 1993).

General Environment: Freshwater/terrestrial species.

Comments: New record to the cyanobacterial flora of Kerala.

Habitat: Appeared as a dark green coloured epiphytic on the pneumatophores of *Aegiceras corniculatum* (L.) Blanco.

Specimen Examined: INDIA: Kerala; Kollam district, Ayiramthengu, 9^0 07'33.93" N 76^0 28' 45.34" E, 13.08.2018, MES 21422. **(Plate 34, Fig. A-C)**.

4. Rivulariaceae

Heterocytous, uniseriate, filamentous cyanobacteria in which the apical part usually ends in terminal hairs. Thallus flat prostrate, bushy or gelatinous, spherical, usually attached to the stony or plant substrate. Filaments always heteropolar, usually with basal heterocytes and apical, often narrowed or widened ends. Filaments enveloped by gelatinous sheaths, at the ends closed or open, funnel-like widened. Typical is false branching, usually with one or geminate branches. Trichomes always uniseriate, often with wider basal parts and narrowed towards ends, thin hair-like formation, constricted or unconstricted at the cross walls. Cells cylindrical or barrel-shaped. Heterocytes present, obligately basal, sometimes also intercalary. Reproduction by disintegration of thallus, by repeated branching and particularly by hormogonia.

The family consists of 9 genera and 168 species. The family, representing 1 genus and 1 species, is known to occur in the mangrove ecosystem of southern Kerala and is presented.

Key to the genera

1. Typical bush like colonies, sheath thin or thickened, but not distinctly wider than the filaments ..... **1. *Dichothrix***

1. *Dichothrix* Zanardini ex Bornet et Flahault 1886

Filaments heteropolar, differentiated into basal and apical parts, obligatory commonly falsely branched, solitary or in fasciculated colonies or strata; false branching lateral, always with only one branch, growing usually at first parallelly with original trichome, later diverging. Trichomes and branches with basal heterocytes, rarely develop intercalary heterocytes, solitary, heterocytes usually heteropolar. Sheaths always present, usually firm, colourless or yellow-brown and lamellated, at the end joined to the trichome or widened and diverging. Trichomes with cylindrical or barrel-shaped cells, at the cross walls constricted or unconstricted, hair-like narrowed to the apical ends; hairs are composed from a row of long, narrow, hyaline cells.

Among the 40 species (infraspecific) reported up to date, 39 species are currently accepted as taxonomically valid taxa (Guiry & Guiry, 2022). Here, only 1 species is described as epiphytic from the mangrove ecosystems of southern Kerala.

1. *Dichothrix orsiniana* (Kutz) Bornet et Flahault 1886

Bornet & Flahault, Annales des Sciences Naturelles, Botanique, 3: 323-381. 1886; Forti in De Toni, Sylloge Algarum, 5: 641. 1907; Fremy, Myxo d'Afr. Equat. Franc., 266. 1929; Geitler, Kryptogamenflora, 588. 1932; Adams, Proc. R. Ir., 27B (2): 11-60. 1908; Chapman, J. Linn. Soc., Bot., 55(360): 333-501. 1956; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Tell, Bibliotheca Phycologica, 70: 1-283. 1985; Poulin et al., Canadian Field-Natur., 109: 27-110. 1995; Hirano, Memoirs of the National Institute of Polar Research, Special Issue 11: 1-25. 1979; Mehwish & Aliya, Int. J. Phycol. Phycochem. 1(2): 117-124. 2005; Patova & Demina, Biodiversity of the Polar Ural ecosystems, 69-89. 2007; Bhakta et al., J.

Indian bot. Soc., 89(1&2): 169-184. 2010; John et al., The freshwater algal flora of the British Isles, 1-878. 2011; Widey & Merican, New Zealand inventory of biodiversity, 50-69. 2012; Gadea et al., Thalassas, 29(1): 35-58. 2013; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far East, 1-271. 2014; Davydov, Botanica, 24(2): 185-201. 2018; Richter et al., Acta Soc. Bot. Pol., 87(4): 1-21. 2018; Davydov, Polar Biol., 1-12. 2021.

References: Komarek (2013); Desikachary (1959).

Description: Thallus caespitose, fasciculate, greenish-brown coloured. Filaments irregularly flexuous, repeatedly false branched, erect, radiating, branches usually attached to the main filaments. Sheaths relatively thin, firm, adjacent to the trichome, not lamellated. Trichome gradually and continually narrowed from the base to the apex, not or slightly constricted at the cross walls, 6.2- 8.3 μm wide at the base. Cells always shorter than wide, olive-green, 2.2-3.9 μm long. Heterocytes basal, usually solitary, hemispherical-oval, 5.4 μm wide, 4.4 μm long.

Distribution: No distributional records were found along with the marine environment.

General Environment: Freshwater species

Comments: New record to the cyanobacterial flora of India.

Habitat: Appeared as a dark green coloured epiphytic on the pneumatophores of *Avicennia officinalis* and aerial roots of *Bruguiera cylindrica* (L.) Blume.

Specimen Examined: INDIA: Kerala; Kollam district, Sakthikulangara, 8^0 56'23.44" N 76^0 33' 09.88" E, 23.11.2017, MES 21545; Ayiramthengu, 9^0 07'33.93" N 76^0 28' 45.34" E, 16.09.2018, MES 21421. **(Plate 34, Fig. D-F)**.

5. Scytonemataceae

Heterocytous, uniseriate filamentous cyanobacteria with obligate false branching. Thallus usually prostrate, in the form of flat or woolly mats. Filaments isopolar, branching starts usually in trichomes between vegetative cells between two slightly distant heterocytes. Trichomes always monoseriate, isopolar, cylindrical or widened or narrowed at both ends. Sheaths usually thick, firm or gelatinous,

lamellated. Heterocytes initially sometimes basal, intercalary, mostly single. Reproduction by disintegration of thallus or by hormogonia.

The family consists of 8 genera and 183 species. The family represents 1 genus and 7 species and is known to occur in the mangrove ecosystem of southern Kerala and is presented.

Key to the genera

1. False branches common, solitary filaments or thallus usually in the form of clusters ..... **1. *Scytonema***

1. *Scytonema* Agardh ex Bornet et Flahault 1887

Filaments solitary branched filaments or mats on the substrate. Filaments are enveloped always with firm, colourless or coloured sheaths. Filaments free or in fascicles, sometimes densely coiled, creeping on the substrate or with erected branches, commonly falsely branched, with one or (obligatory) two lateral branches. Branching initiates after trichome disintegration by help of necridic cells between two heterocytes, usually not at heterocytes; both branches grow parallelly aside or in crossing position; the filaments make sometimes typical loop-like lateral formations before branching, in which tops of the trichomes later divide. Trichomes solitary in sheaths, only single in filaments, isopolar, cylindrical, not diversified in basal and apical parts, uniseriate, usually with solitary heterocytes, constricted (rarely not constricted) at cross walls; terminal parts of branches cylindrical or slightly widened, with rounded apical cell; middle parts of trichomes sometimes with elongated, cylindrical cells. Cells distinctly shorter than wide, or isodiametric or slightly shorter or longer than wide, pale or olive-green, usually with solitary, irregularly disposed granules or with granular content, rarely yellowish or pinkish coloured; apical cells sometimes with large vacuoles. Heterocytes intercalary, solitary, rarely in pairs, cylindrical or barrel-shaped.

Among 208 species (infraspecific) reported up to date, 126 species are currently accepted as taxonomically valid taxa (Guiry & Guiry, 2022). Here, only 7 species are described as epiphytic from the mangrove ecosystems of southern Kerala.

Key to the species

1a. Filaments wider than 20 µm 2

1b. Filaments up to 12 µm ..... **1. *S. bohneri***

2a. Filaments 14.2-24.5 µm wide ..... **2. *S. coactile***

2b. Filaments 15.2-20.5 µm wide ..... **4. *S. millei***

3a. Trichomes up to 7 µm wide ..... **7. *S. varium***

3b. Trichomes more than 10 µm wide 4

4a. Heterocytes cylindrical or subquadrate .....**3. *S. javanicum***

4b. Heterocytes quadrate to ovate ..... **6. *S. tolypothricoides***

5a. Trichomes of two branches having varying cell sizes and shapes .....**5. *Scytonema* sp.**

1. *Scytonema bohneri* Schmidle 1901

Schmidle, Botanische Jahrbucher fur Systematik Pflanzengeschichte und Pflanzengeographie, 30: 58-68. 1901; Forti in De Toni, Sylloge Algarum, 5: 501. 1907; Fremy, Myxo. d'Afr. equat. franc., 302. 1929; Skuja, Nova Acta Regiae Societatis Scientiarum Upsaliensis, Series 4, 14(5): 1-188. 1949; Guarrera et al., Darwiniana, 33(1-4): 97-105. 1995; Aysel, J. Black Sea/Medit. Environ., 11: 1-124. 2005; Adhikary & Kovacik, J. Indian bot. Soc., 89(1&2): 19-23. 2010; Ram & Shamina, Int. J. Recent Sci. Res., 5(11): 2014-2016. 2014; Oinam et al., J. Appl. Biol. Biotechnol., 3(6):1-8. 2015; Pattnaik & Samad, Int J Curr Microbiol App Sci., 7(6): 556-571. 2018; Chaudhari, Int. J. Life Sci., A13: 87-90. 2019; Murialdo et al., Cienc Suelo, 37(2): 383-387, 2019; Basumatary et al., Journal of Global Biosciences, 9(12): 8178-8187. 2020.

Description: Thallus filamentous, blackish green. Filaments creeping, 9.8-11.4 µm wide, falsely branched with solitary branches. The erect filaments 8.3-10.4 µm wide, short, 281.52 µm long and not branched, narrower at the apex, 7.3 µm, rounded at the apex. Sheaths colourless, 1.2-1.7 µm thick, homogenous, sometimes divergent. Trichomes blue-green, 5.3-8 µm wide, cells rectangular, longer or shorter than wide.

Heterocytes ellipsoidal to rectangular, longer than wide, 6.2-8 µm wide, 9.2-14.5 µm long.

References: Komarek (2013); Desikachary (1959).

Distribution: No distributional records were found along with the marine environment.

General Environment: Freshwater/Terrestrial species

Comments: New record to the cyanobacterial flora of Kerala.

Habitat: Appeared as a dark green coloured epiphytic on the pneumatophores of *Sonneratia caseolaris* (L.) Engl.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 18.11.2018, MES 13731. **(Plate 35, Fig. A-D)**.

2. *Scytonema coactile* Montagne ex Bornet et Flahault 1886

Montagne in Kutzing Species Algarum, 305, 1849; Bornet & Flahault, Annales des Sciences Naturelles, Botanique, 5: 51-129. 1886; Forti in De Toni, Sylloge Algarum, 5: 501. 1907; Fremy, Myxo. d'Afr. Equat. Franc. 300. 1928; Geitler, Kryptogamenflora, 753. 1932; Rao, Ibid, 6(6): 355. 1937; Rao, Ibid, 8: 87. 1938; Parukutty, Ibid B, 11(3): 117-124. 1940; Fremy, Blumea, 21-40. 1942; Skuja, Nova Acta Regiae Societatis Scientiarum Upsaliensis, Series 4, 14(5): 1-188. 1949; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Campose & Senna, Acta Bot. Bras. 2(1-2): 7-30. 1988; Santra, Biology of Rice-fields Blue-green Algae, 125. 1993; Poulin et al., The Canadian Field-Naturalist 109: 27-110. 1995; Pari & N'Yeurt, Aust. Syst. Bot., 10: 867-910. 1997; Sherwood, Bishop Museum Occasional Papers, 80: 1-26. 2004; Hu & Wei, The freshwater algae of China, 1-1023. 2006; Gonzalez,Catalogo de las algas y cianoprocariotas dulciacuicolas de Cuba, 1-147. 2009; Smith, Int J Algae, 12(3): 230-256. 2010; Werner, Catalogo de plantas e fungos do Brasil. 1: 356-366. 2010; Widey & Merican, Phylum Cyanobacteria: blue-green bacteria, blue-green algae, 3: 50-69. 2012; Maulood et al., Checklist of algal flora in Iraq, 1-94. 2013; Sato, Humans and Nature, 24: 63−83 2013; Keshri & Adhikary, Int. Biodeterior. Biodegrad., 90: 45-51. 2014; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far

East, 1-271. 2014; Barinova & Niyatbekov, Biodivers. Int. J., 2(3): 236-263. 2018; McGregor, Phytotaxa, 359(1): 1-166. 2018; Sahin & Akar, Turk. J. Bot, 43: 135-142. 2019; Singh & Singh, International Journal of Scientific Research and Reviews, 8(1): 1248-1274. 2019; Skorobogatova et al., Diversity, 11(207): 1-19. 2019.

Description: Thallus expanded, caespitose, green, brush like. Filaments 14.2 – 24.5 μm wide, up to more than 4 cm long. False branching usually geminate, branches clearly divaricated from the main filaments, but morphologically identical. Sheath firm, yellowish, sometimes up to 4.2 μm wide. Trichomes cylindrical, slightly constricted at the cross walls, particularly at the ends, but in some parts almost unconstricted. 11.4-16.5 μm wide, clear blue-green. cells subquadrate or sometimes longer or shorter than wide, at the ends of branches distinctly shortened, terminal cells rounded. Heterocytes solitary, intercalary, cylindrical, isodiametric or longer than wide, 11.2 x 23.1 μm wide, 11.2 - 19.9 μm long.

References: Komarek (2013); Desikachary (1959).

Distribution: No distributional records were found along with the marine environment.

General Environment: Freshwater species

Comments: New record to the cyanobacterial flora of Kerala.

Habitat: Appeared as dark brown coloured epiphytic on the pneumatophores of *Avicennia officinalis* L.

Specimen Examined: INDIA: Kerala; Kollam district, Sakthikulangara, 8^0 56’23.44” N 76^0 33’ 09.88” E, 11.02.2017, MES 21454; Ayiramthengu, 9^0 07’33.93” N 76^0 28’ 45.34” E, 27.08.2018, MES 21569. **(Plate 35, Fig. E-F; Plate 36, Fig. A-F)**.

3. *Scytonema javanicum* Bornet ex Bornet & Flahault 1886

Bornet & Flahault, Annales des Sciences Naturelles, Botanique, 5: 51-129. 1886; Nielsen & Madsen, The American Midland Naturalist, 56(1): 116-125.1956; Singh, Proc.Ind.Acad.Sci., 49 B: 161-66. 1959; Allsopp, Nature, 220. 80. 1968; Alvarez-Cobelas & Gallardo, Acta Botanica Malacitana, 13: 53-76. 1988; Carmeli et al., J. Nat. Prod., 53(6): 1533–1542. 1990; Azevedo et al., Hoehnea, 23(1): 1-38.

1996; Vinogradova et al., Cyanoprocaryota, 32-141. 2000; Vinogradova et al., Int J Algae, 2(1): 41-50. 2000; Chun-Xiang & Yong-Ding, Acta Botanica Sinica, 45(8): 917-928. 2003; Pandey & Tiwari, Pol. J. Microbiol., 53(4):257-265. 2004; Tang et al., J. Arid Environ., 71(3):312-320. 2007; Rai et al., Our Nature, 8: 336-354. 2010; Alwathnani & Johansen, Monographs of the Western North American Naturalist, 5: 71-89. 2011; Lemes-Da-Silva et al., Rev. Bras. Bot., 35(2):169-179, 2012; Hu et al., Adv. Space Res., 53(1): 30-36. 2014; Medvedeva & Nikulina, Catalogue of freshwater algae of the southern part of the Russian Far East, 1-271. 2014; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Vinoth et al., Res. j. life sci. bioinform. pharm. chem. sci., 3(3): 215-241. 2017; Xia, Flora algarum marinarum sinicarum Tomus I Cyanophyta, 1-176. 2017; Klemm et al., Toxins, 10 (130): 1-14. 2018; Zhu et al., Sci. Total Environ., 737(139733): 1-11. 2020; Zhu et al., Environ Sci Pollut Res., 28, 13861–13872. 2021.

Description: Thallus thread-like, prostrate, dark blue-green. Filaments creeping, later up to erect, 10.6-17.3 μm wide. False branches long, flexuous, usually geminate or aggregated, false branches aggregated towards the base. Sheath firm, thin, narrow, yellow, not lamellated. Trichome cylindrical, not constricted at the cross walls, blue-green, 6.8-11.3 μm wide, olive green. Cells cylindrical, quadratic or shorter than wide, 7.0-12.3 μm long in the middle, 3.82-6.38 μm long at the ends. Heterocytes cylindrical or subquadrate, 5.62-7.25 μm wide, 7.3-10.4 μm long.

References: Komarek (2013); Desikachary (1959).

Distribution: No distributional records were found along with the mangrove environment.

General Environment: Terrestrial species

Comments: New record to the cyanobacterial flora of Kerala.

Habitat: Appeared as dark brownish green coloured epiphytic on the pneumatophores of *Avicennia officinalis* L.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54’ 41.96” N, 76^0 18’ 32.36” E, 16.07.2019, MES 13732. **(Plate 37, Fig. A-C)**.

4. *Scytonema millei* Bornet ex Bornet & Flahault 1886

Bornet in Bornet & Thuret, Notes algologiques, 2: 147. 1880; Bornet & Flahault, Annales des Sciences Naturelles, Botanique, 5: 51-129. 1886; Forti in De Toni, Sylloge Algarum, 5: 505. 1907; Fremy, Myxo. d'Afr.equat.franc. 306. 1929; Geitler, Kryptogamenflora, 757. 1932; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Saha et al., Indian J. Microbiol., 47: 219–232. 2007; Gkelis et al., Biodivers Data J., 4(e10084): 1-103. 2016; Barinova & Niyatbekov, Biodivers. Int. J., 2(3): 201-237. 2018.

Description: Thallus cushion-like, widely expanded, dark green to brownish. Filaments 15.2-20.5 μm wide, flexuous, entangled, with divaricated erect false branches, which are of the same width as main filaments. Sheaths firm, brown. Trichomes cylindrical, constricted at cross walls, 10.3-15.3 μm wide. Cells shortly barrel-shaped, shorter than wide. Heterocytes shortly barrel-shaped or rectangular, brown, intercalary, solitary sometimes wider than trichomes, 8.4-11 μm wide, 8.2-11.6 μm long.

References: Komarek (2013); Desikachary (1959).

Distribution: No distributional records were found along with the marine environment.

General Environment: Terrestrial species

Comments: New record to the marine cyanobacterial flora of India.

Habitat: Appeared as dark brown coloured epiphytic on the pneumatophores of *Sonneratia caseolaris* (L.) Engl. cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Ernakulam district, Kumbalam, 9^0 54' 41.96" N, 76^0 18' 32.36" E, 28.08.2018, MES 13766; 14.11.2016, MES 21473. **(Plate 37, Fig. D-F; Plate 38, Fig. A-B)**.

5. *Scytonema* sp.

Description: Filaments falsely branched, 13.4-18.2 μm wide, branches geminate, branches same width as the main filaments. Sheath thick, yellow-brown. Trichomes cylindrical, two branches having varying cell sizes and shapes, cells of one branch

barrel-shaped, 3.5- 4.9 μm wide, 3.2-8.3 μm long, not constricted at cross walls and the other is shorter than long, disc-shaped, 4.3-6.5 μm wide, 3.2-5.9 μm long, constricted at the cross walls. Heterocytes varying shape, 4.8x6.8 μm wide.

Habitat: Appeared as dark brown coloured epiphytic on the aerial roots of *Bruguiera cylindrica* (L.) Blume.

Specimen Examined: INDIA: Kerala; Kollam district, Ayiramthengu, 9^0 07'33.93" N 76^0 28' 45.34" E, 17.10.2017, MES 21524. **(Plate 38, Fig. C)**.

6. *Scytonema tolypothrichoides* Kützing ex Bornet & Flahault 1886

Bornet & Flahault, Annals of Natural Sciences, Botany, 5: 51-129. 1886; Adams, Proc. R. Ir. Acad., 27B(2): 11-60. 1908; Chapman, J. Linn. Soc., Bot., 55(360): 333-501. 1956; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Subhashini & Kaushik, Zentralblatt für Mikrobiologie, 141(3): 177-180. 1986; Day et al., Flora of Australia, 4:1-276. 1995; Poulin et al., Can. Field-Nat., 109: 27-110. 1995; Skulberg, Norsk Polarinstitut Skrifter, 383-395. 1996; Sherwood, Bishop Museum Occasional Papers, 80: 1-26. 2004; Johansen et al., Southeastern Naturalist, 1: 99-134. 2007; Smith, Int J Algae, 12(3): 230-256. 2010; Gadea et al., Thalassas, 29(1): 35-58. 2013; Deb et al., Int. J. Life Sci. Pharma Res., 5(2): 21-31. 2015; Kumar & Adhikary, J. Appl. Phycol., 27(1), 339-349. 2015; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Jaiswal, Algae of north-west Khandesh, 1-448. 2017; Singh et al., Physiol. Mol. Biol. Plants, 24(2): 315-324. 2018; Kvíderová et al., Eng. Life Sci., 19(3): 184-195. 2019; Panda et al., Data in brief, 25:1-6. 2019; Vishnivetskaya et al., FEMS Microbiol. Ecol., 96(12): 1-38. 2020; Dahech et al., J. Appl. Phycol., 33(5): 2795-2804. 2021; Davydov, Polar Biol., 1-12. 2021.

Description: Thallus dark blue-green, brush-like. Filaments coiled, entangled, 10.8-16.7 μm wide, with common solitary or geminate false branching. Sheath wide, yellow to brownish, partly with parallel or divergent layers. Trichomes slightly cylindrical, not or slightly constricted at the cross walls. Cells bright blue-green or olive green, cylindrical, isodiametric or slightly longer than wide, 8.2-10.3 μm wide, 9.3-14.2 μm long. Heterocytes quadrate to ovate, 14.4 μm wide, 14.9 μm long.

References: Komarek (2013).

General Environment: Freshwater/terrestrial species

Comments: New record to the cyanobacterial flora of Kerala

Habitat: Appeared as dark brown coloured epiphytic on the pneumatophores of *Avicennia officinalis* L.

Specimen Examined: INDIA: Kerala; Kollam district, Sakthikulangara, 8^0 56'23.44" N 76^0 33' 09.88" E, 29.09.2018, MES 21480; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 16.09.2015, MES 13725, 16.10.2019, MES 21483. **(Plate 38, Fig. D-F; Plate 39, Fig. A-B)**.

7. *Scytonema varium* Kutzing ex Bornet et Flahault 1886

Kutzing, Spec.Alg., 307, 1849; Zanardini, Veneto, 17:129-170. 1872; Zeller, Hedwigia, 12. 168-176. 1873; Theobald, Hertfor., 16-30. 1883; Bornet and Flahault, Annales des Sciences Naturelles, Botanique, 5: 51-129. 1886; Saunders, Proc. Wash. Acad. Sci., 3: 391-486. 1901; Forti in De Toni, Syllogue Algarum, 5: 512. 1907; Ghose, J.Indian.Bot.Soc., 6(2): 79-84. 1927; Ghose, Ibid., 17(3): 252-256. 1927; Geitler, Kryptogamenflora, 774. 1932; Chapman et al., Trans. Roy. Soc. New Zealand, 84: 695-747. 1957; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Pari and N'Yeurt, Aust. Syst. Bot., 10: 867-910. 1997; Bokesch et al., Biochemistry, 42(9): 2578-2584. 2003; Sherwood, Bishop Museum Occasional Papers, 80: 1-26. 2004; Bhattacharya et al., Phykos, 46(1): 32-39. 2016; Oliveira et al., An. Acad. Bras. Ciênc., 89: 2113-2117. 2017.

Description: Thallus brownish. Filaments entangled, prostrate, 10.3-14.1 μm wide, with single branches. Sheaths gelatinous, thick, colourless in lower parts, yellowish in upperparts. Trichomes 5.4-7 μm wide, not constricted at the cross walls. Cells longer, cylindrical, quadratic up to longer than wide. Heterocytes hemispherical, subquadrate.

Distribution: This species was reported from the mangrove environment of Parangipattai, Tamil Nadu (Silambarasan et al., 2012).

References: Komarek (2013); Desikachary (1959).

General Environment: Freshwater/terrestrial species

Comments: New record to the cyanobacterial flora of Kerala

Habitat: Appeared as dark brown coloured epiphytic on the aerial roots of *Bruguiera cylindrica* (L.) Blume

Specimen Examined: INDIA: Kerala; Kollam district, Sakthikulangara, 8^0 56'23.44" N 76^0 33' 09.88" E, 24.10.2017, MES 21550. **(Plate 39, Fig. C-F)**.

6. Stigonemataceae

Thallus formed by heterocytous filamentous cyanobacteria with true branching. Filaments with branches of the same form and size as the main parts, but sometimes continually narrowed towards ends. Filaments mainly torulous or moniliform, with firm lamellated and coloured sheaths. Trichomes mono to polyseriate, composed often from spheroid or irregular rounded cells. Heterocytes intercalary or lateral. Reproduction by disintegration of thallus.

The family consists of five genera and 81 species. The family, representing 1 genus and 1 species, is known to occur in the mangrove ecosystem of southern Kerala and is presented.

Key to the genera

1. Filaments mono to polyseriate, true branching .....**1. *Stigonema***

1. *Stigonema* Agardh ex Bornet et Flahault 1888

Thallus composed from uniseriate, bi to multiseriate, creeping or erect, irregularly waved filaments, with firm, sometimes slightly widened mucilaginous sheaths, lamellated, colourless or coloured. Filaments irregularly laterally sometimes repeatedly branched, isopolar. Branches similar to the main filaments, or narrower and often tapering towards ends. Cells globose, ovate or irregular rounded and particularly in old parts of filaments with individual, sometimes concentrically lamellated envelopes. Heterocytes usually intercalary or lateral.

Among the 80 species (infraspecific) reported up to date, 68 species are currently accepted as taxonomically valid taxa (Guiry & Guiry, 2022). Here, only 1 species is described as an epiphytic form from the mangrove ecosystems of southern Kerala.

Key to the species

1. Main and lateral branches morphologically distinguishable, filaments uni to biseriate, 18.5-45.4 μm wide .....**1. *S. ocellatum***

1. *Stigonema ocellatum* (Dillwyn) Thuret ex Bornet & Flahault 1886

Bornet & Flahault, Annales des Sciences Naturelles, Botanique, 5: 51-129. 1886; Saunders, Proceedings of the Washington Academy of Sciences 3: 391-486. 1901; Adams, Proc. R. Ir., 27B (2): 11-60. 1908; Fritsch & Rich, Transactions of the Royal Society of South Africa, 25(2): 153-228. 1937; Chapman et al., Trans. Roy. Soc. New Zealand, 84: 695-747. 1957; Prescott, Algae of the Western Great Lakes area, 1-977. 1962; Skuja, Some algae and other protists, 648: 50-55. 1969; Bicudo & Bicudo, Rickia, 4: 1-40. 1970; Hirose et al., Illustrations of the Japanese fresh-water algae, 1-933. 1977; Alvarez-Cobelas, & Gallardo, Acta Bot Malac., 13: 53-76. 1988; Day et al., Flora of Australia, 4(1-7): 1-276. 1995; Cvijan & Blazencic, Flora algi Srbije, 1-290. 1996; Sheath & Steinman, Can J Bot., 60: 1964-1997. 1982; Poulin et al., Can. Field-Nat., 109: 27-110. 1995; Phillips, Algae, 228-244. 2002; Sherwood, Bishop Museum Occasional Papers, 80: 1-26. 2004; Furnari et al., Biologia Marina Mediterranea, 10(1): 1-482. 2003; Hu, & Wei, The freshwater algae of China, 1-1023. 2006; Johansen et al., Southeastern Naturalist, 1: 99-134. 2007; Patova & Demina, Algae of other divisions, 69-89. 2007; Rai et al., Our Nature, 8: 336-354. 2010; Barinova et al., Turk J Bot, 35: 729-774.2011; Lemes-Da-Silva et al., Braz J Bot, 35(2):169-179, 2012; Novakovskaya et al., Botanical Journal, 97(3): 305-320. 2012; Davydov, Algol Stud/Archiv für Hydrobiologie, 142: 29-44. 2013; Ferreira et al., Revista de Biología Tropical, 61(1): 455-466. 2013; Gadea et al., Thalassas, 29(1): 35-58. 2013; Patova et al., Cyanoprokaryotes and algae, 133-166. 2015; Mares et al., Journal of Phycology, 51(2): 288-297. 2015; Vinogradova, Int J Algae, 18(1): 67-80. 2016; Caraus, Studii si Cercetari Biologie, 7: 1-1002. 2017; Davydov, Botanica, 24(2): 185-201.2018; Novakovskaya et al., Phycologia, 59(4): 320-329. 2020; Davydov, Polar Biol, 1-12. 2021; Marter et al., Genes, 12(3), 389:1-22. 2021.

Description: Thallus bush-like, caespitose, brownish. Filaments partly creeping, 18.5-45.4 μm wide, irregularly repeatedly branched. Branches long, curved, as wide as or smaller than main filament, at the ends often produce hormogonia which are slightly thicker. Sheaths thick, 12.4 μm wide, yellow or yellow-brown, slightly

lamellated, sometimes colourless in the young portions at the end of filaments, brown coloured in the older parts. Trichome uni-biseriate. Cells quadrate-globose or globose, usually shorter than wide, 14.9-38.9 μm wide, 8.9-21 μm long, blue-green or olive green, often with a colourless or brown individual envelops.

References: Komarek (2013); Desikachary (1959).

Distribution: No distributional records were found along with the mangrove environment.

General Environment: Freshwater/terrestrial species

Comments: New record to the mangrove cyanobacterial flora of India.

Habitat: Appeared as dark brown coloured epiphytic on the aerial roots of *Rhizophora apiculata* Blume.

Specimen Examined: INDIA: Kerala; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 21.11.2017, MES 21587. **(Plate 40, Fig. A-F)**.

Plate 1

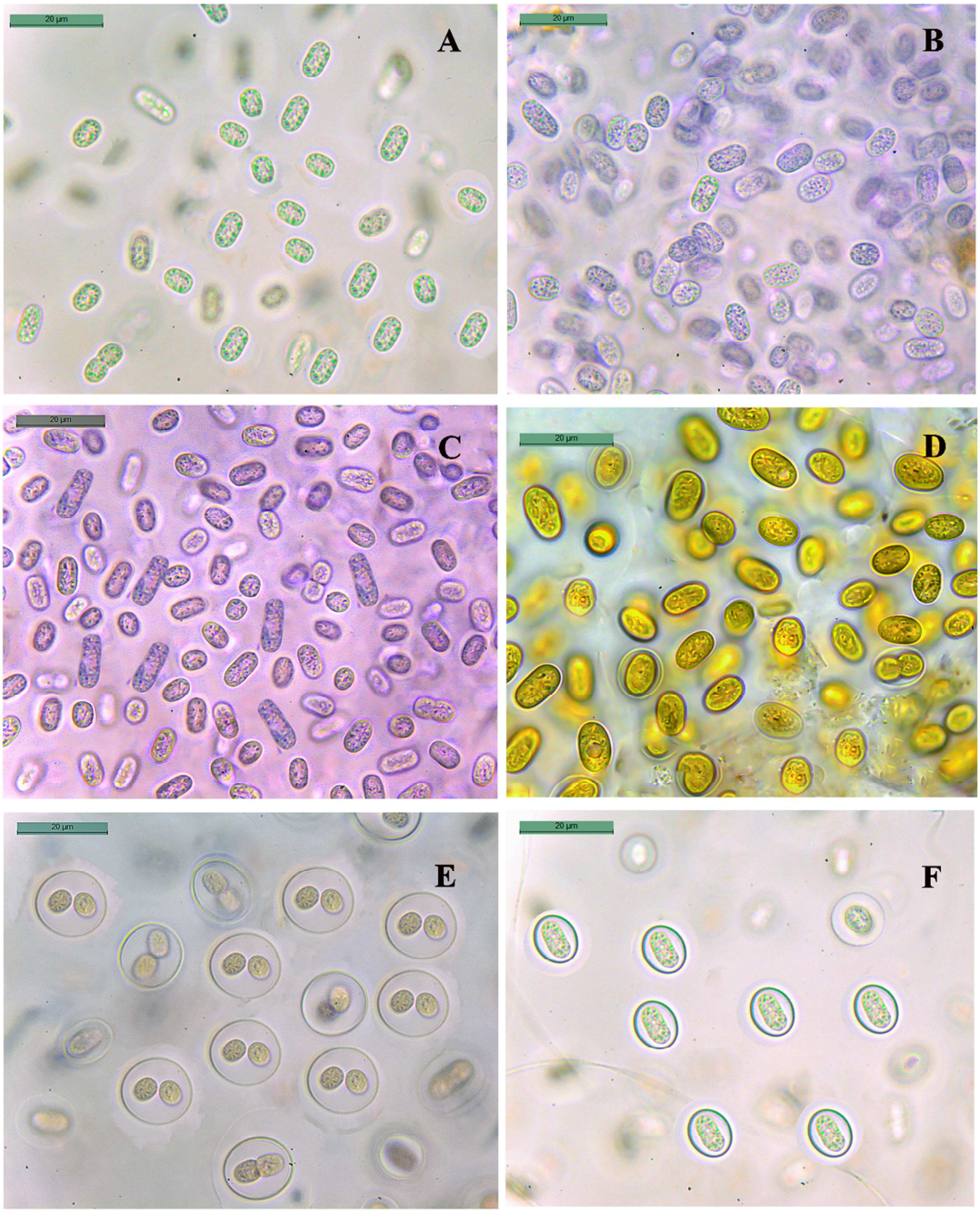


Fig. Fig. A. *Aphanothece bullosa* (Meneghini) Rabenhorst 1865**; B.** *Aphanothece granulosa* (N.L.Gardner) Komárek & Komákova-Legnerova 2007**; C.** *Aphanothece stagnina* (Sprengel) A. Braun in Rabenhort 1863**; D.** *Chroococcus indicus* Zeller 1873**; E.** *Chroococcus pallidus* Nageli 1849**; F.** *Gloeothece rupestris* (Lyngbye) Bornet in Wittrock & Nordstedt 1880.

Plate 2

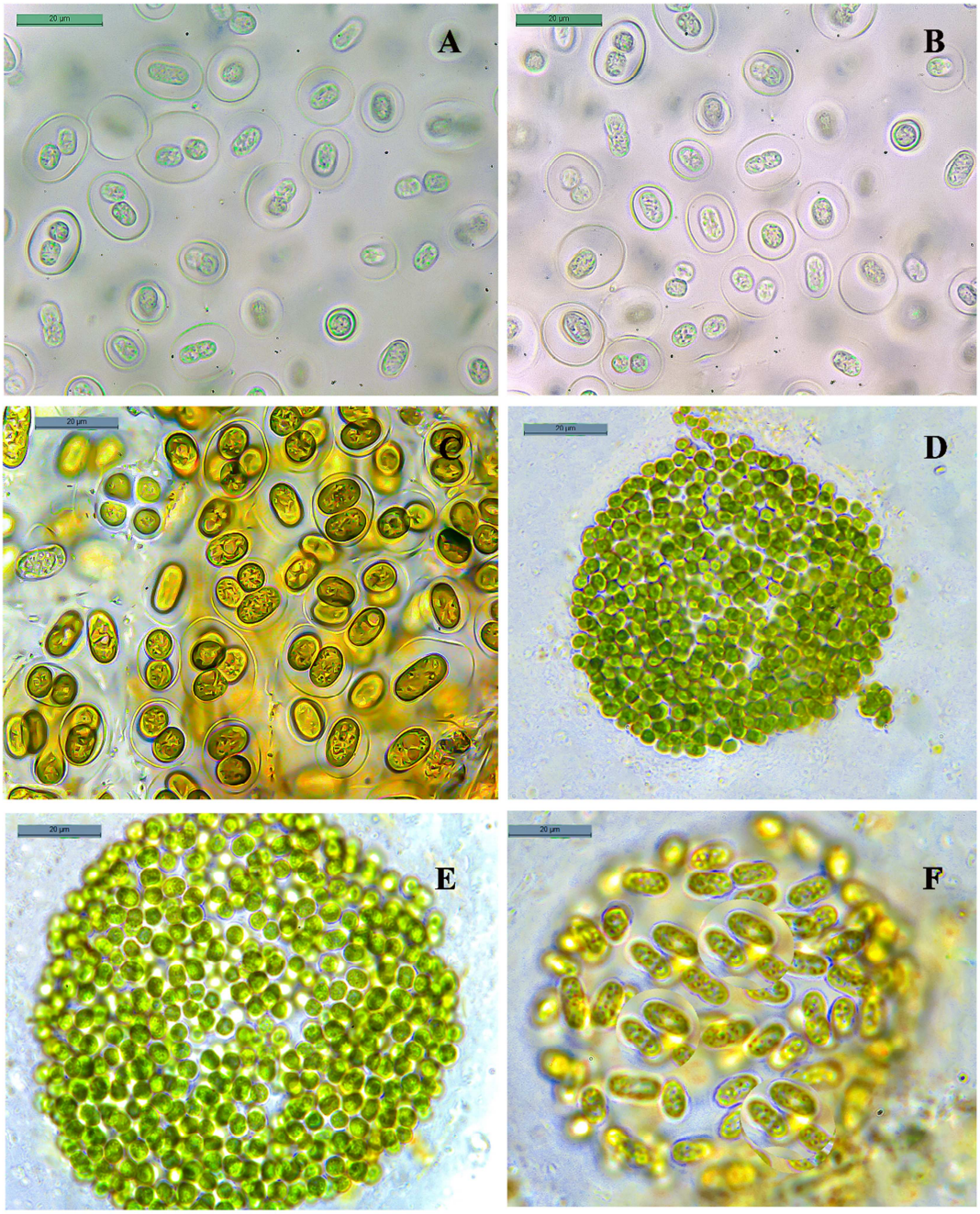


Fig. A-B. *Gloeothece samoensis* Wille 1913**; C.** *Gloeothece ustulata* Beck-Mannagetta 1929**; D-E.** *Aphanocapsa grevillei* (Berkeley) Rabenhorst 1865**; F.** *Anathece bacteriosa* (Komarek & Komarkova-Legnrova) Komarek, Kastovsky & Jezberova 2011.

Plate 3

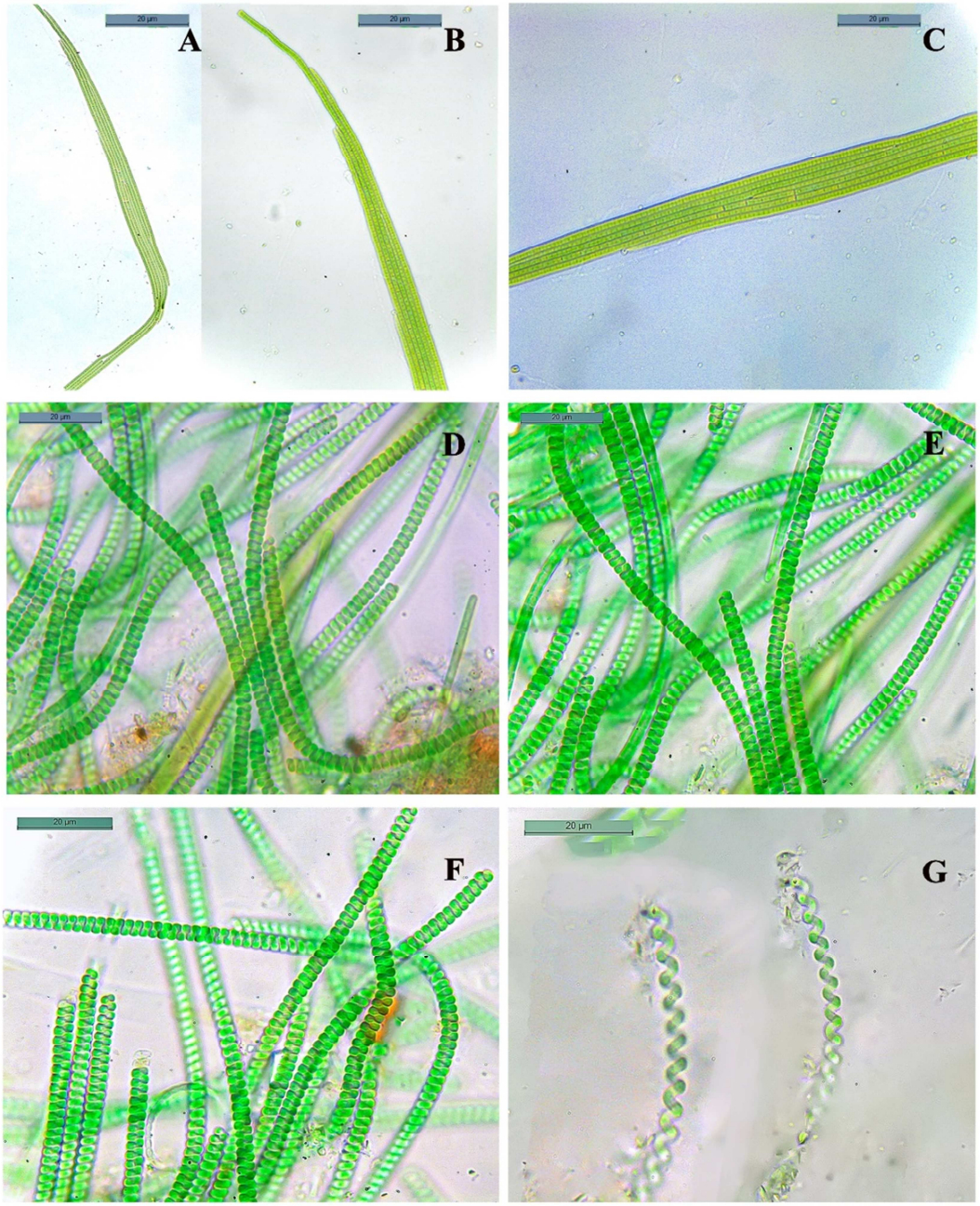


Fig. A-C. *Trichocoleus delicatulus* (West & G.S.West) Anagnostidis 2001**; D-F.** *Spirulina labyrinthiformis* Gomont 1892; **G.** *Spirulina major* Kutzing ex Gomont 1892.

Plate 4

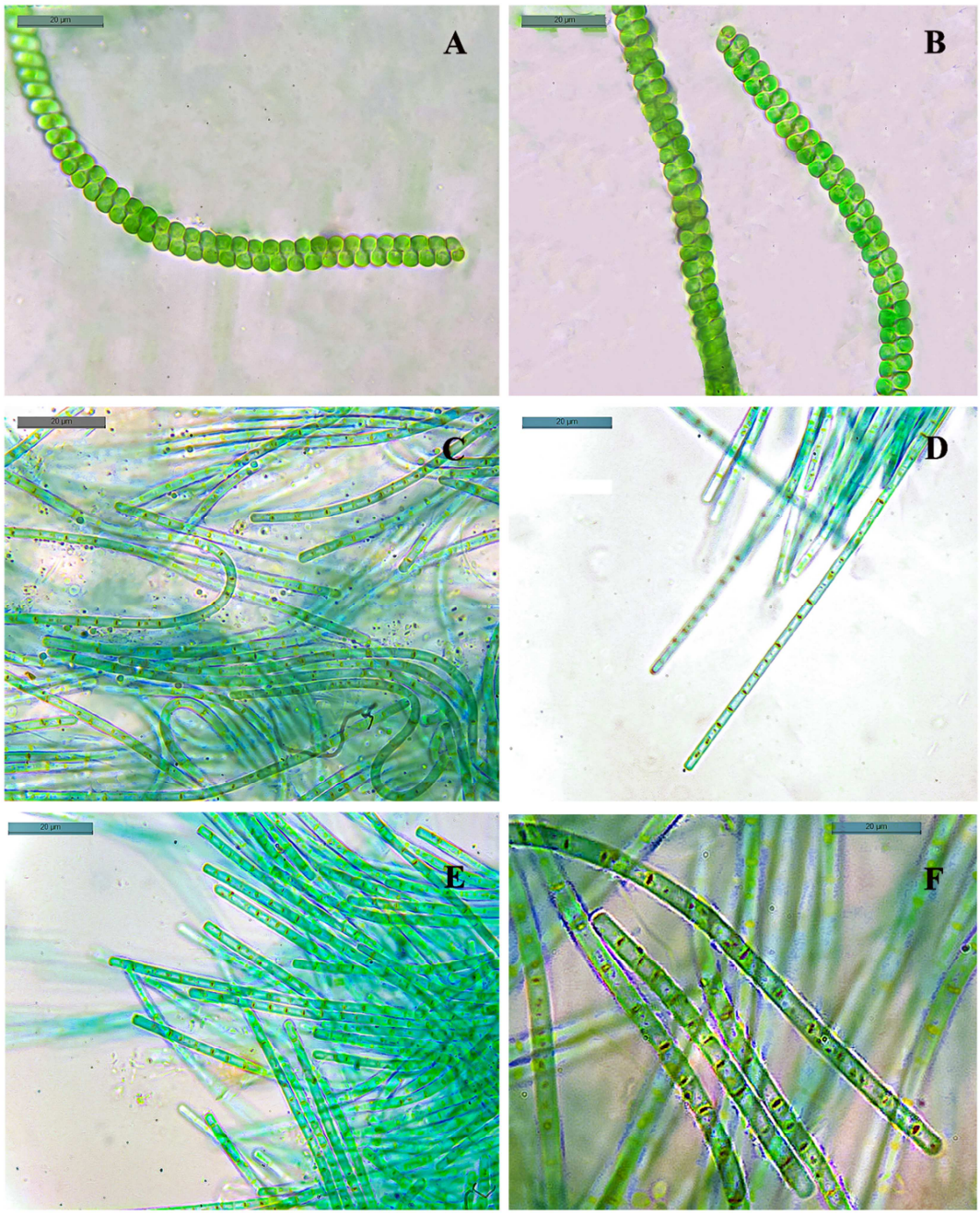


Fig. A-B. *Spirulina spirulinoides* (Ghose) Geitler 1925**; C-F.** *Anagnostidinema pseudacutissimum* (Geitler) Strunecky, Bohunicka, Johansen et Komarek, 2017.

Plate 5

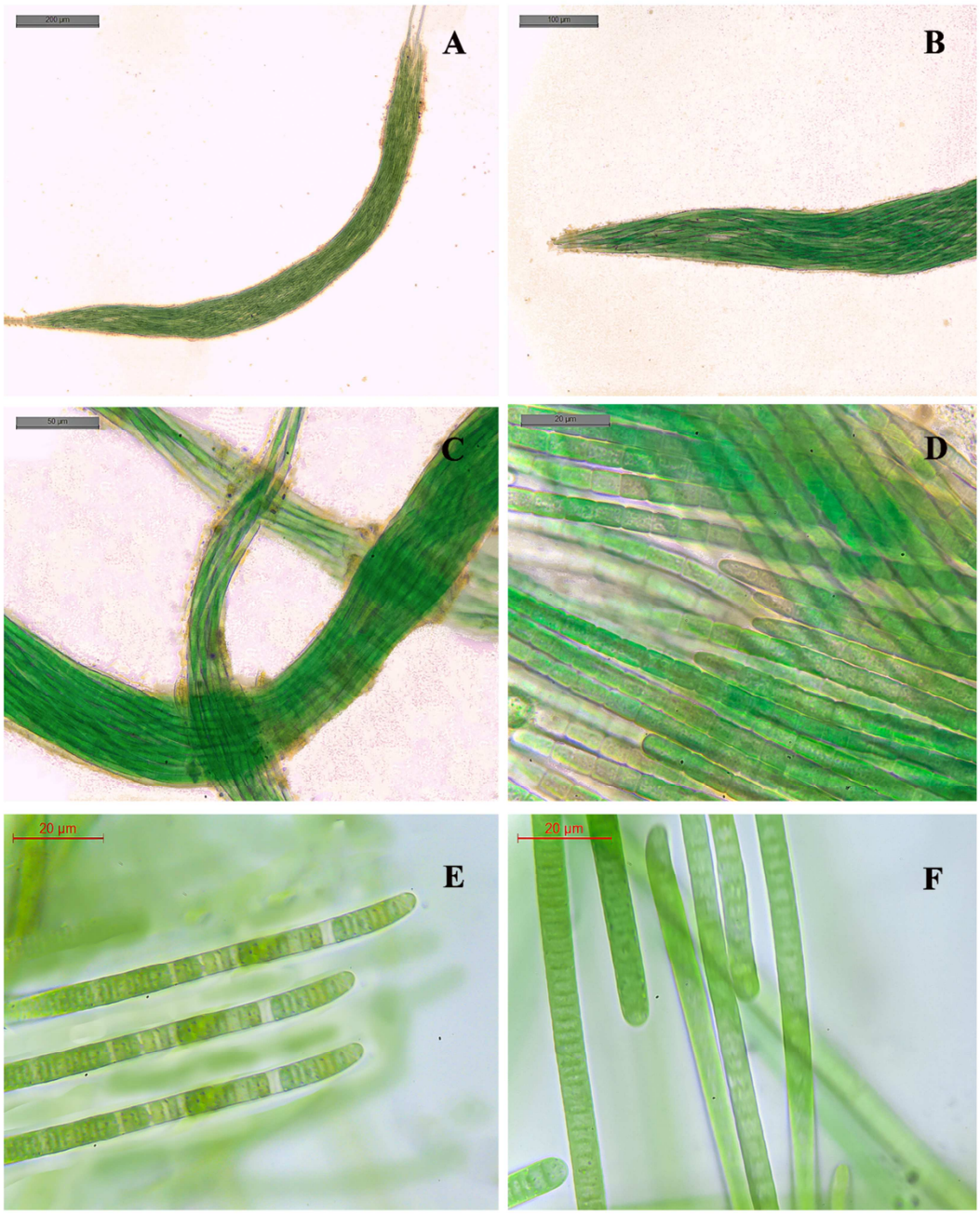


Fig. A-D. *Coleofasciculus chthonoplastes* (Thuret ex Gomont) M.Siegesmund, J.R.Johansen et T.Friedl 2008**; E-F.** *Kamptonema chlorinum* (Kutzing ex Gomont) Strunecky, Komarek et J.Smarda 2014

Plate 6

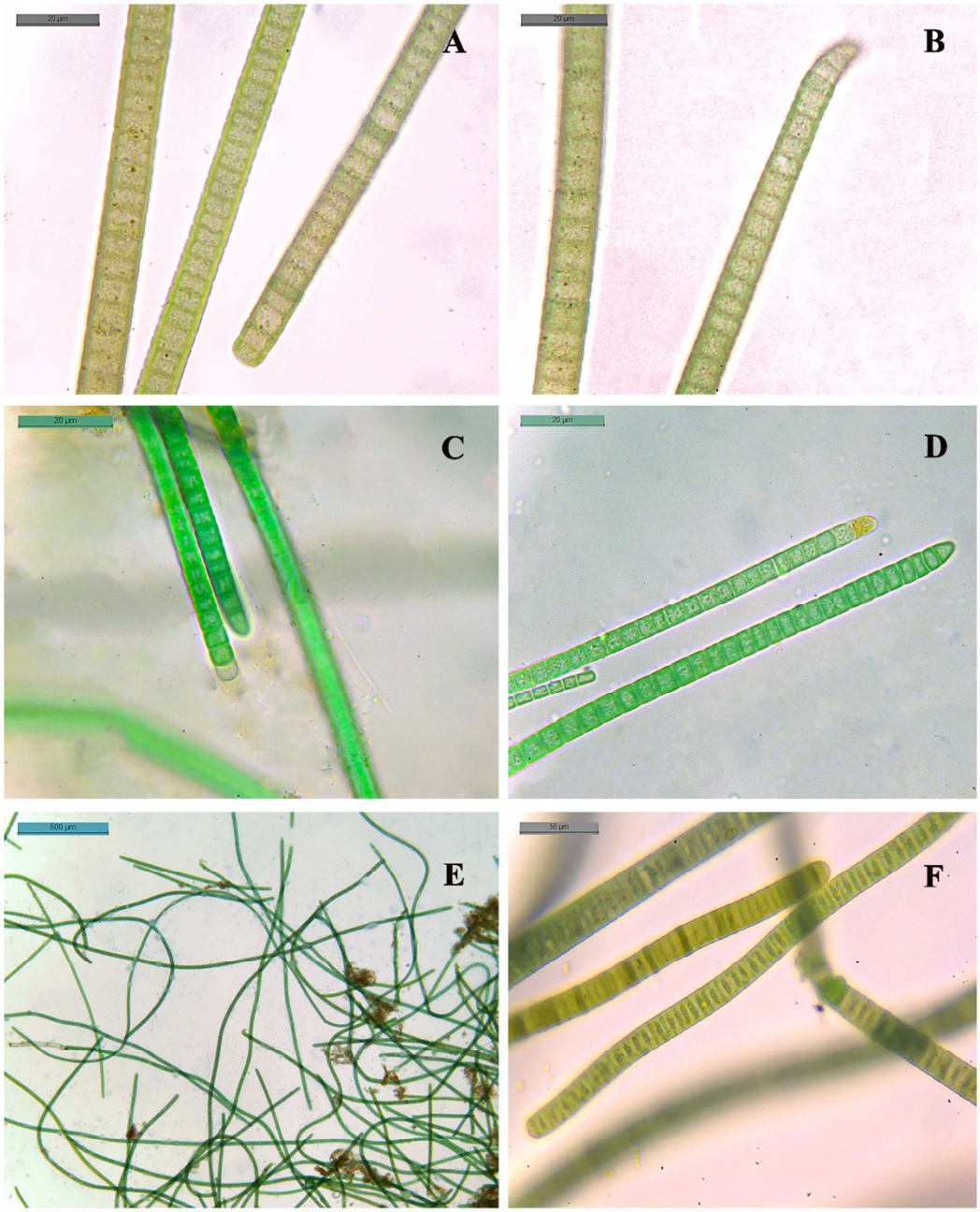


Fig. A-B. *Kamptonema jasorvense* (Vouk) Strunecky, Komarek et J.Smarda 2014**; C-D.** *Kamptonema okenii* (Agardh ex Gomont) Strunecky, Komarek et J.Smarda 2014**; E-F.** *Microcoleus autumnalis* (Trevisan ex Gomont) Strunecky, Komarek et J.R.Johansen 2013.

Plate 7

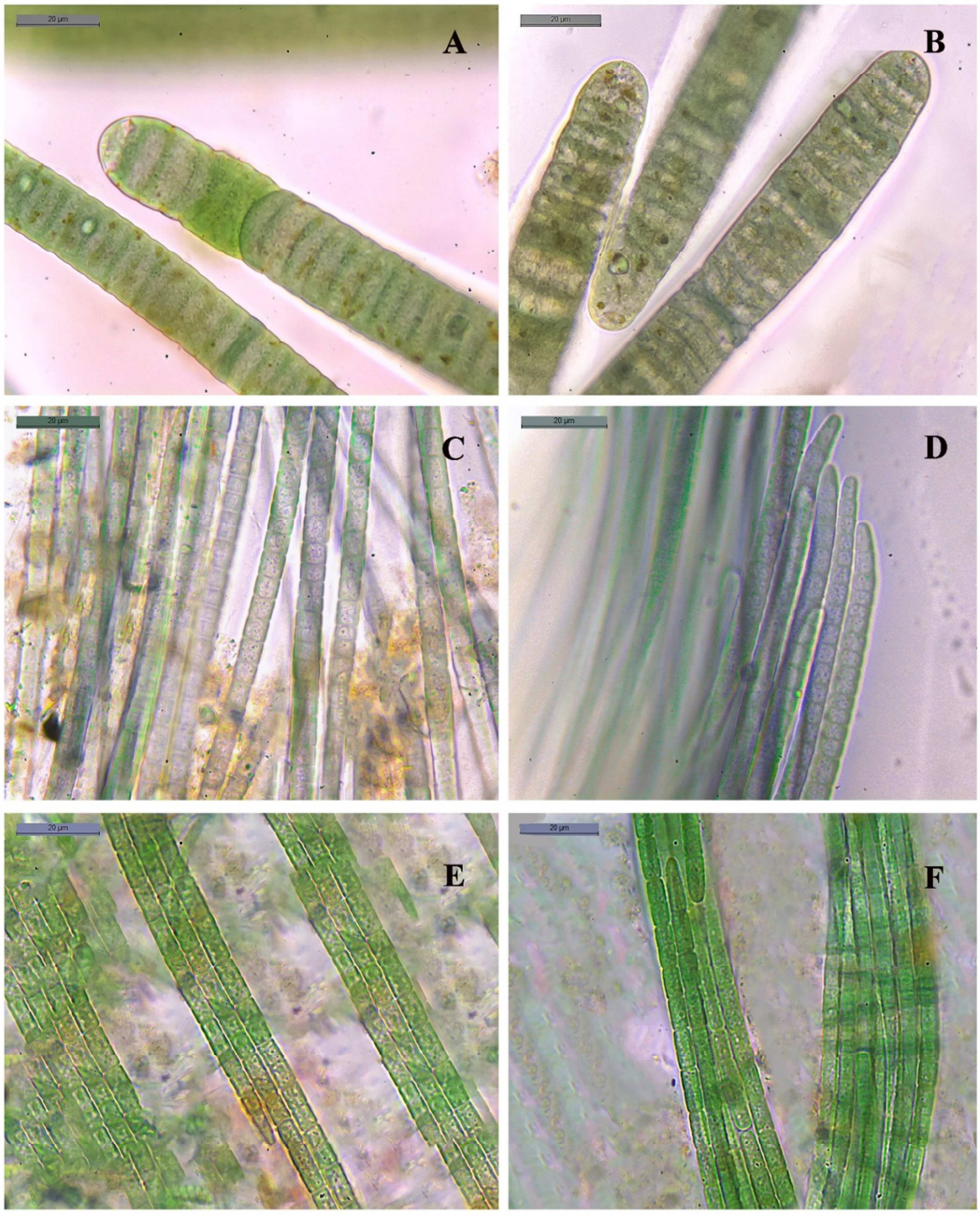


Fig. A-B. *Microcoleus autumnalis* (Trevisan ex Gomont) Strunecky, Komarek et J.R.Johansen 2013**;** **C-D.** *Microcoleus codii* Fremy 1932**;** **E-F.** *Microcoleus lacustris* Farlow ex Gomont 1892.

Plate 8

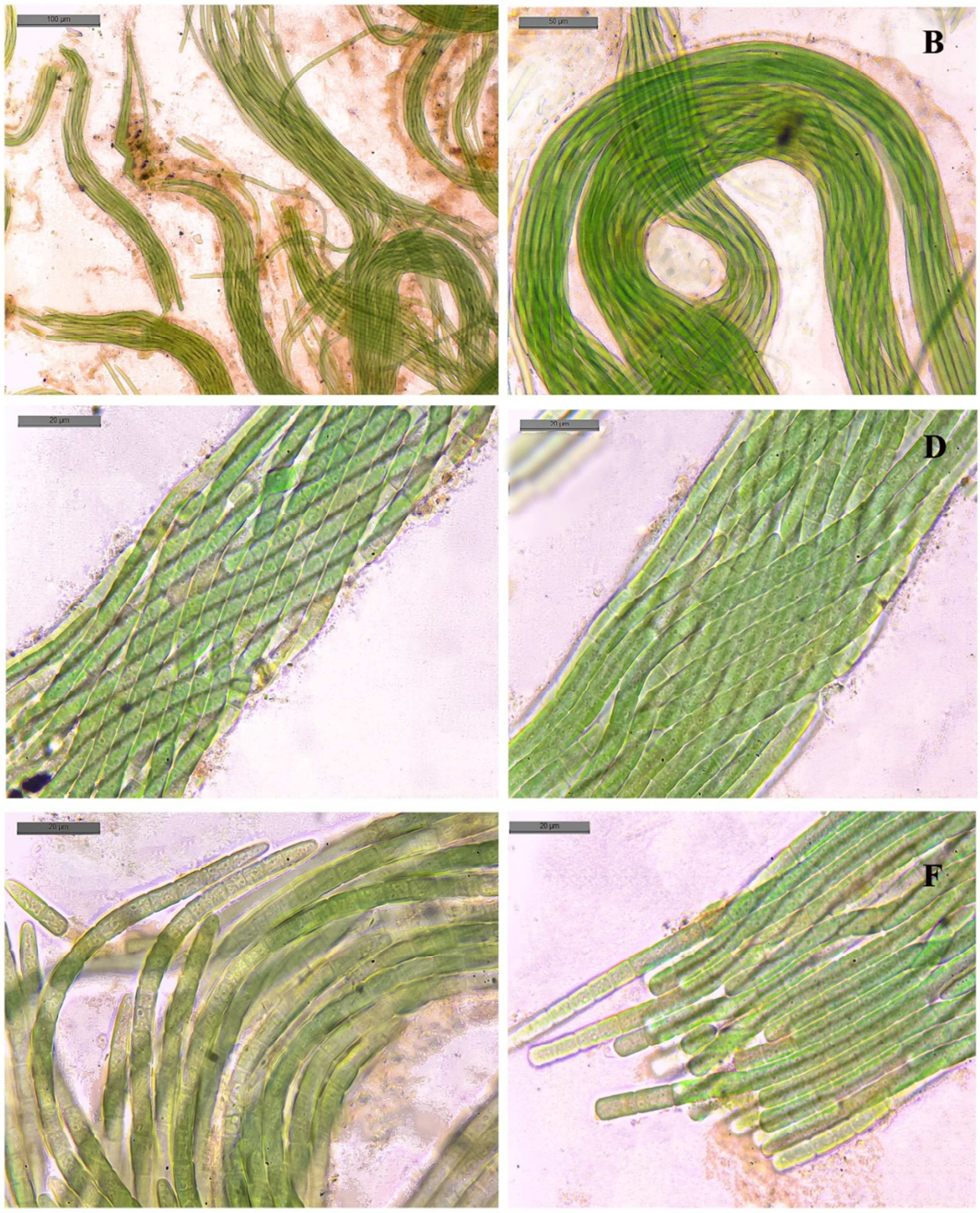


Fig. A-F. *Microcoleus paludosus* Gomont ex Gomont 1892

Plate 9

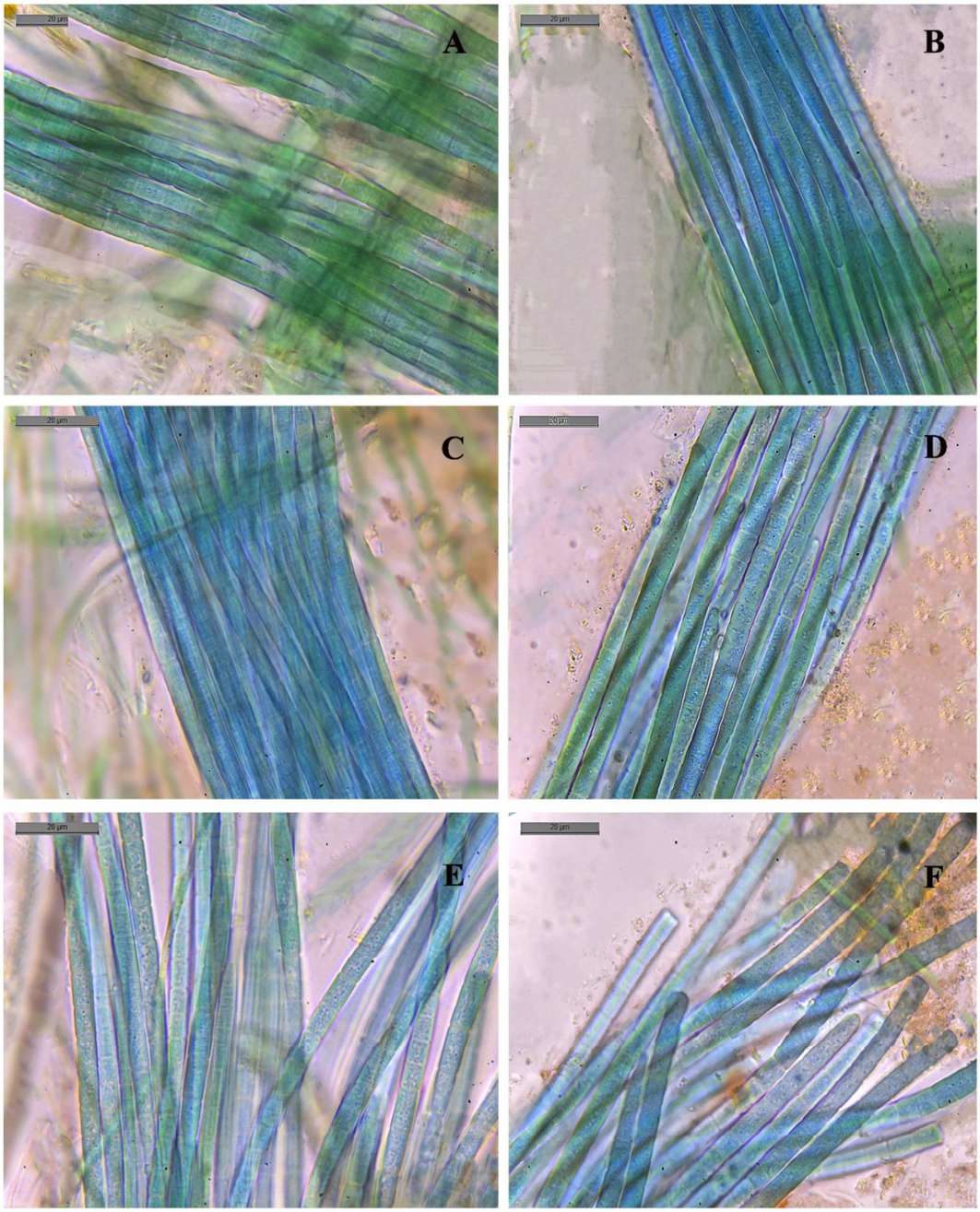


Fig. A-F. *Microcoleus subtorulosus* Gomont ex Gomont 1892

Plate 10

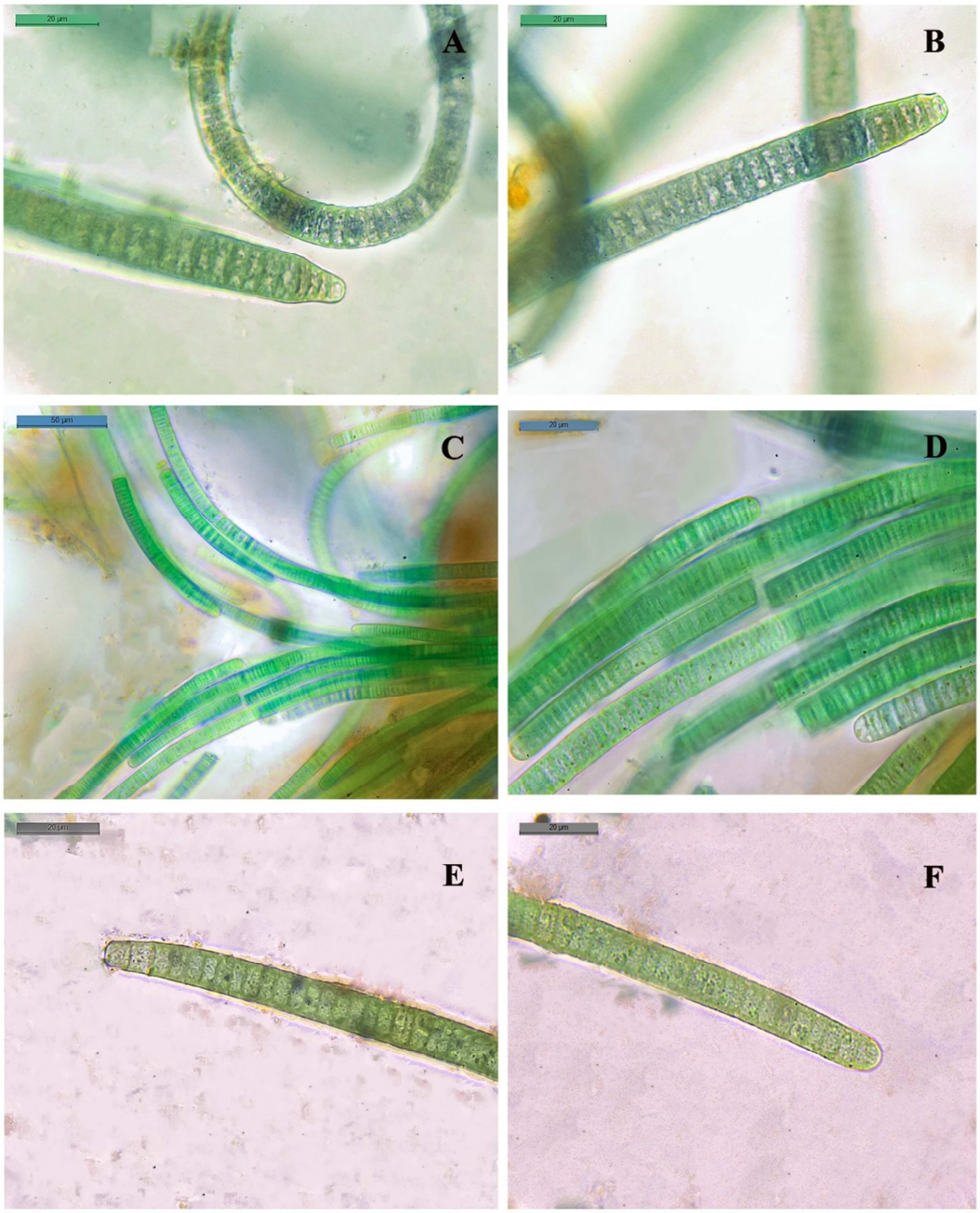


Fig. A-B. *Planktothrix geitleri* (Kisselev) Anangnostidis et Komarek 1998**; C-D.** *Planktothrix isothrix* (Skuja) Komarek & Komarkova 2004**; E-F.** *Planktothrix suspensa* (Pringsheim) Anagnostidis et Komarek 1988

Plate 11

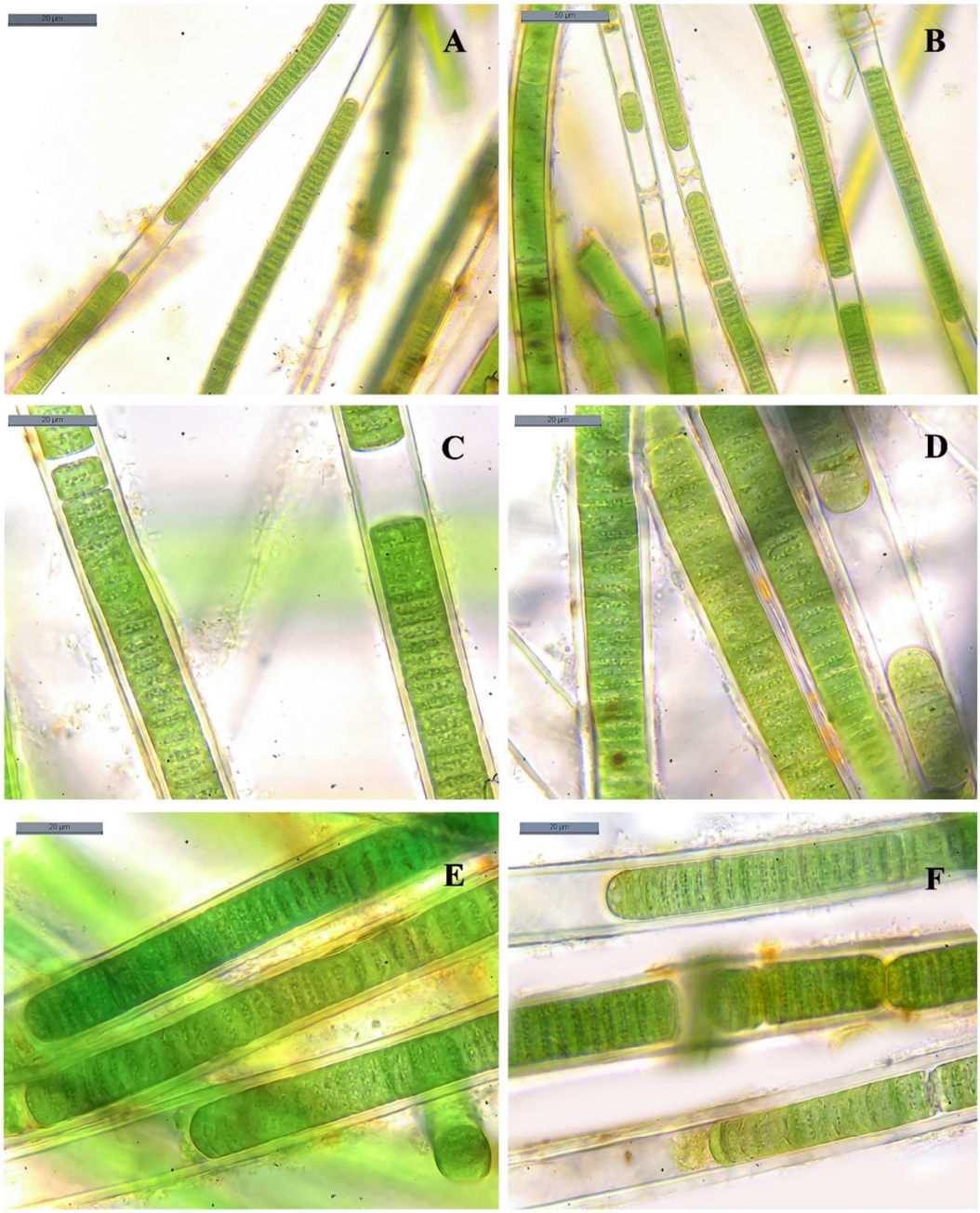


Fig. A-F. *Porphyrosiphon ceylanicus* (Wille) Anagnostidis & Komarek 1988

Plate 12

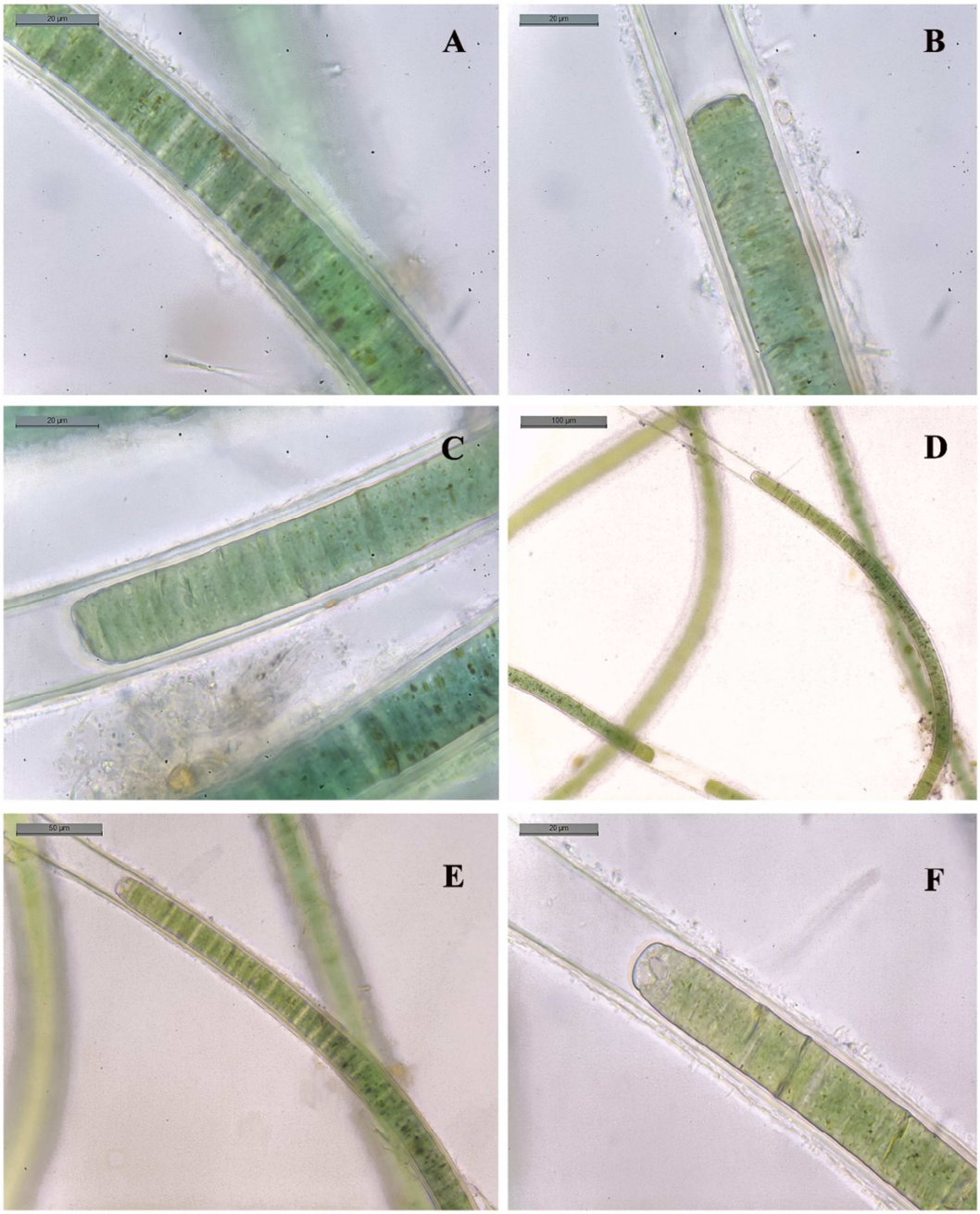


Fig. A-C. *Limnoraphis hieronymusii* (Lemmermann) J.Komarek, E.Zapomelova, J.Smarda, J.Kopecky, E.Rejmankova, J.Woodhouse, B.A.Neilan & J.Komarkova 2013**; D-F.** *Lyngbya aestuarii* Liebman ex Gomont 1892.

Plate 13

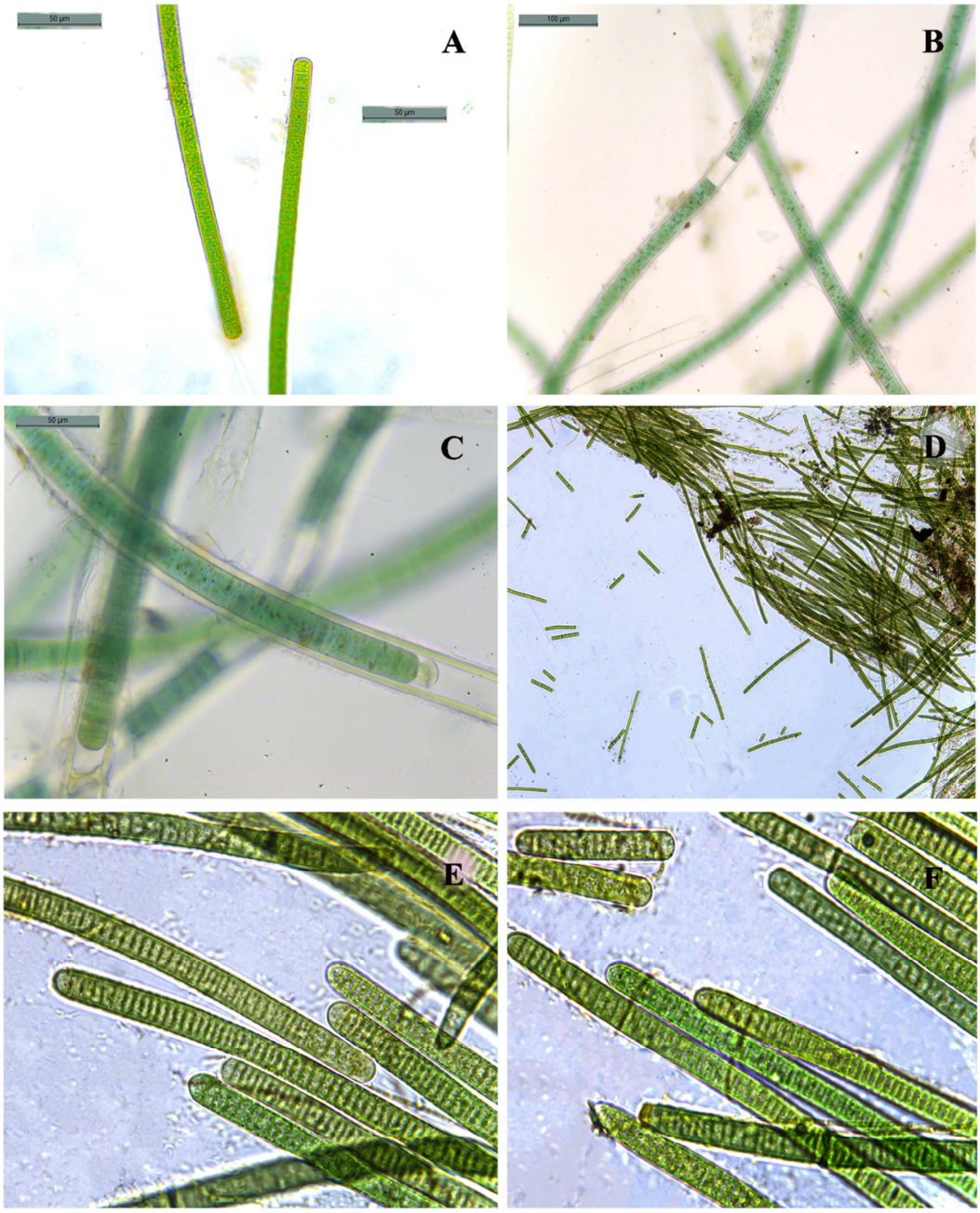


Fig. A. *Lyngbya lutea* Gomont ex Gomont 1892**; B-C.** *Lyngbya truncicola* Ghose 1924**; D-F.** *Oscillatoria curviceps* C.Agardh ex Gomont 1892

Plate 14

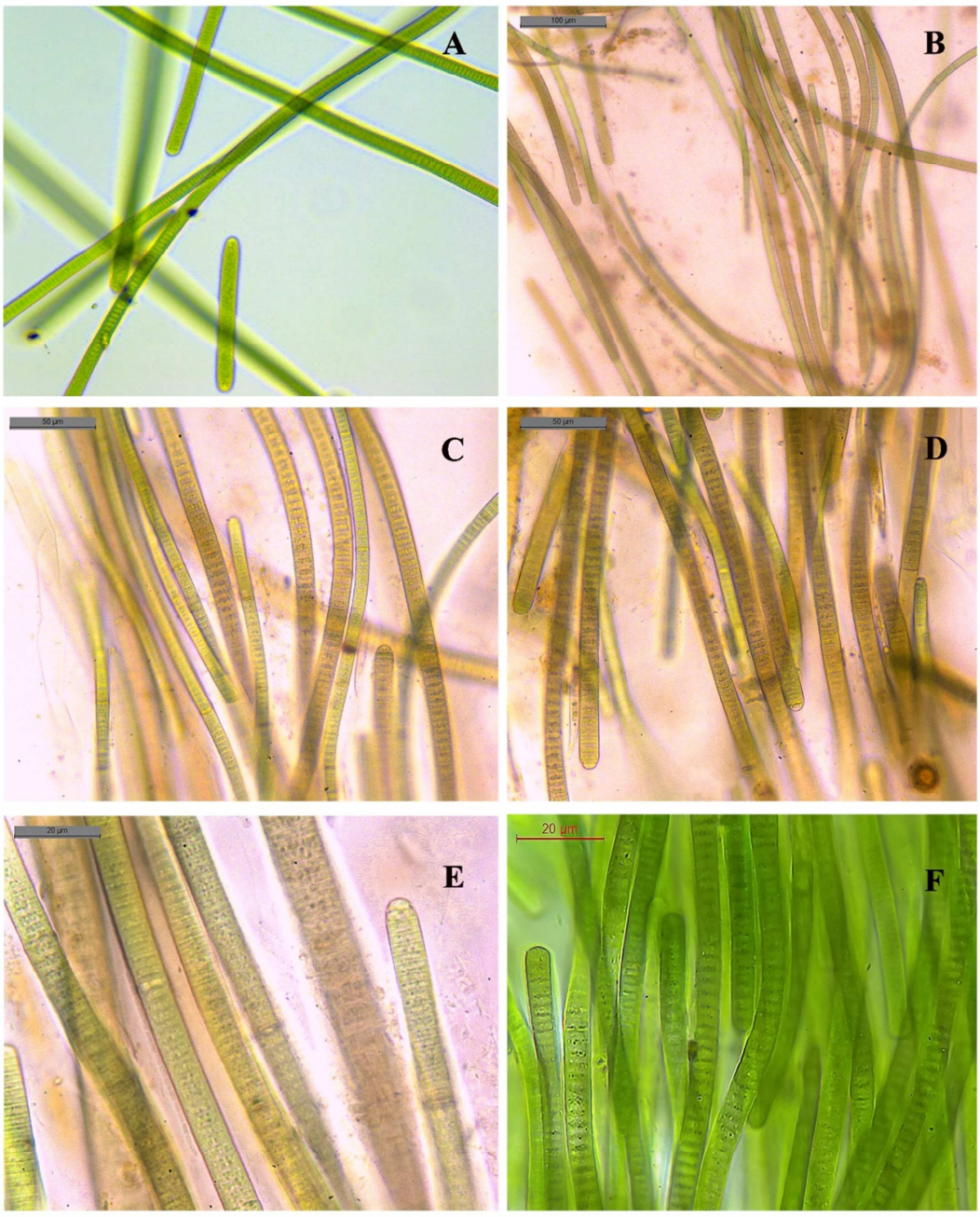


Fig. A. *Oscillatoria curviceps* var. *angusta* Ghose 1927**; B-F.** *Oscillatoria limosa* Agardh ex Gomont 1892.

Plate 15

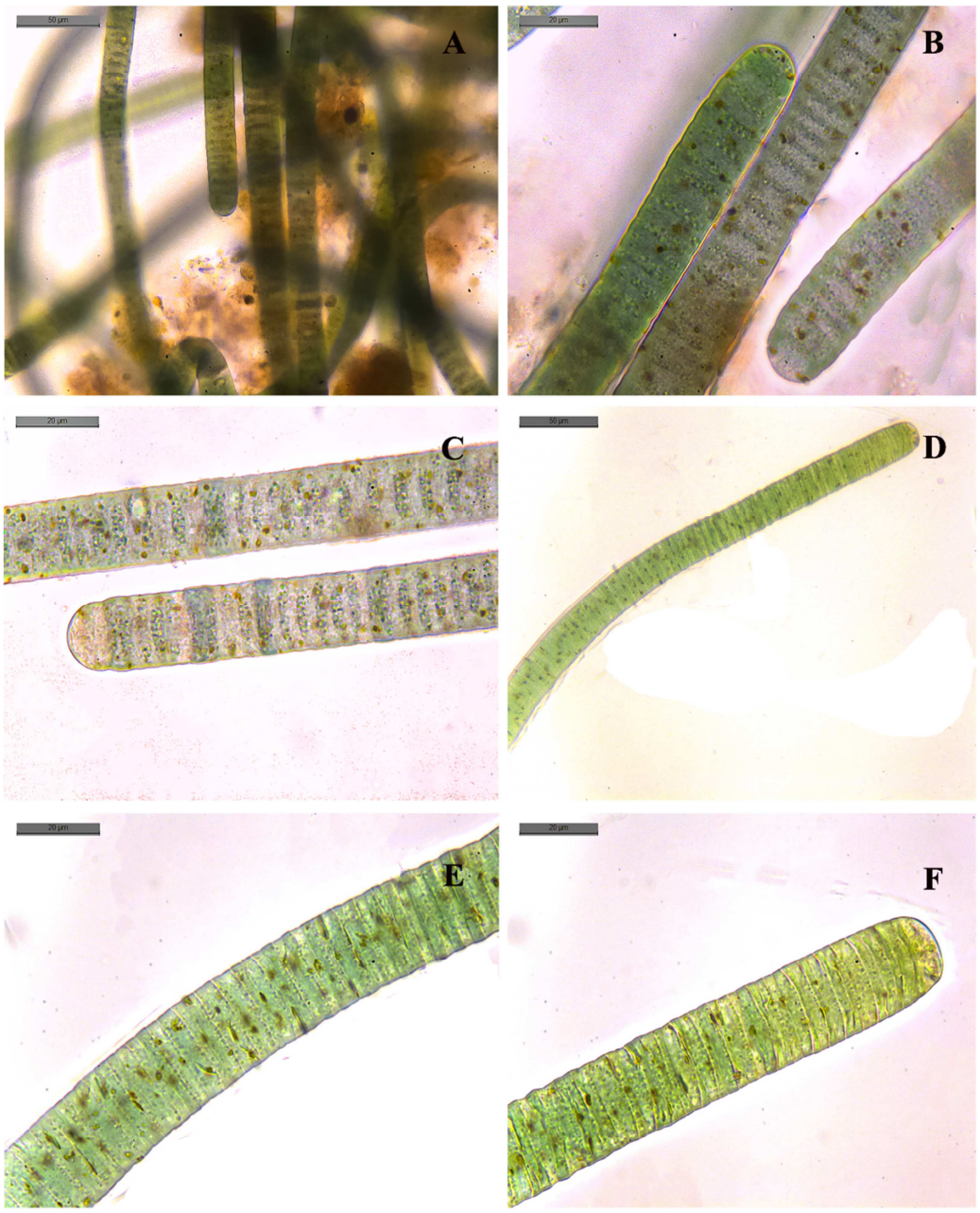


Fig. A-C. *Oscillatoria major* Vaucher ex Forti 1907**; D-F.** *Oscillatoria obtusa* N.L.Gardner 1927.

