

**AN INVENTORY ON THE DIVERSITY OF FAMILY
SCYTONEMATACEAE IN SELECTED DISTRICTS
ADJOINING THE WESTERN GHATS
REGION OF KERALA**

*Thesis submitted to the
University of Calicut in partial fulfillment of
the requirements for the award of the degree of*

DOCTOR OF PHILOSOPHY IN BOTANY

by

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CERTIFICATE

This is to certify that the Ph.D. thesis titled “**AN INVENTORY ON THE DIVERSITY OF FAMILY SCYTONEMATACEAE IN SELECTED DISTRICTS ADJOINING THE WESTERN GHATS REGION OF KERALA**”, submitted to the University of Calicut in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy in Botany by **Ms. Swetha K** is a bonafide record of research work carried out by her under my guidance and supervision in the Division of Environmental Science, Department of Botany, University of Calicut.

No part of the present work has previously formed the basis for the award of any other Degree, Diploma, Fellowship, or similar title, to any candidate in any University. The modifications suggested by the Research Advisory Committee (Botany) of the University of Calicut have been incorporated into the thesis. It is also affirmed that all corrections and modifications suggested by the adjudicators have been fully incorporated into the thesis.

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Prof. (Dr) C. C. Harilal
(Research Supervisor and Guide)

DECLARATION

I hereby declare that the work presented in the thesis entitled “**AN INVENTORY ON THE DIVERSITY OF FAMILY SCYTONEMATACEAE IN SELECTED DISTRICTS ADJOINING THE WESTERN GHATS REGION OF KERALA**” is based on the original work done by me under the guidance and supervision of Prof. (Dr.) C.C. Harilal, Head, Department of Botany (Division of Environmental Science), University of Calicut, and has not been included in any other thesis submitted previously for the award of any degree. The contents of the thesis have undergone a plagiarism check using iThenticate software at C.H.M.K. Library, University of Calicut, and the similarity index found within the permissible limit. I also declare that the thesis is free from AI-generated content. It is also affirmed that all corrections and modifications suggested by the adjudicators have been fully incorporated into the thesis.

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Dedicated to
My Family

ABSTRACT

Cyanobacteria are the largest and most diverse group of photosynthetic microorganisms, thriving in nearly all habitats, including extreme climatic conditions. The Scytonemataceae family is unique among cyanobacteria for its false branching phenotype and includes ecologically significant species, making it especially interesting for agricultural and biotechnological applications. This family is noted for its taxonomic diversity and widespread distribution. The present study was carried out on the diversity of the family Scytonemataceae in 52 sampling sites falling in the Palakkad, Malappuram, Kozhikode, and Wayanad districts of the Western Ghats region of Kerala, India. Collecting cyanobacterial specimens and assessing their microclimatic conditions were carried out on a seasonal basis. Apart from the diversity assessments, the study focused on the habitat characteristics, seasonality, spatio-temporal patterns, and impacts of environmental factors influencing the growth and distribution of the Scytonemataceae family in the Western Ghat mountain chain region. A total of 35 species belonging to the Scytonemataceae family were identified, of which 23 are new to Kerala, and 16 are new to India. The study revealed that in terms of temporal scale, seasonal variation had the most significant effect on the cyanobacteria belonging to the family Scytonemataceae, with the highest diversity during the monsoon season, followed by the post-monsoon. In contrast, the pre-monsoon season exhibited relatively lower cyanobacterial diversity. From a spatial perspective, environmental factors such as moisture, atmospheric temperature, Surface temperature, and diurnal temperature are strong determinants of the growth of the Scytonemataceae family during all

seasons. This research highlights that seasonal variations and specific environmental factors strongly influence the diversity of the Scytonemataceae family in the Western Ghats region of Kerala.

സംഗ്രഹം

സയനോബാക്ടീരിയകൾ ഫോട്ടോസിന്ററിക് സൂക്ഷ്മാണുക്കളുടെ ഏറ്റവും വലുതും വൈവിധ്യ പൂർണ്ണവുമായ കൂട്ടമാണ്. തീവ്രമായ കാലാവസ്ഥ ഉൾപ്പെടെ മിക്കവാറും എല്ലാ ആവാസ വ്യവസ്ഥകളിലും ഇവ വളരുന്നു. സയനോബാക്ടീരിയകളിൽ സൈറ്റോനിമെറ്റോസിയെ കുടുംബം അതിന്റെ ഫാൾസ് ബ്രോഞ്ചിംഗ് ഫീനോടൈപ്പിന് സവിശേഷമാണ്, കൂടാതെ പാരിസ്ഥിതികമായി പ്രാധാന്യമുള്ള സ്പീഷിസുകളും ഇതിൽ ഉൾപ്പെടുന്നു. ഇവ കാർഷിക ജൈവ സാങ്കേതിക പ്രയോഗങ്ങൾക്ക് മുതൽ കൂട്ടാകുന്നു. ഈ കുടുംബം അതിന്റെ വർഗ്ഗീകരണ വൈവിധ്യത്തിനും വ്യാപകമായ വിതരണത്തിനും പേരുകേട്ടതാണ്. ദക്ഷിണേന്ത്യൻ സംസ്ഥാനങ്ങളിൽ കേരളത്തിന്റെ ഭാഗമായ പശ്ചിമഘട്ട മേഖലകളിൽ ഉൾപ്പെട്ട പാലക്കാട്, മലപ്പുറം, കോഴിക്കോട്, വയനാട് ജില്ലകളിലെ 52 സാമ്പിൾ സൈറ്റുകളിലെ സൈറ്റോനിമെറ്റോസിയെ കുടുംബത്തിന്റെ വൈവിധ്യങ്ങളെ വിശകലനം ചെയ്യുന്നതാണ് ഈ പഠനം. കാലാവസ്ഥയുടെ അടിസ്ഥാനത്തിലാണ് സയനോബാക്ടീരിയൽ സാമ്പിളുകൾ ശേഖരിക്കുകയും അവയുടെ സൂക്ഷ്മ കാലാവസ്ഥാ വ്യതിയാനങ്ങൾ വിലയിരുത്തുകയും ചെയ്തു. വൈവിധ്യ വിലയിരുത്തലുകൾക്ക് പുറമേ, പശ്ചിമഘട്ട പർവ്വതനിരയിലെ സൈറ്റോനിമെറ്റോസിയെ കുടുംബത്തിന്റെ വളർച്ചയെയും വിതരണത്തെയും സ്വാധീനിക്കുന്ന ആവാസ വ്യവസ്ഥയുടെ സവിശേഷതകൾ, കാലാനുസൃതത, സ്പേഷ്യോ-ടെമ്പറൽ പാറ്റേണുകൾ, പാരിസ്ഥിതികഘടകങ്ങളുടെ സ്വാധീനം എന്നിവയിലും പഠനം ശ്രദ്ധ കേന്ദ്രീകരിച്ചു. സൈറ്റോനിമെറ്റോസിയെ കുടുംബത്തിൽപ്പെട്ട 35 സ്പീഷിസുകളെ തിരിച്ചറിഞ്ഞു, അതിൽ 23 എണ്ണം കേരളത്തിൽ പുതിയതും 16 എണ്ണം ഇന്ത്യയിൽ പുതിയതുമാണ് എന്ന് ഈ ഗവേഷണം കണ്ടെത്തുന്നു. ടെംപോറൽ സ്കെയിലിന്റെ കാര്യത്തിൽ, സൈറ്റോനിമെറ്റോസിയെ കുടുംബത്തിൽപ്പെട്ട സയനോബാക്ടീരിയകളിൽ, സീസണൽ വ്യതിയാനമാണ് ഏറ്റവും വലിയ സ്വാധീനം ചെലുത്തുന്നതെന്ന് പഠനം വെളിപ്പെടുത്തി, ഇതിൽ ഏറ്റവും കൂടുതൽ വൈവിധ്യം മൺസൂൺ കാലത്തും, തുടർന്ന് മൺസൂണിനു ശേഷമുള്ള കാലത്തും, ഇതിനു വിപരീതമായി, പ്രീ-മൺസൂൺ സീസണിൽ താരതമ്യേന കുറഞ്ഞ സയനോബാക്ടീരിയൽ വൈവിധ്യം പ്രകടമായി. ഒരു സ്പേഷ്യൽ വീക്ഷണകോണിൽ, ഈർപ്പം, അന്തരീക്ഷ താപനില, ഉപരിതല താപനില, ദൈനംദിന