Plate 16

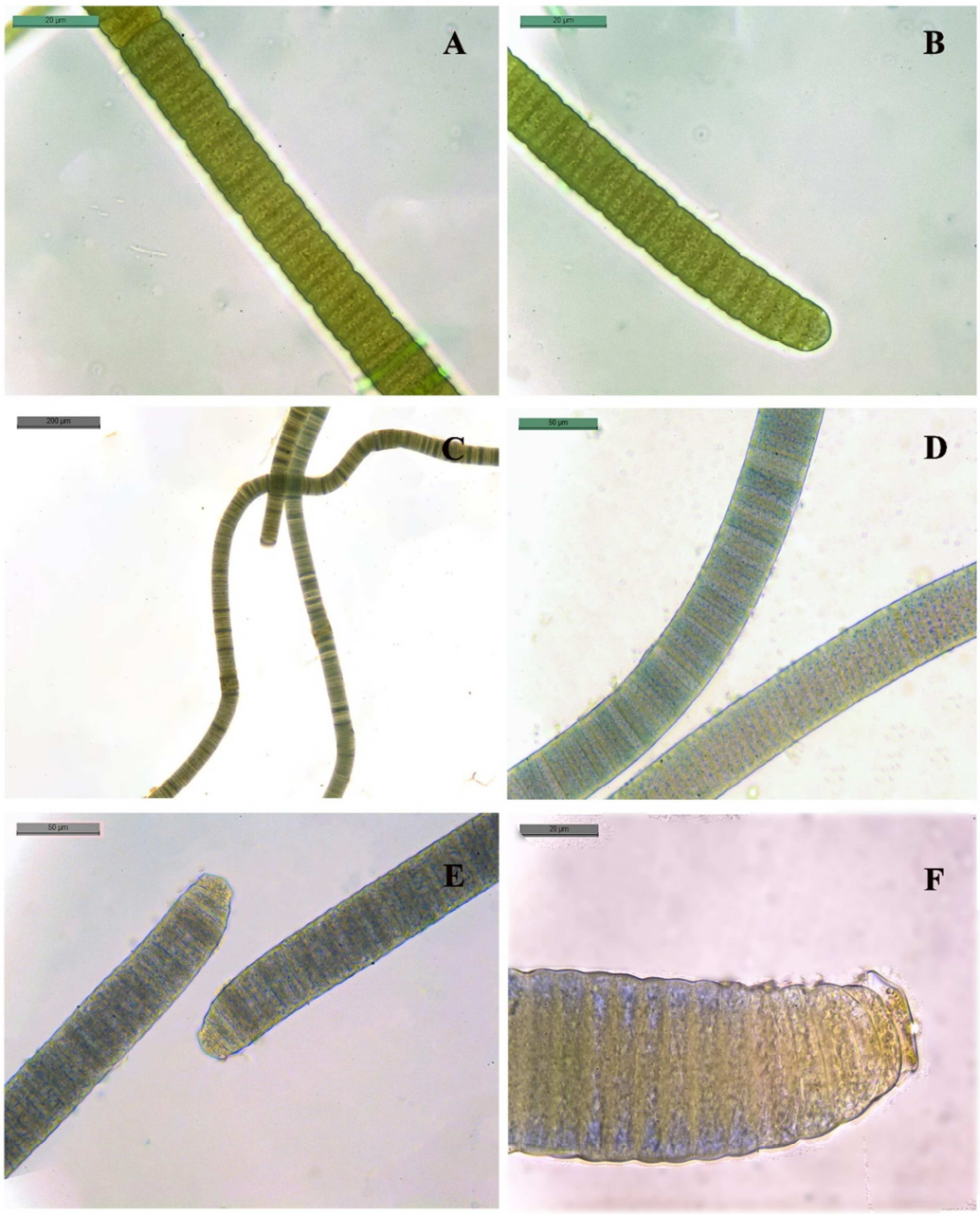


Fig. A-B. *Oscillatoria perornata* Skuja 1949**; C-F.** *Oscillatoria princeps* Vaucher ex Gomont 1892

Plate 17

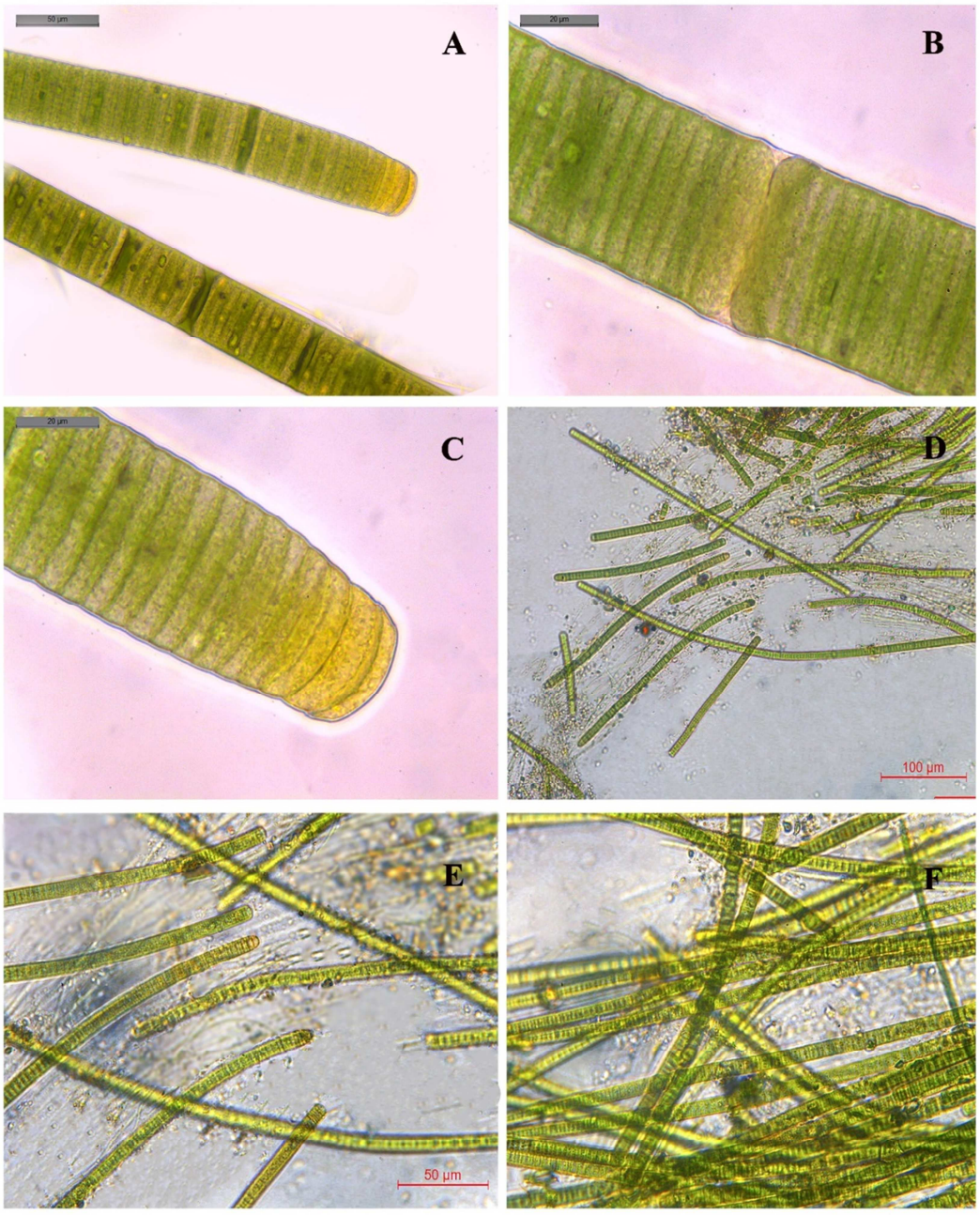


Fig. A-C. *Oscillatoria princeps* var. *pseudolimosa* Ghose 1924; **D-F.** *Oscillatoria rupicola* (Hansgirg) Hansgirg ex Forti 1907

Plate 18

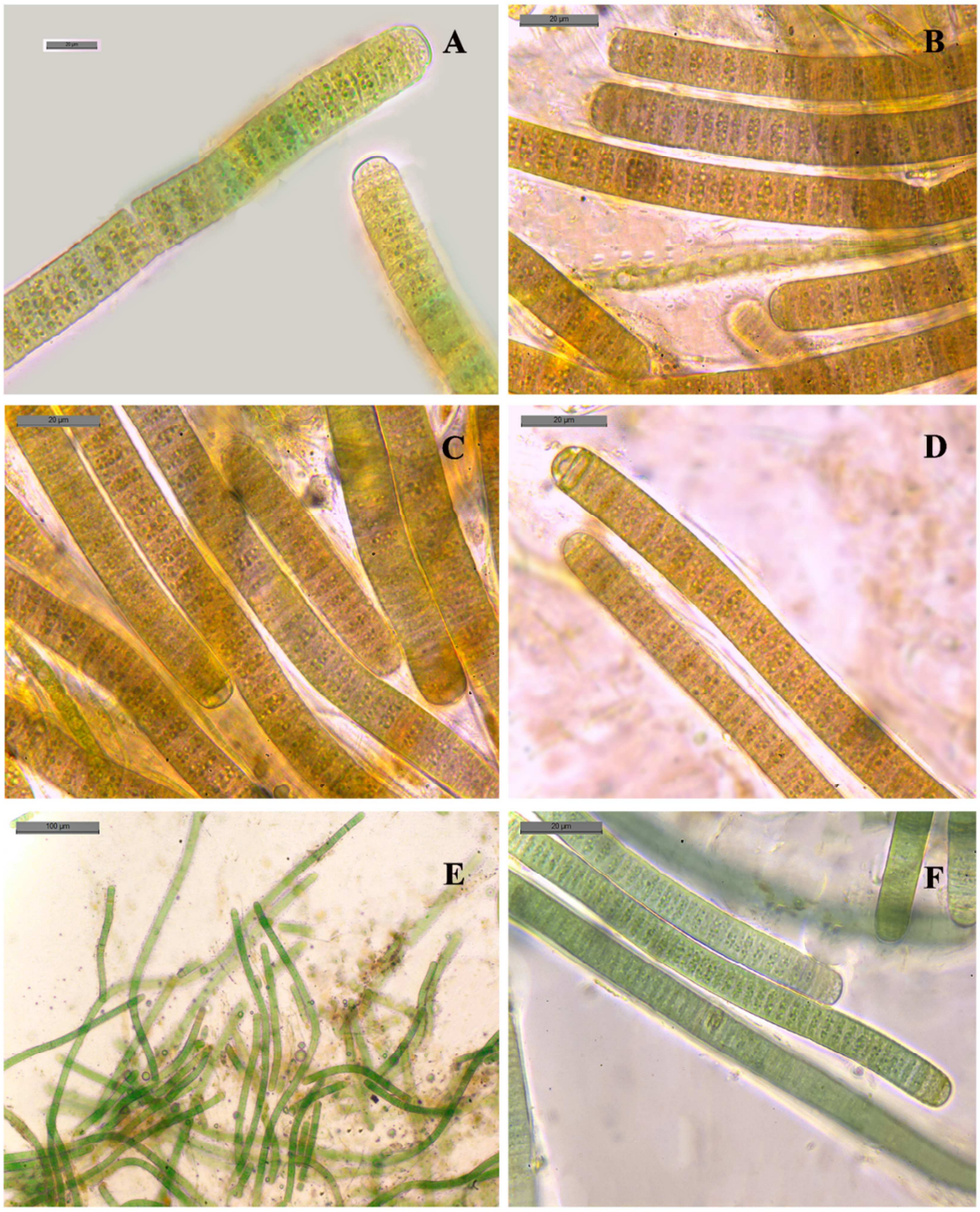


Fig. A. *Oscillatoria sancta* Kutzing ex Gomont 1892**; B-D.** *Oscillatoria simplicissima* Gomont 1892**; E-F.** *Oscillatoria subbrevis* Schmidle 1901

Plate 19

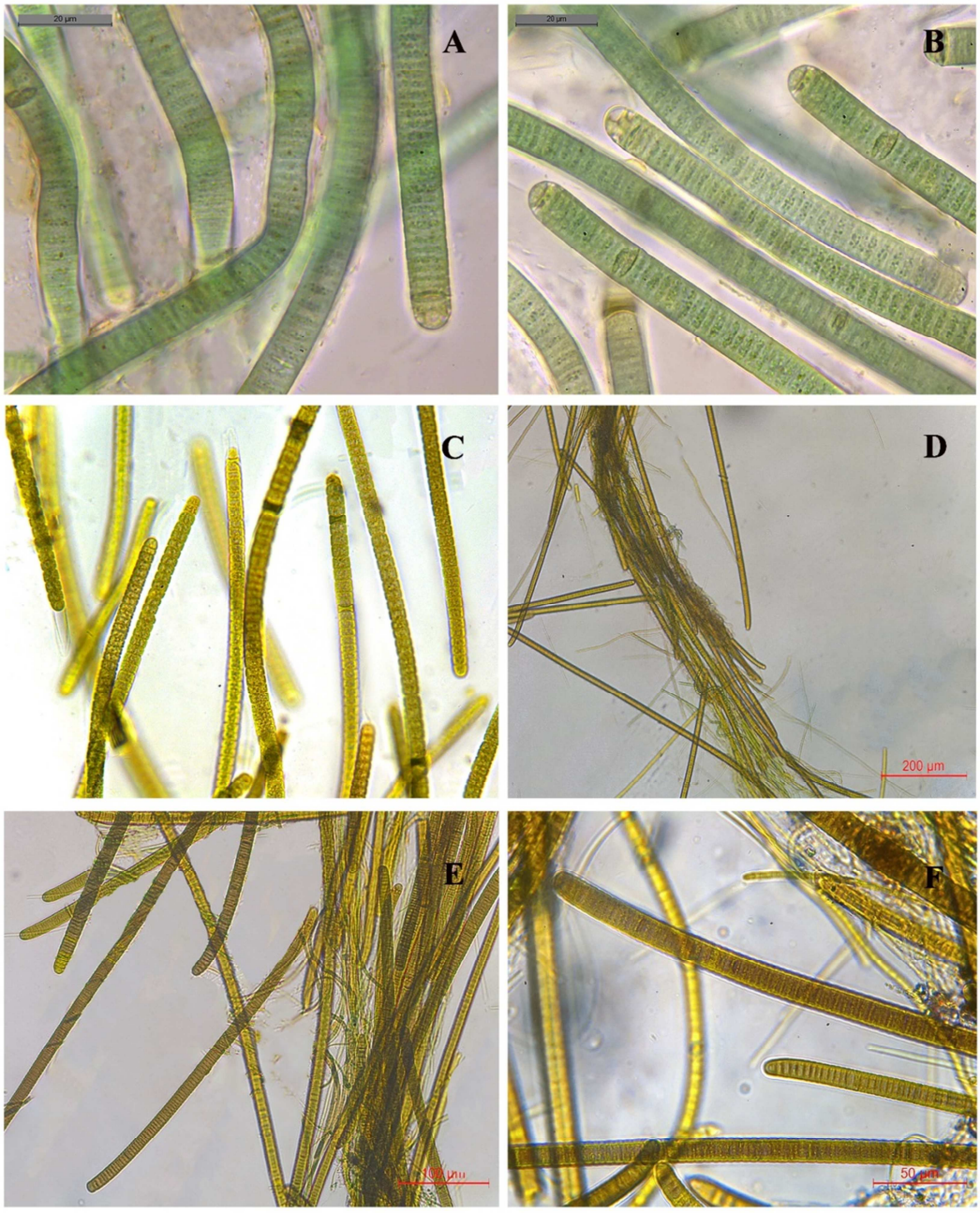


Fig. A-B. *Oscillatoria subbrevis* Schmidle 1901**; C.** *Oscillatoria tenuis* C.Agardh ex Gomont 1892**; D-F.** *Oscillatoria vizagapatensis* C.B.Rao 1938

Plate 20

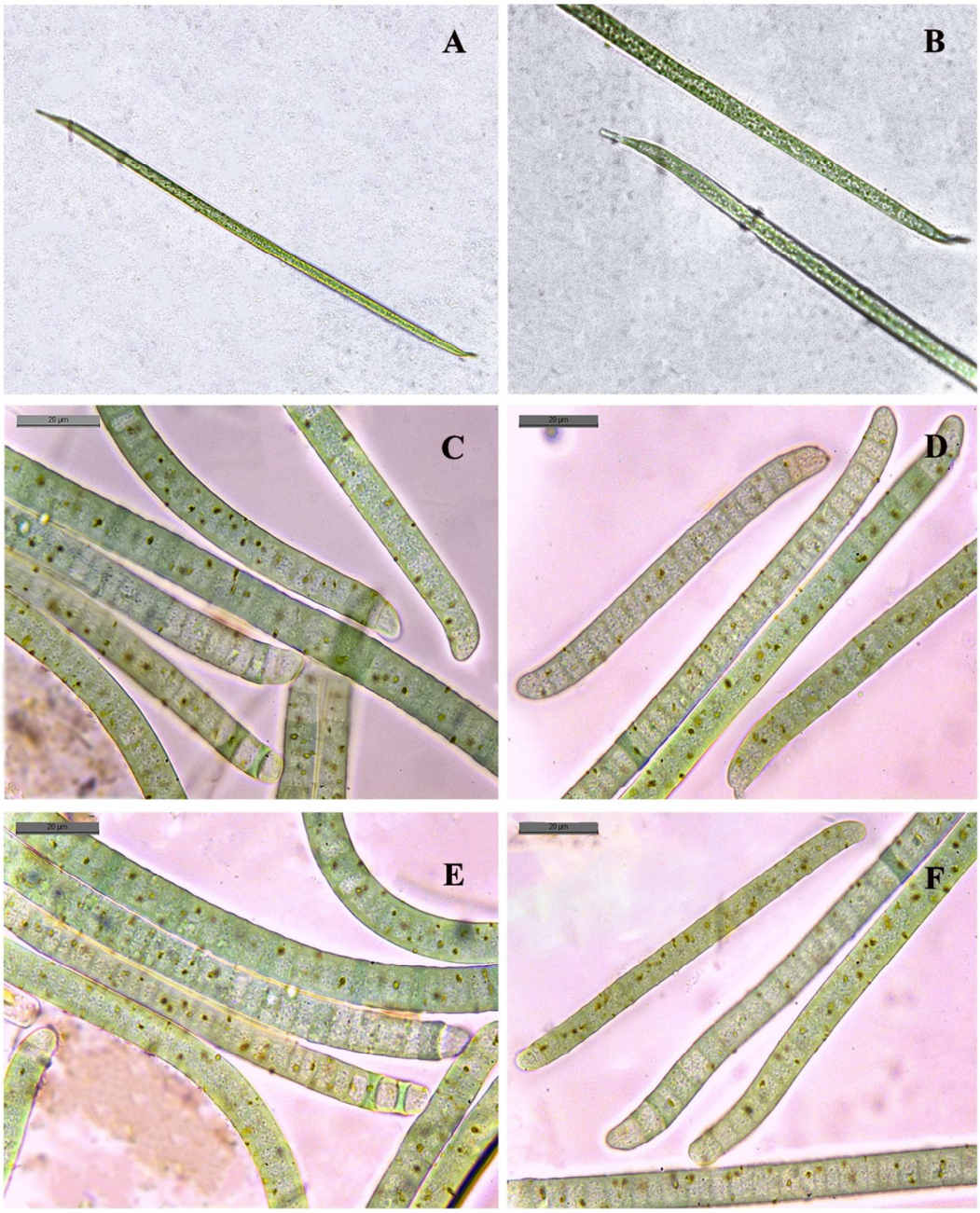


Fig. A-B. *Phormidium acula* (Bruhl & Biswas) Anagnostidis & Komárek 1988**; C-F.** *Phormidium chalybeum* (Mertens ex Gomont) Anagnostidis et Komarek 1988

Plate 21

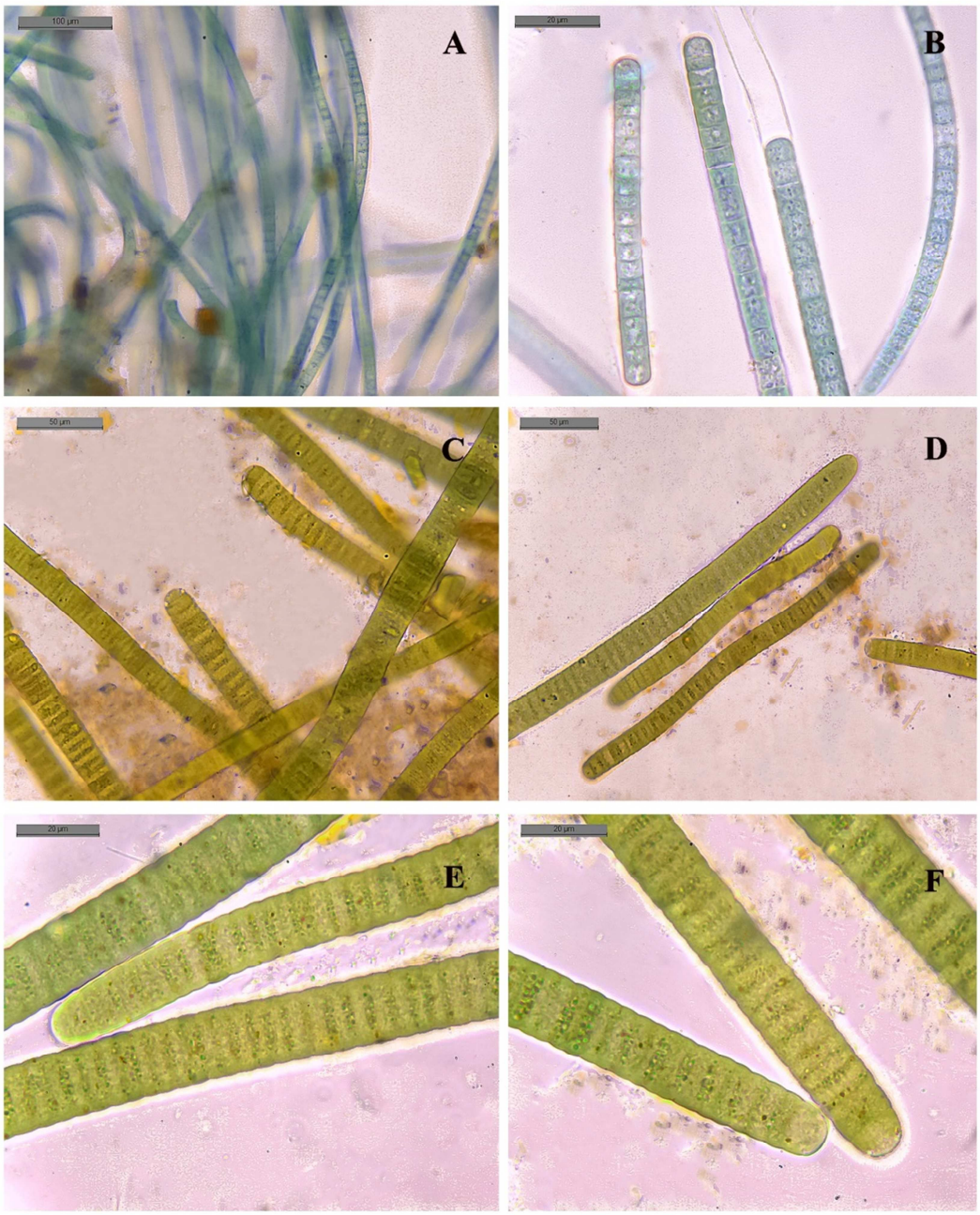


Fig. A-B. *Phormidium crassior* (Behre) Anagnostidis 2001**; C-F.** *Phormidium nigro-viride* (Thwaites ex Gomont) Anagnostidis & Komarek 1988

Plate 22

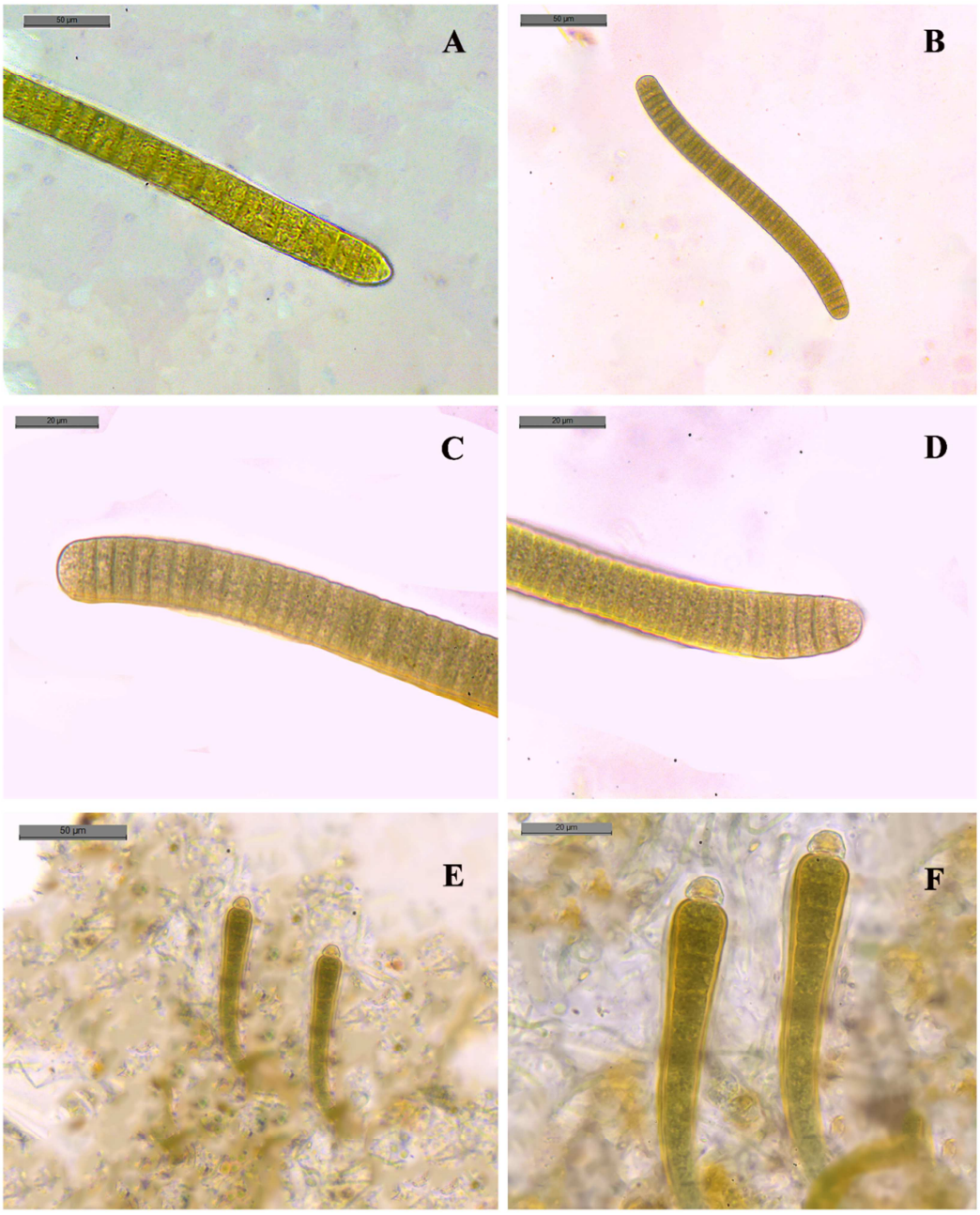


Fig. A. *Phormidium nigrum* (Vaucher ex Gomont) Anagnostidis & Komarek 1988**; B-D.** *Phormidium irriguum* (Kutzing ex Gomont) Anangnostidis et Komarek 1988**; E-F.** *Calothrix braunii* Bornet et Flahault 1886.

Plate 23

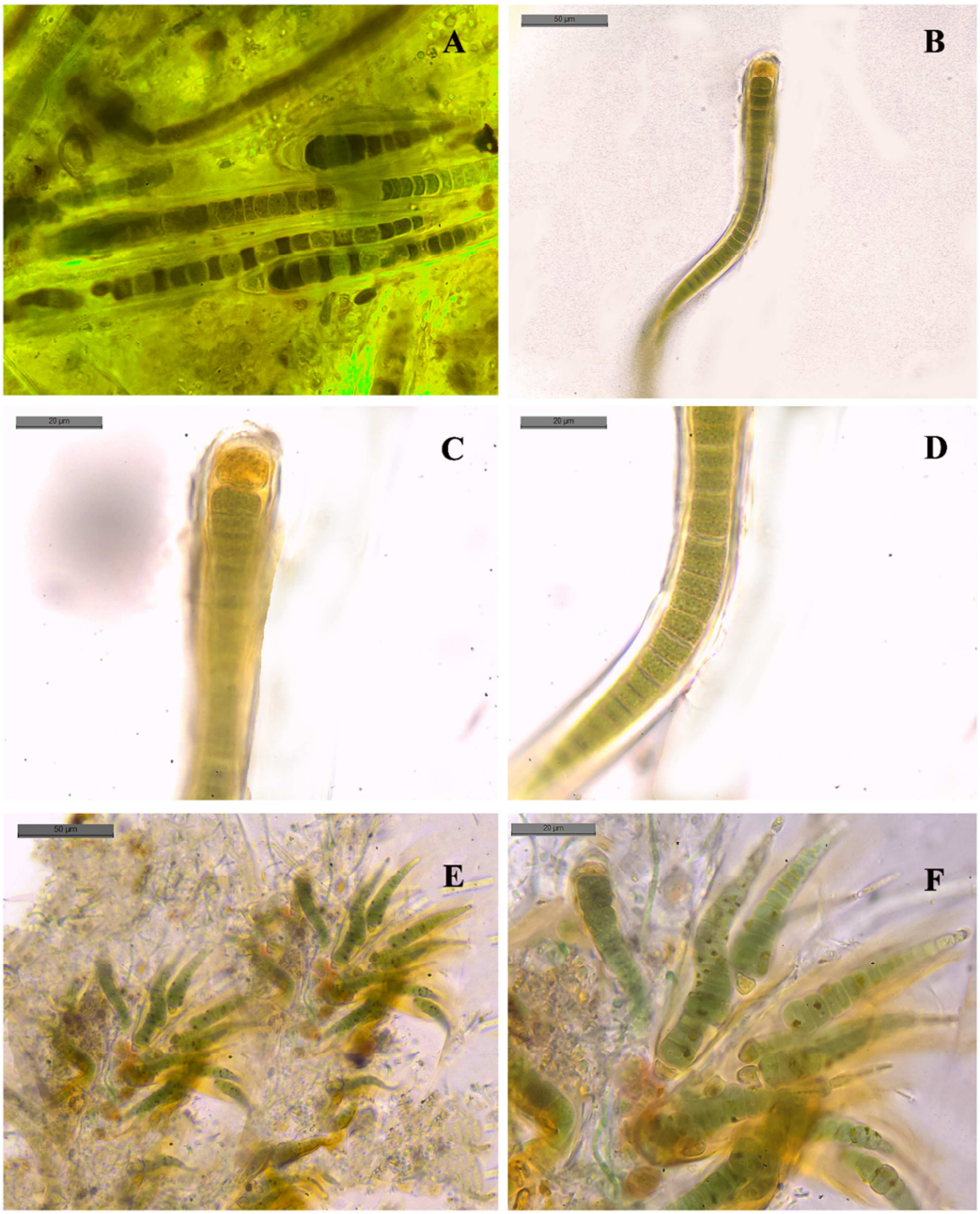


Fig. A. *Calothrix marchica* Lemmerman 1914**; B-D.** *Calothrix marchica* var. *intermedia* C.B.Rao 1937**; E-F.** *Calothrix nidulans* Setchell & N.L.Gardner 1924

Plate 24

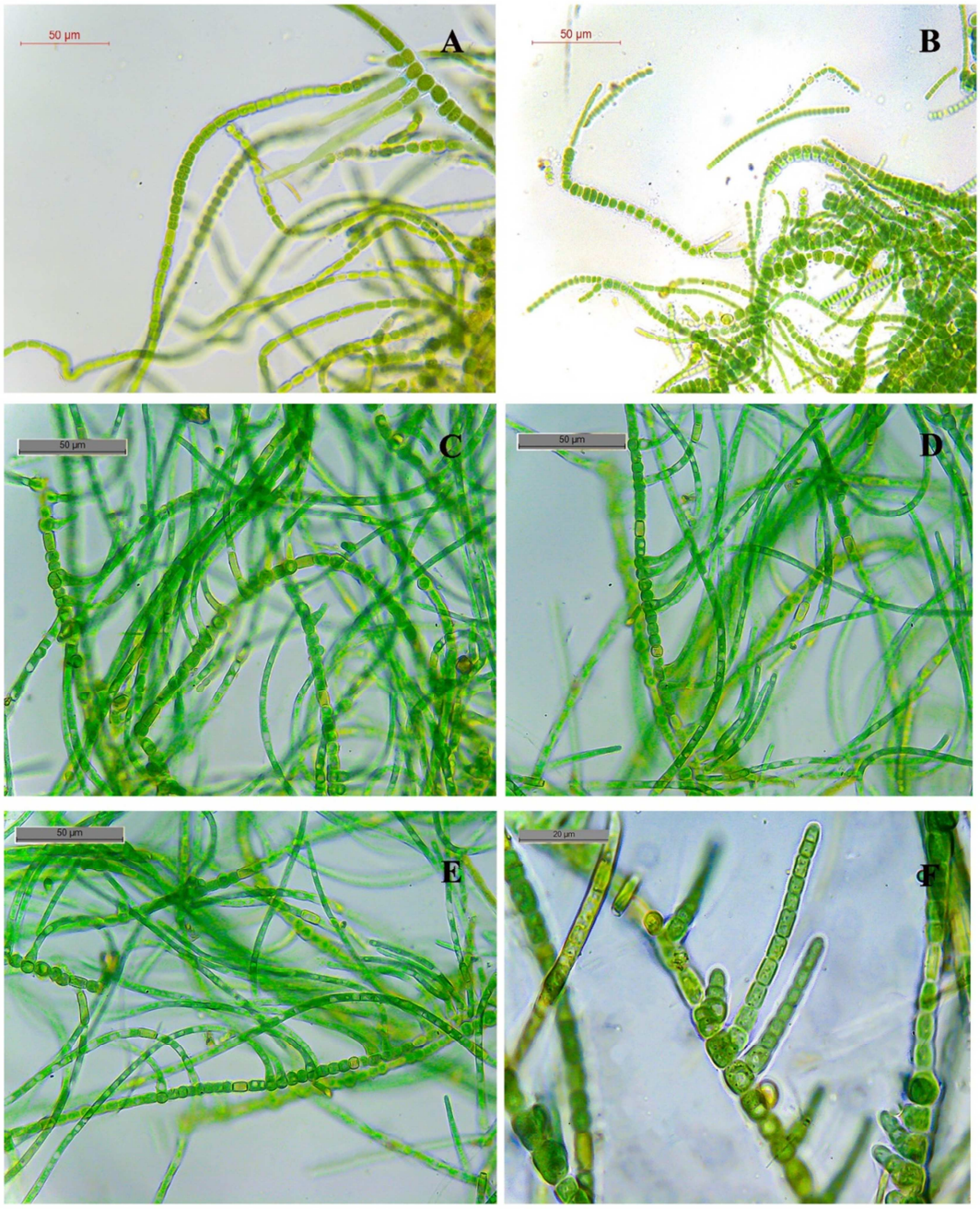


Fig. A. *Hapalosiphon welwitschii* West & G.S.West 1897**; B.** *Mastigocladus laminosus* Cohn ex Kirchner 1898**; C-F.** *Westiellopsis interrupta* Kanthamma 1972.

Plate 25

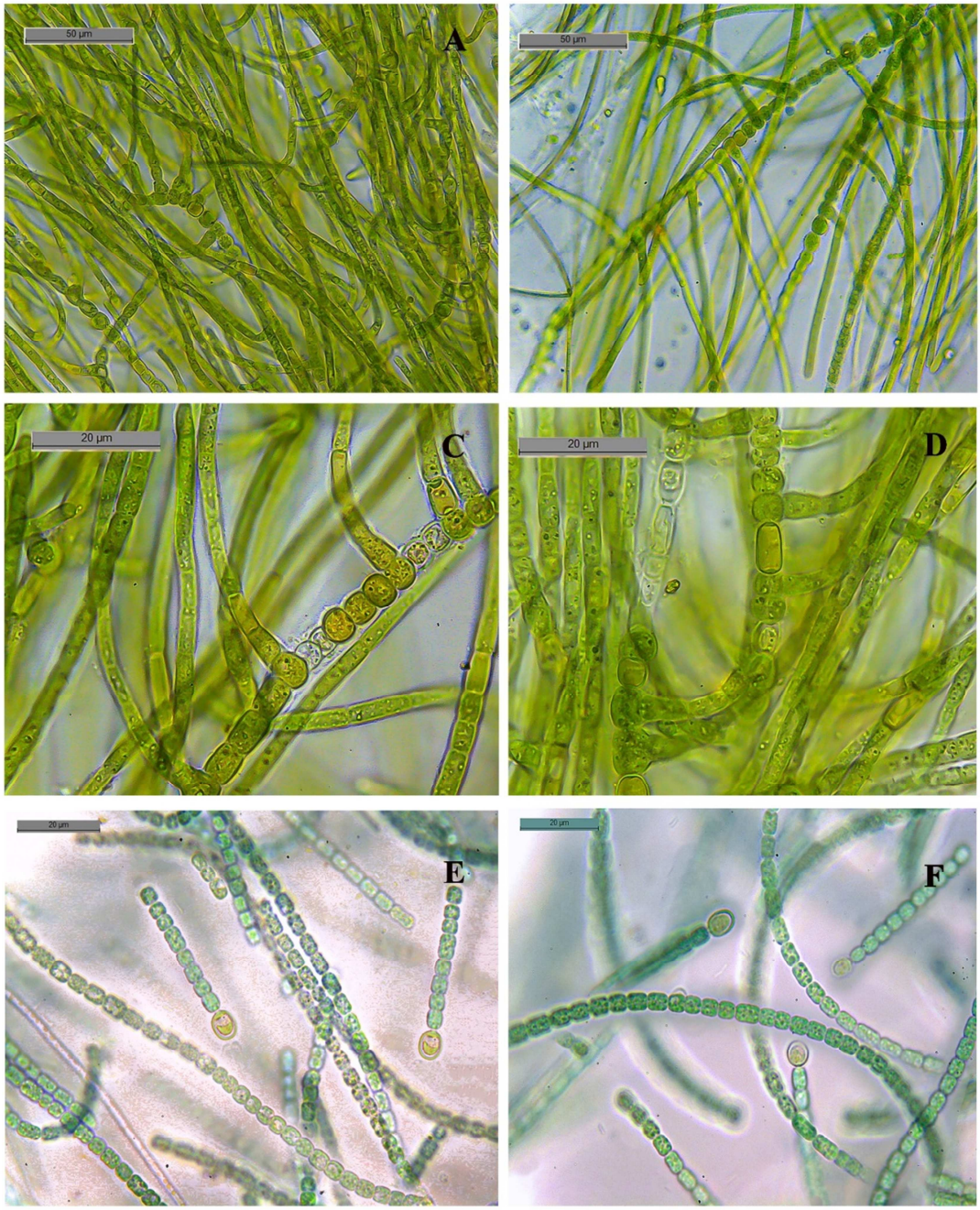


Fig. A-D. *Westiellopsis prolifica* Janet 1941**; E-F.** *Anabaena bispora* Gayral & Mazancourt 1958.

Plate 26

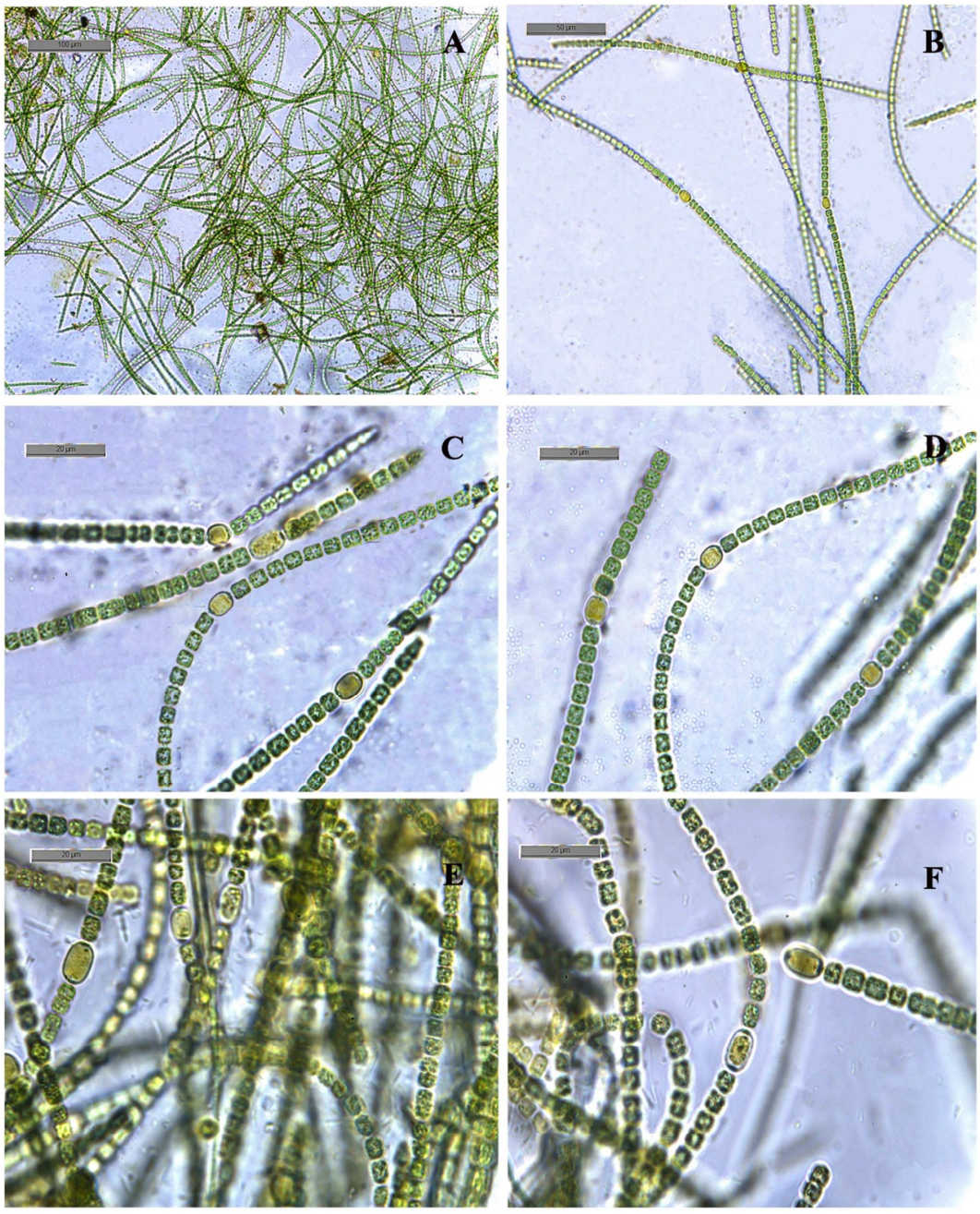


Fig. A-F. *Anabaena inaequalis* Bornet et Flahault 1886

Plate 27

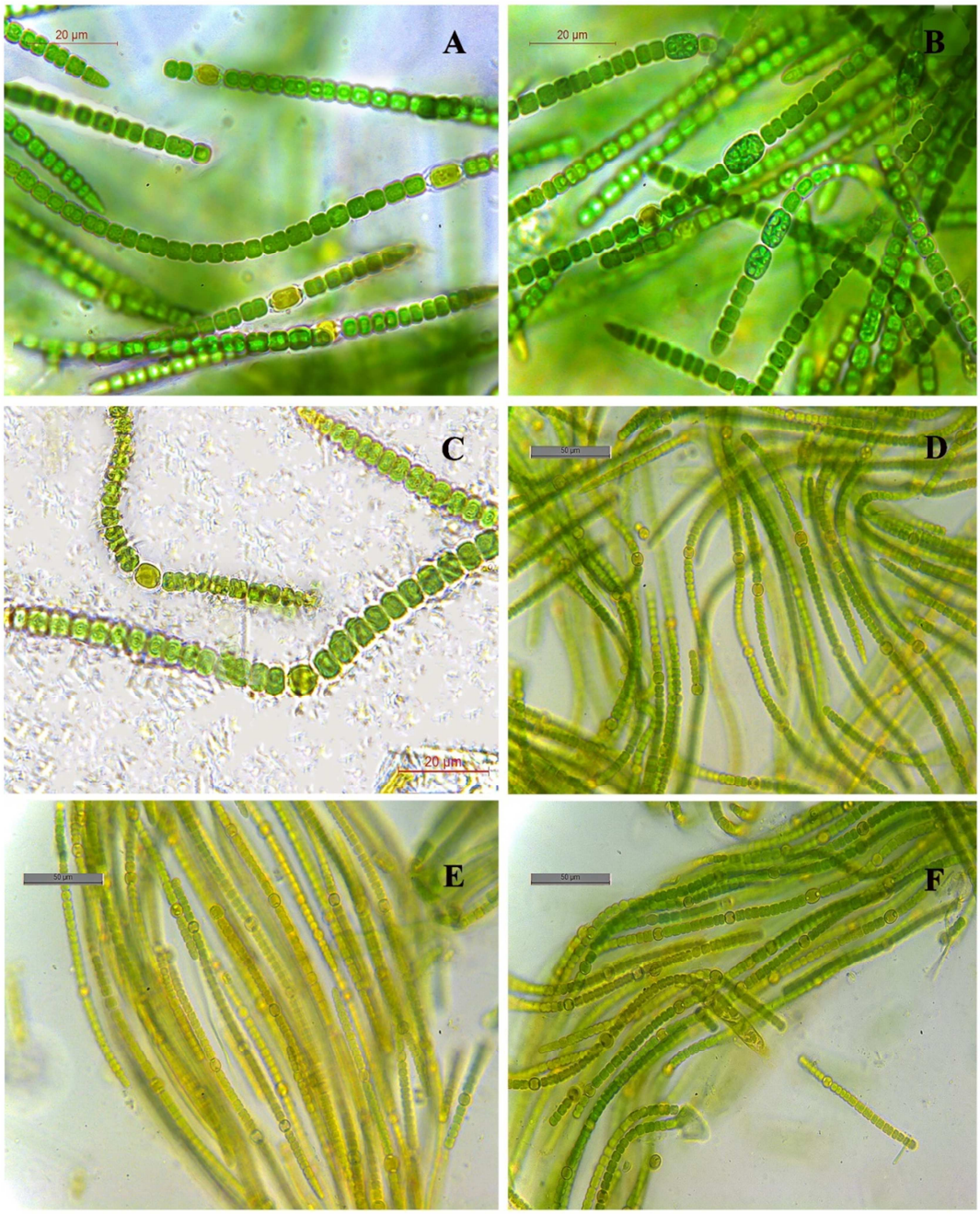


Fig. A-B. *Anabaena laxa* A.Braun 1886**; C.** *Anabaena sedovii* Kossinskaja 1933**; D-F.** *Anabaena torulosa* (Carmichael) Lagerheim ex Bornet et Flahault 1886

Plate 28

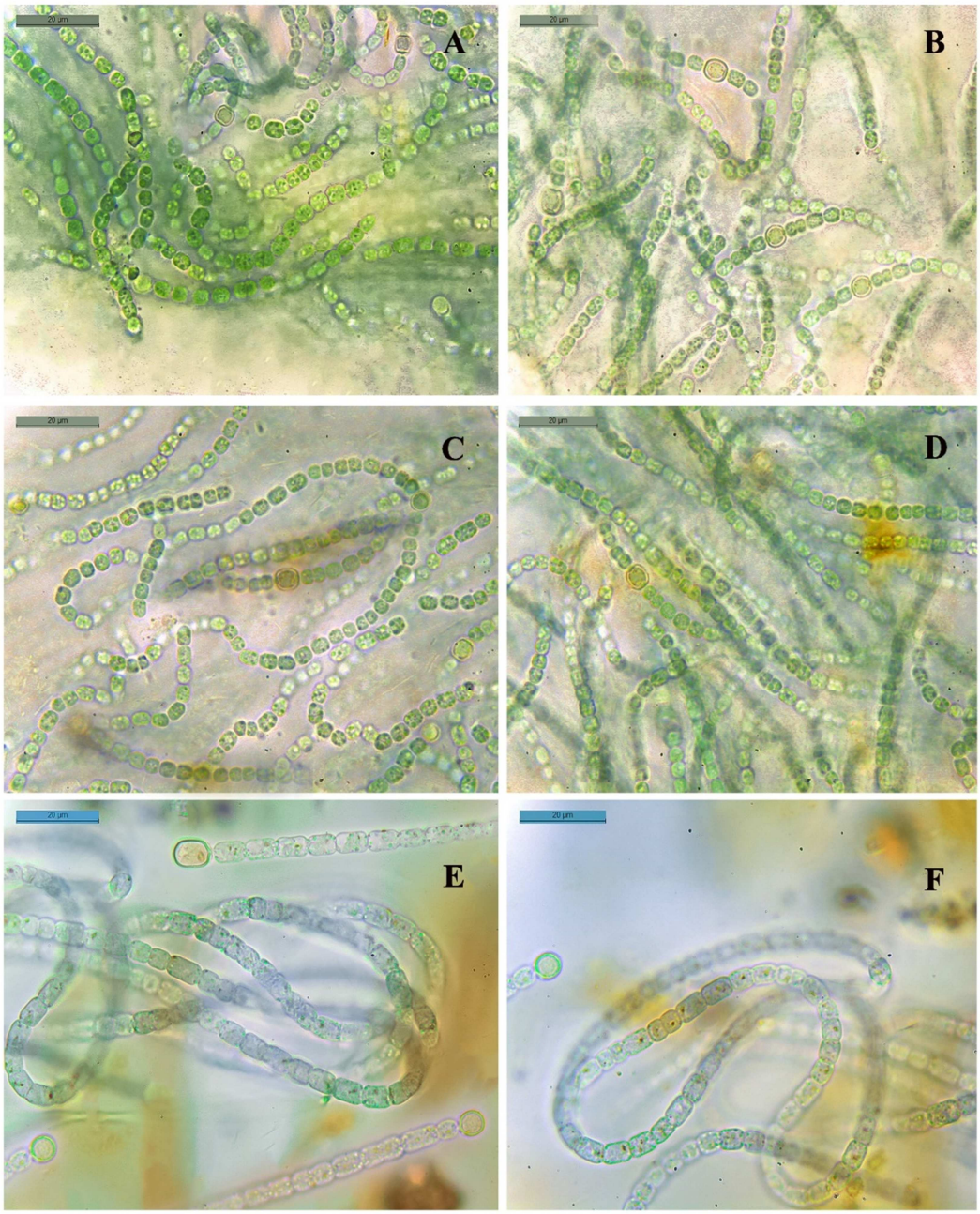


Fig. A-D. *Desmonostoc muscorum* (C.Agardh ex Bornet & Flahault) Hrouzek et Ventura 2013**;** **E-F** *Nostoc bornetii* Gain 1911

Plate 29

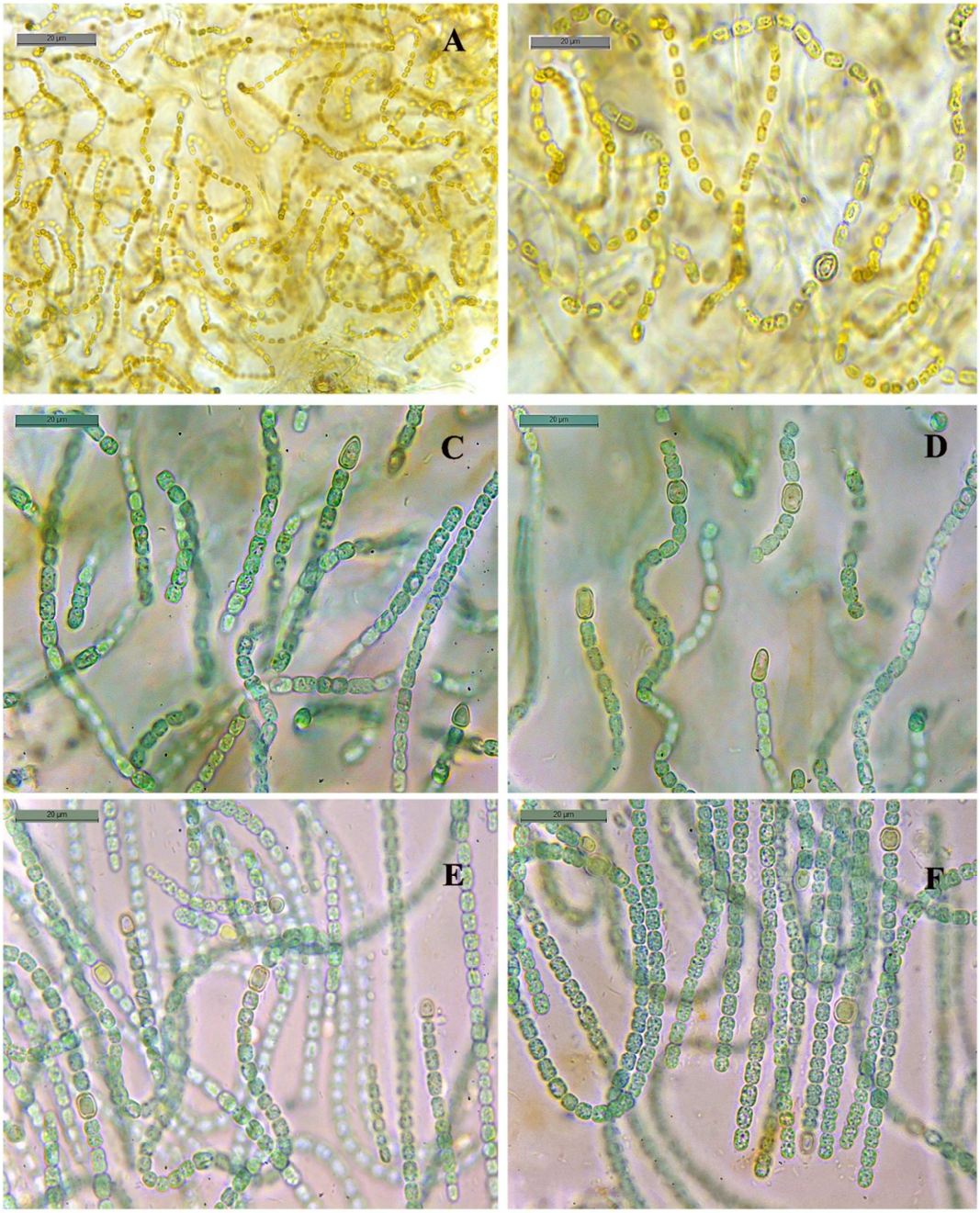


Fig. A-B. *Nostoc calcicola* Brebisson ex Bornet et Flahault 1886**; C-D.** *Nostoc carneum* (Lyngbye) Agardh ex Bornet et Flahault 1886**; E-F.** *Nostoc commune* Vaucher ex Bornet et Flahault 1888

Plate 30

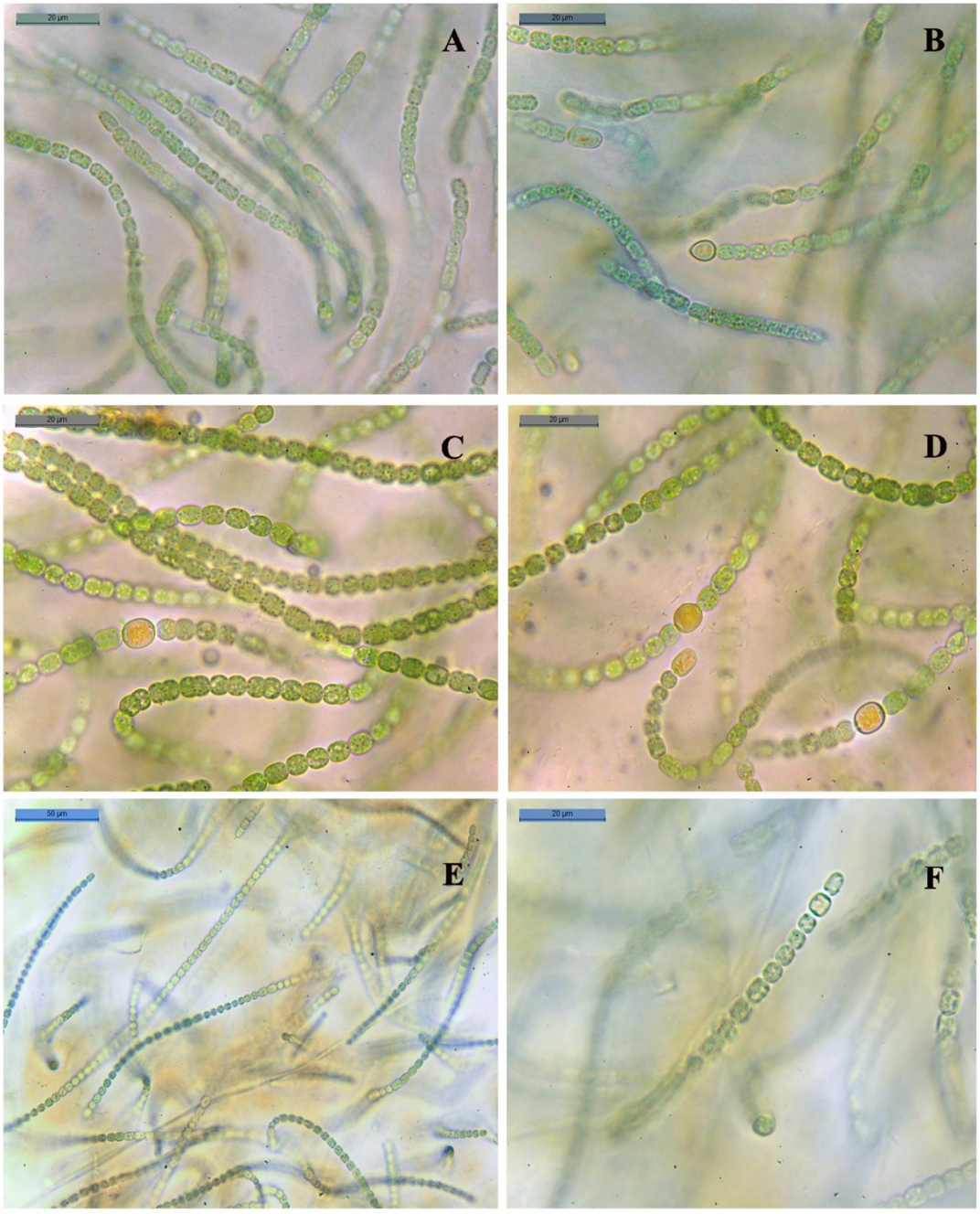


Fig. A-B. *Nostoc ellipsosporum* (Demazieres) Rabenhort ex Bornet et Flahault 1886**; C-D.** *Nostoc linckia* (Roth) Bornet et Flahault 1886**; E-F.** *Nostoc sphaericum* Vaucher ex Bornet et Flahault 1886

Plate 31

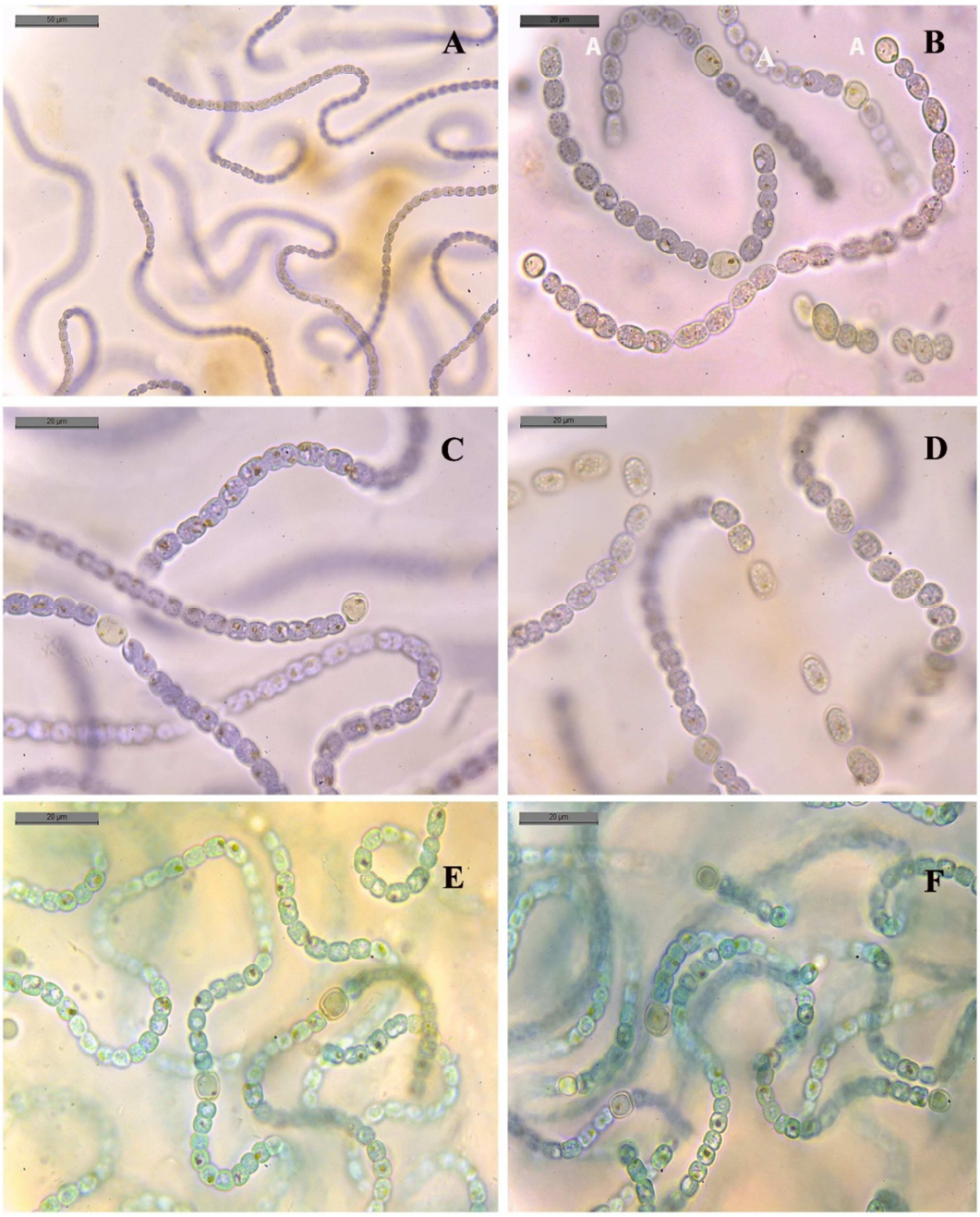


Fig. A-D. *Nostoc spongiaeforme* var. *varians* C.B.Rao 1937**; E-F.** *Nostoc undulatum* Archibald 1967

Plate 32

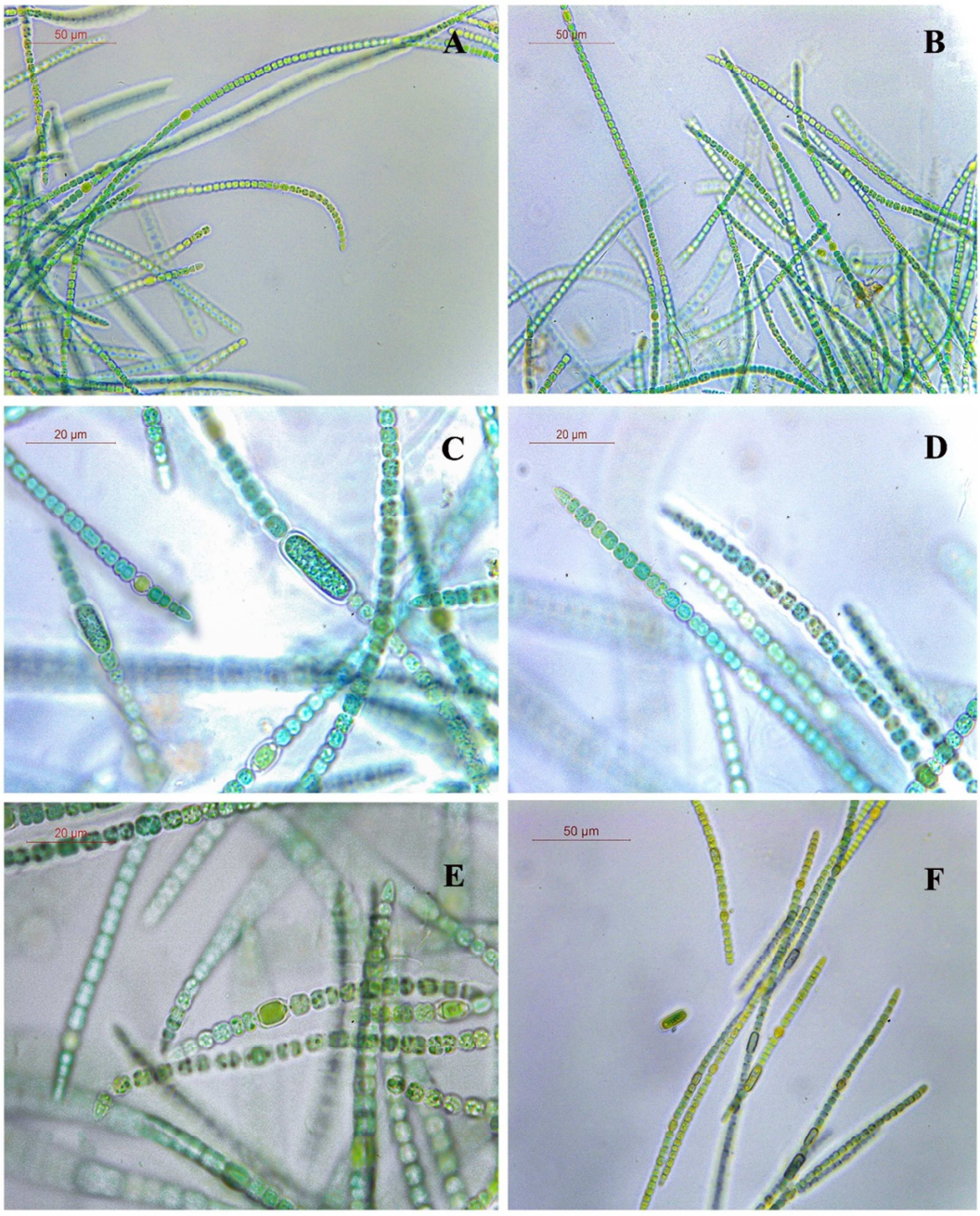


Fig. A-E. *Trichormus ellipsosporus* (Fritsch) Komarek et Anagnostidis 1989**; F.** *Trichormus kashiensis* (Bharadwaja) Komarek 2012

Plate 33

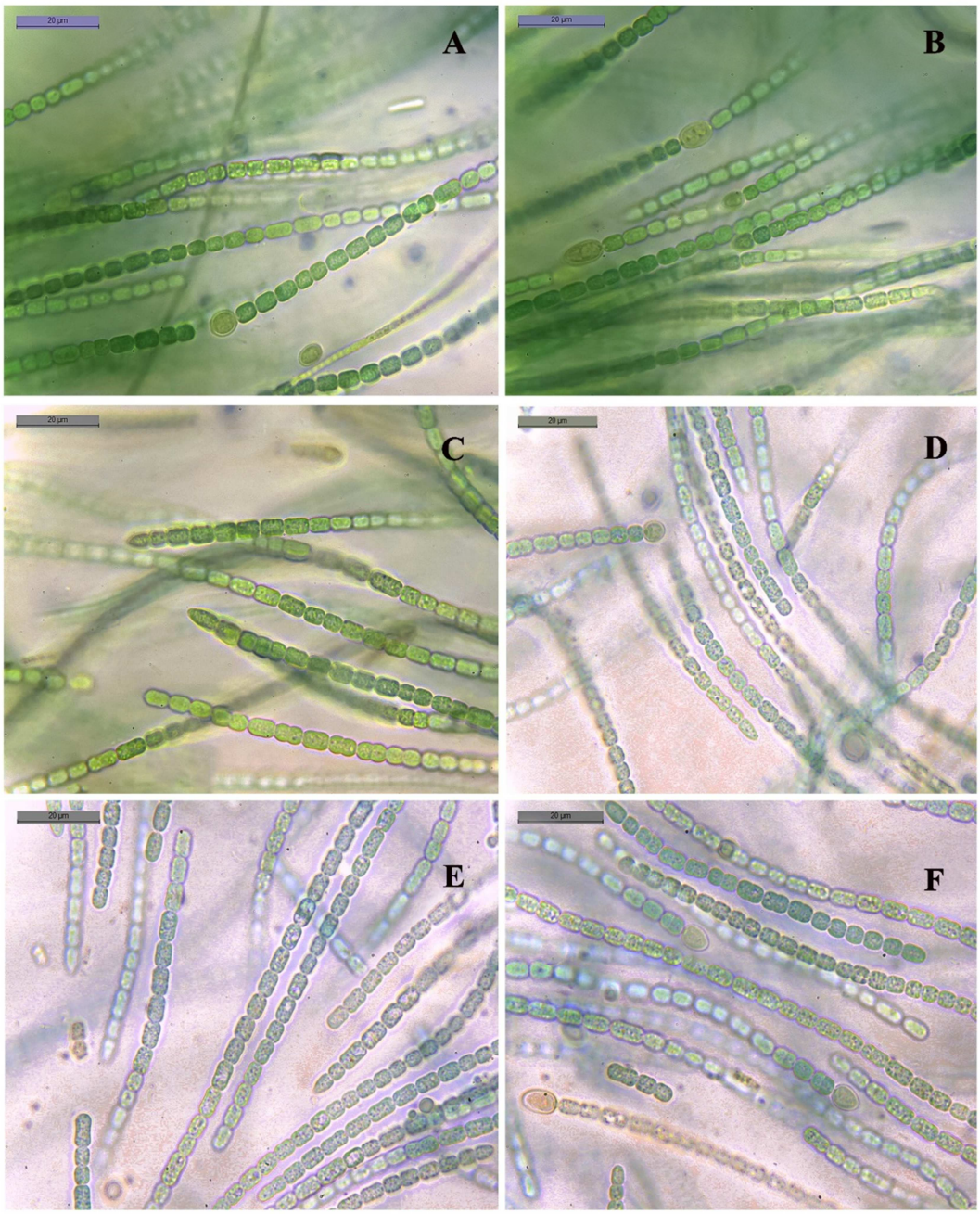


Fig. A-C. *Trichormus pseudovariabilis* (Woronichin) Komarek et Anagnostidis 1989; **D-F.** *Trichormus rotundosporus* (Hollerbach) Komarek & Anagnostidis 1989

Plate 34

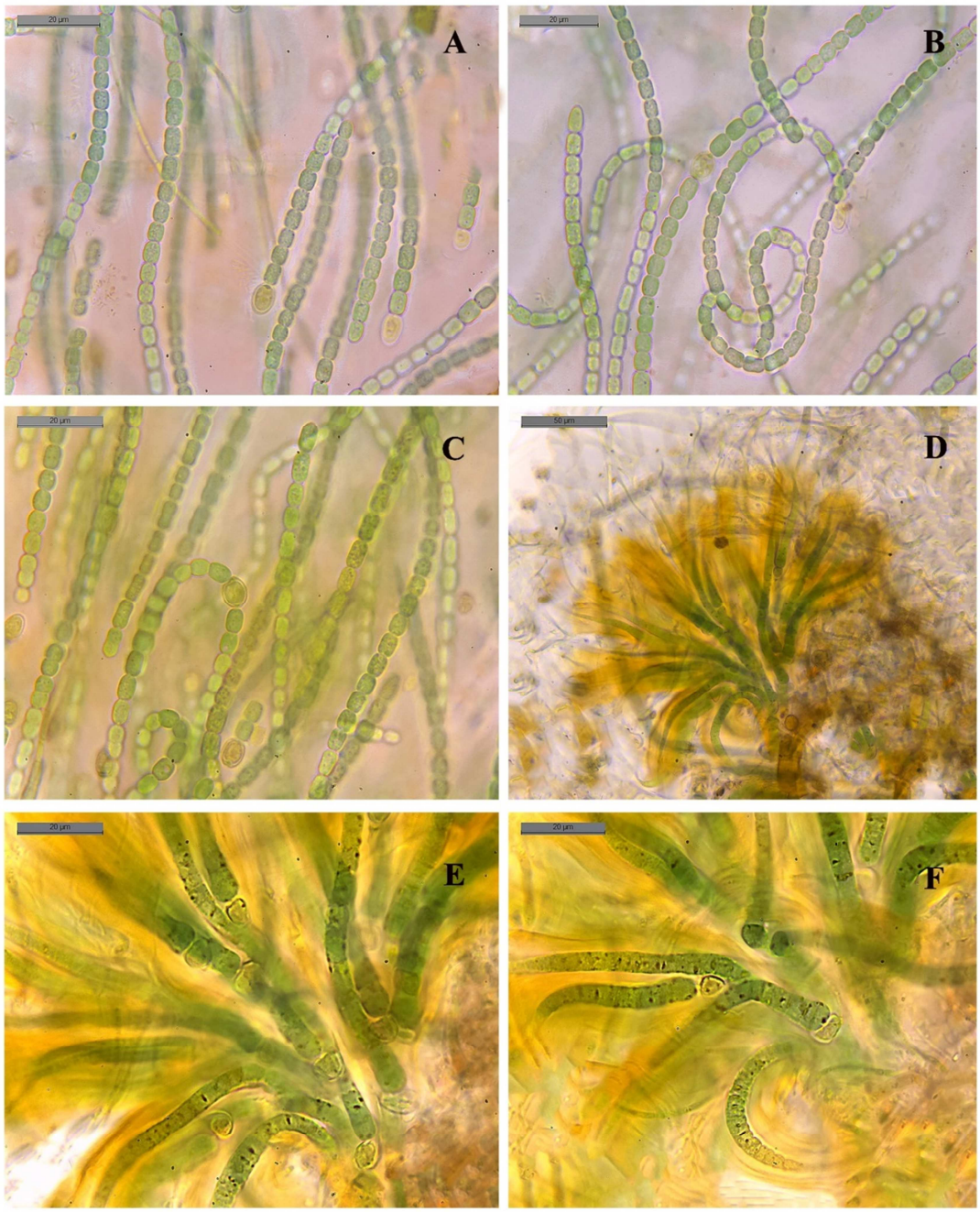


Fig. A-C. *Trichormus variabilis* (Kutzing ex Bornet et Flahault) Koamarek et Anagnostidis 1989**;** **D-F**. *Dichothrix orsiniana* (Kutz) Bornet et Flahault 1886

Plate 35

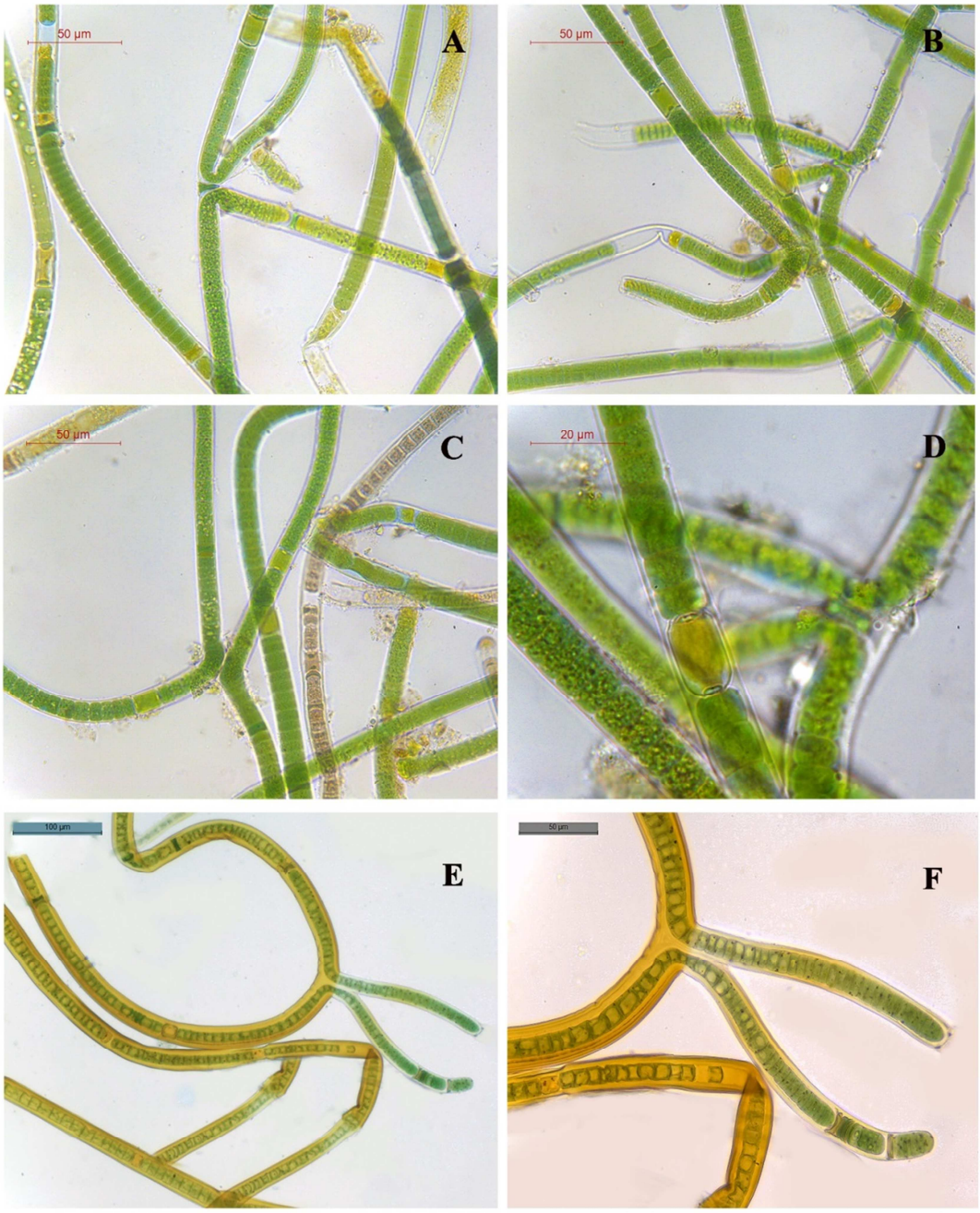


Fig. A-D. *Scytonema bohneri* Schmidle 1901; E-F. *Scytonema coactile* Montagne ex Bornet et Flahault 1886.

Plate 36

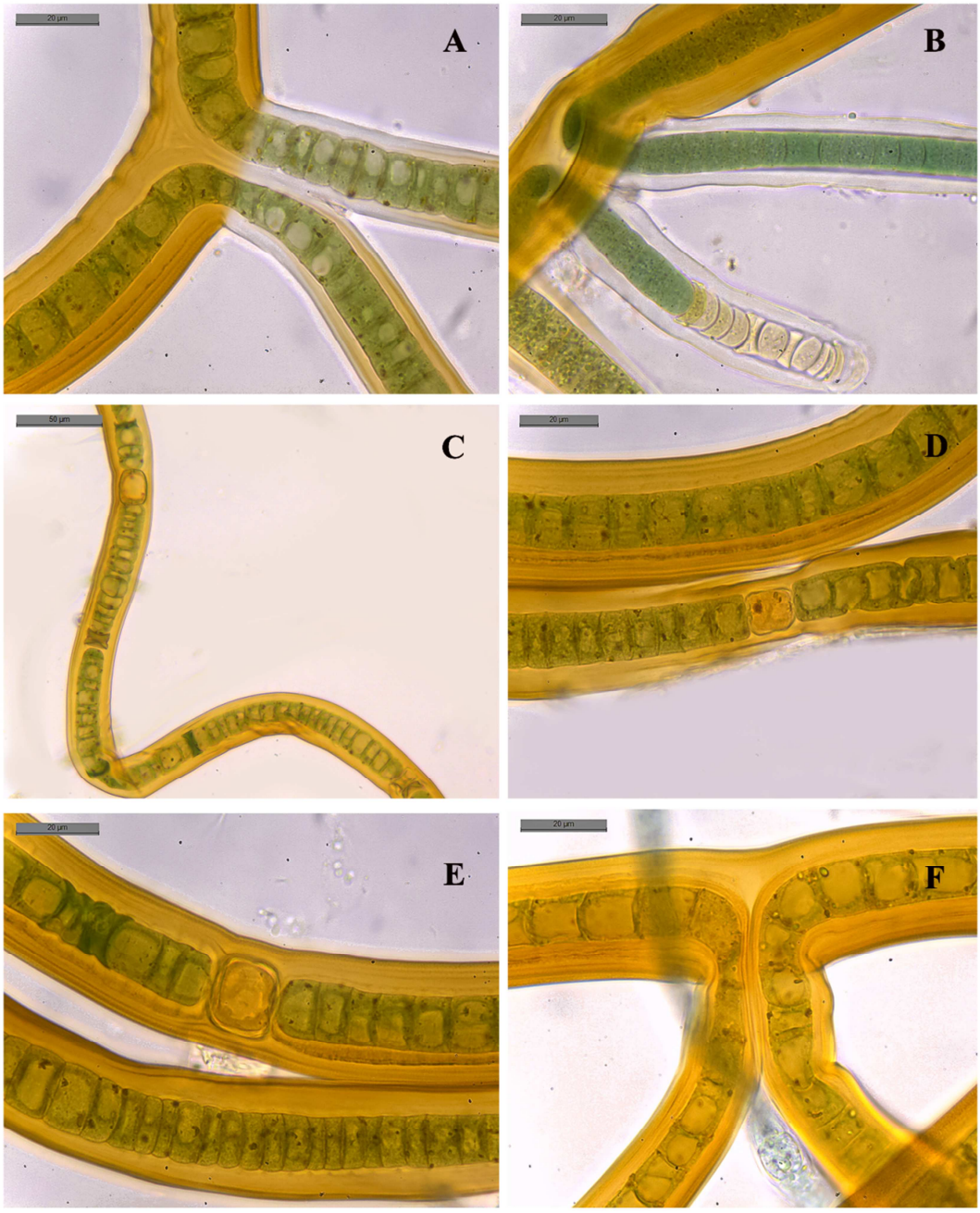


Fig. A-F. *Scytonema coactile* Montagne ex Bornet et Flahault 1886

Plate 37

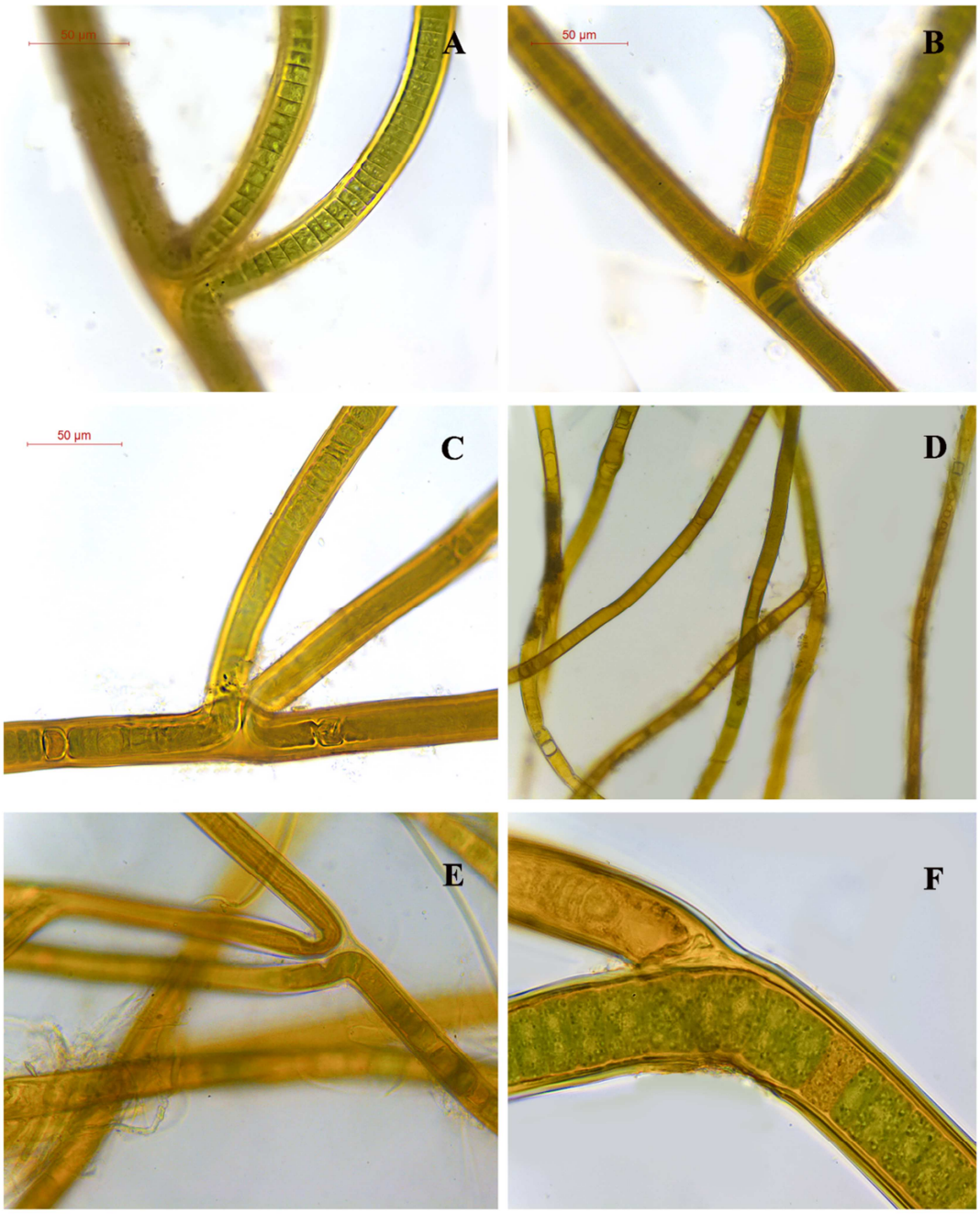


Fig. A-C. *Scytonema javanicum* Bornet ex Bornet & Flahault 1886**; D-F.** *Scytonema millei* Bornet ex Bornet & Flahault 1886

Plate 38

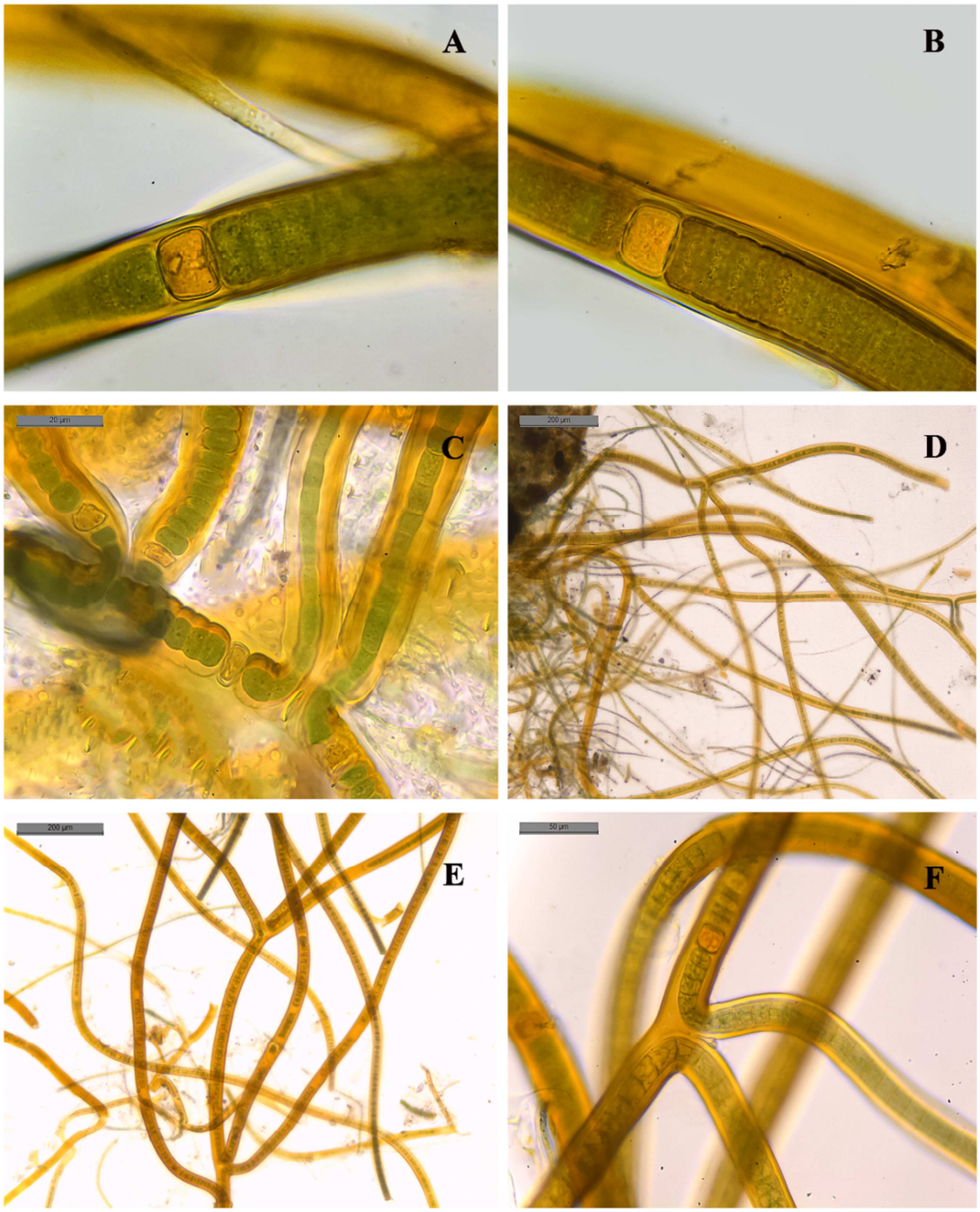


Fig. A-B. *Scytonema millei* Bornet ex Bornet & Flahault 1886; C. *Scytonema* sp.; D-F. *Scytonema tolypothrichoides* Kützing ex Bornet & Flahault 1886

Plate 39

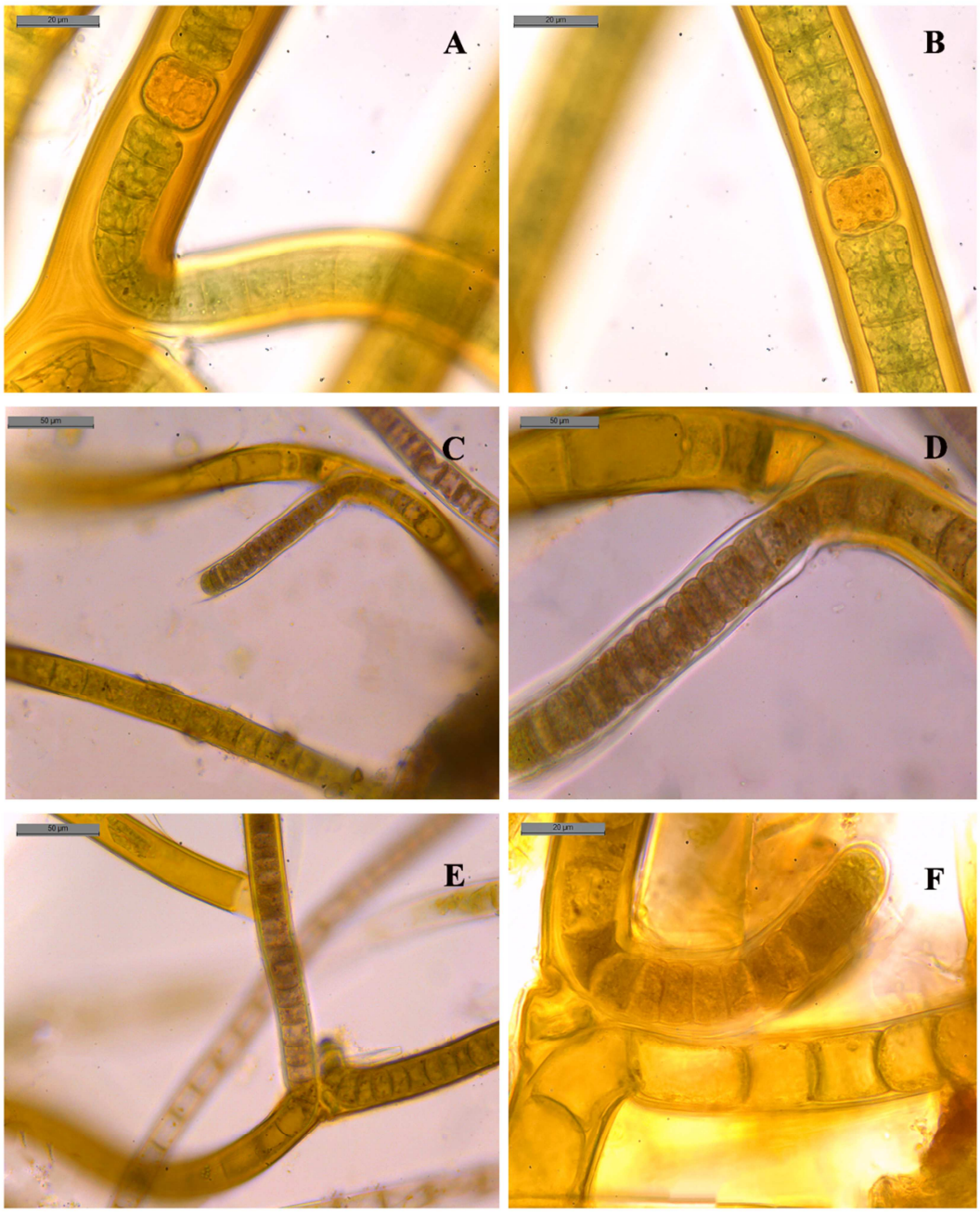


Fig. A-B. *Scytonema tolypothrichoides* Kützing ex Bornet & Flahault 1886; **C-F.** *Scytonema varium* Kutzing ex Bornet et Flahault 1886

Plate 40

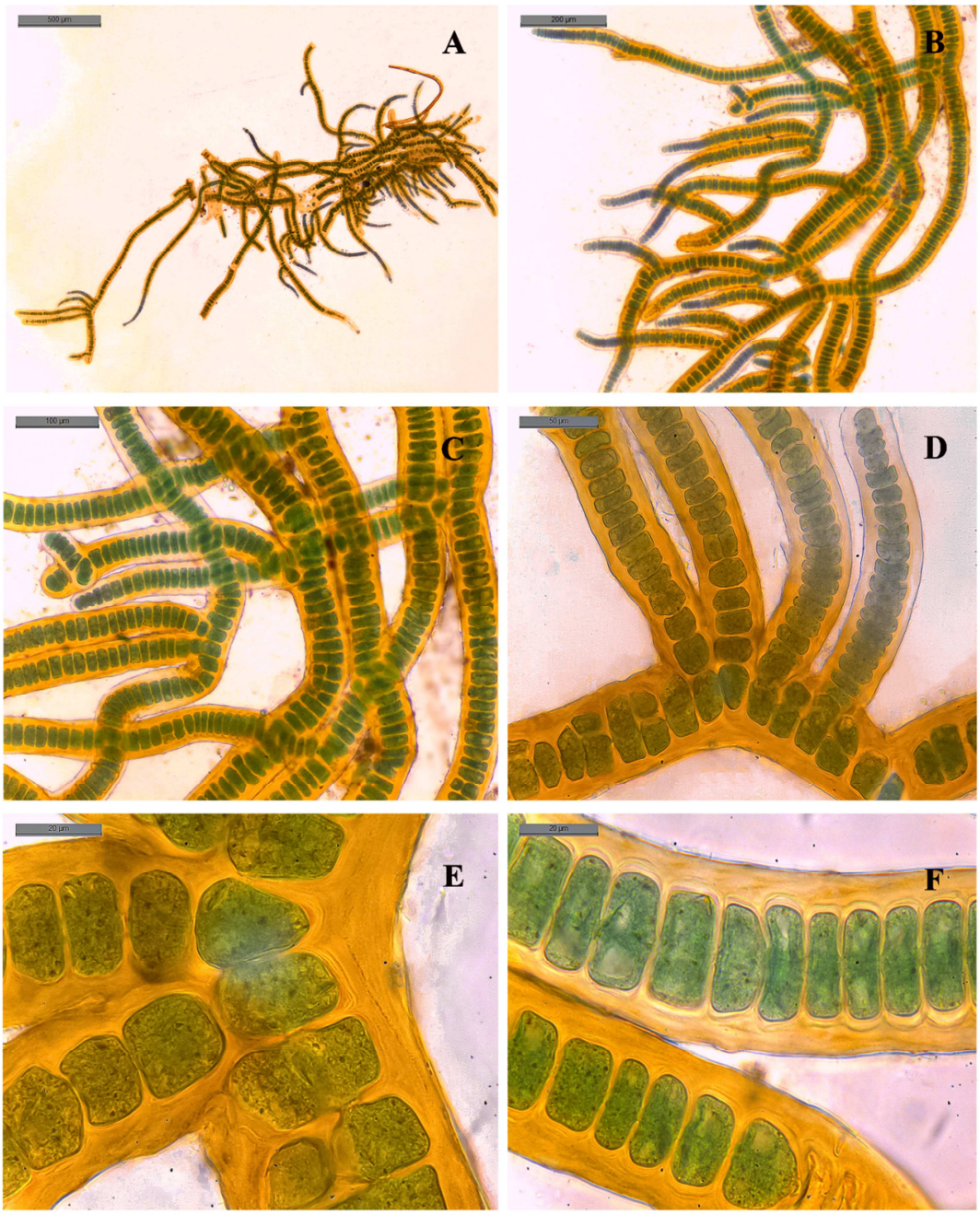


Fig. A-F. *Stigonema ocellatum* (Dillwyn) Thuret ex Bornet & Flahault 1886

4.2. Discussion

Conservation of coastal ecosystems on a global scale is a concern of scientists, ecologists and organizations like UNESCO, UNEP, IUCN etc. The mangrove forests formed on river deltas along the coastal regions have very strong protection against wind and tidal forces, which could otherwise affect the human population in different climatic seasons, due to their complexity. The mangrove ecosystem was one of the most resourceful systems that have been exploited through human and other interventions. Although mangroves are common in Kerala as in other regions, most of the research has been focused only on vegetation, taxonomy and ecology. There has been no exclusive research conducted on the diversity of cyanobacteria in the mangrove environments of Kerala. The present study is on the selected mangrove environments of southern Kerala. A total of 89 species from the different habitats of the mangrove ecosystems were recorded during the period of the present study (Table 4.1. & 4.3.)

4.2.1. Habitat

Cyanobacteria occur in diverse areas and are found in a wide range of habitats, including the extremely cold deserts of the Arctic and Antarctic zones and the very extreme hot springs, thus representing their life form in diverse habitats of various aquatic and terrestrial environments (Dyer & Gafford, 1961, Amarouche-Yala et al., 2014; Vincent et al., 1993; Zaki et al., 2020).

Marine species benefit from mangroves as they provide both a physical environment and nutrients. Thus, they can act as a shelter for many organisms. Pneumatophores and prop roots significantly increase the accessible surface area and provide a hard substrate in contrast to the surrounding mud, while mangrove primary production provides an energy source for numerous species (Hogarth, 2015). Besides mangrove pneumatophores, aerial roots, trunks and mangrove soil also provide a suitable place for fungi, diatoms, algae and cyanobacteria. Desikachary (1959) found that probably 20% of the known cyanobacteria occur in saline situations, the majority of which are truly marine. Cyanobacteria can be found in a variety of colours in nature, including blue-green, blackish green, dark green, brown, violet, and purple. This colouration of cells is determined by the types and

the ratio in which these pigments are present and the range of wavelengths absorbed by the photosynthetic apparatus. Cyanobacteria may be the most prominent mat-builders among microorganisms. Cyanobacterial mats are even more noticeable in extreme environments, particularly at high temperatures and salinities (Oren, 2010). Cyanobacteria are the organisms that are responsible for the formation of a biofilm, which is then colonized by other types of microorganisms. This is because they excrete massive amounts of polysaccharides as extracellular slime or sheaths, and their pigmentation makes them popular objects for microbial mat research (Stal, 1995, 2000). Cyanobacteria can occupy benthic, planktic, corticolous, epiphytic and epipsammic habitats at different periods of the year or even daily and it may appear as a cyanobacterial mat in the mangrove environments.

The majority of the cyanobacterial species occurred in mixed habitats in the mangrove environments, but none of the species was collected from all the habitats. They appear in different colours and structures. The result indicated 89 cyanobacterial species in which 16 epiphytic, 14 planktic, 11 epipsammic/epipelic, 12 co-occur in benthic and planktic, 10 co-occur in epiphytic and planktic, 7 co-occur in epipsammic/epipelic and planktic, 3 co-occur in epiphytic, epipsammic/epipelic and planktic, 2 co-occur in benthic and corticolous, benthic and epiphytic and benthic, epipsammic/epipelic and planktic, every 1 species co-occur in corticolous, benthic and epipsammic/epipelic, corticolous and planktic, benthic, epiphytic, epipsammic/epipelic and planktic and epiphytic and epipsammic habitats (Table 4.1).

4.2.2. Benthic

Benthic cyanobacteria are those living in the bottom or stagnant and flowing waters of the mangrove ecosystem, occupying a variety of microhabitats including sediments, sand grains as well as a variety of artificial substrata. Benthic cyanobacteria have distinct gliding motility (Hoiczyk, 2000). Cyanobacterial coatings on sediment surfaces prevent erosion of the underlying sediments. Sediment stabilisation and protection by microbial mats are common occurrences in a range of marine, freshwater, and terrestrial ecosystems (Golubic et al., 2000).

Anathece bacteriosa (Komarek & Komarkova-Legnrova) Komarek, Kastovsky & Jezberova 2011, *Anagnostidinema pseudacutissimum* (Geitler) Strunecky, Bohunicka, Johansen et Komarek, 2017, *Microcoleus lacustris* Farlow ex Gomont 1892 and *Nostoc bornetii* Gain 1911 were recorded from the benthic habitat of southern Kerala. The species *Microcoleus lacustris* was previously reported from the mangrove environments of Indian Sundarbans (Barman et al., 2015).

4.2.3. Planktic

Planktic cyanobacteria are free-floating in the plankton. They are well adapted to vertical migrations through the buoyancy regulation phenomenon and the production of aerotopes containing gas vesicles (Reynolds et al., 1987; Brookes & Ganf, 2001).

Aphanothece bullosa (Meneghini) Rabenhorst 1865, *Trichocoleus delicatulus* (West & G.S.West) Anagnostidis 2001, *Spirulina spirulinoides* (Ghose) Geitler 1925, *Kamptonema chlorinum* (Kutzing ex Gomont) Strunecky, Komarek et J.Smarda 2014, *Planktothrix suspensa* (Pringsheim) Anagnostidis et Komarek 1988, *Limnoraphis hieronymusii* (Lemmermann) J.Komarek, E.Zapomelova, J.Smarda, J.Kopecky, E.Rejmankova, J.Woodhouse, B.A.Neilan & J.Komarkova 2013, *Oscillatoria curviceps* var. *angusta* Ghose 1927, *Oscillatoria perornata* Skuja 1949, *Phormidium chalybeum* (Mertens ex Gomont) Anagnostidis et Komarek 1988, *Phormidium crassior* (Behre) Anagnostidis 2001, *Hapalosiphon welwitschii* West & G.S.West 1897, *Westiellopsis interrupta* Kanthamma 1972, *Desmonostoc muscorum* (C.Agardh ex Bornet & Flahault) Hrouzek et Ventura 2013 and *Nostoc ellipsosporum* (Demazieres) Rabenhort ex Bornet et Flahault 1886 were recorded as planktic from the mangrove environments of southern Kerala.

The species, *Kamptonema chlorinum* was previously reported from the mangrove environment (Mohammed & Al-Shehri, 2015), epilithic (Bano & Siddiqui, 2003, 2007), epiphytic (Lambert et al., 1989; Steinke et al., 2003) and epipsammic (Sen & Naskar, 2003, Sakthivel & Kathiresan, 2013). The species, *Limnoraphis hieronymusii* was synonymously (*Lyngbya hieronymusii* Lemmermann 1905) recorded as planktic from the mangrove environment of Indian Sundarbans (Sen & Naskar, 2003), mangrove environment of Manakudy, Tamil Nadu

(Ramamurthy & Abhinand, 2016). The species, *Phormidium chalybeum* was synonymously (*Oscillatoria chalybea* (Mertens) Gomont 1892) recorded as benthic from the mangrove environments of Kollam, Kerala (Benny et al., 2021), Tamil Nadu (Sakthivel & Kathiresan, 2013) and from the rocky shores of Pakistan (Bano and Siddiqui, 2007). The species, *Hapalosiphon welwitschii* was previously reported from the mangrove environment of Tamil Nadu (Sudha, 2005; Sudha et al., 2007, Ramamurthy & Abhinand, 2016).

4.2.4. Corticolous

Corticolous cyanobacteria are living on the bark of trees. They appear as greenish or black, gelatinous, red dark or brown spots, and streaks and are exposed to the air, absorbing water, minerals, and other nutrients directly from the environment (Bhakta et al., 2014). This type of habitat is regarded as extreme, since the availability of minimal water resources and high or low temperature and light intensity. These cyanobacteria have developed distinct morphological and physiological adaptations to thrive under such extreme environmental conditions (Lemes-da-Silva et al., 2010). Studies on the diversity of corticolous cyanobacteria are very limited.

Oscillatoria tenuis C.Agardh ex Gomont 1892 was reported as corticolous from the mangrove environment of southern Kerala and this species was previously recorded from the mangrove environment of Tamil Nadu (Ramamurthy & Abhinand, 2016, Sudha, 2005; Sudha et al., 2007, Silambarasan et al., 2012, Sakthivel & Kathiresan, 2013), Saudi Arabia (Mohamed & Al-Shehri, 2015), Kerala (Joseph & Saramma, 2016); as epiphytic from Tamil Nadu (Selvakumar & Sundararaman, 2001), Pakistan (Bano & Siddiqui, 2007); as epipsammic from Sundarbans (Sen & Naskar, 2003).

4.2.5. Epiphytic

Epiphytic cyanobacteria are found attached to or growing on the plant surface and derive their moisture and nutrients from the environment. Epiphytic cyanobacteria may colonize submerged or emergent plants. Epiphytic algal or cyanobacterial colonisation has been compared to terrestrial plant succession which includes temporal changes in vertical structure and biodiversity, an increase in the

dominance of larger species and possible facilitative impacts of earlier colonizers (Hoagland et al., 1982). Epiphytic communities are fundamental and complex components of food webs. Algal-feeding snails, benthic insects, and other invertebrates all have a beneficial impact on epiphytic populations. (Kesler, 1981; Lodge, 1986; Marks & Lowe, 1993). Some studies have emphasized the epiphytic cyanobacteria on mangrove plants that grow on the pneumatophores and aerial roots and their contribution to biological nitrogen fixation has also been evaluated in certain studies (Potts & Whitton, 1977, Sheridan, 1991, Toledo et al., 1995).

Lyngbya truncicola Ghose 1924, *Calothrix marchica* Lemmerman 1914, *Calothrix nidulans* Setchell & N.L.Gardner 1924, *Nostoc commune* Vaucher ex Bornet et Flahault 1888, *Nostoc spongiaeforme* var. *varians* C.B.Rao 1937, *Nostoc undulatum* Archibald 1967, *Trichormus ellipsosporus* (Fritsch) Komarek et Anagnostidis 1989, *Trichormus variabilis* (Kutzing ex Bornet et Flahault) Koamarek et Anagnostidis 1989, *Dichothrix orsiniana* (Kutz) Bornet et Flahault 1886, *Scytonema bohneri* Schmidle 1901, *Scytonema coactile* Montagne ex Bornet et Flahault 1886, *Scytonema javanicum* Bornet ex Bornet & Flahault 1886, *Scytonema millei* Bornet ex Bornet & Flahault 1886, *Scytonema* sp., *Scytonema tolypothrichoides* Kützing ex Bornet & Flahault 1886, *Scytonema varium* Kutzing ex Bornet et Flahault 1886 and *Stigonema ocellatum* (Dillwyn) Thuret ex Bornet & Flahault 1886 were recorded as epiphytic from the mangrove environments of southern Kerala.

The species, *Nostoc commune* was previously recorded in the mangrove environment of Indian Sundarbans (Barman et al., 2015). The species, *Trichormus ellipsosporus* was previously reported from the mangrove environment of Tamil Nadu (Silambarasan et al., 2012). The species, *Trichormus variabilis* was previously reported as planktic from the mangrove environment of Tamil Nadu (Nedumaran et al., 2008), Indian Sundarbans (Barman et al., 2015) and the mangrove swamps of Farasan Archipelago, Saudi Arabia (Hussain & Khoja, 1993). The species *Scytonema varium* was previously reported from the mangrove environment of Parangipattai, Tamil Nadu (Silambarasan et al., 2012). Epiphytic cyanobacteria associated with the true mangroves are represented in Table 4.2.

4.2.6. Epipelic/ Epipsammic

Cyanobacteria that colonize sediments (epipelic) and sand (epipsammic) are the least studied mangrove associations. Since these substrata are frequently mixed and due to wave action, are extremely unstable, it is difficult to distinguish between epipelic and epipsammic environments (Hickman, 1978; Kingston et al., 1983). Cyanobacteria collected from the soil are very difficult to separate. Methods for quantifying living cyanobacterial cells from sediments must be used with caution, since they may still provide a significant relative error (30% or more), which may not be consistent among taxa (Eaton & Moss, 1966).

Aphanothece granulosa (N.L.Gardner) Komárek & Komákova-Legnerova 2007, *Chroococcus pallidus* Nageli 1849; *Gloeothece rupestris* (Lyngbye) Bornet in Wittrock & Nordstedt 1880; *Gloeothece samoensis* Wille 1913, *Spirulina major* Kutzing ex Gomont 1892, *Microcoleus subtorulosus* Gomont ex Gomont 1892, *Planktothrix geitleri* (Kisselev) Anangnostidis et Komarek 1998, *Planktothrix isothrix* (Skuja) Komarek & Komarkova 2004, *Calothrix braunii* Bornet et Flahault 1886, *Mastigocladus laminosus* Cohn ex Kirchner 1898 and *Anabaena sedovii* Kossinskaja 1933 were found both epipelic and epipsammic habitat from the mangrove environments of southern Kerala.

4.2.7. Benthic and Corticolous

Microcoleus autumnalis (Trevisan ex Gomont) Strunecky, Komarek et J.R.Johansen 2013 and *Phormidium acula* (Bruhl & Biswas) Anagnostidis & Komárek 1988 were reported from both benthic and corticolous habitats.

4.2.8. Epipsammic and Planktic

Aphanothece stagnina (Sprengel) A. Braun in Rabenhort 1863, *Microcoleus codii* Fremy 1932, *Oscillatoria limosa* Agardh ex Gomont 1892, *Oscillatoria rupicola* (Hansgirg) Hansgirg ex Forti 1907, *Anabaena bispora* Gayral & Mazancourt 1958, *Trichormus kashiensis* (Bharadwaja) Komarek 2012 and *Trichormus rotundosporus* (Hollerbach) Komarek & Anagnostidis 1989 occurred from both epipsammic and planktic habitats.

4.2.9. Epiphytic and Planktic

Chroococcus indicus Zeller 1873, *Kamptonema okenii* (Agardh ex Gomont) Strunecky, Komarek et J.Smarda 2014, *Porphyrosiphon ceylanicus* (Wille) Anagnostidis & Komarek 1988, *Oscillatoria princeps* Vaucher ex Gomont 1892, *Phormidium nigro-viride* (Thwaites ex Gomont) Anagnostidis & Komarek 1988, *Westiellopsis prolifica* Janet 1941, *Anabaena laxa* A.Braun 1886, *Nostoc calcicola* Brebisson ex Bornet et Flahault 1886, *Nostoc linckia* (Roth) Bornet et Flahault 1886 and *Trichormus pseudovariabilis* (Woronichin) Komarek et Anagnostidis 1989 occurred as epiphytic and planktic habitats of mangrove environments of southern Kerala.

4.2.10. Benthic and Planktic

Gloeothece ustulata Beck-Mannagetta 1929, *Spirulina labyrinthiformis* Gomont 1892, *Kamptonema jasorvense* (Vouk) Strunecky, Komarek et J.Smarda 2014, *Microcoleus paludosus* Gomont ex Gomont 1892, *Oscillatoria curviceps* C.Agardh ex Gomont 1892, *Oscillatoria major* Vaucher ex Forti 1907, *Oscillatoria obtusa* N.L.Gardner 1927, *Oscillatoria sancta* Kutzing ex Gomont 1892, *Oscillatoria subbrevis* Schmidle 1901, *Oscillatoria vizagapatensis* C.B.Rao 1938, *Anabaena inaequalis* Bornet et Flahault 1886 and *Nostoc sphaericum* Vaucher ex Bornet et Flahault 1886 were found as both planktic and benthic habitats.

4.2.11. Benthic and Epiphytic

Aphanocapsa grevillei (Berkeley) Rabenhorst 1865 and *Oscillatoria simplicissima* Gomont 1892 occurred from both benthic and epiphytic habitats of mangrove environments of southern Kerala.

4.2.12. Benthic and Epipsammic

Lyngbya lutea Gomont ex Gomont 1892 occurred both from benthic and epipsammic habitats.

4.2.13. Corticolous and Planktic

Oscillatoria princeps var. *pseudolimosa* Ghose 1924 occurred both from corticolous and planktic habitats.

4.2.14. Benthic, Epiphytic, Epipsammic/Epipelic and Planktic

Coleofasciculus chthonoplastes (Thuret ex Gomont) M.Siegesmund, J.R.Johansen et T.Friedl 2008 was occurred as benthic, epiphytic, epipsammic and planktic habitats.

4.2.15. Epiphytic, Epipsammic/Epipelic and Planktic

Lyngbya aestuarii Liebman ex Gomont 1892, *Calothrix marchica* var. *intermedia* C.B.Rao 1937 and *Nostoc carneum* (Lyngbye) Agardh ex Bornet et Flahault 1886 were recorded as epiphytic, epipsammic and planktic habitats.

4.2.16. Benthic, Epipsammic/Epipelic and Planktic

Phormidium nigrum (Vaucher ex Gomont) Anagnostidis & Komarek 1988 and *Phormidium irriguum* (Kutzing ex Gomont) Anangnostidis et Komarek 1988 were found benthic, epipsammic and planktic habitats.

4.2.17. Epiphytic and Epipsammic/Epipelic

Anabaena torulosa (Carmichael) Lagerheim ex Bornet et Flahault 1886 occurred in both epiphytic and epipsammic habitats.

The result showed that planktic cyanobacteria were prevalent in all study areas, in which Ernakulam district showed the maximum, whereas corticolous showed the minimum. Usually, benthic forms are seen as thick cyanobacterial mats. It is very difficult to demarcate the benthic forms in such cases since some of these planktic forms can be due to diurnal upwelling and tidal inundations.

The mangrove plant *Avicennia* produces a large number of pneumatophores or respiratory roots and is the dominant angiosperm in the majority of the study areas. The plant is mainly inhabited in inner muddy areas of mangrove forests where pneumatophores are completely exposed to the constant flow of tidal water at all times or are completely submerged day and night. These pneumatophores harbour rich cyanobacteria and other microflora that form a vertical or horizontal zonation. The vertical distribution of cyanobacteria was generally limited to heights reached at low and high tide at the aerial roots of mangroves (Phillips et al., 1996).

In this study, *Avicennia officinalis* harbours 22 cyanobacterial species while *Bruguiera cylindrica* (L.) Blume, *Rhizophora mucronata* Lam, and *Sonneratia caseolaris* (L.) Engl was colonised by four species each (Table 4.2). It is interesting to note that 26 species of heterocytous filamentous cyanobacteria are more prevalent than coccoid or non-heterocytous filamentous forms. The basal portion of the pneumatophore was colonised by non-heterocytous forms, especially *Oscillatoria*, *Kamptonema*, *Coleofasciculus* and *Lyngbya* species while the top portion was colonised by heterocytous forms. In the case of pneumatophores above the water level is almost devoid of epiphytes. Epiphytic cyanobacteria were dominated in full sunlight, while the shady pneumatophores nearer the tree trunk mostly had no algae or cyanobacteria cover (Dor, 1984). However, in this study, cyanobacterial colonisation was observed in the pneumatophores at a light intensity of >2000 lux and most of them are heterocytous. This study shows that *Avicennia* pneumatophore has peculiar characteristics for colonising more cyanobacterial species as in the studies of Phillips et al., 1994, 1996 and Steinke et al., 2003.

The aerial root systems of mangrove trees provide a hard substrate for the attachment of epiphytic forms. The prop roots of *Rhizophora* species which anchor themselves along the surface of the water, are also colonised by other macroalgae or predominantly *Spirogyra* and *Rhizoclonium* sp. populated. Some species of cyanobacterial colonization were found along with the aerial roots (prop roots) of mangroves during this study. Such vertical colonization was not found in aerial/prop roots. Cyanobacteria growing epiphytically on the pneumatophores of *Aegiceras corniculatum* (L.) Blanco, *Avicennia officinalis* L., *Rhizophora mucronata* Lam, *Rhizophora apiculata* Blume, *Sonneratia caseolaris* (L.) Engl, are represented in Table 4.1.

A total of 37 cyanobacterial species were observed epiphytically on the true mangrove plants, among which a majority of the cyanobacteria occurred at the mangrove, *Avicennia officinalis* (22 species) and it is depicted in Table 4.2.

Table 4.1

Distribution of Cyanobacteria in different habitats of Southern Kerala, India

No.	Name of cyanobacterial species	BE	CL	EP	EC	PL
1. Order: Chroococcales						
1.1. Family: Aphanothecaceae						
1.	*Aphanothece bullosa* (Meneghini) Rabenhorst 1865	-	-	-	-	+
2.	*Aphanothece granulosa* (N.L.Gardner) Komárek & Komákova-Legnerova 2007	-	-	-	+	-
3.	*Aphanothece stagnina* (Sprengel) A. Braun in Rabenhort 1863	-	-	-	+	+
1.2. Family: Chroococcaceae						
4.	*Chroococcus indicus* Zeller 1873	-	-	+		+
5.	*Chroococcus pallidus* Nageli 1849	-	-	-	+	-
6.	*Gloeothece rupestris* (Lyngbye) Bornet in Wittrock & Nordstedt 1880	-	-	-	+	-
7.	*Gloeothece samoensis* Wille 1913	-	-	-	+	-
8.	*Gloeothece ustulata* Beck-Mannagetta 1929	+	-	-	-	+
2. Order: Synechococcales						
2.1. Family: Merismopediaceae						
9.	*Aphanocapsa grevillei* (Berkeley) Rabenhorst 1865	+	-	+	-	-
2.2. Family: Synechococcaceae						
10.	*Anathece bacteriosa* (Komarek & Komarkova-Legnrova) Komarek, Kastovsky & Jezberova 2011	+	-	-	-	-
2.3. Family: Trichocoleusaceae						
11.	*Trichocoleus delicatulus* (West & G.S.West) Anagnostidis 2001	-	-	-	-	+
3. Order: Spirulinales						
3.1. Family: Spirulinaceae						
12.	*Spirulina labyrinthiformis* Gomont 1892	+	-	-	-	+
13.	*Spirulina major* Kutzing ex Gomont 1892	-	-	-	+	-
14.	*Spirulina spirulinoides* (Ghose) Geitler 1925	-	-	-	-	+

No.	Name of cyanobacterial species	BE	CL	EP	EC	PL
4. Order: Oscillatoriales						
4.1. Family: Coleofasciculaceae						
15.	*Anagnostidinema pseudacutissimum* (Geitler) Strunecky, Bohunicka, Johansen et Komarek, 2017	+	-	-	-	-
16.	*Coleofasciculus chthonoplastes* (Thuret ex Gomont) M.Siegesmund, J.R.Johansen et T.Friedl 2008	+	-	+	+	+
4.2. Family: Microcoleaceae						
17.	*Kamptonema chlorinum* (Kutzing ex Gomont) Strunecky, Komarek et J.Smarda 2014	-	-	-	-	+
18.	*Kamptonema jasorvense* (Vouk) Strunecky, Komarek et J.Smarda 2014	+	-	-	-	+
19.	*Kamptonema okenii* (Agardh ex Gomont) Strunecky, Komarek et J.Smarda 2014	-	-	+	-	+
20.	*Microcoleus autumnalis* (Trevisan ex Gomont) Strunecky, Komarek et J.R.Johansen 2013	+	+	-	-	-
21.	*Microcoleus codii* Fremy 1932	-	-	-	+	+
22.	*Microcoleus lacustris* Farlow ex Gomont 1892	+	-	-	-	-
23.	*Microcoleus paludosus* Gomont ex Gomont 1892	+	-	-	-	+
24.	*Microcoleus subtorulosus* Gomont ex Gomont 1892	-	-	-	+	-
25.	*Planktothrix geitleri* (Kisselev) Anangnostidis et Komarek 1998	-	-	-	+	-
26.	*Planktothrix isothrix* (Skuja) Komarek & Komarkova 2004	-	-	-	+	-
27.	*Planktothrix suspensa* (Pringsheim) Anagnostidis et Komarek 1988	-	-	-	-	+
28.	*Porphyrosiphon ceylanicus* (Wille) Anagnostidis & Komarek 1988	-	-	+	-	+
4.3. Family: Oscillatoriaceae						
29.	*Limnoraphis hieronymusii* (Lemmermann) J.Komarek, E.Zapomelova, J.Smarda, J.Kopecky, E.Rejmankova, J.Woodhouse, B.A.Neilan & J.Komarkova 2013	-	-	-	-	+
30.	*Lyngbya aestuarii* Liebman ex Gomont 1892	-	-	+	+	+
31.	*Lyngbya lutea* Gomont ex Gomont 1892	+	-	-	+	-
32.	*Lyngbya truncicola* Ghose 1924	-	-	+	-	-

No.	Name of cyanobacterial species	BE	CL	EP	EC	PL
33.	*Oscillatoria curviceps* C.Agardh ex Gomont 1892	+	-	-	-	+
34.	*Oscillatoria curviceps* var. *angusta* Ghose 1927	-	-	-	-	+
35.	*Oscillatoria limosa* Agardh ex Gomont 1892	-	-	-	+	+
36.	*Oscillatoria major* Vaucher ex Forti 1907	+	-	-	-	+
37.	*Oscillatoria obtusa* N.L.Gardner 1927	+	-	-	-	+
38.	*Oscillatoria perornata* Skuja 1949	-	-	-	-	+
39.	*Oscillatoria princeps* Vaucher ex Gomont 1892	-	-	+	-	+
40.	*Oscillatoria princeps* var. *pseudolimosa* Ghose 1924	-	+	-	-	+
41.	*Oscillatoria rupicola* (Hansgirg) Hansgirg ex Forti 1907	-	-	-	+	+
42.	*Oscillatoria sancta* Kutzing ex Gomont 1892	+	-	-	-	+
43.	*Oscillatoria simplicissima* Gomont 1892	+	-	+	-	-
44.	*Oscillatoria subbrevis* Schmidle 1901	+	-	-	-	+
45.	*Oscillatoria tenuis* C.Agardh ex Gomont 1892	-	+	-	-	-
46.	*Oscillatoria vizagapatensis* C.B.Rao 1938	+	-	-	-	+
47.	*Phormidium acula* (Bruhl & Biswas) Anagnostidis & Komárek 1988	+	+	-	-	
48.	*Phormidium chalybeum* (Mertens ex Gomont) Anagnostidis et Komarek 1988	-	-	-	-	+
49.	*Phormidium crassior* (Behre) Anagnostidis 2001	-	-	-	-	+
50.	*Phormidium nigro-viride* (Thwaites ex Gomont) Anagnostidis & Komarek 1988	-	-	+	-	+
51.	*Phormidium nigrum* (Vaucher ex Gomont) Anagnostidis & Komarek 1988	+	-	-	+	+
52.	*Phormidium irriguum* (Kutzing ex Gomont) Anangnostidis et Komarek 1988	+	-	-	+	+
5. Order: Nostocales						
5.1. Family: Calotrichaceae						
53.	*Calothrix braunii* Bornet et Flahault 1886	-	-	-	+	-
54.	*Calothrix marchica* Lemmerman 1914	-	-	+	-	-
55.	*Calothrix marchica* var. *intermedia* C.B.Rao 1937	-	-	+	+	+

No.	Name of cyanobacterial species	BE	CL	EP	EC	PL
56.	*Calothrix nidulans* Setchell & N.L.Gardner 1924	-	-	+	-	-
5.2. Family: Hapalosiphonaceae						
57.	*Hapalosiphon welwitschii* West & G.S.West 1897	-	-	-	-	+
58.	*Mastigocladus laminosus* Cohn ex Kirchner 1898	-	-	-	+	-
59.	*Westiellopsis interrupta* Kanthamma 1972	-	-	-	-	+
60.	*Westiellopsis prolifica* Janet 1941	-	-	+	-	+
5.3. Family: Nostocaceae						
61.	*Anabaena bispora* Gayral & Mazancourt 1958	-	-	-	+	+
62.	*Anabaena inaequalis* Bornet et Flahault 1886	+	-	-	-	+
63.	*Anabaena laxa* A.Braun 1886	-	-	+	-	+
64.	*Anabaena sedovii* Kossinskaja 1933	-	-	-	+	-
65.	*Anabaena torulosa* (Carmichael) Lagerheim ex Bornet et Flahault 1886	-	-	+	+	-
66.	*Desmonostoc muscorum* (C.Agardh ex Bornet & Flahault) Hrouzek et Ventura 2013	-	-	-	-	+
67.	*Nostoc bornetii* Gain 1911	+	-	-	-	-
68.	*Nostoc calcicola* Brebisson ex Bornet et Flahault 1886	-	-	+	-	+
69.	*Nostoc carneum* (Lyngbye) Agardh ex Bornet et Flahault 1886	-	-	+	+	+
70.	*Nostoc commune* Vaucher ex Bornet et Flahault 1888	-	-	+	-	-
71.	*Nostoc ellipsosporum* (Demazieres) Rabenhort ex Bornet et Flahault 1886	-	-	-	-	+
72.	*Nostoc linckia* (Roth) Bornet et Flahault 1886	-	-	+	-	+
73.	*Nostoc sphaericum* Vaucher ex Bornet et Flahault 1886	+	-		-	+
74.	*Nostoc spongiaeforme* var. *varians* C.B.Rao 1937	-	-	+	-	-
75.	*Nostoc undulatum* Archibald 1967	-	-	+	-	-
76.	*Trichormus ellipsosporus* (Fritsch) Komarek et Anagnostidis 1989	-	-	+	-	-
77.	*Trichormus kashiensis* (Bharadwaja) Komarek 2012	-	-		+	+

No.	Name of cyanobacterial species	BE	CL	EP	EC	PL
78.	*Trichormus pseudovariabilis* (Woronichin) Komarek et Anagnostidis 1989	-	-	+	-	+
79.	*Trichormus rotundosporus* (Hollerbach) Komarek & Anagnostidis 1989	-	-	-	+	+
80.	*Trichormus variabilis* (Kutzing ex Bornet et Flahault) Koamarek et Anagnostidis 1989	-	-	+	-	-
5.4. Family: Rivulariaceae						
81.	*Dichothrix orsiniana* (Kutz) Bornet et Flahault 1886	-	-	+	-	-
5.5. Family: Scytonemataceae						
82.	*Scytonema bohneri* Schmidle 1901	-	-	+	-	-
83.	*Scytonema coactile* Montagne ex Bornet et Flahault 1886	-	-	+	-	-
84.	*Scytonema javanicum* Bornet ex Bornet & Flahault 1886	-	-	+	-	-
85.	*Scytonema millei* Bornet ex Bornet & Flahault 1886	-	-	+	-	-
86.	*Scytonema* sp.	-	-	+	-	-
87.	*Scytonema tolypothrichoides* Kützing ex Bornet & Flahault 1886	-	-	+	-	-
88.	*Scytonema varium* Kutzing ex Bornet et Flahault 1886	-	-	+	-	-
5.6. Stigonemataceae						
89.	*Stigonema ocellatum* (Dillwyn) Thuret ex Bornet & Flahault 1886	-	-	+	-	-

BE: Benthic; **EP:** Epiphytic; **EC:** Epipsammic/Epipelic; **PL:** Planktic; **CL:** Corticolous; **+:** Present; -: Absent

Table 4.2

Showing epiphytic cyanobacteria associated with mangrove plants

Mangrove plant	Epiphytic cyanobacteria
Aegiceras corniculatum (L.) Blanco	*Trichormus variabilis* (Kutzing ex Bornet et Flahault) Koamarek et Anagnostidis 1989
Aviennia officinalis L.	*Chroococcus indicus* Zeller 1873;
	Aphanocapsa grevillei (Berkeley) Rabenhorst 1865;
	Coleofasciculus chthonoplastes (Thuret ex Gomont) M.Siegesmund, J.R.Johansen et T.Friedl 2008;
	Kamptonema okenii (Agardh ex Gomont) Strunecky, Komarek et J.Smarda 2014
	Porphyrosiphon ceylanicus (Wille) Anagnostidis & Komarek 1988
	Lyngbya aestuarii Liebman ex Gomont 1892
	Lyngbya truncicola Ghose 1924
	Oscillatoria princeps Vaucher ex Gomont 1892
	Oscillatoria simplicissima Gomont 1892
	Westiellopsis prolifica Janet 1941
	Anabaena laxa A.Braun 1886
	Anabaena torulosa (Carmichael) Lagerheim ex Bornet et Flahault 1886
	Nostoc calcicola Brebisson ex Bornet et Flahault 1886
	Nostoc carneum (Lyngbye) Agardh ex Bornet et Flahault 1886
	Nostoc commune Vaucher ex Bornet et Flahault 1888
	Nostoc linckia (Roth) Bornet et Flahault 1886
	Trichormus ellipsosporus (Fritsch) Komarek et Anagnostidis 1989
	Dichothrix orsiniana (Kutz) Bornet et Flahault 1886
	Scytonema bohneri Schmidle 1901
	Scytonema coactile Montagne ex Bornet et Flahault 1886
	Scytonema javanicum Bornet ex Bornet & Flahault 1886

Mangrove plant	Epiphytic cyanobacteria
	Scytonema tolypothrichoides Kützing ex Bornet & Flahault 1886
Bruguiera cylindrica (L.) Blume	*Dichothrix orsiniana* (Kutz) Bornet et Flahault 1886
	Scytonema millei Bornet ex Bornet & Flahault 1886
	Scytonema sp.
	Scytonema varium Kutzing ex Bornet et Flahault 1886
Rhizophora mucronata Lam	*Kamptonema okenii* (Agardh ex Gomont) Strunecky, Komarek et J.Smarda 2014
	Calothrix nidulans Setchell & N.L.Gardner 1924
	Nostoc spongiaeforme var. *varians* C.B.Rao 1937
	Nostoc undulatum Archibald 1967
Rhizophora apiculata Blume	*Trichormus pseudovariabilis* (Woronichin) Komarek et Anagnostidis 1989
	Stigonema ocellatum (Dillwyn) Thuret ex Bornet & Flahault 1886
Sonneratia caseolaris (L.) Engl.	*Phormidium nigro-viride* (Thwaites ex Gomont) Anagnostidis & Komarek 1988
	Calothrix marchica Lemmerman 1914
	Calothrix marchica var. *intermedia* C.B.Rao 1937
	Scytonema bohneri Schmidle 1901

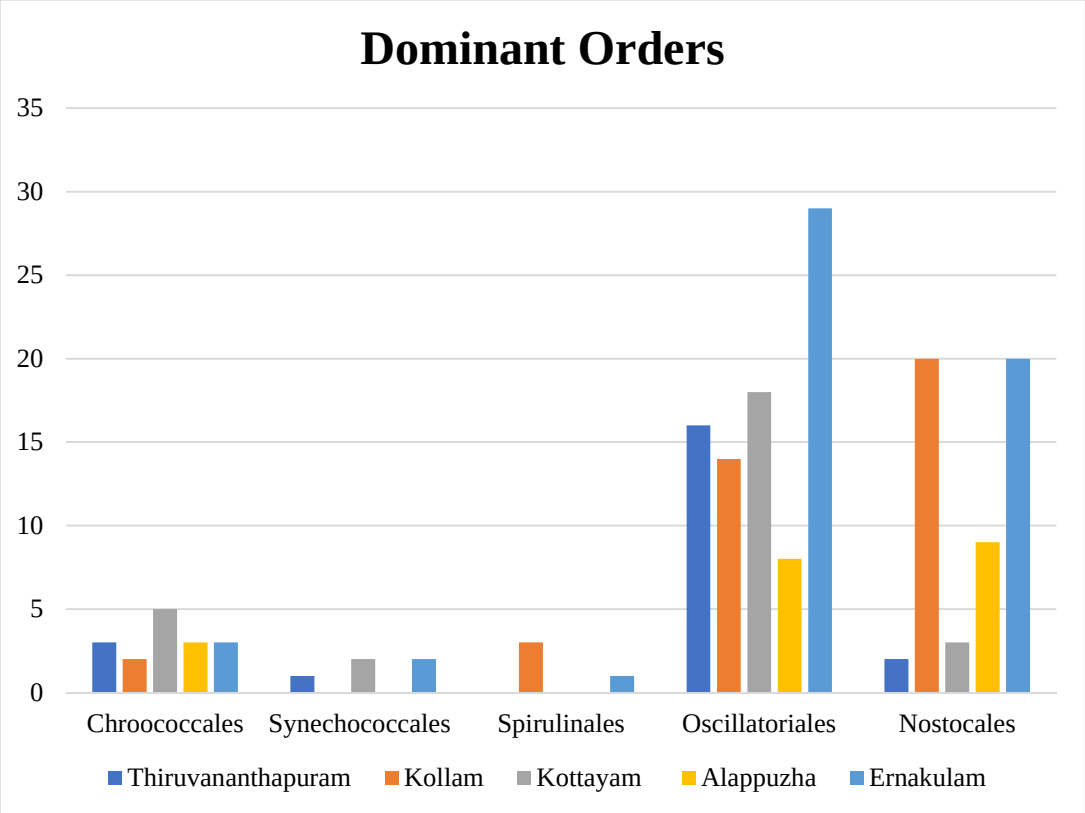
4.3. Dominant orders

Of the five orders recorded, two were dominant, Oscillatoriales with 38 species followed by Nostocales with 37 species. No such similar trend was observed within individual study areas in Kollam and Alappuzha districts whereas a similar trend was seen in Thiruvananthapuram, Kottayam and Ernakulam districts. The order Oscillatoriales was dominant, represented by 29 species (32.58%) in Ernakulam district, 18 species (20.22%) in Kottayam district, and 16 species (17.97%) in Thiruvananthapuram district. The next dominant order was Nostocales, represented by 20 species (22.47%) in Ernakulam and Kollam districts, 9 species (10.11%) in Alappuzha district, and 3 species (3.37%) in Kottayam district and 2 species (2.24%) in Thiruvananthapuram district respectively. Chroococcales was the

third dominant order represented with 5 species in Kottayam district, 3 species in Thiruvananthapuram, Alappuzha and Ernakulam districts and 2 species in Kollam district. Synechococcales were represented with 2 species in Kottayam and Ernakulam and 1 species in Thiruvananthapuram district. The order Spirulinales represented 3 species in Kollam and 1 species in Ernakulam district. The order Spirulinales was not observed in Thiruvanathapuram, Kottayam and Alappuzha districts whereas the order Synechococcales was not observed in Kollam and Alappuzha districts (Fig. 4.1).

Fig. 4.1

Total number of cyanobacterial species in dominant orders arranged district-wise recorded in mangrove areas



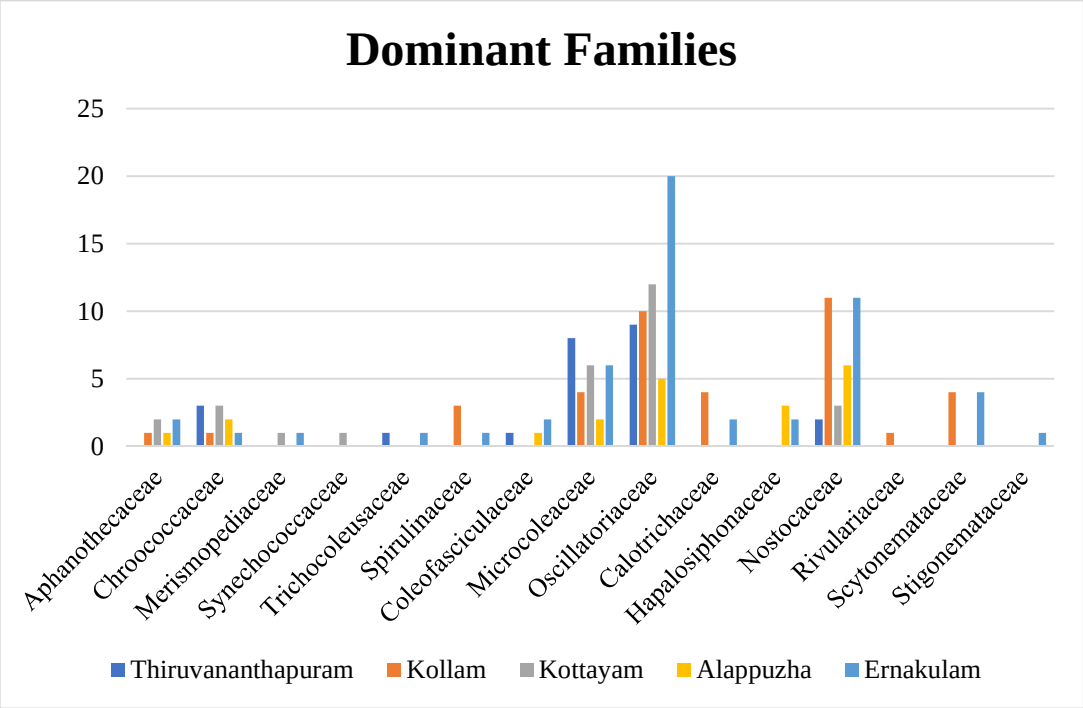
4.4. Dominant families

Of the fifteen families recorded, Oscillatoriaceae was the dominant family represented with 24 species followed by Nostocaceae with 20 species, Microcoleaceae with 12 species, Scytonemataceae with 7 species, Chroococcaceae with 5 species, Calotrichaceae and Hapalosiphonaceae with 4 species each,

Aphanothecaceae and Spirulinaceae with 3 species each, Coleofasciculaceae with 2 species, Merismopediaceae, Synechococcaceae, Trichocoluesaceae, Rivulariaceae and Stigonemataceae with 1 species each. The family Oscillatoriaceae was dominant represented with 20 species in Ernakulam district, 12 species in Kottayam district, 10 species in Kollam district and 9 species in Thiruvananthapuram district. The second dominant family was Nostocaceae (20 species), represented by Kollam and Ernakulam districts represented 11 species each, 6 species in Alappuzha district, 3 species in Kottayam district and 2 species in Thiruvananthapuram district. The third dominant family was Microcoleaceae (12 species) represented with species in Thiruvananthapuram district, 6 species each in Kottayam and Ernakulam districts, 4 species in Kollam district and 2 species in Alappuzha district. The family Scytonemataceae was the fourth dominant family (7 species) represented with 4 species each in Kollam and Ernakulam districts. The family Chroococcaceae (5 species) is represented with 3 species each in Thiruvananthapuram and Kottayam districts, 2 species in Alappuzha district and 1 species each in Kollam and Ernakulam districts. The family Calotrichaceae (4 species) is represented by 4 species in Kollam district and 2 species in Ernakulam district. The family Hapalosiphonaceae (4 species) is represented by 3 species in Alappuzha district and 2 species in Ernakulam district. The family Spirulinaceae (3 species) is represented by 3 species in Kollam district and 1 species in Ernakulam district. The family Coleofasciculaceae (2 species) is represented by 2 species in Ernakulam and 1 species in Alappuzha district. The families Merismopediaceae, Synechococcaceae, Trichocoleusaceae, Rivulariaceae and Stigonemataceae represented only 1 species each (Fig. 4.2).

Fig 4.2

Total number of cyanobacterial species in dominant families arranged district-wise



4.5. Dominant Genera

Of the total 28 genera recorded, the genus *Oscillatoria* was the dominant represented with 14 species followed by *Nostoc* (9 species), *Scytonema* (7 species), *Phormidium* (6 species), *Microcoleus*, *Anabaena* and *Trichormus* with 5 species each, *Calothrix* (4 species), *Aphanothece*, *Gloeothece*, *Kamptonema*, *Planktothrix*, *Lyngbya* with 3 species each, *Chroococcus* (2 species) and *Aphanocapsa*, *Anathece*, *Trichocoleus*, *Anagnostidinema*, *Coleofasciculus*, *Porphyrosiphon*, *Limnoraphis*, *Hapalosiphon*, *Mastigocladus*, *Desmonostoc*, *Dichothrix* and *Stigonema* with 1 species each. The genus *Oscillatoria* is represented by 11 species in Ernakulam district, 8 species in Kottayam district, 6 species in Kollam district, 5 species in Thiruvananthapuram district and 3 species in Alappuzha district. The genus *Nostoc* was the second dominant represented with 5 species in Kollam district, 3 species in Ernakulam district, 2 species each in Thiruvananthapuram and Kottayam districts and 1 species in Alappuzha district. The genus *Scytonema* was the third dominant represented with 4 species each in Kollam and Ernakulam districts. *Phormidium* was

the fourth dominant genus with 5 species in Ernakulam district, 4 species in Kollam district, 3 species in Thiruvananthapuram district, 2 species each in Kottayam and Alappuzha districts. The genus *Microcoleus* was represented by 3 species each in Thiruvananthapuram, Kottayam, and Ernakulam districts. The genus *Anabaena* was represented with 5 species in Ernakulam district, and 2 species each in Kollam and Alappuzha districts. The genus *Trichormus* was represented with 4 species in Kollam district, 3 species in Ernakulam district and 2 species in Alappuzha district. The genus *Calothrix* was represented by 4 species in the Kollam district and 2 species in the Ernakulam district. The genus *Aphanothece* was represented with 2 species each in Kottayam and Ernakulam districts and 1 species each in Kollam and Alappuzha districts. The genus *Gloeothecce* was represented with 2 species in Kottayam and 1 species each in Thiruvananthapuram, Kollam Alappuzha and Ernakulam districts. The genus *spirulina* was represented by 3 species in Kollam district and 1 species in Ernakulam district. The genus *Kamptonema* was represented by 3 species in Thiruvananthapuram district and 2 species each in Kollam, Kottayam and Alappuzha districts and 1 species in Ernakulam district. The genus *Planktothrix* was represented by 2 species in Ernakulam district and 1 species each in Thiruvananthapuram, Kollam and Kottayam districts. The genus *Lyngbya* was represented with 3 species in Ernakulam district and 2 species in Kollam and 1 species in Thiruvananthapuram district. The genus *Chroococcus* was represented with 2 species in the Thiruvananthapuram district and 1 species each in Kottayam and Alappuzha districts. The genus *Westiellopsis* was represented by 2 species in Alappuzha district and 1 species in Ernakulam district. The genus *Aphanocapsa* was represented with 1 species each in Kottayam and Ernakulam districts. The genus *Anathece* was represented with 1 species in the Kottayam district. The genus *Trichocoleus* was represented by 1 species in Thiruvananthapuram and Ernakulam districts. The genus *Anagnostidinema* was represented with 1 species in Ernakulam district. The genus *Coleofasciculus* was represented with 1 species each in Alappuzha and Ernakulam districts. The genus *Porphyrosiphon* was represented with 1 species each in Kollam and Ernakulam districts. The genus *Limnoraphis* was represented with 1 species in Ernakulam district. The genus *Hapalosiphon* was represented by 1 species in the Alappuzha district. The genus *Mastigocladus* was

represented by 1 species in Ernakulam district. The genus *Desmonostoc* was represented with 1 species each in Kottayam and Alappuzha districts. The genus *Dichothrix* was represented with 1 species in Kollam district. The genus *Stigonema* was represented with 1 species in Ernakulam district.

4.6. Study areas having dominant Species

The number of cyanobacterial species was higher in Kumbalam (36 species) followed by Vypin (30 species), Ayiramthengu (25 species), Sakthikulangara (18 species), Kumarakom (15 species), Mekkara (14 species), Pathiramanal and Kadinamkulam (13 species each), Kureekkadavu (10 species) and Ezhupunna (8 species). The most cyanobacteria-rich study areas are naturally established mangrove environments, while the least cyanobacteria-rich study areas are artificially developed mangrove environments or patchy mangrove forests (Sakthivel & Kathiresan, 2013). Study areas such as Kumbalam, Vypin and Ayiramthengu have a naturally developed mangrove environment with rich cyanobacterial diversity and productivity, while Ezhupunna has an artificially developed mangrove area with low biodiversity and productivity (Table 4.3).

Table 4.3

Diversity of cyanobacteria in different mangrove environments of Southern Kerala

No.	Name of cyanobacterial species	TVM		KLM		KTM		ALP		EKM	
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
1. Order: Chroococcales											
1.1. Family: Aphanothecaceae											
1.	*Aphanothece bullosa* (Meneghini) Rabenhorst 1865	-	-	-	-	-	+	-	-	-	+
2.	*Aphanothece granulosa* (N.L.Gardner) Komárek & Komákova-Legnerova 2007	-	-	+	-	-	-	-	-	-	+
3.	*Aphanothece stagnina* (Sprengel) A. Braun in Rabenhort 1863	-	-	-	-	-	+	-	+	-	-
1.2. Family: Chroococcaceae											
4.	*Chroococcus indicus* Zeller 1873	+	-	-	-	-	-	+	-	-	-
5.	*Chroococcus pallidus* Nageli 1849	+	-	-	-	+	-	-	-	-	-

No.	Name of cyanobacterial species	TVM		KLM		KTM		ALP		EKM	
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
6.	*Gloeothece rupestris* (Lyngbye) Bornet in Wittrock & Nordstedt 1880	+	-	-	-	+	-	-	-	-	-
7.	*Gloeothece samoensis* Wille 1913	-	-	-	-	+	-	-	+	-	-
8.	*Gloeothece ustulata* Beck-Mannagetta 1929	-	-	-	+	-	-	-	-	+	+
2. Order: Synechococcales											
2.1. Family: Merismopediaceae											
9.	*Aphanocapsa grevillei* (Berkeley) Rabenhorst 1865	-	-	-	-	-	+	-	-	-	+
2.2. Family: Synechococcaceae											
10.	*Anathece bacteriosa* (Komarek & Komarkova-Legnrova) Komarek, Kastovsky & Jezberova 2011	-	-	-	-	-	+	-	-	-	-
2.3. Family: Trichocoleusaceae											
11.	*Trichocoleus delicatulus* (West & G.S.West) Anagnostidis 2001	-	+	-	-	-	-	-	-	-	+
3. Order: Spirulinales											
3.1. Family: Spirulinaceae											
12.	*Spirulina labyrinthiformis* Gomont 1892	-	-	+	-	-	-	-	-	+	+
13.	*Spirulina major* Kutzing ex Gomont 1892	-	-	+	-	-	-	-	-	-	-
14.	*Spirulina spirulinoides* (Ghose) Geitler 1925	-	-	+	-	-	-	-	-	-	-
4. Order: Oscillatoriales											
4.1. Family: Coleofasciculaceae											
15.	*Anagnostidinema pseudacutissimum* (Geitler) Strunecky, Bohunicka, Johansen et Komarek 2017	-	-	-	-	-	-	-	-	+	-
16.	*Coleofasciculus chthonoplastes* (Thuret ex Gomont) M.Siegesmund, J.R.Johansen et T.Friedl 2008.	-	-	-	-	-	-	-	+	+	+
4.2. Family: Microcoleaceae											
17.	*Kamptonema chlorinum* (Kutzing ex Gomont) Strunecky, Komarek et	+	-	-	-	-	+	-	+	-	-

No.	Name of cyanobacterial species	TVM		KLM		KTM		ALP		EKM	
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
	J.Smarda 2014										
18.	*Kamptonema jasorvense* (Vouk) Strunecky, Komarek et J.Smarda 2014	-	+	+	-	-	-	-	-	-	-
19.	*Kamptonema okenii* (Agardh ex Gomont) Strunecky, Komarek et J.Smarda 2014	+	+	+	+	+	+	+	+	+	-
20.	*Microcoleus autumnalis* (Trevisan ex Gomont) Strunecky, Komarek et J.R.Johansen 2013	+	-	-	-	+	-	-	-	-	-
21.	*Microcoleus codii* Fremy 1932	-	+	-	-	-	-	-	-	-	+
22.	*Microcoleus lacustris* Farlow ex Gomont 1892	-	-	-	-	-	-	-	-	+	+
23.	*Microcoleus paludosus* Gomont ex Gomont 1892	-	+	-	-	+	-	-	-	-	-
24.	*Microcoleus subtorulosus* Gomont ex Gomont 1892	-	-	-	-	+	-	-	-	+	-
25.	*Planktothrix geitleri* (Kisselev) Anangnostidis et Komarek 1998	-	-	+	-	-	-	-	-	+	-
26.	*Planktothrix isothrix* (Skuja) Komarek & Komarkova 2004	+	-	-	-	-	-	-	-	-	-
27.	*Planktothrix suspensa* (Pringsheim) Anagnostidis et Komarek 1988	-	-	-	-	+	-	-	-	-	+
28.	*Porphyrosiphon ceylanicus* (Wille) Anagnostidis & Komarek 1988	-	-	+	-	-	-	-	-	+	+
4.3. Family: Oscillatoriaceae											
29.	*Limnoraphis hieronymusii* (Lemmermann) J.Komarek, E.Zapomelova, J.Smarda, J.Kopecky, E.Rejmankova, J.Woodhouse, B.A.Neilan & J.Komarkova 2013	-	-	-	-	-	-	-	-	+	-
30.	*Lyngbya aestuarii* Liebman ex Gomont 1892	+	-	-	-	+	-	-	-	+	-
31.	*Lyngbya lutea* Gomont ex Gomont 1892	-	-	-	-	-	+	-	-	+	-
32.	*Lyngbya truncicola* Ghose 1924	-	-	-	-	-	-	-	-	+	-
33.	*Oscillatoria curviceps* C.Agardh ex Gomont 1892	-	-	+	-	-	+	-	+	-	-

No.	Name of cyanobacterial species	TVM		KLM		KTM		ALP		EKM	
		S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
34.	*Oscillatoria curviceps* var. *angusta* Ghose 1927	-	-	-	-	+	-	-	-	+	-
35.	*Oscillatoria limosa* Agardh ex Gomont 1892	+	-	-	-	-	-	-	+	-	-
36.	*Oscillatoria major* Vaucher ex Forti 1907	-	-	+	-	-	-	-	-	-	+
37.	*Oscillatoria obtusa* N.L.Gardner 1927	-	+	-	-	+	-	-	-	+	-
38.	*Oscillatoria perornata* Skuja 1949	-	-	+	-	-	+	-	-	+	+
39.	*Oscillatoria princeps* Vaucher ex Gomont 1892	-	+	+	-	-	-	-	-	+	-
40.	*Oscillatoria princeps* var. *pseudolimosa* Ghose 1924	-	-	-	-	-	+	-	-	+	-
41.	*Oscillatoria rupicola* (Hansgirg) Hansgirg ex Forti 1907	-	-	-	-	+	-	-	-	+	-
42.	*Oscillatoria sancta* Kutzing ex Gomont 1892	+	-	-	-	-	-	-	-	+	+
43.	*Oscillatoria simplicissima* Gomont 1892	-	-	+	-	+	-	-	-	-	-
44.	*Oscillatoria subbrevis* Schmidle 1901	-	-	-	-	-	+	-	+	+	-
45.	*Oscillatoria tenuis* C.Agardh ex Gomont 1892	+	-	+	-	-	-	-	-	-	+
46.	*Oscillatoria vizagapatensis* C.B.Rao 1938	-	-	-	-	-	-	-	-	+	+
47.	*Phormidium acula* (Bruhl & Biswas) Anagnostidis & Komárek 1988	+	-	-	-	-	+	-	+	-	+
48.	*Phormidium chalybeum* (Mertens ex Gomont) Anagnostidis et Komarek 1988	-	-	+	-	-	-	-	+	-	+
49.	*Phormidium crassior* (Behre) Anagnostidis 2001	-	+	-	-	-	-	-	-	-	-
50.	*Phormidium nigro-viride* (Thwaites ex Gomont) Anagnostidis & Komarek 1988	+	-	-	+	-	-	-	-	-	+
51.	*Phormidium nigrum* (Vaucher ex Gomont) Anagnostidis & Komarek 1988	-	-	-	+	-	+	-	-	-	+

No.	Name of cyanobacterial species	TVM		KLM		KTM		ALP		EKM	
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
52.	*Phormidium irriguum* (Kutzing ex Gomont) Anangnostidis et Komarek 1988	-	-	+	+	-	-	-	-	+	-
5. Order: Nostocales											
5.1. Family: Calotrichaceae											
53.	*Calothrix braunii* Bornet et Flahault 1886	-	-	-	+	-	-	-	-	-	-
54.	*Calothrix marchica* Lemmerman 1914	-	-	-	+	-	-	-	-	+	-
55.	*Calothrix marchica* var. *intermedia* C.B.Rao 1937	-	-	-	+	-	-	-	-	+	+
56.	*Calothrix nidulans* Setchell & N.L.Gardner 1924	-	-	-	+	-	-	-	-	-	-
5.2. Family: Hapalosiphonaceae											
57.	*Hapalosiphon welwitschii* West & G.S.West 1897	-	-	-	-	-	-	-	+	-	-
58.	*Mastigocladus laminosus* Cohn ex Kirchner 1898	-	-	-	-	-	-	-	-	+	-
59.	*Westiellopsis interrupta* Kanthamma 1972	-	-	-	-	-	-	+	-	-	-
60.	*Westiellopsis prolifica* Janet 1941	-	-	-	-	-	-	+	-	+	+
5.3. Family: Nostocaceae											
61.	*Anabaena bispora* Gayral & Mazancourt 1958	-	-	+	-	-	-	-	-	-	+
62.	*Anabaena inaequalis* Bornet et Flahault 1886	-	-	-	-	-	-	-	+	+	-
63.	*Anabaena laxa* A.Braun 1886	-	-	-	-	-	-	+	-	+	-
64.	*Anabaena sedovii* Kossinskaja 1933	-	-	-	-	-	-	-	-	+	-
65.	*Anabaena torulosa* (Carmichael) Lagerheim ex Bornet et Flahault 1886	-	-	+	-	-	-	-	-	+	-
66.	*Desmonostoc muscorum* (C.Agardh ex Bornet & Flahault) Hrouzek et Ventura 2013	-	-	-	-	+	-	+	-	-	-
67.	*Nostoc bornetii* Gain 1911	-	+	-	-	-	-	-	-	-	-

No.	Name of cyanobacterial species	TVM		KLM		KTM		ALP		EKM	
		S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
68.	*Nostoc calcicola* Brebisson ex Bornet et Flahault 1886	-	+	-	-	-	-	-	-	+	+
69.	*Nostoc carneum* (Lyngbye) Agardh ex Bornet et Flahault 1886	-	-	+	-	-	-	-	+	-	-
70.	*Nostoc commune* Vaucher ex Bornet et Flahault 1888	-	-	-	-	-	-	-	-	-	+
71.	*Nostoc ellipsosporum* (Demazieres) Rabenhort ex Bornet et Flahault 1886	-	-	-	-	-	-	-	-	-	+
72.	*Nostoc linckia* (Roth) Bornet et Flahault 1886	-	-	-	+	+	-	-	-	-	-
73.	*Nostoc sphaericum* Vaucher ex Bornet et Flahault 1886	-	-	-	+	-	+	-	-	-	-
74.	*Nostoc spongiaeforme* var. *varians* C.B.Rao 1937	-	-	-	+	-	-	-	-	-	-
75.	*Nostoc undulatum* Archibald 1967	-	-	+	-	-	-	-	-	-	-
76.	*Trichormus ellipsosporus* (Fritsch) Komarek et Anagnostidis 1989	-	-	-	-	-	-	+	-	-	+
77.	*Trichormus kashiensis* (Bharadwaja) Komarek 2012	-	-	+	-	-	-	+	-	-	-
78.	*Trichormus pseudovariabilis* (Woronichin) Komarek et Anagnostidis 1989	-	-	-	+	-	-	-	-	+	-
79.	*Trichormus rotundosporus* (Hollerbach) Komarek & Anagnostidis 1989	-	-	-	+	-	-	-	-	-	+
80.	*Trichormus variabilis* (Kutzing ex Bornet et Flahault) Koamarek et Anagnostidis 1989	-	-	+	-	-	-	-	-	-	-
5.4. Family: Rivulariaceae											
81.	*Dichothrix orsiniana* (Kutz) Bornet et Flahault 1886	-	-	+	+	-	-	-	-	-	-
5.5. Family: Scytonemataceae											
82.	*Scytonema bohneri* Schmidle 1901	-	-	-	-	-	-	-	-	+	-
83.	*Scytonema coactile* Montagne ex Bornet et Flahault 1886	-	-	+	+	-	-	-	-	-	-

No.	Name of cyanobacterial species	TVM		KLM		KTM		ALP		EKM	
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
84.	*Scytonema javanicum* Bornet ex Bornet & Flahault 1886	-	-	-	-	-	-	-	-	+	-
85.	*Scytonema millei* Bornet ex Bornet & Flahault 1886	-	-	-	-	-	-	-	-	+	-
86.	*Scytonema* sp.	-	-	+	-	-	-	-	-	-	-
87.	*Scytonema tolypothrichoides* Kützing ex Bornet & Flahault 1886	-	-	-	+	-	-	-	-	-	+
88.	*Scytonema varium* Kutzing ex Bornet et Flahault 1886	-	-	-	+	-	-	-	-	-	-
5.6. Stigonemataceae											
89.	*Stigonema ocellatum* (Dillwyn) Thuret ex Bornet & Flahault 1886	-	-	-	-	-	-	-	-	-	+

TVM: Thiruvananthapuram; **KLM**: Kollam; **KTM**: Kottayam; **ALP**: Alappuzha; **EKM**: Ernakulam; **S1**: Kadinamkulam; **S2**: (Edava) Kureekkadavu-Kappil; **S3**: Ayiramthengu; **S4**: Sakthikulangara; **S5**: Kumarakom; **S6**: Mekkara; **S7**: Ezhupunna; **S8**: Pathiramanal; **S9**: Kumbalam; **S10**: Vypin/Puthuvype; **+**: Present; **-**: Absent

4.7. Area-specific/ Site-specific species

Some of the cyanobacterial species were observed as site-specific or area-specific. 8 species were identified only from Kumbalam and they were *Anagnostidinema pseudacutissimum* (Geitler) Strunecky, Bohunicka, Johansen et Komarek 2017, *Limnoraphis hieronymusii* (Lemmermann) J.Komarek, E.Zapomelova, J.Smarda, J.Kopecky, E.Rejmankova, J.Woodhouse, B.A.Neilan & J.Komarkova 2013, *Lyngbya truncicola* Ghose 1924, *Mastigocladus laminosus* Cohn ex Kirchner 1898, *Anabaena sedovii* Kossinskaja 1933, *Scytonema bohneri* Schmidle 1901, *Scytonema javanicum* Bornet ex Bornet & Flahault 1886 and *Scytonema millei* Bornet ex Bornet & Flahault 1886. 5 species were recorded only from Ayiramthengu and they were *Spirulina major* Kutzing ex Gomont 1892, *Spirulina spirulinoides* (Ghose) Geitler 1925, *Nostoc undulatum* Archibald 1967, *Trichormus variabilis* (Kutzing ex Bornet et Flahault) Koamarek et Anagnostidis 1989 and *Scytonema* sp. 4 species were obtained only from Sakthikulangara and they were *Calothrix braunii* Bornet et Flahault 1886, *Calothrix nidulans* Setchell &

N.L.Gardner 1924, *Nostoc spongiaeforme* var. *varians* C.B.Rao 1937 and *Scytonema varium* Kutzing ex Bornet et Flahault 1886. 3 species were recorded only from Vypin and they were *Nostoc commune* Vaucher ex Bornet et Flahault 1888, *Nostoc ellipsosporum* (Demazieres) Rabenhort ex Bornet et Flahault 1886 and *Stigonema ocellatum* (Dillwyn) Thuret ex Bornet & Flahault 1886. 2 species were recorded only from Kureekkadavu and they were *Phormidium crassior* (Behre) Anagnostidis 2001 and *Nostoc bornetii* Gain 1911. *Anathece bacteriosa* (Komarek & Komarkova-Legnrova) Komarek, Kastovsky & Jezberova 2011 was recorded only from Mekkara, *Planktothrix isothrix* (Skuja) Komarek & Komarkova 2004 obtained only from Kadinamkulam, *Hapalosiphon welwitschii* West & G.S.West 1897 was recorded only from Pathiramanal and *Westiellopsis interrupta* Kanthamma 1972 was recorded specifically from Ezhupunna.

The first study of cyanobacteria in mangrove environments was made in 1889 (Moebius, 1889), according to the publications to date. A total of 409 cyanobacterial species have been identified in studies spanning the years 1889 to 2020. The list is compiled from 82 related research publications (books, journals, theses), both nationally and internationally. When compared to the global distribution of cyanobacteria, this study reports 21.76 % of cyanobacteria from Kerala alone. Based on the compiled catalogue of previous research, the order Oscillatoriales (147 species) ranks first, followed by Synechococcales (83 species), Chroococcales (73 species), Nostocales (70 species), Pleurocapsales (26 species), Spirulinales (7 species), Chroococcidiopsidales (2 species), and Gloeobacterales (1 species).

4.8. New records/ New additions to the cyanobacterial flora

Typically, cyanobacterial distribution is described as “cosmopolitan” or “ubiquitous”. Such terms should be used with great care because while certain species are widely distributed, the majority of the group is restricted to well-defined environments (Komarek, 1985, 1994; Komarek & Komarkova-Legnerova, 2007). Komarek and Johansen (2015) ascertained that cyanobacterial species are geographically unrestricted (mostly not cosmopolitan) and occur in multiple, diverse biotopes (i.e., never ubiquitous), despite the fact that they may appear to be so in

older algal floras and culture collections compiled before molecular data changed our knowledge of species.

The diversity of cyanobacteria in tropical and subtropical regions has been understudied, and it is estimated that less than 10% of tropical diversity is known (Komarek, 2006). Reports on the diversity of cyanobacteria in (saline) brackish or marine habitats are rare or meagre. Of the total 89 species recorded, 44 species are considered new records for the marine cyanobacterial flora of India. The distribution of mangrove-associated coccoid cyanobacterial diversity began in the 1980s by Potts (1980) and has continued by many scientists across the world, but there have been very limited reports from the southwest coast of India except the literature of Joseph and Saramma (2016) and Ramamurthy and Abhinand (2016). There have been no exclusive studies on the taxonomy of mangrove-associated cyanobacteria reported from Kerala.

Branco et al. (1996) and León–Tejera et al. (2011) are the only exclusive studies on the mangrove inhabiting Chroococcales. Considering the order Chroococcales, only 8 species were identified from the study areas. When compared to previous studies, this record represents 10.95 % of the global distribution. The distribution pattern of cyanobacterial species obtained in this study is given in the result section. However, in some species, no distribution pattern has been discovered and such species are considered new records of the cyanobacterial flora. The species belongs to the family Aphanotheceae which includes *Aphanothece bullosa* (Meneghini) Rabenhorst 1865 and *Aphanothece granulosa* (N.L.Gardner) Komárek & Komákova-Legnerova 2007. The species belongs to the family Chroococcaceae which includes *Gloeothece samoensis* Wille 1913 and *Gloeothece ustulata* Beck-Mannagetta 1929 were recorded for the first time from the mangrove environments of the southwest coast of India.

Only 3 species were recorded to represent the order Synechococcales which has a 3.61% global distribution. The species belong to the family Merismopediaceae and include *Aphanocapsa grevillei* (Berkeley) Rabenhorst 1865 and *Anathece bacteriosa* (Komarek & Komarkova-Legnrova) Komarek, Kastovsky & Jezberova 2011 belong to the family Synechococcaceae and the species belongs to the family

Trichocoleusaceae which includes *Trichocoleus delicatulus* (West & G.S.West) Anagnostidis 2001 were considered the new record for the cyanobacterial flora of India.

There are only 3 species representing the order Spirulinales that represent 42.85% of the world's distribution. The occurrence of *Spirulina major* Kutzing ex Gomont 1892 was recorded in Saudi Arabia (Hussain & Khoja, 1993, Bano & Siddiqui, 2007, 2003), Pakistan (Ahmed et al., 2016), India (Nedumaran et al., 2008; Sen & Naskar, 2003; Selvakumar & Sundararaman, 2001; Sakthivel & Kathiresan, 2013) and Brazil (Branco et al., 2003). But there were no reports on the distribution of this species in Kerala and therefore the occurrence of this species is considered a new addition to the cyanobacterial flora of Kerala. The occurrence of the species *Spirulina spirulinoides* (Ghose) Geitler 1925 was reported by Peng et al. (2012) and Bamboo et al. (2009) and there have been no further reports available on the distribution pattern. Therefore, the occurrence of this species is regarded as a new addition to the cyanobacterial flora of India.

Based on previous studies, a compiled list of mangrove-associated cyanobacteria showed that the order Oscillatoriales have the richest among all other orders and that represents a total of 25.85% of this study. The species, *Anagnostidinema pseudacutissimum* (Geitler) Strunecky, Bohunicka, Johansen et Komarek, 2017 belongs to the family Coleofasciculaceae was the first new report to the cyanobacterial flora of India. The distribution of the genus *Anagnostidinema* was synonymously reported by some researchers, i.e., the occurrence of *Anagnostidinema acutissimum* (Kufferath) Strunecky, Bohunicka, Johansen et Komarek 2017 reported from Pakistan (Zaib-Un-Nisa et al., 2000, Bano & Siddiqui, 2007), *Anagnostidinema deflexum* (W. et G.S.West) Strunecky, Bohunicka, Johansen, Capkova, Raabova, Dvorak et Komarek 2017 reported from Pakistan (Bano and Siddiqui, 2007) and Kerala (Joseph & Saramma, 2016), *Anagnostidinema ionicum* (Skuja) Strunecky, Bohunicka, Johansen, Capkova, Raabova, Dvorak et Komarek 2017 reported from Pakistan (Bano & Siddiqui, 2007), *Anagnostidinema lemmermannii* (Woloszynska) Strunecky, Bohunicka, Johansen, Capkova, Raabova, Dvorak et Komarek 2017 reported from Pakistan

(Bano & Siddiqui, 2007). The family Coleofasciculaceae has 22.22% compared to global distribution.

The family Microcoleaceae consists of 30.76% of the global distribution. The occurrence of the species *Microcoleus autumnalis* (Trevisan ex Gomont) Strunecky, Komarek et J.R.Johansen 2013, *Microcoleus codii* Fremy 1932, *Microcoleus subtorulosus* Gomont ex Gomont 1892, *Planktothrix geitleri* (Kisselev) Anangnostidis et Komarek 1998, *Planktothrix isothrix* (Skuja) Komarek & Komarkova 2004 and *Planktothrix suspensa* (Pringsheim) Anagnostidis et Komarek 1988 were regarded as the new additions to the cyanobacterial flora of India. The distribution of some species has already been reported from the mangrove environments. *Microcoleus lacustris* Farlow ex Gomont 1892 and *Microcoleus paludosus* Gomont ex Gomont 1892 were reported from Indian Sundarbans (Barman et al., 2015). Therefore, the occurrence of this species is considered a new addition to the cyanobacterial flora of Kerala. *Porphyrosiphon ceylanicus* (Wille) Anagnostidis & Komarek 1988 was reported from the mangrove environments of Saudi Arabia (Hussain & Khoja,1993). There have been no further reports found on the distribution of the cyanobacterial flora of the south-west coast of India. Therefore, this record can also be considered a new report to the cyanobacterial flora of the south-west coast of India.

The family Oscillatoriaceae was the most dominant, including 24 species, which account for 27.27% of the global distribution. The occurrence of the species *Lyngbya truncicola* Ghose 1924, *Oscillatoria curviceps* var. *angusta* Ghose 1927, *Oscillatoria major* Vaucher ex Forti 1907, *Oscillatoria obtusa* N.L.Gardner 1927, *Oscillatoria princeps* var. *pseudolimosa* Ghose 1924, *Oscillatoria rupicola* (Hansgirg) Hansgirg ex Forti 1907, *Oscillatoria simplicissima* Gomont 1892, *Phormidium crassior* (Behre) Anagnostidis 2001 were considered new reports to the cyanobacterial flora of India. *Phormidium nigrum* (Vaucher ex Gomont) Anagnostidis & Komarek 1988 was synonymously reported from South Africa (Silva, 1991) and no evidence for Indian distribution and therefore the species regarded as a new addition to the mangrove-associated cyanobacteria from India while the occurrence of these species, *Limnoraphis hieronymusii* (Lemmermann) J.Komarek, E.Zapomelova, J.Smarda, J.Kopecky, E.Rejmankova, J.Woodhouse,

B.A.Neilan & J.Komarkova 2013, *Lyngbya aestuarii* Liebman ex Gomont 1892, *Lyngbya lutea* Gomont ex Gomont 1892, *Oscillatoria curviceps* C.Agardh ex Gomont 1892, *Oscillatoria limosa* Agardh ex Gomont 1892, *Oscillatoria perornata* Skuja 1949, *Oscillatoria princeps* Vaucher ex Gomont 1892, *Oscillatoria sancta* Kutzing ex Gomont 1892, *Oscillatoria subbrevis* Schmidle 1901, *Oscillatoria vizagapatensis* C.B.Rao 1938 and *Phormidium nigro-viride* (Thwaites ex Gomont) Anagnostidis & Komarek 1988 were not observed in the distribution pattern of Kerala and therefore these records regarded as new additions to the mangrove-associated cyanobacterial flora of Kerala.

The family Calotrichaceae has only 4 species, which account for 33.33% of the global distribution. The occurrence of these species, *Calothrix braunii* Bornet et Flahault 1886, *Calothrix marchica* Lemmerman 1914, *Calothrix marchica* var. *intermedia* C.B.Rao 1937 and *Calothrix nidulans* Setchell & N.L.Gardner 1924 was not observed in any of the mangrove environments and therefore, these records are regarded as new records for cyanobacterial flora of India.

The family Hapalosiphonaceae has 4 species of which only 2 species were recorded in the previous studies. The occurrence of the species *Mastigocladus laminosus* Cohn ex Kirchner 1898, *Westiellopsis interrupta* Kanthamma 1972 were regarded as new records for the cyanobacterial flora of India, while *Westiellopsis prolifica* Janet 1941 considered to add to the mangrove-associated cyanobacterial flora of south-west of India. The occurrence of the species, *Hapalosiphon welwitschii* West & G.S.West 1897 was previously recorded in the mangrove environments of India (Sudha, 2005; Sudha et al., 2007; Ramamurthy & Abhinand, 2016). There were no reports available on the occurrence of this species distribution in Kerala and it was therefore regarded as a new addition to the mangrove-associated cyanobacterial flora of Kerala. While considering the species, *Westiellopsis interrupta* Kanthamma 1972 was previously reported from the paddy field soils of Madras, India in 1972 and it has had no distributional records thereafter. It was obtained on January 17, 2020, from Ezhupunna mangrove environment in Alappuzha, after the original discovery. As a result, the occurrence of this species represents a rediscovery after a 48-year hiatus from the original.

The family Nostocaceae was the second dominant, including 20 species, which account for 74.07% of the global distribution in mangrove environments. *Anabaena bispora* Gayral & Mazancourt 1958, *Anabaena laxa* A.Braun 1886, *Anabaena sedovii* Kossinskaja 1933, *Nostoc bornetii* Gain 1911, *Nostoc calcicola* Brebisson ex Bornet et Flahault 1886, *Nostoc sphaericum* Vaucher ex Bornet et Flahault 1886, *Nostoc spongiaeforme* var. *varians* C.B.Rao 1937, *Trichormus kashiensis* (Bharadwaja) Komarek 2012, *Trichormus pseudovariabilis* (Woronichin) Komarek et Anagnostidis 1989 and *Trichormus rotundosporus* (Hollerbach) Komarek & Anagnostidis 1989 were regarded as new reports to India. The occurrence of these species, *Anabaena torulosa* (Carmichael) Lagerheim ex Bornet et Flahault 1886, *Desmonostoc muscorum* (C.Agardh ex Bornet & Flahault) Hrouzek et Ventura 2013, *Nostoc carneum* (Lyngbye) Agardh ex Bornet et Flahault 1886, *Nostoc commune* Vaucher ex Bornet et Flahault 1888, *Nostoc ellipsosporum* (Demazieres) Rabenhort ex Bornet et Flahault 1886, *Nostoc linckia* (Roth) Bornet et Flahault 1886, *Nostoc sphaericum* Vaucher ex Bornet et Flahault 1886, *Trichormus ellipsosporus* (Fritsch) Komarek et Anagnostidis 1989 and *Trichormus variabilis* (Kutzing ex Bornet et Flahault) Komarek et Anagnostidis 1989 were not observed in Kerala as per available literature and therefore these records are regarded as new additions to the mangrove-associated cyanobacterial flora of Kerala.

The family Rivulariaceae has only 1 species in which 10% of the global distribution in mangrove environments. The occurrence of the species, *Dichothrix orsiniana* (Kutz) Bornet et Flahault 1886 was not observed in any of the mangrove environments and therefore this record is regarded as a new record for the cyanobacterial flora of India.

The family Scytonemataceae has 6 species, which account for 60% of the global distribution in mangrove environments. The occurrence of these species, *Scytonema bohneri* Schmidle 1901, *Scytonema coactile* Montagne ex Bornet et Flahault 1886, *Scytonema javanicum* Bornet ex Bornet & Flahault 1886, *Scytonema tolypothrichoides* Kützing ex Bornet & Flahault 1886 and *Scytonema varium* Kutzing ex Bornet et Flahault 1886 was considered new additions to the mangrove-associated cyanobacterial flora of Kerala, while *Scytonema millei* Bornet ex Bornet & Flahault 1886 was not observed in any of the mangrove environments and

therefore this record is regarded as a new record for cyanobacterial flora of India. *Scytonema* sp. was very much similar to *Scytonema bewsii* Fritsch et Rich 1924. But some characteristics in the cellular organisation are of varying sizes and shapes. This record may be regarded as new species, but a polyphasic approach is very much needed for such confirmation.

According to the available literature, the family Stigonemataceae has not been found in any mangrove environment around the world. The study recorded only one species, *Stigonema ocellatum* (Dillwyn) Thuret ex Bornet & Flahault 1886 in which the species was not recorded from any of the mangrove environments and thus the occurrence of the species is regarded as a new record for the cyanobacterial flora of India.

There were 24 genera (*Chroococcidiopsis*, *Hyella*, *Scytonematopsis*, *Kyrtuthrix*, *Heteroleibleinia*, *Mastigocoleus*, *Schizothrix*, *Pleurocapsa*, *Hormathonema*, *Cyanocystis*, *Hydrococcus*, *Arthrospira*, *Chamaecalyx*, *Blennothrix*, *Merismopedia*, *Microchaete*, *Glaucospira*, *Trichodesmium*, *Nodularia*, *Pseudanabaena*, *Xenococcus*, *Heteroleibleinia* and *Jaaginema*) could not be traced out in the present study, but which were previously recorded by other published works (Potts 1980; Potts & Whitton, 1980; Hussain & Khoja,1993; Branco et al., 1996; Sen & Naskar, 2003; Steinke et al., 2003; Sudha et al., 2007; Bano & Siddiqui, 2007).

4.9. Distribution of heterocytous, non-heterocytous and unicellular cyanobacteria

The present study shows that non-heterocytous filamentous (47.19%) forms are more predominant than heterocytous filamentous (41.57%) or unicellular (11.23%) forms. A total of 42 species were recorded as non-heterocytous filamentous and 37 species were recorded as heterocytous and 10 species were recorded as unicellular or coccoid forms. In the earlier study by Thajuddin and Subramanian (1992), it was found that non-heterocytous filamentous dominated the saline environment. A similar trend has been observed in the mangrove environments of Mexico (Toledo et al., 1995 a; Perez-Estrada et al., 2012; Leon-Tejera et al., 2011), Tanzania (Kyaruzi et al., 2003), South Africa (Silva, 1991;

Mann & Steinke, 1993; Lambert et al., 1989; Toledo et al., 1989; Phillips et al., 1996; Phillips et al., 1994), Saudi Arabia (Hussain & Khoja, 1993), French West Indies (Sheridan, 1991), Tamil Nadu (Selvakumar & Sundararaman, 2001), Pakistan (Saifullah et al., 1997; Zaib-Un-Nisa et al., 2000; Bano & Siddiqui, 2007), Puerto Rico (Steinke & Naidoo, 1990), Brazil (Rigonato et al., 2012 a) and Colombia (Pena-Salamanca, 2008). The ratio of heterocytous to non-heterocytous forms compared to free-living cyanobacteria is usually determined by the nitrogen status of the environment (Sakthivel & Kathiresan, 2013).

4.10. Issues and challenges in cyanobacterial taxonomy and identification

Cyanobacteria face several important issues as they advance in research such as nomenclature, classification, issues in culturing and species identification and validity. Initially, cyanobacterial classification was based on the botanical system, the International Code of Botanical Nomenclature (ICBN), and their nomenclature was based on the International Code of Nomenclature of Algae, Fungi, and Plants (ICN) (McNeill et al., 2012). Stanier et al. (1978) considered cyanobacteria as prokaryotic organisms; their nomenclature has been covered by the provisions of the International Nomenclature of Prokaryotes (ICNP) (Parker et al., 2019). According to a recent literature survey, 29% of new cyanobacterial taxa published in the last 20 years were invalid due to the violation of one or more nomenclatural rules (Johansen et al., 2019). As a result, only a few taxa have been published validly according to the ICNP regulations, with the majority of authors continuing to publish according to the ICN (McGregor & Sendall, 2021).

In the early stages of cyanobacterial identification, authors considered morphological traits subjectively at the time of collection rather than considering aspects of temporal or spatial variability in species distribution. They consider only the morphological features, the presence or absence of a type of branching, and the position of akinetes and heterocytes, as the key characters. The taxonomy of cyanobacteria is always a challenging area that is still in a revolutionary phase with an increase in new taxa using the polyphasic approach, a combination of morphological, ecological, ultrastructural and phylogenetic characteristics. However, it is impossible to incorporate phylogenetic data with the knowledge

acquired from over 150 years of cyanobacterial biodiversity research works (Komarek, 2006). Based on the polyphasic approach, with further revised work on the classification of cyanobacteria, a three-volume series of Süßwasserflora on cyanobacteria has been strongly recommended (Komarek & Anagnostidis, 1998, 2005; Komarek, 2013). The order Chroococcales is covered in the first volume, followed by Oscillatoriales and Heterocytous genera in the second and third volumes. Certain genera, such as *Cyanotheca* Pascher 1914 (type: Caulobacteria) and *Dactylococcopsis* Hansgirg 1888 (type: green algae), have been treated as non-cyanobacterial organisms and have been deleted from the updated classification system.

Komarek et al. (2014) introduced a new classification system intending to validly publish names of cyanobacterial taxa exclusively based on the polyphasic approach. Subsequent revisions and reclassifications in the cyanobacteria taxonomy are still in progress. Komarek et al. (2020) revised and reclassified the cyanobacterial classification and through these classification systems, several new orders and families have emerged. Researchers often have difficulties modifying the cyanobacterial classification from time to time. To tackle this problem, researchers should consult the CyanoDB database (http://www.cyanodb.cz/) (Hauer & Komarek, 2022) for the most up-to-date cyanobacterial taxonomic classification and genus inclusion of cyanobacteria.

According to Hauer and Komarek (2022), cyanobacteria are classified into 10 orders and 61 families, while the other classification system proposed by Guiry and Guiry (2022) (https://www.algaebase.org/) 12 orders and 77 families with 5147 species. AlgaeBase classified cyanobacteria differently than the classification system proposed by Hauer and Komarek (2022). Certain species in AlgaeBase are placed in a separate section called *'ordo insertae sedis*' or *'familia insertae sedis*', which means the order or family of ‘uncertainty’. There is a debate as to whether the order Pseudanabaenales should be included, as Guiry and Guiry (2022) marked it as an 'unknown authority' and therefore consider it invalid. Like the entities of the order, Pseudanabaenales was never accepted by Guiry and Guiry (2022), even if the new species was discovered through the polyphasic approach.

Another major issue was verifying the validity or current status of cyanobacterial species nomenclature. This is due to the revised cyanobacterial nomenclature changing frequently. Certain genera have undergone several nomenclatural changes, either to new or existing names. Like some species of *Anabaena* have been renamed *Trichormus*, *Oscillatoria* has been renamed *Kamptonema*, *Geitlerinema* has been renamed *Anagnostidinema*, and so on. The AlgaeBase database provides the updated names, synonyms and current status of the species. Therefore, researchers should refer to the CyanoDB database for updated information. However, cyanobacteriologists should refer to CyanoDB (http://www.cyanodb.cz/) as a holy place for cyanobacterial research. Desikachary (1959) classified cyanobacteria into 5 orders: Chroococcales, Chamaesiphonales, Plerocapsales, Nostocales and Stigonematales; however, this classification is currently considered obsolete or invalid. Cyanobacteria currently contain 10 orders supported by molecular sequence data: Gloeobacterales, Chroococcales, Chroococcidiopsidales, Nostocales, Oscillatoriales, Pleurocapsales, Pseudanabaenales, Spirulinales and Thermostichales. The present study recorded 89 species from 5 orders, such as Chroococcales, Synechococcales, Spirulinales, Oscillatoriales and Nostocales and they are arranged based on the revised cyanobacterial classification proposed by Hauer and Komarek (2022). Listed below are some of the problems encountered while considering cyanobacterial species in these orders, and they are discussed.

4.10.1. Study on the members of the order Chroococcales

Desikachary (1959) arranged Chroococcales into two families, Chroococcaceae and Entophysalidaceae. Chroococcaceae consists of 17 genera whereas Entophysalidaceae with 4 genera. But Komarek & Anagnostidis (1998) consolidated unicellular cyanobacteria into a single volume, namely Chroococcales. In this volume, cyanobacteria were arranged into 11 families as Gloeobacteraceae with 1 genus, Synechococcaceae (Subfamily: Aphanothecoideae with 15 genera), (Subfamily: Synechococcoideae with 12 genera), Merismopediaceae (Subfamily: Merismopedioideae with 8 genera; Subfamily: Gomphosphaerioideae with 7 genera), Microcystaceae with 4 genera, Chroococcaceae with 8 species, Entophysalidaceae (subfamily: Entophysalidoideae

with 5 genera; subfamily: Siphononematoideae with 1 genus), Hydrococcaceae with 7 genera, Chamaesiphonaceae with 6 genera, Dermocarpellaceae with 3 genera, Xenococcaceae with 6 genera, Hyellaceae (subfamily: Podocapsoideae with 3 genera), (subfamily: Hyelloideae with 7 genera). Komarek et al. (2014) classified Chroococcales into 8 families such as Aphanothecaceae, Microcystaceae, Cyanobacteriaceae, Cyanothrichaceae, Stichosiphonaceae, Chroococcaceae, Gomphosphaeriaceae and Entophysalidaceae. Later Hauer and Komarek (2022) revised again the order Chroococcales into Aphanothecaceae with 10 genera, Cyanothrichaceae with 1 genus, Entophysalidaceae with 7 genera, Geminocystaceae with 3 genera, Gomphosphaeriaceae with 1 genus, Chroococcaceae with 22 genera, Microcystaceae with 4 genera and Stichosiphonaceae with 1 genus. But Guiry and Guiry (2022) classified Chroococcales into 9 families with the inclusion of the family, Cyanobacteriaceae with 2 genera, *Cyanobacterium* and *Erythrosphaera*. The genus *Cyanobacterium* Rippka et Cohen-Bazire, 1983 is currently considered an invalid genus and is suggested for further investigation (Tuji et al., 2021) and the entity of the genus, *Chroogloeocystis* Brown, Mummey et Cooksey, 2005 is also considered invalid.

Traditional genera like *Cyanotheca* Pascher 1914 and *Dactylococcopsis* Hansgirg 1888 were regarded as non-cyanobacterial organisms by Komarek and Anagnostidis (1998) and therefore it was excluded from the revised classification system. But the entity of the genus *Dactylococcopsis* Hansgirg 1888 was confirmed by Guiry and Guiry (2022) with 17 taxonomically accepted species. Earlier the genus *Aphanothece* was placed in the family Chroococcaceae (Desikachary, 1959) and Synechococcaceae of the subfamily, Aphanothecoideae (Komarek & Anagnostidis, 1989). According to the revised classification system proposed by Hauer and Komarek (2022), the genus *Aphanothece* is placed in the family, Aphanothecaceae. The genus *Gloeothece* was placed in the order Chroococcaceae (Desikachary, 1959) and later in Synechococcaceae of the subfamily, Aphanothecoideae by Komarek and Anagnostidis (1989). Currently, the genus is retained in the family Chroococcaceae, as suggested by Desikachary (1959). *Pseudochroococcus* Duval, Hamlaoui et Bernard 2021, *Neochroococcus* R. Geng et G. Yu 2021, *Alborzia* Nowruzi et Soares 2021, *Cryptochroococcus* Y. Wang, N. Jia

et R. Li 2021, *Cryptococcum* Gama, Rigonato, Fiore et Sant Anna 2019 and *Inacoccus* Gama, Rigonato, Fiore et Sant Anna 2019 are the recently emerged genera via polyphasic approach.

4.10.2. Study on the members of the order Synechococcales

The members of the order Synechococcales are still extremely problematic as they encompass coccoid, bacilloid unicellular and colonial genera as well as simple filamentous forms. According to Hauer and Komarek (2022), the order Synechococcales has13 families and the AlgaeBase database have the same number. But, Guiry and Guiry (2022) included the families Prochlorotrichaceae, Pseudanabaenaceae with three subfamilies, (Heteroleibleinioideae, Leptolyngbyoideae and Pseudanabaenoideae) and '*Synechococcales families insertae sedis'* with 8 genera such as *Cyanocatenula*, *Dasygloea*, *Heteroleibleinia*, *Inactis*, *Jaaginema*, *Schizothrix*, *Tubiella* and *Wolskyella.* Guiry and Guiry (2022) never accepted the entity of the order Pseudanabaenales. Mai et al. (2018) introduced two new families, Oculatellaceae and Trichocoleusaceae to the order Synechococcales. The discovery of a new genus, *Thalassoporum* Konstantinou et Gkelis 2021 (Konstantinou et al., 2021), confirms the existence of the family Psedudanabaenaceae of the order Pseudanabaenales (Komarek et al., 2020) and the study also established a new family, Thermosynechococcaceae, that includes the species, *Thermosynechococcus vestitus* (Copeland) Komárek et Strunecký 2020. However, Guiry and Guiry (2022) never accepted their entities in the order Pseudanabaenales and placed the genus *Thermosynechococcus* in the family Synechococcaceae and *Thalassoporum* in the family Leptolyngbyaceae of the order Synechococcales. The genus *Halomicronema* Abed, Garcia-Pichel et Hernández-Mariné, 2002, *Leptodesmis* Raabová, Kováčik, Elster et Strunecký 2019, *Cyanobium* Rippka et Cohen-Bazire 1983, *Inactis* (Gomont) Kirchner 1898 are now regarded as invalid.

The genus *Aphanocapsa* was previously placed in Chroococcaceae by Desikachary (1959) and Merismopediaceae of subfamily Merismopedioideae by Komarek & Anagnostidis (1998). Currently, the genus is placed in the family, Merismopediaceae (Komarek et al., 2014; Hauer & Komarek, 2022). The genus

Anathece is characterised by rod-like or small oval cells, usually >2µm wide. Since the genus has morphological, ultrastructural and phylogenetic characters, it, therefore, supports the separation of *Anathece* from *Aphanothece* and it belongs to the family, Synechococcaceae. The genus *Trichocoleus* was previously recorded as a member of Schizotrichaceae (Komarek & Anagnostidis, 2005). Currently, the genus belongs to the order Synechococcales of the family Trichocoleusaceae.

Amazoninema D. B. Genuário et al. 2020, *Cymatolege* Konstantinou et Gkelis 2021, *Euryhalinema* Chakraborty et Mukherjee 2019, *Leptoelongatus* Chakraborty et Mukherjee 2019, *Leptothoe* Konstantinou et Gkelis 2019, *Rhodoploca* Konstantinou et Gkelis 2021, *Altericista* Averina, E. Polyakova, Senatskaya & Pinevich 2021, *Aerofilum* Chakraborty et Mukherjee 2021, *Trichotorquatus* Pietrasiak et Johansen 2021, *Parasynechococcus* Coutinho, Tschoeke, Thompson et Thompson in Komárek et al. 2020, *Prochlorococcus* Chisholm, Frankel, Goericke, Olson, Palenik, Waterbury, West-Johnsrud et Zettler in Komárek et al., 2020 *Aegeococcus* Konstantinou et Gkelis 2021 and *Thainema* Rasouli-Dogaheh et Hauer 2022 are the recently emerged genera via polyphasic approach.

4.10.3. Study on the members of the order Spirulinales

Earlier, the genus *Spirulina* was placed under the family Oscillatoriaceae by Desikachary (1959) and later under the Pseudanabaenaceae of the subfamily Spirulinoideae by Anagnostidis & Komarek (2005). Currently, the genus is placed under the separate family Spirulinaceae, which was proposed by Komarek et al. (2014) and Hauer and Komarek (2022).

4.10.4. Study on the members of the order Oscillatoriales

Traditionally, the Oscillatoriacean members belonged to the order Nostocales (Desikachary, 1959). Later Komarek and Anagnostidis (2005), included all the non-heterocytous filamentous forms into a single order Oscillatoriales which include 6 families, Pseudanabaenaceae, Schizotrichaceae, Borziaceae, Phormidiaceae, Gomontiellaceae and Oscillatoriaceae. According to the recently revised classification proposed 10 families such as Borziaceae, Coleofasciculaceae, Cyanothecaceae, Desertifilaceae, Gomontiellaceae, Homeotrichaceae,

Laspinemaceae, Microcoleaceae, Oscillatoriaceae and Vermifilaceae by Hauer and Komarek (2021), while Guiry and Guiry (2022) were classified in 14 families. There were no entities recorded in the Cyanothecaceae family by Hauer and Komarek (2022), while AlgaeBase recorded 6 species of *Cyanothece* Komárek, 1976. Nevertheless, the genus *Cyanothece* Komárek, 1976 is placed under the family Gomontiellaceae of the order Oscillatoriales (Hauer & Komarek, 2022).

The genus *Anagnostidinema* occurs rarely, which was previously recorded from the extreme habitats of the polar regions of the Antarctic and as an isolated form from the various habitats of freshwater, in the littoral lakes, thermal springs and isolated pools (Strunecky et al., 2017; Zaki et al., 2020). *Anagnostidinema pseudacutissimum* (Geitler) Strunecky, Bohunicka, Johansen et Komarek, 2017 was originally registered as *Oscillatoria pseudacutissima* Geitler 1956 and Komarek and Anagnostidis (1988) renamed as *Phormidium pseudacutissimum* (Geitler) Anagnostidis et Komárek 1988, belongs to the family Phormidiaceae (Phormidioideae). Anagnostidis (1989) revised and reclassified based on the re-evaluation of the diacritical features of this species, *Phormidium pseudacutissimum* was replaced by *Geitlerinema pseudacutissimum* (Geitler) Anagnostidis, and placed in the family Pseudanabaenaceae of subfamily Pseudanabaenoideae (Komarek & Anagnostidis, 2005). Komarek et al. (2014) positioned the genus *Geitlerinema* and *Anagnostidinema* to the newly established family, Coleofasciculaceae and very recently *Geitlerinema* was revised and assigned to the family Pseudanabaenaceae (Hauer & Komarek, 2022). A polyphasic reassessment of *Geitlerinema pseudacutissimum* led to the establishment of the new genus Anagnostidinema Strunecky, Bohunicka, Johansen et Komarek (Strunecky et al., 2017).

Based on the polyphasic analysis, 11 *Geitlerinema* species were transferred to *Anagnostidinema* (Strunecky et al., 2017; Guiry & Guiry, 2022). The occurrence of *Anagnostidinema* species has been reported from the mangrove areas, but they have all been reported synonymously. *Anagnostidinema deflexum* (West & G.S.West) Strunecky et al. 2017 was recorded as *Oscillatoria deflexa* West & G.S.West 1911 as epiphytic from Pakistan (Bano & Siddiqui, 2007) and Cochin mangroves (Joseph & Saramma, 2016), *Anagnostidinema lemmermannii* (Woloszynska) Strunecky et al. 2017 were recorded as *Oscillatoria lemmermannii*

Woloszynska 1912 as epilithic from Pakistan (Bano & Sddiqui, 2007), *Anagnostidinema acutissimum* (Kufferath) Strunecký, Bohunická, J.R.Johansen & J.Komárek 2017 was recorded as *Phormidium acutissimum* (Kufferath) Anagnostidis & Komárek 1988 as epiphytic from Pakistan (Bano & Siddiqui, 2007, Zaib-Un-Nisa et al., 2000), *Anagnostidinema ionicum* (Skuja) Strunecky et al. 2017 were recorded as *Phormidium ionicum* (Skuja) Anagnostidis & Komárek 1988 as edaphic from Pakistan (Bano & Siddiqui, 2007).

Desikachary (1959) placed the genus *Microcoleus* under the family Oscillatoriaceae of the order Nostocales. Later, Komarek and Anagnostidis (2005) reclassified and placed them in the family Phormidiaceae, whose subfamily Microcoleoideae belongs to the order Oscillatoriales. Siegesmund et al. (2008) revised the genus *Microcoleus* based on the polyphasic approach and the species *Microcoleus chthonoplastes* was recently reclassified into the new genus, *Coleofasciculus chthonoplastes* which belongs to the family Coleofasciculaceae. The cyanobacterium *Coleofasciculus chthonoplastes* is very characteristic of the appearance of cyanobacterial layers that can be found in microbial mat habitats around the world and *Microcoleus* (including *Coleofaciculus*) mats generally occur in shallow marine environments where the salinity has increased by evaporation (Oren, 2010). Prufert-Bebout and Garcia-Pichel (1994) and Garcia-Pichel et al. (1996), studied the cosmopolitan nature of the cyanobacterial mat formation of *Coleofasciculus chthonoplastes* collected from geographically diverse sites, including intertidal marine habitats and hypersaline environments.

Strunecky et al. (2013) again revised the genus *Microcoleus* and established a new family, Microcoleaceae Strunecky, Johansen et Komarek 2013. Strunecky et al. (2014) established a new genus *Kamptonema*, which was derived from the polyphyletic *Phormidium* based on molecular and cytomorphological markers. *Kamptonema* is mainly characterised by the absence of sheaths whereas, in another genus, *Planktothrix* is identified mainly by the presence of gas vacuoles within the cell. *Planktothrix* has been separated from *Oscillatoria* concerning ultrastructural and phylogenetic characteristics (Anagnostidis & Komarek, 1988; Komarek & Komarkova, 2004) and placed in the family Phormidiaceae, subfamily Phormidioideae. Currently, the family Phormidiaceae is merged into

Oscillatoriaceae and subsequently, all the members now belong to Oscillatoriaceae (Hauer & Komarek, 2022).

The genus *Phormidium* (Oscillatoriaceae) belongs to the taxonomically most difficult cyanobacterial genus and includes numerous morphotypes with many transient forms. For easier identification, Komarek & Anagnostidis (2005) divided the genus into 8 categories purely based on the morphological variation, especially focussing on the apical trichome ends. Category 1: apical trichome ends with pointed or sharply pointed; Category 2: apical trichome ends gradually narrowed, rounded, without calyptra; Category 3: apical trichome ends shortly narrowed, bent, rounded without calyptra; Category 4: apical trichome ends distinctly conical; Category 5: apical trichome ends widely rounded, without calyptra; Category 6: apical trichome ends shortly attenuated; Category 7: apical trichome ends shortly or gradually narrowed; Category 8: cells always distinctly shorter and apical cell calyptrate.

Komarek et al. (2013) established a genus *Limnoraphis* Komárek, Zapomělová, Šmarda, Kopecký, Rejmánková, Woodhouse, Neilan et Komárková 2013 as a new member of the family, Oscillatoriaceae by selecting *Lyngbya hieronymusii* Lemmermann 1905 as a type species.

Desikachary (1959) assigned the genus *Oscillatoria* into the family Oscillatoriales, which also includes the order Nostocales. Komarek & Anagnostidis (2005) reassigned *Oscillatoria* into a separate family Oscillatoriaceae of the subfamily Oscillatorioideae. Currently, the genus is placed in the family Oscillatoriaceae (Komarek et al., 2014; Hauer & Komarek, 2022). The genus *Oscillatoria* is considered taxonomically more diverse and very difficult to identify at the species level.