താപനില തുടങ്ങിയ പാരിസ്ഥിതിക ഘടകങ്ങൾ എല്ലാ സീസണുകളിലും സൈറ്റോനിമെറ്റോസിയെ കുടുംബത്തിന്റെ വളർച്ചയെ ശക്തമായി നിർണ്ണയിക്കുന്ന ഘടകങ്ങളാണ്. കേരളത്തിലെ പശ്ചിമഘട്ട മേഖലയിലെ സൈറ്റോനി മെറ്റോസിയെ കുടുംബത്തിന്റെ വൈവിധ്യത്തെ കാലാനുസൃതമായ വ്യതിയാനങ്ങളും പ്രത്യേക പാരിസ്ഥിതിക ഘടകങ്ങളും ശക്തമായി സ്വാധീനിക്കുന്നുവെന്ന് ഈ ഗവേഷണം തെളിയിക്കുന്നു.

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ABBREVIATIONS

%	-	Percentage
°C	-	Degree Celsius
µm	-	Micrometer
CaCl ₂ .2H ₂ O	-	Calcium chloride dihydrate
CaCO ₃	-	Calcium carbonate
Co (NO ₃) ₂ .6H ₂ O	-	Cobalt (II) nitrate hexahydrate
CuSO ₄ .5H ₂ O	-	Copper (II) sulfate pentahydrate
cyanoHABs	-	Cyanobacterial harmful algal blooms
EDTA	-	Ethylenediaminetetraacetic
EPS	-	Extracellular polymeric substances
g/L	-	Grams per Litre
H ₃ BO ₃	-	Boric acid
ITS	-	Internal transcribed spacer
K ₂ HPO ₄ .3H ₂ O	-	Potassium phosphate dibasic trihydrate
MgSO ₄ .7H ₂ O	-	Magnesium sulfate heptahydrate
MIC	-	Minimum inhibitory concentration
MnCl ₂ .4H ₂ O	-	Manganese dichloride tetrahydrate
Na ₂ CO ₃	-	Sodium carbonate
Na ₂ MoO ₄ .2H ₂ O	-	Sodium molybdate
NaNO ₃	-	Sodium nitrate
NO ₂	-	Nitrogen dioxide
OMEP	-	Outer membrane efflux protein
PAF	-	Platelet activating factor
PAR	-	Photosynthetically active radiation
pH	-	Potential of hydrogen
SO ₂	-	sulfur dioxide
STDEV	-	Standard deviation
UV	-	Ultraviolet
ZnSO ₄ .7H ₂ O	-	Zinc sulfate heptahydrate

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INTRODUCTION

1. Introduction

Cyanobacteria are a group of prokaryotic microscopic organisms that have a long evolutionary history (Nuriyeva 2019; Rasmussen et al. 2008). They are recognized as the first oxygen-producing photosynthetic microorganisms on Earth (Sukenic et al. 2009). Over the past 3 billion years, through photosynthesis, they contributed to the oxygen production in the Earth's atmosphere, which ultimately changed the composition of life forms and increased biodiversity on Earth. These organisms possess the unique ability to perform mutually compatible functions such as nitrogen fixation and photosynthesis. Cyanobacteria have a comparatively higher degree of morphological characteristics compared to other prokaryotes (Dvorak et al. 2017). Morphological features such as cell size, colour, shape, type of branching, sheath characteristics, and cell contents are used for the identification and categorization of cyanobacteria (Komarek 2013). Cyanobacteria help in the carbon and nitrogen biogeochemical cycles, particularly in the deep oceans. Recently, they have become significant due to their potential use in various research fields, including Biotechnology, Pharmacology, and Agriculture.

1.1 Ecology and Diversity

Cyanobacteria are an extremely diverse group that performs a crucial role in the global ecosystem. Cyanobacteria exist in different forms, such as unicellular, colonial, filamentous, and branched-filamentous (Whitton and Potts 2000). These morphologically diverse cyanobacteria can be seen in a broad spectrum of environments, including the extremely cold deserts of the Arctic and Antarctic Zones (Mataloni and Komarek 2004) to the very extreme hot springs, making them one of the most intriguing forms of life in a vast array of aquatic and terrestrial environments (Whitton and Potts 2000).

A better understanding of cyanobacterial diversity provides insights into their ecology, morphology, and physiology (Pal and Singh 2022). Cyanobacteria have several advantages as hosts for biotechnological applications such as minimal growth requirements, easy genetic manipulation, and appealing platforms that enable carbon-neutral production processes (Lau et al. 2015; Kumar et al. 2016). Cyanobacteria are of significant importance in the agricultural sector due to their ability to improve soil fertility, consequently leading to enhanced rice growth and yield. Hence, they can be applied as biofertilizers. Cyanobacteria are remarkably effective for wastewater treatment and bioremediation since these organisms can degrade environmental pollutants and remove heavy metals. Photosynthetic cyanobacteria have the potential to directly convert carbon dioxide into biofuels, which is an exciting new field. Cyanobacteria are sources of bioactive compounds with intriguing biological properties, such as antimicrobial, antifungal, antiviral, anti-algal, anticancer, and anti-inflammatory. Some strains of cyanobacteria are commercially significant for their high-quality compounds such as pigments, vitamins, and enzymes. Recent advancements in biotechnological strategies have enabled researchers to increase the production of the desired products in cyanobacteria and utilize their potential for a range of industrial applications. This ability of cyanobacteria to have such variations in their physiological aspects is due to their high “adaptability” (Nandagopal et al. 2021)

Cyanobacteria have evolved several adaptations that enable them to survive, compete, and eventually dominate in a wide array of ecosystems (Rastogi and Madamwar 2015; Menamo and Wolde 2015). Cyanobacterial diversity owing to their adaptive capacities occupies a wide range of ecosystems across the Earth. Their diversity arises from the cellular mechanisms that allow them to adapt in response to environmental changes and grow rapidly as a dense population with remarkable speed. Nevertheless, their rapid growth rate varies depending on biotic factors, nutrient levels, climate change, and global warming (Sukenic et al. 2012; Paerl and Paul 2012).

Cyanobacteria face multiple challenges and stresses in their natural surroundings, including variations in temperature, pH levels, moisture content (droughts and floods), and salinity. These factors impact the diversity and distribution of cyanobacteria in a given area. Among these factors, pH is a critical determinant as cyanobacteria prefer a neutral to alkaline pH for optimal growth (Singh 1961; Kaushik 1994; Whitton and Sinclair 1975; Prasad et al. 1978; Chikkaswamy 2001).

1.2 Morphological diversity

Cyanobacteria are diverse microorganisms that can exist in varied forms. Taxonomically, they are identified based on their morphological features such as cell dimensions, colour, shape, sheath characteristics, type of branching, and cell contents (Komarek and Anagnostidis 1998, 2005; Komarek 2013). Recent studies have focused on phylogenetic analysis to classify cyanobacterial organisms. Cyanobacteria are classified into three major categories. The first category is unicellular cyanobacteria, such as *Aphanothece* and *Chroococcus*, which can exist singly or in irregular colonies held together by a mucilaginous membrane. These cyanobacteria lack specialized cells like heterocysts. The second type of cyanobacteria is non-heterocystous filamentous cyanobacteria. Filamentous morphology arises from repetitive cell divisions in a single plane perpendicular to the filament's main axis. Trichomes are multicellular structures made up of a chain of cells. Filaments of this group consist of vegetative cells, necridia, and akinetes such as *Phormidium* and *Oscillatoria*. The third category of cyanobacteria is heterocystous cyanobacteria, which can be categorized into two, namely unbranched and branched forms. Examples of unbranched heterocystous cyanobacteria are *Anabaena* and *Nostoc*. They exhibit heterocysts that are located either in the terminal or intercalary position and are uniseriate, forming chain-like structures without branches. Branched heterocystous forms include both heterocysts and branches, and there are two types of branching such as false and true branching. False branching occurs when a sheathed filament splits into two distinct filaments, each of which grows independently of the other. For instance, *Scytonema* exhibits false branching. True branching, on the other hand, happens when cells within a

filament can divide into several planes. True branching is seen in cyanobacteria such as *Hapalosiphon* and *Stigonema* (Waterbury 2006; Fogg 2012).

Filamentous cyanobacteria produce two types of specialized cells, heterocytes (heterocysts), and akinetes, other than the vegetative cells. The heterocytes play a vital role in anaerobic fixation of atmospheric nitrogen using the enzyme nitrogenase. Unlike vegetative cells, heterocytes have homogenous content and polar pores and can be found intercalary or terminally in filaments. Conversely, akinete cells are larger than vegetative cells and have a substantial amount of stored nutrients visible as granules. Akinetes are reproductive cells that can endure adverse conditions and remain dormant in the environment during unfavorable conditions. When a favorable environment occurs, they germinate into normal vegetative cyanobacterial filaments (Sukenik et al. 2019)

The cell walls of cyanobacteria have a composition similar to other gram-negative bacteria, including the presence of outer membrane and lipopolysaccharides, with a thick and highly cross-linked peptidoglycan layer. Some cyanobacteria have S-layers, which are proteinaceous layers covering the entire cell surface. These S-layers play a pivotal role in filament motility (Hoiczyk and Hansel 2000). The EPS (Extracellular Polymeric Substances) produced by many strains of cyanobacteria are mainly composed of heteropolysaccharides. These EPS can remain on the cell surface as sheaths, capsules, and slimes, or they can be released into the surrounding environment as released polysaccharides (RPS) (De Philippis and Micheletti 2009; Pereira et al. 2009; Ehling-Schulz and Scherer 1999). To survive in harsh environments, cyanobacteria have developed various adaptive strategies, including morphological, biochemical, and physiological ones. Among the biochemical strategies, the production of EPS allows them to survive diverse environmental conditions (De Philippis and Vincenzini 1998). The EPS has several functions, such as protecting cells against desiccation and UV radiation, forming biofilms, and concentrating nutrients and metal ions (Rossi and De Philippis 2015). In coastal intertidal zones, cyanobacteria are exposed to extremely stressful conditions such as desiccation, temperature, and salinity fluctuations. These conditions often lead to the

formation of cohesive mats and it is believed that EPS plays both protective and structural roles (Stal 2000; Diez et al. 2007).