Zimba et al. (2020) established a new family, Laspinemaceae under the order of Oscillatoriales with the inclusion of new genera, *Perforafilum* Zimba, Shalygin et Huang 2020. *Limnospira* Nowicka-Krawczyk, Mühlsteinová et Hauer 2019, *Affixifilum* Lefler, Berthold et Laughinghouse 2021, *Baaleninema* Samylina, Sinetova, Kupriyanova and Tourova 2021, *Capilliphycus* Caires, Sant´Anna et Nunes in Caires 2019, *Moorena* Engene et Tronholm 2019, *Potamosiphon* G.B.

McGregor & B.C. Sendall 2019, *Tenebriella* Hauerová, Hauer et Kaštovský 2021, *Sirenicapillaria* D.E. Berthold, Lefler et Laughinghouse 2022 and *Tigrinifilum* .E. Berthold, Lefler & Laughinghouse 2022 are the recently emerged genera via polyphasic approach, whereas the entity of the genus *Pseudoscillatoria* Rasoulouniriana et al. 2009 considered invalid.

4.10.5. Study on the members of the order Nostocales

Formerly, the heterocytous cyanobacteria were divided into two orders, Nostocales and Stigonematales. Nostocales represent non- branching or pseudo-branching species and Stigonematales represent true-branching (Desikachary, 1959). According to Desikachary (1959), the order Nostocales were divided into five families, Oscillatoriaceae, Microchaetaceae, Nostocaceae, Scytonemataceae and Rivulariaceae. But Komarek (2013) considered heterocytous cyanobacteria as a separate section and consolidated all the heterocytous cyanobacteria into a single volume. Komarek (2013) classified heterocytous genera into 10 families such as Scytonemataceae, Symphyonemataceae, Rivulariaceae, Microchaetaceae, Chlorogloeopsidaceae, Hapalosiphonaceae, Nostochopsidaceae, Fischerellaceae, Stigonemataceae and Nostocaceae. But with the continuous revision of the order Nostocales, recently Hauer and Komarek (2022) classified them into 19 families, Aphanizomenonaceae, Calotrichaceae, Capsosiraceae, Cyanomargaritaceae, Dapisostemonaceae, Fortieaceae, Geitleriaceae, Gloeotrichiaceae, Godleyaceae, Hapalosiphonaceae, Heteroscytonemataceae, Chlorogleopsidaceae, Microchaetaceae, Nostocaceae, Rivulariaceae, Scytonemataceae, Stigonemataceae, Symphyonemataceae and Tolypothrichaceae. Even though Luecking et al. (2014) established a new family, Rhizonemataceae with the inclusion of a new genus *Rhizonema*, it became invalid due to the lack of phylogenetic or polyphasic data. Guiry & Guiry (2022) classified Nostocales into 24 families including '*Nostocales insertae sedis'* with 1531 species.

Saraf *et al.* (2019) re-created the family, Calotrichaceae Bennet and Murray 1889, with the inclusion of a new genus *Dulcicalothrix* Saraf, Sudkar, Dawda, Gaysina, Gabidullin, Kumat, Behere, Kotulkar, Batule et Singh 2019. Desikachary

(1959) and Komarek (2013) previously assigned the genus to the family Rivulariaceae.

Formerly, the genus *Hapalosiphon* was assigned to the family Stigonemataceae (Desikachary, 1959) and later under the family, Hapalosiphonaceae (Komarek, 2013; Komarek et al., 2014; Hauer & Komarek, 2022) with a total of 27 genera. Whilst, Desikachary (1959) recorded the genus *Mastigocladus* under the separate family, Mastigocladaceae which also includes the other species, *Brachytrichia*. Currently, the genus *Mastigocladus* is assigned to the family Hapalosiphonaceae.

The genus *Westiellopsis* Janet was first described as a novel member of the Stigonemataceae family of the order Stigonematales from the Indian subcontinent (Janet, 1941; Desikachary, 1959; Gugger & Hoffman, 2004) and later it was reclassified in the family Fischerellaceae Komarek (2013). The revised classification system proposed by Komarek et al. (2014) assigned the genus to the family, Hapalosiphonaceae. Hapalosiphonaceae is the most widely studied family among the heterocytous cyanobacteria and is referred to as morphologically complex (Singh et al., 2017; Mishra et al., 2020). The occurrence of akinetes in *Westiellopsis prolifica* has been reported from certain geographical areas (Agrawal & Sharma, 1994; Gugger & Hoffmann, 2004; Agrawal, 2009), however, Komarek (2013) identified akinetes but suggested that they might just be enlarged cells with thick cell walls.

Due to their morphological similarity and diversity, the taxa *Nostoc*, *Anabaena*, and *Trichormus* are difficult to distinguish. Species of the genus *Trichormus* were originally described under the traditional genus *Anabaena,* but the morphology and apoheterocytic formation of akinetes indicate its close relation to the genus *Nostoc* or *Nostoc*-morphotypes with amorphous, gelatinous thalli (Komarek, 2013). The traditional genus *Nostoc* was found to be heterogeneous (Johansen et al., 1981; Lyra et al., 2001; Meeks et al., 2001; Henson et al., 2002; Hrouzek et al., 2005; Rajaniemi et al., 2005; Rehakova et al., 2007). From the genus, *Nostoc* has separated the genera *Mojavia* (Rehakova et al., 2007), *Aliinostoc* (Bagchi et al., 2017), *Komarekiella* (Hentschke et al., 2017) and *Compactonostoc* (Cai et al.,

2019). The other genus, *Desmonostoc* formed a supported group separated from strains belonging to the related taxa *Nostoc*, *Trichormus*, and *Mojavia* based on the polyphasic approach (Hrouzek et al., 2013). Desmonostoc forms a sister group of the main Nostoc cluster as the nearest relative. Such phylogenetic position was confirmed by several authors and is consistent with the morphology of strains (Hrouzek et al., 2003, 2005; Rehakova et al., 2007). It was formed by the replacement of the species *Nostoc muscorum* into *Desmonostoc muscorum*.

Desikachary (1959) classified the family Rivulariaceae with 6 genera while according to Hauer and Komarek (2022), there are 9 genera. Currently, the genus *Scytonema* includes 164 taxonomically accepted species, which have been separated into several definable clusters like *Brasilonema*, *Scytonema* sect. *Myochrotes*, and *Petalonema* still need taxonomic revision (Komarek, 2013). However, sect. *Myochrotes* division has been taken away from the classification system (Komarek et al., 2014; Hauer & Komarek, 2021). The phylogeny of the species within the genus, as well as their relationships, are still unknown due to difficulties in isolating these organisms and a lack of available molecular data (Hentschke & Komarek, 2014).

Amphiheterocytum Sant Anna et al. 2019, *Dulcicalothrix* Saraf, Sudkar, Dawda, Gaysina, Gabidullin, Kumat, Behere, Kotulkar, Batule et Singh 2019, *Reptodigitus* Casamatta, Villanueva, Stocks, Vaccarino et Johansen 2020, *Amazonocrinis* Alvarenga et al. 2021, *Atlanticothrix* Alvarenga et al. 2021, *Compactonostoc* F. Cai et R. Li 2019, *Constrictifilum* Chavadar et al. 2021, *Dendronalium* Alvarenga et al. 2021, *Desikacharya* Saraf et al. 2019, *Parakomarekiella* Soares, Ramos et Portugal 2020, *Pseudoaliinostoc* Lee, Ki et Lee 2021, *Purpureonostoc* Cai et Li 2020 and *Violetonostoc* F. Cai et R. Li 2020, *Nunduva* González–Resendiz, León–Tejera et Johansen in González–Resendiz et al., 2018 are the recently emerged Nostocalean members based on the polyphasic approach while the other genera like *Cyanospira* Florenzano, Sili, Pelosi et Vincenzini 1985, *Toxopsis* Lamprinou, Skaraki, Kotoulas, Economou-Amilli et Pantazidou 2012, *Amphithrix* Bornet et Flahault, 1886, *Physactis* Küzing 1843, *Iphinoe* Lamprinou et Pantazidou in Lamprinou et al., 2011, *Loriellopsis*

Hernández-Mariné et Canals in Lamprinou et al., 2011, *Minunostoc* F. Cai et R. Li 2019, *Neowollea* Tawong 2019 are considered invalid.

McGregor & Sendall (2022) scrutinised the validity of all the newly emerged cyanobacterial genera published between January 2000 and July 2020 and found that 96% were supported by at least one gene sequence, 62% include multiple genome sequences and only 6 discussed without any molecular support, emerging solely based on morphological characters. Nowadays, it is unusual to describe new species of cyanobacteria without molecular analysis, but despite numerous attempts, the cyanobacterial species could not be isolated it was not been possible to isolate cyanobacterial species or molecular studies based on environmental material could not be carried out. In these cases, however, it is still necessary to describe new taxa without molecular analysis to improve our understanding of cyanobacterial diversity. If this does not happen, diversity will be underestimated.

4.10.6. Issues associated with cyanobacterial culturing and isolation

The most important problem in cyanobacterial research is the isolation of species. Extensive categorization of the sampling sites is considered the most important step in isolating cyanobacteria. Location of the study area and physico-chemical parameters of the ecosystem such as light intensity, pH, salinity and temperature should be recorded from the sampling sites themselves. This information helps to describe the natural habitat of cyanobacteria, which is useful when designing culture media and incubation conditions (Waterbury, 2006). The chemical composition of the environment from which cyanobacteria are to be isolated should be replicated in the media. Nevertheless, there is a difficulty in that we must provide nitrogen to non-heterocytous species while denying nitrogen to heterocytous species. However, in the case of an increase in the number of sampling sites with varying environmental conditions, such as mangrove areas, it is not always practical to provide different laboratory conditions. This is considered to be the major problem in the culturing and isolation of cyanobacterial species.

Cyanobacterial colonies were isolated from planktic, benthic, epipsammic and mainly epiphytic habitats, and they grow well on the solid and liquid medium of BG-11. Some cultures have been pure, while others are still contaminated. Some

cyanobacterial species can be isolated from the BG-11 medium even by providing the medium with seawater or freshwater. The present study isolated four non-heterocytous forms belonging to three families: Spirulinaceae, Coleofasciculaceae and Oscillatoriaceae and five heterocytous forms belonging to two families, Halosiphonaceae and Nostocaceae (Table 4.4). Sudden acclimatization (drastic changes from nature to laboratory conditions) procedures may disintegrate cyanobacterial cells and cause their natural colour to fade. Cyanobacteria are entirely different when they are collected from nature rather than cultured; their structure, colour and appearance can vary. This may be due to the sudden transition from natural conditions to controlled or laboratory conditions.

Table 4.4

Cyanobacteria isolated from the mangrove environments

No.	Cyanobacterial species	Habitat and Place
1.	*Spirulina labyrinthiformis* Gomont 1892	Planktic from Kumbalam
2.	*Coleofasciculus chthonoplastes* (Thuret ex Gomont) M.Siegesmund, J.R.Johansen et T.Friedl 2008	Benthic from Vypin
3.	*Oscillatoria curviceps* C.Agardh ex Gomont 1892	Planktic from Mekkara
4.	*Oscillatoria princeps* Vaucher ex Gomont 1892	Epiphytic from Ayiramthengu
5.	*Westiellopsis prolifica* Janet 1941	Epiphytic from Kumbalam
6.	*Anabaena torulosa* (Carmichael) Lagerheim ex Bornet et Flahault 1886	Epiphytic from Kumbalam
7.	*Anabaena laxa* A.Braun 1886	Epiphytic from Ezhupunna
8.	*Nostoc linckia* (Roth) Bornet et Flahault 1886	Epiphytic from Sakthikulangara
9.	*Trichormus ellipsosporus* (Fritsch) Komarek et Anagnostidis 1989	Epiphytic from Ezhupunna and Vypin

The culturable cyanobacteria that are collected from mangrove habitats are usually underestimated compared to their actual numbers. Silva et al. (2014) isolated 50 cyanobacterial strains from Cardoso Island mangrove ecosystem in Brazil and they belong to five orders (Synechococcales - 31 strains, Chroococcales - 3 strains, Oscillatoriales - 1 strain, Pseudanabaenales - 8 strains and Nostocales - 7 strains), seven families (Synechococcaceae, Cyanobacteriaceae, Entophysalidaceae,

Pseudanabaenaceae, Phormidiaceae, Nostocaceae and Microchaetaceae) and eight genera (*Synechococcus*, *Cyanobium*, *Cyanobacterium*, *Chlorogloea*, *Leptolyngbya*, *Phormidium*, *Nostoc* and *Microchaete*). Temraleeva et al. (2016) found that the stab inoculation technique could enrich the growth of cyanobacteria on a solid nutrient medium. This is because some species of cyanobacteria grow poorly on the agar surface but develop well inside the agar. Waterbury (2006) mentioned that purification of unicellular cyanobacteria could be achieved by re-streaking on a solid medium, but this is not successful in isolating cyanobacterial species. There is no efficient method for the rapid isolation or purification of cyanobacteria from fungal or bacterial contaminants, especially in dynamic environments like mangrove areas, where the solution is still being processed.

4.11. Measuring the diversity indices: Statistical analysis

Biodiversity, a multidimensional characteristic of natural systems, is difficult to quantify, owing to the large number of indices proposed for this objective. Measuring diversity is critical to understanding the structure and dynamics of communities, but it has proven extremely problematic for microorganisms as there is no single index that sufficiently summarizes the concept (Hurlbert, 1971; Purvis & Hector, 2000). Understanding the differences in the composition of microbial communities is of great importance to microbial ecology. In environmental microbiology, determining microbial diversity and distribution is a major concern. Diversity indices are used to define the general characteristics of communities and to compare them across regions, taxa, and trophic levels. Taxon-based approaches are frequently used to estimate microbial diversity, ignoring the reality that not all species are similarly related, which could obscure vital patterns in the data. Alpha (α) diversity focuses on community variation within a community (sample), beta (β) diversity quantifies (dis-)/ similarities among communities (samples) which is based on the number of shared species.

4.11.1. Alpha (α) diversity indices

Alpha diversity, sometimes referred to as species diversity, summarizes the distribution of species abundances in a given sample into a single number that depends on species richness and evenness. Alpha Diversity indices measure the

overall heterogeneity of the community. To ensure that the diversity ordering is robust, the study tests the validity of various diversity indices. The results of the distribution of the mangrove-associated cyanobacterial diversity are depicted in Table 4.3. and the calculated diversity indices of the mangrove-associated cyanobacteria are depicted in Table 4.5.

Table 4.5

Showing alpha (α) diversity indices of mangrove-associated cyanobacteria based on various parameters across study areas

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Taxa_S	13	10	**25**	118	15	14	8	13	**36**	30
Individuals	286	197	593	378	311	288	187	310	**1047**	635
Dominance_D	0.086	0.110	0.045	0.067	0.071	0.078	**0.141**	0.086	0.031	0.036
Simpson_1-D	0.913	0.889	0.954	0.932	0.929	0.922	0.858	0.914	**0.969**	0.963
Shannon_H	2.504	2.253	3.151	2.798	2.676	2.594	2.009	2.511	**3.53**	3.353
Evenness_e^H/S	0.940	0.951	0.935	0.911	0.968	0.956	0.932	**0.947**	0.948	0.953
Brillouin	2.406	2.15	3.054	2.693	2.571	2.49	1.923	2.419	**3.472**	3.245
Menhinick	0.768	0.712	1.027	0.925	0.850	0.825	0.585	0.738	1.143	**1.191**
Margalef	2.122	1.704	3.759	2.864	2.439	2.296	1.338	2.092	**5.177**	4.494
Equitability_J	0.976	0.978	0.979	0.967	0.988	0.983	0.966	**0.979**	0.985	0.985
Fisher_alpha	2.805	2.225	5.287	3.934	3.29	3.077	1.698	2.745	**7.476**	6.542
Berger-Parker	0.126	0.157	0.088	0.145	0.102	0.118	**0.187**	0.155	0.055	0.050
Chao-1	13	10	25	18	15	14	8	13	**36**	30

(Abbreviations used: S1: Kadinamkulam; **S2**: (Edava) Kureekkadavu-Kappil; **S3**: Ayiramthengu; **S4**: Sakthikulangara; **S5**: Kumarakom; **S6**: Mekkara; **S7**: Ezhupunna; **S8**: Pathiramanal; **S9**: Kumbalam; **S10**: Vypin/Puthuvype**)**

4.11.1.1. Taxa indexing analysis

The distribution of species indicates that Kumbalam (S9) has the highest number (36 species) followed by Vypin (30 species), Ayiramthengu (25 species), Sakthikulangara (18 species), Kumarakom (15 species), Mekkara (14 species),

Pathiramanal (13 species), Kadinamkulam (13 species) and the least distribution was recorded at Kureekkadavu (10 species) and Ezhupunna (8 species) (Fig. 4.3).

4.11.1.2. Individuals indexing analysis

The results of the individual analysis of each study area showed that Kumbalam (S9) has the highest number (1025) followed by Vypin (635), Ayiramthengu (587), Sakthikulangara (378), Kumarakom (311), Mekkara (288), Pathiramanal (284), Kadinamkulam (286) and the least distribution was recorded at Kureekkadavu (197) and Ezhupunna (187) (Table 4.5; Fig. 4.4).

Fig. 4.3

Showing the number of taxa from the study areas

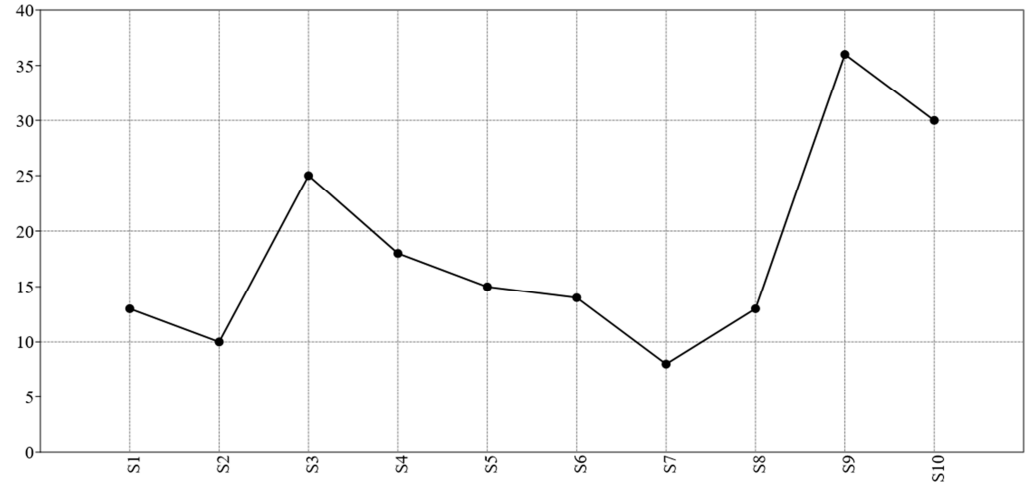
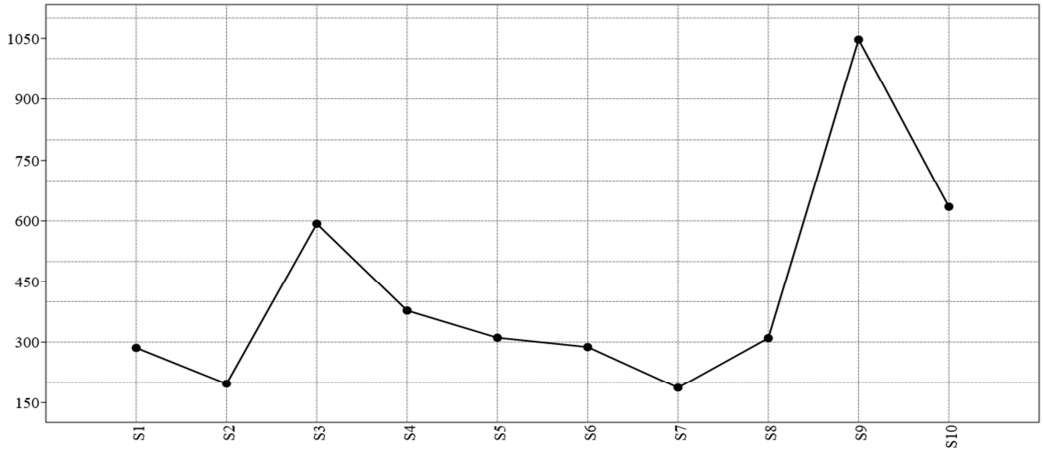


Fig. 4.4

Showing the number of Individuals from the study areas



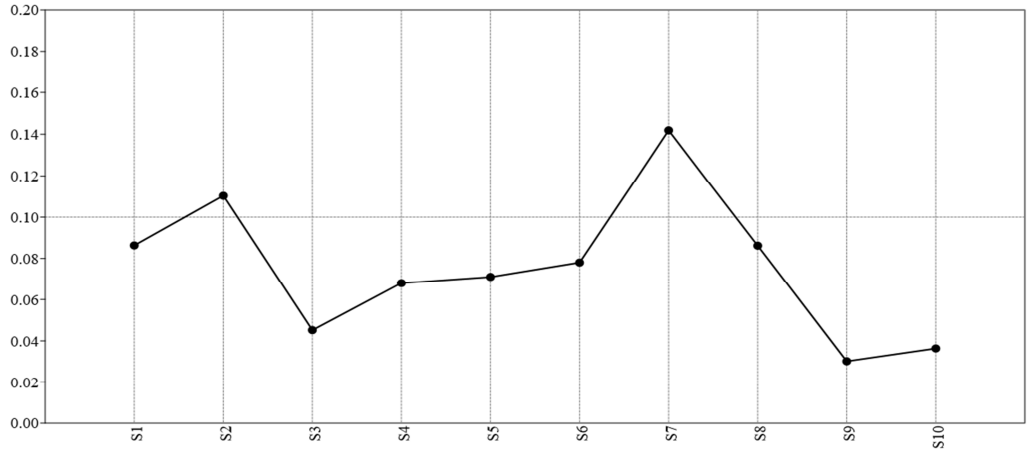
4.11.1.3. Dominance (D) index analysis

The dominant index in the present study indicated that Ezhupunna (0.141) has the highest dominance index followed by Kureekkadavu (0.110), Kadinamkulam (0.086), Pathiramanal (0.080), Mekkara (0.078), Kumarakom (0.071), Sakthikulangara (0.067), Ayiramthengu (0.045), Vypin (0.036) whereas Kumbalam (0.031) showed the least dominant index (Table 4.5; Fig. 4.5). With this index, the value of D ranges between 0 and 1. The value zero (0) represents infinite diversity and 1 represents no diversity. The high dominance index is influenced by the diversity value. i.e., the higher the diversity value, the lower the dominance value and vice versa. The higher the dominance value, the lower the diversity and the lower the dominance, the higher will be diversity.

The term 'dominant species' is not clearly defined yet or established in vague concepts, and different authors use the term to convey different information. Avolio et al. (2019) demystified the concepts of dominant species and clearly defined those "species that have high abundance relative to other species in a community and have proportionate effects on environmental conditions, community diversity, and/or ecosystem function. Dominant species can be common (widespread) or restricted in their range (limited)". Avoilio et al. (2019) strongly recommended a greater focus on dominant species, especially their identity and impact on the community and at the ecosystem level and concluded that it is unknown how generalizable the effects of dominant species are on the characteristics of communities and ecosystems, which requires more research on dominant species. When compared to rare species, dominant species have a higher abundance and ubiquity, hence their extinction is rarely observed (Gaston, 2010). Nevertheless, dominant species are also at high risk of extinction (Gaston, 2011), and anthropogenic changes harm them all over the world (Gaston, 2010). Thus the concept of dominant species research should be relied upon as the key to understanding the impact of global change.

Fig. 4.5

Showing Dominance indices from the study areas



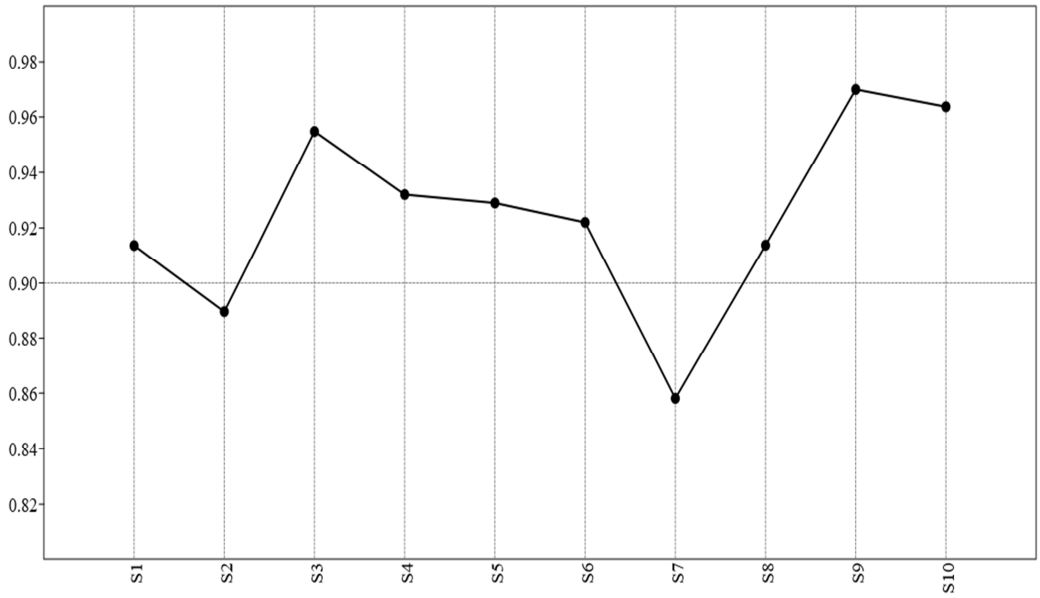
4.11.1.4. Simpson index

Simpson's index is widely used to measure habitat biodiversity. It takes into account both the number of species present and their abundance. The Simpson diversity index has been used to measure the degree of homogeneity/diversity within communities. The Simpson index ranges from 0 to 1, with 0 indicating the absence of diversity (i.e., maximum homogeneity) and 1 indicating maximum heterogeneity/diversity. Guajardo (2015) insisted on a further subdivision while interpreting the Simpson index, i.e., Simpson score 0.00 indicates absence of diversity/homogeneity, 0.01-0.40 - low degree of diversity/heterogeneity, 0.41-0.60 - moderate degree of diversity/heterogeneity, 0.61-0.80 - moderately high degree of diversity/heterogeneity, 0.81-0.99 - high degree of diversity/heterogeneity, and 1.00- absolute (perfect) diversity/heterogeneity.

The values of the Simpson diversity index were between 0.858-0.969. According to Guajardo (2015), all the study areas possess a high degree of cyanobacterial diversity whereas the lowest value (0.858) was reported from Ezhupunna (S7) and the highest value (0.969) was reported from Kumbalam (S9). The greater the index value, the greater the sample diversity, i.e., Kumbalam (S9) mangrove ecosystem has the maximum cyanobacterial diversity whereas Ezhupunna (S7) has the minimum cyanobacterial diversity (Table 4.5; Fig. 4.6).

Fig. 4.6

Showing Simpson diversity indices values of study areas



4.11.1.5. Shannon-Wiener index

Shannon-Wiener index represents the number of individuals as well as the number of taxa. Normally index values vary from 0 to 4.5 and this value is a combination of species present and the evenness of the species. Shanthala et al. (2009) interpreted the Shannon-Weiner index values, 3.00-4.50 - High diversity, 2.00-3.00 - Moderate diversity, 1.00-2.00 - Less diversity and 0.00-1.00 represents very less diversity.

The values of the Shannon Diversity Index were between 2.00-3.53, i.e., the study areas have a moderate and high diversity of cyanobacteria in mangrove environments. The lowest value (2.009) was for Ezhupunna (S7) and the highest value (3.53) was for Kumbalam (S9). The greater the index value, the greater the sample diversity, i.e., the Kumbalam (S9) mangrove ecosystem has the maximum cyanobacterial diversity, whereas Ezhupunna (S7) has the minimum cyanobacterial diversity (Table 4.6; Figure 4.7).

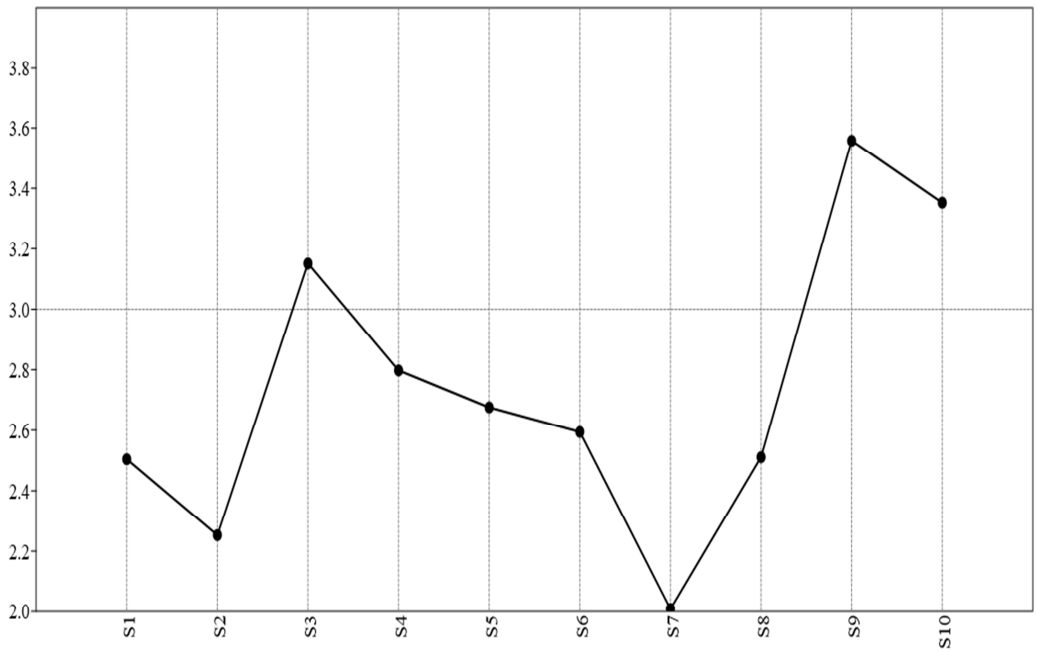
Table 4.6

Showing study areas and Shannon-Wiener index interpretation

Study area	Shannon-Wiener index interpretation
Kadinamkulam (S1)	Moderate
Kureekkadavu (S2)	Low
Ayiramthengu (S3)	High
Sakthikulangara (S4)	Moderate
Kumarakom (S5)	Moderate
Mekkara (S6)	Moderate
Ezhupunna (S7)	Low
Pathiramanal (S8)	Moderate
Kumbalam (S9)	Very high
Vypin (S10)	High

Fig. 4.7

Showing Shannon-Wiener index indices values of study areas

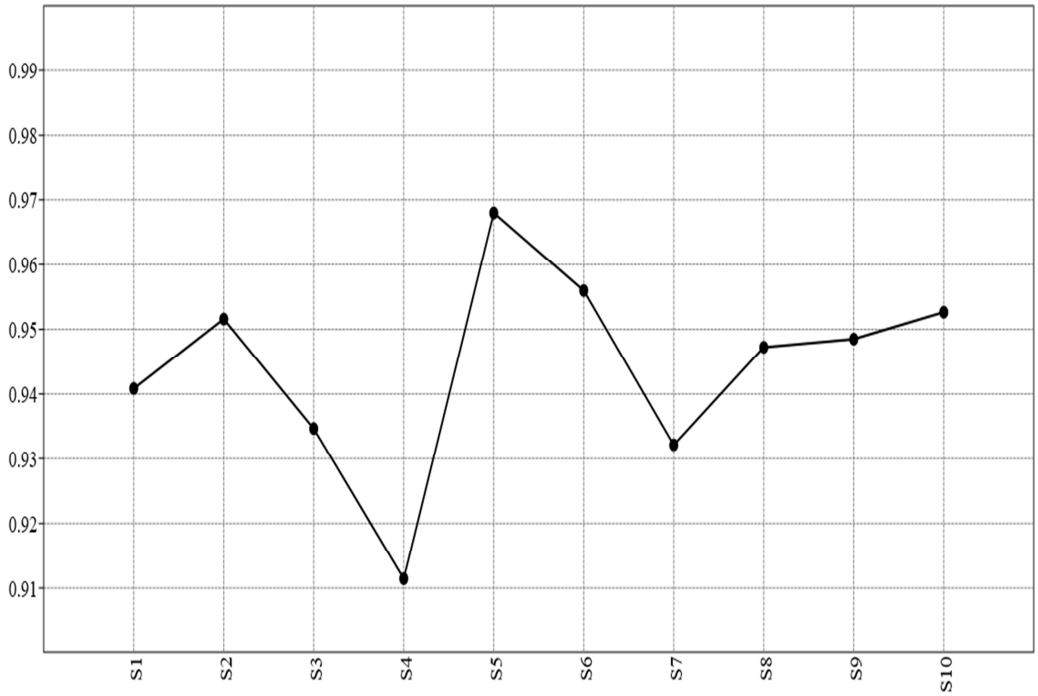


4.11.1.6. Pielou's Evenness index

Evenness is a measure of how diverse a community is relative to the maximum possible diversity and also quantifies how equal the community is in numerical. The value of evenness ranges from 0 to 1. The value 0 represents not evenly distributed whereas 1 represents the taxa are evenly distributed in a community. When the evenness value is close to one, it suggests that the majority of the individuals belong to one or a few species or categories and it also shows that each species/category has the same number of individuals. Hussain et al. (2012) subdivided the evenness value, >0.8-0.9 as balanced, >0.5-0.8 as semi-balanced, and ≤0.5 as unbalanced. This study recorded the evenness values from 0.911-0.978. The lowest value (0.911) for Sakthikulangara (S4) and the highest value (0.978) for Pathiramanal (S8). The study, therefore, concluded that the individuals are not evenly distributed or almost balanced among communities/study areas (Fig. 4.8).

Fig. 4.8

Showing Evenness values of study areas



4.11.1.7. Brillouin index

The Brillouin index measures the diversity of a collection, as opposed to the Shannon index which measures a sample. The value obtained rarely exceeds 4.5 and both the Brillouin and Shannon indices tend to give similar comparative measures. This study recorded Brillouin diversity index values from 1.923 to 3.444. The lowest value (1.923) was recorded for Ezhupunna (S7) and the highest value (3.444) for Kumbalam (S9). i.e., Kumbalam (S9) has high diversity whereas Ezhupunna (S7) has a very low cyanobacterial abundance (Table 4.7; Fig. 4.9).

Table 4.7

Showing study areas and Brillouin index interpretation

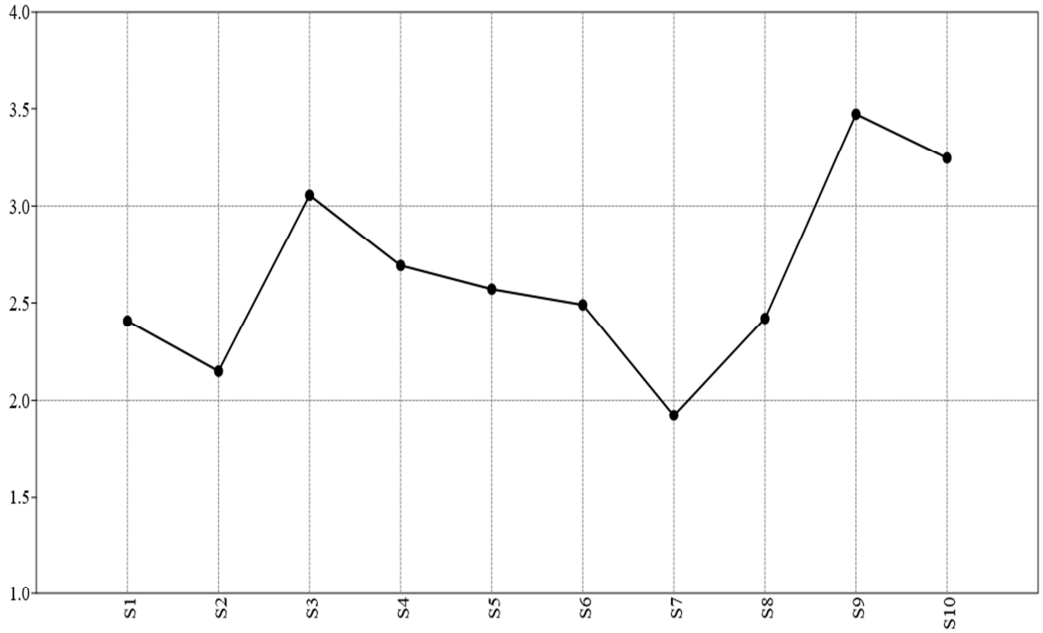
Study area	Brillouin index interpretation
Kadinamkulam (S1)	Low
Kureekkadavu (S2)	Low
Ayiramthengu (S3)	High
Sakthikulangara (S4)	Moderate
Kumarakom (S5)	Moderate
Mekkara (S6)	Low
Ezhupunna (S7)	Very low
Pathiramanal (S8)	Low
Kumbalam (S9)	High
Vypin (S10)	High

From a conservationist's point of view, a species-rich area, Kumbalam (S9), might be more valuable for conservation than a species-rich area with fewer individuals, Ezhupunna (S7), therefore the Brillouin index may have some advantages over the Shannon index and can be preferable in conservation biology. When applying the Brillouin index, rare species with single individuals do not affect the overall value of the index. Brillouin index changes when the total individual abundance changes. Shannon index does not change as long as the number of

species and their proportional abundance remain constant. Brillouin index discriminates among communities, while the Shannon index does not and therefore Brillouin index has a better discriminant ability. While considering the total number of individuals in a community is important, the Brillouin index is useful. However, a second significant distinction between the two indices is that using factorials in the equations quickly yields large, awkward numbers and because of its computational simplicity, the Shannon index is widely used (Stiling, 2012).

Fig. 4.9

Showing Brillouin index values of study areas



4.11.1.8. Menhinick index

The simplest diversity indices ignore the relative abundance of taxa that including Menhinick index. The values of the Menhinick diversity index were between 0.585-1.191. Kanieski et al. (2018) interpreted the Menhinick diversity index value, <1.96 indicates high diversity, 0.80-1.96 medium diversity, and >0.80 indicates low diversity. None of the study areas represented high diversity as per Menhinick index value (Table 4.8; Fig.4.10).

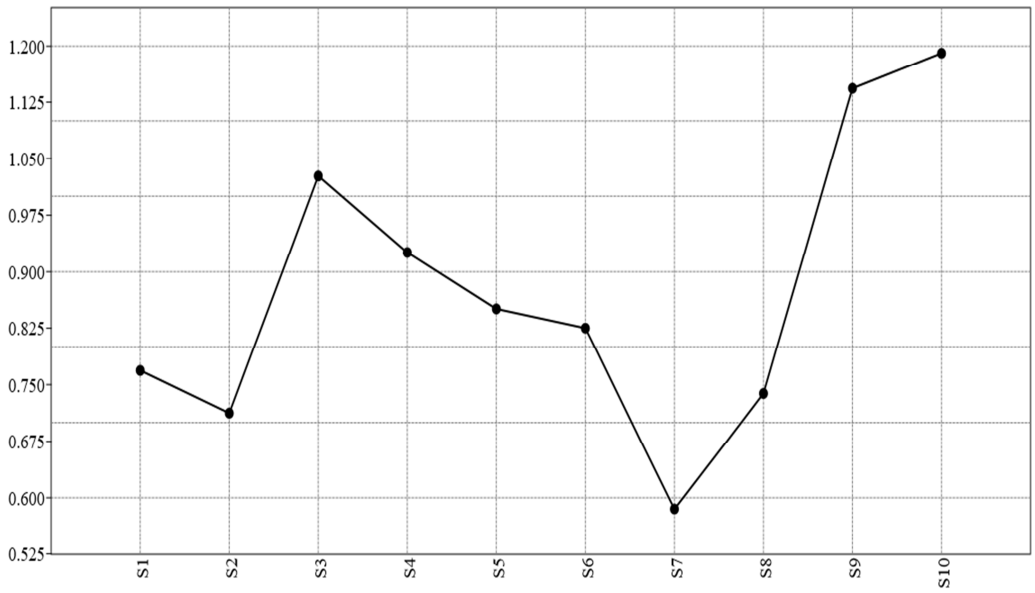
Table 4.8

Showing study areas and Menhinick index interpretation

Study area	Menhinick index interpretation
Kadinamkulam (S1)	Low
Kureekkadavu (S2)	Low
Ayiramthengu (S3)	Medium
Sakthikulangara (S4)	Medium
Kumarakom (S5)	Medium
Mekkara (S6)	Medium
Ezhupunna (S7)	Low
Pathiramanal (S8)	Low
Kumbalam (S9)	Medium
Vypin (S10)	Medium

Fig. 4.10.

Showing Menhinick index values of study areas



4.11.1.9. Margalef index

The normal value of the Margalef diversity index ranges from 0-5. Hussain et al. (2012), Yeom and Kim (2011) and Kanieski et al. (2018) interpreted this value as, above 4 represents high diversity, 2.05-3.99 represents medium diversity and ≤2.05 represents low diversity. This study recorded Margalef diversity index values from 1.338-5.049. The lowest value (1.338) was recorded for Ezhupunna (S7) and the highest value (5.049) for Kumbalam (S9). i.e., Kumbalam (S9) has high diversity whereas Ezhupunna (S7) has a very low cyanobacterial richness (Table 4.9: Fig.4.11).

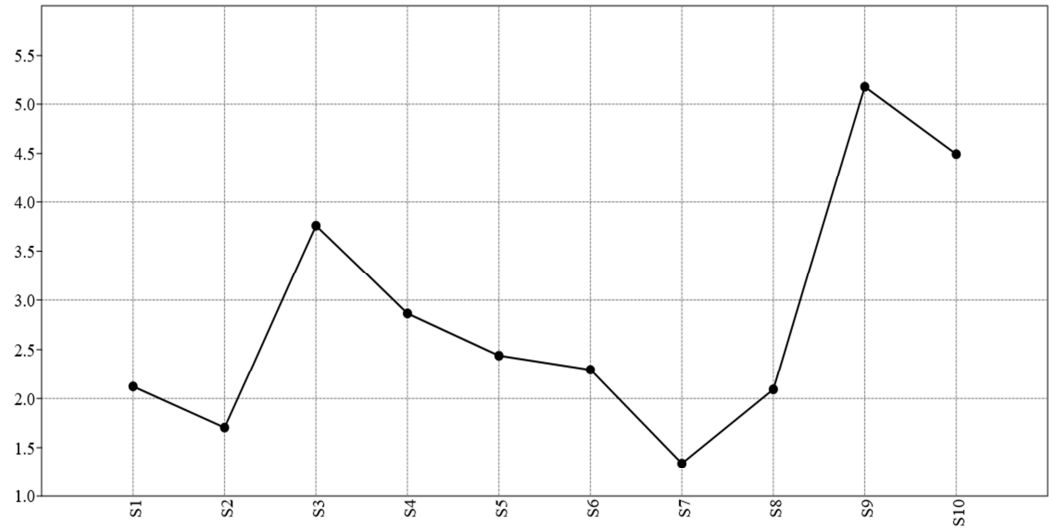
Table 4.9

Showing study areas and Margalef index interpretation

Study area	Margalef index interpretation
Kadinamkulam (S1)	Medium
Kureekkadavu (S2)	Low
Ayiramthengu (S3)	Medium
Sakthikulangara (S4)	Medium
Kumarakom (S5)	Medium
Mekkara (S6)	Medium
Ezhupunna (S7)	Low
Pathiramanal (S8)	Medium
Kumbalam (S9)	High
Vypin (S10)	High

Fig. 4.11

Showing Margalef index values of study areas

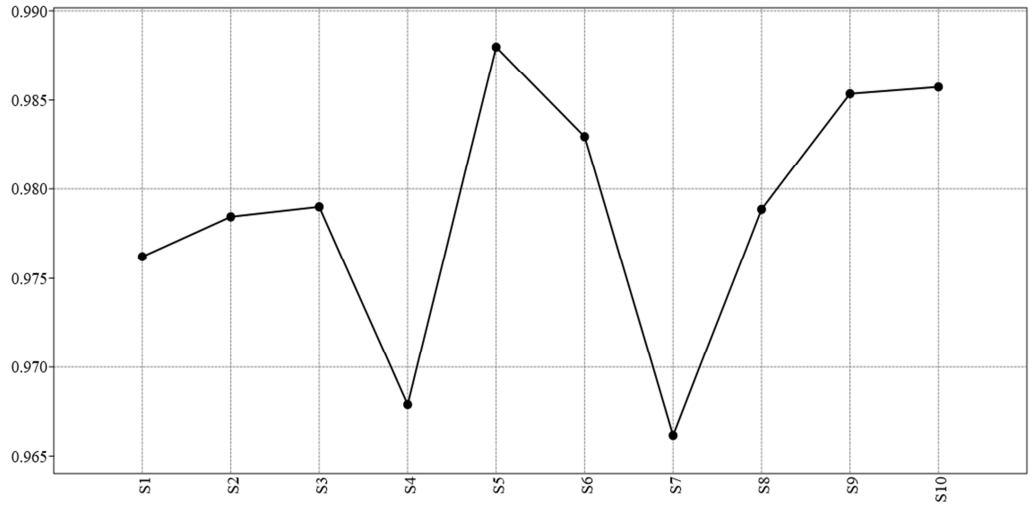


4.11.1.10. Equitability index

The equitability index measures the evenness with which individuals are divided among the taxa present. The Equitability Index typically has values between 0 and 1, with the higher the value, the more equitable the sample (Sklenar et al., 2001). This study indicates that the species are not evenly or equitably distributed in all the study areas, with values ranging from 0.966 to 0.985 (Fig. 4.12).

Fig. 4.12

Showing Equitability index values of study areas

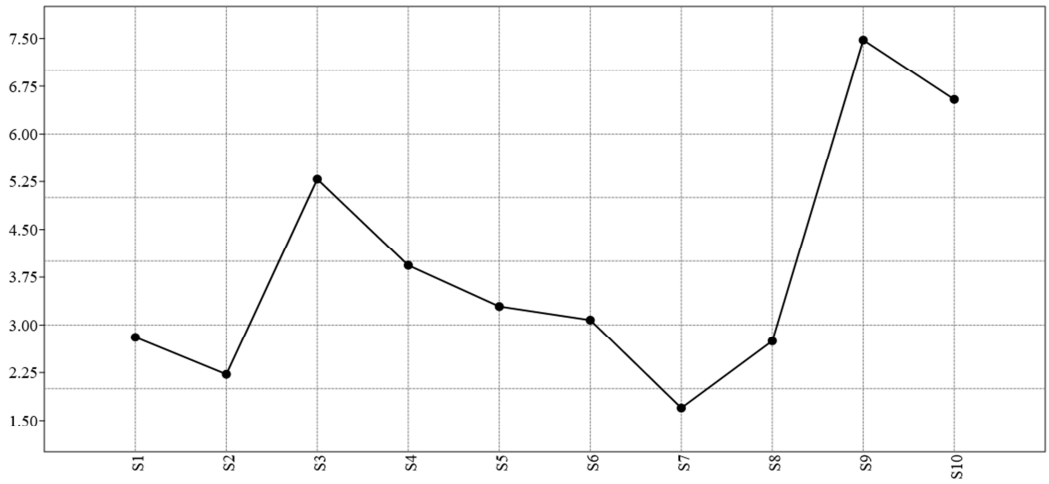


4.11.1.11. Fisher's alpha index

The value of the Fisher-alpha index varies from 1.698-7.263. the greater the index value, the greater the diversity. The lowest value (1.698) was recorded for Ezhupunna (S7) and the highest value (7.263) for Kumbalam (S9). i.e., Kumbalam (S9) has high diversity whereas Ezhupunna (S7) has a very low cyanobacterial diversity (Fig. 4.13).

Fig. 4.13

Showing Fisher's alpha index values of study areas



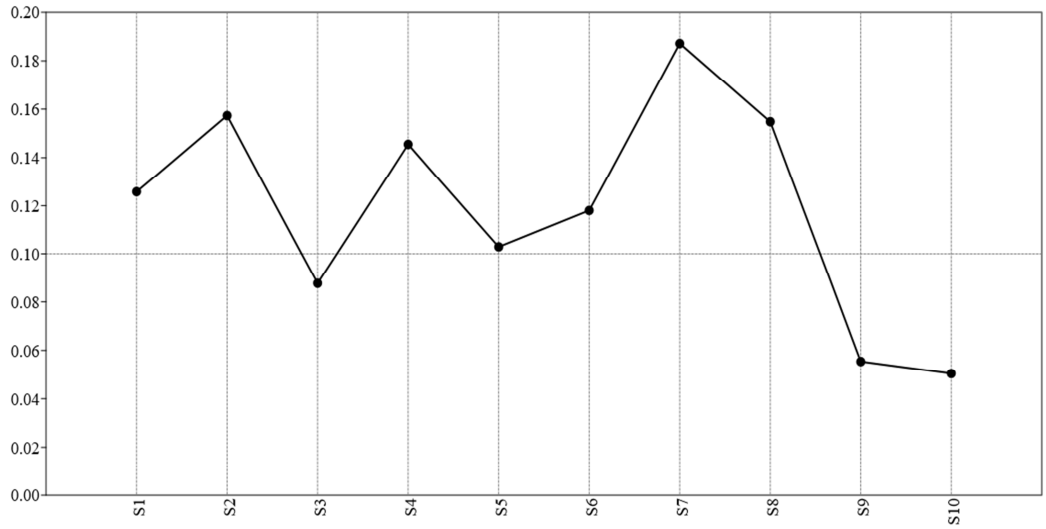
4.11.1.12. Berger-Parker index

The value of the Berger-Parker index varies from 0.050-0.187. The lower the index value, the higher the richness. The lowest value (0.050) was recorded for Kumbalam (S9) and the highest value (0.187) for Ezhupunna (S7). i.e., Kumbalam (S9) has high cyanobacterial diversity whereas Ezhupunna (S7) has low cyanobacterial diversity (Fig. 4.14).

The ecological significance of the Berger-Parker Index had not previously been determined (Magurann, 1988), but Caruso et al. (2007) found it to be an effective tool for monitoring biodiversity assessments. While applying the Berger-Parker index, the more diverse communities have a lower value than less diverse communities. It is assumed that if the values of the Berger-Parker index are high, the community is dominated by the most common species or the study area is not evenly distributed.

Fig. 4.14

Showing Berger-Parker index values of study areas

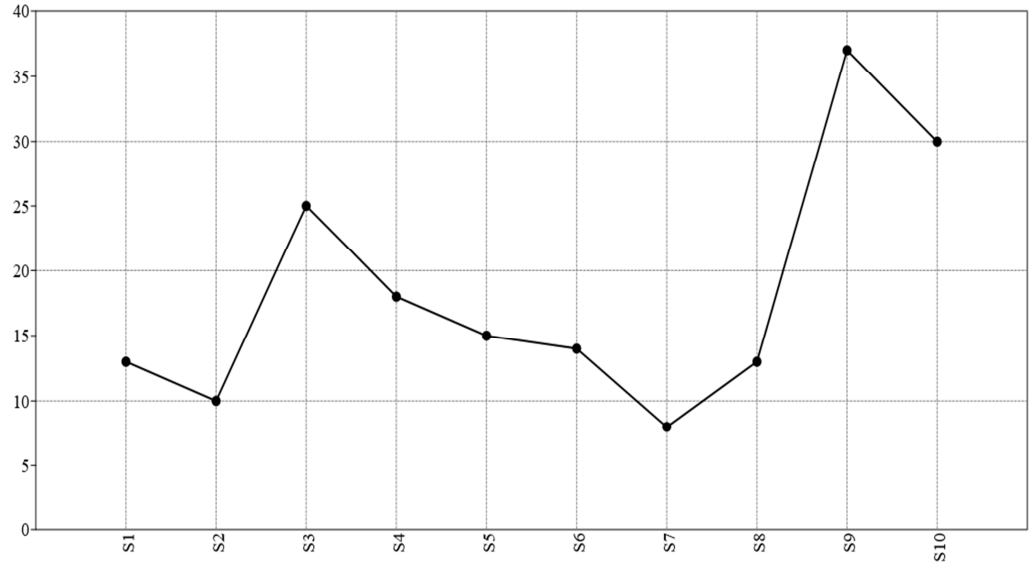


4.11.1.13. Chao-1 index

The Chao-1 is a nonparametric method that estimates the total number of taxa in a community. Kumbalam (S9) showed a maximum number of cyanobacterial species whereas Ezhupunna shows a minimum number of cyanobacterial species and it is depicted in Fig. 4.15.

Fig. 4.15

Showing Chao-1 index values of study areas

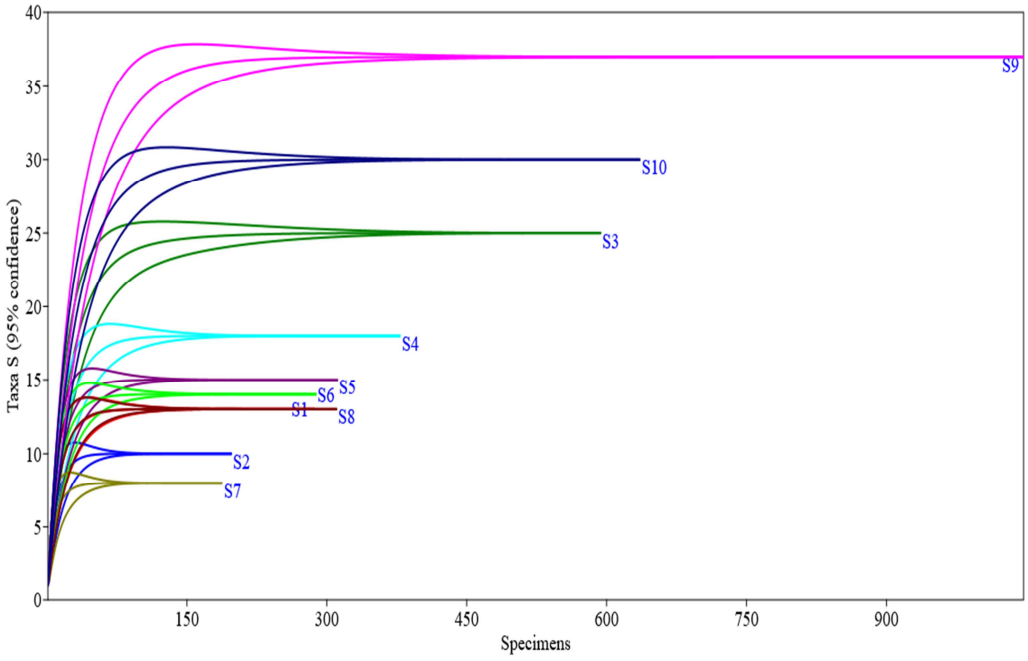


4.11.1.14. Individual Rarefaction

Individual rarefaction allows comparing the sample that has different numbers of cyanobacterial species. The rarefaction plot shows the number of individual OTUs (Operational Taxonomic Units) in a given number of individual samples. The rarefaction curve indicates that the study area Kumbalam (S9) is more diverse as the number of different species (OTUs) is increasing more rapidly than in other study areas, with an increasing number of cyanobacterial species. In contrast, the study area of Ezhupunna (S7) is the least diverse, as the number of species does not increase very much (Fig.4.16).

Fig. 4.16

Showing Individual Rarefaction curve

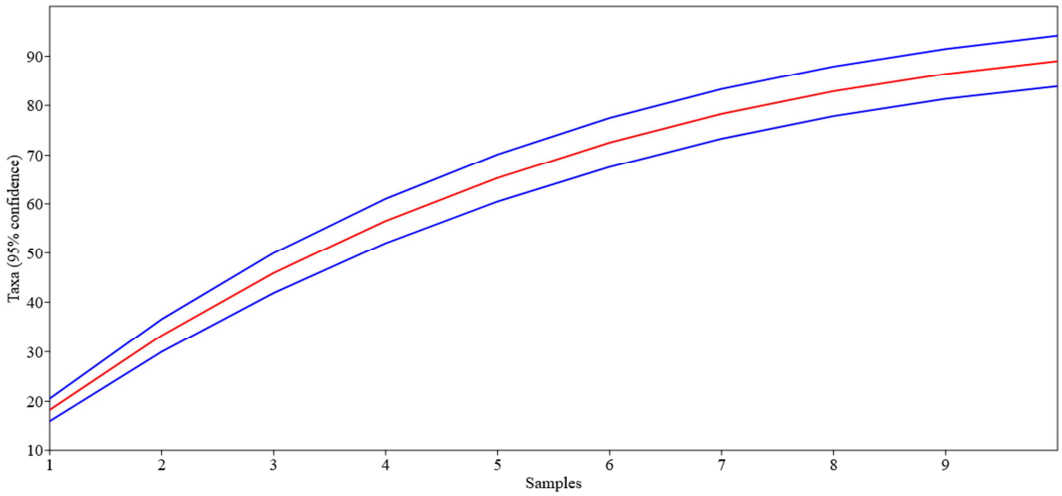


4.11.1.15. Sample Rarefaction Curve/ Species accumulation curve

In the sample rarefaction curve, the number of cyanobacterial species increased as the sampling area increased. It is found that the curve is still trending upward rapidly, suggesting that there are more species out there to be discovered if the study area is increased. Therefore, the curve is also referred to as the 'species discovery curve' (Fig.4.17).

Fig. 4.17

Showing Sample Rarefaction curve

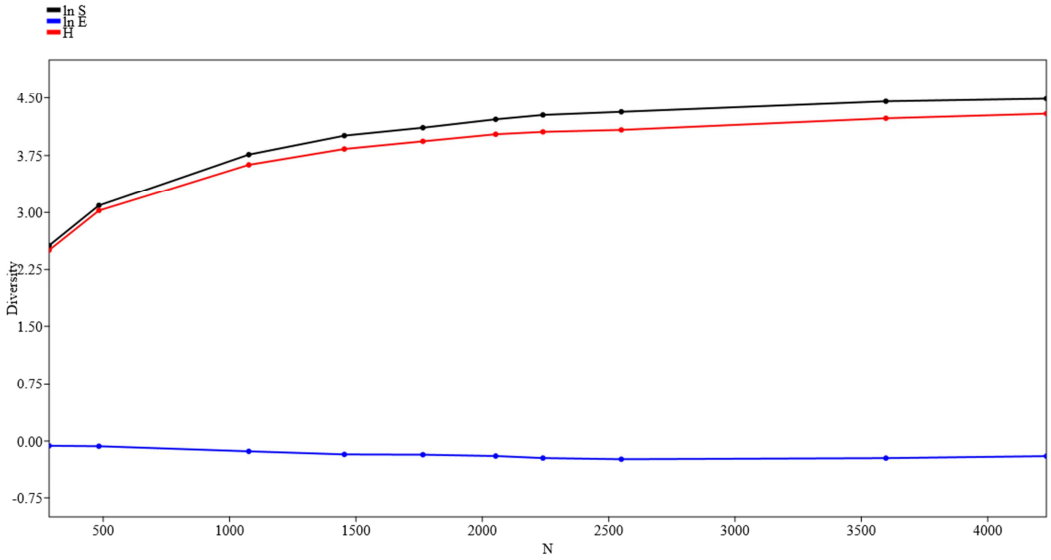


4.11.1.16. SHE analysis

SHE analysis refers to the combination of statistical methods that examine the relationship between the species richness (S), Shannon-Wiener diversity index (H), and evenness index (E). SHE analysis was employed to highlight the richness and abundance of cyanobacterial species using evenness and the number of species present in the study areas concerned. Through SHE plotting, it reflects the variation in richness, evenness, and relative abundance pattern in a single plot (Fig. 4.18).

Fig. 4.18

Showing the SHE curves

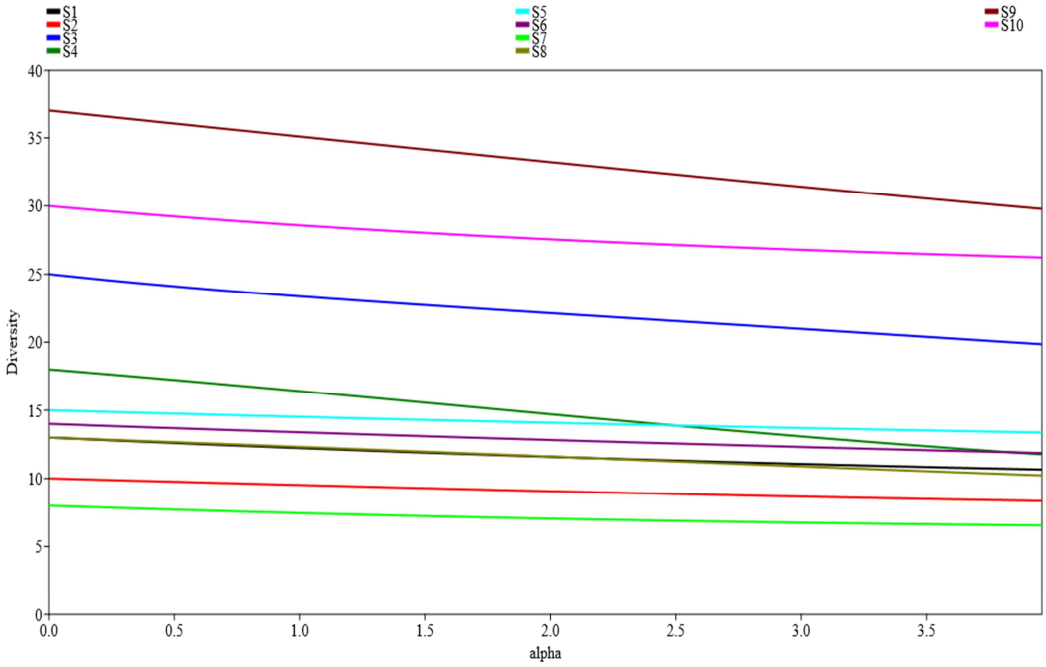


4.11.1.17. Creating diversity Profile

The creation of a diversity profile is the most important task of this study to monitor the mangrove-associated cyanobacterial diversity. It is observed that study area S9 (Kumbalam) has the greatest cyanobacterial diversity, while S7 (Ezhupunna) has the least diversified study area. S1 (Kadinamkulam) and S8 (Pathiramanal) have an equal number of cyanobacterial diversities (Fig. 4.19).

Fig. 4.19

Showing diversity profile plot



4.11.2. Beta (β) diversity indices

Beta diversity is also referred to as sample similarity. Ecologists often refer to multivariate to analyse the ordering of or relationships between different samples and species distribution. This study aims to analyse the similarity index using Hierarchical Cluster Analysis based on Bray-Curtis, Jaccard and Sorensen-Dice similarity indices. As suggested by Zuur et al. (2007), Non-metric multidimensional scaling (NMDS) and Principal coordinates analysis (PCoA) are also employed to analyse the beta diversity.

4.11.2.1. Hierarchical Cluster Analysis

By plotting the dendrogram of Hierarchical Cluster Analysis (HCA), species-wise analysis occurred from the sampling sites, which revealed that the most shared species in the sampling sites are clustered together as depicted in Figure 4.20. Clusters that join together sooner are more similar to one another than clusters that form later. Subsequently, an agglomerative hierarchical cluster analysis was performed to analyse the similarity index based on the commonly used measuring indices like Bray-Curtis, Jaccard and Sorensen-Dice coefficient, indenting to compare the similarity of HCA plots among the sampling sites/study areas. Ecologists treated both the diversity indices, the Bray-Curtis and the Sorensen indices, are almost similar, with the Bray-Curtis index being based on species abundance/richness, while the Sorensen index is based on the presence or absence of species. All similarity indices assume a range of values from 0 to 1, where the value 1 means that the sampling sites are shared by all their species and the value 0 means that the sampling sites do not share any species.

In the Bray-Curtis similarity index, the sampling sites S9 and S10 are observed in the same cluster at 32% similarity, S6 and S8 have 38% similarity, while S5 and S1 are observed at 28% similarity (Fig. 4.21). The Jaccard similarity index represents S9 and S10 formed in the same cluster having 20% similarity, S5 and S1 having formed at 22% similarity, while S6 and S8 have occurred at 28% similarity (Fig. 4.22). Sorensen-Dice coefficient index represented the sampling sites, S9 and S10 formed in the same cluster at 33% similarity, S5 and S1 have 35% similarity, and S6 and S8 formed in the same cluster at 45% similarity (Fig. 4.23).

Fig. 4.20

A Circular Dendrogram depicting the similar species from the sampling sites clustered together.

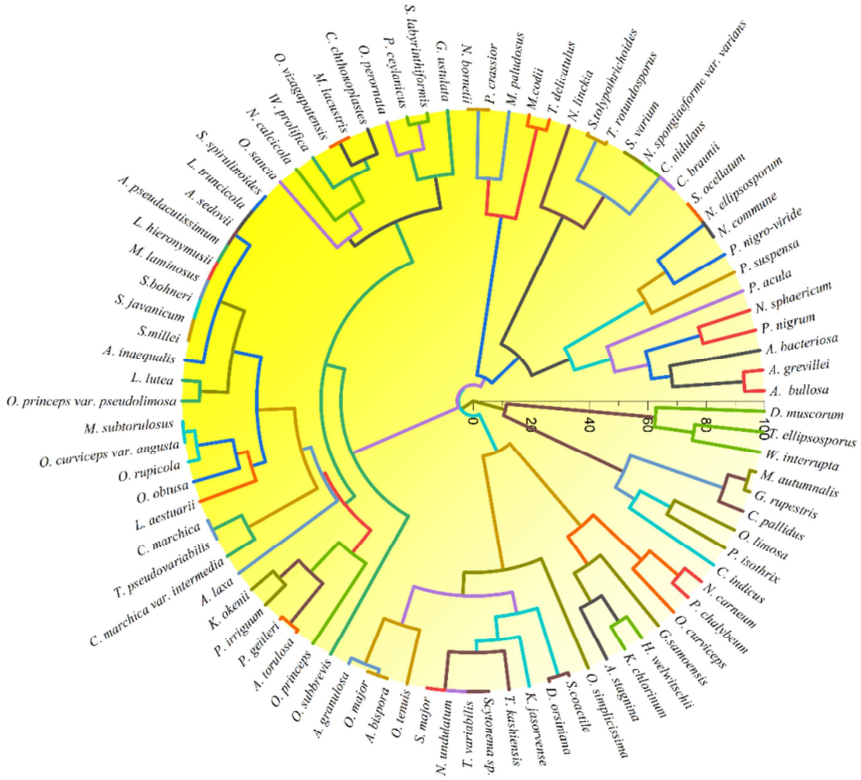


Fig. 4.21

Agglomerative hierarchical cluster analysis using Bray-Curtis similarity coefficients (similarity in species composition) among all the sampling sites.

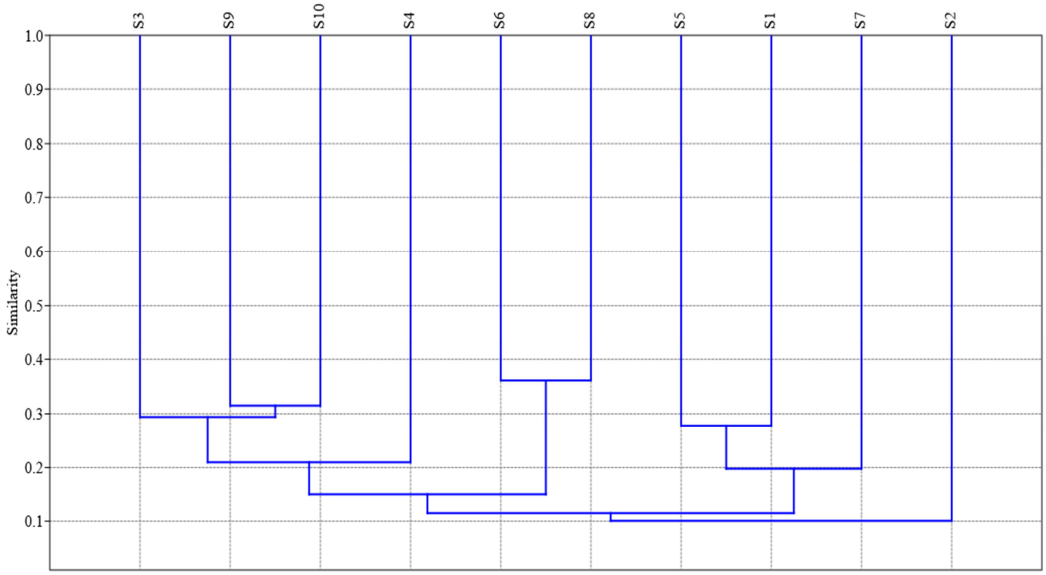


Fig. 4.22

Agglomerative hierarchical cluster analysis using Jaccard similarity coefficients (similarity in species composition) among all the sampling sites.

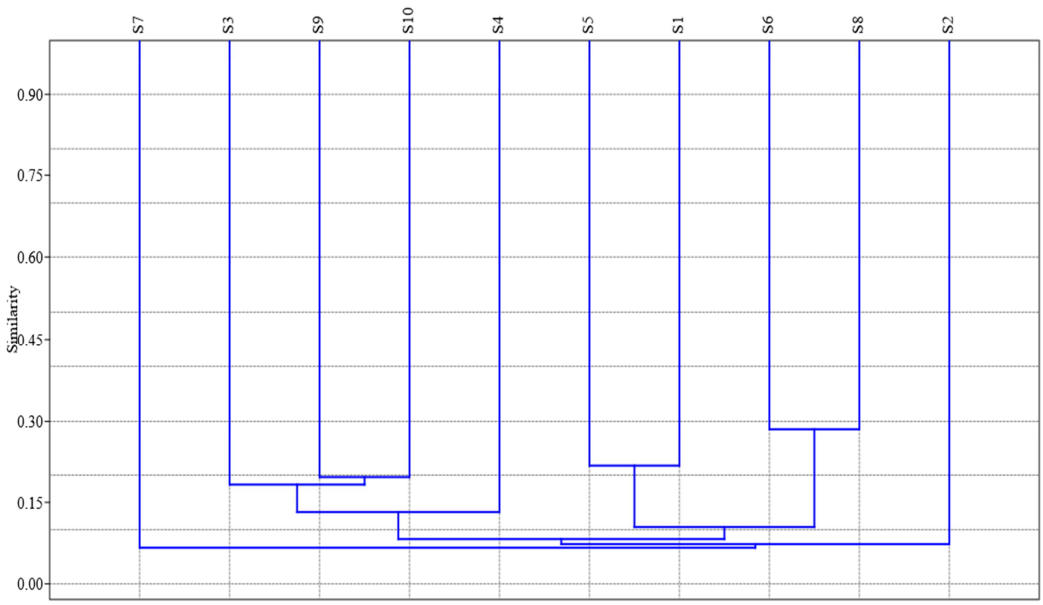
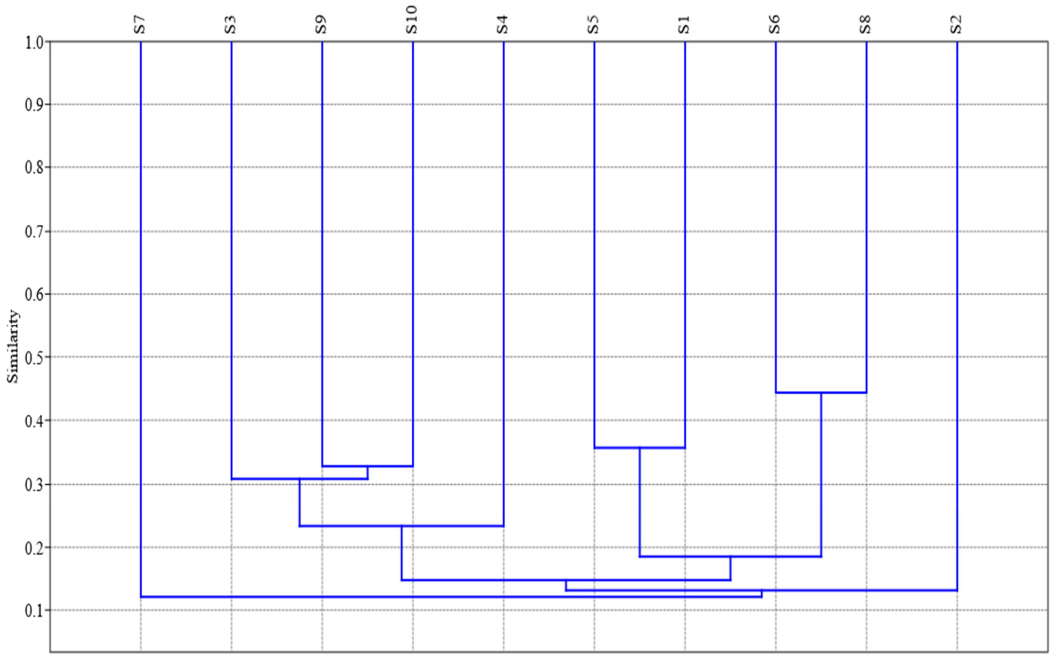


Fig. 4.23

Agglomerative hierarchical cluster analysis using Sorenson-Dice similarity coefficients (similarity in species composition) among all the sampling sites

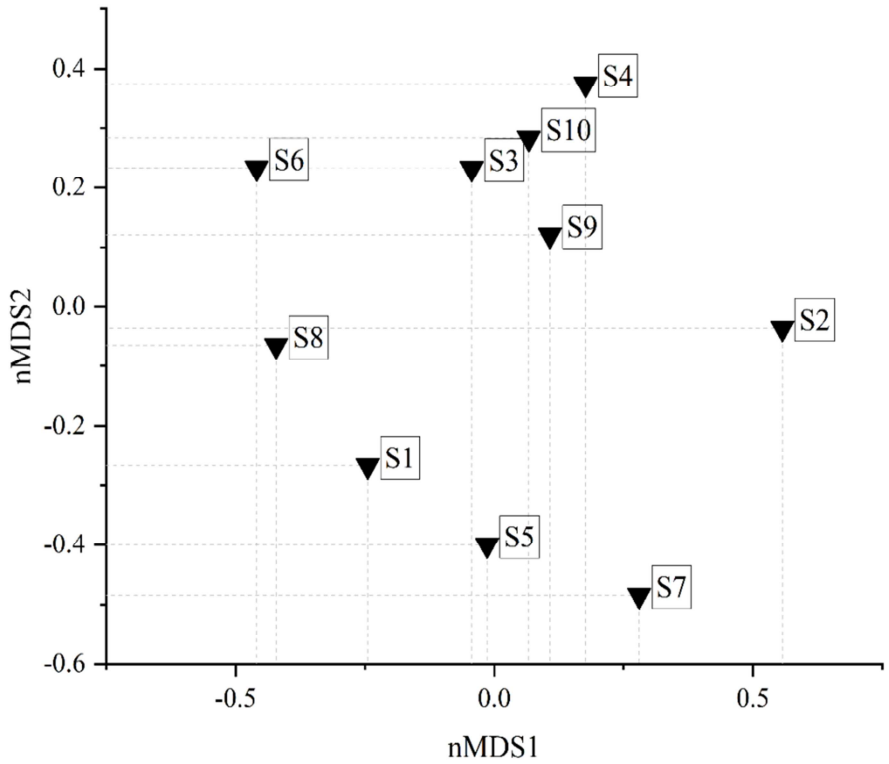


4.11.2.2. Non-metric multidimensional scaling (NMDS)

Non-metric multidimensional scaling (NMDS) is a method of indirect gradient analysis that generates an ordination based on a distance or dissimilarity matrix. NMDS is widely used for the analysis of species richness or abundance data. While plotting NMDS, it can be interpreted that the samples that are similar in terms of their species distribution are closer together and samples that are very different are further apart, they are very dissimilar in terms of species distribution. The sampling sites S3, S4, S9 and S10 show a good representation of cyanobacterial species distribution while the other sampling sites show a poor representation concerning the species composition (Fig. 4.24).

Fig. 4.24

Schematic representation of NMDS plot



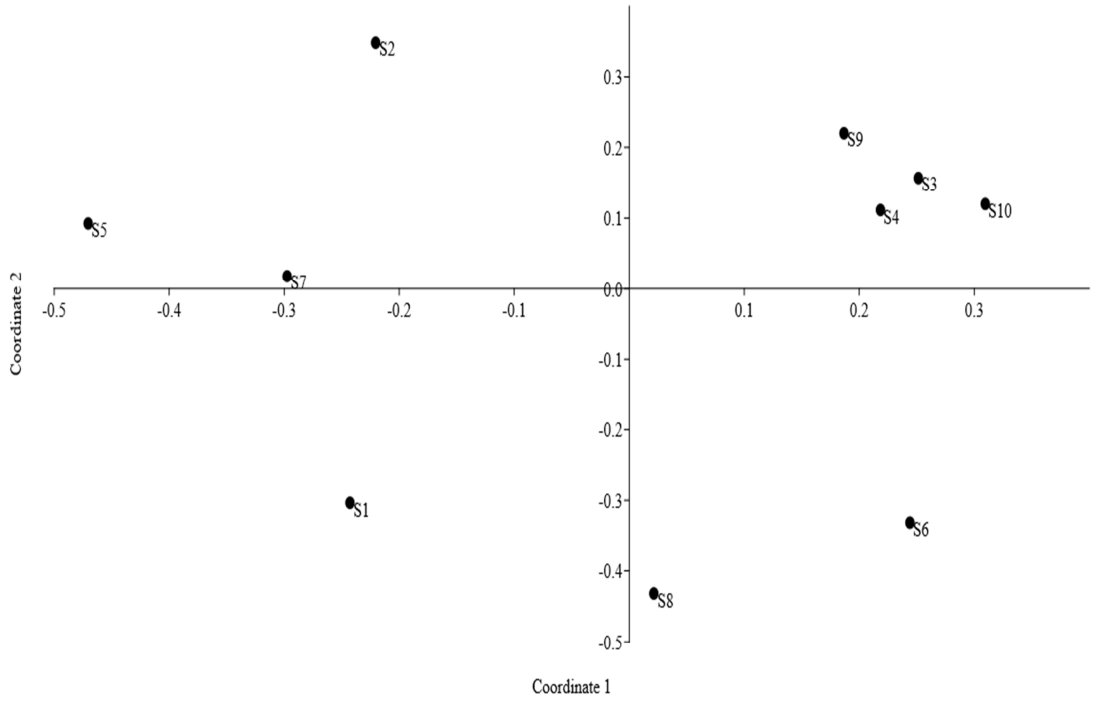
4.11.2.3. Principal coordinates analysis (PCoA)

PCoA is an efficient method to explore and visualise the similarities or dissimilarities in species composition among sampling sites. PCoA is generally used to analyse biogeographic data. This study aims to plot the PCoA based on the Bray-Curtis index. The sampling sites S3, S4, S9 and S10 represent in coordinate axis 1 and indicate that these sampling sites have similar species composition whereas the other sampling sites have a poor representation of species composition (Fig. 4.25).

Since the NMDS is presented in two dimensions, which is very easy, the PCoA has four dimensions, which are very difficult to interpret (Ruokolainen & Salo, 2006). According to the results, NMDS was the only ordination method that performed visually best indicating clear differences among all the different sites as compared to PCoA.

Fig. 4.25

Schematic representation of PCoA plot



4.12. Ecological Analysis

The spatiotemporal variations of environmental parameters of water have been calculated based on descriptive and multivariate analysis. Here, mean, standard deviation, ANOVA, Pearson correlation coefficient matrix, Principal Component Analysis (PCA) Canonical Correspondence Analysis (CCA) and JASP network analysis were employed to correlate the environmental variables with the cyanobacterial diversity.

4.12.1. Hydrographical Parameters

The hydrological parameters of the water from the study areas were estimated and correlated with the cyanobacterial species that occurred in the water bodies (planktic). Several physico-chemical parameters of water such as temperature, pH, salinity, dissolved oxygen, electrical conductivity, total dissolved solids, total alkalinity, total phosphorus, total nitrogen, potassium, calcium, magnesium and sodium were estimated and analysed for their influence on the cyanobacterial diversity in the study areas were analysed based on the multivariate statistical analysis.

The mean and standard deviation (SD) of physico-chemical characteristics of water is summarised in Table 4.10.1 & 4.10.2. The seasonal and spatial variations of physico-chemical parameters of mangrove water were analysed and depicted in Fig.4.26-4.38. The range of distribution of the physico-chemical parameters of water is shown in Fig. 4.39-4.51. Seasonal variations of water temperature along the study areas of the mangrove ecosystem were statistically significant (Table 4.11). Water temperature varied from 23.5^{o}C (avg. 24.5±1.00^{o}C) to 32.3^{o}C with a minimum at Vypin (S10) during monsoon and a maximum at Kumbalam (S9) pre-monsoon season (30.9±1.20 ^{o}C) (Fig. 4.26; Fig. 4.39). The surface water temperature is affected by the intensity of solar radiation, evaporation, freshwater inflow and cooling and mixed by the ebb and flow from surrounding areas (Govindasamy et al., 2000).

Water pH showed a minimum of 7.06 (avg.7.2±0.14) at S4 during monsoon and a maximum of 8.34 (avg. 8±0.34) at Kumbalam (S9) during pre-monsoon

season (Fig. 4.27; Fig. 4.40) and seasonal variations along the study areas of the mangrove environment were statistically significant (Table 4.12). Seasonal fluctuations in pH values due to the influx of freshwater, reduction of salinity and temperature and decomposition of organic matter (Upadhyay, 1988; Rajasegar, 2003).

Salinity showed a wide range of fluctuation with a minimum of 1.72 ppt (avg. 12.21±10.49 ppt) at Kureekkadavu (S2) during the post-monsoon season and a maximum of 40.10 ppt (avg.36.22±3.88 ppt) at Kadinamkulam (S1) during the pre-monsoon season (Fig. 4.28; Fig. 4.41). Statistically significant seasonal variations were observed in the salinity distribution pattern (Table 4.13) during the study. The observed salinity changes might be due to an influx of freshwater from adjoining areas which could be induced by monsoon or tidal inundation.

The dissolved oxygen (DO) of mangrove water ranged between 1.29 mg/L (avg. 3.12±1.39 mg/L) at Kureekkadavu (S2) during monsoon and 7.75 mg/L (avg. 6.11±1.64 mg/L) at Kureekkadavu (S2) during the post-monsoon season (Fig. 4.29; Fig.4.42). Seasonal variations along the study areas of the mangrove environment were statistically significant (Table 4.14) during the study. Elevated dissolved oxygen levels have been reported during the monsoon season, which may be due to the cumulative effect of higher wind speed combined with significant rainfall and the resulting freshwater mixing (Padmavathi & Satyanarayana, 1999; Govindasamy et al., 2000; Rajasegar, 2003).

The electrical conductivity was a minimum of 0.95 dS/m (avg. 3.09±2.14 dS/m) at Kadinamkulam (S1) during the monsoon season and a maximum of 36.29 (avg. 34.3±1.99 dS/m) at Vypin (S10) during the pre-monsoon season (Fig 4.30; Fig.4.43). Statistically significant seasonal variations were observed in the electrical conductivity distribution pattern (Table 4.15) during the study.

Total dissolved solids were found at a minimum of 4.33 ppt (avg. 4.84±0.51 ppt) at Kadinamkulam (S1) during the monsoon season and a maximum of 14.25 ppt (avg. 160.24±3.81 ppt) at Kureekkadavu (S2) during the pre-monsoon season (Fig.4.31; Fig.4.44) and seasonal variations along the study areas of the mangrove environment were significantly present (Table 4.16).

Total alkalinity varied from 25.90 mg/L $CaCO_3$ (avg. 42.71±16.81 mg/L $CaCO_3$) to 166.34 mg/L $CaCO_3$ (avg. 153.36±12.98 mg/L $CaCO_3$) with the minimum value recorded at Kureekkadavu (S2) during monsoon and the maximum value recorded at Kadinamkulam (S1) during pre-monsoon season (Fig.32; Fig.45). Statistically significant seasonal variations along the study areas of the mangrove environments were significantly present during the present study (Table 4.17). The alkalinity concentration of water samples is directly affected by rainfall (Michael, 1969).

Statistically significant seasonal variations were observed in the total phosphorus distribution pattern (Table 4.18) during the study. Total phosphorus was a minimum of 0.50 (avg. 0.82±0.21 mg/L) at Sakthikulangara (S4) during the pre-monsoon season and a maximum of 23.13 (avg. 19.2±3.93 mg/L) during the monsoon season at Kadinamkulam (S1) (Fig.4.33; Fig. 4.46). High phosphorus concentration during the monsoon season may be due to the intrusion of rising seawater into the stream, which can increase phosphate levels (Nair et al., 1984) as well as turbulence and mixing may regenerate and disperse phosphorus from the bottom mud into the water column (Chandran & Ramamoorthy, 1984).

Total nitrogen was found to vary from 29.7 mg/L (avg. 46.68±16.98 mg/L) to 178.72 (avg. 164.93±13.79 mg/L) with a minimum value during the post-monsoon season at Mekkara (S6), and a maximum value occurring during the monsoon season at Mekkara (S6) (Fig. 4.34; Fig. 4.47). Statistically significant seasonal variation was observed in the total nitrogen distribution pattern (Table 4.19) during the study. Variations in phytoplankton excretion, ammonia oxidation and nitrate reduction, as well as nitrogen recycling and bacterial decomposition of planktonic detritus present in the environment (Govindasamy et al., 2000) and denitrification and air-sea interaction of chemicals, can all contribute to high nitrogen concentrations during the monsoon season (Mathew & Pillai, 1990).

Significant seasonal variation for potassium was observed from ANOVA ($p<.05$) (Table 4.20). The potassium content of water samples varied from 4.78 mg/L (avg. 55.42±50.64 mg/L) to 311.14 mg/L (avg. 229.38±81.76 mg/L), with a minimum value recorded during monsoon at Ezhupunna (S7) and a maximum value

recorded during pre-monsoon at Vypin (S10) (Fig. 4.35; Fig. 4.48). Calcium content of water samples was found to vary from 5.95 mg/L (avg. 38.67±32.72 mg/L) to 410.90 mg/L (avg. 276.65±134.25 mg/L) with a minimum value recorded during monsoon at Kureekkadavu (S2) and a maximum value recorded during pre-monsoon at Kadinamkulam (S1) (Fig. 4.36; Fig. 4.49). Statistically significant seasonal variation was observed in the distribution of calcium content in mangrove water (Table 4.21) in the study areas.

Statistically significant variations in the magnesium content of water samples were observed in the study areas (Table 4.22). Magnesium content was found to vary from 37.03 mg/L (avg. 213.38±176.35 mg/L) to 1707.70 mg/L (avg. 1021.35±686.35 mg/L), with a minimum value recorded at Pathiramanal (S8) during the post-monsoon season and a maximum value recorded during pre-monsoon season at Sakthikulangara (S4) (Fig. 4.37; Fig. 4.50).

Sodium content of water samples was found to vary from 71.83 mg/L (avg. 825.5±753.52 mg/L) to 7125.68 mg/L (avg. 5231.84±1893.84 mg/L) with a minimum value during the monsoon season at Kadinamkulam (S1), and a maximum value occurred during the pre-monsoon season at Kumbalam (S9) (Fig. 4.38; Fig 4.51). Statistically significant seasonal variation was observed in the sodium distribution pattern in mangrove water (Table 4.23) in the study areas.