Cyanobacteria have developed interesting reproductive strategies. Unicellular cyanobacteria, for instance, can produce baeocytes and exocytes. These are distinguished from the mother cell by their size, shape, and successive multiple fission, which ultimately results in their release into the environment (Komarek and Anagnostidis 1998). Filamentous cyanobacteria produce short filaments known as hormogonia, which are involved in reproduction and dispersal. Hormogonia are simpler in structure compared to other filaments and are rich in nitrogen and phosphorus stores (Rippka et al. 1979). They play a crucial role in various physiological processes in cyanobacteria (Tandeau de Marsac 1994). Some species of cyanobacteria facilitate the dispersal of hormogonia by rapidly moving them across surfaces or through the formation of gas vacuoles.

1.3 Symbiotic Associations

Symbiotic relationships play a vital role in the ecology and life cycle of many cyanobacterial lineages. Cyanobacteria can establish these relationships because of their efficient mechanism of photosynthesis. Consequently, they can sustain their activity even in low light conditions, which are typical in many symbiotic associations (Usher 2008). These relationships involve interactions with various organisms, such as plants (Rai et al. 2000), fungi (Rai 1990), animals (Wilkinson 1992), and eukaryotic algae (Janson 2002; Murakami et al. 2004). When maintained over a long period, these relationships can lead to coevolutionary patterns, such as asymmetric evolutionary rates (Law and Lewis 1983), gene-for-gene interactions (Flor 1955), or even co-speciation (Brooks 1979). For coevolution to occur, each partner must have a significant fitness effect on the other. It has been suggested that if a species limits the number of partners with which it interacts (specialization), it may increase its response to the selection imposed by those partners, thus facilitating coevolution (Whitlock 1996; Kawecki 1998). The genus *Nostoc* is a filamentous heterocystous cyanobacteria that is well-known for its ability to form symbiotic relationships with a variety of eukaryotic model systems, including protists, animals,

fungi, and plants (Rai et al. 2002). It has been found that certain cyanobacteria establish a symbiotic relationship with *Cycas*. For instance, *Nostoc muscorum* and *Nostoc punctiforme* have been identified in *Cycas* (Costa et al. 1999), while *Anabaena azollae* forms a symbiotic association with *Azolla*. The *Nostoc* species (*Nostoc azollae*) also forms a symbiotic relationship with the *Azolla filiculoides* species (Eily et al. 2019). Additionally, *Nostoc punctiforme* is known to form a symbiotic association with the angiosperm genus *Gunnera*.

1.4 Economic importance:

1.4.1 Medicinal Applications

Cyanobacteria have gained significant attention in recent research due to their potential in Biotechnology. They produce secondary metabolites with potential applications in medicine and Biotechnology. The Nostocales, Oscillatoriales, Chroococcales, Pleurocapsales, and Stigonematales of the Cyanobacteria phylum are predominantly known to contain secondary metabolites (Gerwick et al. 2008). These metabolites have demonstrated intriguing bioactivities, such as antimicrobial, antiviral, anti-inflammatory, anticancer, antimalarial, immunosuppressant, and anti-HIV (human immunodeficiency virus). Cyanovirin-N, Scytovirin N, and sulfoglycolipid isolated from *Nostoc ellipsosporum*, *Scytonema varium*, and *Scytonema* sp., respectively, have demonstrated significant antiviral activity against the HIV, providing potential aid for AIDS therapy (Boyd et al. 1997; Loya et al. 1998; Bokesch et al. 2003). Apratoxin and its derivatives, present in various types of cyanobacteria, have shown potential in fighting against multiple types of cancer cells. Curacin A, derived from *Lyngbya majuscula*, has also been shown to be effective in the treatment of breast cancer (Gerwick et al. 1994). Cryptophycin is a potent anti-cancer drug that targets various types of solid tumors, including lung, prostate, breast, pancreatic, ovarian, colon, and brain and can also target cells of multi-drug-resistant tumors (Panda et al. 1997). Scientists have synthesized several cryptophycin analogs to enhance their anticancer efficacy and bioavailability (Magarvey et al. 2006).

1.4.2 Production of anti-microbial compounds

Noscomin, a diterpenoid compound isolated from *Nostoc commune*, has been observed to have antibacterial effects against *Bacillus cereus*, *Staphylococcus epidermidis*, and *Escherichia coli* at minimum inhibitory concentration (MIC) comparable to standard drugs and nostofungicide has antifungal efficacy against *Aspergillus candidus* (Jaki et al. 1999). Several studies reported that extracts from cyanobacteria species such as *Westiellopsis prolifica*, *Hapalosiphon hibernicus*, *Nostoc muscorum*, *Scytonema* sp., and *Fischerella* have shown antibacterial properties against *Pseudomonas striata*, *Bacillus subtilis*, and *Escherichia coli* (Tyagi et al. 2014). Antibacterial activity against *Escherichia coli*, *Bacillus subtilis*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Micrococcus flavus*, and *Proteus mirabilis* was assessed using biomass from *Scytonema schmidtii* species (Nehul 2021). *Anabaena* sp. has also been shown to have antibacterial activity against various strains including *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Salmonella typhi*, and *Klebsiella pneumonia* (Chauhan et al. 2010).

1.4.3 Production of antioxidant compounds

Phycobiliproteins are photosynthetic light-harvesting and water-soluble proteins abundantly present in cyanobacteria. These proteins are of great ecological and economic importance as they exhibit a high level of anti-oxidant activity. As a result, they are being extensively researched for their potential application in synthesizing anti-aging drugs (Sonani et al. 2015). Several studies have demonstrated the antioxidant properties of certain cyanobacteria, particularly *Scytonema bohnerii* (Sharathchandra and Rajashekhar 2013). Species such as *Synechocystis aquatilis*, *Oscillatoria limosa*, and *Synechococcus elongatus* exhibit significant antioxidant activity. These activities include nitric oxide scavenging, high phenolic content, lipid peroxidation inhibition, and superoxide radical scavenging. These properties may be beneficial in preventing or slowing the progression of various oxidative stress-induced diseases (Rajishamol et al. 2016). Another study also revealed that *Lyngbya* sp. and *Oscillatoria* sp. can serve as excellent sources of antioxidants. Consequently, these cyanobacteria strains can be

utilized as raw materials in the pharmaceutical, cosmetic, and food industries (Hossain et al. 2016).