Table 4.10.1

Physico-chemical characteristics of water (Mean ±SD) recorded along the study areas (S1-S5)

Variable	S1			S2			S3			S4			S5		
	MS	PRS	POS	MS	PRS	POS	MS	PRS	POS	MS	PRS	POS	MS	PRS	POS
Temp. (°C)	25.7 ± 1.21	29.1 ± 0.57	26.1 ± 0.36	25.6 ± 0.42	29.2 ± 0.72	25.9 ± 0.53	25.0 ± 0.40	29.2 ± 0.75	26.5 ± 0.90	24.3 ± 0.15	28.6 ± 1.04	26.0 ± 0.73	25.4 ± 0.54	29.3 ± 1.37	25.9 ± 0.38
pH	7.3± 0.15	7.9± 0.31	7.5± 0.15	7.5± 0.28	7.7± 0.22	7.4± 0.11	7.7± 0.12	7.9± 0.22	7.5± 0.23	7.2± 0.14	7.8± 0.21	7.4± 0.2	7.5± 0.28	7.7± 0.13	7.4± 0.1
Salinity (ppt)	7.86± 0.78	36.22± 3.88	10.78± 3.75	7.75± 2.43	33.38± 2.63	12.21± 10.49	6.69± 2.53	35.2± 4.49	14.92± 6.37	7.68± 1.91	32.31± 2.34	10.6± 6.03	8.83± 2.25	32.19± 3.56	15.78± 5.84
DO (mg/L)	3.12± 1.39	3.64± 0.98	5.96± 1.22	2.56± 1.27	5.85± 0.82	6.11± 1.64	3.25± 0.15	4.56± 1.24	5.75± 1.65	3.25± 1.46	4.25± 0.65	5.07± 1.81	3.33± 0.45	3.34± 1.2	4.99± 2.04
EC (dS/m)	3.09± 2.14	32.64± 2.03	23.47± 3.4	5.59± 1.16	32.41± 1.6	20.32± 2.9	5.71± 2.04	31.92± 1.79	19.23± 2.94	6.19± 1.2	30.64± 3.02	16.18± 1.96	7.61± 2.7	32.67± 2.0	21.29± 4.12
TDS (ppt)	4.84 ±0.51	11.34± 0.56	7.52± 0.29	5.09± 0.3	13.33± 0.92	8.04± 0.31	4.95± 0.52	11.29± 0.52	7.13± 0.59	4.8± 0.35	12.23± 0.4	7.57±0.5	5.13± 0.35	10.21± 0.79	7.71± 0.53
T A (mg/L CaCO3)	38.25± 6.11	153.36± 12.98	72.82± 6.1	42.71± 16.81	160.24± 3.81	76.45± 5.68	52.54± 15.56	156.07± 7.6	70.82 ± 5.63	49.38 ± 11.56	156.88± 7.62	67.66± 6.12	34.17± 5.95	149.28± 9.42	70.74± 2.33
T P (mg/L)	19.2± 3.93	0.81±0.25	5.46± 1.05	13.59± 3.82	0.77± 0.27	7.01± 0.8	15.76± 4.52	0.87± 0.33	5.99± 1.21	11.84± 3	0.82± 0.21	6.07± 0.92	15.17± 3.14	0.84± 0.22	6.96± 0.91
TN (mg/L)	139.78± 18.99	100.26± 7.1	43.74± 14.15	161.94± 16	97.57± 7.27	50.82± 8.7	167.6± 8.95	84.87± 21.67	49.42± 12.11	159.69± 10.52	87.58± 14.45	46.12± 9.9	158.21± 12.78	71.75± 28.41	52.2± 12.51

K (mg/L)	48.26± 32.15	229.65±70.24	57.26± 33.24	52.64± 30.18	201.35± 83.15	54.62± 28.63	53.41± 32.42	234.35± 78.61	46.23± 31.25	53.14± 30.51	224.11± 80.43	48.32± 29.35	51.62± 32.53	183.24± 72.14	51.62± 31.22
Ca (mg/L)	43.54± 31.65	276.65±134.25	78.65± 54.35	38.67± 32.72	211.98± 125.63	81.65±52.64	46.84± 31.65	246.35± 134.21	68.21± 55.34	51.68± 29.67	224.35± 132.24	76.51± 54.92	42.61± 31.65	220.54± 128.33	81.94± 54.68
Mg (mg/L)	212.31± 122.85	964.35±623.65	186.95± 138.35	272.64± 151.24	930.07± 583.64	245.3± 114.65	242.12± 135.62	940.45± 508.04	224.47± 126.741	213.5± 122.01	1021.35± 686.35	225.07± 132.13	221.12± 130.03	983.65± 593.58	214.3± 142.04
Na (mg/L)	825.35± 753.52	5425.23± 1024.11	1312.82± 768.24	832.64± 724.35	3945.25± 1425.87	582.65± 154.91	765.25± 526.35	4283.11± 1243.22	583.69± 121.31	821.34± 764.35	3488.42± 1022.35	531.48± 171.39	768.95± 648.2	2466.38± 963.84	514.79± 176.54

(Abbreviations used: S1: Kadinamkulam; **S2:** Kureekkadavu; **S3:** Ayiramthengu; **S4:** Sakthikulangara; **S5:** Kumarakom; **MS:** Monsoon season; **PRS:** Pre-monsoon season; **POS:** Post-monsoon season; **Temp.:** Temperature; **DO:** Dissolved Oxygen; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **TA:** Total Alkalinity; **TP:** Total Phosphorus; **TN:** Total Nitrogen; **K:** Potassium; **Ca:** Calcium; **Mg:** Magnesium; **Na:** Sodium**)**

Table 4.10.2

Physico-chemical characteristics of water (Mean ±SD) recorded along the study areas (S6-S10)

Variable	S6			S7			S8			S9			S10		
	MS	PRS	POS	MS	PRS	POS	MS	PRS	POS	MS	PRS	POS	MS	PRS	POS
Temp. (°C)	25.4 ± 0.85	29.0 ± 0.59	26.9 ± 1.23	25.5 ± 0.7	28.5 ± 1.05	25.6 ± 0.41	24.5 ± 0.35	28.5 ± 0.68	26.8 ± 1.00	25.2 ± 0.67	30.6 ± 1.70	26.0 ± 1.06	24.5 ± 1.00	30.9 ± 1.20	26.3 ± 0.74
pH	7.6± 0.14	7.8± 0.19	7.3± 0.13	7.6± 0.18	7.6± 0.16	7.5± 0.1	7.5± 0.24	7.8± 0.11	7.4± 0.16	7.6± 0.12	8.0± 0.34	7.4± 0.13	7.5± 0.26	7.7± 0.37	7.3± 0.09
Salinity (ppt)	7.32± 2.37	30.31± 3.92	10.55± 6.31	9.88± 4.96	30.84± 5.03	11.79± 7.78	7.93± 2.42	32.92± 5.86	14.56± 3.95	7.0± 1.61	31.22± 3.94	13.39± 8.6	8.56± 3.61	32.64± 4.12	14.67± 8.22
DO (mg/L)	3.25± 0.25	4.21± 1.13	5.08± 2.35	3.24± 0.94	4.04± 1.51	4.53± 1.01	3.62± 1.25	4.98± 1.44	5.36± 2.36	3.24± 0.46	4.24± 1.5	5.26± 1.94	4.01± 0.64	4.71± 1.35	5.1± 1.44
EC (dS/m)	7.75± 2.4	33.68± 2.44	17.03± 3.21	6.68± 2.27	31.49± 1.62	21.03± 4.19	5.7± 2.75	32.88± 2.69	20.08± 4.13	6.94± 2.64	31.86± 2.26	17.26± 3.56	8.69± 3.01	34.3± 1.99	18.9± 2.87
TDS (ppt)	5.06± 0.26	10.26± 0.82	7.61± 0.71	5.05± 0.46	11.0 ± 1.52	7.46± 0.52	5.15± 0.32	11.59± 1.67	8.12± 0.54	5.08± 0.31	11.24± 2.15	7.95± 0.82	5.19± 0.42	11.68± 1.89	8.03± 0.56
T A (mg/L CaCO3)	42.37 ± 7.92	156.52± 8.38	66.14 ± 9.18	62.38 ± 16.04	158.9 ± 6.7	64.32± 10.66	54.01± 12.09	148.25± 8.25	68.33± 9.35	48.66± 18	151.17± 13.12	69.24± 5.37	60.27± 13.75	145.51± 8.39	71.61± 7.62
T P (mg/L)	18.56± 4.44	1.15± 0.21	6.68± 1.19	17.23± 3.33	0.91± 0.18	6.53± 2.01	18.14± 2.47	0.93± 0.16	6.83± 1.18	20.54± 2.24	1.63± 0.54	7.18± 1.2	16.22± 3.31	1.6± 0.62	6.85± 1.33
TN (mg/L)	164.93± 3.79	87.64± 15.79	46.68± 16.98	160.68± 16.73	73.27± 26.16	48.52± 14.91	157.37± 13.31	80.13± 22.21	49.3± 13.03	162.24± 16.16	95.56± 16.22	41.92± 11.73	156.06± 15.73	90.95± 20.68	45.83± 12.92

K (mg/L)	54.26± 29.62	192.56± 79.35	39.65± 29.34	55.42± 50.64	204.38± 81.47	58.22± 24.33	56.21± 41.62	225.64± 82.61	51.24± 18.32	54.32 ± 32.61	193.45± 78.53	48.35± 21.35	52.14± 30.51	229.38± 81.76	46.22± 26.11
Ca (mg/L)	48.51± 30.66	249.52± 131.54	76.95± 61.54	52.35± 39.65	262.31± 127.62	82.25± 54.67	46.55± 28.65	241.26± 131.25	83.15± 53.41	54.65± 32.61	231.51± 127.64	87.64± 61.25	50.33± 30.16	234.25± 137.65	79.61± 51.64
Mg (mg/L)	211.26± 132.33	1004.35± 502.65	214.41± 153.96	214.12± 132.03	891.52± 561.54	224.52± 163.04	238.97± 122.71	928.65± 591.83	213.38± 176.35	211.7± 132.18	869.86± 424.68	258.62± 181.65	222.14± 131.22	968.18± 414.64	216.35± 173.88
Na (mg/L)	682.35± 583.64	4385.64± 1134.45	597.97± 119.54	683.14± 593.58	5246.25± 1245.95	616.16± 221.85	805.68± 721.21	4942.33± 1158.27	985.33± 68.98	835.64± 706.55	5231.84± 1893.84	1023.33± 97.86	751.32± 692.64	4255.73± 2138.35	1324.52± 80.78

(Abbreviations used: S6: Mekkara; **S7:** Ezhupunna; **S8:** Pathiramanal; **S9:** Kumbalam; **S10:** Vypin; **MS:** Monsoon season; **PRS:** Pre-monsoon season; **POS:** Post-monsoon season; **Temp.:** Temperature; **DO:** Dissolved Oxygen; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **TA:** Total Alkalinity; **TP:** Total Phosphorus; **TN:** Total Nitrogen; **K:** Potassium; **Ca:** Calcium; **Mg:** Magnesium; **Na:** Sodium**)**

Fig. 4.26

Seasonal variations of Temperature in mangrove water in the study areas

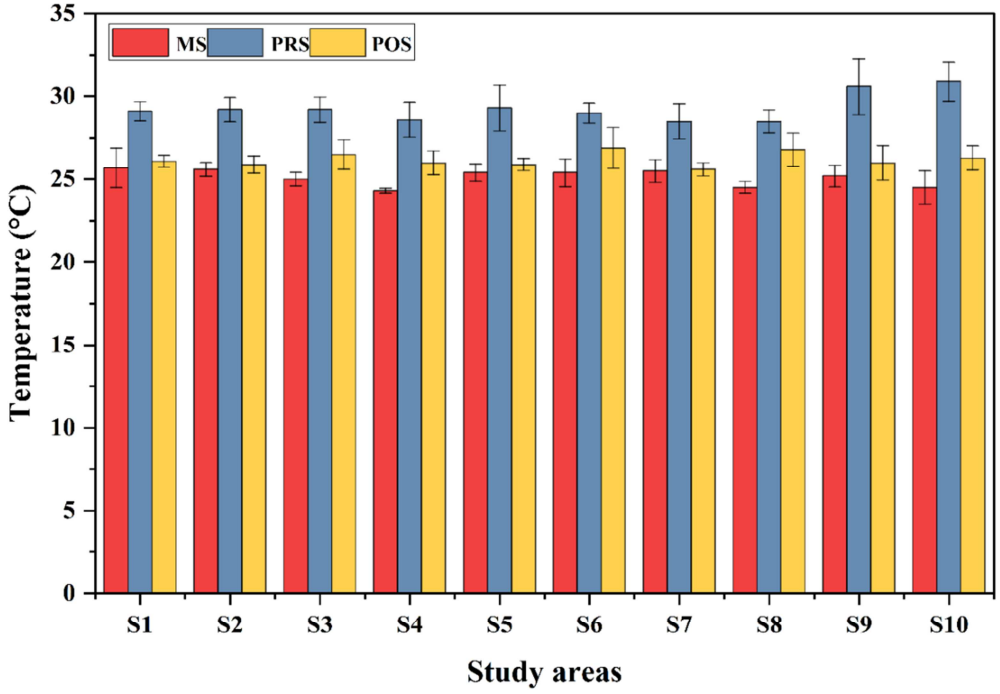


Fig. 4.27

Seasonal variations of pH in mangrove water in the study areas

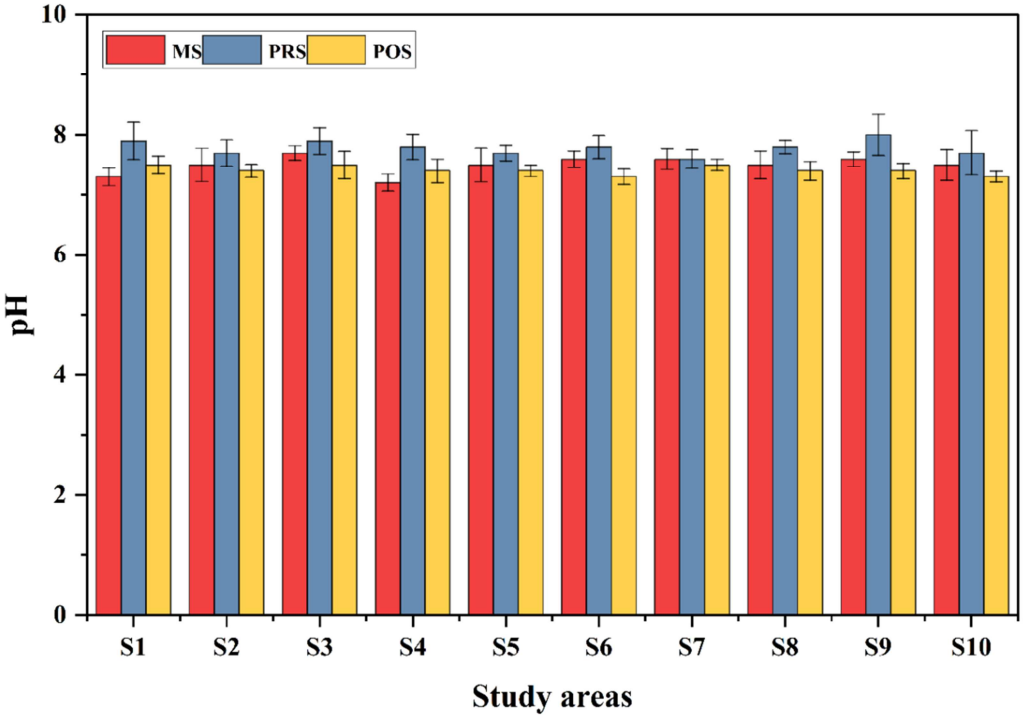


Fig. 4.28

Seasonal variations of salinity in mangrove water in the study areas

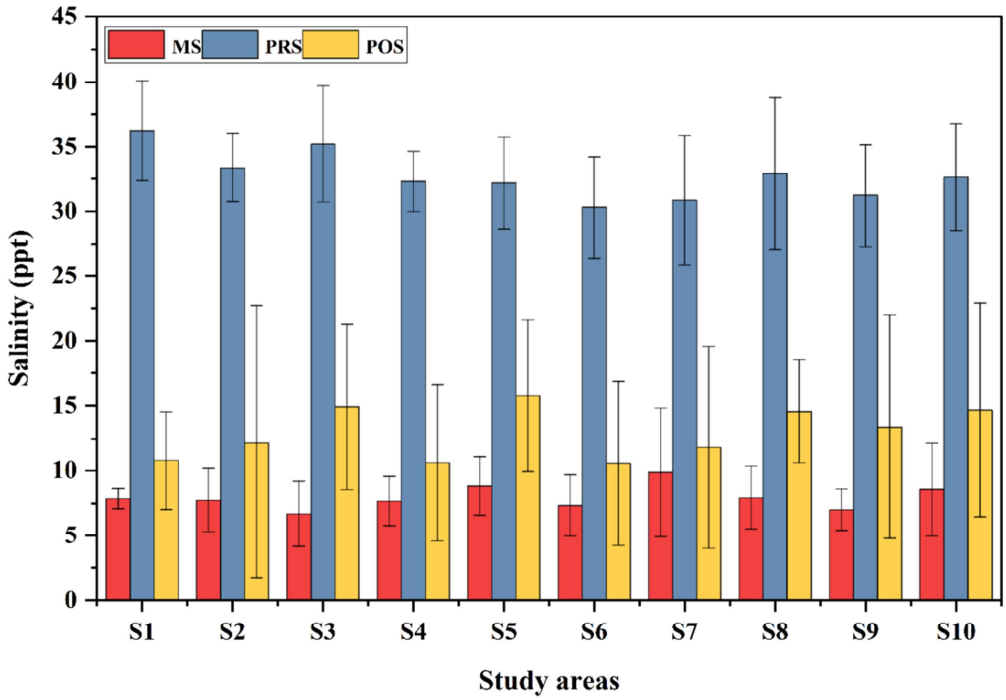


Fig. 4.29

Seasonal variations of dissolved oxygen in mangrove water in the study areas

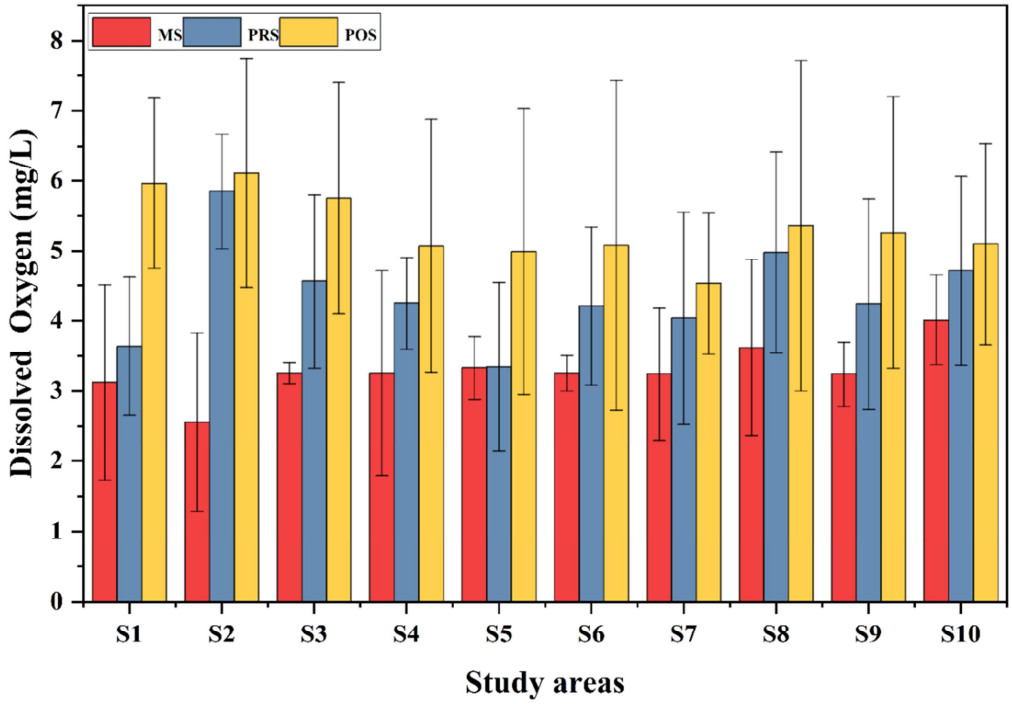


Fig. 4.30

Seasonal variations of electrical conductivity in mangrove water in the study areas

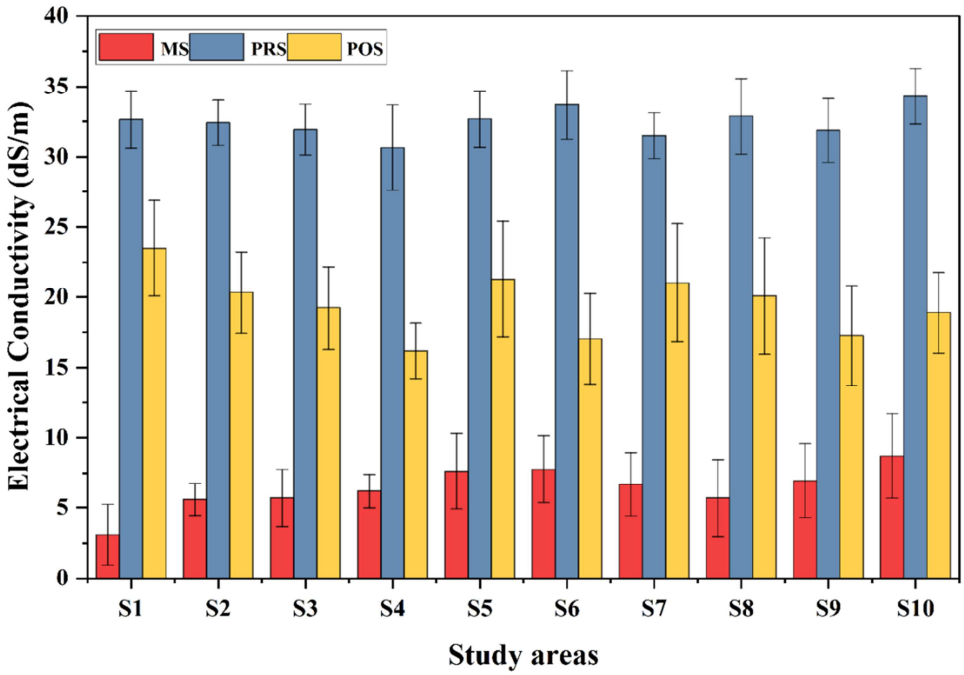


Fig. 4.31

Seasonal variations of total dissolved solids in mangrove water in the study areas

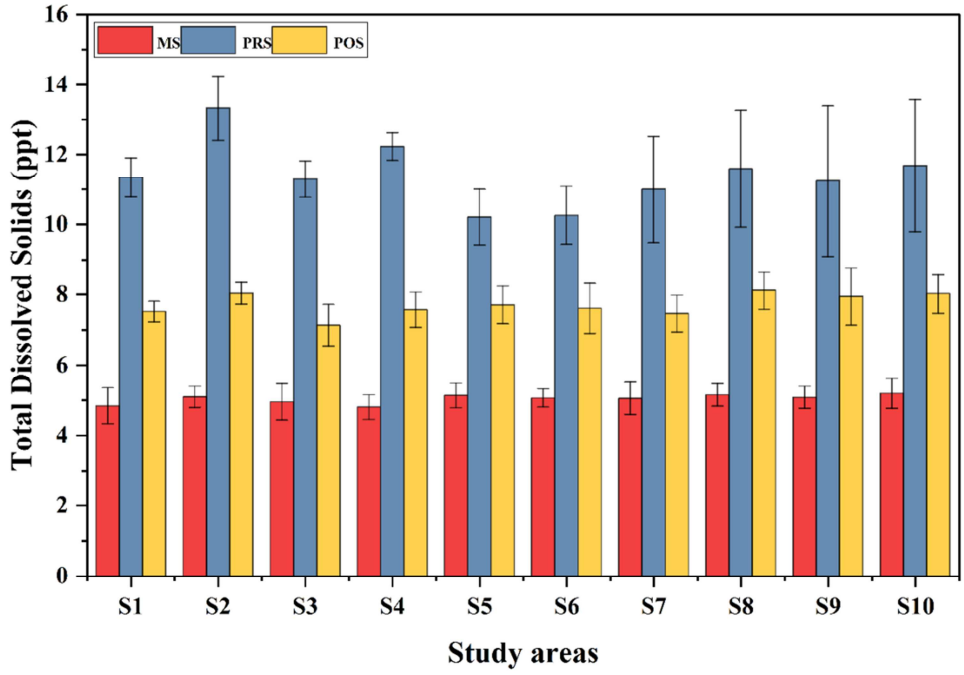


Fig. 4.32

Seasonal variations of total alkalinity in mangrove water in the study areas

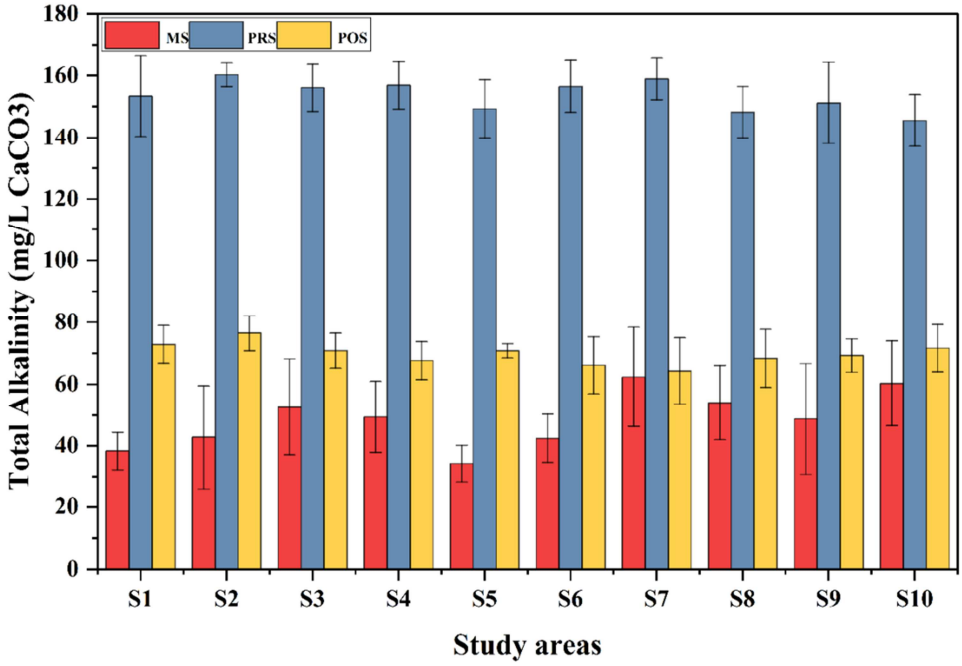


Fig. 4.33

Seasonal variations of total phosphorus in mangrove water in the study areas

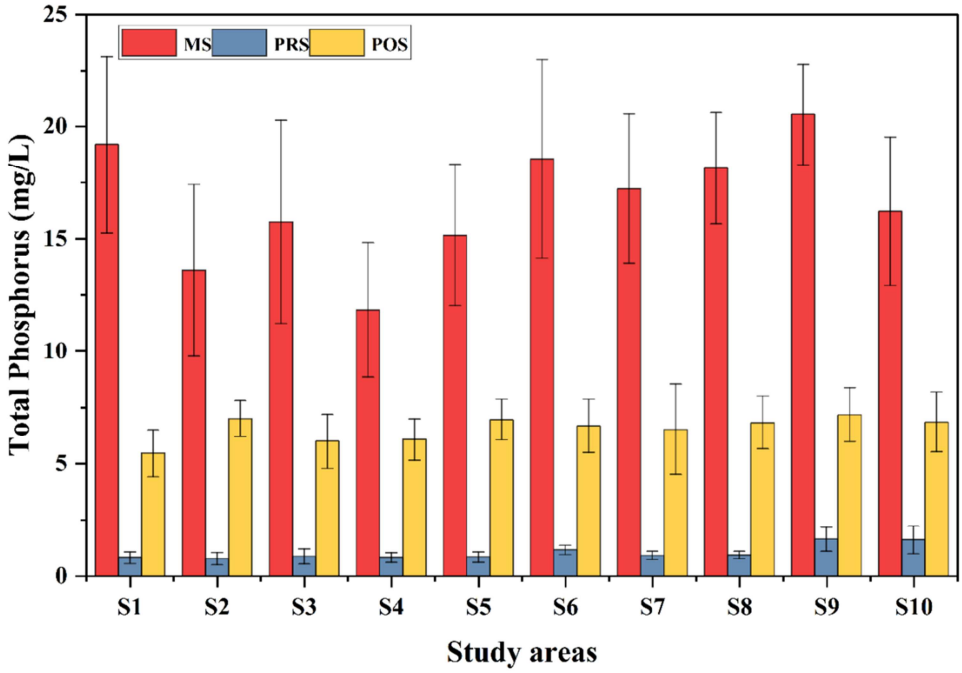


Fig. 4.34

Seasonal variations of total nitrogen in mangrove water in the study areas

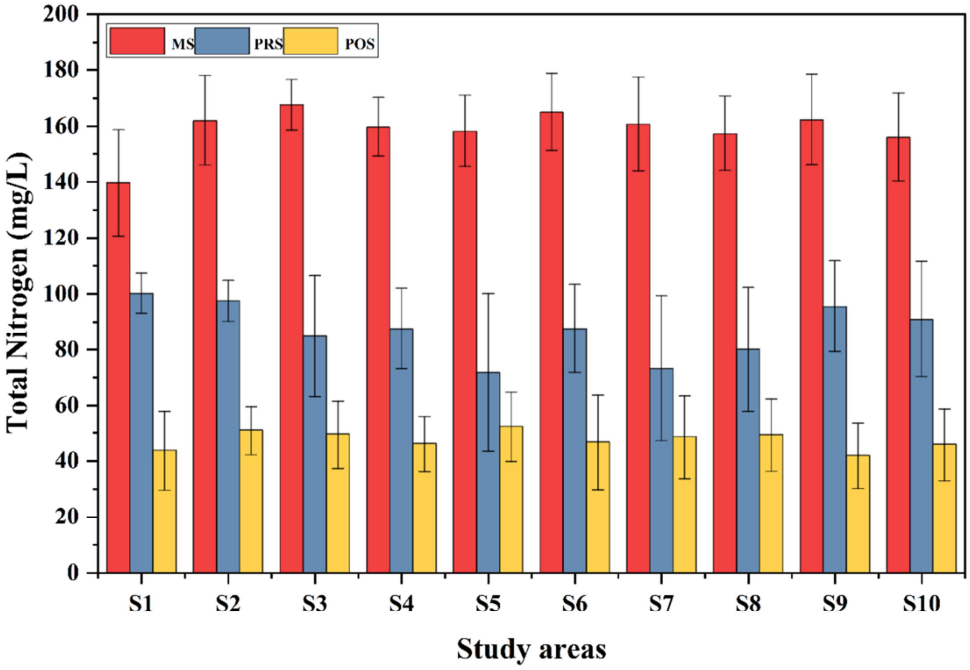


Fig. 4.35

Seasonal variations of potassium in mangrove water in the study areas

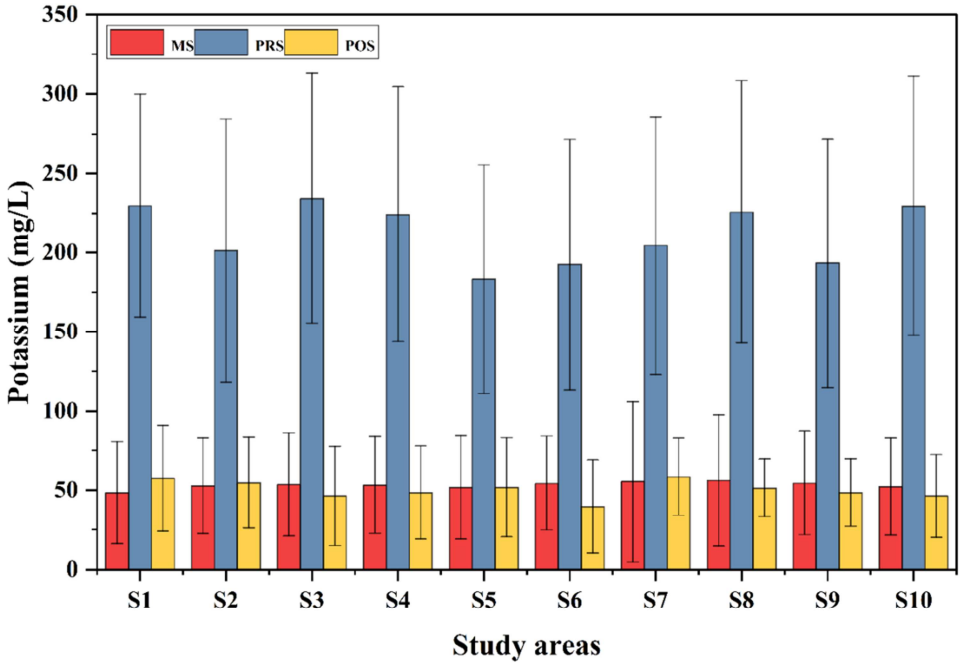


Fig. 4.36

Seasonal variations of calcium in mangrove water in the study areas

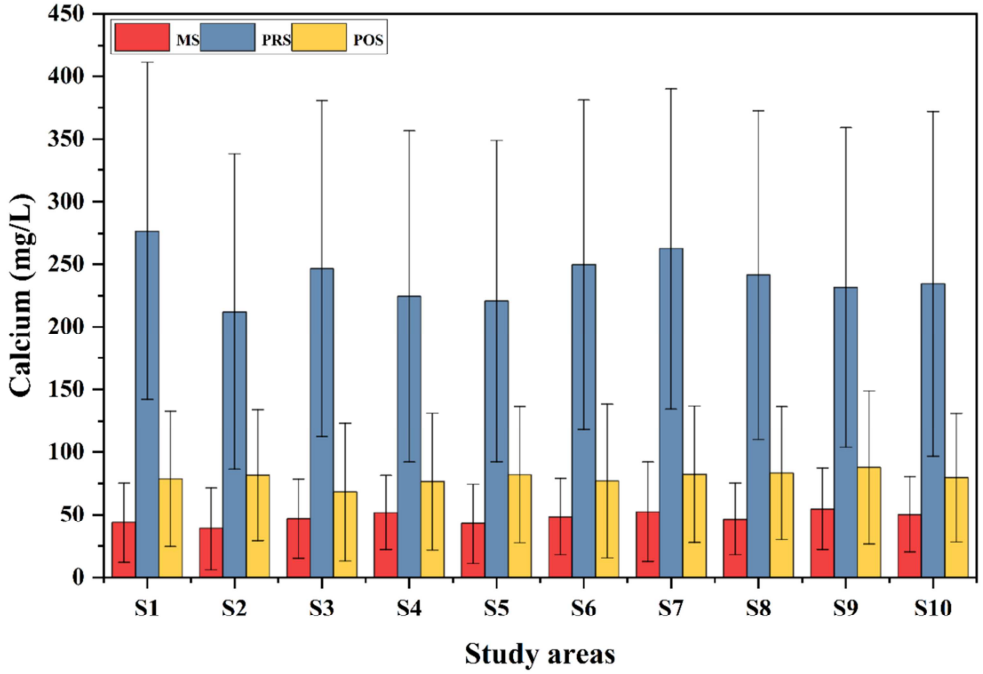


Fig. 4.37

Seasonal variation of Magnesium in mangrove water in the study areas

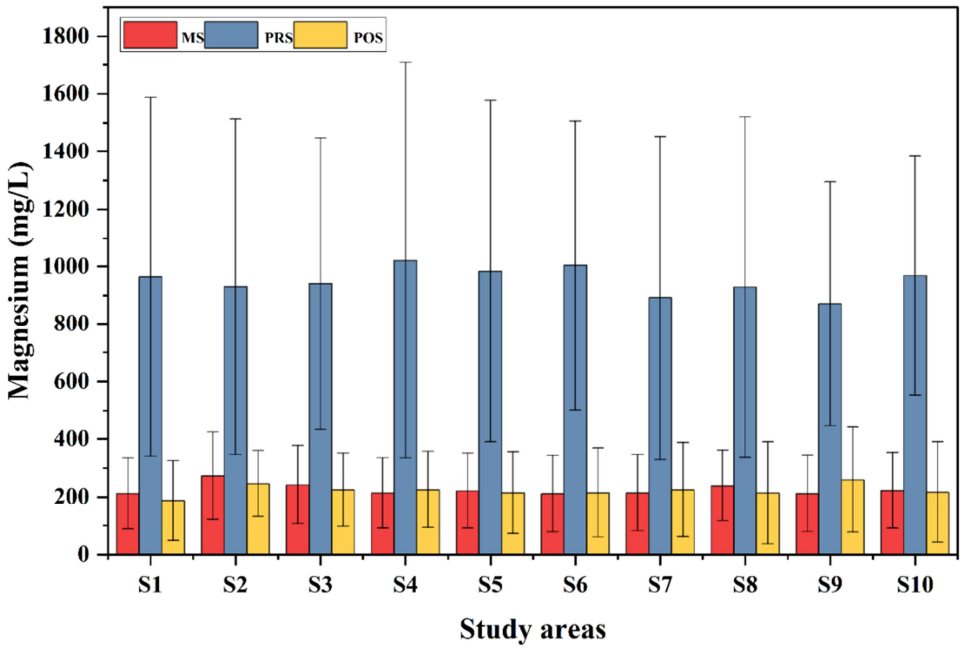


Fig. 4.38

Seasonal variation of sodium in mangrove water in the study areas

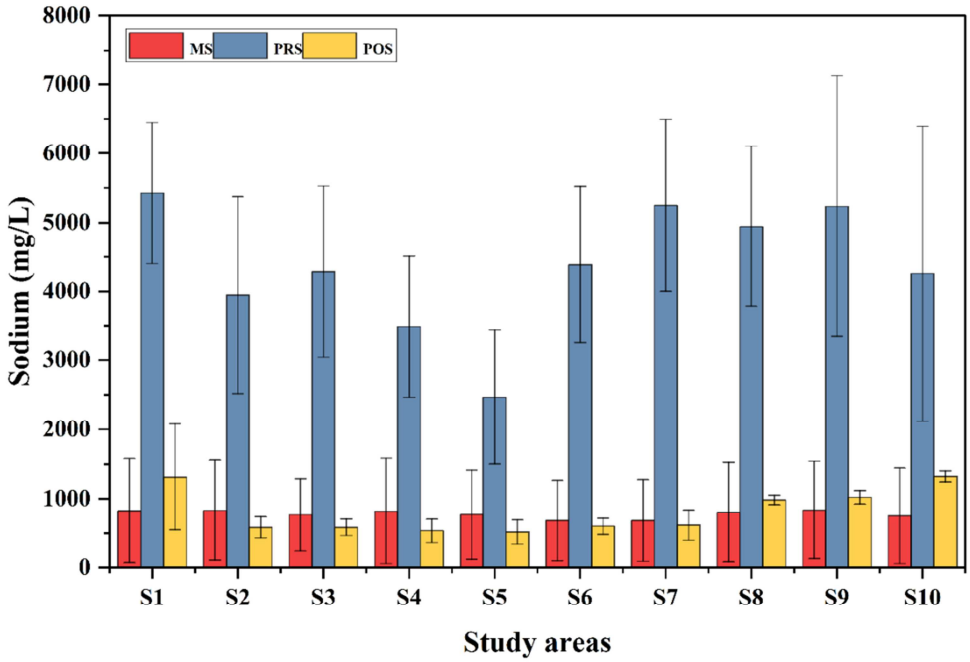


Fig. 4.39

Range of seasonal distribution of Temperature in the study areas

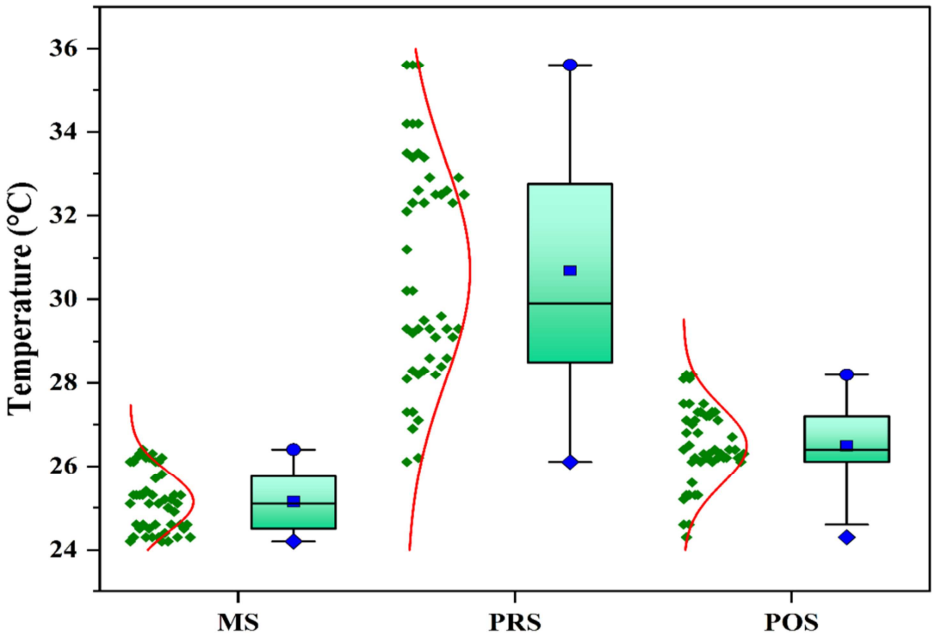


Fig. 4.40

Range of seasonal distribution of pH in the study areas

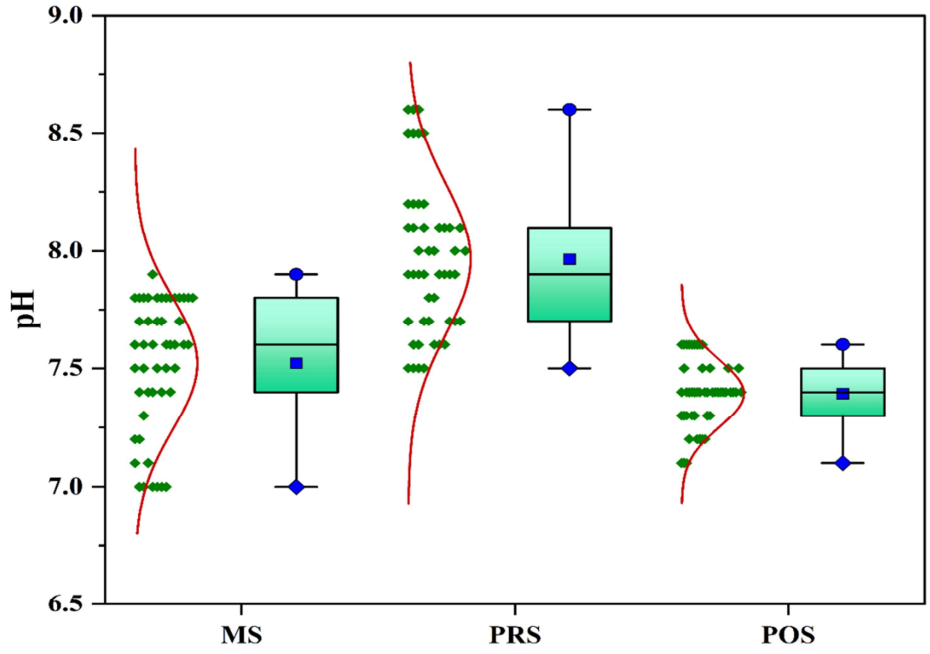


Fig. 4.41

Range of seasonal distribution of Salinity in the study areas

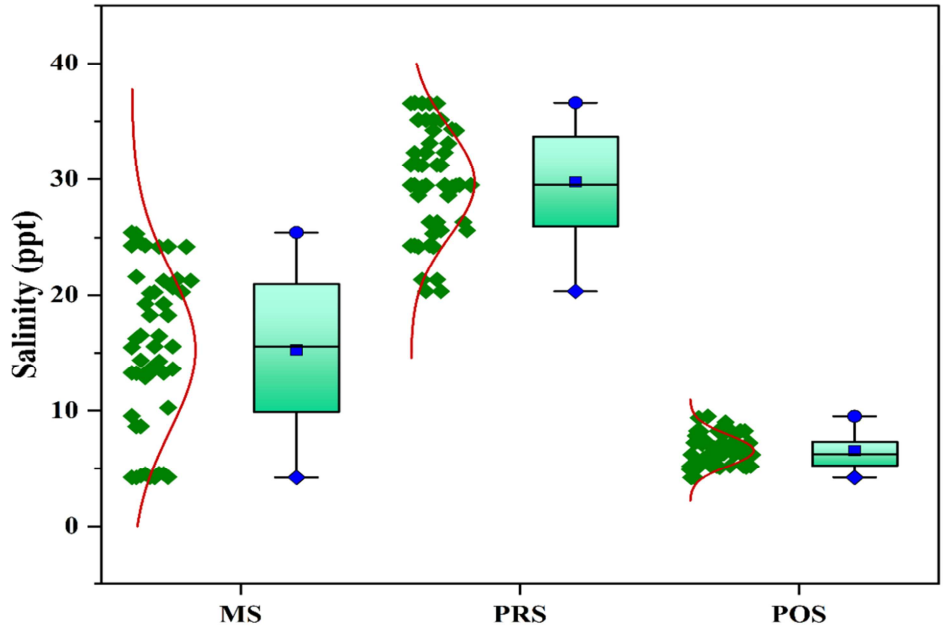


Fig. 4.42

Range of seasonal distribution of Dissolved Oxygen in the study areas

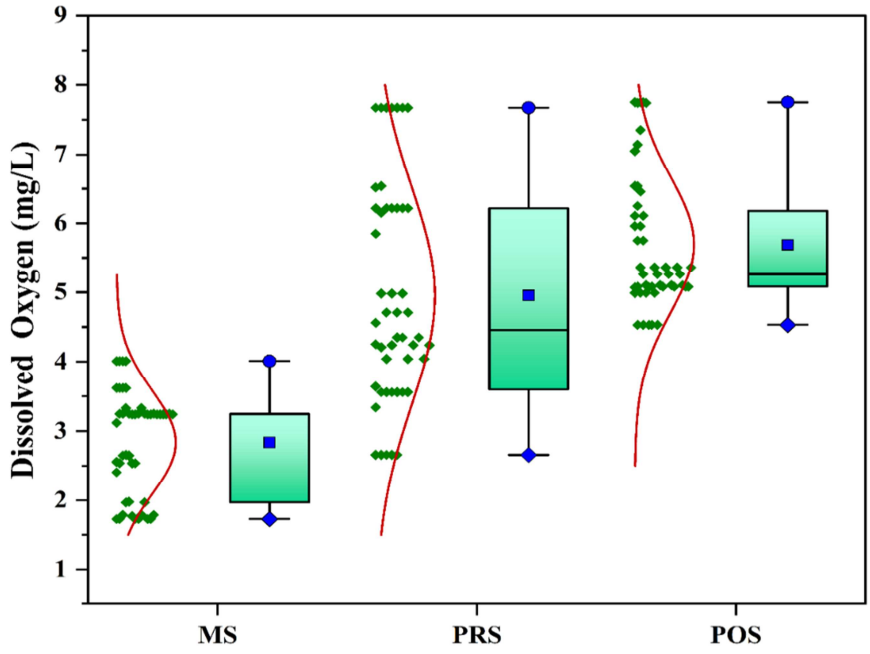


Fig. 4.43

Range of seasonal distribution of Electrical Conductivity in the study areas

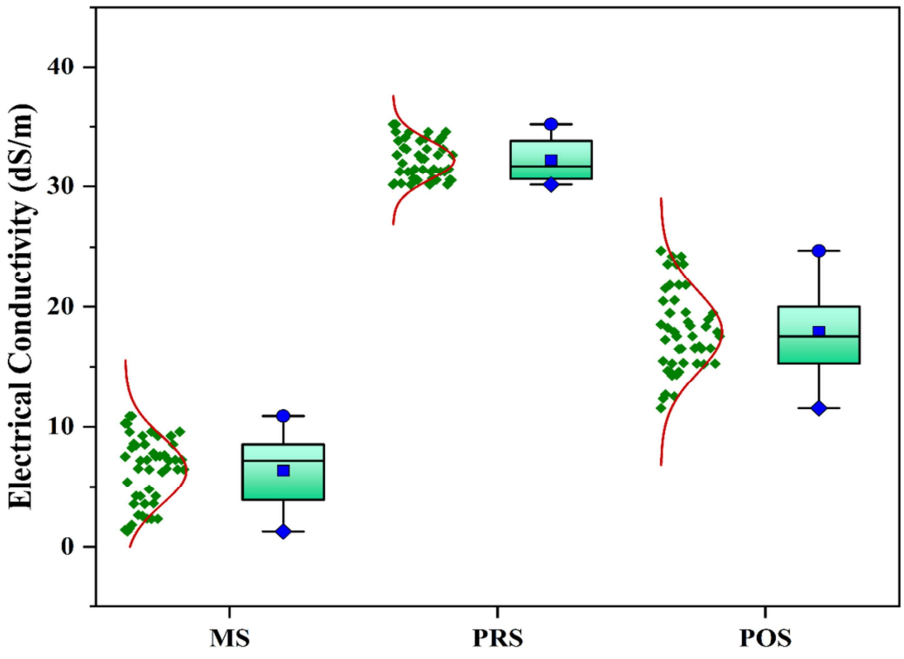


Fig. 4.44

Range of seasonal distribution of Total Dissolved Solids in the study areas

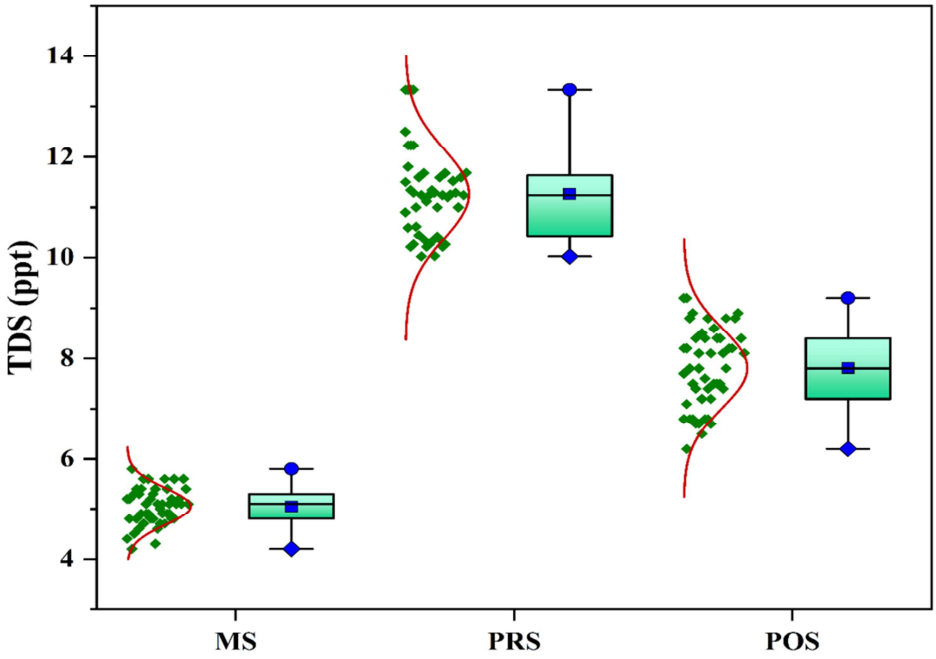


Fig. 4.45

Range of seasonal distribution of Total Alkalinity in the study areas

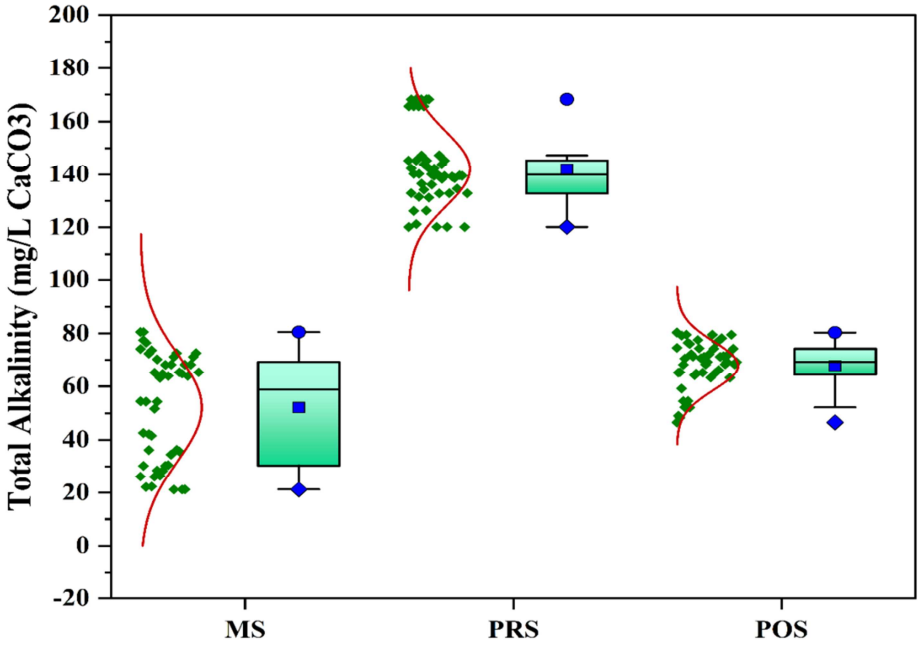


Fig. 4.46

Range of seasonal distribution of Total Phosphorus in the study areas

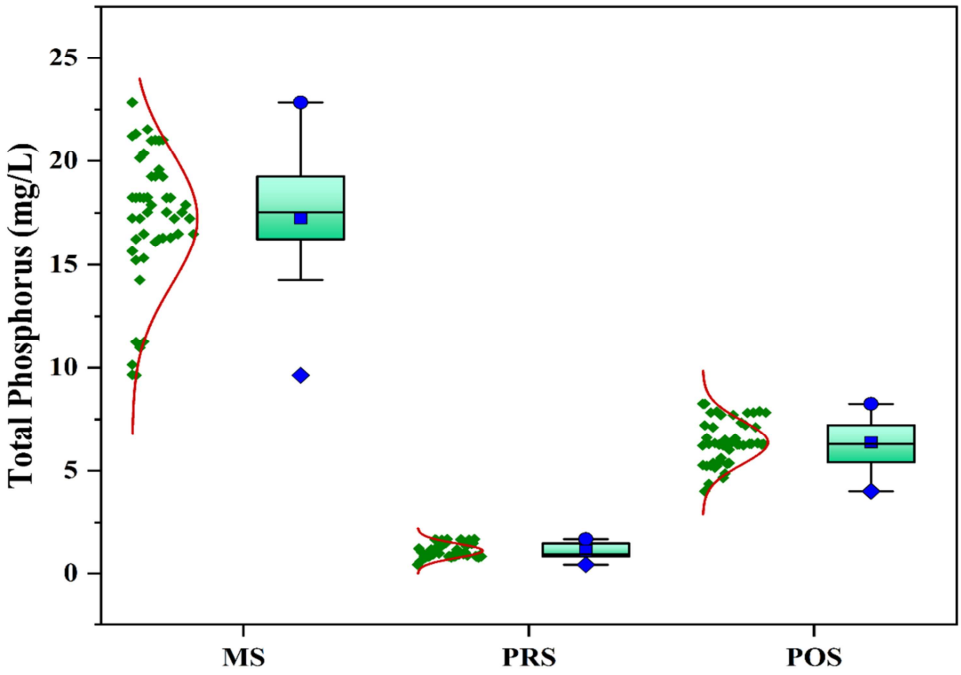


Fig. 4.47

Range of seasonal distribution of Total Nitrogen in the study areas

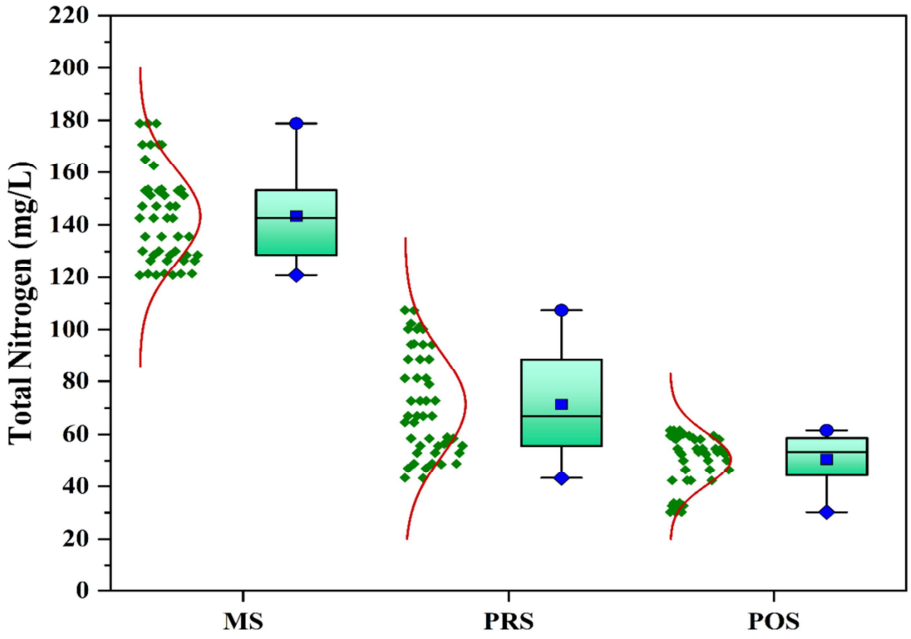


Fig. 4.48

Range of seasonal distribution of Potassium in the study areas

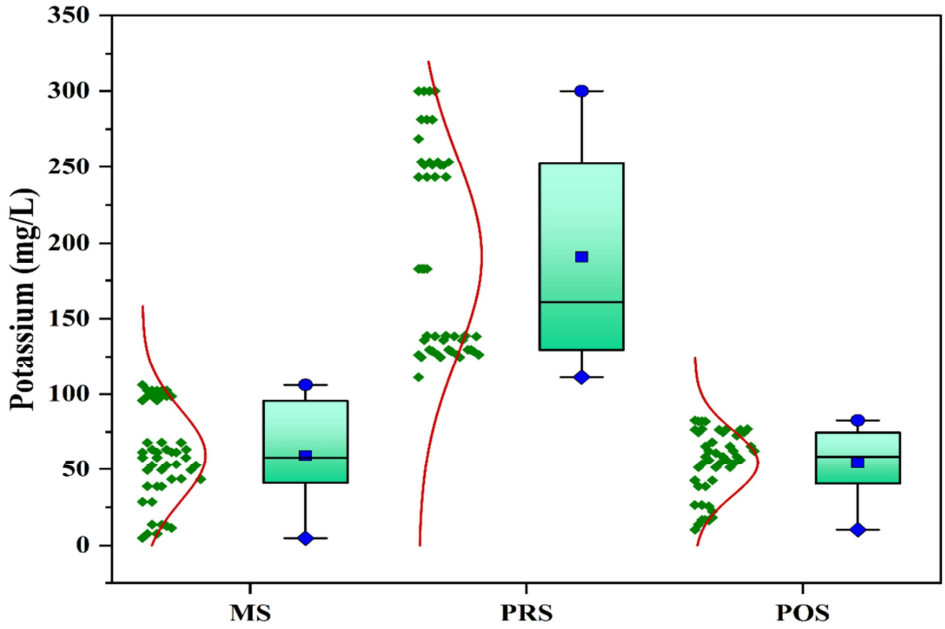


Fig. 4.49

Range of seasonal distribution of Calcium n the study areas

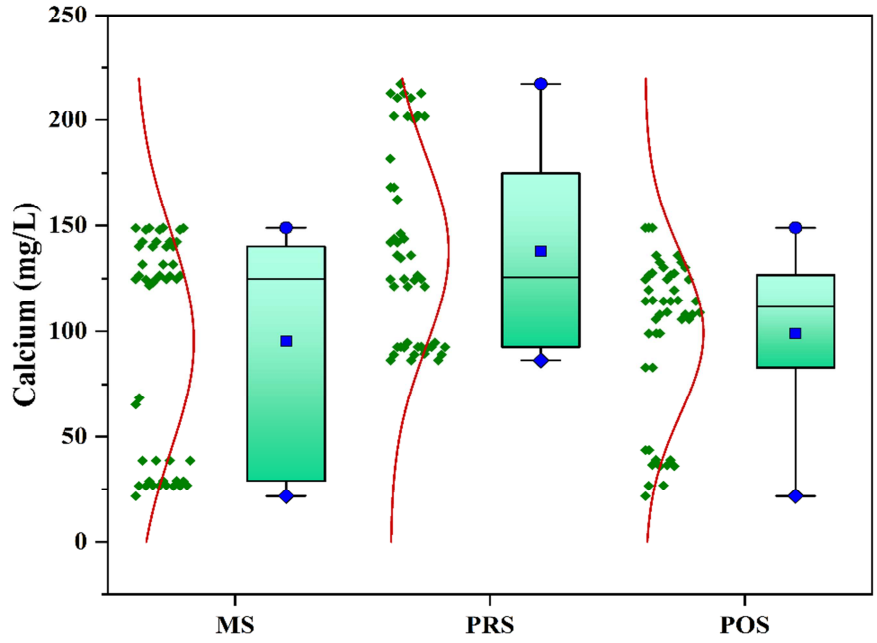


Fig. 4.50

Range of seasonal distribution of Magnesium in the study areas

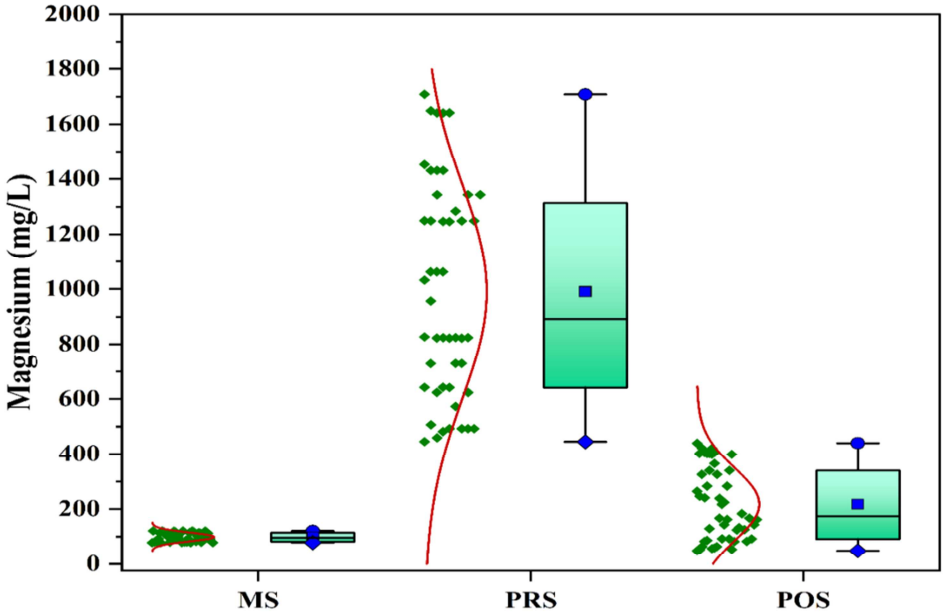


Fig. 4.51

Range of seasonal distribution of sodium in the study areas

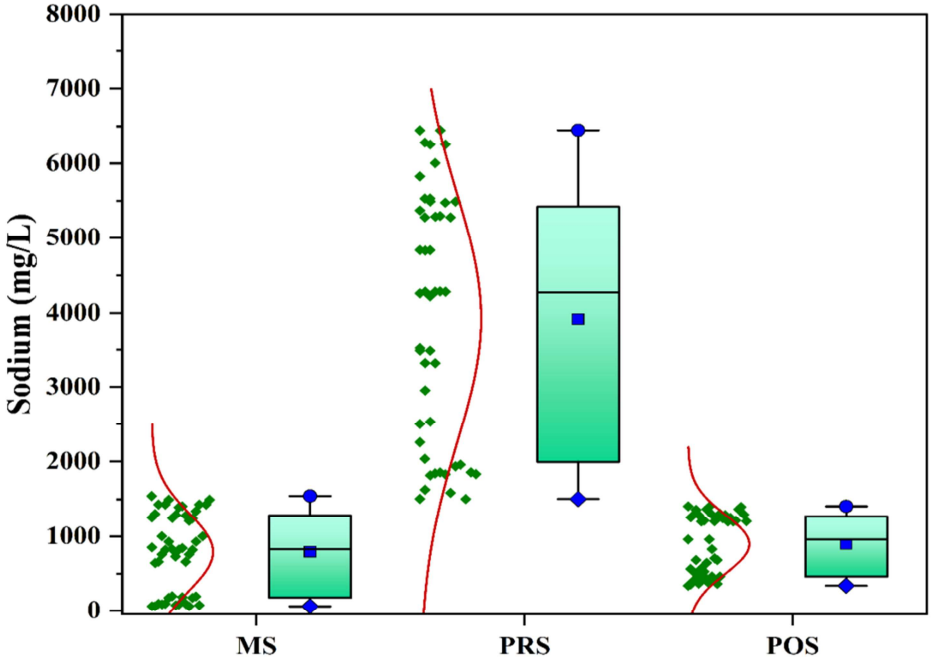


Table 4.11

Summary of ANOVA for the seasonal distribution of Temperature (°C)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	802.10	401.0509			
Within groups	141	397.32	2.8179	142.32	1.49	p < .05
Total	143	1199.43				

Table 4.12

Summary of ANOVA for the seasonal distribution of pH

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	8.62	4.31132			
Within groups	141	9.38	0.0665	64.83	1.08	P < .05
Total	143	17.99				

Table 4.13

Summary of ANOVA for the seasonal distribution of Salinity (ppt)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	13144.40	6572.20			
Within groups	141	3353.25	23.78	276.35	1.65	p < .05
Total	143	16497.65				

Table 4.14

Summary of ANOVA for the seasonal distribution of Dissolved Oxygen (mg/L)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	210.55	105.28			
Within groups	141	188.16	1.33	78.89	1.02	$p < .05$
Total	143	398.71				

Table 4.15

Summary of ANOVA for the seasonal distribution of Electrical Conductivity (dS/m)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	16089.95	8044.98			
Within groups	141	1044.48	7.41	1086.03	2.21	$p < .05$
Total	143	17134.44				

Table 4.16

Summary of ANOVA for the seasonal distribution of TDS (ppt)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	931.42	465.71			
Within groups	141	72.76	0.516	902.52	4.31	$p < .05$
Total	143	1004.18				

Table 4.17

Summary of ANOVA for the seasonal distribution of Total Alkalinity (mg/L $CaCO_3$)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	221753.12	110876.56			
Within groups	141	32270.59	228.87	484.45	6.72	$p < .05$
Total	143	254023.72				

Table 4.18

Summary of ANOVA for the seasonal distribution of Total Phosphorus (mg/L)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	6514.06	3257.03			
Within groups	141	545.38	3.87	842.06	3.97	$p < .05$
Total	143	7059.45				

Table 4.19

Summary of ANOVA for the seasonal distribution of Total Nitrogen (mg/L)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	227590.21	113795.10			
Within groups	141	37365.34	265.00	429.41	1.06	$p < .05$
Total	143	264955.55				

Table 4.20

Summary of ANOVA for the seasonal distribution of Potassium (mg/L)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	576408.84	288204.42			
Within groups	141	273000.04	1936.17	148.85	1.76	$p < .05$
Total	143	849408.87				

Table 4.21

Summary of ANOVA for the seasonal distribution of Calcium (mg/L)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	53517.74	26758.87			
Within groups	141	291992.55	2070.87	12.92	7.03	$p < .05$
Total	143	345510.29				

Table 4.22

Summary of ANOVA for the seasonal distribution of Magnesium (mg/L)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	22502743.36	11251371.68			
Within groups	141	7981000.40	56602.84	198.78	9.29	$p < .05$
Total	143	30483743.76				

Table 4.23

Summary of ANOVA for the seasonal distribution of Sodium (mg/L)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	303540151.72	151770075.86			
Within groups	141	151567858.67	1074949.35	141.19	2.17	$p < .05$
Total	143	455108010.39				

4.12.1.1. Pearson Correlation Matrix

In ecological analysis, it is very important to analyse the inter-relationships of the environmental parameters of the habitat to check whether there exists any relation among them for the propagation of the cyanobacterial diversity in the mangrove ecosystem is the utmost importance. The correlation coefficient matrix can help to determine the relationship between environmental variables or to use these relationships to make predictions. The correlation matrix of the seasonal variations of hydrological analysis is represented in Table 4.24, 4.25, 4.26 and Fig.4.52, 4.53 & 4.54. Some of the hydrological parameters were found to have statistically significant correlation with each other, which denotes the close association of these parameters with each other. The value of the correlation coefficient varies from -1 to +1.

The results of the correlation coefficient matrix indicates that in monsoon season, there was a positive correlation between total phosphorus and electrical conductivity ($r= 0.401$, $p< .001$), total phosphorus and total dissolved solids ($r= 0.401$, $p< .01$), total phosphorus and potassium ($r= 0.460$, $p< .01$), total alkalinity and salinity ($r= 0.390$, $p< .01$), sodium and magnesium ($r= 0.373$, $p< .01$), total alkalinity and electrical conductivity ($r= 0.324$, $p< .05$), total alkalinity and total dissolved solids($r=0.309$, $p< .05$), total phosphorus and total alkalinity($r=0.304$, $p< .05$), total nitrogen and pH($r=0.326$, $p< .05$), calcium and potassium($r= 0.355$, $p< .05$), magnesium and total dissolved solids($r=0.316$, $p< .05$), sodium and total dissolved solids($r= 0.310$, $p< .05$), whereas negatively correlated with potassium and dissolved oxygen ($r= -0.297$, $p< .05$), total dissolved solids and dissolved oxygen ($r= -0.297$, $p< .05$), total phosphorus and dissolved oxygen ($r= -0.318$, $p< .05$). There was no correlation with the other parameters, i.e., ($p> .05$) and the results and represented in Table 4.24 and Fig.4.52.

Table 4.24

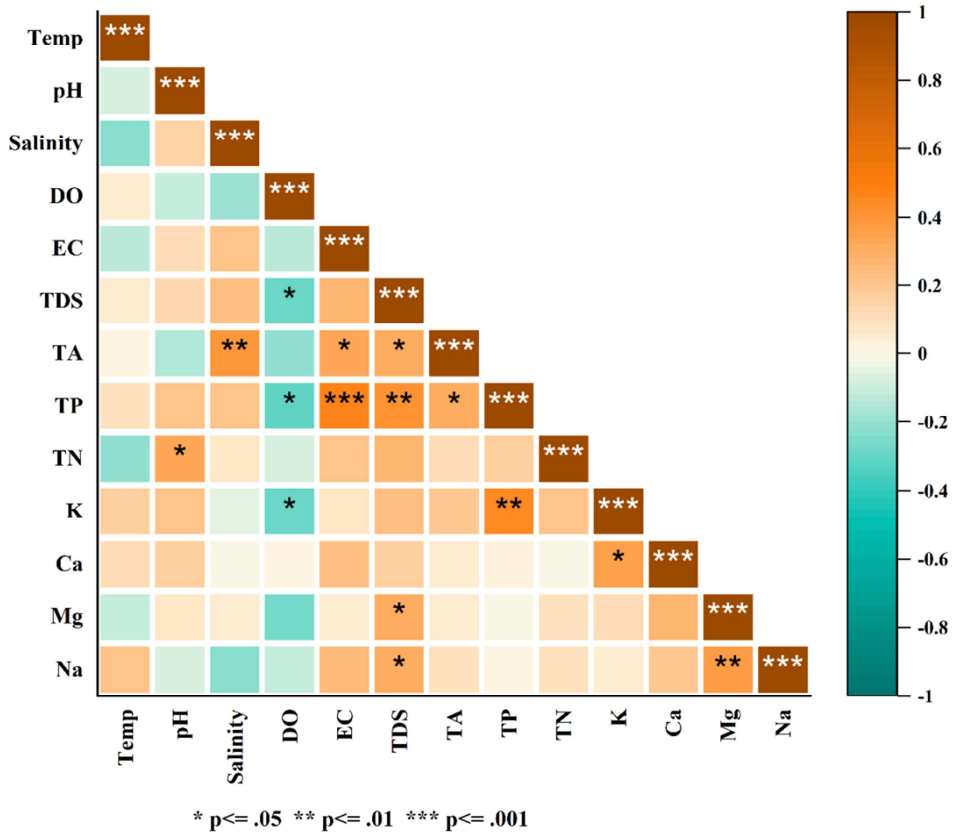
Correlation matrix between the physico-chemical parameters of water in the study areas during monsoon season

	Temp	pH	Salinity	DO	E C	TDS	T A	T P	T N	K	Ca	Mg	Na
Temp	1												
pH	-0.062	1											
Salinity	-0.230	0.153	1										
DO	0.041	-0.111	-0.197	1									
E C	-0.136	0.103	0.214	-0.137	1								
TDS	0.058	0.129	0.233	**-0.297***	0.267	1							
T A	0.008	-0.157	**0.390****	-0.208	**0.324***	**0.309***	1						
T P	0.091	0.214	0.208	**-0.318***	**0.462***	**0.401*****	**0.304****	1					
T N	-0.214	**0.326***	0.074	-0.069	0.200	0.271	0.107	0.175	1				
K	0.178	0.214	-0.054	**-0.297***	0.066	0.234	0.1823	**0.460****	0.206	1			
Ca	0.101	0.175	-0.016	0.003	0.233	0.162	0.051	0.035	-0.009	**0.355***	1		
Mg	-0.106	0.076	0.054	-0.273	0.043	**0.316***	0.056	-0.019	0.083	0.119	0.270	1	
Na	0.214	-0.077	-0.226	-0.117	0.259	**0.310***	0.094	0.012	0.098	0.0564	0.181	**0.373****	1

(*2- tailed test of significance is used; *Correlation is significant at p < .05 level; **Correlation is significant at p < .01 level; ***Correlation is significant at p < .001 level). (Abbreviations used: Temp.: Temperature; **DO:** Dissolved Oxygen; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **TA:** Total Alkalinity; **TP:** Total Phosphorus; **TN:** Total Nitrogen; **K:** Potassium; **Ca:** Calcium; **Mg:** Magnesium; **Na:** Sodium**).**

Fig. 4.52

Graphical representation of the correlation matrix plot for the estimated physico-chemical parameters of the water during monsoon season



(Abbreviations used: Temp: Temperature; **DO:** Dissolved Oxygen; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **TA:** Total Alkalinity; **TP:** Total Phosphorus; **TN:** Total Nitrogen; **K:** Potassium; **Ca:** Calcium; **Mg:** Magnesium; **Na:** Sodium**)**

In pre-monsoon season, there was a positive correlation between total dissolved solids and pH (r= 0.378, p< .01), sodium and dissolved oxygen (r= 0.341, p< .05) whereas negatively correlated with salinity and temperature (r= -0.400, p< .01), total alkalinity and salinity (r= -0.319, p< .05), electrical conductivity and dissolved oxygen (r= -0.351, p< .05). There was no correlation with the other parameters, i.e., (p> .05) and the results are depicted in Table 4.25 and Fig. 4.53.

Table 4.25

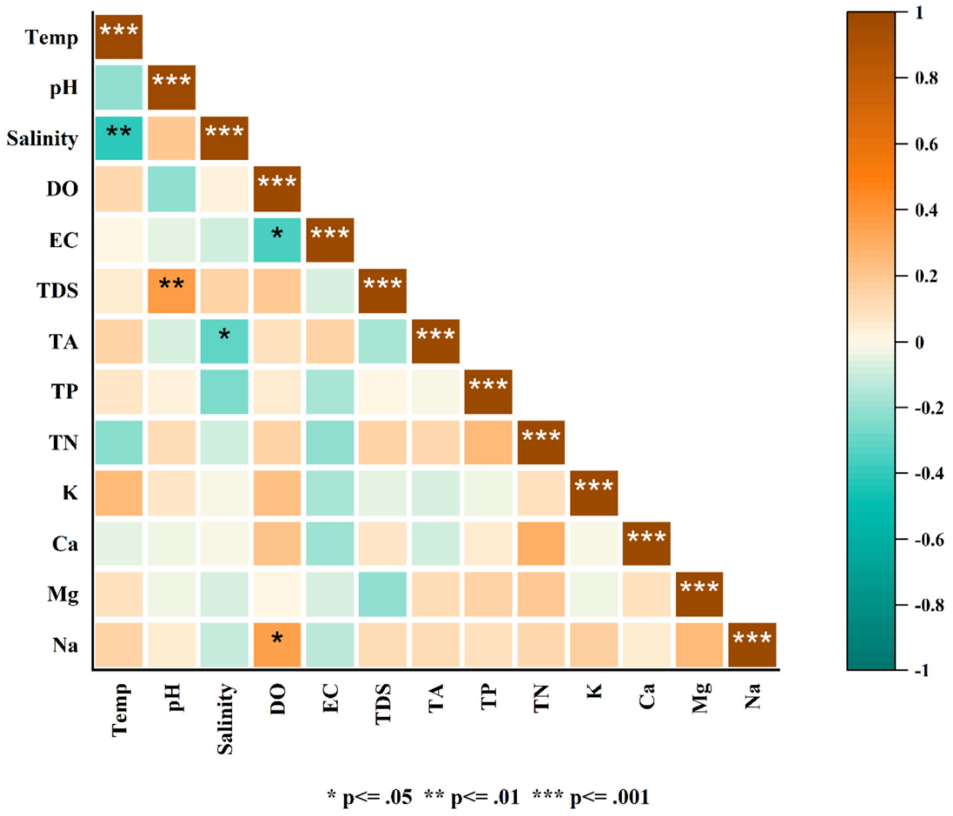
Correlation matrix between the physico-chemical parameters of water in the study areas during pre-monsoon season

	Temp	pH	Salinity	DO	E C	TDS	T A	T P	T N	K	Ca	Mg	Na
Temp	1												
pH	-0.205	1											
Salinity	**-0.400***	0.198	1										
DO	0.126	-0.214	0.022	1									
E C	0.0177	-0.053	-0.098	**-0.351***	1								
TDS	0.057	**0.378***	0.148	0.189	-0.065	1							
T A	0.149	-0.063	**-0.319***	0.098	0.152	-0.167	1						
T P	0.071	0.026	-0.243	0.049	-0.162	0.0051	-0.004	1					
T N	-0.228	0.105	-0.085	0.160	-0.207	0.148	0.137	0.242	1				
K	0.242	0.066	-0.019	0.234	-0.167	-0.044	-0.074	-0.023	0.091	1			
Ca	-0.041	-0.026	-0.005	0.204	-0.199	0.0689	-0.084	0.059	0.280	-0.014	1		
Mg	0.087	-0.029	-0.073	0.004	-0.070	-0.209	0.101	0.157	0.183	-0.029	0.093	1	
Na	0.149	0.052	-0.114	**0.341***	-0.135	0.107	0.109	0.086	0.124	0.165	0.040	0.254	1

(*2- tailed test of significance is used; *Correlation is significant at p < .05 level; **Correlation is significant at p < .01 level; ***Correlation is significant at p < .001 level). (Abbreviations used: Temp.: Temperature; **DO:** Dissolved Oxygen; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **TA:** Total Alkalinity; **TP:** Total Phosphorus; **TN:** Total Nitrogen; **K:** Potassium; **Ca:** Calcium; **Mg:** Magnesium; **Na:** Sodium**).**

Fig. 4.53

Graphical representation of the correlation matrix plot for the estimated physico-chemical parameters of the water during pre-monsoon season.



(Abbreviations used: Temp: Temperature; **DO:** Dissolved Oxygen; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **TA:** Total Alkalinity; **TP:** Total Phosphorus; **TN:** Total Nitrogen; **K:** Potassium; **Ca:** Calcium; **Mg:** Magnesium; **Na:** Sodium**).**

In post-monsoon season, there was a positive correlation between salinity and temperature (r= 0.445, p< .01), total dissolved solids and electrical conductivity (r= 0.376, p< .01), total phosphorus and total alkalinity (r= 0.293, p< .05), total nitrogen and total dissolved solids (r= 0.364, p< .05), potassium and electrical conductivity (r= 0.513, p< .001), potassium and total dissolved solids (r= 0.322, p< .05), potassium and total nitrogen (r= 0.387, p< .01), magnesium and potassium (r= 0.300, p< .05) and magnesium and calcium (r= 0.363, p< .05). There was no correlation with the other parameters, i.e., (p> .05) and the results are depicted in Table 4.26 and Fig. 4.54.

Table 4.26

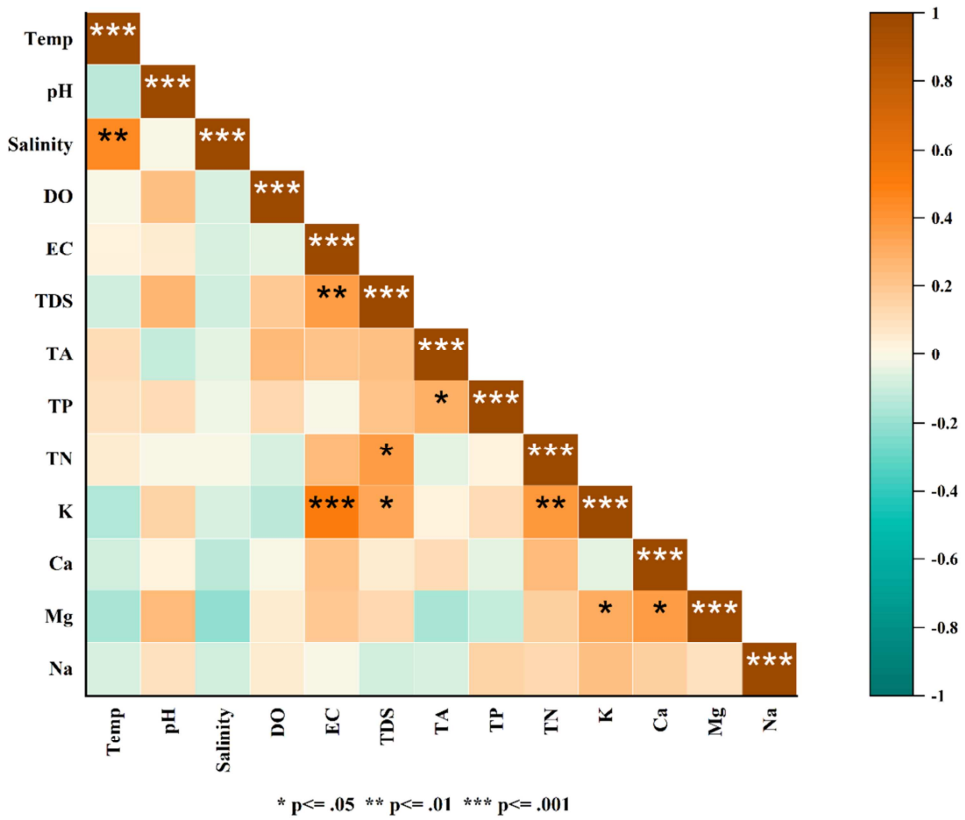
Correlation matrix between the physico-chemical parameters of water in the study areas during post-monsoon season

	Temp	pH	Salinity	DO	E C	TDS	T A	T P	T N	K	Ca	Mg	Na
Temp	1												
pH	-0.129	1											
Salinity	**0.445***	-0.018	1										
DO	-0.020	0.223	-0.069	1									
E C	0.033	0.0578	-0.072	-0.048	1								
TDS	-0.088	0.276	-0.096	0.188	**0.376***	1							
T A	0.105	-0.102	-0.059	0.255	0.212	0.224	1						
T P	0.085	0.105	-0.025	0.134	-0.010	0.201	**0.293***	1					
T N	0.058	-0.010	-0.0108	-0.069	0.252	**0.364***	-0.055	0.028	1				
K	-0.159	0.145	-0.071	-0.122	**0.513***	**0.322***	0.035	0.104	**0.387***	1			
Ca	-0.081	0.033	-0.137	-0.009	0.202	0.044	0.109	-0.043	0.259	-0.047	1		
Mg	-0.167	0.242	-0.204	0.044	0.182	0.132	-0.173	-0.117	0.173	**0.300***	**0.363***	1	
Na	-0.072	0.098	-0.089	0.057	-0.015	-0.096	-0.072	0.152	0.139	0.230	0.167	0.094	1

(*2- tailed test of significance is used; *Correlation is significant at p < .05 level). (Abbreviations used: Temp.: Temperature; **DO:** Dissolved Oxygen; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **TA:** Total Alkalinity; **TP:** Total Phosphorus; **TN:** Total Nitrogen; **K:** Potassium; **Ca:** Calcium; **Mg:** Magnesium; **Na:** Sodium**).**

Fig. 4.54

Graphical representation of the correlation matrix plot for the estimated physico-chemical parameters of the water during post-monsoon season



(Abbreviations used: Temp: Temperature; **DO:** Dissolved Oxygen; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **TA:** Total Alkalinity; **TP:** Total Phosphorus; **TN:** Total Nitrogen; **K:** Potassium; **Ca:** Calcium; **Mg:** Magnesium; **Na:** Sodium**)**

4.12.1.2. Multivariate Statistical Analysis

Principal Component Analysis (PCA), Canonical Correspondence Analysis (CCA) and JASP network analysis were employed to find out the relation of physico-chemical parameters of water to the planktic cyanobacterial abundance. The results of the PCA were carried out in two main components, PC1 and PC2, representing 49% and 21.6% respectively.

Based on the eigenvalues scree plot, the 13 physico-chemical parameters were reduced to two main principal component factors PC1 and PC2. The largest eigenvalue corresponds to 6.36523 which accounts for 49% of the total variance. It

is comprised of the water parameters such as dissolved oxygen, pH, salinity, magnesium, total alkalinity, sodium and temperature. The second component, PC2 corresponds to the eigenvalue 2.81096 which accounts for 21.6% of the total variance with electrical conductivity, total dissolved solids and calcium. The remaining principal components have eigenvalues of less than unity. Eigenvalues and percentage of cumulative variances are shown in Table 4.27, and 4.28 and Figure 4.55 represents the respective eigenvectors.

The PCA plot showed that dissolved oxygen, pH and salinity had a strong influence on the water parameters, to lesser extent magnesium, total alkalinity, sodium and temperature during the pre-monsoon season. During the monsoon season, the parameters had a high correlation with the potassium, total nitrogen and total phosphorus. During the post-monsoon season, electrical conductivity, TDS and Calcium had a strong correlation with water parameters (Fig. 4.56).

Table 4.27

Representation of principal component number, eigenvalue, percentage of cumulative variance.

Principal Component Number	Eigenvalue	Percentage of Variance (%)	Cumulative (%)
1	6.36523	48.96335	48.96335
2	2.81096	21.62275	70.58609
3	1.00326	7.71736	78.30345
4	0.78188	6.01446	84.31791
5	0.55172	4.24399	88.5619
6	0.35602	2.73863	91.30053
7	0.25923	1.9941	93.29463
8	0.25249	1.94224	95.23687
9	0.20791	1.59933	96.8362
10	0.14917	1.14744	97.98364
11	0.1107	0.85156	98.8352
12	0.07818	0.60138	99.43657
13	0.07325	0.56343	100

Fig. 4.55

Scree plot of principal component analysis based on eigenvalue

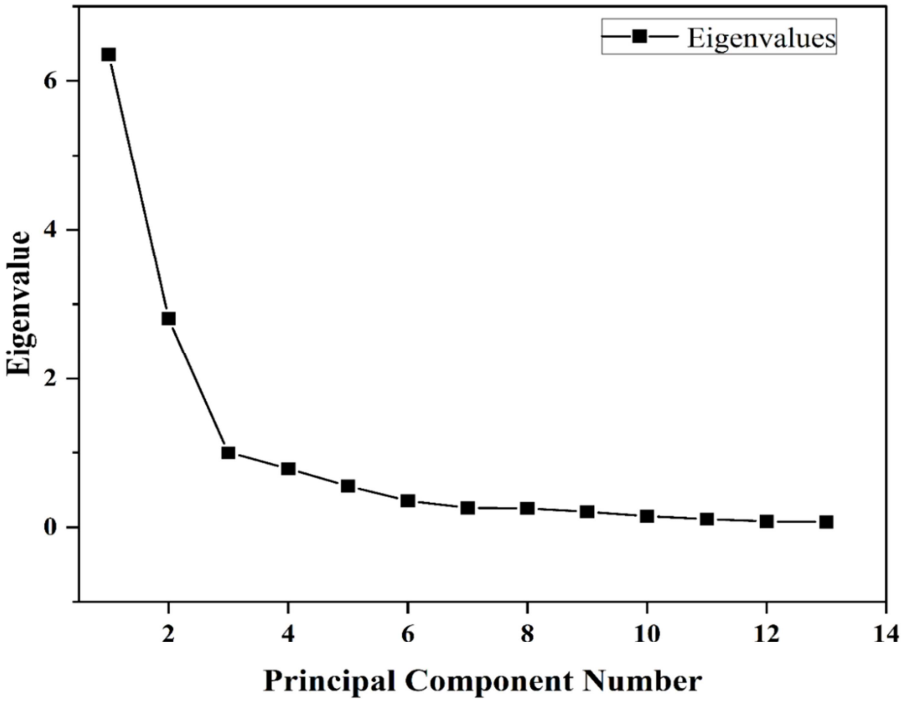


Table 4.28

Eigenvectors of principal components

	PC1	PC2	PC3	PC4
Temperature	0.33752	0.03579	0.03871	-0.06209
pH	0.07713	0.53133	-0.063	-0.22096
Salinity	0.09791	0.51703	-0.01199	-0.13124
Dissolved Oxygen	0.04041	0.33708	-0.24948	0.87248
Electrical Conductivity	0.37002	-0.05001	0.00535	0.0942
Total Dissolved Solids	0.37846	-0.04594	0.00912	0.03815
Total Alkalinity	0.31088	0.19417	0.13385	-0.26589
Total Phosphorus	-0.33409	0.25747	-0.0183	-0.03415
Total Nitrogen	-0.29205	0.3472	0.04257	-0.11862
Potassium	-0.02812	0.09778	0.95448	0.25391
Calcium	0.33131	-0.17544	0.0027	0.08097
Magnesium	0.30567	0.22365	-0.00977	-0.02244
Sodium	0.30203	0.12633	-0.02894	-0.03284

Fig. 4.56

Bi-plot ordination of the principal component analysis showing correlation

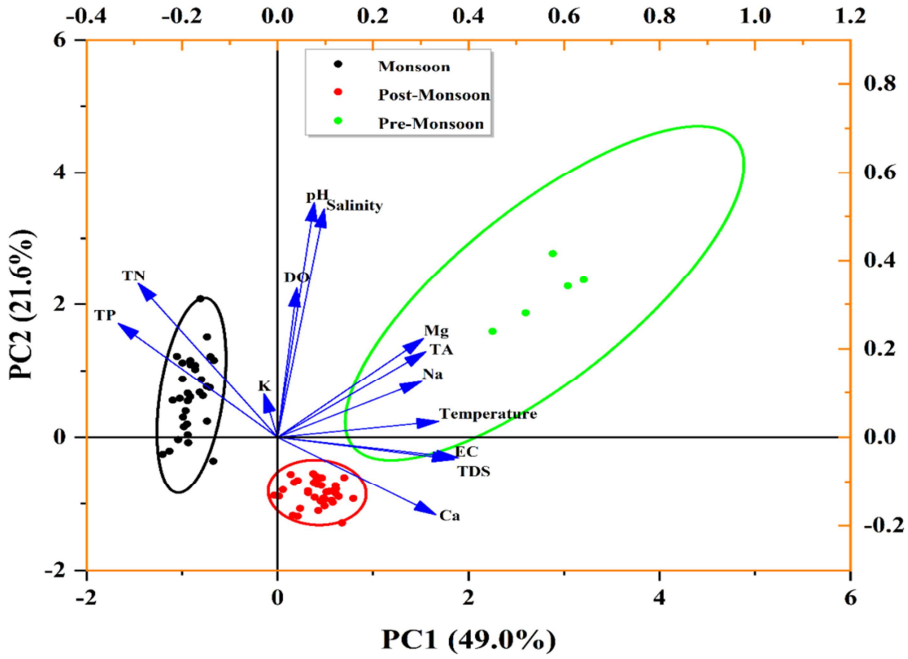
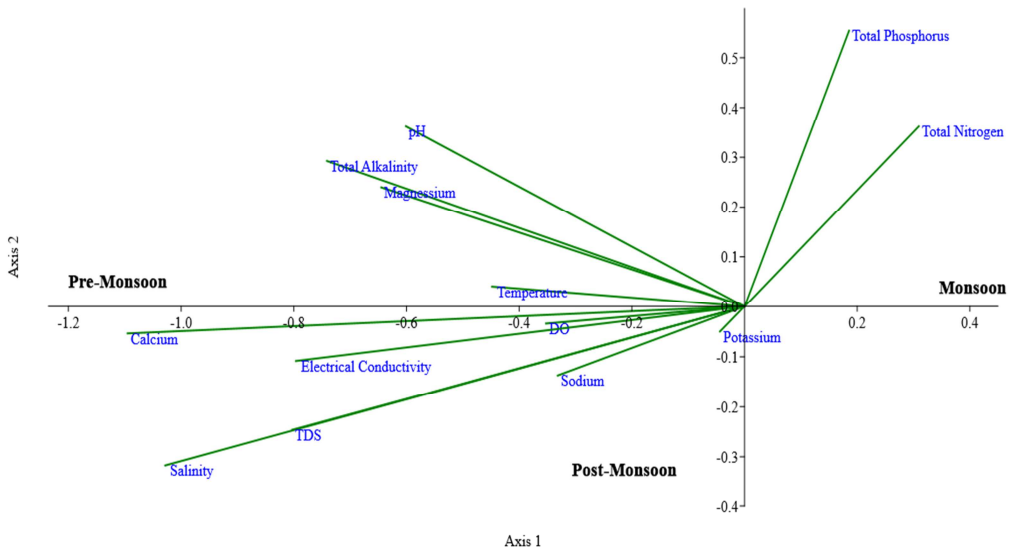


Fig. 4.57

Tri-plot ordination of the canonical correspondence analysis (CCA) showing correlation with the physico-chemical parameters of water



4.12.1.2.1. Canonical Correspondence Analysis (CCA)

Based on the tri-plot ordination of Canonical Correspondence Analysis (CCA), the formation of four groups confirms the influence of physico-chemical parameters of water on the planktic cyanobacterial diversity (Fig. 4.57). Based on the eigenvalue, the first two axes (Axis 1 and Axis 2) were considered for correlating with the cyanobacterial diversity. Axis 1 has the largest eigenvalue corresponding to 0.97146 which accounts for 12.22% of the total variance while axis 2 corresponds to the eigenvalue 0.92533 which accounts for 11.64% of the total variance (Table 4.29).

The tri-plot ordination of CCA analysis showed that the cyanobacterial diversity was positively correlated with the total phosphorus and total nitrogen during monsoon season, pH, total alkalinity, magnesium and temperature showed significant positive correlation during pre-monsoon season and calcium, dissolved oxygen, electrical conductivity, TDS, salinity, sodium and potassium during the post-monsoon season.

Table 4.29

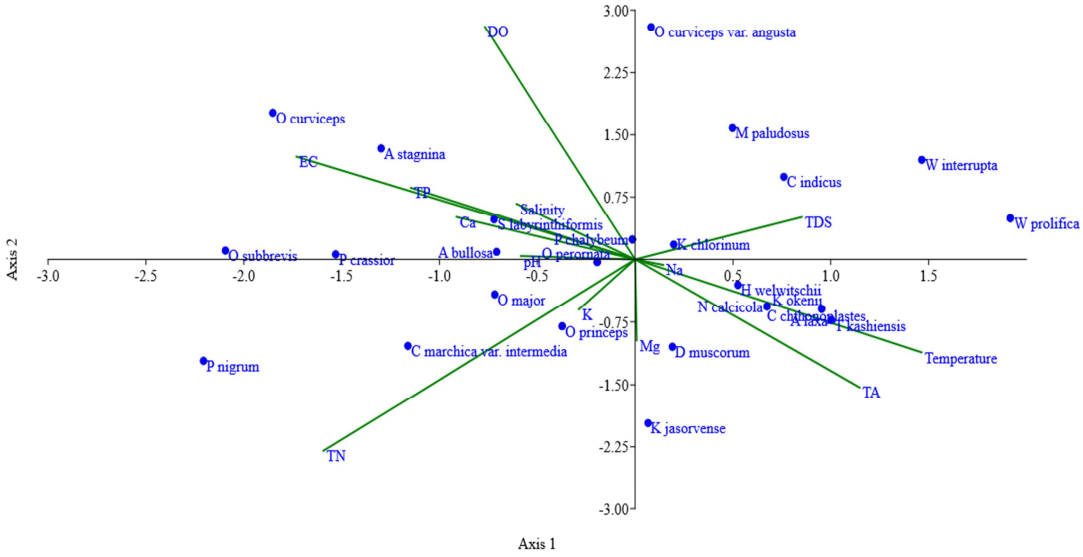
Representation of canonical correspondence axis, eigenvalue, percentage of variance

Axis	Eigenvalue	%
1	0.97146	12.22
2	0.92533	11.64
3	0.91324	11.48
4	0.89593	11.27
5	0.83556	10.51
6	0.78628	9.888
7	0.71889	9.04
8	0.56702	7.131
9	0.47048	5.917
10	0.42361	5.327
11	0.29376	3.694
12	0.15032	1.89
13	5.9919E-06	7.535E-05

The canonical correspondence analysis revealed a statistically significant influence of physico-chemical parameters on the cyanobacterial species composition and abundance. A detailed analysis of seasonal variation between planktic cyanobacterial diversity and environmental parameters has been represented in Fig. 4.58, 4.59, and 4.60.

Fig. 4.58

Tri-plot ordination of the canonical correspondence analysis (CCA) showing the effect of phyico-chemical parameters of water with the planktic cyanobacterial diversity during monsoon season

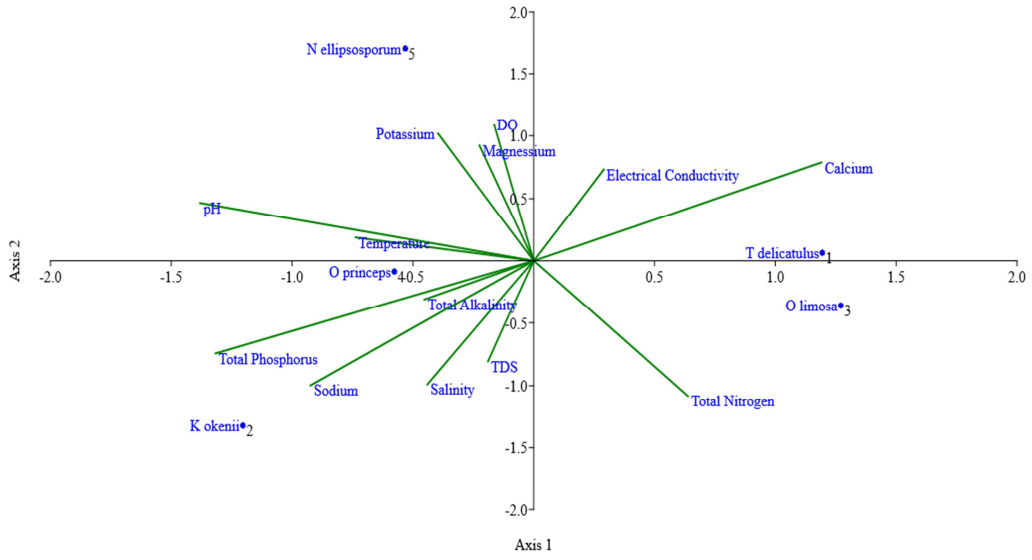


In the CCA plot of monsoon season (Fig.4.58), the first axis explained the cyanobacterial species distribution (*Oscillatoria curviceps* var. *angusta*, *Microcoleus paludosus*, *Chroococcus indicus*, *Kamptonema chlorinum*, *Westiellopsis interrupta* and *Westiellopsis prolifica*) was mainly influenced by total dissolved solids. The second axis represents total alkalinity, sodium and temperature influenced by the distribution of *Hapalosiphon welwitschii*, *Kamptonema okenii*, *Nostoc calcicola*, *Coleofasciculus chthonoplastes*, *Anabaena laxa* and *Trichormus kashiensis*. The third axis in the CCA plot explained the distribution of species like *Oscillatoria major*, *Oscillatoria princeps* and *Calothrix marchica* var.*intermedia* were influenced by potassium and total nitrogen. The fourth axis explained the distribution of the cyanobacterial species like *Oscillatoria curviceps*, *Aphanothece*

stagnina, *Spirulina labyrinthiformis*, *Phormidium chalybeum*, *Oscillatoria perornata* and *Aphanothece bullosa* were greatly influenced by dissolved oxygen, electrical conductivity, total phosphorus, calcium and pH. The outcome of the CCA plot proved that the main physico-chemical parameters that were influencing the distribution and abundance of cyanobacteria were total dissolved solids, sodium, temperature, total alkalinity and magnesium.

Fig. 4.59

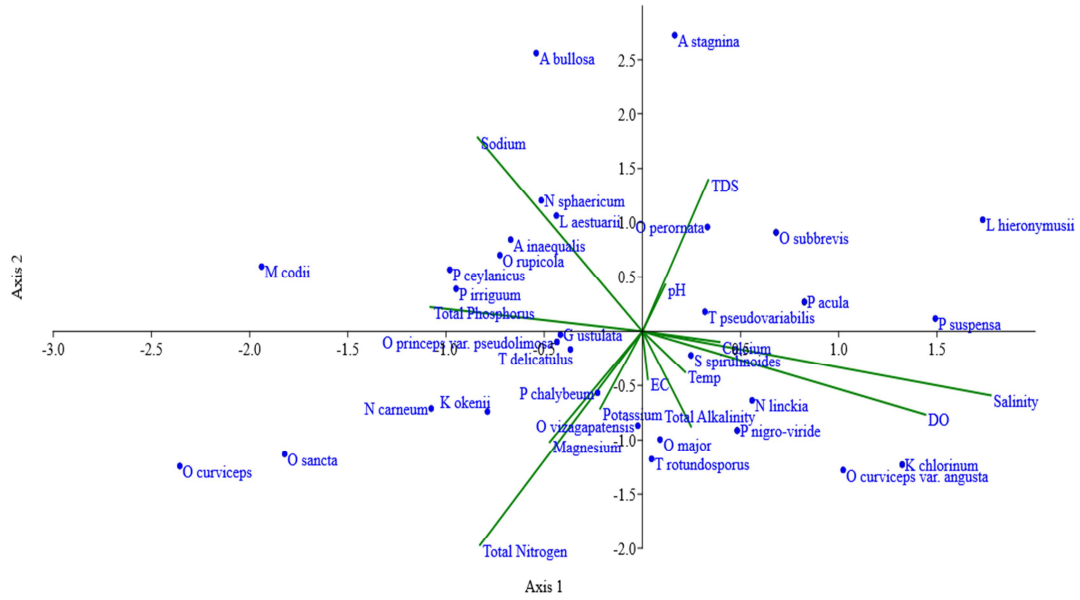
Tri-plot ordination of the canonical correspondence analysis (CCA) showing the effect of phyico-chemical parameters of water with the planktic cyanobacterial diversity during pre-monsoon season



In the CCA plot of the pre-monsoon season (Fig.4.59) the first axis explained the distribution of the cyanobacteria was influenced by electrical conductivity and calcium. The second axis represented the influence of total nitrogen on cyanobacterial distribution. The third axis explained the influence of total phosphorus, total alkalinity, sodium, salinity and TDS. The fourth axis explained the distribution of the cyanobacteria, *Nostoc ellipsosprum* was influenced by the dissolved oxygen, magnesium, potassium, pH and temperature. The outcome of the CCA plot proved that the main physico-chemical parameters that were influencing the distribution and abundance of cyanobacteria were calcium, electrical conductivity and total nitrogen.

Fig. 4.60

Tri-plot ordination of the canonical correspondence analysis (CCA) showing the effect of phyico-chemical parameters of water with the planktic cyanobacterial diversity during post-monsoon season



In the CCA plot of the post-monsoon season (Fig. 4.60) the first axis explained total dissolved solids and pH were influenced by the distribution and abundance of *Aphanothece stagnina*, *Oscillatoria perornata*, *Oscillatoria subbrevis*, *Limnoraphis hieronymusii*, *Phormidium acula*, *Phormidium suspensa* and *Trichormus pseudovariabilis*. The second axis exhibits calcium, salinity, dissolved oxygen, temperature, total alkalinity and electrical condutivity had a significant influence on the distribution of *Spirulina spirulinoides*, *Nostoc linckia*, *Phormidium nigro-viride*, *Oscillatoria major*, *Trichormus rotundosporus*, *Kamptonema chlorinum*, *Oscillatoria curviceps* var. *angusta*. The third axis explained the significant influence of total nitrogen, magnesium and potassium on the distribution of cyanobacterial species like *Gloeothece ustulata*, *Trichocoleus delicatulus*, *Oscillatoria princeps* var. *pseudolimosa*, *Phormidium chalybeum*, *Nostoc carneum*, *Kamptonema okenii*, *Oscillatoria vizagapatensis*, *Oscillatoria sancta* and *Oscillatoria curviceps*. The fourth axis connoted the influence of sodium and total phosphorus on the distribution of *Phormidium irriguum*, *Microcoleus codii*, *Porphyrosiphon ceylanicus*, *Oscillatoria rupicola*, *Anabaena inaequalis*, *Lyngbya*

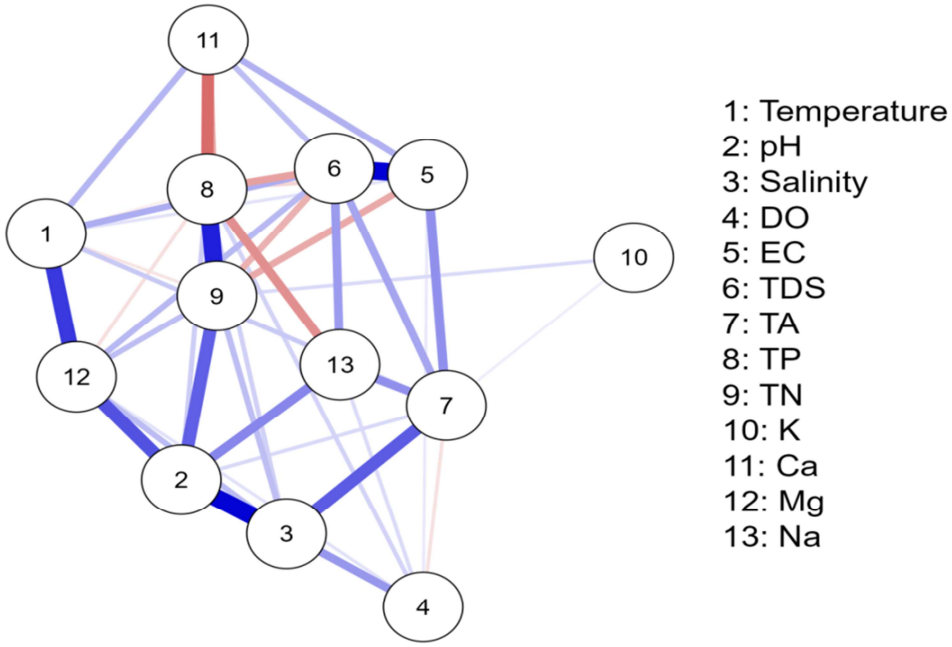
aestuarii, *Nostoc sphaericum* and *Aphanothece bullosa.* The outcome of the CCA plot proved that the main physico-chemical parameters that were influencing the distribution and abundance of cyanobacteria were total dissolved solids, pH, calcium, salinity, dissolved oxygen, temperature, total alkalinity and electrical conductivity.

4.12.1.2.2. JASP Network Analysis

Network analysis is a graphical representation based on statistical techniques that allow for quick visualization and interpretation of relationships between multiple variables (Leme et al., 2020). JASP network plot for correlation of cyanobacterial species abundance and physico-chemical parameters of water revealed that all variables are interrelated in the strength of those relationships (Fig. 61).

Fig. 4.61

JASP network plot for correlation of species abundance and environmental variables in the study areas.



(Abbreviations used: Temp.: Temperature; **DO:** Dissolved Oxygen; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **TA:** Total Alkalinity; **TP:** Total Phosphorus; **TN:** Total Nitrogen; **K:** Potassium; **Ca:** Calcium; **Mg:** Magnesium; **Na:** Sodium**).**

The blue lines indicate the positive correlation and the red lines indicate the negative correlation. The line thickness corresponds to the power of correlation. There was a strong positive correlation between the nodes, 2 and 3, 8 and 9, and 1 and 12. i.e., pH and salinity, total nitrogen and total phosphorus, temperature and magnesium. There was a weaker association between pH and total nitrogen, salinity and total alkalinity, electrical conductivity and total alkalinity, pH and salinity and total dissolved solids and sodium. There was a strong negative relationship between nodes 11 and 8, i.e., calcium and total phosphorus and also a weaker negative correlation between the nodes total phosphorus and sodium, total dissolved solids and total phosphorus, total dissolved solids and total nitrogen and electrical conductivity and total nitrogen.

4.12.2. Soil Analysis

The spatiotemporal fluctuations of physico-chemical parameters of soil were calculated based on descriptive and multivariate analysis. Mean, standard deviation, ANOVA, Pearson correlation coefficient matrix, Principal Component Analysis (PCA), Canonical Correspondence Analysis (CCA) and JASP network analysis were employed to correlate the environmental variables with cyanobacterial diversity.

Soil physico-chemical parameters from the study areas were estimated and correlated with the cyanobacterial abundance that occurred as epipsammic/epipelic. Soil associated cyanobacteria were not observed in the study areas Kureekkadavu (S2) and Mekkara (S6). Physico-chemical parameters of soil such as pH, salinity, electrical conductivity, organic carbon, total nitrogen, total phosphorus, potassium, sodium, calcium and magnesium were estimated and analysed for their influence on the cyanobacterial diversity in the study areas were analysed based on the multivariate statistical analysis. The mean and standard deviation (SD) of physico-chemical characteristics of soil is summarised in Table 4.30.1. & 4.30.2. The seasonal and spatial variations of physico-chemical parameters of soil were analysed and depicted in Fig.4.62-4.71. The range of distribution of the physico-chemical parameters of soil is shown in Fig. 4.72-4.81.

pH showed a minimum of 4.44 (avg.5.4±0.96) at Ayiramthengu (S3) during pre-monsoon and a maximum of 7.66 (avg.7.2±0.46) at Pathiramanal (S8) during

the post-monsoon season (Fig.4.62; Fig.4.72) and seasonal variations along the study areas of the mangrove environment were statistically significant (Table 4.31). Mangrove soils are mostly acidic, especially in areas that are periodically flooded and are located in the higher reaches of the intertidal zone (Vijayakumar & Kumara, 2020). But in most of the months, soil pH was found to be near neutral (6.5-7.4) which facilitates microbial nitrogen and phosphorus release while reducing hazardous product accumulation (Weissengruber et al., 2018).

Salinity showed a minimum of 0.35 ppt (avg. 1.06±0.71 ppt) at Kumarakom (S5) during the monsoon season and a maximum of 5.74 ppt (avg. 5.03±0.71 ppt) at Vypin (S10) during the pre-monsoon season (Fig.4.63; Fig. 4.73). Statistically significant seasonal variations were observed in the salinity distribution pattern (Table 4.32) during the study. Electrical conductivity was a minimum of 3.47 dS/m (avg. 9.12±5.65 dS/m) at Kumbalam (S9) during the pre-monsoon season and a maximum of 21.94 dS/mn(avg.16.88±5.06 dS/m) at Kadinamkulam (S1) during the monsoon season (Fig 4.64; Fig.4.74). Statistically significant seasonal variations were observed in the electrical conductivity distribution pattern (Table 4.33) during the study. The high electrical conductivity of the soil is due to the permeation of seawater at high tide, the evaporation of water and the capillary rise of soil water at low tide (Ataullah et al., 2017). The electrical conductivity values of the mangrove soils were slightly lower because the soils under the mangrove zones were periodically inundated by tidal waters and ultimately balanced with the salinity of the estuary water (Dasgupta et al., 2018).

Organic carbon was a minimum of 0.29% (avg. 0.76±0.47 and 0.71±0.42 %) at Kadinamkulam (S1) and Kumbalam (S9) respectively, during the monsoon season and a maximum of 7.10 % (avg.5.8±1.3%) at Pathiramanal (S8) during the pre-monsoon season (Fig 4.65; Fig.4.75). Statistically significant seasonal variations were observed in the organic carbon distribution pattern (Table 4.34) during the study.

Total nitrogen was found to vary from 211.17 (avg.1048.62± 837.45 Kg/ha) with a minimum value during the post-monsoon season at Ayiramthengu (S3), and a maximum value of 2072.64 (avg.1243.22±829.42 Kg/ha) occurred during the post-monsoon season at Ezhupunna (S7) (Fig. 4.66; Fig 4.76). Statistically significant

seasonal variation was observed in the total nitrogen distribution pattern (Table 4.35) during the study.

Statistically significant seasonal variations were observed in the total phosphorus distribution pattern (Table 4.36) in the study areas during the study. Total phosphorus was a minimum of 340.91 (avg. 553.42±212.51 Kg/ha) at Ayiramthengu (S3) during the pre-monsoon season and a maximum of 1314.62 (avg. 1132.01±182.61 Kg/ha) during the post-monsoon season at Ezhupunna (S7) (Fig.4.67; Fig. 4.77).

Statistically significant seasonal variation for potassium was observed in the study area (Table 4.37). Potassium content varied from 3261.63 (avg.4688.47±1426.84 Kg/ha), with a minimum value recorded during pre-monsoon at Kumbalam (S9) and a maximum value recorded during the post-monsoon season, 13172.24 (avg.10968.17±2204.07 Kg/ha) at Vypin (S10) (Fig. 4.68; Fig. 4.78). The sodium content of soil samples was found to vary from 866 (avg.1034.65±168.65 Kg/ha) to 4443.86 (avg. 3925.62±518.24 Kg/ha) with a minimum value during the post-monsoon season at Kumbalam (S9), and a maximum value occurring during the pre-monsoon season at Kumarakom (S5) (Fig. 4.69; Fig 4.79). Statistically significant seasonal variation was observed in the sodium distribution pattern in mangrove soil (Table 4.38) in the study areas.

The calcium content of soil samples was found to vary from 7.38 (avg. 18.68±11.3 mg/Kg) to 195.40 (avg. 131.52±63.88 mg/Kg) with a minimum value recorded during monsoon at Pathiramanal (S8) and a maximum value recorded during post-monsoon at Ezhupunna (S7) (Fig. 4.70; Fig. 4.80). Statistically significant seasonal variation was observed in the distribution of calcium content in mangrove soil (Table 4.39) in the study areas.

Statistically significant variations in the magnesium content of soil samples were observed in the study areas (Table 4.40). Magnesium content was found to vary from 653.86 (avg. 1328.14±674.28 mg/Kg) to 4265.37 (avg. 3465.05±800.32 mg/Kg), with a minimum value recorded at Ayiramthengu (S3) during the monsoon season and a maximum value recorded during the post-monsoon season at Vypin (S10) (Fig. 4.71; Fig. 4.81).

Table 4.30.1

Physico-chemical characteristics of soil (Mean ± SD) recorded in the study areas (S1,S3,S4 & S5)

Variable	S1			S3			S4			S5		
	MS	PRS	POS	MS	PRS	POS	MS	PRS	POS	MS	PRS	POS
pH	6.9± 0.38	5.6± 0.97	6.9± 0.38	6.8± 0.39	5.4± 0.96	6.7± 0.41	6.4± 0.61	5.4± 0.94	6.6± 0.61	6.7± 0.42	5.6± 1.01	6.8± 0.65
Salinity (ppt)	1.01± 0.63	3.82± 0.84	2.59± 0.56	1.2± 0.52	4.81± 0.62	3.02± 0.43	1.1± 0.62	4.72± 0.59	2.95± 0.39	1.06± 0.71	4.62± 0.84	3.12± 0.62
EC (dS/m)	16.88± 5.06	9.16± 4.37	26.6± 9.47	15.94± 5.04	8.62± 4.01	25.9± 10.1	16.25± 5.32	8.53± 3.95	26.21± 11.32	15.97± 4.65	9.06± 4.35	26.15± 9.53
OC (%)	0.76± 0.47	5.2± 1.17	2.41± 0.52	0.95± 0.51	5.6± 1.23	2.68± 0.67	0.82± 0.42	4.9± 1.62	2.51± 0.71	0.92± 0.31	5.12± 1.06	2.65± 0.66
T N (Kg/ha)	472.87± 115.16	799.92± 187.31	1143.8± 845.17	482.24± 112.35	803.24± 186.24	1048.62± 837.45	470.64± 116.51	786.48± 179.54	1124.21± 842.51	466.15± 119.45	802.65± 182.4	1108.34± 804.12
T P g/ha)	845.17± 114.25	572.63± 209.95	1053.08± 196.2	840.54± 115.24	553.42± 212.51	989.43± 202.15	864.32± 112.47	561.48± 205.16	989.47± 208.61	852.47± 117.54	568.22± 224.02	1005.31± 214.62
K (Kg/ha)	5192.46± 1326.97	4763.6± 1270.92	11082.7± 1850.9	5241.5± 1321.51	4627.16± 1324.62	10953.25± 2015.61	5043.1± 1452.74	4638.27± 1362.47	11125.51± 1848.52	4928.64± 1625.07	4708.61± 1382.06	11118.24± 1 1768.51
Na (mg/Kg)	1873.02± 512.22	3482.9± 542.15	1161.61± 131.84	1812.42± 562.14	3315.82± 601.32	1152.62± 142.15	1914.72± 512.04	3628.46± 504.15	1064.82± 153.42	1904.17± 504.92	3925.62± 518.24	1183.55± 154.15

Variable	S1			S3			S4			S5		
	MS	PRS	POS	MS	PRS	POS	MS	PRS	POS	MS	PRS	POS
Ca (mg/Kg)	20.23± 7.17	131.66± 63.32	45.28± 4.7	19.51± 8.62	133.52± 61.22	44.15± 5.1	21.62± 8.99	128.94± 64.85	46.15± 5.4	20.34± 10.05	129.22± 64.28	45.21± 4.9
Mg (mg/L)	1350.82± 656.83	1080.4± 292.6	3385.69± 792.18	1328.14± 674.28	1121.32± 246.31	3254.15± 801.62	1425 ± 586.33	1042.65± 291.6	3425.62± 783.15	1405.62± 598.15	1105.62± 251.33	3152.58± 811.42

(Abbreviations used: S1: Kadinamkulam; **S3:** Ayiramthengu; **S4:** Sakthikulangara; **S5:** Kumarakom; **MS:** Monsoon season; **PRS:** Pre-monsoon season; **POS:** Post-monsoon season; **EC:** Electrical Conductivity; **TN:** Total Nitrogen; **TP:** Total Phosphorus; **K:** Potassium; **Na:** Sodium; **Ca:** Calcium; **Mg:** Magnesium**)**

Table 4.30.2

Physico-chemical characteristics of soil (Mean ± SD) recorded in the study areas (S7, S8, S9 & S10)

Variable	S7			S8			S9			S10		
	MS	PRS	POS	MS	PRS	POS	MS	PRS	POS	MS	PRS	POS
pH	6.3± 0.39	6.2±0.95	7.1±0.42	6.5±0.41	5.8±0.98	7.2± 0.46	6.8±0.40	5.7±1.03	6.8±0.58	6.6±0.38	5.6±1.1	6.9±0.68
Salinity (ppt)	1.04±0.15	5.03± 0.42	2.66± 0.52	1.08±0.72	5.12±0.39	3.15±0.38	1.04±0.62	4.82±0.38	2.76±0.34	0.97±0.58	5.03±0.71	2.64±0.4
EC (dS/m)	16.08±4.26	8.94± 3.15	27.41± 10.48	16.35± 4.82	8.65±4.33	25.64± 9.15	14.62±6.24	9.12±5.65	26.54±10.24	16.52±4.06	8.15±6.52	25.42±10.34
OC (%)	0.79±0.34	5.4± 1.52	2.57± 0.81	0.82± 0.38	5.8±1.3	2.62± 0.64	0.71±0.42	4.8±2.01	2.48±0.83	0.92±0.45	5.6±1.48	2.46±0.51
T N (Kg/ha)	459.15± 116.25	804.65± 180.47	1243.22± 829.42	468.67 ± 124.62	778.14± 200.14	1207.57± 837.51	476.82± 120.41	812.24± 194.81	1127.77± 789.84	483.84± 118.61	783.15± 183.44	1067.65 ± 842.74
T P g/ha)	816.77± 124.15	568.25± 220.47	1132.01± 182.61	834.48± 121.54	576.15± 218.43	973.54± 205.66	847.15± 116.45	578.25± 207.44	975.92± 212.43	835.22± 118.42	570.61± 216.43	1032.77± 194.52
K (Kg/ha)	5316.42± 1240.05	4731.52± 1281.62	11035.72± 1821.42	5100.64± 1421.51	4694.68± 1357.82	10862.46± 2201.21	4922.08± 1427.52	4688.47± 1426.84	10934.81± 2018.51	5173.84± 1335.28	4728.91± 1405.61	10968.17± 2204.07
Na (mg/Kg)	1864.27± 553.44	3382.15± 552.15	1191.46± 161.44	1892.43± 582.47	3426.25± 510.33	1182.65± 152.62	1884.11± 537.48	3526.22± 540.33	1034.65± 168.65	1873.42± 561.25	3581.52± 524.21	1152.27± 154.15
Ca (mg/Kg)	19.82± 10.51	131.52± 63.88	44.08± 5.6	18.68± 11.3	129.55± 63.47	46.35± 4.9	21.66± 7.82	127.16± 63.54	45.82± 5.8	20.42± 7.62	128± 64.15	45.61± 5.1
Mg (mg/L)	1364.52± 604.25	1092.62± 262.03	3308.62± 804.65	1342.11± 601.05	1098.24± 267.15	3204.82± 815.32	1374.84± 583.05	1108.95± 257.15	3362.08± 792.15	1382.84± 604.22	1115.09± 261.32	3465.05± 800.32

(Abbreviations used: S7: Ezhupunna; **S8:** Pathiramanal; **S9:** Kumbalam; **S10:** Vypin; **MS:** Monsoon season; **PRS:** Pre-monsoon season; **POS:** Post-monsoon season; **EC:** Electrical Conductivity; **TN:** Total Nitrogen; **TP:** Total Phosphorus; **K:** Potassium; **Na:** Sodium; **Ca:** Calcium; **Mg:** Magnesium**)**

Fig. 4.62

Seasonal variations of pH in mangrove soil in the study areas

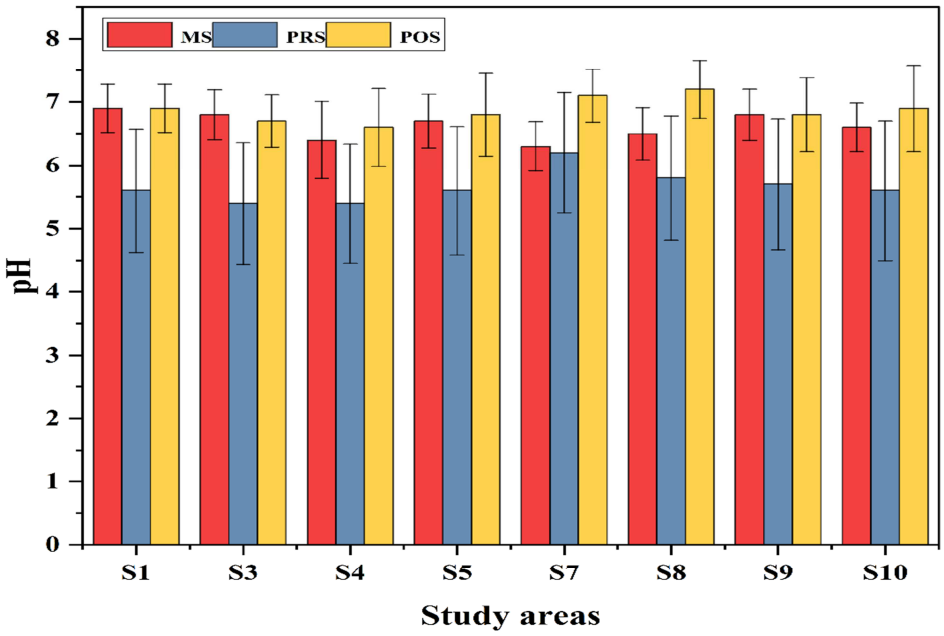


Fig. 4.63

Seasonal variations of salinity (ppt) in mangrove soil in the study areas

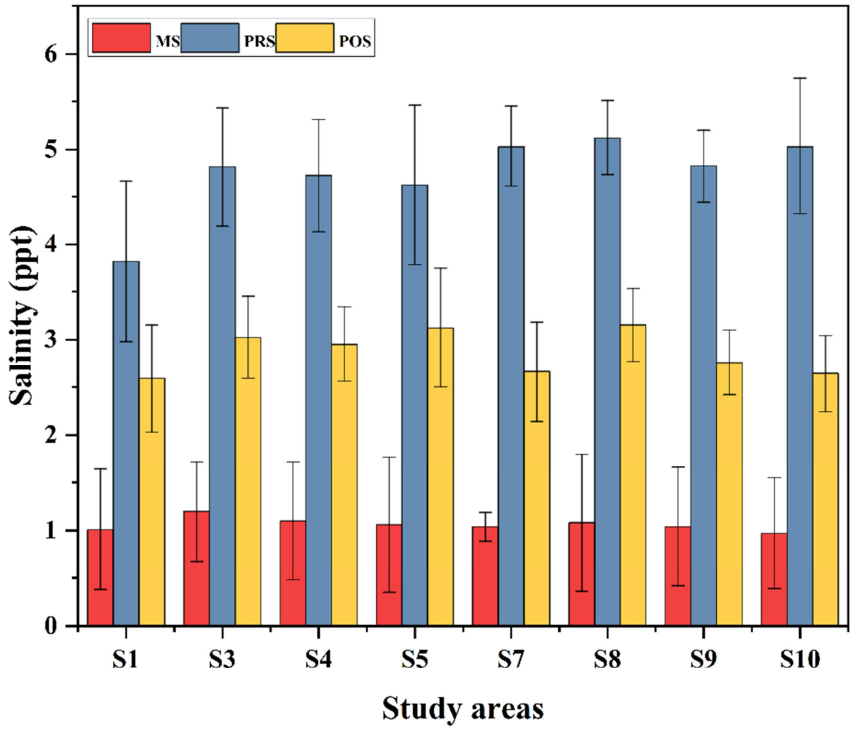


Fig. 4.64

Seasonal variations of electrical conductivity (dS/m) in mangrove soil in the study areas

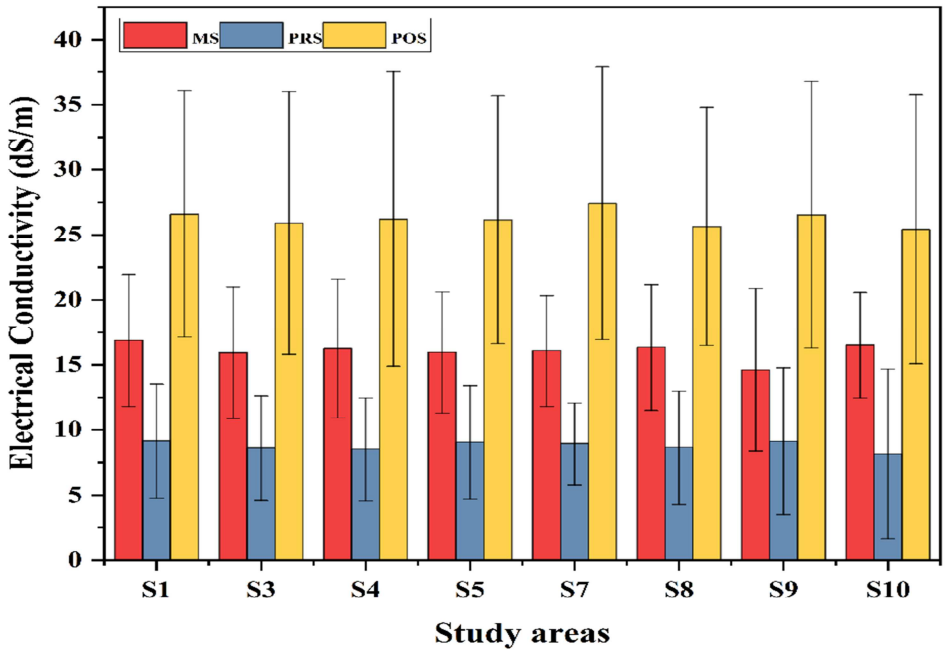


Fig. 4.65

Seasonal variations of organic carbon (%) in mangrove soil in the study areas

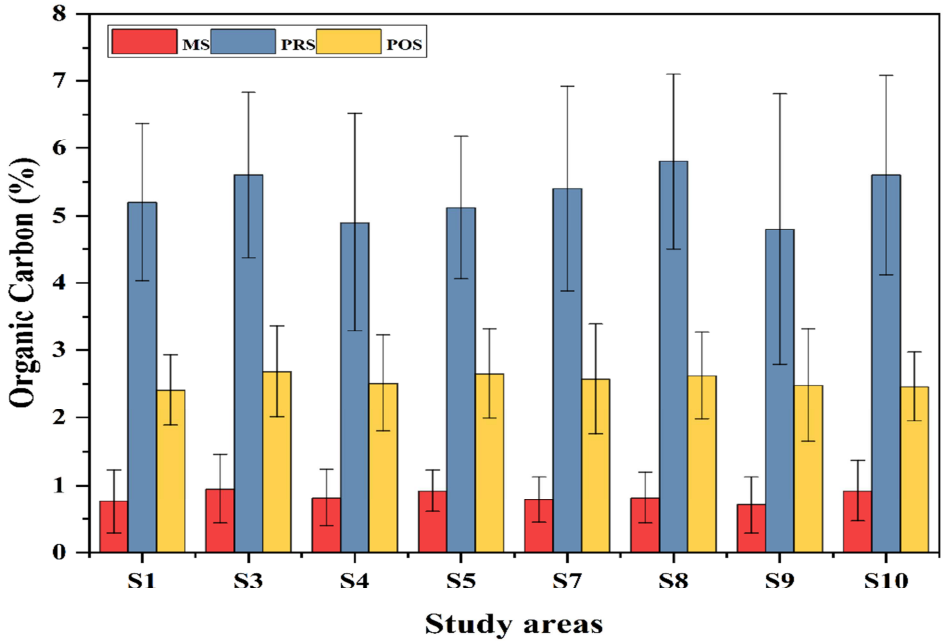


Fig. 4.66

Seasonal variations of total nitrogen (Kg/ha) in mangrove soil in the study areas

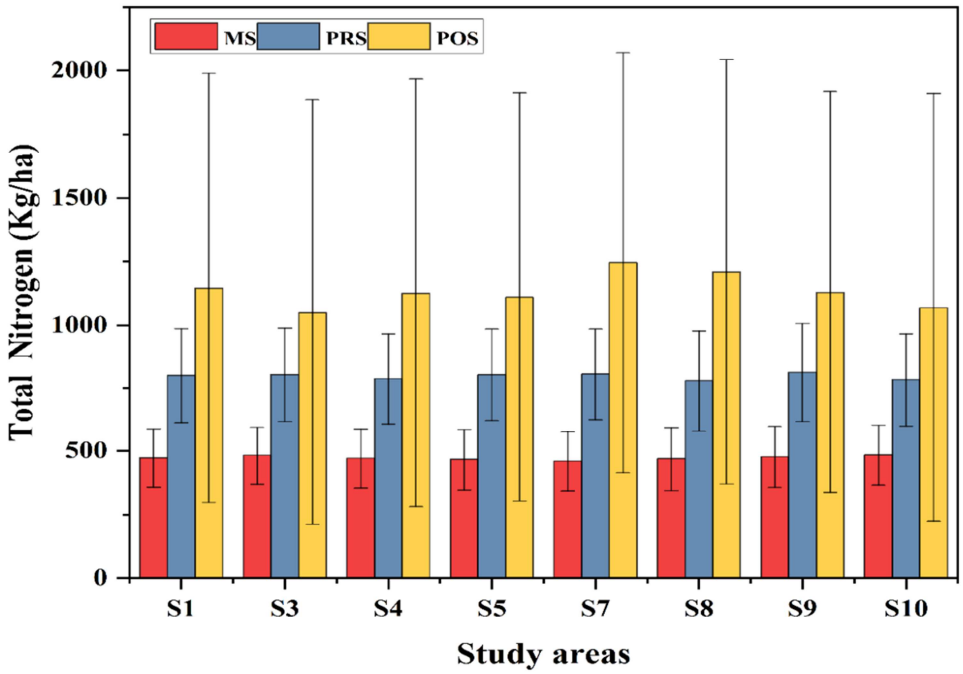


Fig. 4.67

Seasonal variations of total phosphorus (Kg/ha) in mangrove soil in the study areas

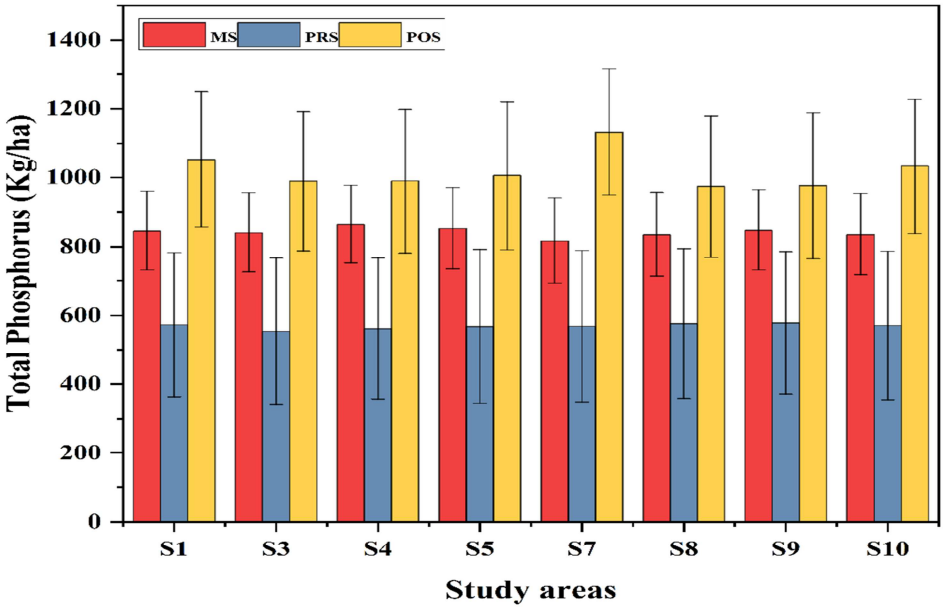


Fig. 4.68

Seasonal variations of potassium (Kg/ha) in mangrove soil in the study areas

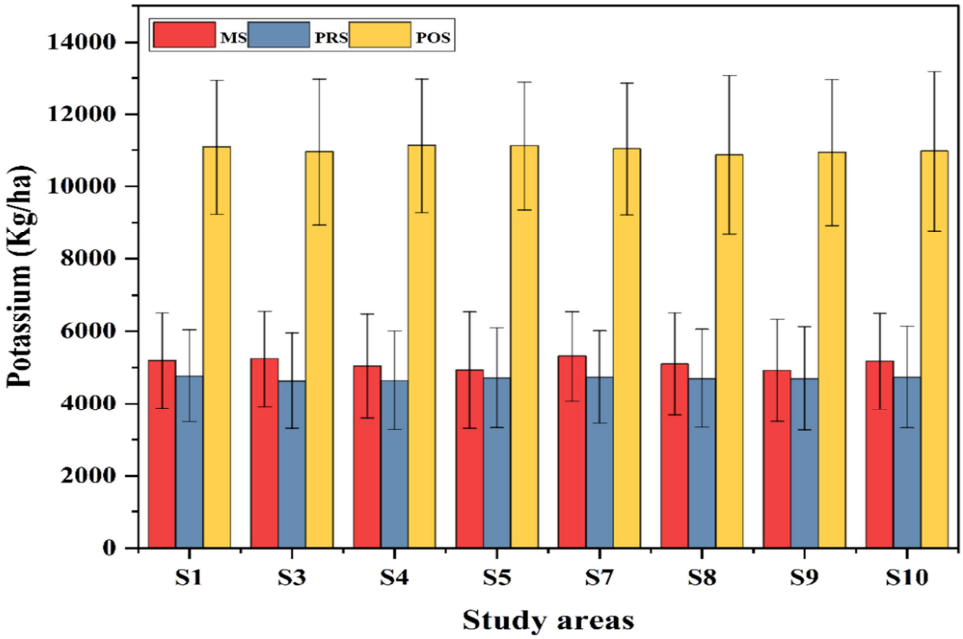


Fig. 4.69

Seasonal variations of sodium (mg/Kg) in mangrove soil in the study areas

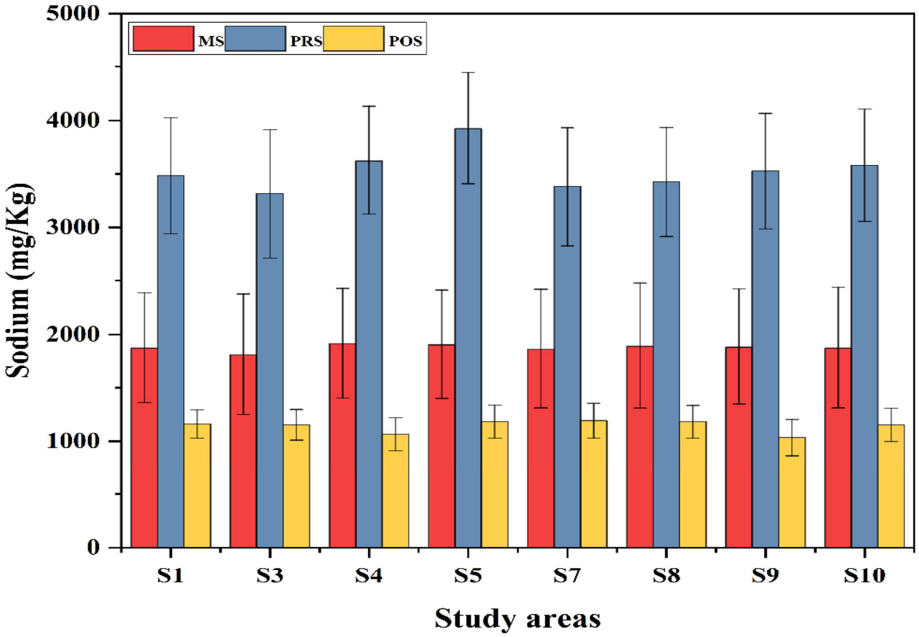


Fig. 4.70

Seasonal variations of calcium (mg/Kg) in mangrove soil in the study areas

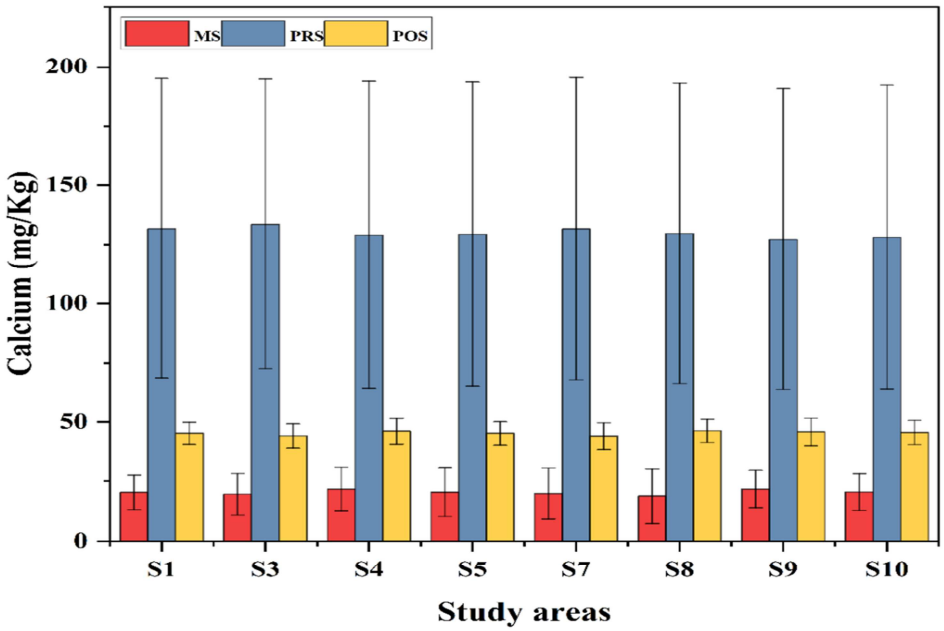


Fig. 4.71

Seasonal variations of magnesium (mg/Kg) in mangrove soil in the study areas

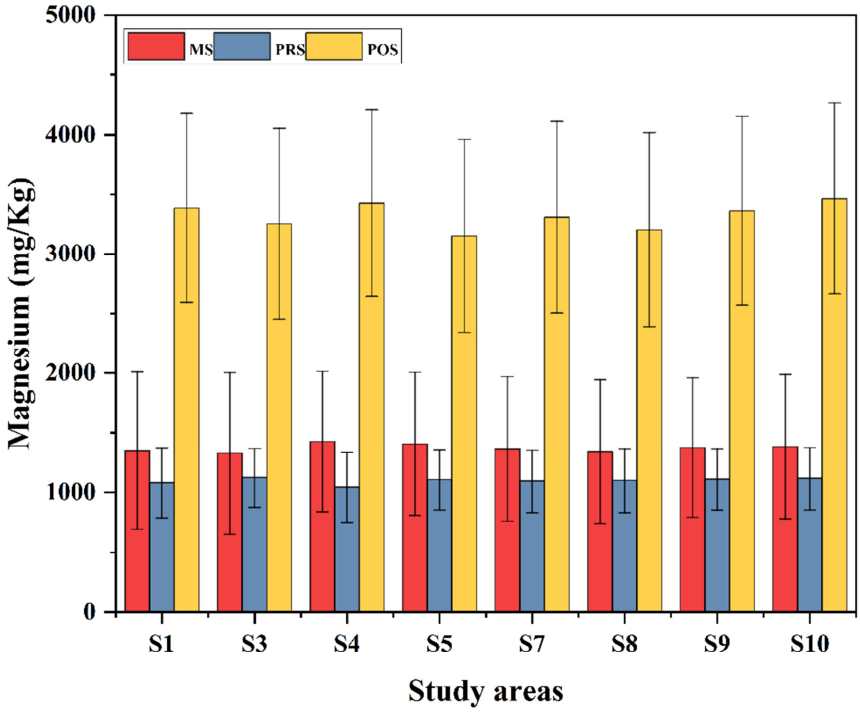


Fig. 4.72

Range of seasonal distribution of pH in the study areas

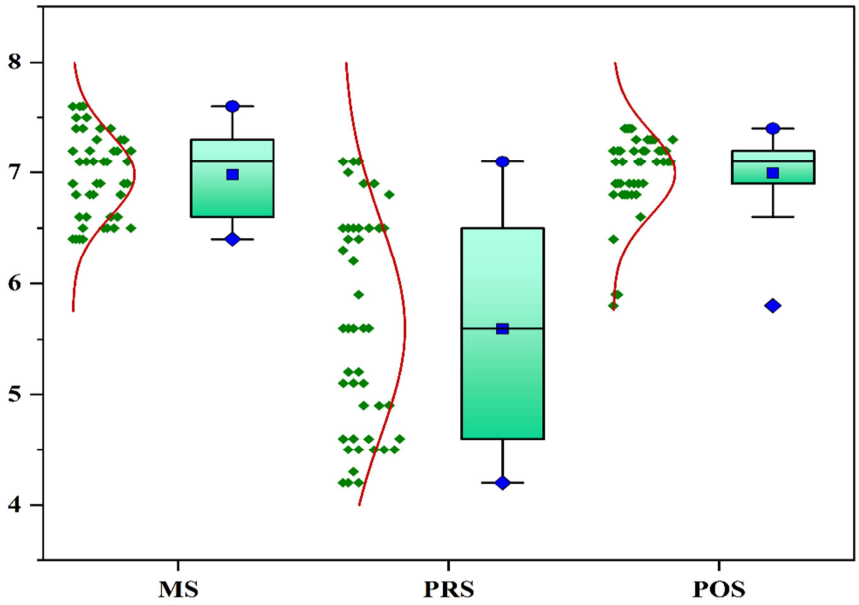


Fig. 4.73

Range of seasonal distribution of salinity (ppt) in the study areas

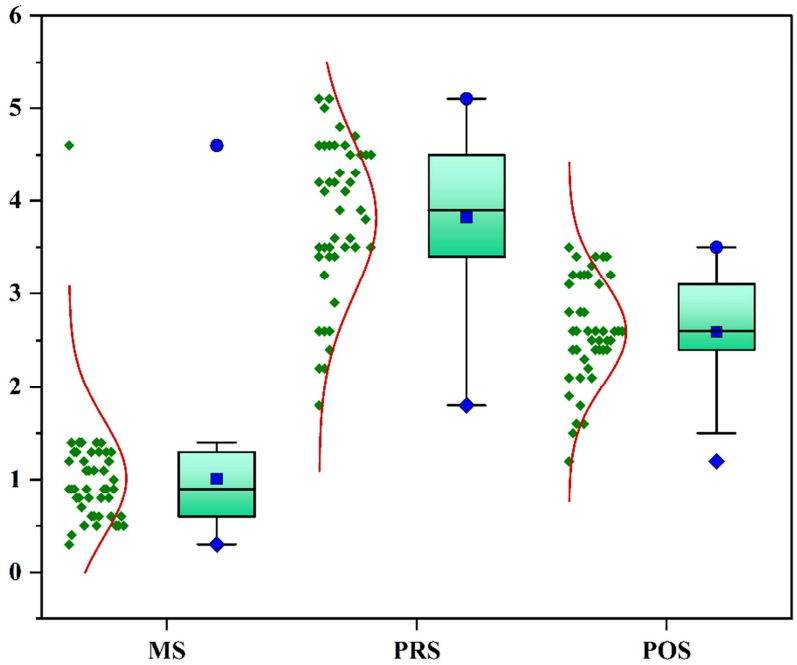


Fig. 4.74

Range of seasonal distribution of electrical conductivity (dS/m) in the study areas

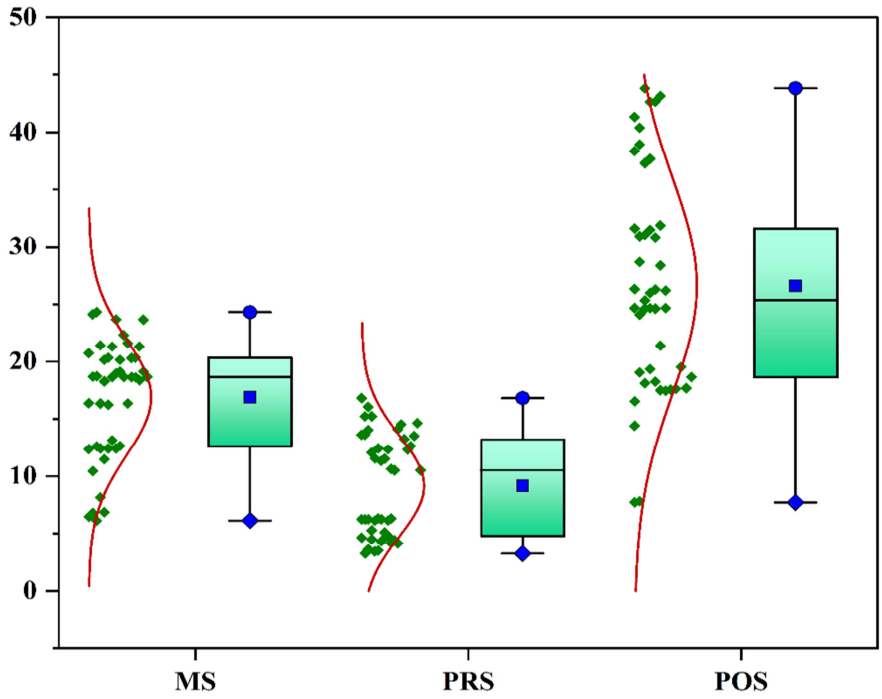


Fig. 4.75

Range of seasonal distribution of organic carbon (%) in the study areas

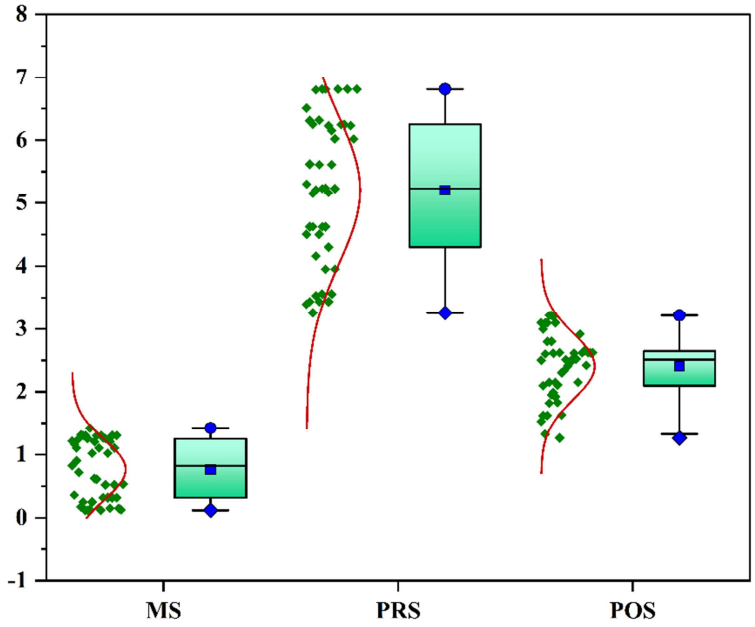


Fig. 4.76

Range of seasonal distribution of total nitrogen (Kg/ha) in the study areas

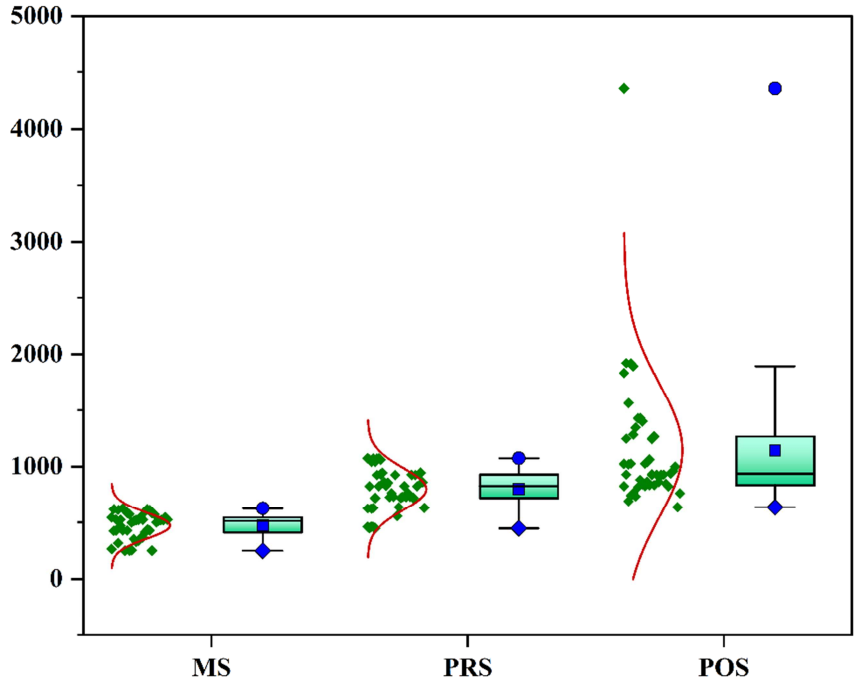


Fig. 4.77

Range of seasonal distribution of total phosphorus (Kg/ha) in the study areas

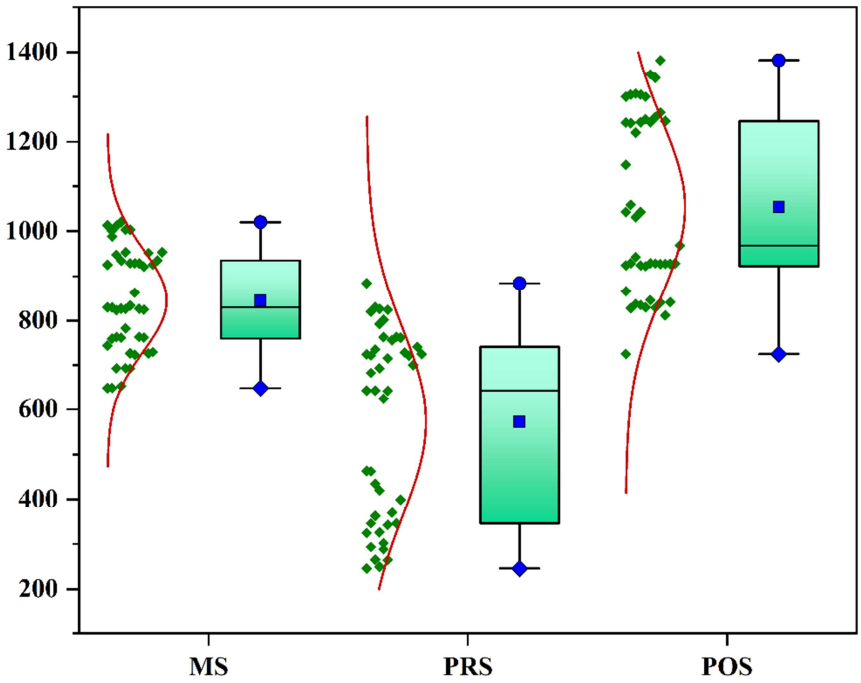


Fig. 4.78

Range of seasonal distribution of potassium (Kg/ha) in the study areas

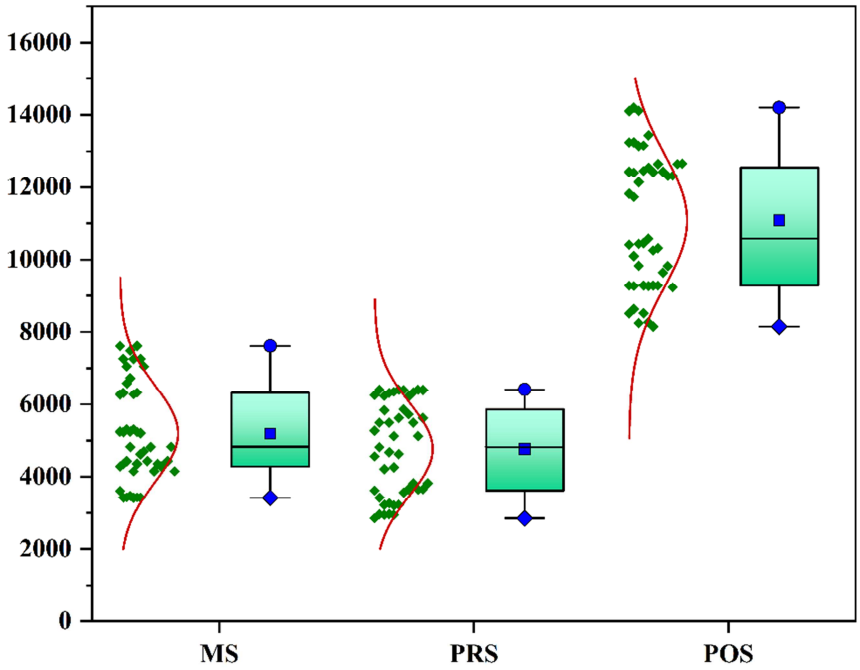


Fig. 4.79

Range of seasonal distribution of sodium (mg/Kg) in the study areas

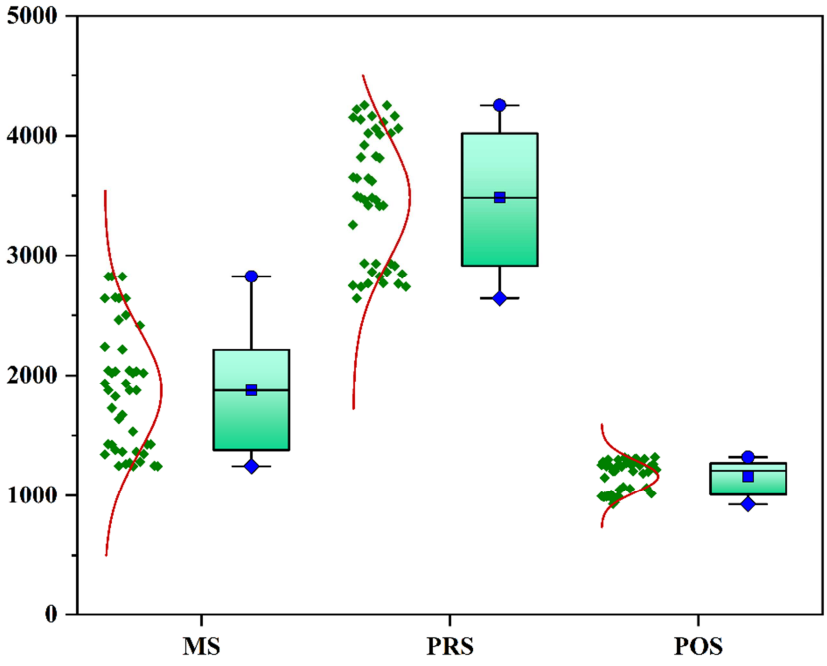


Fig. 4.80

Range of seasonal distribution of calcium (mg/Kg) in the study areas

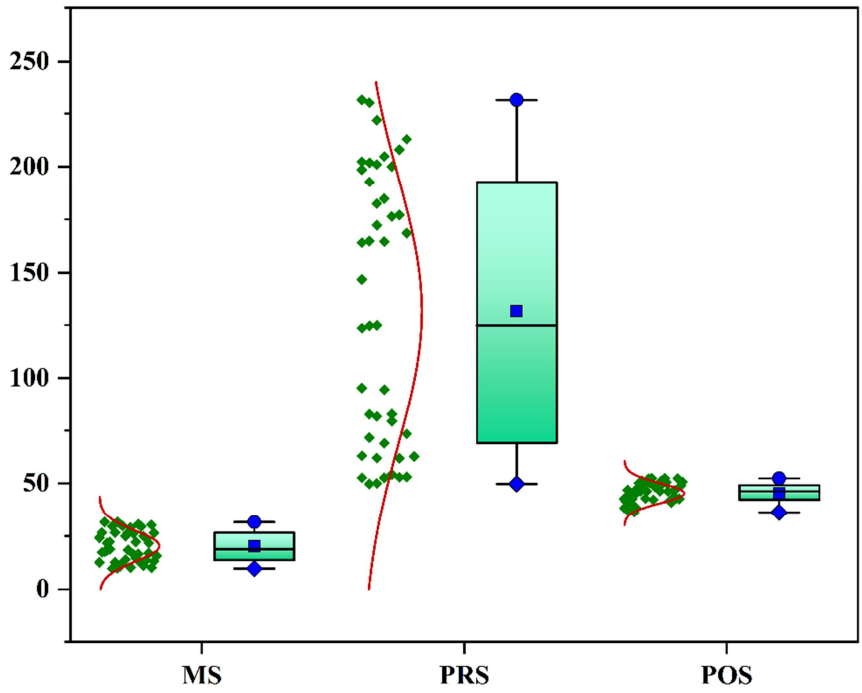


Fig. 4.81

Range of seasonal distribution of magnesium (mg/Kg) in the study areas

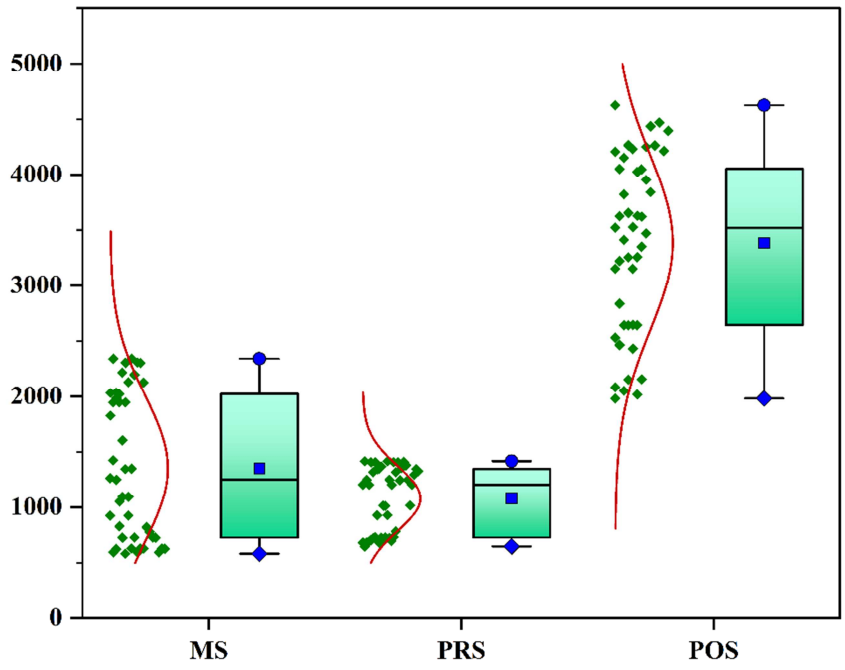


Table 4.31

Summary of ANOVA for the seasonal distribution of pH

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	58.0597	29.02985			
Within groups	132	54.15911	0.4103	70.75339	1.31	p < .05
Total	134	112.21881				

Table 4.32

Summary of ANOVA for the seasonal distribution of salinity (ppt)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	177.88504	88.94252			
Within groups	132	62.35422	0.47238	188.28577	2.18094E-39	p < .05
Total	134	240.23926				

Table 4.33

Summary of ANOVA for the seasonal distribution of electrical conductivity (dS/m)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	6872.38625	3436.19312			
Within groups	132	5915.00786	44.81067	76.68248	7.96959E-23	p < .05
Total	134	12787.39411				

Table 4.34

Summary of ANOVA for the seasonal distribution of organic carbon (%)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	454.20034	227.10017			
Within groups	132	81.6407	0.61849	367.18477	1.17346E-54	p < .05
Total	134	535.84104				

Table 4.35

Summary of ANOVA for the seasonal distribution of total nitrogen (Kg/ha)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	1.01323E7	5066136.53121			
Within groups	132	1.76758E7	133907.19925	37.83319	1.02733E-13	p < .05
Total	134	2.7808E7				

Table 4.36

Summary of ANOVA for the seasonal distribution of total phosphorus (Kg/ha)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	5225087.90348	2612543.95174			
Within groups	132	4207678.42509	31876.35171	81.95869	7.25485E-24	p < .05
Total	134	9432766.32857				

Table 4.37

Summary of ANOVA for the seasonal distribution of potassium (Kg/ha)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	1.12214E9	5.61072E8			
Within groups	132	2.99284E8	2267306.31896	247.46211	2.19627E-45	$p < .05$
Total	134	1.42143E9				

Table 4.38

Summary of ANOVA for the seasonal distribution of sodium (mg/Kg)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	1.27294E8	6.36472E7			
Within groups	132	2.52415E7	191223.45435	332.84218	2.73545E-52	$p < .05$
Total	134	1.52536E8				

Table 4.39

Summary of ANOVA for the seasonal distribution of calcium (mg/Kg)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	307542.44689	153771.22345			
Within groups	132	179619.98037	1360.75743	113.00414	2.51731E-29	$p < .05$
Total	134	487162.42726				

Table 4.40

Summary of ANOVA for the seasonal distribution of magnesium (mg/Kg)

Source of variation	DF	Sum of squares	Mean squares	F-Value	P-Value	Level of significance
Between groups	2	1.42922E8	7.14611E7			
Within groups	132	5.03618E7	381528.615	187.30198	2.81678E-39	p < .05
Total	134	1.93284E8				

4.12.2.1. Pearson Correlation Matrix

Pearson correlation matrix analyses the association of the physico-chemical parameters of the study area to check if there is a relationship between them for the propagation of cyanobacteria that appeared as epipsammic or epipelic. The correlation matrix of the seasonal variations of the physico-chemical characteristics of the soil analysis is represented in Tables 4.41, 4.42, 4.43 and Fig. 4.82,4.83 and 4.84. The strength of the association between the parameters depends on the correlation coefficient values that range from -1 to +1.

The results of the correlation coefficient matrix indicates that in monsoon season, there was a positive correlation between total phosphorus and pH (r= 0.472, p< .01), calcium and organic carbon (r= 0.392, p< .01), magnesium and potassium (r= 0.406, p< .01), potassium and organic carbon (r= 0.300, p< .05), potassium and total nitrogen (r= 0.372, p< .05), calcium and potassium (r= 0.357, p< .05), calcium and sodium (r=0.342, p< .05) and magnesium and calcium(r=0.321, p< .05), whereas negatively correlated with electrical conductivity and salinity (r= -0.321, p< .05), total nitrogen and salinity (r= -0.341, p< .05). There was no correlation with the other parameters, i.e., (p> .05) and the results are represented in Table 4.41 and Fig.4.82.

Table 4.41

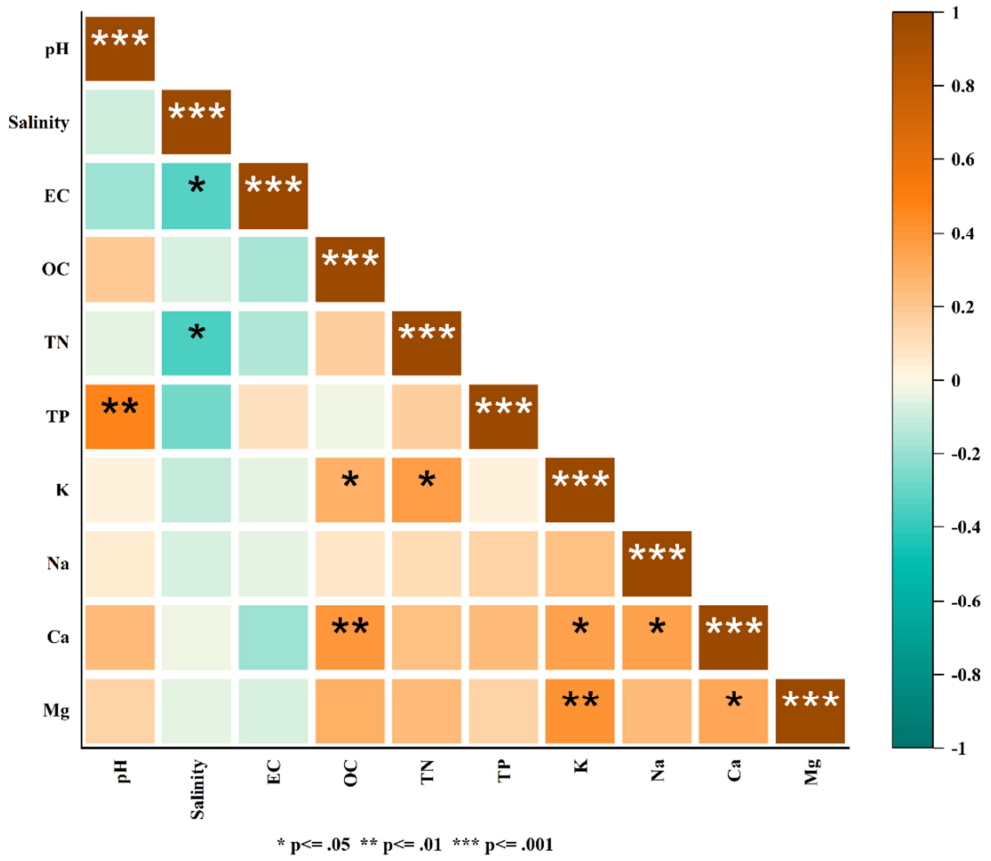
Correlation matrix between the physico-chemical parameters of soil in the study areas during the monsoon season

	pH	Salinity	EC	OC	TN	TP	K	Na	Ca	Mg
pH	1									
Salinity	-0.094	1								
EC	-0.199	**-0.321***	1							
OC	0.195	-0.069	-0.165	1						
TN	-0.059	**-0.341***	-0.143	0.172	1					
TP	**0.472****	-0.275	0.082	-0.021	0.179	1				
K	0.023	-0.109	-0.059	**0.300***	**0.372***	0.023	1			
Na	0.049	-0.070	-0.059	0.071	0.109	0.158	0.232	1		
Ca	0.250	-0.0251	-0.184	**0.395****	0.231	0.257	**0.357****	**0.342***	1	
Mg	0.145	-0.046	-0.079	0.289	0.253	0.159	**0.406***	0.241	**0.321***	1

(*2- tailed test of significance is used; *Correlation is significant at p < .05 level; **Correlation is significant at p < .01 level) (Abbreviations used: EC: Electrical Conductivity; **OC:** Organic Carbon; **TN:** Total Nitrogen; **TP:** Total Phosphorus; **K:** Potassium; **Na:** Sodium; **Ca:** Calcium; **Mg:** Magnesium**)**

Fig. 4.82

Graphical representation of the correlation matrix plot for the estimated physico-chemical parameters of the soil during the monsoon season



(Abbreviations used: EC: Electrical Conductivity; **OC:** Organic Carbon; **TN:** Total Nitrogen; **TP:** Total Phosphorus; **K:** Potassium; **Na:** Sodium; **Ca:** Calcium; **Mg:** Magnesium**)**

In pre-monsoon season, there was a positive correlation between total nitrogen and organic carbon (r= 0.295, p< .05), calcium and total phosphorus (r= 0.370, p< .05) and calcium and potassium (r= 0.315, p< .05), whereas negatively correlated with total phosphorus and electrical conductivity (r= -0.354, p< .05), There was no correlation with the other parameters, i.e., (p> .05) and the results are depicted in Table 4.42 and Fig. 4.83.

Table 4.42

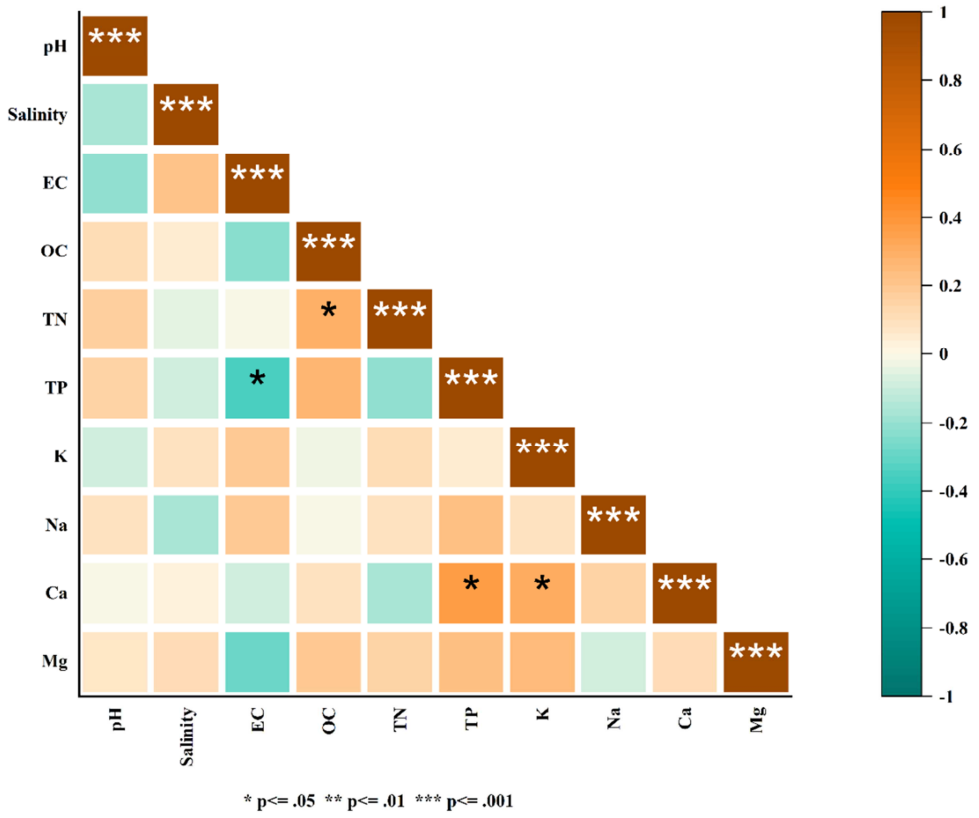
Correlation matrix between the physico-chemical parameters of soil in the study areas during the pre-monsoon season

	pH	Salinity	EC	OC	TN	TP	K	Na	Ca	Mg
pH	1									
Salinity	-0.161	1								
EC	-0.211	0.204	1							
OC	0.115	0.0534	-0.234	1						
TN	0.171	-0.055	-0.012	**0.295***	1					
TP	0.160	-0.095	**-0.354***	0.270	-0.217	1				
K	-0.099	0.082	0.186	-0.023	0.115	0.045	1			
Na	0.099	-0.165	0.197	-0.014	0.091	0.230	0.098	1		
Ca	-0.001	0.022	-0.085	0.097	-0.177	**0.370***	**0.315***	0.146	1	
Mg	0.061	0.105	-0.288	0.191	0.157	0.237	0.257	-0.094	0.120	1

(*2- tailed test of significance is used; *Correlation is significant at p < .05 level) (Abbreviations used: EC: Electrical Conductivity; **OC:** Organic Carbon; **TN:** Total Nitrogen; **TP:** Total Phosphorus; **K:** Potassium; **Na:** Sodium; **Ca:** Calcium; **Mg:** Magnesium**)**

Fig. 4.83

Graphical representation of the correlation matrix plot for the estimated physico-chemical parameters of the soil during the pre-monsoon season



(Abbreviations used: EC: Electrical Conductivity; **OC:** Organic Carbon; **TN:** Total Nitrogen; **TP:** Total Phosphorus; **K:** Potassium; **Na:** Sodium; **Ca:** Calcium; **Mg:** Magnesium**)**

In post-monsoon season, there was a positive correlation between magnesium and calcium (r= 0.510, p< .001), calcium and sodium (r= 0.432, p< .01), calcium and total nitrogen (r= 0.328, p< .05), calcium and electrical conductivity (r= 0.305, p< .05), sodium and total phosphorus (r= 0.332, p< .05) and total phosphorus and total nitrogen (r= 0.317, p< .05), whereas there was a negative association between organic carbon and salinity (r= -0.349, p< .05). There was no correlation with the other parameters, i.e., (p> .05) and the results are depicted in Table 4.43 and Fig. 4.84.

Table 4.43

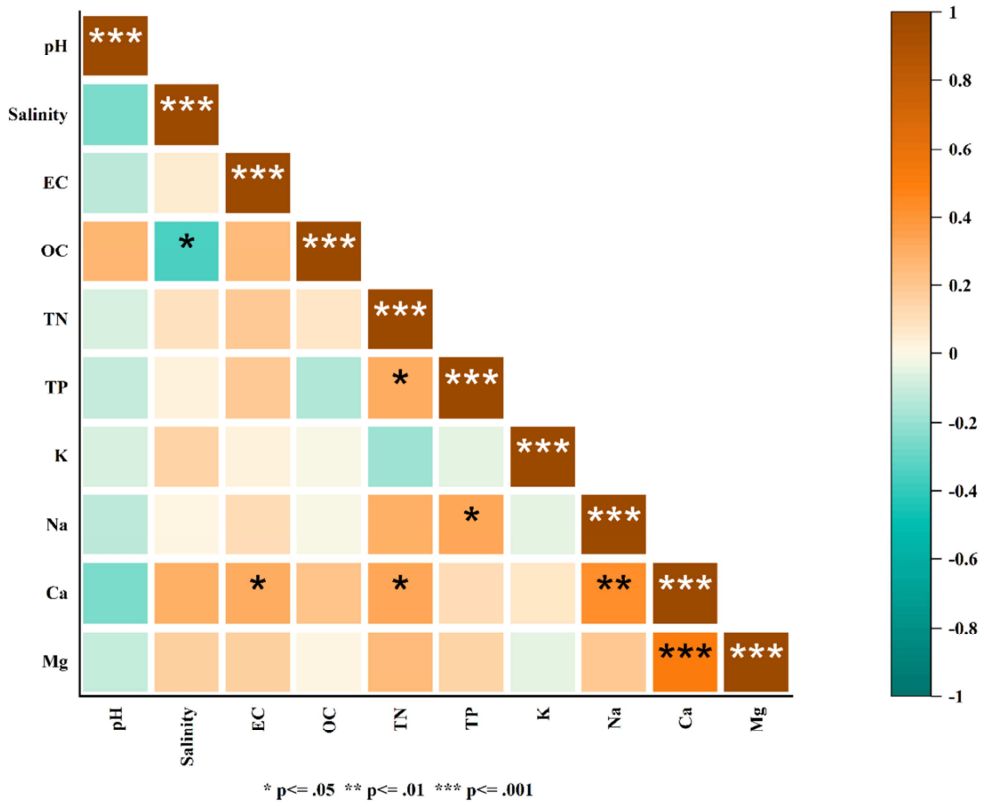
Correlation matrix between the physico-chemical parameters of soil in the study areas during the post-monsoon season

	pH	Salinity	EC	OC	TN	TP	K	Na	Ca	Mg
pH	1									
Salinity	-0.242	1								
EC	-0.132	0.055	1							
OC	0.273	**-0.349***	0.246	1						
TN	-0.071	0.092	0.192	0.067	1					
TP	-0.104	0.033	0.194	-0.147	**0.317***	1				
K	-0.067	0.149	0.022	-0.014	-0.195	-0.043	1			
Na	-0.135	0.001	0.102	-0.005	0.281	**0.332***	-0.054	1		
Ca	-0.241	0.290	**0.305***	0.201	**0.328***	0.104	0.065	**0.432****	1	
Mg	-0.116	0.176	0.176	0.014	0.255	0.146	-0.050	0.196	**0.510*****	1

(*2- tailed test of significance is used; *Correlation is significant at p < .05 level; **Correlation is significant at p < .01 level; ***Correlation is significant at p < .001 level; Abbreviations used: EC: Electrical Conductivity; **OC:** Organic Carbon; **TN:** Total Nitrogen; **TP:** Total Phosphorus; **K:** Potassium; **Na:** Sodium; **Ca:** Calcium; **Mg:** Magnesium**)**

Fig. 4.84

Graphical representation of the correlation matrix plot for the estimated physico-chemical parameters of the soil during the post-monsoon season



(Abbreviations used: EC: Electrical Conductivity; **OC:** Organic Carbon; **TN:** Total Nitrogen; **TP:** Total Phosphorus; **K:** Potassium; **Na:** Sodium; **Ca:** Calcium; **Mg:** Magnesium**)**

4.12.2.2. Multivariate Statistical Analysis

Principal Component Analysis (PCA), Canonical Correspondence Analysis (CCA) and JASP network analysis were employed to find out the relation of soil physico-chemical parameters to the cyanobacterial diversity. The results of the PCA were carried out in two main components, PC1 and PC2, representing 37.7% and 21.5% respectively.

Based on the eigenvalues scree plot, the 10 physico-chemical parameters were reduced to two main principal component factors PC1 and PC2. The largest eigenvalue corresponds to 3.77154 which accounts for 37.7% of the total variance. It

is comprised of the water parameters such as calcium, organic carbon and salinity. The second component, PC2 corresponds to the eigenvalue 2.14966 which accounts for 21.5% of the total variance with total nitrogen, potassium, magnesium, electrical conductivity and total phosphorus. The remaining principal components have eigenvalues of less than unity. Eigenvalues and percentage of cumulative variances are shown in Table 4.44, 4.45 and Figure 4.85 represents the respective eigenvectors. The biplot of the PC1 and PC2 showed calcium, organic carbon, salinity, total nitrogen, potassium, magnesium, electrical conductivity and total phosphorus during the post-monsoon season. During the monsoon season, pH had a high correlation. During the pre-monsoon season, sodium had a close association with soil parameters (Fig. 4.86).

Table 4.44

Representation of principal component number, eigenvalue, percentage of cumulative variance.

Principal Component Number	Eigenvalue	Percentage of Variance (%)	Cumulative (%)
1	3.77154	37.72%	37.72%
2	2.14966	21.50%	59.21%
3	1.12163	11.22%	70.43%
4	0.98681	9.87%	80.30%
5	0.63379	6.34%	86.63%
6	0.58238	5.82%	92.46%
7	0.29959	3.00%	95.45%
8	0.21524	2.15%	97.61%
9	0.17587	1.76%	99.37%
10	0.06348	0.63%	100.00%

Fig. 4.85

Scree plot of principal component analysis based on eigenvalue

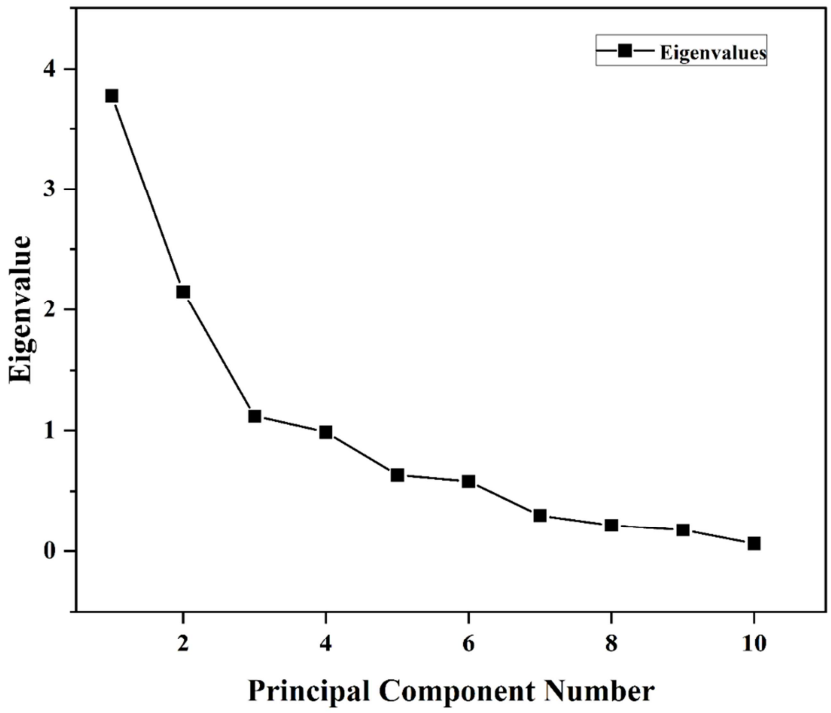


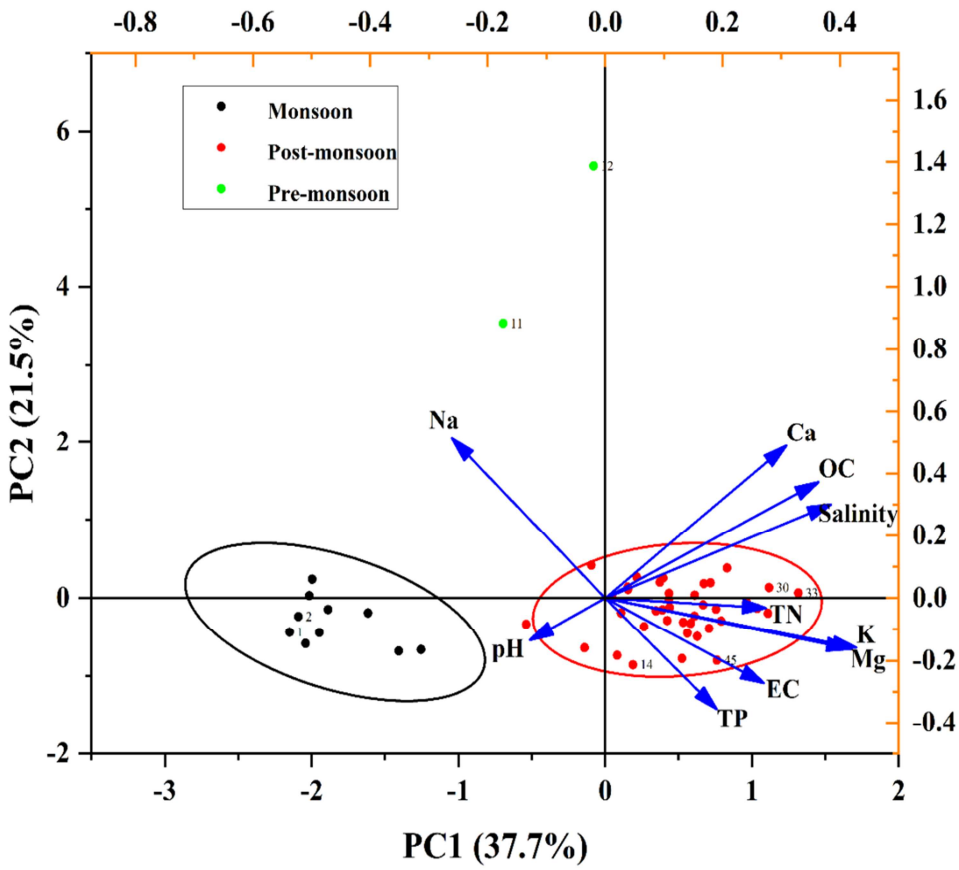
Table 4.45

Eigenvectors of principal components

	PC1	PC2	PC3	PC4
pH	-0.12834	-0.13434	0.77046	-0.44167
Salinity	0.38451	0.30012	-0.271	-0.02483
EC	0.27042	-0.27201	-0.30322	-0.21366
OC	0.36315	0.37179	0.19953	-0.21781
TN	0.27343	-0.03108	0.31633	0.57472
TP	0.18984	-0.35533	0.2077	0.51511
K	0.42759	-0.15827	-0.00377	-0.25922
Na	-0.26093	0.51155	0.08791	0.21626
Ca	0.30853	0.48907	0.17996	0.03449
Mg	0.41684	-0.16286	0.13369	-0.02055

Fig. 4.86

Bi-plot ordination of the principal component analysis showing correlation

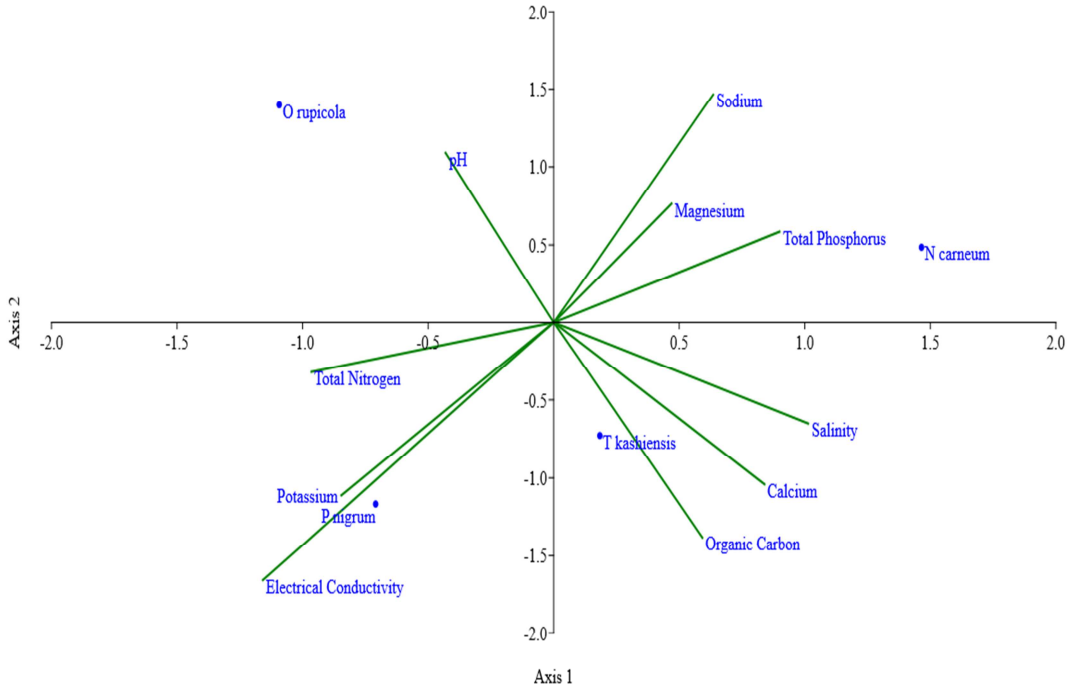


4.12.2.2.1. Canonical Correspondence Analysis (CCA)

The canonical correspondence analysis revealed a statistically significant influence of physico-chemical parameters of soil on the cyanobacterial species diversity. A detailed analysis of seasonal variation between cyanobacterial diversity and physico-chemical parameters of soil has been represented in Fig. 4.87, 4.88, and 4.89.

Fig. 4.87

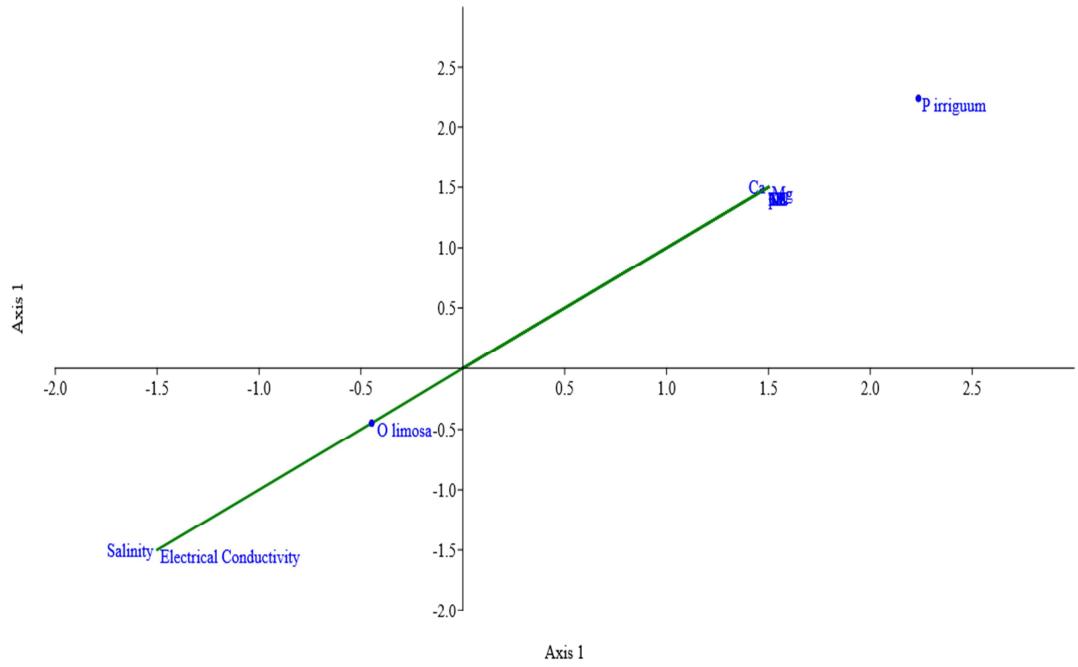
Canonical correspondence analysis (CCA) plot showing the effect of physico-chemical parameters of soil with the cyanobacterial diversity during the monsoon season



In the CCA plot of monsoon season (Fig.4.87), the first axis explained the distribution of *Nostoc carneum* was mainly influenced by sodium, magnesium and total phosphorus. The second axis explained the distribution of *Trichormus kashiensis* was greatly influenced by calcium, salinity and organic carbon. The third axis in the CCA plot explained the distribution of *Phormidium nigrum* was influenced by potassium total nitrogen and electrical conductivity. The fourth axis represents the total pH that was influenced by the distribution of *Oscillatoria rupicola.* The outcome of the CCA plot proved that the main physico-chemical parameters that were influencing the distribution and abundance of cyanobacteria were sodium, magnesium, total phosphorus, salinity, calcium and organic carbon.

Fig. 4.88

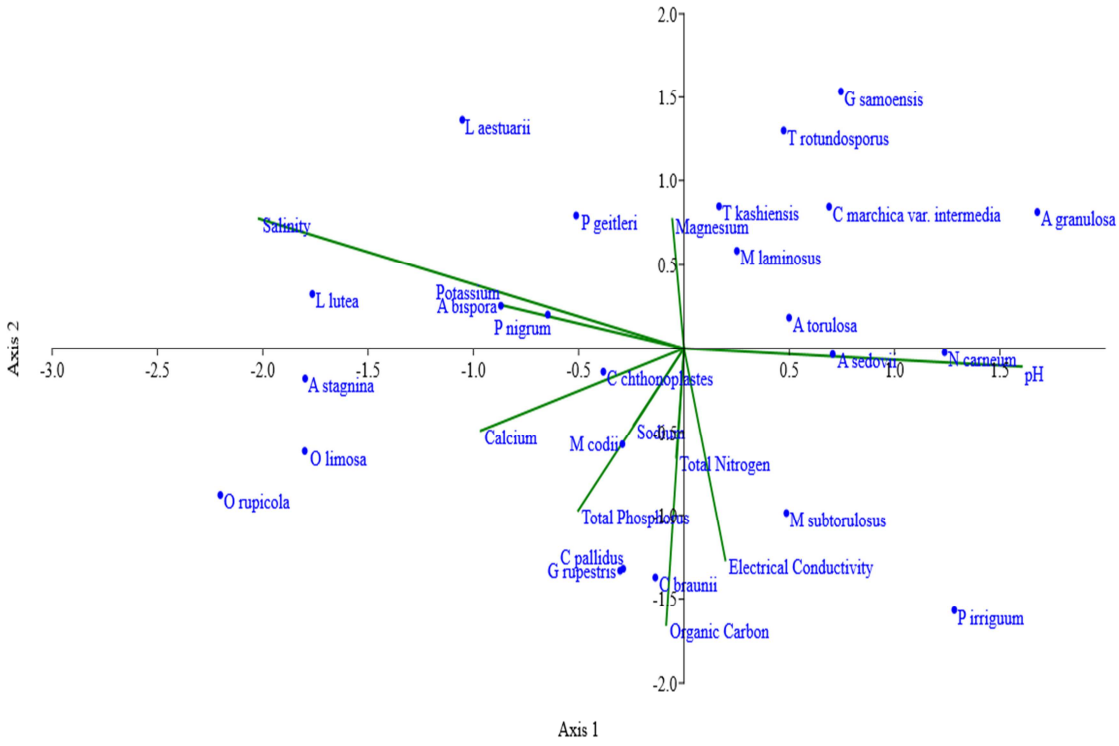
Canonical correspondence analysis (CCA) plot showing the effect of physico-chemical parameters of soil with the cyanobacterial diversity during the pre-monsoon season



In the CCA plot of the pre-monsoon season (Fig.4.88) the first axis explained the distribution of the cyanobacterium, *Phormidium irriguum* was influenced by calcium, magnesium, sodium, potassium, total phosphorus and organic carbon. The third axis explained the influence of salinity and electrical conductivity on the distribution of *Oscillatoria limosa*. The outcome of the CCA plot proved that the main physico-chemical parameters that were influencing the distribution and abundance of cyanobacteria were calcium, magnesium, sodium, potassium, total phosphorus and organic carbon.

Fig. 4.89

Canonical correspondence analysis (CCA) plot showing the effect of physico-chemical parameters of soil with the cyanobacterial diversity during the post-monsoon season



In the CCA plot of the post-monsoon season (Fig.4.89) the first axis explained distribution of cyanobacterial species like *Gloeothece samoensis, Trichormus rotundosporus, Trichormus kashiensis, Mastigocladus laminosus, Calothrix marchica var.intermedia, Aphanothece granulosa* and *Anabaena torulosa*. The second axis exhibits pH electrical conductivity and total nitrogen had a significant influence on the distribution of *Nostoc carneum, Anabaena sedovii, Microcoleus subtorulosus and Phormidium irriguum.* The third axis explained the influence of organic carbon, total phosphorus, sodium and calcium on the distribution of cyanobacterial species like *Calothrix braunii, Chroococcus pallidus, Gleoethece rupestris, Microcoleus codii, Coleofasciculus chthonoplastes, Aphanothece stagnina*, *Oscillatoria limosa* and *Oscillatoria rupicola*. The fourth axis connoted the influence of magnesium, salinity and potassium on the distribution of *Lyngbya aestuarii*, *Anabaena bispora* and *Planktothrix geitleri*. The outcome of

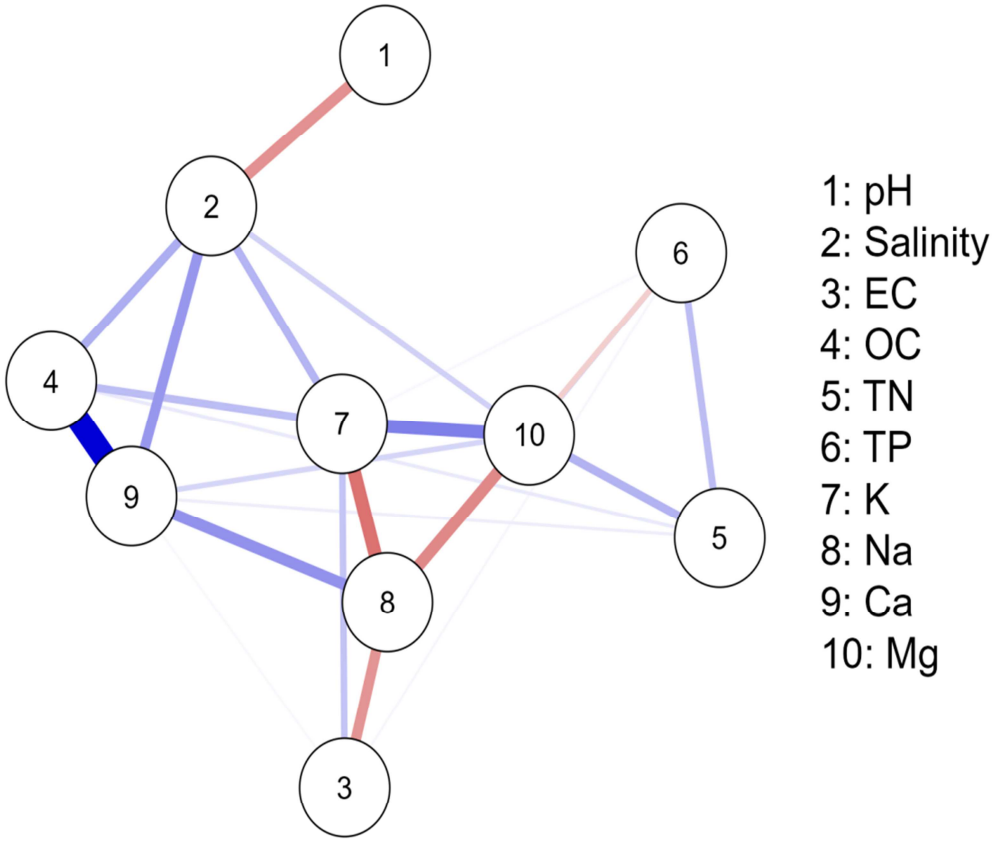
the CCA plot proved that the main physico-chemical parameters that were influencing the distribution and abundance of cyanobacteria were pH, electrical conductivity and total nitrogen.