1.4.4 Nutrition/Food Supplements

Some strains of *Anabaena* and *Nostoc* are consumed as food in various countries including Chile, Peru, China, Mexico, and the Philippines. *Nostoc commune*, a good source of dietary fibre and a moderate amount of protein can be a valuable source of dietary fiber and play a significant role in the human diet (Facciola 1998). *Spirulina* (*Arthrospira platensis*) is used as a food supplement due to its excellent nutrient composition and digestibility. *Spirulina* is a great source of riboflavin, thiamine, beta-carotene, and vitamin B12. It is available in different forms, including powder, granules, tablets, and capsules (Asowata-Ayodele et al. 2024). Commercial *Spirulina* tablets contain a maximum of 244 micrograms of vitamin B12 per dry weight. Furthermore, according to the US Food and Drug Administration (2013), the use of colour additives derived from *Arthrospira platensis* pigments has been authorized in candies and chewing gum.

1.4.5 Biofertilizers

Cyanobacteria are present in agricultural soils, where they enhance soil fertility and crop productivity through nitrogen fixation, phosphate solubilization, and mineral release (Singh 2014). *Anabaena*, *Aulosira*, *Nostoc*, *Scytonema*, *Calothrix*, and *Plectonema* are some examples of nitrogen-fixing cyanobacteria species, which act as biofertilizers contributing to long-term soil fertility and sustainability. These species convert atmospheric dinitrogen into ammonium, solubilize fixed nutrients, and convert insoluble phosphorus in soil into phytoavailable forms (Sahu et al. 2012). Compared to conventional synthetic fertilizers like urea, cyanobacteria-based biofertilizers are more environmentally and economically sustainable as they require less capital and energy input. Additionally, they can promote the growth of heterotrophic bacteria and act as growth-promoting substances for plants (Misra and Kaushik 1989). Besides their natural fertilizing and mineral-nutrient-balancing properties, many cyanobacteria release a variety of biologically active substances

like vitamins, carbohydrates, proteins, polysaccharides, amino acids, and phytohormones. These substances act as elicitor molecules promoting plant growth and enhancing resistance to biotic and abiotic stress (Singh 2014).

1.4.6 Use in genetic engineering

Several strains of cyanobacteria are valuable sources of commercially high-valued compounds such as pigments, vitamins, and enzymes. Cyanobacteria have a variety of pigments, including chlorophylls (Chls a, b, d, and f), carotenoids (β -carotene, astaxanthin, fucoxanthin, lutein, lycopene), phycobiliproteins (phycocyanin, phycoerythrin, and allophycocyanin), and scytonemin. Some of these pigments like lutein, fucoxanthin, and phycocyanin have therapeutic applications such as treating cataracts, cardiovascular, and renal diseases, and cancer cell chemotherapy (Mandal et al. 2020). β -carotene is necessary for the synthesis of vitamins and for the production of rhodopsin in the retina. Pigments that are commonly utilised as food colourants, food additives, and supplements for human and animal feeds include zeaxanthin, nostoxanthin, echinenone, and canthaxanthin. Scytonemin, primarily found in *Scytonema javanicum*, is a UV-A protective pigment capable of absorbing UV-C, UV-B, and UV-A and can be utilized as a sunscreen. Scytonemin also inhibits the proliferation of human fibroblasts, endothelial cells, and tumour cells, making it a potential anti-inflammatory and antiproliferative medication (Stevenson et al. 2002). Many marine cyanobacteria have also drawn a lot of attention as a valuable source of vitamins, particularly vitamin E and the B-complex group with economic significance. For instance, *Spirulina (Arthrospira)* is thought to be a significant source of iron, copper, and vitamin B12. A wide range of enzymes secreted by cyanobacteria have proven to have industrial applications. Protease, amylase, and phosphatases are some of these crucial industrial enzymes. Alpha-amylases are widely employed in the starch industry, phosphatases and acid phosphatases are frequently used as diagnostic markers, and proteases are mostly used in the food processing industry. Cyanobacteria have potential applications in the cosmetics industry. For example, the exopolysaccharide (EPS) extracted from *Pseudomonas fluorescens* has been found to have a higher moisturizing retention

ability, making it a potential ingredient in cosmetics and medicinal products (Zhao et al. 2013). Additionally, Sacran, a jelly-like extracellular matrix extracted from *Aphanothece sacrum*, is renowned for its moisturizing properties and can also be used in cosmetics (Okajima et al. 2008; Morone et al. 2019).

Cyanobacteria can also be used to produce biofuels and serve as a source of enzymes for industrial processes. Organisms like *Synechococcus elongatus* can assist with biofuel production in a more cost-effective and environmentally sustainable manner, potentially replacing a significant proportion of fossil fuel consumption. The exploration of cyanobacteria's secondary metabolites has the potential to transform various industries, advance medical science, and contribute to sustainable energy production.

1.4.7 Environmental applications

Cyanobacteria are valuable for wastewater treatment and bioremediation due to their ability to break down environmental pollutants and remove heavy metals. They are also capable of degrading hydrocarbons, including crude oil and its components from oil spills in marine and terrestrial environments. Cyanobacteria such as *Oscillatoria salina*, *Plectonema terebrans*, and *Aphanocapsa* species form cyanobacterial mats that effectively mitigate oil pollution on seashores (Raghukumar et al. 2001). Numerous investigations have demonstrated the ability of cyanobacteria to extract nutrients from wastewater containing high concentrations of nitrogen and phosphorus (Shi et al. 2007; Delgadillo-Mirquez et al. 2016; Araujo et al. 2021). Cyanobacteria including *Oscillatoria*, *Phormidium*, *Aphanocapsa*, and *Westiellopsis* can remove phosphate and nitrogenous ions from wastewater. Cyanobacteria, particularly *Spirulina* strains such as *Spirulina platensis*, *Spirulina indica*, and *Spirulina maxima* have significant potential for mitigating metal pollution through the biosorption of nickel and zinc (Diaconu et al. 2023; Malletzidou et al. 2025)

1.5 Negative impacts

Despite the numerous benefits of cyanobacteria, they are also recognized for their negative impact on aquatic ecosystems due to the occurrence of widespread harmful blooms (cyanoHABs) (Huisman et al. 2018). These substances have the potential to negatively impact the aquatic environment, drinking water, and public health (Paerl and Huisman 2009; Hallegraeff 1993; Anderson et al. 2012). The occurrence and intensity of cyanobacterial blooms, including the toxic ones in marine, freshwater, and estuarine systems may rise as a result of climate change, global warming, and eutrophication. Gas-vacuolated taxa, including *Anabaena*, *Planktothrix*, *Microcystis*, *Aphanizomenon*, and *Cylindrospermopsis*, are frequently responsible for the formation of these blooms. Examples of organisms capable of producing microcystins (MCs) are *Microcystis*, *Planktothrix*, and *Anabaena* (Sivonen 2009). Additionally, *Cylindrospermopsis*, *Aphanizomenon*, and *Anabaena* belong to the group of species that possess the capability to excrete cylindrospermopsin (CYN) (Schembri et al. 2001; Preubel et al. 2006; Codd et al. 2016). Several species of cyanobacteria produce a range of cyanotoxins, including Anatoxins, Nodularins, Lyngbyatoxins, Saxitoxins, Aplysiatoxins, Lipopolysaccharides (LPS), and 2,4-diaminobutyric acid (DAB) (Codd et al. 2016). The release of these toxins into the water occurs due to the death or lysis of cyanobacteria cells during the occurrence of toxic algal blooms (Wang et al. 2016).

Even though enough research is being carried out on biodiversity, the total number of species in different taxonomic groups remains uncertain. Cyanobacterial species are estimated to be between 2000 and 8000, comprising over 300 genera. However, a more accurate estimate was derived using a model of discovery curves—which suggests a total of 6280 species, of which only 43% have been described so far (Nabout et al. 2013). The classification of unculturable species still has not been confirmed. Although cyanobacteria represent 23.4% of total prokaryotes, only 15 new species are added per year (Dvorak et al. 2017).

1.6 Cyanobacterial Taxonomy and Systematics

Cyanobacteria are a group of organisms that are extremely complex and difficult to study taxonomically. A major difficulty is in the diversity of morphological features, which are often hard to distinguish. Additionally, they exhibit a high degree of morphological plasticity, meaning their appearance can change significantly depending on environmental and cultural conditions (Komarek and Komarakova 2004). They are also genetically diverse and have a broad range of ecological flexibility (Bagchi and Singh 2019). These factors, combined with a complex and varying mode of asexual reproduction, make them very difficult to assess and classify systematically.

The classification of cyanobacteria has been revised multiple times since the first system proposed by Bornet and Flahault during 1886-1888. Geitler (1925) provided the first revised classification scheme, followed by Frey (1929), Geitler (1942), and Rippka et al. (1979). Initially, the classification of cyanobacteria was based on the botanical criterion. However, it was later recognized that they have a prokaryotic cell structure and therefore belong to the Bacteria phylogenetically (Stanier and van Niel 1962). The taxonomic classification proposed by Rippka et al. (1979) formed the basis of Bergey's Manual of Systematic Bacteriology, which was widely accepted. This led to immediate nomenclature problems as the rules of the International Code of Nomenclature (ICN) for algae, fungi, and plants differ from those of the International Code of Nomenclature of Prokaryotes (ICNP). Efforts have been made to harmonize both codes but with lesser progress. As a result, the nomenclature of cyanobacteria is currently governed by both ICN and ICNP systems (Oren and Ventura 2017). Along with the nomenclatural system, the classification of cyanobacteria is also under constant debate.

In the last 50 years, various research groups have introduced new schemes for the classification of cyanobacteria using electron microscopy and molecular characterization techniques (Drouet 1981; Bourrelly 1970; Otsuka et al. 2001; Casamatta et al. 2005; Rehakova et al. 2007; Perkerson et al. 2011). Recent revisions have made a significant contribution to our understanding of the diversity

and taxonomy of cyanobacteria (Anagnostidis and Komarek 1985, 1988, 1990; Komarek and Anagnostidis 1986, 1989; Budel and Kauff 2012). Studies on cyanobacterial diversity and phylogeny from various ecosystems worldwide have used different techniques and methodologies (Giovannoni et al. 1988; Urbach et al. 1992; Wilmotte 1994; Versalovic et al. 1994; Neilan et al. 1995; Lee et al. 1996; Nelissen et al. 1996; Lyra et al. 1997; Turner 1997; Zehr et al. 1997; Rasmussen and Svenning 1998; Lehtimaki et al. 2000; Castenholz 2001; Rudi et al. 2000; Garcia-Pichel et al. 2001; Suda et al. 2002; Neilan et al. 2002; Henson et al. 2004; Lyra et al. 2005; Rajaniemi et al. 2005; Sihvonen et al. 2007; Berrendero et al. 2008; Komarek 2010, 2013, 2016; Thomazeau et al. 2010; Suradkar et al. 2017; Bagchi et al. 2017; Kabirataj et al. 2018). More than 60 genera of cyanobacteria have been described since 2000, making the work on cyanobacterial taxonomy in the past few decades revolutionary on the international platform.

Cyanobacterial identification and classification used to rely solely on visible morphological and ecological characteristics. However, with the advancements in sequencing and phylogenetic approaches, it has become clear that these physical traits alone are insufficient for modern cyanobacterial taxonomy (Castenholz 1992; Komarek 2005). The currently accepted classification scheme has been proposed by Komarek et al. (2014) and employs a polyphasic approach, followed by multi-locus molecular characterization of the conserved sequences, including *nif*, *rpoC1*, *gyrB*, *hetR*, *rpoB*, *rbcLX*, *cpcBA-IGS*, outer membrane efflux protein (OMEP) region, and the 16S-23S internal transcribed spacer (ITS) (Rott et al. 2018; Mares 2018; Moten et al. 2018). This approach has led to the revision of some traditional species or genera as their phylogenetic positioning did not match their morphological descriptions. The polyphasic method has resolved many confusions concerning the systematic position, and morphological, and ecological characteristics of genetically cryptic species (Dvorak et al. 2017; Komarek 2018). As a result, the classical coccoid and filamentous lineages have been re-grouped into a new order, Synechococcales (Dvorak et al. 2017). Moreover, heterocystous cyanobacteria have been combined into a single order, Nostocales. Nevertheless, recent research has indicated that the Nostocales order might be phylogenetically complex (Berrendero

Gomez et al. 2016; Bagchi et al. 2017; Kabirnataj et al. 2018; McGregor and Sendall 2017a, b; Shalygin et al. 2017; Dvorak et al. 2017). Hence, the combination of modern and traditional methods is necessary for the precise classification of disputed groups.