4.12.2.2.2. JASP Network Analysis

JASP network plot for correlation of cyanobacterial species abundance and physico-chemical parameters of soil revealed that all variables are interrelated in the strength of those relationships (Fig. 4.90).

Fig. 4.90

JASP network plot for correlation of species abundance and environmental variables in the study areas.



(Abbreviations used: EC: Electrical Conductivity; **OC:** Organic Carbon; **TN:** Total Nitrogen; **TP:** Total Phosphorus; **K:** Potassium; **Na:** Sodium; **Ca:** Calcium; **Mg:** Magnesium**)**

The thickness of the blue and red lines determines the strength of the relationships. The blue lines determine the positive correlation while the red lines determine the negative correlation. There was a strong positive correlation between the nodes, 4 and 9 i.e., organic carbon and calcium. There was a weaker association between potassium and magnesium, sodium and calcium, salinity and calcium, salinity and organic carbon, total nitrogen and magnesium and total nitrogen and total phosphorus. There was a strong negative relationship between nodes 7 and 8, i.e., potassium and sodium and also had a weaker negative correlation between the nodes, pH and salinity, sodium and magnesium and electrical conductivity and sodium.

Chapter 5

SUMMARY AND CONCLUSION

The present investigation was carried out on the exploration of mangrove-associated cyanobacterial diversity in southern Kerala, India. This study is so important not only within the scope of science but also for human welfare. The study summarises a particular group of microorganisms, cyanobacteria, in a particular time and space. It provides primary information regarding cyanobacterial diversity and environmental monitoring or for applied ecological research, and the study can also act as a reliable baseline data for future studies, particularly in this research field.

According to the available review of literature, a consolidated list of mangrove-associated cyanobacteria revealed that a total of 409 species have been reported all over the world. In this study, a total of 89 cyanobacterial species were collected from the mangrove-associated cyanobacteria of southern Kerala. Therefore, this study occupies 21.76% of cyanobacterial diversity from the most neglected study areas like mangroves.

A total of ten study areas were selected for cyanobacterial exploration and ecological monitoring. The main objectives of the present investigation were to evaluate the qualitative and quantitative distribution of mangrove-associated cyanobacterial diversity and their ecological characteristics. This investigation presents a detailed account of the distribution of cyanobacteria in the mangrove environments in southern Kerala, analyses the spatiotemporal variations in the nutrients of the sampling sites and evaluates the effect of physico-chemical parameters on the cyanobacterial distribution and abundance. The identification of cyanobacterial taxa up to the species level was carried out with the help of keys and descriptions.

The important findings derived from the present investigation are depicted below:

The present study considered an exclusive study on the diversity, distribution and taxonomy of mangrove-associated cyanobacteria. A total of 89 mangrove-associated cyanobacterial species were found during the period of study. The dominant order was Oscillatoriales with 38 species (2 Coleofasciculaceae, 12 Microcoleaceae and 24 Oscillatoriaceae) followed by Nostocales with 37 species (4 Hapalosiphonaceae, 20 Nostocaceae, 1 Rivulariaceae, 7 Scytonemataceae and 1 Stigonemataceae), Chroococcales was the third dominant order represented with 8 species (3 Aphanothecaceae and 5 Chroococcaceae), Synechococcales was represented with 3 species (1 Merismopediaceae, 1 Synechococcaceae and 1 Trichocoleusaceae), Spirulinales represented 3 species (3 Sprirulinaceae).non-heterocytous forms of cyanobacteria were more prevalent (42 species) in the mangrove habitat followed by heterocytous (37 species) and unicellular forms (10 species).

Cyanobacterial diversity was more prevalent in natural vegetation like Kumbalam, Vypin and Ayiramthengu whereas low diversity was found in the discrete or patchy mangrove vegetation. Also, mangroves residing in natural habitats, anthropogenic and fish farming would affect the mangrove vegetation, thereby cyanobacterial diversity. Moreover, the majority of mangrove vegetation is under private ownership, and this would be considered and protected lawfully for the welfare of local livelihoods and the planet.

It is also observed that cyanobacterial diversity was highest during the post-monsoon season, whereas the least diversity was found during the pre-monsoon season. High tide is a common phenomenon called Vrishchikam veliyettam or spring tide (between November and February) during the post-monsoon season. Sea level rise could also have contributed to this condition. In the evening, the coastal areas are flooded and the water recedes slightly in the morning and completely subsides in the afternoon. At this time, the majority of species were washed into the mangrove ecosystem from the adjacent areas including open ocean, freshwater and estuarine environments. But in the evening neap tides again formed and this process continued. This may also be the reason the cyanobacterial diversity was more prevalent in the post-monsoon season, moreover, the time for sample collection is of utmost importance.

The present study reports the new records or new additions to the cyanobacterial flora of India. Of the 89 cyanobacterial species recorded, the following 44 species were new records to the cyanobacterial flora of India:

1) *Aphanothece bullosa* (Meneghini) Rabenhorst 1865
2) *Aphanothece granulosa* (N.L.Gardner) Komárek & Komákova-Legnerova 2007
3) *Gloeothece samoensis* Wille 1913
4) *Gloeothece ustulata* Beck-Mannagetta 1929
5) *Aphanocapsa grevillei* (Berkeley) Rabenhorst 1865
6) *Anathece bacteriosa* (Komarek & Komarkova-Legnrova) Komarek, Kastovsky & Jezberova 2011
7) *Trichocoleus delicatulus* (West & G.S.West) Anagnostidis 2001
8) *Spirulina spirulinoides* (Ghose) Geitler 1925
9) *Anagnostidinema pseudacutissimum* (Geitler) Strunecky, Bohunicka, Johansen et Komarek, 2017
10) *Microcoleus autumnalis* (Trevisan ex Gomont) Strunecky, Komarek et J.R.Johansen 2013
11) *Microcoleus codii* Fremy 1932
12) *Microcoleus subtorulosus* Gomont ex Gomont 1892
13) *Planktothrix geitleri* (Kisselev) Anangnostidis et Komarek 1998
14) *Planktothrix isothrix* (Skuja) Komarek & Komarkova 2004
15) *Planktothrix suspensa* (Pringsheim) Anagnostidis et Komarek 1988
16) *Porphyrosiphon ceylanicus* (Wille) Anagnostidis & Komarek 1988
17) *Lyngbya truncicola* Ghose 1924
18) *Oscillatoria curviceps* var. *angusta* Ghose 1927
19) *Oscillatoria major* Vaucher ex Forti 1907

20) *Oscillatoria obtusa* N.L.Gardner 1927

21) *Oscillatoria princeps* var. *pseudolimosa* Ghose 1924

22) *Oscillatoria rupicola* (Hansgirg) Hansgirg ex Forti 1907

23) *Oscillatoria simplicissima* Gomont 1892

24) Phormidium crassior (Behre) Anagnostidis 2001

25) Phormidium nigrum (Vaucher ex Gomont) Anagnostidis & Komarek 1988

26) *Calothrix braunii* Bornet et Flahault 1886

27) *Calothrix marchica* Lemmerman 1914

28) *Calothrix marchica* var. *intermedia* C.B.Rao 1937

29) *Calothrix nidulans* Setchell & N.L.Gardner 1924

30) *Mastigocladus laminosus* Cohn ex Kirchner 1898

31) *Westiellopsis prolifica* Janet 1941

32) Westiellopsis interrupta Kanthamma 1972

33) *Anabaena bispora* Gayral & Mazancourt 1958

34) *Anabaena laxa* A.Braun 1886

35) *Anabaena sedovii* Kossinskaja 1933

36) *Nostoc bornetii* Gain 1911

37) *Nostoc calcicola* Brebisson ex Bornet et Flahault 1886

38) *Nostoc sphaericum* Vaucher ex Bornet et Flahault 1886

39) *Nostoc spongiaeforme* var. *varians* C.B.Rao 1937

40) *Trichormus kashiensis* (Bharadwaja) Komarek 2012

41) *Trichormus pseudovariabilis* (Woronichin) Komarek et Anagnostidis 1989

42) *Trichormus rotundosporus* (Hollerbach) Komarek & Anagnostidis 1989

43) *Dichothrix orsiniana* (Kutz) Bornet et Flahault 1886, *Scytonema millei* Bornet ex Bornet & Flahault 1886

44) *Stigonema ocellatum* (Dillwyn) Thuret ex Bornet & Flahault 1886

The following 29 species were recorded as new records or new additions to the mangrove-associated cyanobacterial flora of Kerala:

1) *Spirulina major* Kutzing ex Gomont 1892
2) *Microcoleus lacustris* Farlow ex Gomont 1892
3) *Microcoleus paludosus* Gomont ex Gomont 1892
4) *Limnoraphis hieronymusii* (Lemmermann) J.Komarek, E.Zapomelova, J.Smarda, J.Kopecky, E.Rejmankova, J.Woodhouse, B.A.Neilan & J.Komarkova 2013
5) *Lyngbya aestuarii* Liebman ex Gomont 1892
6) *Lyngbya lutea* Gomont ex Gomont 1892
7) *Oscillatoria curviceps* C.Agardh ex Gomont 1892
8) *Oscillatoria limosa* Agardh ex Gomont 1892
9) *Oscillatoria perornata* Skuja 1949
10) *Oscillatoria princeps* Vaucher ex Gomont 1892
11) *Oscillatoria sancta* Kutzing ex Gomont 1892
12) *Oscillatoria subbrevis* Schmidle 1901
13) *Oscillatoria vizagapatensis* C.B.Rao 1938
14) *Phormidium nigro-viride* (Thwaites ex Gomont) Anagnostidis & Komarek 1988
15) *Hapalosiphon welwitschii* West & G.S.West 1897
16) *Anabaena torulosa* (Carmichael) Lagerheim ex Bornet et Flahault 1886
17) *Desmonostoc muscorum* (C.Agardh ex Bornet & Flahault) Hrouzek et Ventura 2013
18) *Nostoc carneum* (Lyngbye) Agardh ex Bornet et Flahault 1886
19) *Nostoc commune* Vaucher ex Bornet et Flahault 1888

20) *Nostoc ellipsosporum* (Demazieres) Rabenhort ex Bornet et Flahault 1886

21) *Nostoc linckia* (Roth) Bornet et Flahault 1886

22) *Nostoc sphaericum* Vaucher ex Bornet et Flahault 1886

23) *Trichormus ellipsosporus* (Fritsch) Komarek et Anagnostidis 1989

24) *Trichormus variabilis* (Kutzing ex Bornet et Flahault) Komarek et Anagnostidis 1989

25) *Scytonema bohneri* Schmidle 1901

26) *Scytonema coactile* Montagne ex Bornet et Flahault 1886

27) *Scytonema javanicum* Bornet ex Bornet & Flahault 1886

28) *Scytonema tolypothrichoides* Kützing ex Bornet & Flahault 1886

29) *Scytonema varium* Kutzing ex Bornet et Flahault 1886

Among 89 cyanobacterial species, 16 epiphytic, 14 planktic, 11 epipsammic/epipelic, 12 co-occur in benthic and planktic, 10 co-occur in epiphytic and planktic, 7 co-occur in epipsammic/epipelic and planktic, 3 co-occur in epiphytic, epipsammic/epipelic and planktic, 2 co-occur in benthic and corticolous, benthic and epiphytic and benthic, epipsammic/epipelic and planktic, every 1 species co-occur in corticolous, benthic and epipsammic/epipelic, corticolous and planktic, benthic, epiphytic, epipsammic/epipelic and planktic and epiphytic and epipsammic habitats.

Alpha-diversity indices represented that the study area, Kumbalam, showed a high degree of cyanobacterial diversity. Beta diversity analysis showed that the sampling sites Kumbalam (S9) and Vypin (S10) are observed in the same cluster at 32% similarity, S6 and S8 have 38% similarity, whereas S5 and S1 are observed at 28% similarity. The non-metric multidimensional scaling **(**NMDS) plot explained the study area, Ayiramthengu, Sakthikulangara, Kumbalam and Vypin showed a good representation of cyanobacterial species distribution, while the other sampling sites showed a poor representation of cyanobacterial species composition. Principal coordinates analysis (PCoA) explained the sampling sites Ayiramthengu, Sakthikulangara, Kumbalam and Vypin indicated that these sampling sites have

similar species composition whereas the other sampling sites have poor representation of species composition.

The physico-chemical characteristics of water such as temperature, pH, salinity, dissolved oxygen, electrical conductivity, total dissolved solids, total alkalinity, total phosphorus, total nitrogen, potassium, calcium, magnesium and sodium were analysed and compared with the cyanobacterial diversity. ANOVA, Pearson correlation coefficient matrix, principal component analysis (PCA), canonical correspondence analysis (CCA), and JASP network analysis were used to correlate the physico-chemical parameters of water with the cyanobacterial diversity.

The PCA plot showed that there was a strong influence on dissolved oxygen, pH, salinity, magnesium and temperature had a strong influence during the pre-monsoon season; potassium, total nitrogen and total phosphorus during the monsoon season; electrical conductivity, TDS and calcium during the post-monsoon season. The CCA plot of the monsoon season explained that the physico-chemical parameters that were influencing the distribution and abundance of cyanobacteria were temperature, total dissolved solids, dissolved oxygen, electrical conductivity, total phosphorus, calcium, and sodium and pH. The CCA plot of the pre-monsoon season indicated that the main physico-chemical parameters that were influencing the distribution and abundance of cyanobacteria were calcium, electrical conductivity, dissolved oxygen, magnesium, potassium, pH and temperature. The CCA plot of the post-monsoon season proved that the physico-chemical parameters that were influencing the distribution and abundance of cyanobacteria were total dissolved solids, pH, calcium, salinity, sodium, total phosphorus and dissolved oxygen. JASP network analysis exhibited that there was a strong positive correlation between pH and salinity, total nitrogen and total phosphorus, temperature and magnesium and a strong negative relationship between calcium and total phosphorus.

Soil physico-chemical characteristics such as pH, salinity, electrical conductivity, organic carbon, total nitrogen, total phosphorus, potassium, sodium, calcium and magnesium were analysed and compared with the cyanobacterial

diversity. ANOVA, Pearson correlation coefficient matrix, principal component analysis (PCA), canonical correspondence analysis (CCA), and JASP network analysis were used to correlate the physico-chemical parameters of soil with the cyanobacterial diversity. The PCA plot indicated that there was a strong correlation with calcium, organic carbon, salinity, total nitrogen, potassium, magnesium, electrical conductivity and total phosphorus during the post-monsoon season; pH during the monsoon season; and sodium during the pre-monsoon season. The CCA plot of monsoon season exhibited that the physico-chemical parameters that were influencing the distribution and abundance of cyanobacteria were sodium, magnesium, total phosphorus, salinity, calcium and organic carbon. The CCA plot of the pre-monsoon season indicated that the physico-chemical parameters that were influencing the distribution and abundance of cyanobacteria were calcium, magnesium, sodium, potassium, total phosphorus and organic carbon. The CCA plot of the post-monsoon season explained that the physico-chemical parameters that were influencing the distribution and abundance of cyanobacteria were pH, electrical conductivity and total nitrogen. JASP network plot explained that there was a strong positive correlation between organic carbon and calcium and a strong negative relationship between potassium and sodium.

Chapter 6

RECOMMENDATIONS

Although much research has been done on the biodiversity, taxonomy and ecological monitoring of mangrove forests, we still have little knowledge of the cyanobacteria in mangrove environments, their taxonomy, and their ecological significance. The present investigation would be served as baseline data for future studies in the cyanobacterial diversity and taxonomy. This research also helps in the understanding of geographical distribution and habitat types, which will be helpful in further study on the exploration of these microorganisms and environmental monitoring.

Since cyanobacteria play an important ecological role, their biodiversity needs to be properly studied, conserved and managed effectively in the context of current climate change situations. To remove the uncertainty in the taxonomic identification of cyanobacteria, researchers should apply a polyphasic approach (morphological, ecological, ultrastructural and molecular aspects) to the discovery of new cyanobacterial species around the world.

It can be assumed that over the next decade, the studies on cyanobacterial diversity carried out at the state level will be sufficient to cover about 90% of the flora present in that area. During this period studies need to be started or increased using the data generated by the knowledge of the biodiversity. Research works dealing with aspects of the phylogeny of specific groups should be progressively increased and will incorporate modern study techniques. In addition, books on the biodiversity of cyanobacteria in mangrove environments are to be published.

Due to the particular properties of some cyanobacteria, prospecting for products produced by these organisms such as carbohydrates, oils and proteins can be expected to be quite desirable and promising initiatives. They can produce substances of biotechnological interest and with relevant potential biological activity, such as antitumor products, anticholinesterases and antifungals. As a result

of these efforts, the characterization and manufacturing of interest compounds must be several research areas with good prospects in the long-term future.

The research provides an overall picture of cyanobacterial diversity in the mangrove ecosystem. In light of the present study, it is recommended that the following research be conducted without any limitations.

1) Diversity and ecology of cyanobacteria in mangrove environments of northern Kerala, India.
2) Spatiotemporal variation of mangrove-associated cyanobacterial diversity in Kerala, India and their conservation
3) Biodiversity documentation and assessment of mangrove-associated cyanobacteria using GIS-based tools
4) Multivariate analysis to determine the ecological preference for the diversity and distribution of mangrove-associated cyanobacteria of Kerala, India
5) Monitoring and assessment of water and soil quality parameters on the diversity and distribution of cyanobacteria in mangrove ecosystems along Kerala coast: A statistical approach
6) Development of a simple, efficient and rapid in vitro culture protocol for the isolation and purification of mangrove-associated cyanobacteria of Kerala, India
7) Morphological and phylogenetic analysis of the cyanobacterium *Scytonema* sp. (Scytonemataceae) from epiphytic habitats of the mangrove environments of Kerala, India
8) Polyphasic analysis of mangrove-associated cyanobacteria along the Kerala coast, India
9) Phylogenetic analysis of culturable cyanobacteria from the Kerala mangroves
10) Polyphasic assessment of benthic mat-forming cyanobacteria isolated from the mangrove environments of Kerala, India

Creating a database for information regarding mangrove-associated cyanobacteria, their taxonomy and conservation strategies will be an asset to the biodiversity researchers of the world. It will help to get an idea regarding the species richness of cyanobacteria in a particular locality.

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APPENDICES

Appendix 1
Format of Field Book

Collection No.	**:**	
Date	**:**	
Locality	**:**	
Microphotograph No.	**:**	
Culture No.	**:**	
Field observations	**:**	
Habitat	**:**	Planktic/ Benthic/ Epiphytic/ Epipsammic/ Corticolous
Specimen colour	**:**	
Specimen type	**:**	Gelly-like/ mat-like/ hair-like structure
Microscopic observations	**:**	
Thallus organisation	**:**	Unicellular/ Branched/Unbranched/ Heterocyotus/ Non-Heterocytous
Thallus colour	**:**	
Cell size (µm)	**:**	
Cell colour	**:**	
Cell shape	**:**	
Heterocytes shape	**:**	
Heterocytes colour	**:**	
Heterocytes size (µm)	**:**	
Notes		
	:	

Appendix 2
List of Publications

2.1. Arun T. Ram & Tessy Paul P. (2021 a). Revised and an updated checklist of cyanobacteria in mangrove environments: Chroococcales, Chroococcidiopsidales, Gloeobacterales and Synechococcales. *Species, 22*(70), 364-387. **(ISSN: 2319-5746).** http://www.discoveryjournals.org/Species/ current_issue/2021/ v22/n70/A25.pdf

2.2. Arun T. Ram & Tessy Paul P. (2021 b). Morpho-taxonomic identification of mangrove-associated coccoid cyanobacteria from the southwest coast of India. *International Journal of Botany Studies*, *6*(6), 836-840. **(ISSN: 2455-541X)**

https://www.botanyjournals.com/archives/2021/vol6/issue6/6-6-111

2.3. Arun T. Ram & Tessy Paul P. (2021 c). A review on the distribution records of mangrove-associated heterocytous cyanobacteria: an update. *Egyptian Journal of Phycology*, *22*(1), 119-136. **(ISSN: 1110-8649).** https://dx.doi.org/10.21608/egyjs.2021.102836.1008

2.4. Arun T. Ram & Tessy Paul P. (2021 d). Updated Checklist of Mangrove-Associated Cyanobacterial Diversity to the End of 2020. *International Journal on Algae*, *23*(4), 341-358. **(ISSN: 1940-4328)** https://dx.doi.org/10.1615/InterJAlgae.v23.i4.30

2.5. Arun T. Ram & Tessy Paul P. (2021 e). New Records and Distribution Pattern of Mangrove – Associated Cyanobacteria of South West Coast of India. *Indian Journal of Geo-Marine Sciences, 50*(12), 1018-1028. **(ISSN: 2582-6727).** http://nopr.niscair.res.in/handle/123456789/59760

2.6. Arun T. Ram & Tessy Paul P. (2020). The genus *Oscillatoria* Vaucher (Cyanobacteria) from selected mangrove environments of Southern Kerala, India. *Chronicle of Humanities & Cultural Studies (CHCS)*, 2020, *6*(5), 13-14. **(ISSN: 2454-5503).**

SPECIES I CHECKLIST

Species

22(70), 2021

Revised and an updated checklist of cyanobacteria in mangrove environments: Chroococcales, Chroococcidiopsidales, Gloeobacterales and Synechococcales

Arun T Ram[1]✉, Tessy Paul P[2]

To Cite:
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ABSTRACT

Based on the literature about cyanobacteria from the mangrove environments of representing the orders, Chroococcales, Chroococcidiopsidales, Gloeobacterales and Synechococcales, we consulted 42 publications (national and international journals and books published from 1980 to 2020). A total of 141 species were referred, in which 72 taxa of Chroococcales, 66 taxa of Synechococcales, 2 taxa of Chroococcidiopsidales and 1 taxon of Gloeobacterales respectively. The dominant family was Chroococcaceae with 46 species, followed by Merismopediaceae and Oculatellaceae with 23 species each, Microcystaceae with 11 species, Aphanothecaceae with 8 species, Heteroleibleiniaceae with 6 species, Shizotrichaceae and Synechococcaceae with 3 species, Entophysalidaceae, Gomphosphaeriaceae, Stichosiphonaceae, Chroococcidiopsidaceae, Chamaesiphonaceae, Coleofasciculaceae, Oculatellaceae and Trichocoleusaceae with 2 species each, Cyanothrichaceae and Gloeobacteraceae with one species each. Cyanobacterial diversity is underestimated in mangrove ecosystems when compared to the number of recognised species.

Keywords: Cyanobacteria, Taxonomy, Mangrove environment, Biodiversity, Distribution

1. INTRODUCTION

Cyanobacteria are a vast and diverse category of prokaryotes with significant biological relevance. They range from unicellular to colonial filamentous and are important components of photosynthetic assemblages in planktic, benthic, epiphytic and edaphic habitats of the mangrove ecosystem (Rajaneesh et al.,

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2020). Nowadays, knowledge on the diversity and distribution of cyanobacteria in mangrove environments is very inconsistent. The order Chroococcales embraces all the unicellular or colonial cyanobacteria which do not form true filaments. The families of Chroococcales are classified based on the type of cell division, the polarity of cells and colonies, the form and structure of a colony, formation of various types of mucilaginous strands, layers and the position of cells in a colony (Komarek and Anagnostidis, 1998). According to this work, the cyanobacteria group contains four orders such as Chroococcales, Chroococcidiopsidales, Gloeobacterales and Synechococcales. The taxonomy and classification of Synechococcales and Synechococcus-like cyanobacteria has been extensively studied by Mai et al., 2018 and Komarek et al., 2020. The members of the order Synechococcales are still problematic since it contains coccoid, bacilloid unicellular and colonial genera to simple filamentous forms. This work aims to create a real list of recent cyanobacterial taxa inhabiting the mangrove environment based on modern taxonomic revisions and update nomenclature to reflect current taxonomic understanding for previously described taxa.

2. MATERIAL AND METHODS

The data of coccoid and non-heterocytous members of the order Synechococcales of cyanobacteria in mangrove habitats has been compiled solely from published works of literature from 1980-2020. We used 42 research papers and books published nationally and internationally to create a catalogue of cyanobacterial species and the articles in which they are cited. In mangrove ecosystems, cyanobacteria can be found in a variety of habitats, including epipsammic/edaphic, epizoic, epiphytic, planktic, benthic, and epilithic forms. Some publications may not explicitly mention the occurrence of cyanobacterial species, such species are included under the category 'mangrove environment'. Different techniques for collecting cyanobacteria were described in the original literature mentioned in this study.

The list of cyanobacterial species is based on the published works of literature. We considered only the published works that mentioned cyanobacteria at the species level. Names of taxa are given with proper author citation. Species are classified according to respective family. The species are classified based on the current classification system proposed by Komarek et al., 2014 and Hauer and Komarek, 2021 and the entity of the taxonomically accepted species are verified by Guiry and Guiry, 2021. When a specific or infraspecific taxon is recorded under a synonym if cited, it is represented under the currently accepted names and marked with an equal symbol (=). Newly discovered species are marked with an asterisk symbol (*).

3. RESULT AND DISCUSSION

The total list of cyanobacteria in mangrove environments comprises 141 species that occupy a variety of habitats, including epipsammic/edaphic, epizoic, epiphytic, planktic, benthic, and epilithic forms. From 42 research articles, books and theses published nationally and internationally from 1980 to 2020, we considered cyanobacteria having species-level identification (Table 1). The result showed that 141 cyanobacterial species belong to the orders, Chroococcales (72 taxa), Chroococcidiopsidales (2 taxa), Gloeobacterales (1 taxon) and Synechococcales (66 taxa). From this documentation analysis, the dominant family was Chroococcaceae with 46 species, followed by Merismopediaceae and Oculatellaceae with 23 species in each, Microcystaceae with 11 species, Aphanothecaceae with 8 species, Heteroleibleiniaceae with 6 species, Shizotrichaceae and Synechococcaceae with 3 species, Entophysalidaceae, Gomphosphaeriaceae, Stichosiphonaceae, Chroococcidiopsidaceae, Chamaesiphonaceae, Coleofasciculaceae, Oculatellaceae and Trichocoleusaceae with 2 species in each, Cyanothrichaceae and Gloeobacteraceae with one species in each (Table 2; Figure 1).

Table 1. Studies used in the compilation of the taxa occurring from the mangrove environments from 1980 to 2020.

No.	Reference	Country / Province
1.	Potts, 1980	Sinai estuary
2.	Potts and Whitton, 1980	Aldabra Islands
3.	Lambert et al.,1989	Africa
4.	Coppejans and Gallin, 1989	Kenya
5.	Rodriguez and Stoner, 1990	Puerto Rico
6.	Silva, 1991	Africa
7.	Hussain and Khoja, 1993	Saudi Arabia
8.	Branco et al., 1994	Africa

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9.	Dhargalkar, 1994	India
10.	Phillips et al., 1994	Africa
11.	Branco et al., 1996	Brazil
12.	Phillips et al., 1996	Africa
13.	Branco et al., 1997	Brazil
14.	Saifullah et al., 1997	Pakistan
15.	Zaib-Un-Nisa et al., 2000	Pakistan
16.	Nogueira and Ferrieira-Correia, 2001	Brazil
17.	Selvakumar and Sundararaman, 2001	India
18.	Sen and Naskar, 2003	India
19.	Branco et al., 2003	Brazil
20.	Steinke et al., 2003	Africa
21.	Sudha, 2005	India
22.	Sudha et al., 2007	India
23.	Bano and Siddiqui, 2007	Pakistan
24.	Nedumaran et al., 2008	India
25.	Boopathi, 2011	India
26.	Leon-Tejera et al., 2011	Mexico
27.	Perez-Estrada et al., 2012	Mexico
28.	Silambarasan et al., 2012	India
29.	Sakthivel and Kathiresan, 2013	India
30.	Shamina et al., 2014	India
31.	Barman et al., 2015	India
32.	Ram and Shamina, 2015	India
33.	Mohammed and Al-Shehri, 2015	Saudi Arabia
34.	Ahmed et al., 2016	Pakistan
35.	Bhuvaneshwari and Muruganandam, 2016	India
36.	Joseph and Saramma, 2016	India
37.	Ramamurthy and Abhinand, 2016	India
38.	Kumar et al., 2017	India
39.	Ram and Shamina, 2017	India
40.	Chakraborty et al., 2019	India
41.	Priya et al., 2019	India
42.	Singh and Bhadury, 2019	India

Table 2. Occurrence of cyanobacteria from mangrove environments, habitat and respective citations are given below. (=) symbol represents the synonyms cited in the consulted work, (*) symbol represents the new species discovered from the mangrove environment.

List of cyanobacterial species	Habitat	References
Chroococcales - Aphanothecaceae		
Aphanothece bullosa (Meneghini) Rabenhorst 1865	Epiphytic	Bano and Siddiqui, 2007

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Aphanothece castagnei (Kutzing) Rabenhorst 1865	Epipsammic	Branco et al., 1996
	Mangrove environment	Branco et al., 2003
	Mangrove environment	Nogueira and Ferrieira-Correia, 2001
	Mangrove environment	Joseph and Saramma, 2016
Aphanothece elabens (Brebisson ex Meneghini) Elenkin 1938	Mangrove environment	Mohammed and Al-Shehri, 2015
Aphanothece microscopica Nageli 1849	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
	Epizoic	Bano and Siddiqui, 2007
Aphanothece nidulans P.Richter 1884	Epiphytic	Saifullah et al.,1997
	Epiphytic, Coastal waters of Mangrove environment	Bano and Siddiqui, 2007
Aphanothece pallida (Kutzing) Rabenhorst 1863	Epiphytic	Ram and Shamina, 2015
	Mangrove environment	Ram and Shamina, 2017
Aphanothece saxicola Nageli 1849	Mangrove environment	Dhargalkar, 1994
	Epiphytic	Branco et al., 1996
Aphanothece stagnina (Sprengel) A.Braun 1863	Epiphytic	Silva, 1991
	Mangrove environment	Nogueira and Ferrieira-Correia, 2001
	Planktic	Sen and Naskar, 2003
	Epilithic	Bano and Siddiqui, 2007
Chroococcales - Chroococcaceae		
Chondrocystis dermochroa (Nageli ex Kutzing) Komarek and Anagnostidis 1995 (=) *Gloeocapsa dermochroa* Nägeli ex Kützing 1849	Mangrove environment	Joseph and Saramma, 2016
Chroococcus cohaerens (Brebisson) Nageli 1849	Epizoic, Epilithic, Edaphic, Coastal waters of mangrove environment	Bano and Siddiqui, 2007
	Mangrove environment	Joseph and Saramma, 2016
Chroococcus dispersus (Keissler) Lemmermann 1904	Epiphytic	Bano and Siddiqui, 2007
Chroococcus giganteus West 1892	Mangrove Swamps	Hussain and Khoja,

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		1993
Chroococcus gomontii Nygaard 1926	Epiphytic	Bano and Siddiqui, 2007
Chroococcus hansgirgii Schmidle 1900	Epiphytic, Epilithic	Lambert et al.,1989
	Epiphytic	Steinke et al., 2003
	Epiphytic	Bano and Siddiqui, 2007
Chroococcus indicus Zeller 1873	Epiphytic, Edaphic	Bano and Siddiqui, 2007
Chroococcus macrococcus (Kutzing) Rabenhorst 1863	Mangrove Swamps	Hussain and Khoja, 1993
	Epiphytic, Mangrove swamps	Bano and Siddiqui, 2007
Chroococcus major Komarek and Komakova-Legnerova 2007	Mangrove environment	Sakthivel and Kathiresan, 2013
Chroococcus membraninus (Meneghini) Nageli 1849	Epiphytic	Branco et al., 1996
Chroococcus minor (Kutzing) Nageli 1849	Epiphytic	Silva 1991
	Epiphytic	Branco et al., 1996
	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
	Epiphytic, Epilithic, Epizoic	Bano and Siddiqui, 2007
	Planktic	Nedumaran et al., 2008
	Mangrove environment	Mohammed and Al-Shehri, 2015
	Mangrove environment	Bhuvaneswari and Muruganandam, 2016
	Mangrove environment	Priya et al., 2019
Chroococcus minutus (Kutzing) Nageli 1849	Mangrove Swamps	Hussain and Khoja, 1993
	Mangrove environment	Sudha 2005
	Mangrove environment	Sudha et al., 2007
	Epiphytic, Epizoic, Epilithic, Edaphic, Rockpool waters of mangrove environment	Bano and Siddiqui, 2007
	Epiphytic	Boopathi, 2011
	Mangrove environment	Sakthivel and Kathiresan, 2013
	Mangrove environment	Mohammed and Al-Shehri, 2015

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	Mangrove environment	Joseph and Saramma, 2016
Chroococcus montanus Hansgirg 1893	Epiphytic, Epizoic	Bano and Siddiqui, 2007
	Epiphytic	Boopathi, 2011
	Mangrove environment	Joseph and Saramma, 2016
Chroococcus obliteratus Richter 1885	Epiphytic	Leon-Tejera et al., 2011
	Epiphytic	Perez-Estrada et al., 2012
Chroococcus pallidus Nageli 1849	Epilithic	Bano and Siddiqui, 2007
Chroococcus schizodermaticus West 1892	Rockpool waters of mangrove environment	Bano and Siddiqui, 2007
Chroococcus spelaeus Ercegovic 1925	Mangrove Swamps	Hussain and Khoja, 1993
Chroococcus tenax (Kirchner) Hieronymus 1892	Mangrove Swamps, Epilithic	Hussain and Khoja, 1993
	Epiphytic	Bano and Siddiqui, 2007
	Planktic	Nedumaran et al., 2008
	Mangrove environment	Silambarasan et al., 2012
	Mangrove environment	Joseph and Saramma, 2016
Chroococcus turgidus (Kützing) Nageli 1849	Mangrove environment	Coppejans and Gallin, 1989
	Epiphytic	Lambert et al., 1989
	Mangrove environment	Hussain and Khoja, 1993
	Mangrove environment	Dhargalkar, 1994
	Epiphytic	Steinke et al., 2003
	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
	Epiphytic, Epizoic, Edaphic, Coastal waters of mangrove environment	Bano and Siddiqui, 2007
	Planktic	Nedumaran et al., 2008
	Mangrove environment	Silambarasan et al., 2012
	Mangrove	Sakthivel and

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	environment	Kathiresan, 2013
	Mangrove environment	Shamina et al., 2014
	Mangrove environment	Mohammed and Al-Shehri, 2015
	Mangrove environment	Joseph and Saramma, 2016
	Mangrove environment	Ramamurthy and Abhinand, 2016
	Mangrove environment	Ram and Shamina, 2017
Chroococcus turgidus var. maximus Nygaard 1926	Epiphytic	Silva, 1991
Chroococcus turicensis (Nageli) Hansgirg 1887	Mangrove environment	Hussain and Khoja, 1993
Chroococcus varius A.Braun 1876	Mangrove environment	Silambarasan et al., 2012
Chroococcus westii J.B.Petersen 1923	Microbial mat, Mangrove Swamps	Hussain and Khoja, 1993
Cyanobacterium cedrorum (Sauvageau) Komarek, J.Kopecky and Cepak 1999 (=) *Synechococcus cedrorum* Sauvageau 1892	Mangrove swamps	Bano and Siddiqui, 2007
	Mangrove environment	Joseph and Saramma, 2016
	Mangrove environment	Bhuvaneswari and Muruganandam, 2016
	Mangrove environment	Priya et al., 2019
Cyanosarcina spectabilis (Geitler) Kovacik 1988 (=) *Myxosarcina spectabilis* Geitler 1933	Epiphytic	Zaib-Un-Nisa et al., 2000
	Epiphytic, Epizoic, Epilithic, Edaphic, Rockpool water, mangrove swamps	Bano and Siddiqui, 2007
	Mangrove environment	Sakthivel and Kathiresan, 2013
Gloeocapsa aeruginosa Kutzing 1843	Planktic	Sen and Naskar, 2003
	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
Gloeocapsa calcarea Tilden 1898	Epiphytic	Bano and Siddiqui, 2007
	Mangrove environment	Bhuvaneswari and Muruganandam, 2016
	Mangrove environment	Priya et al., 2019
Gloeocapsa compacta Kutzing 1847	Epiphytic, Epilthic	Bano and Siddiqui,

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		2007
	Mangrove environment	Joseph and Saramma, 2016
	Mangrove environment	Bhuvaneswari and Muruganandam, 2016
	Mangrove environment	Priya et al., 2019
Gloeocapsa decorticans (A.Braun) P.Richter 1930	Epipsammic	Sen and Naskar, 2003
Gloeocapsa gelatinosa Kutzing 1843	Epiphytic, Epizoic, Epilithic, Edaphic, mangrove swamps	Bano and Siddiqui, 2007
	Mangrove environment	Joseph and Saramma, 2016
Gloeocapsa granosa (Berkeley) Kutzing 1847	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
Gloeocapsa kuetzingiana Nageli ex Kutzing 1849	Planktic	Sen and Naskar, 2003
	Edaphic	Bano and Siddiqui, 2007
Gloeocapsa livida (Carmichael) Kutzing 1847	Mangrove environment	Joseph and Saramma, 2016
Gloeocapsa punctata Nageli 1849	Epilithic	Sen and Naskar, 2003
	Epizoic	Bano and Siddiqui, 2007
	Mangrove environment	Barman et al., 2015
Gloeocapsa quaternata Kutzing 1846	Mangrove environment	Joseph and Saramma, 2016
Gloeocapsa rupestris Kutzing 1847	Epipsammic	Sen and Naskar 2003
	Mangrove environment	Joseph and Saramma, 2016
Gloeocapsa sanguinea (C.Agardh) Kutzing 1843	Mangrove environment	Hussain and Khoja, 1993
Gloeocapsa stegophila (Itzigsohn) Rabenhorst 1863	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
	Mangrove environment	Sakthivel and Kathiresan, 2013
	Mangrove environment	Mohammed and Al-Shehri, 2015
Gloeocapsopsis crepidinum (Thuret) Geitler ex Komarek 1993	Mangrove Swamps, Epilithic	Hussain and Khoja, 1993
	Epiphytic	Zaib-Un-Nisa et al.,

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		2000
	Mangrove environment	Nogueira and Ferrieira-Correia, 2001
	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
	Epiphytic, Epizoic, Epilithic, Edaphic	Bano and Siddiqui, 2007
	Mangrove environment	Sakthivel and Kathiresan, 2013
	Mangrove environment	Joseph and Saramma, 2016
Gloeocapsopsis pleurocapsoides (Novacek) Komarek and Anagnostidis ex Komarek 1993	Epiphytic	Bano and Siddiqui, 2007
	Mangrove environment	Sakthivel and Kathiresan, 2013
Gloeothece fuscolutea (Nageli ex Kutzing) Nageli 1849	Epiphytic	Bano and Siddiqui, 2007
Gloeothece palea (Kutzing) Nageli 1849	Epipsammic	Branco et al.,1996
	Epizoic	Bano and Siddiqui, 2007
Gloeothece rhodochlamys Skuja 1949	Epizoic	Bano and Siddiqui, 2007
Gloeothece rupestris (Lyngbye) Bornet 1880	Epiphytic	Branco et al.,1996
	Epiphytic, Epizoic	Bano and Siddiqui, 2007
	Epiphytic	Zaib-Un-Nisa et al., 2000
Gloeothece samoensis Wille 1913	Epiphytic, Epizoic, Epilithic, Edaphic, Rockpool water, coastal waters of mangrove environment	Bano and Siddiqui, 2007
Lightfootiella montana (Lightfoot) Hasler, Pentecost, Jahodarova, Dvorak et Pouluckova 2018 (=) *Anacystis montana* (Lightfoot) Drouet and Daily 1952	Epiphytic	Rodriguez and Stoner, 1990
Chroococcales - Cyanothrichaceae		
Johannesbaptistia pellucida (Dickie) W.R.Taylor and Drouet 1938	Mangrove environment	Coppejans and Gallin, 1989
	Mangrove Swamps	Hussain and Khoja, 1993
	Epiphytic	Selvakumar and Sundararaman, 2001
	Planktic	Sen and Naskar, 2003

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	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
	Epilithic	Bano and Siddiqui, 2007
	Mangrove environment	Sakthivel and Kathiresan, 2013
	Mangrove environment	Joseph and Saramma, 2016
Chroococcales - Entophysalidaceae		
Entophysalis conferta (Kutzing) Drouet and Daily 1948 (=) *Chlorogloea conferta* (Kutzing) Setchell and N.L.Gardner 1918	Microbial mat, Mangrove Swamps	Hussain and Khoja, 1993
Entophysalis granulosa Kutzing 1843	Epipsammic	Potts and Whitton, 1980
	Mangrove Swamps	Hussain and Khoja, 1993
	Mangrove environment	Sakthivel and Kathiresan, 2013
Chroococcales - Gomphosphaeriaceae		
Gomphosphaeria aponina Kutzing 1836	Mangrove Swamps	Hussain and Khoja, 1993
	Mangrove environment	Ramamurthy and Abhinand, 2016
Gomphosphaeria aponina var. *multiplex* Nygaard 1926	Microbial mat	Hussain and Khoja, 1993
Chroococcales - Microcystaceae		
Microcystis aeruginosa (Kutzing) Kutzing 1846	Planktic	Nedumaran et al., 2008
	Mangrove environment	Silambarasan et al., 2012
	Mangrove environment	Sakthivel and Kathiresan, 2013
	Mangrove environment	Bhuvaneswari and Muruganandam, 2016
	Mangrove environment	Kumar et al., 2017
	Mangrove environment	Priya et al., 2019
Microcystis bengalensis Banerjii 1936	Planktic	Sen and Naskar, 2003
Microcystis flosaquae (Wittrock) Kirchner 1898	Mangrove environment	Ramamurthy and Abhinand, 2016
Microcystis halophila var. *macrococca* (Hansgirg) P.C.Silva 1996 (=) *Aphanocapsa litoralis* var. *macrococca* Hansgirg 1893	Mangrove environment	Hussain and Khoja, 1993

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Microcystis lamelliformis Holsinger 1954	Mangrove environment	Ramamurthy and Abhinand, 2016
Microcystis orissica West 1911	Mangrove environment	Joseph and Saramma, 2016
Microcystis protocystis W.B.Crow 1923	Mangrove environment	Bhuvaneswari and Muruganandam, 2016
	Mangrove environment	Priya et al., 2019
Microcystis pulverea (H.C.Wood) Forti 1907	Mangrove environment	Ramamurthy and Abhinand, 2016
Microcystis robusta (H.W.Clark) Nygaard 1925	Epiphytic	Selvakumar and Sundararaman, 2001
	Mangrove environment	Bhuvaneswari and Muruganandam, 2016
	Mangrove environment	Priya et al., 2019
Microcystis smithii Komarek and Anagnostidis 1995 (=) *Aphanocapsa pulchra* (Kutzing) Rabenhorst 1865	Planktic	Sen and Naskar, 2003
	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
	Epiphytic	Boopathi, 2011
Microcystis viridis (A.Braun) Lemmermann 1903	Edaphic	Bano and Siddiqui, 2007
Chroococcales - Stichosiphonaceae		
**Stichosiphon mangle* L.H.Z.Branco, S.M.F.Silva, and C.L.Sant'Anna 1995	Epiphytic	Branco et al.,1994
	Epiphytic	Branco et al.,1996
Stichosiphon sansibaricus (Hieronymus) F.E.Drouet and W.A.Daily 1956	Mangrove environment	Sen and Naskar, 2003
	Mangrove environment	Ramamurthy and Abhinand, 2016
Chroococcidiopsidales – Chroococcidiopsidaceae		
Chroococcidiopsis cubana Komarek and Hindak 1975	Epiphytic	Branco et al., 1996
Chroococcidiopsis indica Desikachary 1959	Epiphytic	Zaib-Un-Nisa et al., 2000
	Epiphytic, Epizoic, Edaphic, mangrove swamps	Bano and Siddiqui, 2007
Gloeobacterales - Gloeobacteraceae		
Gloeobacter violaceus Rippka, J.B.Waterbury and Cohen-Bazire 1974 (=) *Gloeothece linearis* Nageli 1849	Mangrove environment	Ramamurthy and Abhinand, 2016

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Synechococcales – Chamaesiphonaceae		
Chamaesiphon confervicola A.Braun 1864 (=) *Chamaesiphon curvatus* Nordstedt 1878	Epiphytic	Sen and Naskar, 2003
Chamaesiphon sideriphilus Starmach 1929	Mangrove environment	Ramamurthy and Abhinand, 2016
Synechococcales – Coelosphaeriaceae		
Coelosphaerium dubium Grunow 1865	Mangrove environment	Joseph and Saramma, 2016
Coelosphaerium kuetzingianum Nageli 1849	Epiphytic	Bano and Siddiqui, 2007
	Epiphytic	Boopathi, 2011
Synechococcales – Heteroleibleiniaceae		
Heteroleibleinia gardneri (Geitler) Anagnostidis and Komarek 1988 (=) *Lyngbya gardneri* Geitler 1932	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
	Epiphytic, Epizoic, Epilithic, Edaphic, coastal waters	Bano and Siddiqui, 2007
	Epiphytic	Boopathi, 2011
Heteroleibleinia infixa (Fremy) Anagnostidis and Komarek 1988 (=) *Lyngbya infixa* Frémy 1932	Coastal waters of mangrove environment	Bano and Siddiqui, 2007
	Mangrove environment	Sakthivel and Kathiresan, 2013
Heteroleibleinia mesotricha (Skuja) Anagnostidis and Komarek 1988 (=) *Lyngbya mesotricha* Skuja 1949	Mangrove environment	Silambarasan et al., 2012
	Mangrove environment	Sakthivel and Kathiresan, 2013
Heteroleibleinia willei (Setchell and N.L.Gardner) Guiry and D.M.John 2021 (=) *Lyngbya nordgaardii Wille 1919* (=) *Leibleinia nordgaardii* Anagnostidis and Komárek 1988	Mangrove Swamps	Hussain and Khoja, 1993
	Mangrove environment	Branco et al.,1997
	Epiphytic, Epilithic, Edaphic, Rockpool waters of mangrove environment	Bano and Siddiqui, 2007
	Mangrove environment	Joseph and Saramma, 2016
Heteroleibleinia chaetomorphae (Iyengar and Desikachary) Anagnostidis and Komarek 1988 (=) *Lyngbya chaetomorphae Iyengar and Desikachary 1944*	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
	Epiphytic	Boopathi, 2011
	Mangrove environment	Sakthivel and Kathiresan, 2013
Heteroleibleinia kuetzingii (Schmidle) Compere 1985 (=) *Lyngbya kuetzingii* Schmidle 1897	Among other algae	Potts, 1980
	Epiphytic	Branco et al.,1997

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Synechococcales – Leptolyngbyaceae		
**Euryhalinema mangrovii* Chakraborty et Mukherjee 2019	Epipsammic	Chakraborty et al., 2019
Leibleinia epiphytica (Hieronymus) Compere 1985 (=) *Lyngbya epiphytica Hieronymus 1898*	Microbial mat	Hussain and Khoja, 1993
Leibleinia subtilis (Holden) Anagnostidis and Komarek 1988	Epiphytic	Perez-Estrada et al., 2012
**Leptoelongatus litoralis* Chakraborty et Mukherjee in Chakraborty 2019	Epipsammic	Chakraborty et al., 2019
Leptolyngbya africana (Lemmermann) Anagnostidis and Komarek 1988 (=) *Phormidium africanum* Lemmermann 1911	Mangrove swamps	Bano and Siddiqui, 2007
Leptolyngbya angustissima (West and G.S.West) Anagnostidis and Komarek 1988 (=) *Phormidium angustissimum* West and G.S.West 1897	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
	Mangrove environment	Joseph and Saramma, 2016
Leptolyngbya cebennensis (Gomont) I.Umezaki and M.Watanabe 1994 (=) *Phormidium cebennense Gomont 1899*	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
	Epiphytic, Epizoic, Epilithic, Edaphic, rock pool water	Bano and Siddiqui, 2007
Leptolyngbya crosbyana (Tilden) Anagnostidis and Komarek 1988 (=) *Phormidium crosbyanum* Tilden 1909	Epiphytic	Rodriguez and Stoner, 1990
	Mangrove environment	Nogueira and Ferrieira-Correia, 2001
Leptolyngbya foveolarum (Gomont) Anagnostidis and Komarek 1988 (=) *Phormidium foveolarum Gomont 1892*	Epiphytic, Epizoic, Epilithic, Edaphic, coastal waters	Bano and Siddiqui, 2007
	Mangrove environment	Barman et al., 2015
	Mangrove environment	Joseph and Saramma, 2016
Leptolyngbya fragilis (Gomont) Anagnostidis and Komarek 1988 (=) *Phormidium fragile* Gomont 1893	Microbial mat	Hussain and Khoja, 1993
	Mangrove environment	Dhargalkar, 1994
	Epiphytic	Saifullah et al., 1997
	Mangrove environment	Nogueira and Ferrieira-Correia, 2001
	Epiphytic	Sen and Naskar, 2003
	Mangrove environment	Sudha, 2005

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	Mangrove environment	Sudha et al., 2007
	Epilithic	Bano and Siddiqui, 2007
	Epiphytic	Nedumaran et al., 2008
	Epiphytic	Boopathi, 2011
	Mangrove environment	Silambarasan et al., 2012
	Mangrove environment	Sakthivel and Kathiresan, 2013
	Mangrove environment	Mohammed and Al-Shehri, 2015
	mangrove environment	Ramamurthy and Abhinand, 2016
Leptolyngbya lagerheimii (Gomont ex Gomont) Anagnostidis and Komarek 1988 (=) *Lyngbya lagerheimii* Gomont ex Gomont 1892	Epiphytic	Branco et al., 1997
	Epilithic	Bano and Siddiqui, 2007
Leptolyngbya laminosa (Gomont ex Gomont) Anagnostidis and Komárek 1988 (=) *Phormidium laminosum* Gomont ex Gomont 1892	Epiphytic	Bano and Siddiqui, 2007
Leptolyngbya nostocorum (Bornet ex Gomont) Anagnostidis and Komarek 1988 (=) *Plectonema nostocorum* Bornet ex Gomont 1892	mangrove environment	Joseph and Saramma, 2016
Leptolyngbya perelegans (Lemmermann) Anagnostidis and Komarek 1988 (=) *Lyngbya perelegans* Lemmermann 1899	Mangrove environment	Branco et al., 1997
	Mangrove environment	Branco et al., 2003
	Epiphytic	Bano and Siddiqui, 2007
Leptolyngbya polysiphoniae (Fremy) Anagnostidis 2001 (=) *Lyngbya polysiphoniae* Frémy 1930	Epiphytic	Bano and Siddiqui, 2007
Leptolyngbya purpurascens (Gomont ex Gomont) Anagnostidis and Komarek 1988 (=) *Phormidium purpurascens* Gomont ex Gomont 1892	Mangrove environment	Branco et al., 2003
	Mangrove environment	Joseph and Saramma, 2016
Leptolyngbya tenuis (Gomont) Anagnostidis and Komarek 1988 (=) *Phormidium tenue* Gomont 1892	Mangrove environment	Branco et al., 1997
	Epiphytic	Zaib-Un-Nisa et al., 2000
	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
	Epiphytic, Epizoic, Rockpool water, Coastal pool water	Bano and Siddiqui, 2007
	Epiphytic	Nedumaran et al., 2008

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	Epiphytic	Boopathi 2011
	Mangrove environment	Silambarasan et al., 2012
	Mangrove environment	Sakthivel and Kathiresan, 2013
	Mangrove environment	Mohammed and Al-Shehri, 2015
	Mangrove environment	Barman et al., 2015
	Mangrove environment	Ahmed et al., 2016
	Mangrove environment	Joseph and Saramma, 2016
	Mangrove environment	Priya et al., 2019
Leptolyngbya terebrans (Bornet and Flahault ex Gomont) Anagnostidis and Komarek 1988 (=) *Plectonema terebrans* Bornet and Flahault ex Gomont 1892	Mangrove environment	Hussain and Khoja,1993
	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
	Mangrove environment	Silambarasan et al., 2012
	Mangrove environment	Sakthivel and Kathiresan, 2013
	Mangrove environment	Priya et al., 2019
Leptolyngbya valderiana (Gomont) Anagnostidis and Komarek 1988 (=) *Phormidium valderianum* Gomont 1892	Epiphytic, Epizoic, Epilithic, Edaphic, rock pool water, coastal waters	Bano and Siddiqui, 2007
	Epiphytic	Boopathi, 2011
	Mangrove environment	Silambarasan et al., 2012
	Mangrove environment	Sakthivel and Kathiresan, 2013
	Mangrove environment	Barman et al., 2015
	Mangrove environment	Joseph and Saramma, 2016
	Mangrove environment	Ramamurthy and Abhinand 2016
Phormidesmis mollis (Gomont) Turicchia, Ventura, Komarkova and Komarek 2009 (=) *Phormidium molle* Gomont 1892	Mangrove environment	Hussain and Khoja, 1993
	Epiphytic	Branco et al., 1997
	Epiphytic	Zaib-Un-Nisa et al., 2000
	Mangrove environment	Branco et al., 2003

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	Epiphytic	Bano and Siddiqui, 2007
	Mangrove environment	Shamina et al., 2014
	Epiphytic	Ram and Shamina, 2015
	Mangrove environment	Joseph and Saramma, 2016
	Mangrove environment	Ram and Shamina, 2017
Planktolyngbya limnetica (Lemmermann) Komarkova-Legnerova and Cronberg 1992 (=) *Lyngbya limnetica* Lemmermann 1898	Mangrove environment	Ram and Shamina, 2017
Planktolyngbya minor (Geitler and Ruttner) Komarek and Cronberg 2001	Mangrove environment	Barman et al., 2015
Stenomitos frigidus (F.E.Fritsch) Miscoe and J.R.Johansen 2016 (=) *Leptolyngbya frigida* (F.E.Fritsch) Anagnostidis and Komárek 1988	Mangrove environment	Barman et al., 2015
Synechococcales – Merismopediaceae		
Aphanocapsa stagnalis (Lemmermann) Belyakova 2004 (=) *Microcystis stagnalis* (Lemmermann) Lemmermann 1903	Mangrove environment	Joseph and Saramma, 2016
Aphanocapsa roeseana De Bary in Rabenhorst 1870	Epiphytic	Ram and Shamina, 2015
	Mangrove environment	Ram and Shamina, 2017
Aphanocapsa biformis A.Braun 1879	Edaphic	Bano and Siddiqui, 2007
	Mangrove environment	Bhuvaneswari and Muruganandam, 2016
	Mangrove environment	Priya et al., 2019
Aphanocapsa brunnea (A.Baun ex Kützing) Nägeli 1849	Mangrove environment	Joseph and Saramma, 2016
Aphanocapsa conferta (West and G.S.West) Komarkova-Legnerova and Cronberg 1994 (=) *Aphanocapsa elachista* var. *conferta* West and G.S.West 1912	Epiphytic	Lambert et al., 1989
	Epiphytic	Phillips et al., 1994
	Epiphytic	Phillips et al., 1996
	Epiphytic	Steinke et al., 2003
Aphanocapsa grevillei (Berkeley) Rabenhorst 1865	Mangrove Swamps, Epilithic	Hussain and Khoja, 1993
	Epiphytic	Ram and Shamina, 2015
	Mangrove environment	Ram and Shamina, 2017
Aphanocapsa koordersii K.M.Strom 1923	Epiphytic	Selvakumar and

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		Sundararaman, 2001
Aphanocapsa litoralis Hansgirg 1892 (=) *Microcystis litoralis* (Hansgirg) Aboal 1988	Mangrove Swamps	Hussain and Khoja, 1993
	Epiphytic	Saifullah et al., 1997
	Epiphytic	Selvakumar and Sundararaman, 2001
	Planktic, Epipsammic	Sen and Naskar, 2003
	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
	Epiphytic, Epizoic, Epilithic, Coastal waters of Mangrove environment	Bano and Siddiqui, 2007
	Epiphytic	Nedumaran et al., 2008
	Epiphytic	Leon-Tejera et al., 2011
	Epiphytic	Perez-Estrada et al., 2012
	Mangrove environment	Silambarasan et al., 2012
	Mangrove environment	Sakthivel and Kathiresan, 2013
	Mangrove environment	Bhuvaneswari and Muruganandam, 2016
	Mangrove environment	Joseph and Saramma, 2016
	Mangrove environment	Priya et al., 2019
Aphanocapsa muscicola (Meneghini) Wille 1919 (=) *Aphanocapsa montana* Cramer 1862	Epiphytic, Epilithic	Lambert et al., 1989
	Epiphytic	Steinke et al., 2003
Aphanocapsa reinboldii (Richter) Komarek and Anagnostidis 1995 (=) *Microcystis reinboldii* (Richter) Forti 1907	Epipsammic	Potts, 1980
Aphanocapsa rivularis (Carmichael) Rabenhorst 1865	Epiphytic, Rockpool waters of mangrove environment	Bano and Siddiqui, 2007
Eucapsis minuta F.E.Fritsch 1912	Mangrove environment	Joseph and Saramma, 2016
Limnococcus limneticus (Lemmermann) Komarkova, Jezberova, O.Komarek and Zapomelova 2010 (=) *Chroococcus limneticus* Lemmermann 1898	Coastal waters of mangrove environment	Bano and Siddiqui, 2007
Merismopedia convoluta Brebisson ex Kutzing 1849	Epiphytic, Mangrove swamps	Bano and Siddiqui, 2007
	Microbial mat,	Hussain and Khoja,

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	Mangrove Swamps, Pelagic	1993
Merismopedia elegans A.Braun ex Kutzing 1849	Mangrove Swamps	Hussain and Khoja, 1993
	Edaphic, Mangrove swamps	Bano and Siddiqui, 2007
	Mangrove environment	Sakthivel and Kathiresan, 2013
	Mangrove environment	Shamina et al., 2014
	Mangrove environment	Ram and Shamina, 2017
Merismopedia glauca (Ehrenberg) Kutzing 1845	Microbial mat, Mangrove Swamps	Hussain and Khoja, 1993
	Epiphytic, Epizoic, Epilithic, Edaphic, coastal water, mangrove swamps	Bano and Siddiqui, 2007
	Mangrove environment	Sakthivel and Kathiresan, 2013
	Mangrove environment	Barman et al., 2015
	Mangrove environment	Ramamurthy and Abhinand, 2016
Merismopedia litoralis (Oersted) Rabenhorst 1865	Microbial mat, Mangrove Swamps	Hussain and Khoja, 1993
Merismopedia minima G.Beck 1897	Epiphytic, Epilithic	Bano and Siddiqui, 2007
	Mangrove environment	Barman et al., 2015
Merismopedia tenuissima Lemmermann 1898	Microbial mat, Mangrove Swamps	Hussain and Khoja, 1993
	Epipsammic	Sen and Naskar, 2003
	Epiphytic, Edaphic	Bano and Siddiqui, 2007
Merismopedia tranquilla (Ehrenberg) Trevisan 1845 (=) *Merismopedia punctata* Meyen 1839	Mangrove Swamps	Hussain and Khoja, 1993
	Mangrove environment	Branco et al., 1996
	Epiphytic	Bano and Siddiqui, 2007
	Mangrove environment	Barman et al., 2015
Synechocystis aquatilis Sauvageau 1892	Epiphytic	Zaib-Un-Nisa et al., 2000
	Mangrove swamps	Bano and Siddiqui, 2007
	Mangrove environment	Barman et al., 2015

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	Mangrove environment	Joseph and Saramma, 2016
Synechocystis pevalekii Ercegovic 1925	Epiphytic	Zaib-Un-Nisa et al., 2000
	Epiphytic, Epizoic, Epilithic, Edaphic, Rockpool water, coastal water, mangrove swamps	Bano and Siddiqui, 2007
	Mangrove environment	Sakthivel and Kathiresan, 2013
	Mangrove environment	Barman et al., 2015
	Mangrove environment	Bhuvaneswari and Muruganandam, 2016
	Mangrove environment	Ramamurthy and Abhinand, 2016
	Mangrove environment	Priya et al., 2019
Synechocystis salina Wislouch 1924	Mangrove Swamps	Hussain and Khoja, 1993
	Mangrove environment	Joseph and Saramma, 2016
Synechococcales – Oculatellaceae		
Drouetiella lurida (Gomont) Mai, J.R.Johansen and Pietrasiak 2018 (=) *Phormidium luridum* Gomont 1892	Epiphytic	Bano and Siddiqui, 2007
Dasygloea lamyi (Gomont ex Gomont) Senna and Komarek 1998 (=) *Schizothrix lamyi* Gomont ex Gomont 1892	Planktic	Sen and Naskar, 2003
Synechococcales – Schizotrichaceae		
Schizothrix arenaria Gomont 1892	Epiphytic	Lambert et al., 1989
	Mangrove Swamps	Hussain and Khoja, 1993
	Mangrove environment	Branco et al., 1997
Schizothrix calcicola Gomont 1892	Epiphytic	Potts, 1980
	Epipsammic	Potts and Whitton, 1980
	Microbial mat, Mangrove Swamps	Hussain and Khoja, 1993
Schizothrix telephoroides Gomont 1890	Epiphytic	Selvakumar and Sundararaman, 2001
Synechococcales – Synechococcaceae		
Lemmermanniella obesa M.T.P.Azevedo, C.A.Souza and M.Menezes 1999	Epiphytic	Branco et al., 1997
	Mangrove	Nogueira and

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(=) *Leibleinia pellucida* (I.Umezaki) I.Umezaki and M.Watanabe	environment	Ferrieira-Correia, 2001
Synechococcus elongatus (Nageli) Nageli 1849	Epiphytic	Branco et al., 1996
	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
	Epiphytic	Bano and Siddiqui, 2007
	Mangrove environment	Silambarasan et al., 2012
	Mangrove environment	Joseph and Saramma, 2016
***Synechococcus moorigangaii* Singh and Bhadury 2019**	Planktic	Singh and Bhadury, 2019
Synechococcales – Trichocoleusaceae		
Trichocoleus acutissimus (N.L.Gardner) Anagnostidis 2001 (=) *Microcoleus acutissimus* N.L.Gardner 1927	Mangrove environment	Sudha, 2005
	Mangrove environment	Sudha et al., 2007
	Mangrove environment	Shamina et al., 2014
Trichocoleus tenerrimus (Gomont) Anagnostidis 2001 (=) *Microcoleus tenerrimus* Gomont 1892	Mangrove Swamps	Hussain and Khoja, 1993
	Mangrove environment	Branco et al., 1997
	Mangrove environment	Nogueira and Ferrieira-Correia, 2001

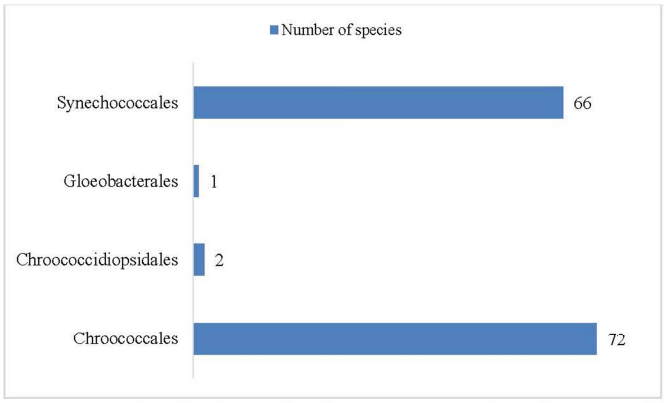

Figure 1: Graphical representation with number of species from the mangrove-associated cyanobacteria according to order.

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Studies on the biodiversity of coccoid cyanobacteria from the mangrove environments had started in the 1980s (Potts, 1980; Potts and Whitton, 1980). Research on mangrove-associated cyanobacterial diversity has become increasingly focused since 1990, and there has been a large increase in biodiversity research over the last few decades, although no taxonomic studies have been published in 2020.

The greatest diversity was found in the 'mangrove environment' and epiphytic form (Table 2). Even though planktic cyanobacterial flora has been extensively investigated, it has a low diversity when compared to mangrove ecosystems according to this study. However, the following cyanobacterial species commonly occur as planktic: *Aphanocapsa litoralis*, *Aphanothece stagnina*, *Chroococcus minor*, *Chroococcus tenax*, *Chroococcus turgidus* and *Gloeocapsa aeruginosa*.

It is very difficult to check the validity while considering the misspelt species name, genus abbreviations in the literature and improper author citations are missing in publications. Therefore, the authors should write the species name and its respective author citation properly.

Several traditional Chroococccales genera were confirmed as non-cyanobacterial organisms, eg. *Cyanotheca* Pascher 1914 (type: Caulobacteria) and *Dactylococcopsis* Hansgirg 1888 (type: Green algae) and they were removed from the revised classification system of cyanobacteria (Komarek and Anagnostidis, 1998). But the genus *Dactylococcopsis* was included under the order Chroococcales (family: Chroococcaceae) with 31 species names in the database (https://www.algaebase.org/) at present as well as 22 infraspecific names. Of the species names, 17 have been labelled as taxonomically accepted based on the literature under the species name. Thus, the inclusion of this genus is the subject of controversy.

Some researchers reported the occurrence of *Synechococcus cedrorum* from the mangrove environments and it is currently known as *Cyanobacterium cedrorum*. According to recent taxonomic revision (Guiry and Guiry, 2021; Hauer and Komarek, 2021), the genus *Cyanobacterium* is currently regarded as an invalid genus and suggested for further investigation (Tuji et al., 2021). Thus, the entity of this species name is taxonomically uncertain. Many Cyanobacterial species lack gene sequence information. Despite the current method (Komarek et al., 2014) it depicts phylogeny for cyanobacteria because many morphologically similar taxa are polyphyletic and their taxonomy is a particularly vexing topic.

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Author Contributions

Arun T Ram: Contributed substantially to the conception and design of the work, literature collection, preparation of the checklist and interpretation of data for the work.

Tessy Paul P: Contributed substantially to the conception and design of the work, literature collection, and revised the manuscript.

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The authors declare no conflict of interest.

Data and materials availability

All data associated with this study are present in the paper.

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Morpho-taxonomic identification of mangrove-associated coccoid cyanobacteria from the southwest coast of India

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Abstract
A total of 10 coccoid cyanobacterial species belonging to 5 genera were reported from the different study areas of mangrove ecosystems of the southwest coast of India from July 2015 to June 2020. All the collected cyanobacterial samples were identified up to species level. The study recorded 5 epipsammic (*Aphanothece granulosa* (N.L.Gardner) Komárek & Komákova-Legnerova 2007, *Aphanothece stagnina* (Sprengel) A. Braun in Rabenhort 1863, *Gloeothece samoensis* Wille 1913, *Gloeothece rupestris* (Lyngbye) Bornet in Wittrock & Nordstedt 1880, *Chroococcus pallidus* Nageli 1849), 2 benthic (*Gloeothece ustulata* Beck-Mannagetta 1929, *Anathece bacteriosa* (Komarek & Komarkova-Legnrova) Komarek, Kastovsky & Jezberova 2011),1 epiphytic (*Chroococcus indicus* Zeller 1873), 1 planktic (*Aphanothece bullosa* (Meneghini) Rabenhorst 1865), while *Aphanocapsa grevillei* (Berkeley) Rabenhorst 1865) was occurred from epiphytic and benthic habitat.

Keywords: coccoid cyanobacteria, mangrove environment, diversity, taxonomy

Introduction
Cyanobacteria are one of the pioneer species of earth and research has been conducted to better understand their evolutionary, ecological, biochemical, and taxonomic difficulties (Alvarenga *et al.,* 2017) [2]. Through the ability to fix atmospheric nitrogen, cyanobacteria are the only prokaryotes that can significantly contribute to oxygen-evolving photosynthesis and the nitrogen economy of aquatic and terrestrial environments (Kirsch *et al.,* 2019; Fay, 1981) [9, 6]. For the research in the taxonomy of cyanobacteria, microscopy has always been vital, and light microscopy has been the foundation of such research (Stolz, 2000) [20]. The identification of cyanobacteria based on the morphology requires visible characteristics that can be recognised even at low magnifications using light microscopy. This can be problematic, especially for groups (eg. Chroococcales and Synechococcales) that lack such characteristics and have small cell sizes (Albrecht *et al.,* 2017) [1].
Biodiversity research on mangrove-dwelling coccoid cyanobacteria began in 1980 with a focus on cyanobacterial distribution, zonation, and taxonomic diversity (Potts, 1980) [15]. Coccoid cyanobacteria in mangrove habitats are rarely reported from the southwest coast of India and the majority of the species were referred to in the literature of Joseph and Saramma (2016) [8] and Ramamurthy and Abhinand (2016) [16]. This paper aims to extend our knowledge of the coccoid cyanobacteria from the mangrove environments of southern Kerala.

Materials and Methods
Study area
The study was conducted through extensive field visits for five years, from July 2015 to June 2020, in the mangrove areas of southern Kerala, distributed along the South West Coast of India. The sampling sites of cyanobacterial samples were provided in Table 1.

Table 1: Sampling sites of cyanobacterial samples

No.	Study Area	Latitude	Longitude
1.	Kadinamkulam	8° 37'15.01" N	76° 48' 43.81" E
2.	Pathiramanal	9° 37' 09.78" N	76° 23' 06.43" E
3.	Ezhupunna	9° 49' 24.43" N	76° 18' 39.54" E
4.	Kumarakom	9° 36'59.46" N	76° 25' 21.46" E
5.	Mekkara	9° 48'54.31" N	76° 21' 57.54" E
6.	Vypin	9° 58' 26.46" N	76° 14' 38.14" E

Collection, storage and identification of samples
Cyanobacterial samples were collected from the water bodies, soil, bark and pneumatophores of mangrove plants. Sterile plastic bottles were used for the collection of cyanobacterial samples. With the help of sterile blades, the samples were scraped, transferred into sterile plastic bottles and transported to the Department of Botany, MES Asmabi College, Kodungallur, Kerala, for taxonomic and culture studies. Bottles were labelled according to date, sampling sites and voucher numbers. In the laboratory, within 6-8 hours one set of samples were preserved in 4% formaldehyde solution. The other set of live samples were observed under a compound microscope and then transferred to BG11 medium (Rippka *et al.,* 1979) [17] for culture, and they were maintained in the culture room under a white fluorescent lamp (±3000 lux), 14"10 L/day at ±25°C.
Microscopic analysis was done for the identification of cyanobacteria. Photomicrographs were taken using a Leica DM 1000 LED compound microscope. A Leica DM 1000 microscope system can incorporate a digital camera, image

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processing workstation and sophisticated software for image organization and archiving. Measurements were taken by using Leica Application Suite (LAS version 5.0.2). The cyanobacterial species were identified using the monographs and standard works of literature (Desikachary, 1959; Komarek and Anagnostidis, 1998; Komarek and Komarkova-Legnerova, 2007; Komarek *et al.,* 2011) [5, 11, 12, 13]. Using all available information, morpho-taxonomic identification was done up to the species level.

Result and Discussion

A total of 10 cyanobacterial species belonging to five genera were reported from different study areas of mangrove environments in southern Kerala. All the cyanobacterial samples were identified taxonomically up to species level. Classification of cyanobacteria is based on the revised classification system of Komarek *et al.* (2014) [10] and (http://www.cyanodb.cz/) Hauer and Komarek, (2021) [7]. The details were as follows;

Phylum/Class: Cyanobacteria
Order: Chroococcales
Family: Aphanothecaceae
Genus: *Aphanothece* Nägeli 1849
Species: *A. bullosa* (Meneghini) Rabenhorst 1865
A. granulosa (N.L.Gardner) Komárek & Komákova-Legnerova 2007
A. stagnina (Sprengel) A. Braun in Rabenhort 1863
Family: Chroococcaceae
Genus: *Chroococcus* Nägeli 1849
Species: *C. indicus* Zeller 1873 *C. pallidus* Nageli 1849
Genus: *Gloeothece* Nägeli 1849
Species: *G. rupestris* (Lyngbye) Bornet in Wittrock & Nordstedt 1880 *G. samoensis* Wille 1913 *G. ustulata* Beck-Mannagetta 1929
Order: Synechococcales
Family: Merismopediaceae
Genus: *Aphanocapsa* Nägeli 1849
Species: *A. grevillei* (Berkeley) Rabenhorst 1865
Family: Synechococcaceae
Genus: *Anathece* Komárek *et al.* 2011.
Species: *A. bacteriosa* (Komarek et Komarkova-Legnrova) Komarek, Kastovsky et Jezberova 2011.

1. Aphanothecaceae

Aphanothece bullosa (Meneghini) Rabenhorst 1865
Description: Colonies macroscopic, mucilaginous, more or less spherical. Cells oval to elongate cylindrical with rounded ends, with more or less homologous content, sometimes finely granular, pale blue-green, without individual envelops, 2.52-4.51 µm broad, 5.23-7.11 µm long.
Habitat: Planktic form appeared as green in colour.
Specimen Examined: INDIA: Kerala; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 16.07.2015, MES 13761. Kottayam district, Mekkara, 9^0 48'54.31" N 76^0 21' 57.54" E. 18.09.2016, MES 13786. (Fig. 1. A).
Aphanothece granulosa (N.L.Gardner) Komárek & Komákova-Legnerova 2007
Description: Colonies microscopic, cells loosely arranged, in older colonies densely agglomerated cells in fine, colourless mucilage, usually well-defined at the margin and overlapping the cells. Cells oval, granulated, 4.62 – 5.27 µm broad, 7.43 – 12.52 µm long.
Habitat: On mangrove-soil appeared as dark brownish/black coloured cyanobacterial mat
Specimen Examined: INDIA: Kerala; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 24.09.2017, MES 13774. (Fig. 1. B).
Aphanothece stagnina (Sprengel) A. Braun in Rabenhort 1863
Description: Thallus gelatinous, spherical, ellipsoidal, brownish or violet colour; cells oblong, more or less ovoid or widely cylindrical with rounded ends, 3.6 µm to 6.2 µm broad, 6.7 µm to 12.3 µm long, densely or sparsely arranged, without individual envelopes, homogeneous mucilage.
Habitat and Ecology: Dark blackish or brownish mat collected from the mangrove soil surface.
Specimen Examined: INDIA: Kerala; Alappuzha district, Pathiramanal, 9^0 37' 09.78" N, 76^0 23' 06.43" E, 28.09.2016. MES 13716. Kottayam district, Mekkara, 12.08.2016. MES 13752. (Fig. 1. C).

2. Chroococcaceae

Chroococcus indicus Zeller 1873
Description: Thallus gelatinous, thin, pale brownish; cells single, oblong to sub-spherical, 3.5 µm to 7.5 µm broad, 3.4 µm to 10.8 µm long, olive-green; sheath hyaline, conspicuous, contents granular.
Distribution: This species was reported as epiphytic, edaphic (Bano and Siddiqui, 2007) [3], planktonic form (Sahoo *et al.,* 2020) [18].
Habitat: Appeared as dark brownish coloured cyanobacterial mass on the pneumatophores of *Avicennia officinalis* L.
Specimen Examined: INDIA: Kerala; Alappuzha district, Ezhupunna, 9^0 49' 24.43" N, 76^0 18' 39.54" E, 24.11.2019. MES 13707.Thiruvananthapuram district, Kadinamkulam, 8^0 37'15.01" N 76^0 48' 43.81" E, 14.07.2016. MES 13751. **(Fig. 1. D).**
Chroococcus pallidus Nageli 1849
Description: Colonies usually microscopic, gelatinous, amorphous. Cells single or in 2-3, without sheath 4.82 – 7.22 µm broad, with sheath 9.64- 13.92 µm broad, elliptic-oblong colonies, cells arranged in a common sheath, common sheath more or less delimited, inside confluent, colourless, structureless. Around the cells special colourless, more or less rounded, not lamellate envelops present.
Habitat: On soil surface which is appeared as green coloured cyanobacterial mat
Specimen Examined: INDIA: Kerala; Thiruvananthapuram district, Kadinamkulam; 14.07.2016. MES 13750. Kottayam district, Kumarakom, 9^0 36'59.46" N 76^0 25' 21.46" E, 13.11.2018. MES 13793. (Fig. 1. E).
Gloeothece rupestris (Lyngbye) Bornet in Wittrock & Nordstedt 1880
Description: Colonies small, enveloped by small sheaths, with solitary sheathed cells. Gelatinous envelops around the cell. Cells ellipsoidal to cylindrical, without envelope 4.13-5.80 µm broad, 7.58- 8.74 µm long, contents pale blue-green, with sheath 8.76 µm broad, 10.75 µm long.
Habitat: On soil surface which is appeared as green coloured cyanobacterial mat
Specimen Examined: INDIA: Kerala; Thiruvananthapuram district, Kadinamkulam, 9^0 49' 24.43" N, 76^0 18' 39.54" E, 14.07.2016. MES 13750. Kottayam district, Kumarakom, 9^0

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36'59.46" N 76^0 25' 21.46" E, 13.11.2018. MES 13793. (Fig. 1. F).

Gloeothece samoensis Wille 1913

Description: Round, oblong to elliptical colonies, with sheath 9.85-20.43 µm diam., with 2 cells. Sheath firm to diffluent, hyaline, conspicuous, smooth. Cells oblong to ellipsoid, 3.33-5.82 µm broad, 5.26–8.42 µm long. Cell content granulated, blue-green to olive green.

Habitat: On soil surface which is appeared as green coloured cyanobacterial mat

Specimen Examined: INDIA: Kerala; Alappuzha district, Pathiramanal; 28.09.2016. MES 13775. Kottayam district, Kumarakom, 9^0 36'59.46" N 76^0 25' 21.46" E, 17.09.2018, MES 13792, 05.06.2020, MES 13768. (Fig. 1. G).

Gloeothece ustulata Beck-Mannagetta 1929

Description: Colonies yellowish, irregularly spherically elongate, envelopes around cells hyaline, not lamellated, colourless or slightly bluish coloured. Cells broadly elliptical, with rounded, almost twice approaching or longer than wide, with homogeneous, slightly granulate content, 7.52 – 8.63 µm broad, 15.5 µm long.

Habitat: Appeared as dark brownish coloured benthic cyanobacterial mat

Specimen Examined: INDIA: Kerala; Ernakulam district, Vypin, 9^0 58' 26.46" N, 76^0 14' 38.14" E, 18.08.2016, MES 13764. 24.09.2017, MES 13776. (Fig. 1. H).

3. Merismopediaceae

Aphanocapsa grevillei (Berkeley) Rabenhorst 1865

Description: Thallus or colonies more or less spherical or hemispherical, greenish, mucilaginous, with irregularly and densely aggregated cells. Cells spherical or oval, 3.72 – 4.75 µm diameter, contents finely granular, individual envelops not distinct.

Habitat: Found attached to the pneumatophores of *Avicennia officinalis* L. and as benthic form from the mangrove environment.

Specimen Examined: INDIA: Kerala; Kottayam district, Mekkara, 9^0 48'54.31" N 76^0 21' 57.54" E. 07.04.2015, MES 13770. 18.09.2016, MES 13787. (Fig. 1. I).

4. Synechococcaceae

Anathece bacteriosa (Komarek & Komarkova-Legnrova) Komarek, Kastovsky & Jezberova 2011.

Description: Thallus gelatinous, colonies macroscopic, irregular, mucilaginous, diffluent or with delimited margin, olive green, with irregularly agglomerated cells. Cells shortly rod-like, 1.32- 2.6 x 0.83-1.21 µm diameter.

Habitat: Dark green coloured benthic cyanobacterial mat.

Specimen Examined: INDIA: Kerala; Kottayam district, Mekkara, 9^0 48'54.31" N 76^0 21' 57.54" E. 14.03.2016, MES 13738. 14.07.2019, MES 13788. (Fig. 1. J).

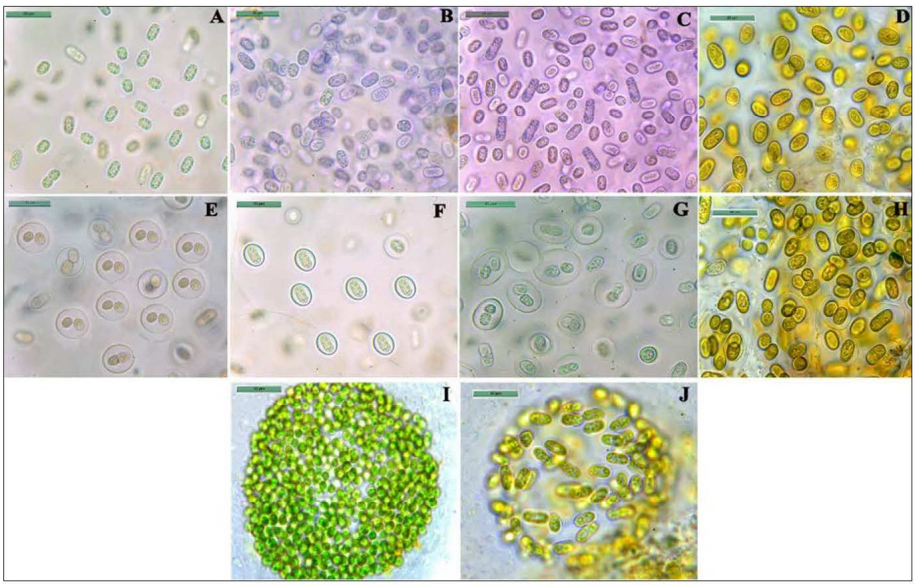

Fig 1: A) *Aphanothece bullosa* (Meneghini) Rabenhorst 1865, B) *Aphanothece granulosa* (N.L.Gardner) Komárek & Komákova-Legnerova 2007; C) *Aphanothece stagnina* (Sprengel) A. Braun in Rabenhort 1863; D) *Chroococcus indicus* Zeller 1873; E) *Chroococcus pallidus* Nageli 1849; F) *Gloeothece rupestris* (Lyngbye) Bornet in Wittrock & Nordstedt 1880; G) *Gloeothece samoensis* Wille 1913; H) *Gloeothece ustulata* Beck- Mannagetta 1929; I) *Aphanocapsa grevillei* (Berkeley) Rabenhorst 1865; J) *Anathece bacteriosa* (Komarek & Komarkova-Legnrova) Komarek, Kastovsky & Jezberova 2011.

The majority of the species were recorded from the mangrove soil surface (*Aphanothece granulosa* (N.L.Gardner) Komárek & Komákova-Legnerova 2007, *Aphanothece stagnina* (Sprengel) A. Braun in Rabenhort 1863, *Gloeothece samoensis* Wille 1913, *Gloeothece rupestris* (Lyngbye) Bornet in Wittrock & Nordstedt 1880, *Chroococcus pallidus* Nageli 1849), two species were reported as benthic forms (*Gloeothece ustulata* Beck-

Mannagetta 1929, *Anathece bacteriosa* (Komarek & Komarkova-Legnrova) Komarek, Kastovsky & Jezberova 2011), 1 planktic (*Aphanothece bullosa* (Meneghini) Rabenhorst 1865), *Chroococcus indicus* Zeller 1873 occurred from the pneumatophores of *Avicennia officinalis* L., while *Aphanocapsa grevillei* (Berkeley) Rabenhorst 1865) was occurred from the pneumatophores of *Avicennia officinalis* L. and benthic habitat.

Regarding the taxonomy of mangrove-associated cyanobacteria, there were no exclusive studies reported from southern Kerala. The occurrence of *Aphanothece stagnina* (Sprengel) A. Braun in Rabenhort 1863, *Gloeothece rupestris* (Lyngbye) Bornet in Wittrock & Nordstedt 1880, *Chroococcus pallidus* Nageli 1849 and *Chroococcus indicus* Zeller 1873 have been reported from the mangrove environments (Silva, 1991; Branco *et al.,* 1996; Zaib-Un-Nisa, 2000; Nogueira and Ferreira-Correia, 2001; Bano and Siddiqui, 2007; Joseph and Saramma, 2016) [19, 4, 21, 14, 3, 8].

During this research, *Aphanothece bullosa* (Meneghini) Rabenhorst 1865, *Aphanothece granulosa* (N.L.Gardner) Komárek & Komákova-Legnerova 2007, *Gloeothece samoensis* Wille 1913, *Gloeothece ustulata* Beck-Mannagetta 1929, *Aphanocapsa grevillei* (Berkeley) Rabenhorst 1865 and *Anathece bacteriosa* (Komarek & Komarkova-Legnrova) Komarek, Kastovsky & Jezberova 2011 were recorded for the first time from the mangrove environments of the southwest coast of India.

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A review on the distribution records of mangrove-associated heterocytous cyanobacteria: an update

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Abstract:

Microorganisms associated with mangrove habitats have an important role in this ecosystem, contributing significantly to its productivity and ecosystem maintenance. Studies on the distribution of mangroves inhabiting cyanobacterial diversity are scarce and meagre. This study aims to record the occurrence and geographic distribution of the heterocytous cyanobacteria in mangrove environments during 43 years of research carried out by different countries in the world. We consulted 33 publications (national and international journals and books published from 1977 to 2020). There are a total of 70 heterocytous cyanobacterial species. The dominant family was Nostocaceae with 27 species, followed by Calotrichaceae with 12 species, Rivulariaceae and Scytonemataceae with 10 species each, Aphanizomenonaceae with 5 species, Hapalosiphonaceae with 2 species, Chlorogloeopsidaceae, Heteroscytonemataceae, Microchaetaceae and Tolypothrichaceae with one species each. This study will be a contribution to our knowledge of cyanobacterial biodiversity in mangrove ecosystems and generate data for future taxonomic, ecological and biogeographic studies.

Keywords: Cyanobacteria, heterocytous, mangrove environment, biodiversity.

Introduction

Cyanobacteria are the most ancestral lineage responsible for the generation of an oxygen-rich atmosphere that originated before 3.0 Ga **(Schirrmeister *et al.*, 2015).** Taxonomic classification of cyanobacteria is the only method for understanding their diversity and diversification processes **(Komarek, 2013).** The modern taxonomic classification of cyanobacteria must be continually revised to

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incorporate data resulting from the polyphasic evaluation of cyanobacterial diversity. **Komarek and Anagnostidis (1998)** classified cyanobacteria into 14 families based on the presence or absence of false branching, true branching and heterocytes, for discussion, they used the terms 'heterocytes' and 'hormogonia' rather than 'heterocysts' and 'hormogones', as recommended by the International Association for Cyanophyte Research (IAC) **(Mollenhauer *et al.*, 1994)**.

Cyanobacteria play a pivotal role in mangrove ecosystems as they are the primary producers of organic carbon and nitrogen. Many cyanobacterial species provide nitrogen by biological nitrogen fixation and as a significant group within the diazotrophic guild, contribute to the availability of nitrogen in the system **(Toledo *et al.*, 1995)**. Studies on the nitrogen-fixing capability of cyanobacteria in mangroves have been carried out in a few regions of the world **(Ramachandran and Venugopalan, 1987; Kyaruzi *et al.*, 2003; Boopathi, 2011)**. Some studies focused on cyanobacteria that grow on the surface of mangrove tree trunks, aerial roots, pneumatophores and leaves and their contribution to biological nitrogen-fixing capability has been assessed **(Mann and Steinke, 2003; Lugomela and Bergman, 2002)**.

Data on mangrove-associated cyanobacteria are scarce throughout the world. Research on this topic is particularly rare and is restricted to certain regions **(Lambert *et al.*, 1987)**. To the best of our knowledge, the first published literature appeared in 1977 **(Potts and Whitton, 1977)** who reported the occurrence of heterocytous mangrove-associated cyanobacteria *Calothrix crustacea* Thuret ex Bornet & Flahault 1886 (Current name: *Scytonematopsis crustacea* (Thuret ex Bornet & Flahault) Kovacik & Komarek 1988) from the intertidal zone of the lagoon shores of West Island, Aldabra. The general aim of this work is to provide an updated revision of the diversity and distribution of previously recorded cyanobacteria in mangrove ecosystems. The need for conducting surveys to fulfil research gaps in this field, including the global distribution pattern of mangrove-associated cyanobacteria, can be used as a reliable database for future major research studies in this field.

Materials and Methods

The data on heterocytous cyanobacteria associated with mangroves has been compiled solely from published works of literature from 1977-2020. We used 33 research papers and books published nationally and internationally to create a catalogue of cyanobacterial species and the articles in which they are cited. Cyanobacteria can be found in diverse habitats, including epipsammic/edaphic, epizoic, epiphytic, planktic, benthic, and epilithic forms, all of which are common in mangrove ecosystems. The occurrence of cyanobacterial species may not be explicitly indicated in some publications; instead, such species are included under the category 'mangrove environment'. Different methods for collecting cyanobacteria were discussed in the original research literature, which is cited in this study.

The list is exclusively based on published works of literature. We considered only published works that referenced cyanobacteria at the species level of identification. Names of taxa are given with the proper author citation. Species are classified according to their respective families. The species are classified based on the current classification system proposed by **Komarek *et al.* (2014)** and **Hauer and Komarek (2021)** and the entities of the taxonomically accepted species are verified by **Guiry and Guiry (2021).** When a specific or infraspecific taxon is recorded under a synonym if cited, it is represented under the currently accepted names.

Results and Discussion

This study aims to compile a catalogue of mangroves inhabiting cyanobacteria and to revise and update the nomenclature to reflect current taxonomically accepted names for the previously documented species. From the 33 research articles and books published nationally and internationally from 1977 to 2020, we considered cyanobacteria to have species-level identification. The results indicated 70 heterocytous cyanobacterial species in which 47 are from mangrove environments, 17 epiphytic, 11 planktic, 12 epilithic, 5 epipsammic/edaphic, 2

benthic, 1 epiphyllic and 1 epizoic, while 4 species co-occur among mangrove environments, epipsammic and epiphytic, 2 species co-occur in mangrove environments, epilithic and epiphytic, 4 species co-occur in both epiphytic and mangrove environments, 4 species co-occur in both planktic and mangrove environments, 1 species co-occurs in both epilithic and epizoic, 1 species co-occurs in both epilithic and mangrove environments, 1 species co-occurs in both planktic and benthic environments (Table 1). From this documentation study, the family Nostocaceae was the dominant family with 27 taxa, followed by Calotrichaceae had 12 taxa, Rivulariaceae and Scytonemataceae had 10 taxa each, Aphanizomenonaceae had 5 taxa, Hapalosiphonaceae had 2 taxa and Chlorogleopsidaceae, Heteroscytonemataceae, Microchaetaceae and Tolypothrichaceae had one species each (Figure 1).

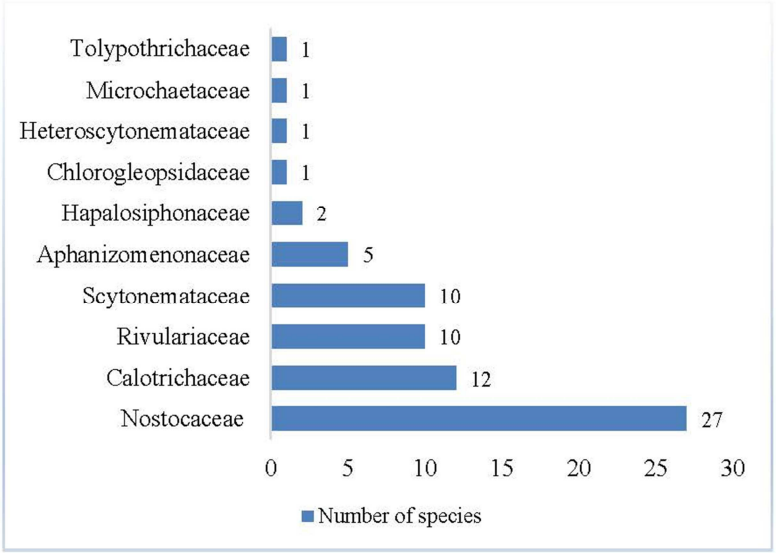

Figure 1: Graphical position and number of species from the mangrove-associated cyanobacteria according to family.

A review on the distribution records of mangrove- associated heterocytous cyanobacteria: an update

Table 1: Occurrence of cyanobacterial species from the mangrove environments, habitat, country/provinces and their respective citations are provided. The updated species name was based on Algaebase; (=) symbol indicates the species synonyms if cited in the referred work.