The order Nostocales has a high degree of phylogenetic complexity due to the polyphyly observed at both the genera and family levels. Many well-established genera such as *Nostoc*, *Scytonema*, *Calothrix*, *Rivularia*, *Anabaena*, *Westiellopsis*, and others have been discovered to be polyphyletic (Berrendero Gomez et al. 2016; Zapomelova et al. 2016; Bagchi et al. 2017; Kabirnataj et al. 2018; McGregor and Sendall 2017a, b; Shalygin et al. 2017). To achieve monophyly, which is the fundamental goal of cyanobacterial taxonomists, these polyphyletic genera are continuously revised using the polyphasic approach. This has resulted in the description of new genera (Berrendero Gomez et al. 2016; Bagchi et al. 2017; Kabirnataj et al. 2018; McGregor and Sendall 2017a, b; Shalygin et al. 2017) and the unification of existing ones (Aguilera et al. 2018). Additionally, the intermixing of traditional families has been observed (Vaccharino and Johansen 2011; Komarek 2013, Shalygin et al. 2017), further complicating the phylogenetic complexity within the heterocystous clade. In a study, genus *Kyrtuthrix* was reclassified from the family Scytonemataceae to Rivulariaceae based on phylogenetic relatedness (Leon-Tejera et al. 2016). An updated classification of cyanobacterial orders and families was conducted by Strunecky et al. (2023) based on phylogenomic and polyphasic analysis.

The taxonomic classification of cyanobacteria is complicated since the phylogenetic patterns, cytomorphological characteristics, and rapid adaptations have developed differently in all diversified groups. However, this method is not without problems, and different methods must be used to study many special groups of cyanobacteria. This means that previously described species may need to be revised according to new findings and methodologies. Cyanobacterial taxonomy is plagued with constantly changing classifications and the lack of a consensus in the phylogenetic scheme. Further taxonomic and phylogenetic investigations on filamentous

heterocystous cyanobacteria at both lower and higher taxonomic levels are needed to resolve this issue.

1.7 Relevance of the Study

Referring to the literature on cyanobacterial taxa concerning Kerala, research on the diversity in the Scytonemataceae family is scarce. Also, the Western Ghats region of Kerala, which contributes to a spectrum of microhabitats, has not been extensively studied for cyanobacterial diversity, especially for the family Scytonemataceae. Initial investigations on Kerala's Western Ghats produced astounding findings, indicating that the cyanobacteria in these regions are extremely diversified.

The Scytonemataceae is the only traditional cyanobacterial family that exhibits the false branching phenotype and includes diverse species, that are of great interest in an ecological as well as economic perspective. A deeper understanding of the family provides greater insights into their morphology, physiology, distribution, and ecology. These microorganisms show great promise, and gaining a comprehensive understanding of the distribution of the Scytonemataceae family in the Western Ghats region requires a detailed taxonomic as well as ecological analysis incorporating multiple parameters. Therefore, the present study was designed and implemented to explore this diversity and ecology, further. The specific objectives of the study are detailed below:

1.8 Objectives

- To carry out an inventory on the diversity and distribution of members of the family Scytonemataceae in selected districts adjoining the Western Ghats of Kerala.
- To analyse the habitat preferences of members of the family Scytonemataceae in the region under study.
- To analyse the seasonality of occurrence and differences in morphometric characteristics of members of the family Scytonemataceae in heterogeneous habitats falling in the area under study

REVIEW OF LITERATURE

Diversity and distribution of Family Scytonemataceae

The diversity of cyanobacteria is expressed by their various morphological, biochemical, and physiological properties, which allow them to inhabit and thrive in a wide range of environments. These diverse characteristics also determine their taxonomic distinction based on their phenotypic properties. From an ecological perspective, research on cyanobacterial diversity is crucial since it provides information on their distribution, abundance, dominance, and richness in specific regions. Gaining more knowledge about the diversity of cyanobacteria can help us comprehend their morphology, physiology, and ecology. Also, research on cyanobacteria has highlighted their potential in various fields, including Biotechnology, Pharmacology, and Medicine. The family Scytonemataceae contains ecologically significant species that contribute significantly to nitrogen fixation, making them promising contributors in the area of agriculture. Nevertheless, this family has not gained total attention from the perspective of research. Some of the important studies undertaken in the family Scytonemataceae are listed below.

Thajuddin and Subramanian (2005) conducted a study on the biodiversity of cyanobacteria and their potential applications in Biotechnology. The study focused on the diversity of cyanobacteria in different environments, as well as emerging applications and novel advancements reshaping potential commercial exploitation fields. Another study was conducted by Ray et al. (2018) to investigate the cyanobacterial diversity in various habitats within the Kling area, Ri-Bhoi district, Meghalaya. They reported a total of 45 taxa, including 4 species of *Scytonema* (*Scytonema bewsii*, *Scytonema guyanense*, *Scytonema mirabile*, and *Scytonema subtile*), representing 4 orders and 6 families. Tagad (2016) investigated the taxonomic diversity of planktonic algae in Junnar Taluka of Pune district, India. The study reported the presence of 78 species belonging to 12 families from 9 orders. The research also aimed to document the algal flora of this region. Within the

Scytonemataceae family, three species of the *Scytonema* genus such as *Scytonema chiastum*, *Scytonema pseudohofmanni*, and *Scytonema schmidtii* were identified and reported.

Syiem et al. (2010) worked on the importance of cyanobacterial diversity in different ecological conditions in Meghalaya, India. 75 specimens were collected from ten different ecosystems. Their diversity study was ecologically significant as it quantified the abundance, diversity, dominance, and richness of various cyanobacteria in acidic soil and water pH. Suresh et al. (2012) undertook studies in the Kodaikanal, Gudalur, and Agasthiyar Falls regions and reported 41 cyanophycean members including *Scytonema schmidtii*.