List of cyanobacterial species	Habitat	Country/ Province	References
Nostocales - Aphanizomenonaceae			
Anabaenopsis arnoldii Aptekar 1926	Planktic	India	**Sen and Naskar, 2003**
Dolichospermum flosaquae (Brebisson ex Bornet & Flahault) P.Wacklin, L.Hoffmann & J.Komarek 2009 (=) *Anabaena flosaquae* Brebisson ex Bornet & Flauhault 1886	Mangrove environment	India	**Barman *et al.*, 2015**
Dolichospermum spiroides (Klebhan) Wacklin, L.Hoffmann & Komarek 2009 (=) *Anabaena spiroides* Klebahn 1895	Mangrove environment	India	**Bhuvaneshwari and Muruganandam, 2016**
			Priya *et al.*, 2019
Nodularia spumigena Mertens ex Bornet & Flahault 1888	Mangrove environment	India	**Ramamurthy and Abhinand, 2016**
	Mangrove Swamps	Saudi Arabia	**Hussain and Khoja, 1993**
	Mangrove environment	India	**Sudha, 2005**
	Mangrove environment	India	**Sudha *et al.*, 2007**
	Epipsammic	Nigeria	**Essien *et al.*, 2008**
	Epiphytic	India	**Nedumaran *et al.*, 2008**
Nodularia spumigena var. *major* Bornet & Flahault 1886	Mangrove Swamps	Saudi Arabia	**Hussain and Khoja, 1993**
Nostocales – Calotrichaceae			
Calothrix aeruginosa Woronichin 1923	Epiphytic	Australia	**Huisman *et al.*, 2015**
	Epiphytic	Egypt	**Potts, 1980**
Calothrix bharadwajae G.De Toni 1939	Mangrove environment	India	**Silambarasan *et al.*, 2012**

Calothrix breviarticulata West & G.S.West 1897	Mangrove environment	Saudi Arabia	**Mohammed and Al-Shehri, 2015**
Calothrix brevissima G.S.West 1907	Epiphytic, Edaphic	Pakistan	**Bano and Siddiqui, 2007**
	Mangrove environment	India	**Silambarasan *et al.*, 2012**
Calothrix castellii Bornet & Flahault 1886	Epiphytic	India	**Boopathi, 2011**
Calothrix clavata G.S.West 1914	Mangrove environment	India	**Barman *et al.*, 2015**
Calothrix confervicola C.Agardh ex Bornet & Flahault 1886	Micrbial mat, Mangrove Swamps	Saudi Arabia	**Hussain and Khoja,1993**
Calothrix contarenii Bornet & Flahault 1886	Epipsammic	Aldabra Islands	**Potts and Whitton, 1980**
	Epiphytic	Africa	**Lambert *et al.*, 1989**
	Epiphytic	Africa	**Steinke et al., 2003**
	Mangrove environment	India	**Sudha, 2005**
	Mangrove environment	India	**Sudha et al., 2007**
	Mangrove environment	India	**Sakthivel and Kathiresan, 2013**
	Mangrove environment	India	**Bhuvaneshwari and Muruganandam, 2016**
	Mangrove environment	India	**Priya *et al.*, 2019**
Calothrix fusca Bornet & Flahault 1886	Epilithic	Pakistan	**Bano and Siddiqui, 2007**
Calothrix ghosei Bharadwaja 1935	Mangrove environment	India	**Bhuvaneshwari and Muruganandam, 2016**
			Priya et al., 2019
Calothrix pulvinata C.Agardh ex Bornet & Flahault 1886	Mangrove Swamps, Epilithic	Saudi Arabia	**Hussain and Khoja, 1993**
	Epiphytic	India	**Nedumaran *et al.*, 2008**

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Calothrix scopulorum C.Agardh ex Bornet & Flahault 1886	Epilithic	Egypt	**Potts, 1980**
	Epiphytic	Africa	**Lambert *et al.*, 1989**
	Epiphytic	Africa	**Silva, 1991**
	Microbial mat, Mangrove Swamps	Saudi Arabia	**Hussain and Khoja, 1993**
	Epiphytic	Africa	**Steinke *et al.*, 2003**
	Mangrove environment	India	**Sudha, 2005**
	Mangrove environment	India	**Sudha *et al.*, 2007**
	Mangrove environment	India	**Sakthivel and Kathiresan, 2013**
	Mangrove environment	Saudi Arabia	**Mohammed and Al-Shehri, 2015**
Nostocales – Chlorogloeopsidaceae			
Chlorogloea fritschii A.K.Mitra 1950; Nostoc fritschii (Mitra) Schwabe & El Ayouty 1966	Epiphytic	Pakistan	**Bano and Siddiqui, 2007**
	Mangrove environment	India	**Sakthivel and Kathiresan, 2013**
	Mangrove environment	India	**Joseph and Saramma, 2016**
Nostocales – Hapalosiphonaceae			
Hapalosiphon welwitschii West & G.S.West 1897	Mangrove environment	India	**Sudha, 2005**
	Mangrove environment	India	**Sudha *et al.*, 2007**
	Mangrove environment	India	**Ramamurthy and Abhinand, 2016**
Mastigocoleus testarum Lagerheim ex Bornet & Flahault 1886	Epilithic	Egypt	**Potts, 1980**
	Epizoic	India	**Sen and Naskar, 2003**

Nostocales – Heteroscytonemataceae			
Heteroscytonema crispum (Bornet ex De Toni) G.B.McGregor & Sendall 2018 (=) *Scytonema crispum* Bornet ex De Toni 1907	Epiphytic	Australia	**Huisman *et al.*, 2015**
	Mangrove environment	India	**Sakthivel and Kathiresan, 2013**
Nostocales – Microchaetaceae			
Microchaete grisea Thuret ex Bornet & Flahault 1886	Epilithic	Pakistan	**Bano and Siddiqui, 2007**
	Mangrove environment	India	**Sakthivel and Kathiresan, 2013**
Nostocales – Nostocaceae			
Anabaena iyengarii Bharadwaja 1935	Mangrove environment	India	**Silambarasan *et al.*, 2012**
	Mangrove environment	India	**Sakthivel and Kathiresan, 2013**
Anabaena orientalis S.C.Dixit 1936	Mangrove environment	India	**Bhuvaneshwari and Muruganandam, 2016**
	Mangrove environment	India	**Priya *et al.*, 2019**
Anabaena oscillarioides Bory ex Bornet & Flahault 1886	Microbial mat	Saudi Arabia	**Hussain and Khoja, 1993**
Anabaena sphaerica Bornet & Flahault 1886	Mangrove environment	India	**Silambarasan et al., 2012**
	Mangrove environment	India	**Sakthivel and Kathiresan, 2013**
	Mangrove environment	India	**Barman *et al.*, 2015**
	Mangrove environment	Saudi Arabia	**Mohammed and Al-Shehri, 2015**
	Mangrove environment	India	**Ramamurthy and Abhinand, 2016**
Anabaena torulosa Lagerheim ex Bornet & Flahault 1886	Mangrove environment	India	**Silambarasan *et al.*, 2012**
Cylindrospermum majus Kutzing ex Bornet & Flahault 1888	Planktic	India	**Nedumaran *et al.*, 2008**

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Desmonostoc muscorum (C.Agardh ex Bornet & Flahault) Hrouzek & Ventura 2013 (=) *Nostoc muscorum* C.Agardh ex Bornet & Flahault 1888	Planktic, Benthic	India	**Ram and Shamina, 2015**
	Mangrove environment	India	**Ramamurthy and Abhinand, 2016**
	Mangrove environment	India	**Ram and Shamina, 2017**
Hydrocoryne enteromorphoides (Grunow ex Bornet & Flahault) Umezaki & M.Watanabe 1994	Mangrove Swamps, Pelagic	Saudi Arabia	**Hussain and Khoja, 1993**
Nostoc carneum C.Agardh ex Bornet & Flahault 1886	Mangrove environment	India	**Barman *et al.*, 2015**
Nostoc commune Vaucher ex Bornet & Flahault 1888	Mangrove environment	India	**Barman *et al.*, 2015**
Nostoc ellipsosporum Rabenhorst ex Bornet & Flahault 1886	Mangrove environment	India	**Barman *et al.*, 2015**
	Mangrove environment	India	**Ram and Shamina, 2017**
Nostoc linckia Bornet ex Bornet & Flahault 1886 (=) *Nostoc piscinale* Kutzing ex Bornet & Flahault 1886	Epiphytic	India	**Sen and Naskar, 2003**
	Mangrove environment	India	**Bhuvaneshwari and Muruganandam, 2016**
	Mangrove environment	India	**Priya *et al.*, 2019**
Nostoc microscopicum Carmichael ex Bornet & Flahault 1886	Mangrove environment	India	**Shamina *et al.*, 2014**
	Mangrove environment	India	**Ram and Shamina, 2017**
Nostoc oryzae (F.E.Fritsch) J.Komarek & K.Anagnostidis 1989 (=) *Anabaena oryzae* F.E.Fritsch 1949	Epiphytic	India	**Boopathi, 2011**
Nostoc paludosum Kutzing ex Bornet & Flahault 1886	Mangrove environment	India	**Nedumaran *et al.*, 2008**
	Mangrove environment	India	**Ram and Shamina, 2017**
Nostoc passerinianum Bornet & Thuret ex Bornet & Flahault 1886	Benthic	India	**Ram and Shamina, 2015**
	Mangrove environment	India	**Ram and Shamina, 2017**
Nostoc punctiforme Hariot 1891	Planktic	India	**Sen and Naskar, 2003**

Raphidiopsis curvata Fritsch & M.F.Rich 1930	Planktic	India	**Sen and Naskar, 2003**
Raphidiopsis indica R.N.Singh 1942	Planktic	India	**Sen and Naskar, 2003**
	Mangrove environment	India	**Sakthivel and Kathiresan, 2013**
Richelia intracellularis J.Schmidt 1901	Mangrove environment	India	**Ramamurthy and Abhinand, 2016**
Trichormus doliolum (Bharadwaja) Komarek & Anagnostidis 1989 (=) *Anabaena doliolum* Bharadwaja 1935	Planktic	India	**Sen and Naskar, 2003**
Trichormus khannae (Skuja) Komarek & Anagnostidis 1989 (=) *Anabaena khannae* Skuja 1949	Mangrove environment	India	**Joseph and Saramma, 2016**
Trichormus anomalus (F.E.Fritsch) Komarek & Anagnostidis 1989 (=) *Anabaena anomala* F.E.Fritsch 1949	Planktic	India	**Sen and Naskar, 2003**
	Rock pool water, Coastal waters of mangrove waters	Pakistan	**Bano and Siddiqui, 2007**
Trichormus ellipsosporus (F.E.Fritsch) Komarek & Anagnostidis 1989 (=) *Anabaena variabilis* var. *ellipsospora* F.E. Fritsch 1949	Mangrove environment	India	**Silambarasan *et al.*, 2012**
Trichormus gelatinicola (Ghose) Komarek & Anagnostidis 1989 (=) *Anabaena gelatinicola Ghose 1924*	Planktic	India	**Sen and Naskar, 2003**
Trichormus variabilis (Kutzing ex Bornet & Flahault) Komarek & Anagnostidis 1989 (=) *Anabaena variabilis* Kutzing ex Bornet & Flahault 1886	Mangrove Swamps	Saudi Arabia	**Hussain and Khoja, 1993**
	Planktic	India	**Nedumaran *et al.*, 2008**
	Mangrove environment	India	**Barman *et al.*, 2015**
Wollea ambigua (C.B.Rao) R.Y.Singh 1942 (=) *Anabaena ambigua* C.B.Rao 1937	Planktic	India	**Kannan and Vasantha, 1992**
	Planktic	India	**Nedumaran *et al.*, 2008**

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Nostocales – Rivulariaceae			
Dichothrix baueriana Bornet & Flahault 1886	Mangrove environment	India	**Silambarasan *et al.*, 2012**
	Mangrove environment	India	**Sakthivel and Kathiresan, 2013**
	Mangrove environment	India	**Ramamurthy and Abhinand, 2016**
Dichothrix penicillata Zanardini ex Bornet & Flahault 1886	Mangrove Swamps, Epilithic	Saudi Arabia	**Hussain and Khoja, 1993**
Dichothrix utahensis Tilden 1898	Epiphytic	Australia	**Huisman *et al.*, 2015**
Phyllonema aviceniicola Alvarenga, Rigonato, Branco, Melo & M.F.Fiore 2016	Epiphyllic	Brazil	**Alvarenga *et al.*, 2016**
Kyrtuthrix dalmatica Ercegovic 1929	Epilithic	Egypt	**Potts, 1980**
Kyrtuthrix maculans (Gomont) I.Umezaki 1958	Epilithic	Egypt	**Potts, 1980**
Gardnerula corymbosa De Toni 1936	Epipsammic	Egypt	**Potts, 1980**
Rivularia atra Roth ex Bornet & Flahault 1886	Epiphytic	Australia	**Beanland and Woelkerling, 1983**
	Epiphytic	Australia	**Huisman *et al.*, 2015**
Rivularia bullata Berkeley ex Bornet & Flahault 1886	Epiphytic	Africa	**Lambert *et al.*, 1989**
	Epiphytic	Africa	**Steinke *et al.*, 2003**
Rivularia polyotis Roth ex Bornet & Flahault 1886	Epiphytic	Australia	**Beanland and Woelkerling, 1983**
	Mangrove Swamps	Saudi Arabia	**Hussain and Khoja, 1993**
	Epiphytic	Egypt	**Gab-Alla, 2000**
Nostocales – Scytonemataceae			
Scytonema hofmanii C.Agardh ex Bornet & Flahault 1886	Epiphytic	Africa	**Lambert *et al.*, 1989**
	Epilithic	Saudi Arabia	**Hussain and Khoja, 1993**
	Epilithic	India	**Sen and Naskar, 2003**
	Epiphytic	Africa	**Steinke *et al.*, 2003**
Scytonema arcangelii Bornet & Flahault 1886	Mangrove environment	Brazil	**Nogueira and Ferrieira-Correia, 2001**

Scytonema bohneri Schmidle 1901	mangrove environment	India	**Barman *et al.*, 2015**
	Planktic	India	**Ram and Shamina, 2015**
	Mangrove environment	India	**Ram and Shamina, 2017**
Scytonema chiastum Geitler 1925	mangrove environment	India	**Silambarasan *et al.*, 2012**
Scytonema insulare C.L.Sant'Anna 1988	Mangrove environment	Brazil	**Nogueira and Ferrieira-Correia, 2001**
Scytonema leptobasis S.L.Ghose 1931	Planktic	India	**Ram and Shamina, 2015**
	Mangrove environment	India	**Ram and Shamina, 2017**
Scytonema saleyeriense Weber Bosse 1913	Mangrove Swamps	Saudi Arabia	**Hussain and Khoja, 1993**
Scytonema varium Kutzing ex Bornet & Flahault 1886	Mangrove environment	India	**Silambarasan *et al.*, 2012**
Scytonematopsis crustacea (Thuret ex Bornet & Flahault) Kovacik & Komarek 1988 (=) *Calothrix crustacea* Thuret ex Bornet & Flahault 1886	Mangrove environment	India	**Sakthivel and Kathiresan, 2013**
	Mangrove environment	Saudi Arabia	**Mohammed and Al-Shehri, 2015**
	Epipsammic	Aldabra	**Potts and Whitton, 1977**
	Epiphytic	Egypt	**Potts, 1980**
	Epipsammic	Aldabra Islands	**Potts and Whitton, 1980**
	Epiphytic	Epiphytic	**Silva, 1991**
	Mangrove Swamps, Epilithic	Saudi Arabia	**Hussain and Khoja,1993**
	Mangrove environment	India	**Dhargalkar, 1994**
	Epiphytic	Pakistan	**Saifullah *et al.*, 1997**
	Epiphytic	India	**Sen and Naskar, 2003**
	Mangrove environment	India	**Sudha, 2005**
	Mangrove environment	India	**Sudha *et al.*, 2007**

Scytonematopsis pilosa (Harvey ex Bornet & Flahault) I.Umezaki & M.Watanabe 1994 (–) *Calothrix pilosa* Harvey ex Bornet & Flahault 1886	Epilithic	Egypt	**Potts, 1980**
Nostocales – Tolypothricaceae			
Tolypothrix tenuis Kutzing ex Bornet & Flahault 1886	Mangrove environment	India	**Joseph and Saramma, 2016**

While compiling the elaborate list of cyanobacterial diversity with a special focus on mangrove environments, we consider only the specimen taxonomically identified up to the species level. It is noticed that research on mangrove-associated cyanobacterial diversity has become more focused since 1990 and a significant rise in biodiversity research has been recorded over recent decades. However, no taxonomic studies have been published as of 2020. There is a total lack of knowledge on the taxonomy of mangrove-associated cyanobacteria and are very scarce and meagre. As a result, the diversity and ecological importance of these habitats are highly neglected.

Based on existing data, it is clear that cyanobacterial floristic surveys should be carried out in diverse biotopes of tropical regions that are still to be explored as they can greatly contribute to our understanding of geographic distribution as well as relevant information for the taxonomy of these organisms. Recent developments in polyphasic approaches will help to explore a good percentage of the cyanobacterial community that can be exploited for the benefit of mankind.

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Updated Checklist of Mangrove-Associated Cyanobacterial Diversity to the End of 2020

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ABSTRACT: This review presents an overview of the diverse habitats of mangrove-associated cyanobacteria, based on published literature records from 1889 to 2020. The primary goal of this study is to document the cyanobacteria and to revise and update nomenclature to reflect current taxonomic knowledge for previously reported species. There are a total of 409 cyanobacterial species. The dominant order was *Oscillatoriales* with 147 species (88 *Oscillatoriaceae*, 40 *Microcoleaceae*, 9 *Coleofasciculaceae*, 8 *Gomontiellaceae,* and 2 *Borziaceae*). *Synechococcales* (23 *Merismopediaceae,* and *Leptolyngbyaceae*, 11 *Pseudanabaenaceae*, 16 *Synechococcales familia insertae sedis*, 3 *Synechococcaceae*, 2 *Chamaesiphonaceae*, *Coleosphaeriaceae Trichocoleusaceae* and *Oculatellaceae* had only one species) was the second most abundant order with 83 species. *Chroococcales* (47 *Chroococcaceae*, 11 *Microcystaceae*, 8 *Aphanothecaceae*, 2 *Entophysalidaceae*, *Gomphosphaeriaceae*, *Stichosiphonaceae* and *Cyanothricaceae* had only 1 species) was the third most abundant order with 73 species. *Nostocales* (27 *Nostocaceae*, 12 *Calotrichaceae*, 10 *Scytonemataceae* and *Rivulariaceae*, 5 *Aphanizomenonaceae*, 2 *Hapalosiphonaceae* and *Chlorogloeopsidaceae*, *Heteroscytonemataceae*, *Microchaetaceae* and *Tolypothrichaceae* had one species each) was the fourth most abundant order with 70 species. *Pleurocapsales* had 26 species (8 *Xenococcaceae*, 7 *Dermocarpellaceae* and *Hyellaceae* and 4 *Hydrococcaceae*). *Spirulinales* had 7 *Spirulinaceae* species, *Chroococcidiopsidales* had 2 *Chroococcidiopsidaceae* species and *Gloeobacterales* had only one *Gloeobacteraceae* species.

KEY WORDS: Cyanobacteria, mangrove environment, marine, edaphic, epiphytic, epipsammic, benthic, planktic

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INTRODUCTION

Cyanobacteria are one of the most fascinating and significant groups of oxygen-evolving, gram-negative, photoautotrophic microorganisms from evolutionary, phylogenetic and ecological perspectives. Due to their wide range of adaptability to harsh and unfavourable conditions, cyanobacteria are found in all ecological habitats extending from the extremely cold deserts of the Arctic and Antarctic Zones (Mataloni, Komárek, 2004; Zaki et al., 2020) to the very extreme hot springs (Miller, Castenholz, 2000). Whilst cyanobacteria are regarded as cosmopolitans, this term should be used carefully because while certain species are extensively distributed, the majority of the group is confined to well-delimited habitats (Komárek, 1985, 1994; Komárek, Komarkova-Legnerova, 2007). Certain species are widely distributed but always occur in the same sort of environment, reflecting their ecological preferences and adaptations to diverse habitats.

Regarding cyanobacterial biodiversity, the literature shows that the tropics and subtropics are still understudied, and their biodiversity is considerably underestimated. It is assumed that less than 10% of tropical cyanobacterial diversity is known (Komárek, 2006). The studies on cyanobacteria in mangrove environments are very important because of their high capability to fix nitrogen, making them ideal candidates for future restoration and rehabilitation of destroyed mangroves (Bashan et al., 1998).

Conducting surveys is necessary to fulfil the research gaps that exist in this area regarding the distribution pattern of the mangrove-associated cyanobacteria across the world. The given checklist serves as a reliable catalogue for the forthcoming principal research interest in this area.

MATERIAL AND METHODS

The documentation of mangroves-associated cyanobacteria have been listed purely based on the available published works of literature. To create a catalogue of species and respective articles in which they are cited, we referred to 82 research papers and books published nationally and internationally. Cyanobacteria are observed in a variety of habitats, including epipsammic/edaphic, epiphytic, planktic, benthic and epilithic forms, which are considered to be prevalent in mangrove environments. A list of publications, together with the location of study areas and their respective country are given in the Table. In some literature, the occurrence of cyanobacterial species may not be mentioned specifically, such species are listed under the category, 'mangrove environment'. Different methods adopted for the cyanobacterial collection were discussed in the original research literature which is cited in the present study.

The list is exclusively based on the published research findings. Names of taxa are given with author citations. Species are classified according to their respective family. The species are classified based on the current classification system and the entity of the taxonomically accepted species are verified by Guiry and Guiry (2021).

TABLE: List of scientific publications used in this study. References habitats and locations/countries are provided here. References are arranged in chronological order

No.	References	Habitat	Location/Country
1	Moebius, 1889	Mangrove environment	Joinville's mangroves, Brazil
2	Joly, 1951	Mangrove environment	Paraná State, Brazil
3	Joly, 1957	Mangrove environment	Santos, Brazil
4	Millard, Broekhuysen, 1970	Mangrove environment	St. Lucia estuary, South Africa
5	Burkholder, Almodovar, 1973	Epiphytic	Puerto Rico
6	Dor, 1975	Epiphytic	Sinai estuary
7	Potts, Whitton, 1977	Epipsammic	Aldabra Atoll
8	Potts, 1979	Epipsammic	Sinai estuary
9	Potts, 1980	Epilithic, Epiphytic	Sinai estuary
10	Potts, Whitton, 1980	Epipsammic	Aldabra Atoll
11	Beanland, Woelkerling, 1983	Epiphytic	Spencer Gulf, South Australia
12	Sant'Anna et al., 1983	Mangrove environment	Ilha do Cardoso, Brazil
13	Oliveira, 1984	Mangrove environment	Brazil
14	Carmo, 1987	Mangrove environment	North of Baía de Vitória, Espírito Santo State, Brazil
15	Ramachandran, Venugopalan, 1987	Planktic	Portonovo, TamilNadu, India
16	Sant'Anna, 1988	Mangrove environment	São Paulo, Southern Brazil
17	Santra et al., 1988	Epiphytic	West Bengal, India
18	Coppejans, Gallin, 1989	Mangrove environment	Gazi Bay, Kenya
19	Lambert et al., 1989	Epiphytic	South Africa
20	Rodriguez, Stoner, 1990	Epiphytic	Laguna Joyuda, west coast of Puerto Rico
21	Steinke, Naidoo, 1990	Epiphytic	St. Lucia estuary, South Africa
22	Silva, 1991	Epiphytic	Inhaca Island, Mozambique
23	Kannan, Vasantha, 1992	Planktic	Pichavaram, Tamil Nadu, India
24	Hussain, Khoja, 1993	Mangrove Swamps, Epilithic	Farasan Archipelago, Saudi Arabia
25	Mann, Steinke, 1993	Epiphytic	Beachwood Mangrove Nature Reserve, South Africa
26	Branco et al., 1994	Epiphytic	South-east region of Brazil and the south of Mozambique
27	Dhargalkar, 1994	Mangrove environment	India
28	Phillips et al., 1994	Epiphytic	Beachwood Mangrove Nature Reserve, South Africa
29	Saifullah, Taj, 1995	Epiphytic	Karachi, Pakistan
30	Toledo et al., 1995a	Epiphytic	North-western Mexico
31	Toledo et al., 1995b	Epiphytic	North-western Mexico
32	Branco et al., 1996	Epipsammic, Epiphytic	Cardoso Island mangroves, São Paulo State, Brazil

33	Phillips et al., 1996	Epiphytic	Beachwood Mangrove Nature Reserve, South Africa
34	Branco et al., 1997	Epiphytic, Mangrove environment	Cardoso Island mangroves, São Paulo State, Brazil
35	Saifullah et al., 1997	Epiphytic	Balochistan, Pakistan
36	Bashan et al., 1998	Epiphytic	Laguna de Balandra and western Ensenada de La Paz, Mexico
37	Gab-Alla, 2000	Epiphytic	Nabq area, Egypt
38	Zaib-Un-Nisa et al., 2000	Epiphytic	Karachi, Pakistan
39	Banerjee, Santra, 2001	Planktic	Sundarbans, India
40	Nogueira, Ferrieira-Correia, 2001	Mangrove environment	São luís, state of Maranhão, Brazil
41	Selvakumar, Sundararaman, 2001	Epiphytic	Muthupet estuary, Tamil Nadu, India
42	Branco et al., 2003	Epiphytic, Mangrove environment	Ilha de Itamaracá, north coast of the State of Pernambuco, Brazil
43	Kyaruzi et al., 2003	Mangrove environment	Maruhubi, Zanzibar
44	Sen, Naskar, 2003	Planktic, Epipsammic, Epilithic, Epizoic	Sundarbans, India
45	Steinke et al., 2003	Epiphytic	Kosi System, South Africa
46	Sudha, 2005	Mangrove environment	Muthupet, Tamil Nadu, India
47	Sudha et al., 2007	Mangrove environment	Muthupet, Tamil Nadu, India
48	Bano, Siddiqui, 2007	Edaphic, Epiphytic, Epizoic, Epilithic, Coastal waters of mangrove environment, Rock pool waters of mangrove environment, mangrove swamps	Buleji, Pakistan
49	Essien et al., 2008	Epipsammic	Qua Iboe Estuary, Nigeria
50	Nedumaran et al., 2008	Epiphytic, Planktic	Pichavaram, Tamil Nadu, India
51	Pena-Salamanca, 2008	Epiphytic	Buenaventura bay, Pacific coast of Colombia
52	Rajkumar et al., 2009	Planktic	Pichavaram, Tamil Nadu, India
53	Tessy, Saritha, 2010	Mangrove environment	Poyya, Thrissur, Kerala, India
54	Boopathi, 2011	Epiphytic	Pichavaram and Muthupet, Tamil Nadu, India
55	Leon-Tejera et al., 2011	Epiphytic	Baja California Sur, Mexico
56	Rigonato et al., 2012a	Epiphytic	Cardoso Island, Sao Paulo State, Brazil
57	Rigonato et al., 2012b	Epipsammic	Cardoso Island, Sao Paulo State, Brazil
58	Perez-Estrada et al., 2012	Epiphytic	Baja California Sur, Mexico

59	Silambarasan et al., 2012	Mangrove environment	Parangipettai, Ariyankuppam and Mudasal odai, Tamil Nadu, India
60	Sakthivel, Kathiresan, 2013	Mangrove environment	Pichavaram, Parangipettai and Mudasal odai, Tamil Nadu, India
61	Paul, Saritha, 2013	Mangrove environment	Poyya, Thrissur, Kerala, India
62	Saifullah et al., 2014	Planktic	Sarawak, Malaysia
63	Fatimahsari et al., 2014	Epiphytic	Cagar Alam Pulau Dua (CAPD) Serang, Banten Indonesia
64	Shamina et al., 2014	Mangrove environment	Kerala, India
65	Rao et al., 2015	Planktic	Visakhapatnam, India
66	Barman et al., 2015	Mangrove environment	Sundarbans, India
67	Huisman et al., 2015	Epiphytic	Shark Bay, Western Australia
68	Mohamed, Al-Shehri, 2015	Mangrove environment	Ash Shuqaiq, Al Qahmah and Amaq, Saudi Arabia
69	Ram, Shamina, 2015	Epiphytic, Planktic, Benthic	Kerala, India
70	Ahmed et al., 2016	Mangrove environment	Karachi, Pakistan
71	Joseph, Saramma, 2016	Mangrove environment	Cochin, India
72	Bhuvaneshwari, Muruganandam, 2016	Mangrove environment	Thondiyakadu, Tamil Nadu, India
73	Alvarenga et al., 2016	Epiphyllic	Sao Paulo, Brazil
74	Ramamurthy, Abhinand, 2016	Mangrove environment	Manakudy, Tamil Nadu, India
75	Ans, Mendez, 2017	Mangrove environment	Ernakulam, Kerala, India
76	Kumar et al., 2017	Mangrove environment	Muthukuda, Tamil Nadu, India
77	Ram, Shamina, 2017	Mangrove environment	Kerala, India
78	Chakraborty et al., 2018	Epipsammic	Sundarbans, India
79	Chakraborty et al., 2019	Epipsammic	Sundarbans, India
80	Priya et al., 2019	Mangrove environment	Kodiakkarai, Tamil Nadu, India
81	Singh, Bhadury, 2019	Planktic	Sundarbans, India
82	Ram, Paul, 2020	Mangrove environment	Kerala, India

RESULTS AND DISCUSSION

As the goal was to look for scientific papers published in this respective study area, we noted that the first published works date the year 1889. The results of the survey indicated 409 mangrove-associated cyanobacterial species (List). The order *Oscillatoriales* was the richest one (147 taxa) followed by *Synechococcales* (83), *Chroococcales* (73), *Nostocales* (70), *Pleurocapsales* (26), *Spirulinales* (7), *Chroococcidiopsidales* (2), and *Gloeobacterales* (1) (List, see below; Fig. 1).

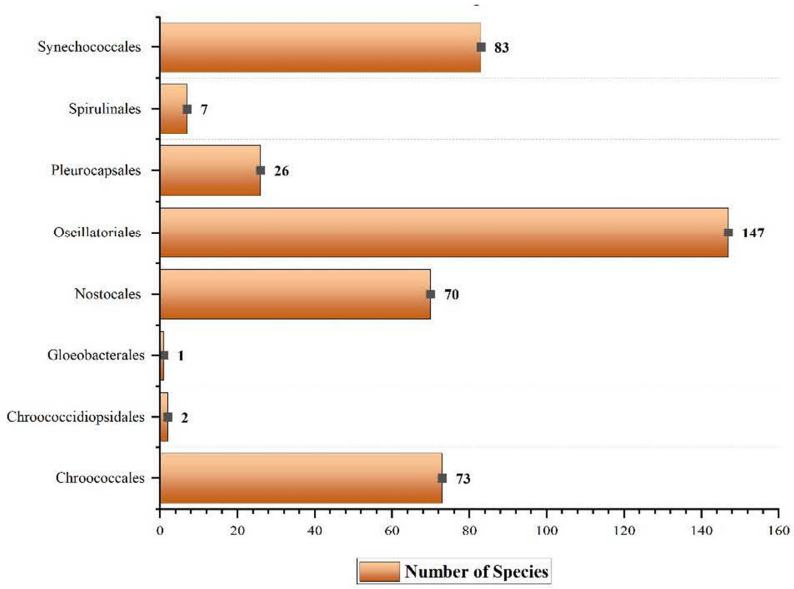

FIG. 1: Graphical position and taxon number of mangrove-associated cyanobacteria according to order

List of cyanobacterial species reported from the previous studies from 1889–2020

(**Habitat**: BE – Benthic; EC – Epiphyllic; ED – Edaphic; EL – Epilithic; EP – Epiphytic; ES – Epipsammic; EZ – Epizoic; ME – Mangrove environment; PC – Pelagic; PH – Periphytic; PL – Planktic). Citations – in brackets cited literature taken from the Table).

Chroococcales – Aphanothecaceae: *Aphanothece bullosa* (Meneghini) Rabenhorst 1865, EP (47); *A. castagnei* (Kützing) Rabenhorst 1865, ES (31), ME (39, 41, 70); *A. elabens* (Brébisson ex Meneghini) Elenkin 1938, ME (68); *A. microscopica* Nageli 1849, ME (46, 47), EZ (48); *A. nidulans* P.Richter 1884, ME (46, 47), EZ (48); *A nidulans* P.Richter 1884, ME (46, 47), EZ (48); *A. pallida* (Kützing) Rabenhorst 1863, EP (69), ME (77); *A saxicola* Nageli 1849, ME (27), EP (32); *A. stagnina* (Sprengel) A.Braun 1863, EP (22), ME (40), PL (44), EL (48).

Chroococcales – Chroococcaceae: *Chondrocystis dermochroa* (Nageli ex Kützing) Komárek & Anagnostidis 1995, ME (71); *Chroococcus cohaerens* (Brébisson) Nageli 1849, EZ, EL, ED, Coastal waters of ME (48), ME (71); *C. dispersus* (Keissler) Lemmermann 1904, EP (48); *C. giganteus* West 1892, ME (24); *C. gomontii* Nygaard 1926, EP (48); *C. hansgirgii* Schmidle 1900, EP, EL (19, 45, 48); *C. indicus* Zeller 1873, EP, ED (48); *C. macrococcus* (Kützing) Rabenhorst 1863, ME (24), EP, ME (48); *C. major* Komárek & Komakova-Legnerova 2007, ME (60); *C. membraninus* (Meneghini) Nageli 1849, EP (32); *C. minor* (Kützing) Nageli 1849, EP (22, 32), ME (46, 47, 68, 72, 80), EP, EL, EZ (48), PL (50); *C. minutus* (Kützing) Nageli 1849, ME (24, 46, 47, 60, 68, 71), EP, EZ, EL, ED, Rockpool waters of ME (48), EP (54); *C. montanus* Hansgirg 1893, EP, EZ (48, 54), ME (71); *C. obliteratus* Richter 1885, EP (55, 58); *C. pallidus* Nageli 1849, EL (48); *C. schizodermaticus* West 1892 Rockpool waters of ME (48); *C. spelaeus* Ercegovic 1925 ME (24, 59, 71); *C. tenax* (Kirchner) Hieronymus 1892, ME, EL (24), EP (48), PL (50); *C. turgidus* (Kützing) Nageli 1849, ME (18, 24, 27, 46, 47, 59, 60, 64, 68, 71, 74, 77), EP, EZ, ED, Coastal waters of ME (19, 45, 48), PL (50); *C. turgidus* var. *maximus* Nygaard 1926, EP (22); *C. turicensis* (Nageli) Hansgirg 1887, ME (24); *C. varius* A.Braun 1876, ME (59); *C. westii* J.B.Petersen 1923, ME (24); *Cyanobacterium cedrorum* (Sauvageau) Komárek, J.Kopecky & Cepak 1999, ME (48, 71, 72, 80);

Cyanosarcina spectabilis (Geitler) Kovacik 1988, EP, EZ, EL, ED, Rockpool waters of ME (38, 48), ME (60); *Dactylococcopsis rhaphidioides* Hansgirg 1888, ME (71); *Gloeocapsa aeruginosa* Kützing 1843, PL (44), ME (46, 47); *G. calcarea* Tilden 1898, EP (48), ME (72, 80); *G. compacta* Kützing 1847, EP, EL (48), ME (71, 72, 80); *G. decorticans* (A.Braun) P.Richter 1930, ES (44); *Gloeocapsa gelatinosa* Kützing 1843, EP, EZ, EL, ED, ME (48, 71), *G. granosa* (Berkeley) Kützing 1847, ME (46, 47); *G. kuetzingiana* Nageli ex Kützing 1849, PL (44), ED (48); *G. livida* (Carmichael) Kützing 1847, ME (71); *G. punctata* Nageli 1849, EL (44), EZ (48), ME (66); *G. quaternata* Kützing 1846, ME (71); *G. rupestris* Kützing 1847, ES (44), ME (71); *G. sanguinea* (C.Agardh) Kützing 1843, ME (24); *G. stegophila* (Itzigsohn) Rabenhorst 1863, ME (46, 47, 60, 68); *Gloeocapsopsis crepidinum* (Thuret) Geitler ex Komárek 1993, ME, EL (24, 38, 40, 46, 47, 48, 60, 71); *G. pleurocapsoides* (Novacek) Komárek & Anagnostidis ex Komárek 1993, EP (48), ME (60); *Gloeothece fuscolutea* (Nageli ex Kützing) Nageli 1849, EP (48); *G. palea* (Kützing) Nageli 1849, ES (32), EZ (48); *G. rhodochlamys* Skuja 1949, EZ (48); *G. rupestris* (Lyngbye) Bornet 1880, EP, EZ (32, 48, 38); *G. samoensis* Wille 1913, EP, EZ, EL, ED, Rockpool water, coastal waters of ME (48); *Lightfootiella montana* (Lightfoot) Hasler, Pentecost, Jahodarova, Dvorak et Pouluckova 2018, EP (20).

Chroococcales – Cyanothrichaceae: *Johannesbaptistia pellucida* (Dickie) W.R.Taylor & Drouet 1938, ME (18, 24, 46, 47, 60, 71), EP (41), PL (44), EL (48).

Chroococcales – Entophysalidaceae: *Entophysalis conferta* (Kützing) Drouet & Daily 1948, ME (24); *E. granulosa* Kützing 1843, ES (10), ME (24, 60).

Chroococcales – Gomphosphaeriaceae: *Gomphosphaeria aponina* Kützing 1836, ME (24, 74); *G. aponina* var. *multiplex* Nygaard 1926, ME (24).

Chroococcales – Microcystaceae: *Microcystis aeruginosa* (Kützing) Kützing 1846, PL (50), ME (59, 60, 72, 76, 80); *M. bengalensis* Banerjii 1936, PL (44); *M. flosaquae* (Wittrock) Kirchner 1898, ME (74); *Microcystis halophila* var. *macrococca* (Hansgirg) P.C.Silva 1996, ME (24); *M. lamelliformis* Holsinger 1954, ME (74); *M. orissica* West 1911, ME (71); *M. protocystis* W.B.Crow 1923, ME (72, 80); *M. pulverea* (H.C.Wood) Forti 1907, ME (74); *M. robusta* (H.W.Clark) Nygaard 1925, EP (41), ME (72, 80); *M. smithii* Komárek & Anagnostidis 1995, PL (44), ME (46, 47), EP (54); *M. viridis* (A.Braun) Lemmermann 1903, ED (48).

Chroococcales – Stichosiphonaceae: *Stichosiphon mangle* L.H.Z.Branco, S.M.F.Silva, & C.L.Sant'Anna 1995, EP (26, 32); *S. sansibaricus* (Hieronymus) F.E.Drouet & W.A.Daily 1956, ME (44, 74).

Chroococcidiopsidales – Chroococcidiopsidaceae: *Chroococcidiopsis cubana* Komárek & Hindak 1975, EP (32); *C. indica* Desikachary 1959, EP (38), EP, EZ, ED, ME (48).

Gloeobacterales – Gloeobacteraceae: *Gloeobacter violaceus* Rippka, J.B.Waterbury & Cohen-Bazire 1974, ME (74).

Nostocales – Aphanizomenonaceae: *Anabaenopsis arnoldii* Aptekar 1926, PL (44); *Dolichospermum flosaquae* (Brébisson ex Bornet & Flahault) P.Wacklin, L.Hoffmann & J.Komárek 2009, ME (66); *D. spiroides* (Klebhan) Wacklin, L.Hoffmann & Komárek 2009, ME (72, 80); *Nodularia spumigena* Mertens ex Bornet & Flahault 1888, ME (24, 46, 47, 74); ES (49); EP (50); *N. spumigena* var. *major* Bornet & Flahault 1886, ME (24).

Nostocales – Calotrichaceae: *Calothrix aeruginosa* Woronichin 1923, EP (9, 67); *C. bharadwajae* G.De Toni 1939, ME (59); *C. breviarticulata* West & G.S.West 1897, ME (68); *C. brevissima* G.S.West 1907, EP, ED (48), ME (59); *C. castellii* Bornet & Flahault 1886, EP (54); *C. clavata* G.S.West 1914, ME (66); *C. confervicola* C.Agardh ex Bornet & Flahault 1886, ME (24); *C. contarenii* Bornet & Flahault 1886, ES (10), EP (19, 45), ME (46, 47, 60, 72, 80); *C. fusca* Bornet & Flahault 1886, EL (48); *C. ghosei* Bharadwaja 1935, ME (72, 80); *C. pulvinata* C.Agardh ex Bornet & Flahault 1886, ME, EL(24), EP (50); *C. scopulorum* C.Agardh ex Bornet & Flahault 1886, EL (9), EP (19, 22, 45), ME (24, 46,47, 60, 68).

Nostocales – Chlorogloeopsidaceae: *Chlorogloeopsis fritschii* (A.K.Mitra) A.K.Mitra & D.C.Pandey 1967, EP (48), ME (60, 71).

Nostocales – Hapalosiphonaceae: *Hapalosiphon welwitschii* West & G.S.West 1897, ME (46, 47, 74); *Mastigocoleus testarum* Lagerheim ex Bornet & Flahault 1886, EL (9), EZ (44).

Nostocales – **Heteroscytonemataceae:** *Heteroscytonema crispum* (Bornet ex De Toni) G.B.McGregor & Sendall 2018, EP (67), ME (60).

Nostocales – **Microchaetaceae:** *Microchaete grisea* Thuret ex Bornet & Flahault 1886, EL (48), ME (60).

Nostocales – **Nostocaceae:** *Anabaena iyengarii* Bharadwaja 1935, ME (59, 60); *A. orientalis* S.C.Dixit 1936, ME (72, 80); *A. oscillarioides* Bory ex Bornet & Flahault 1886, ME (24); *A. sphaerica* Bornet & Flahault 1886, ME (59, 60, 66, 68, 74); *A. torulosa* Lagerheim ex Bornet & Flahault 1886, ME (59); *Cylindrospermum majus* Kützing ex Bornet & Flahault 1888, PL (50); *Desmonostoc muscorum* (C.Agardh ex Bornet & Flahault) Hrouzek & Ventura 2013, PL, BE (69), ME (74, 77); *Hydrocoryne enteromorphoides* (Grunow ex Bornet & Flahault) Umezaki & M.Watanabe 1994, ME, PC (24); *Nostoc carneum* C.Agardh ex Bornet & Flahault 1886, ME (66); *N. commune* Vaucher ex Bornet & Flahault 1888, ME (66); *N. ellipsosporum* Rabenhorst ex Bornet & Flahault 1886, ME (66, 77); *N. linckia* Bornet ex Bornet & Flahault 1886, EP (44), ME (72, 80); *N. microscopicum* Carmichael ex Bornet & Flahault 1886, ME (64, 77); *N. oryzae* (F.E.Fritsch) J.Komárek & K.Anagnostidis 1989, EP (54); *N. paludosum* Kützing ex Bornet & Flahault 1886, ME (50, 77); *N. passerinianum* Bornet & Thuret ex Bornet & Flahault 1886, BE (69), ME (77); *N. punctiforme* Hariot 1891, PL (44); *Raphidiopsis curvata* Fritsch & M.F.Rich 1930, PL (44); *R. indica* R.N.Singh 1942, PL (44), ME (60); *Richelia intracellularis* J.Schmidt 1901, ME (74); *Trichormus doliolum* (Bharadwaja) Komárek & Anagnostidis 1989, PL (44); *T. khannae* (Skuja) Komárek & Anagnostidis 1989, ME (71); *T. anomalus* (F.E.Fritsch) Komárek & Anagnostidis 1989, PL (44), Rock pool water, Coastal waters of ME (48); *T. ellipsosporus* (F.E.Fritsch) Komárek & Anagnostidis 1989, ME (59); *T. gelatinicola* (Ghose) Komárek & Anagnostidis 1989, PL (44); *T. variabilis* (Kützing ex Bornet & Flahault) Komárek & Anagnostidis 1989, ME (24, 66), PL (50); *Wollea ambigua* (C.B.Rao) R.Y.Singh 1942, PL (23, 50).

Nostocales – **Rivulariaceae:** *Dichothrix baueriana* Bornet & Flahault 1886, ME (59, 60, 74); *D. penicillata* Zanardini ex Bornet & Flahault 1886, ME, EL (24); *D. utahensis* Tilden 1898, EP (67); *Phyllonema aviceniicola* Alvarenga, Rigonato, Branco, Melo & M.F.Fiore 2016, EC (73); *Kyrtuthrix dalmatica* Ercegovic 1929, EL (9); *K. maculans* (Gomont) I.Umezaki 1958, EL (9); *Gardnerula corymbosa* De Toni 1936, ES (9); *Rivularia atra* Roth ex Bornet & Flahault 1886, EP (19, 45), *R. bullata* Berkeley ex Bornet & Flahault 1886, EP (19, 45); *R. polyotis* Roth ex Bornet & Flahault 1886, EP (11, 37), ME (24).

Nostocales – **Scytonemataceae:** *Scytonema hofmanii* C.Agardh ex Bornet & Flahault 1886, EP (19, 45), EL (24, 44); *S. arcangelii* Bornet & Flahault 1886, ME (40); *S. bohneri* Schmidle 1901, ME (66, 77), PL (69); *S. chiastum* Geitler 1925, ME (59); *S. insulare* C.L.Sant'Anna 1988, ME (16, 40); *S. leptobasis* S.L.Ghose 1931, PL (69), ME (77); *S. saleyeriense* Weber Bosse 1913, ME (24); *S. varium* Kützing ex Bornet & Flahault 1886, ME (59); *Scytonematopsis crustacea* (Thuret ex Bornet & Flahault) Kovacik & Komárek 1988, ME (27, 46, 47, 60, 68), ES (7, 10), EP (9, 22, 35, 44), ME, EL (24); *S. pilosa* (Harvey ex Bornet & Flahault) I.Umezaki & M.Watanabe 1994, EL (9).

Nostocales – **Tolypothricaceae:** *Tolypothrix tenuis* Kützing ex Bornet & Flahault 1886, ME (71).

Oscillatoriales – **Borziaceae:** *Borzia susedana* Ercegovic 1925, EP (48); *B. trilocularis* Cohn ex Gomont 1892, EP, EZ, EL, rock pool water, ME (48).

Oscillatoriales – **Coleofasciculaceae:** *Anagnostidinema acutissimum* (Kufferath) Strunecky, Bohunicka, Johansen et Komárek 2017, EP, ME (38, 48); *A. deflexum* (W. et G.S.West) Strunecky, Bohunicka, Johansen, Capkova, Raabova, Dvoraak et Komárek 2017, EP (48), ME (71); *A. ionicum* (Skuja) Strunecky, Bohunicka, Johansen, Capkova, Raabova, Dvorak et Komárek 2017, ED, ME (48); *A. lemmermannii* (Woloszynska) Strunecky, Bohunicka, Johansen, Capkova, Raabova, Dvorak et Komárek 2017, EL (48); *Coleofasciculus chthonoplastes* (Thuret ex Gomont) Siegesmund, Johansen et Friedl 2008, ME (1, 4, 18, 24, 27, 34, 40, 42, 44, 45, 46, 47, 60, 64, 66, 68, 74, 77), ES (7, 10), EP (19, 21, 22, 25, 28, 33, 35, 36, 50, 54); *Geitlerinema calcuttense* (Biswas) Anagnostidis 1989, EP (41), ME (71); *Geitlerinema claricentrosum* (N.L.Gardner) Anagnostidis 1989, EP (41), Coastal waters of ME (48); *G. earlei* (N.L.Gardner) Anagnostidis 1989, ME (27); *G. splendidum* (Greville ex Gomont) Anagnostidis 1989, EL, ED (48), ME (60).

Oscillatoriales – Gomontiellaceae: *Hormoscilla pringsheimii* Anagnostidis & Komárek 1988, ED (48); *Katagnymene accurata* Geitler 1982, EL, EZ, EP (48); *Komvophoron anabaenoides* (C.-C.Jao & Y.Y.Li) Anagnostidis & Komárek 1988, ME (48); *K. crassum* (Vozzhennikova) Anagnostidis & Komárek 1988, EZ 48; *K. epiphyticum* Anagnostidis & Komárek 1988, ED (48); *K. minutum* (Skuja) Anagnostidis & Komárek 1988, ED (48); *K. pallidum* (Skuja) Anagnostidis & Komárek 1988, EZ (48); *K. schmidlei* (Jaag) Anagnostidis & Komárek 1988, ME (48, 46, 47, 71).

Oscillatoriales – Microcoleaceae: *Arthrospira gigantea* (Schmidle) Anagnostidis 1998, EP, EL, Rock pool water of ME (48); *A. platensis* Gomont 1892, PL (44, 65), ME (24, 66, 74), EP (22); *A. tenuis* Bruhl & Biswas 1922, ME (71); *Johanseninema constrictum* (Szafer) Hasler, Dvorak & Poulickova 2014, EL, ME (48); *Kamptonema animale* (C.Agardh ex Gomont) Strunecky, Komárek & J.Smarda 2014, ME (46, 72, 80), EP, ME (47, 48); *K. (chlorinum* (Kützing ex Gomont) Strunecky, Komárek & J.Smarda 2014, ED (48), ME (60, 68, 82), ES (44), EP (19, 45); *K. cortianum* (Meneghini ex Gomont) Strunecky, Komárek & J.Smarda 2014, ME (46, 47, 59); *K. formosum* (Bory ex Gomont) Strunecky, Komárek & J.Smarda 2014, ME (24, 46,4759, 60, 68, 72, 74, 75, 80); *K. jasorvense* (Vouk) Strunecky, Komárek & J.Smarda 2014, ME (71); *K. laetevirens* (H.M.Crouan & P.L.Crouan ex Gomont) Strunecký, Komárek & J.Smarda 2014, ME (46, 47, 71), EP (48); *K. okenii* (C.Agardh ex Gomont) Strunecky, Komárek & J.Smarda 2014, ED (48), ME (24, 72, 77, 80, 82), EP (28, 33); *K. proteus* (Skuja) Strunecky, Komárek & J.Smarda 2014, ME (48); *Limnospira maxima* (Setchell & N.L.Gardner) Nowicka-Krawczyk, Muhlsteinova & Hauer 2019, ME (72, 80); *Microcoleus amoenus* (Gomont) Strunecky, Komárek & J.R.Johansen 2013, ME (74); *M. favosus* (Gomont) Strunecky, Komárek & J.R.Johansen 2013, EP (48); *M. lacustris* Farlow ex Gomont 1892, ME (66); *M. lyngbyaceus* Kützing ex Forti 1907, EP (5); *M. paludosus* Gomont 1892, ME (66); *M. vaginatus* Gomont ex Gomont 1892, ME (14, 24); *M. weeksiae* Setchell & N.L.Gardner 1918, ME (34, 42); *Oxynema aestuarii* Chakraborty et Mukherjee 2018, ES (78); *O. acuminatum* (Gomont) Chatchawan, Komárek, Strunecky, Smarda & Peerapornpisal 2012, ME (46, 47, 68, 71, 72, 80), EP (48); *Planktothrix agardhii* (Gomont) Anagnostidis & Komárek 1988, EP, EL, ED (48), PL, EP (50); *P. clathrata* (Skuja) Anagnostidis & Komárek 1988, EP, EZ, ED, rock pool waters, coastal waters of ME (48); *P. compressa* (Utermohl) Anagnostidis & Komárek 1988, EP, EZ, EL, ED, ME (48); *P. mougeotii* Anagnostidis & Komárek 1988, EP, EZ, EL, ED, rock pool water of ME (48); *P. planctonica* (Elenkin) Anagnostidis & Komárek 1988, EP (48); *P. rubescens* (De Candolle ex Gomont) Anagnostidis & Komárek 1988, EP (54), ME (72, 80); *Porphyrosiphon ceylanicus* (Wille) Anagnostidis & Komárek 1988, ME (24); *P. notarisii* Kützing ex Gomont 1892, EP (41); *Pseudophormidium radiosum* (Gomont) Anagnostidis & Komárek 1988, ME (72, 80); *Pseudoscytonema malayense* (Biswas) Elenkin 1949, EP, EZ, EL, ED (48); *Sirocoleum guyanense* Kützing ex Gomont 1892, ME (3); *Symploca hydnoides* Kützing ex Gomont 1892, EL (24), ME (60); *S. muscorum* Gomont ex Gomont 1892, ME (24), EL (48), *Symplocastrum friesii* (Gomont) Kirchner 1898, ME (46, 47); *Trichodesmium erythraeum* Ehrenberg ex Gomont 1892, PL (23, 50, 52, 62), ME (59, 60, 74, 76), PC (24); *Tychonema bornetii* (Zukal) Anagnostidis & Komárek 1988, ME (12); *T. bourrellyi* (J.W.G.Lund) Anagnostidis & Komárek 1988, EL, ED (48); *T. rhodonema* (Skuja) Anagnostidis & Komárek 1988, EZ (48).

Oscillatoriales – Oscillatoriaceae: *Blennothrix cantharidosma* (Gomont ex Gomont) Anagnostidis & Komárek 1988, ME (24); *B. lyngbyacea* (Kützing ex Gomont) Anagnostidis & Komárek 1988, ME (24), EP (29), ES (44); *Limnoraphis birgei* (G.M.Smith) J.Komárek, E.Zapomelova, J.Smarda, J.Kopecky, E.Rejmankova, J.Woodhouse, B.A.Neilan & J.Komarkova 2013, ME (24, 60, 66, 68), EP (35), PL (44); *L. cryptovaginata* (Schkorbatov) J.Komárek, E.Zapomelova, J.Smarda, J.Kopecky, E.Rejmankova, J.Woodhouse, B.A.Neilan & J.Komarkova 2013, EP (48), ME (71); *L. hieronymusii* (Lemmermann) J.Komárek, E.Zapomelova, J.Smarda, J.Kopecky, E.Rejmankova, J.Woodhouse, B.A.Neilan & J.Komarkova 2013, ME (74), PL (44); *Lyngbya aestuarii* Liebman ex Gomont 1892, ME (46, 47), EP, ME (48), PL (50), EP (51), ES (8); ME (24, 40, 4, 47, 60); *L. borgertii* Lemmermann 1907, EP, ED (48); *L. cinerascens* Kützing ex Biswas 1926, EP (19); *L. confervoides* C.Agardh ex

Gomont 1892, EP (19, 21, 22, 25, 28, 33, 51), ME (2, 4, 24, 34, 44, 46, 47, 59, 60, 66, 72, 80), PL (50), ES (10); *L. lutea* Gomont ex Gomont 1892, ME (24, 46,47), ES (44), EP (19, 20); *L. major* Meneghini ex Gomont 1892, EP (48, 50), ME (59); *L. majuscula* Harvey ex Gomont 1892, EP (22, 29, 35, 54), ME (46, 47, 59, 60, 66, 72, 74, 80), ES (10, 49), ME, EL, PC (24), PL (44);*L. martensiana* Meneghini ex Gomont 1892, ME (24, 34, 42, 46, 47, 60, 64, 66, 68, 71, 77), EL (9), EP, ED, Coastal waters of ME (48), EP (54); *L. semiplena* J.Agardh ex Gomont 1892, EP (35, 42, 67), ME (46, 47, 71), PL (44); *L. sordida* Gomont 1892, ME (24, 66); *L. spiralis* Geitler 1932, ME (24); *L. spirulinoides* Gomont ex Gomont 1892, Rock pool waters of ME (48); *L. usteri* Schmidle 1904, EP (54); *Oscillatoria lutea* C.Agardh 1824, ME (34, 40); *O. nitida* C.Agardh ex Corda 1836, EZ (48); *O. annae* Goor 1918, EP (69), ME (27, 56, 47, 77), EZ, Rock pool waters of ME (48); *O. chilkensis* Biswas 1932, ME (77); *O. corallinae* Gomont ex Gomont 1890, EP (19, 35), ME (40); *O. crassa* (C.B.Rao) Anagnostidis 2001, ME (77); *O. curviceps* C.Agardh ex Gomont 1892, ME (24, 34, 82); *O. earlei* N.L.Gardner 1927, EP (41); PL (44); ME (24, 34, 60, 64, 68, 77, 82), EZ, ED, Rock pool waters of ME (48); *O. geitleriana* Elenkin 1949, EP (54), ME (60); *O. grossegranulata* Skuja 1956, EZ (48); *O. indica* P.C.Silva 1996, PL (50), ME (46, 47, 59, 60, 64, 68, 71, 72,76, 77, 80); *O. jenensis* G.Schmid 1921, EP (22); *O. limosa* C.Agardh ex Gomont 1892, EP (19, 25, 45), ME (27, 70, 72, 80, 82), PH (44), PL (65); *O. obscura* Bruhl & Biswas 1922, EP (54), ME (66, 77); *O. ornata* Kützing ex Gomont 1892, EP (69), ME (64, 77, 82); *O. peromata* f. *attenuata* Skuja 1949, ME (64, 77); *O. perornata* Skuja 1949, ME (72, 80), EZ, Rock pool water, coastal waters of ME (48); *O. princeps* Vaucher ex Gomont 1892, EP (48), ME (24, 27, 34, 60, 66, 70, 82), PL (44); *O. proboscidea* Gomont 1892, EP (19, 28, 33); ME (46, 47); *O. raytonensis* Cholnoky 1955, EP (48); *O. sancta* Kützing ex Gomont 1892, ED, Rock pool waters of ME (48), ME (60, 68); *O. simplicissima* Gomont 1892, ME (34); *O. subbrevis* Schmidle 1901, ME (34, 44, 46, 47, 66, 72, 80, 82), EP (19, 21, 28, 33, 54), PL (23); *O. tenuis* C.Agardh ex Gomont 1892, EP (41, 48), ME (46, 47, 59, 60, 68, 71, 74) ES (44); *O. variabilis* C.B.Rao 1936, EP, EZ, EZ, ED, rock pool waters of ME, (48); *O. vizagapatensis* C.B.Rao 1938, EP (41, 48), ME (77); *Phormidium anomalum* (Bharadwaja) Anagnostidis & Komárek 1988, EP, EZ, EL, ED, rock pool water, coastal waters of ME (48); *P. stagninum* Anagnostidis 2001, ME (68); *P. abronema* Skuja 1949, ME (71); *P. acula* (Bruhl & Biswas) Anagnostidis & Komárek 1988, ME (66, 71, 82); *P. allorgei* (Fremy) Anagnostidis & Komárek 1988, EL, EP (9), ME (24, 34), EP, EZ, EL, coastal water of ME (48); *P. ambiguum* Gomont 1892, EP (19, 29, 45, 48, 54, 59, 60, 68, 72); *P. anomalum* C.B.Rao 1937, ME (72); *P. baculum* (Gomont ex Gomont) Anagnostidis 2001, EP (19, 21); *P. bohneri* Schmidle 1902, ME (71, 77), EP (69); *P. boryanum* (Bory ex Gomont) Anagnostidis & Komárek 1988, EP (69), ME (77); *P. breve* (Kützing ex Gomont) Anagnostidis & Komárek 1988, ME (46, 47, 70, 72, 80), EP, EL, ED, rock pool water of ME (48); *P. ceylanicum* Wille 1924, EP, EZ, EL, ED, rock pool water, coastal waters of ME (48); *P. chalybeum* (Mertens ex Gomont) Anagnostidis & Komárek 1988, ME (48, 60, 82); *P. corium* Gomont ex Gomont 1892, ED (48), ME (34, 46, 47, 60, 71); *P. diguetii* (Gomont) Anagnostidis & Komárek 1988, EP (54); *P. dimorphum* Lemmermann 1908, ME (71); *P. endolithicum* Ercegovic 1932, EP (48); *P. foreaui* (Fremy) Umezaki & Watanabe 1994, ME (71); *P. holdenii* (Forti) Branco, Sant'Anna, Azevedo & Sormus 1997, EP (34); *P. incrustatum* Gomont ex Gomont 1892, EP, EZ, EL, ED, rock pool waters of ME (48); *P. insigne* Anagnostidis 2001, EL (48); *P. inundatum* Kützing ex Gomont 1892, EP, EL (48); *P, jadinianum* Gomont 1893, EP, EZ, EL, ED, rock pool water, coastal waters of ME (48); *P. jenkelianum* G.Schmid 1914, ME (71); *P. koprophilum* (Skuja) Anagnostidis 2001, EP, EZ, ED (48), EP (54); *P. kuetzingianum* (Kirchner ex Hansgirg) Anagnostidis & Komárek 1988, EP (48); *P. lucidum* Kützing ex Gomont 1892, EP, EZ, ED, rock pool waters of ME (48); *P. martinii* (Fremy) Anagnostidis & Komárek 1988, EP, Rock pool waters of ME (48), ME (71); *P. minnesotense* (Tilden) Drouet 1942, ME (27); *P. muscorum* (C.Agardh) Dalla Torre & Sarnthein 1901, EP (48); *P. nigroviride* (Thwaites ex Gomont) Anagnostidis & Komárek 1988, ES (49), ME (27, 42, 46, 47, 53, 60, 61, 68), EP (19, 21), EP (28, 33), PL (44), EP, ME (48); *P. nigrum* (Vaucher ex Gomont) Anagnostidis & Komárek 1988, EP (22); *P. puteale* (Montagne ex Gomont) Anagnostidis & Komárek 1988, ME (71, 72, 80); *P. rubidum* (Fremy) Anagnostidis & Komárek 1988, ME (66); *P. rubriterricola* N.L.Gardner 1927, EP (34, 54), ME (66); *P. schultzii* (Lemmermann) Anagnostidis & Komárek 1988, ME (48, 71, 77, 80), EP (19, 28, 33); *P. stagninum* C.B.Rao 1938, PL (44), EP (54), ME (59, 60); *P. subincrustatum* Fritsch &

M.F.Rich 1929, EP (48); *P. submembranaceum* Kützing ex Gomont 1892, ES (10), ME (42); *P. uncinatum* Gomont ex Gomont 1892, EP, EL, ED, ME (48), EP (54), ME (72); *P. usteri* Schmidle 1904, EP (54); *P. willei* (N.L.Gardner) Anagnostidis & Komárek 1988, ME (46, 47, 60, 68, 71), EP, EZ, EL (48); *Plectonema puteale* Kirchner ex Hansgirg 1893, ME (59); *Potamolinea aerugineo-caerulea* (Gomont) M.D.Martins & L.H.Z.Branco 2016, EP (69), ME (71, 77).

Pleurocapsales – Dermocarpellaceae: *Cyanocystis flahaultii* (Sauvageau) Komárek & Anagnostidis 1995, EP, EZ, Rock pool water of ME (48); *C. hemisphaerica* (Setchell & N.L.Gardner) Kaas 1985, EP, EZ, ED (48), ME (24); *C. olivacea* (Reinsch) Komárek & Anagnostidis 1986, ME (60, 71), EP (19, 45); *C. sphaeroidea* (Setchell & N.L.Gardner) Komárek & Anagnostidis 1986, EP (32); *Dermocarpella stellata* H.Leon-Tejera & G.Montejano 2000, EP (55, 58); *Stanieria cyanosphaera* (Komárek & Hindak) Komárek & Anagnostidis 1986, EP (38), EP, EZ (48); *S. sphaerica* (Setchell & N.L.Gardner) Anagnostidis & Pantazidou 1991, ME (46, 47).

Pleurocapsales – Hydrococcaceae: *Hormathonema violaceonigrum* Ercegovic 1930, ES (10); *H. luteobrunneum* Ercegovic 1930, ES (9); *Hydrococcus rivularis* Kützing 1833, EP (45); *Myxohyella papuana* L.Hoffmann 1992, EP (67).

Pleurocapsales – Hyellaceae: *Chamaecalyx leibleiniae* (Reinsch) Komárek & Anagnostidis 1986, EP (22, 44), ME (46, 47, 59, 60); *C. swirenkoi* (Schirschoff) Komárek & Anagnostidis 1986, EP, EZ, ME (48), ME (24); *Hyella balani* Lehmann 1903, ES (7, 8), ME (24); *H. caespitosa* Bornet & Flahault 1888, ES (9), EP (38), ME (46, 47, 48, 60); *Pleurocapsa fuliginosa* Hauck 1885, ES (10); *Radaisia gardneri* Komárek & Anagnostidis 1995, ME (24); *Solentia stratosa* Ercegovic 1927, EL (9).

Pleurocapsales – Xenococcaceae: *Myxosarcina burmensis* Skuja 1949, EP (38), ME (46, 47, 60, 71); *M. concinna* Printz 1921, ME (46, 47, 59, 74); *Foliisarcina bertiogensis* D.O.Alvarenga, J.Rigonato, L.H.Z.Branco, I.S.Melo & M.F.Fiore 2016, EC (73); *Xenococcus chaetomorphae* Setchell & N.L.Gardner 1918, ME (24), EP (55, 58); *X. cladophorae* (Tilden) Setchell & N.L.Gardner 1918, ME (24), EP (44, 48); *X. pyriformis* Setchell & N.L.Gardner 1918, ME (40); *X. schousboei* Thuret 1880, EP (42), ME (24); *Xenotholos kerneri* (Hansgirg) M.Gold-Morgan, G.Montejano & J.Komárek 1994, EP (19, 21, 45), EP, EZ, EL (48).

Spirulinales – Spirulinaceae: *Glaucospira laxissima* (G.S.West) Simic, Komárek & Dordevic 2014, ME (24, 66); *Spirulina labyrinthiformis* Gomont 1892, ME (46, 47, 48, 60, 70, 71, 75), ES (10); *S. major* Kützing ex Gomont 1892, ME (24, 34, 42, 59, 60, 68, 70), EP (41), PL (44, 50), EP, EZ, EL, ED, Rock pool waters of ME (48); *S. meneghiniana* Zanardini ex Gomont 1892, ME (24, 66), ED (48); *S. princeps* West & G.S.West 1902, ME (24), ES (44); *S. subsalsa* Oersted ex Gomont 1892, EP (45, 54), ME (24, 46, 47, 53, 59, 60, 61, 64, 66, 68, 72, 74, 80), EP, EZ, ED, Rock pool waters of ME (48), PL (50), ES (10), EP, ES (19), EP (28, 33, 35); *S. subtilissima* Kützing ex Gomont 1892, ED (48), EP (54), ME (74, 76).

Synechococcales – Chamaesiphonaceae: *Chamaesiphon confervicola* A.Braun 1864, EP (44); *C. sideriphilus* Starmach 1929, ME (74).

Synechococcales – Coelosphaeriaceae: *Coelosphaerium dubium* Grunow 1865, ME (71); *C. kuetzingianum* Nageli 1849, EP (48, 54).

Synechococcales – Leptolyngbyaceae: *Euryhalinema mangrovii* Chakraborty et Mukherjee 2019, ES (79); *Leibleinia epiphytica* (Hieronymus) Compere 1985, ME (24); *L. subtilis* (Holden) Anagnostidis & Komárek 1988, EP (58); *Leptoelongatus litoralis* Chakraborty et Mukherjee in Chakraborty 2019, ES (79); *Leptolyngbya africana* (Lemmermann) Anagnostidis & Komárek 1988, ME (48); *L. angustissima* (West & G.S.West) Anagnostidis & Komárek 1988, ME (46, 47, 71); *L. cebennensis* (Gomont) I.Umezaki & M.Watanabe 1994, ME (46, 47), EP, EZ, EL, ED, rock pool waters of ME (48); *L. crosbyana* (Tilden) Anagnostidis & Komárek 1988, EP (20), ME (40); *L. foveolarum* (Gomont) Anagnostidis & Komárek 1988, EP, EZ, EL, ED, coastal waters of ME (48), ME (66, 71); *L. fragilis* (Gomont) Anagnostidis & Komárek 1988, ME (24, 27, 40, 46, 47, 59, 60, 68, 74), EP (35, 44, 50, 54), EL (48); *L. lagerheimii* (Gomont ex Gomont) Anagnostidis & Komárek 1988, EP (34), EL (48); *L. laminosa* (Gomont ex Gomont) Anagnostidis & Komárek 1988, EP (48); *L. nostocorum* (Bornet ex Gomont) Anagnostidis & Komárek 1988, ME (71); *L. perelegans* (Lemmermann) Anagnostidis & Komárek 1988, ME (34, 42), EP (48); *L. polysiphoniae* (Fremy) Anagnostidis 2001, EP (48); *L. purpurascens* (Gomont ex Gomont) Anagnostidis &

Komárek 1988, ME (42), ME (71); *L. tenuis* (Gomont) Anagnostidis & Komárek 1988, ME (34, 46, 47, 59,60, 66, 68, 70, 71, 80), EP (38, 50, 54), EP, EZ, Rockpool water, Coastal pool water of ME (48); *L. terebrans* (Bornet & Flahault ex Gomont) Anagnostidis & Komárek 1988, ME (24, 46, 47, 59, 60, 80); *L. valderiana* (Gomont) Anagnostidis & Komárek 1988, EP, EZ, EL, ED, rock pool water, coastal waters of ME (48), EP (54), ME (59, 60, 66, 71, 74); *Phormidesmis mollis* (Gomont) Turicchia, Ventura, Komarkova & Komárek 2009, ME (24, 42, 64, 71, 77), EP (34, 38, 48, 69); *Planktolyngbya limnetica* (Lemmermann) Komarkova-Legnerova & Cronberg 1992, ME (77); *P.* minor (Geitler & Ruttner) Komárek & Cronberg 2001, ME (66); *Stenomitos frigidus* (F.E.Fritsch) Miscoe & J.R.Johansen 2016, ME (66).

Synechococcales – Merismopediaceae: *Aphanocapsa stagnalis* (Lemmermann) Belyakova 2004, ME (71); *A. roeseana* De Bary in Rabenhorst 1870, EP (69), ME (77); *A. biformis* A.Braun 1879, ED (48), ME (72, 80); *A. brunnea* (A.Baun ex Kützing) Nägeli 1849, ME (71); *A. conferta* (West & G.S.West) Komarkova-Legnerova & Cronberg 1994, EP (19, 28, 33, 45); *A. grevillei* (Berkeley) Rabenhorst 1865, ME, EL (24), EP (69), ME (77); *A. koordersii* K.M.Strom 1923, EP (41); *A. litoralis* Hansgirg 1892, ME (24, 46, 47, 59, 60, 72, 80), EP (35, 41, 50, 55, 58), PL, ES (44), EP, EZ, EL, Coastal waters of ME (48); *A. muscicola* (Meneghini) Wille 1919, EP, EL (19), EP (45); *A. reinboldii* (Richter) Komárek & Anagnostidis 1995, ES (9); *A. rivularis* (Carmichael) Rabenhorst 1865, EP, Rockpool waters of ME (48); *Eucapsis minuta* F.E.Fritsch 1912, ME (71); *Limnococcus limneticus* (Lemmermann) Komarkova, Jezberova, O.Komárek & Zapomelova 2010,Coastal waters of ME (48); *Merismopedia convoluta* Brébisson ex Kützing 1849, EP, ME (48), ME, PC (24); *M. elegans* A.Braun ex Kützing 1849, ME (24, 60, 64, 77), ED, ME (48); *M. glauca* (Ehrenberg) Kützing 1845, ME (24, 60, 66, 74), EP, EZ, EL, ED, coastal water of ME (48); *M. litoralis* (Oersted) Rabenhorst 1865, ME (24); *M. minima* G.Beck 1897, EP, EL (48), ME (66); *M. tenuissima* Lemmermann 1898, ME (24); ES (44), EP, ED (48); *M. tranquilla* (Ehrenberg) Trevisan 1845, ME (24, 32, 66), EP (48); *Synechocystis aquatilis* Sauvageau 1892, EP (38), ME (48, 66, 71); *S. pevalekii* Ercegovic 1925, EP (38), EP, EZ, EL, ED, Rockpool water, coastal water of ME (48), ME (60, 66, 72, 74, 80); *S. salina* Wislouch 1924, ME (24, 71).

Synechococcales – Oculatellaceae: *Drouetiella lurida* (Gomont) Mai, J.R.Johansen & Pietrasiak 2018, EP (48).

Synechococcales – Pseudanabaenaceae: *Limnothrix chlorospira* (Skuja) Hindak & Trifonova 1989, EP, EZ, EL, ED, rock pool water, coastal waters of ME (48); *L. guttulata* (Goor) I.Umezaki & M.Watanabe 1994, ED, Rock pool waters of ME (48); *Pseudanabaena amphigranulata* (Goor) Anagnostidis 2001, EP (54); *P. biceps* Bocher 1946, EP (48); *P. catenata* Lauterborn 1915, ME (24, 68), EP, EZ, EL, ED, rock pool water, coastal waters of ME (48); *P. galeata* Bocher 1949, EP, rock pool water of ME (48); *P. limnetica* (Lemmermann) Komárek 1974, EZ (48), ME (60, 68, 71, 72, 80); *P. lonchoides* Anagnostidis 1961, EP, ED (48), EP (38); *P. mucicola* (Naumann & Huber-Pestalozzi) Schwabe 1964, ME (71), EP, ED (48); *P. papillaterminata* (Kisselev) Kukk 1959, EP, Coastal waters of ME (48), EP (38); *Yonedaella lithophila* (Ercegovic) Umezaki 1962, EP (34, 42).

Synechococcales – Synechococcales *familia insertae sedis*: *Dasygloea lamyi* (Gomont ex Gomont) Senna & Komárek 1998, PL (44); *Heteroleibleinia gardneri* (Geitler) Anagnostidis & Komárek 1988, ME (46, 47), EP, EZ, EL, ED, coastal waters of ME (48), EP (54); *H. infixa* (Fremy) Anagnostidis & Komárek 1988, Coastal waters of ME (48), ME (60); *H. mesotricha* (Skuja) Anagnostidis & Komárek 1988, ME (59, 60); *H. willei* (Setchell & N.L.Gardner) Guiry & D.M.John 2021, ME (24, 34, 71), EP, EL, ED, Rockpool waters of ME (48), ME (71); *H. chaetomorphae* (Iyengar & Desikachary) Anagnostidis & Komárek 1988, ME (46, 47, 60), EP (54); *H. kuetzingii* (Schmidle) Compere 1985, Among other algae (9), EP (34); *Jaaginema angustissimum* (West & G.S.West) Anagnostidis & Komárek 1988, ME (71); *J. kuetzingianum* (Nageli ex Gomont) Anagnostidis & Komárek 1988, ME (71); *J. neglectum* (Lemmermann) Anagnostidis & Komárek 1988, ED, Rock pool waters of ME (48), EP (54), ME (71), ED, Rock pool waters of ME (48); *J. pseudogeminatum* (G.Schmid) Anagnostidis & Komárek 1988, ME (48, 71); *J. quadripunctulatum* (Bruhl & Biswas) Anagnostidis & Komárek 1988, EP (48); *J. subtilissimum* (Kützing ex Forti) Anagnostidis & Komárek 1988, ME (46, 47, 71); *Schizothrix arenaria* Gomont 1892, EP (19), ME (24, 34); *S. calcicola* Gomont 1892, EP (9), ES (10), ME (24); *S. telephoroides* Gomont 1890, EP (41).

Synechococcales – Synechococcaceae: *Lemmermanniella obesa* M.T.P.Azevedo, C.A.Souza & M.Menezes 1999, EP (34), ME (40); *Synechococcus elongatus* (Nageli) Nageli 1849, EP (32, 48), ME (46, 47, 59, 71); *S. moorigangaii* Singh & Bhadury 2019, PL (81).

Synechococcales – Trichocoleusaceae: *Trichocoleus acutissimus* (N.L.Gardner) Anagnostidis 2001, ME (46, 47, 64); *T. tenerrimus* (Gomont) Anagnostidis 2001, ME (24, 34, 40).

As we compiled this list, we verified that several materials could not be included because they were not up to the species-level identification. Since these cyanobacteria are composed of simple filaments and frequently exhibit high morphological variability, the identification of specific and even generic levels becomes considerably more challenging. The insufficiency of literature focused on the cyanobacterial flora in mangrove environments, which would minimise inappropriate comparisons with the specimens of major misidentifications, adding to the problem of biodiversity research in cyanobacteria in general.

It was from the 1990s that the cyanobacteria in mangrove environments began to be more intensely studied and with that there was a significant increase in the knowledge of mangrove-associated cyanobacterial biodiversity (Fig. 2).

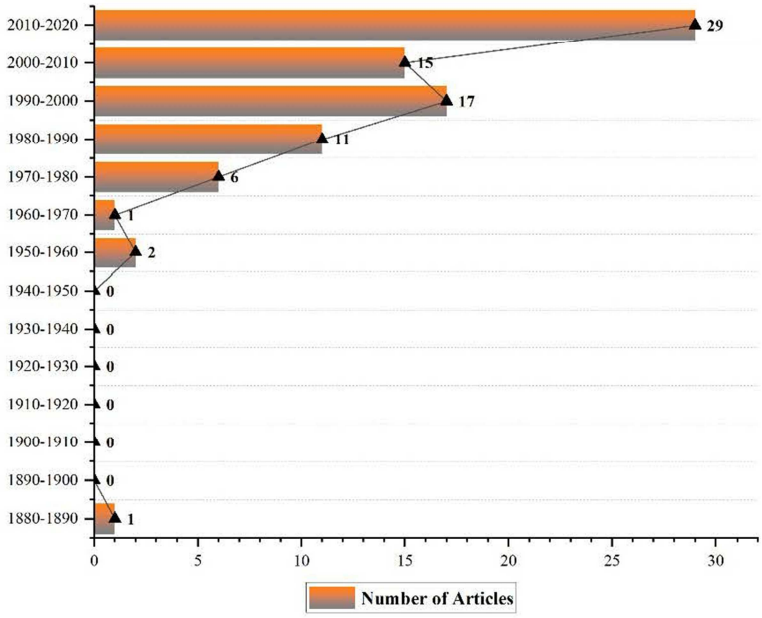

FIG. 2: Nunber of research articles used in this study (from 1889–2020)

A pronounced increase in taxonomic studies has been carried out during the previous decades. Based on this scenario, it is critical to address methods for studying and learning about the great wealth of cyanobacteria in the mangrove ecosystem, as well as their biotechnological potential, in the face of rapid destruction of their environments with the consequent loss of biodiversity.

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

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

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

Introduction

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

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

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

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

Materials and Methods

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

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

Results

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

Systematics

Order: Chroococcales

Family: Aphanothecaceae

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

References

(Komarek and Anagnostidis 1998; Desikachary 1959).

Synonyms

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

Description

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

Distribution

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

Habitat

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

Specimen examined

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

Order: Chroococcales

Family: Chroococcaceae

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

References

(Komarek and Anangnostidis 1998; Desikachary 1959)

Description

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

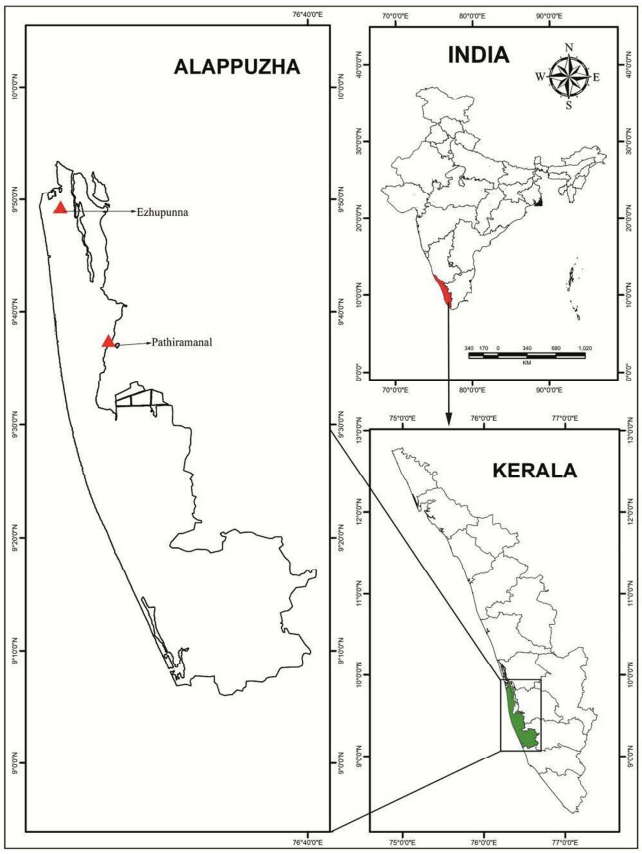

Fig. 1 — Map showing the location of sampling sites in the Alappuzha mangrove ecosystem

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

Distribution

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

Habitat

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

Specimen examined

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

Order: Oscillatoriales

Family: Microcoleaceae

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

Reference

(Strunecky *et al.* 2014)

Synonyms

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

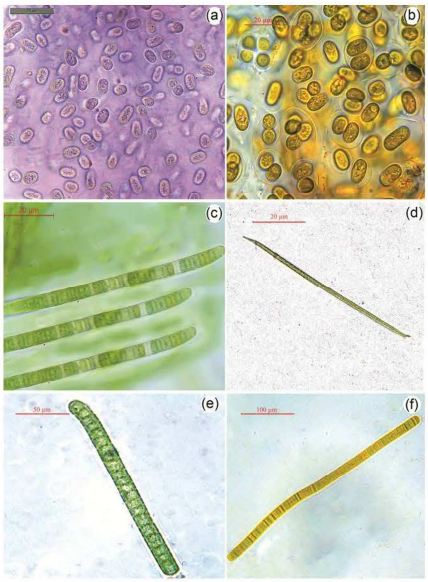

Fig. 2 — A) *Aphanothece stagnina* (Sprengel) A. Braun in Rabenhorst, B) *Chroococcus indicus* Zeller, C) *Kamptonema chlorinum* (Kutzing ex Gomont) Strunecky, Komarek, D) *Phormidium acula* (Bruhl & Biswas) Anangnostidis & Komarek, E) *Phormidium chalybeum* (Mertens ex Gomont) Anagnostidis et Komarek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

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

Description

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

Distribution

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

Habitat

Dark greenish planktic form.

Specimen examined

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

Order: Oscillatoriales
Family: Oscillatoriaceae

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

Reference

(Komarek and Anagnostidis 2005).

Synonym

Oscillatoria acula Bruhl & Biswas 1922.

Description

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

Distribution

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

Habitat

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

Specimen examined

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

Order: Oscillatoriales
Family: Oscillatoriaceae

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

Reference

(Komarek and Anagnostidis 2005).

Synonyms

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

Description

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

Distribution

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

Habitat

Green coloured planktic form.

Specimen examined

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

Order: Oscillatoriales

Family: Oscillatoriaceae

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

References

(Komarek and Anangnostidis 2005; Desikachary 1959).

Description

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

Distribution

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

Habitat

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

Specimen examined

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

Order: Oscillatoriales

Family: Oscillatoriaceae

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

References

(Komarek and Anagnostidis 2005; Desikachary 1959).

Synonyms

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

Description

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

Distribution

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

Habitat

Dark greenish coloured planktic form.

Specimen examined

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

Order: Oscillatoriales

Family: Oscillatoriaceae

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

References

(Komarek and Anagnostidis 2005; Desikachary 1959).

Description

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

Distribution

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

Habitat

Dark Greenish mat collected from the soil surface.

Specimen examined

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

Order: Nostocales

Family: Hapalosiphonaceae

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

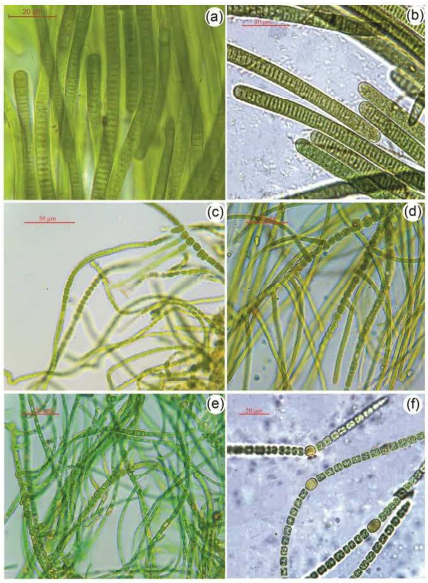

Fig. 3 — A) *Oscillatoria limosa* C. Agardh ex Gomont, B) *Oscillatoria curviceps* Agardh ex Gomont, C) *Hapalosiphon welwitschii* West & G. S. West, D) *Westiellopsis prolifica* Janet, E) *Westiellopsis interrupta* Kanthamma, and F) *Anabaena inaequalis* (Kutzing) Bornet et Flahault

References

(Komarek 2013; Desikachary 1959).

Description

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

Distribution

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

Habitat

Green coloured planktic.

Specimen examined

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

Order: Nostocales
Family: Hapalosiphonaceae

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

References

(Komarek 2013; Desikachary 1959).

Synonym

Parthasarathiella prolifica Suba Raju 1962.

Description

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

Distribution

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

Habitat

Green coloured planktic.

Specimen examined

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

Order: Nostocales
Family: Hapalosiphonaceae

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

References

(Jeeji-Bai 1972; Komarek 2013)

Description

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

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

Distribution

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

Habitat

Dark green coloured planktic.

Specimen examined

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

Order: Nostocales
Family: Nostocaceae

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

References

(Komarek 2013; McGregor 2018).

Synonyms

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

Description

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

Distribution

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

Habitat and ecology

Dark greenish coloured benthic cyanobacterial mat.

Specimen examined

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

Order: Nostocales
Family: Nostocaceae

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

References

(Komarek 2013; Desikachary 1959).

Description

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

Distribution

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

Habitat

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

Specimen examined

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

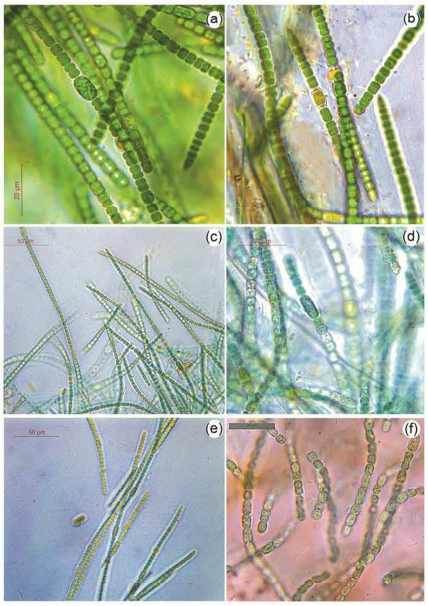

Fig. 4 — A-B) *Anabaena laxa* (Rabenhorst) ex Bornet et Flahault, C-D) *Trichormus ellipsosporus* (Fritsch) Komarek et Anagnostidis, E) *Trichormus kashiensis* (Bharadwaja) Komarek, and F) *Nostoc carneum* (Lyngbye) Agardh ex Bornet et Flahault

Order: Nostocales
Family: Nostocaceae

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

Reference

(Komarek, 2013).

Synonyms

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

Description

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

Distribution

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

Habitat

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

Specimen examined

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

Order: Nostocales
Family: Nostocaceae

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

Reference

(Komarek 2012).

Synonyms

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

Description

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

Distribution

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

Specimen examined

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

Habitat

Found on the mangrove soil (green in colour).

Order: Nostocales
Family: Nostocaceae

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

References

(Desikachary 1959; Komarek 2013).

Synonyms

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

Description

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

Distribution

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

Habitat

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

Specimen examined

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

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

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

Discussion

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

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

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

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

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

Conclusion

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

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Conflict of Interest

The authors have no conflict of interest.

Author Contributions

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

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

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1

THE GENUS *OSCILLATORIA* VAUCHER (CYANOBACTERIA) FROM SELECTED MANGROVE ENVIRONMENTS OF SOUTHERN KERALA, INDIA

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Abstract -

The present work deals with the diversity of *Oscillatoria* Vaucher from the selected mangrove environments of Southern Kerala. The genus *Oscillatoria* is the most ubiquitous genus of Oscillatoriales of Cyanobacteria growing in almost all seasons and habitat. 10 species of *Oscillatoria* (*O. subbrevis* Schmidle, *O. curviceps* C.Agardh ex Gomont, *O. limosa* C.Agardh ex Gomont, *O. chlorina* Kutzing ex Gomont, *O. princeps* Vaucher ex Gomont, *O. chalybea* Mertens ex Gomont, *O. inaequalis* (Kutzing) Bornet & Flahault, *O. acula* Bruhl & Biswas, *O. ornata* Kützing ex Gomont and *O. schultzii* Lemmermann) have been identified from different mangrove environments *viz.* Alappuzha (Ezhupunna, Pathiramanal), and Kottayam (Kumarakom and Mekkara) districts. The least species diversity of *Oscillatoria* in the selected mangrove areas has been recorded at Kottayam district whereas the highest species diversity at Alappuzha district.

Keywords: Mangroves, Cyanobacteria, *Oscillatoria*, Southern Kerala

Introduction -

Cyanobacterial diversity in mangrove ecosystems is mainly controlled by the fluctuations in the physico-chemical characteristics of the water. The genus *Oscillatoria* is the most ubiquitous genus of Oscillatoriales of Cyanobacteria growing in almost all seasons and habitat. The species identification of Oscillatoriales has been carried out based on colour, sheath, cell measurement, constriction, granulation and end cell. The genus *Oscillatoria* is commonly identified with the visible motility of trichomes consisting of cells that are distinctly shorter than wide with a standard "ruler-like" cell division occurring in meristematic zones and, overall, simple filaments without any branching or specialized cells, such as heterocysts or akinetes (Vaucher 1803, Gomont 1892, Anagnostidis and Komárek 1988, Komárek and Anagnostidis 2005). The concept of classification of Oscillatoriales by Komarek and Anagnostidis (2005) is a comprehensive study and various taxa are arranged in a single order, 6 families and 12 subfamilies.

A survey of literature on Oscillatoriales revealed that according to the classical concept, 128 species of *Oscillatoria* has been reported from India (Tiwari *et al.*, 2007). Mangroves are occupied by numerous cyanobacterial communities and many of them are capable of nitrogen fixation (Hoffmann, 1999). The present communication is to distinguish different species of *Oscillatoria* from the selected mangrove ecosystems of Southern Kerala.

Materials and Methods -

The samples were collected from two districts viz. Alappuzha (Ezhupunna and Pathiramanal), and Kottayam (Kumarakom and Mekkara).

Table 1. Study areas.

District	Place	GPS Location
	Ezhupunna	9^0**49' N, 76^{0}18'"E**
	Pathiramanal	9^0**36'N, 76^{0}23'** E
	Kumarakom	9^0 **36' N, 76^0 25'** E
	Mekkara	9^0 **48' N, 76^0** 21' E

The cyanobacterial specimens were observed on the water bodies, soil, bark and pneumatophores of mangrove plants. Light-green, dark-green, dark-brown, olive coloured cyanobacterial samples were collected using forceps, needles, scalpel and knife. Photomicrographs were taken using a Leica DM 1000 LED compound microscope. Cyanobacterial identification was done using the relevant taxonomic publications.

Result and Discussion

Cyanobacteria is one of the most important primary production groups in aquatic environments and their productivity depends greatly on them. (Kamath *et al.* 2006). A total of 10 species of *Oscillatoria* were recorded. The least species diversity of *Oscillatoria* in the selected mangrove areas has been recorded at Kottayam district whereas the highest species diversity at Alappuzha district. Pathiramanal mangrove area occupies the most diverse species of *Oscillatoria*.

Table 2: List of *Oscillatoria* species identified from the different study areas

No	Species identified
1.	*Oscillatoria subbrevis* Schmidle

2.	*Oscillatoria curviceps* C.Agardh ex Gomont
3.	*Oscillatoria limosa* C.Agardh ex Gomont
4.	*Oscillatoria chlorina* Kutzing ex Gomont
5.	*Oscillatoria princeps* Vaucher ex Gomont
6.	*Oscillatoria chalybea* Mertens ex Gomont
7.	*Oscillatoria okenii* C.Agardh ex Gomont
8.	*Oscillatoria acula* Bruhl & Biswas
9.	*Oscillatoria ornata* Kützing ex Gomont
10.	*Oscillatoria schultzii* Lemmermann

Taxonomic work on Cyanobacteria from mangrove environments of Southern Kerala has been ignored for a long time. In habitats such as wetlands, the high cyanobacterial diversity is beneficial for aquaculture and habitats with lower diversity are more stable, it is because variations in the abundance of individual species have less impact on the role of the entire ecosystem (Boyd, 1973). The genus *Oscillatoria* can thrive well in low to high salinity conditions and also survive in low to high temperature conditions (Naskar *et al*., 2008).

The present findings on the distribution of the genus *Oscillatoria* conform with the observations of Selvakumar and Sundararaman (2001), Nedumaran *et al*. (2008), Sakthivel and Kathiresan (2013), Nagarajan *et al*. (2014) and Sivakamasundari and Rajendran (2015). The temperature, pH and salinity are considered an important factor in controlling the dominance of *Oscillatoria* species.

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Appendix 3

List of paper presentations in the International/National Seminar, Conference, Symposium

3.1. Arun T. Ram & Tessy Paul P. (2022). Taxonomy of Cyanobacteria: Issues and Prospects. Abstract published in the International Conference on sustainable Utilization of Bioresources, on 10-15 January 2022, at the Department of Botany, University of Kerala, India. Pp. 117.

3.2. Arun T. Ram & Tessy Paul P. (2020). The genus *Oscillatoria* Vaucher (Cyanobacteria) from selected mangrove environments of southern Kerala, India. Presented and published a paper as proceedings in the National Virtual Conference on Biodiversity and Sustainable Development on 5-6 June 2020 organised by GP Gogate College of Arts and Science and R V Joglekar College of Commerce, Ratnagiri, pp. 13-14.

3.3. Arun T. Ram & Shamina, M. (2018). Cyanobacterial epiphytes on mangroves of southern Kerala, India. Abstract published in the International Conference on Biotechnological Research and Innovation for Sustainable Development (BioSD 2018) and XV Annual Convention of the Biotech Research Society, India, pp. 304.

3.4. Arun T. Ram & Shamina, M. (2018). Cyanobacterial diversity from selected mangrove ecosystems of Southern Kerala, India. Abstract published in the National Symposium on Advances in Biology of Algae and Cyanobacteria (ABAC) 2018 organized by the Centre of Advanced Study in Botany, Institute of Science, Banaras Hindu University, Varanasi on February 8 and 9, 2018.


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Taxonomy of Cyanobacteria: Issues and Prospects

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Abstract

Traditionally, cyanobacteria were described as algae and referred to as 'blue-green algae', 'Cyanophyta' or 'Cyanoprokaryota' and their taxonomy and classification are largely based on morphological or phenotypic characters (Bornet and Flahault, 1886-1888; Gomont, 1892; Geitler, 1932; Desikachary, 1959; Prescott, 1962). Nowadays, cyanobacterial taxonomy and classification are based on molecular data. However, a correct phylogenetic system cannot be implemented without combining phylogeny with knowledge acquired over 150 years of cyanobacterial diversity research (Komarek, 2006).Therefore, an integration of all the aspects, such as morphological, ultrastructural, ecological, biochemical, and phylogenetic studies, called the "polyphasic approach", is applied in the current cyanobacterial taxonomy. Based on the polyphasic approach with a revision of the cyanobacterial taxonomy, a three-volume series of Süßwasserflora was recommended (Komarek and Anagnostidis, 1998; Komarek and Anagnostidis, 2005; Komarek, 2013). Komarek*et al.* (2014) introduced a new classification system with a polyphasic approach and the goal is to publish legitimate names for cyanobacterial taxa.Several new orders and families have emerged through this system. Komarek et al. (2020) revised and newly classified cyanobacteria classification with the introduction of the new order and family, Thermostichales and Thermostichaceae. To resolve this issue on frequent taxonomic revision, researchers should refer to the database of CyanoDB (http://www.cyanodb.cz/) (Hauer and Komarek, 2021), for the updated cyanobacterial taxonomic classification and refer to the genus inclusion. According to Hauer and Komarek, (2021), cyanobacteria are classified into 10 orders and 61 families while the other classification system proposed by Guiry and Guiry (2021) (https://www.algaebase.org/)12 orders and 77 families with 5146 species. The treatment of cyanobacterial classification in AlgaeBase is extremely different from CyanoDB.In AlgaeBase, certain species are divided into a separate section, namely '*ordo insertaesedis*' or '*familiainsertaesedis*', which means the order or family of 'uncertainty'. Some orders or families are still debated, even when discovered using the polyphasic approach they have been labelled as "unknown authority" and thus regarded it as invalid. Another important problem was to check the validity or current status of the nomenclature of cyanobacterial species. This is because of the frequent alternation of the updated nomenclature of cyanobacteria. Certain genera have changed their nomenclature to new ones or existing ones. Cyanobacteriologists should rely on AlgaeBaseto confirm the species name or to check its validity or current status in the cyanobacteria nomenclature.

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FAMB-P-44

Cyanobacterial epiphytes on mangroves of southern Kerala, India

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Mangrove forests are very productive and dynamic ecosystem found in tropical and subtropical regions. Cyanobacteria are an important group in most marine systems. The distribution of cyanobacteria growing on mangrove pneumatophores were studied. In all a total of 12 species were observed, including 3 unicellular, 7 non-heterocystous and 2 heterocytous filamentous species. Among cyanobacteria, *Oscillatoria* sp. was dominant in its distribution. The cyanobacterial association with *Avicenniaofficinalis* and *Sonneratiacaseolaris* were very distinct. Totally 8 cyanobacterial species were associated with *Avicennia officinalis* whereas only 2 species were associated with *Sonneratiacaseolaris*. It is interesting to note that the pneumatophores of *Rhizophoramucronata*and *Kandeliacandel*harbours equal distribution of cyanobacterial species.

Keywords: *Mangrove; Pneumatophore; Avicennia officinalis; Oscillatoria* sp.

Symposium on

Advances in Biology of Algae and Cyanobacteria (ABAC - 2018)

February 8-9, 2018



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PP-40: Cyanobacterial Diversity from Selected Mangrove Ecosystems of Southern Kerala, India

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Mangrove ecosystem considered as a reservoir of a plethora of plant and animal species. Due to immense biotic interference and multiple use of mangrove vegetation, this resource is threatened with great destruction. Even though the mangroves are characterized by highly specialized but low plant diversity in comparison to other tropical ecosystems, they support a diverse microbial community. Mangrove habitat greatly enriched with different species of cyanobacteria. Cyanobacterial diversity was studied at selected mangrove areas of Aayiram thengu (Kollam district) (9^0 7' 32" NL 76^0 28'48" EL), Kumarakom (Kottayam district) (9^0 36' 15" NL, 76^0 25' 53" EL), Mekkara (Kottayam district) (9^0 48' 54" NL, 76^0 21' 57"EL) and Kumbalam (Ernakulam district) (9°54'14"NL, 76°18'40"EL). Almost 12 species of cyanobacteria coming under 5 genera and 3 families were recorded from these areas. The species includes *Lyngbya limnetica*, *Oscillatoria ornata*, *Oscillatoria salina*, *Oscillatoria vizagapatensis*, *Oscillatoria chilkensis*, *Oscillatoria schultzii*, *Oscillatoria annae*, *Nostoc paludosum*, *Nostoc muscorum*, *Scytonema leptobasis*, *Scytonema bohneri* and *Anabaena* sp. Maximum species of cyanobacteria were recorded from Kumbalam (7 species) in Ernakulam district whereas the minimum was recorded at Mekkara (4 species) in Kottayam district. As many as two species namely *Oscillatoria salina* and *Oscillatoria vizagapatensis* were found common in all mangrove areas except Mekkara in Kottayam district.