Chandra and Rajashekar (2015) studied the distribution of freshwater cyanobacteria in the Kaiga region of the Western Ghats region of Karnataka. They reported that the cyanobacterial diversity is greatest during the monsoon, and lowest during the post-monsoon. Non-heterocystous filamentous forms predominated, followed by unicellular forms, with heterocystous forms being the least numerous. *Scytonema* species were also discovered.

Nikam et al. (2010) investigated the cyanobacterial diversity in the Western Ghats region of Maharashtra. Their research pointed out a diverse range of cyanobacteria in the districts of Ahmednagar, Pune, and Satara. After screening 627 soil samples from different locations, 94 cyanobacterial species were discovered. These included *Scytonematopsis kashyapi*, *Scytonema schmidtii*, *Scytonema pascheri*, *Scytonema subtile*, *Scytonema tolypothrichoides*, and *Scytonema mirabile*. Also, Priyadarshani et al. (2014) conducted a taxonomic survey of blue-green algae in the Western Ghats of Maharashtra, identifying 127 species from 36 genera, including *Scytonema* species such as *S. saleyeriense*, *S. burmanicum*, *S. julianum*, *S. cincinnatum*, and *S. amplum*.

In a study conducted by Caires et al. (2019), the biodiversity of benthic filamentous cyanobacteria in tropical marine environments of Bahia State, Northeastern Brazil was elucidated. The researchers reported one species of *Brasilonema* and two

species of *Scytonema*, namely *Scytonema arcangelii* and *Scytonema siculum*. Similarly, Crispino and Sant'Anna (2006) also reported the occurrence of *Scytonema siculum* in different reef regions, including both intertidal and supralittoral zones.

Das and Keshri (2017) investigated algal diversity in the Eastern Himalayas-III foothills (Cyanoprokaryota: Nostocales). They concentrated on the biodiversity of Koch Bihar, a West Bengal district located at the foot of the Eastern Himalayas. Nostocales, a cyanoprokaryote group commonly known as the N₂ fixing group, are abundant in this district. A total of 25 taxa were identified in this study. *Scytonema javanicum* Bornet ex Bornet and Flahault, *Scytonema pascheri* Bharadwaja was first discovered in West Bengal.

In tropical environments, Budel (1999) investigated the ecology and diversity of cyanobacteria that live on rocks. They looked at the diversity, quantity, and range of rock settings that terrestrial, lithophytic cyanobacteria inhabited in tropical biomes. Many different species of *Scytonema* have been identified, including *S. amplum*, *S. densum*, *S. guyanense*, *S. hofmannii*, *S. minus*, *S. multiramosum*, *S. myochrous*, *S. ocellatum*, *S. stuposum*, and *S. subcoactile*.

On the southeast coast of India, in the Uppanar estuary, Nedumaran and Perumal (2012) conducted a study on the diversity of cyanobacteria. At two stations of the Uppanar estuary on the southeast coast of India, the spatial and seasonal patterns of distribution of cyanobacterial species and abundance to physicochemical parameters were examined. There were 15 different cyanobacterial species discovered, including members of the Chroococcaceae, Oscillatoriaceae, and Nostocaceae groups. They reported that the concentration of nutrients was low throughout the summer, whereas the monsoon season has witnessed an upsurge in cyanobacteria.

Song et al. (2012) investigated the distribution and ecological aspects of aerial algae inhabiting stoneworks in Korea. Based on this data, species such as *Scytonema coactile* var. *thermalis* and *Scytonema coactile* var. *minor*, were first discovered in Korea. The morphotaxonomic characteristics and ecological preferences of 10

cyanobacterial and algal morphospecies from various Egyptian biotopes were discussed by Sabre et al. (2021). *Scytonema myochrous*, a cyanobacterium, emerged as a new record for the Egyptian algal inventory was one out of these ten.

The diversity of cyanobacteria from five different temples in Thanjavur District was studied by Bhavani et al. (2013). A total of 70 taxa of cyanobacteria belonging to 16 genera were recorded from the exteriors of the temple and exposed rock surfaces of monuments. Their study revealed that filamentous forms of cyanobacteria predominated on the walls of temples than the non-filamentous types including the Scytonemataceae family. The microbial communities inhabiting the rocks were dominated by filamentous microorganisms capable of inducing carbonate formation and deposition of cement (Webb and Kamber 2000). They concluded that temples and monuments were colonized by a higher number of cyanobacteria and that could be destroyed by secreting enzymes and producing carbonic acid.

Hoffmann and Demoulin (1985) studied the morphological variation of a few species of Scytonemataceae (Cyanophyceae) from the Grand Duchy of Luxembourg's Gutland region. Ten Scytonemataceae strains of aerophytic origin and one freshwater strain were incubated under various light conditions. Both liquid and solid media were used to cultivate the strain. Chu, BG-11, and BG-110 media were used. They examined the heterocyst, sheath breadth, false branching type, and cell dimension variability and concluded that the sheath colour is dependent on the amount of light. Additionally, it is noted that cell length increases as light intensity decreases, but cell breadth remains constant.

Babu and Sivakumar (2013) studied the diversity of cyanobacteria in the rice fields of Guntur area of Andhra Pradesh. During their investigation of the diversity and occurrence of cyanobacteria in diverse rice fields, they reported 36 species of cyanobacteria. The species belonged to the orders Stigonematales, Chroococcales, and Nostocales. They also identified *Scytonema hofmannii*, a member of the Scytonemataceae family. They concluded that paddy soil improves the species diversity of cyanobacteria, which in turn raises the soil fertility and preserves the physical and chemical qualities of soil. Selvi and Sivakumar (2012) focused on the

diversity and distribution of cyanobacteria in the rice fields of Cuddalore district, Tamilnadu. The *Scytonema hofmanni* and *Scytonema iyengri* species were among the 30 heterocystous forms they listed. In 2013, Bharadwaj and Baruah published a study on the diversity of nitrogen-fixing cyanobacteria in soil crusts from various rice fields in the Lower Brahmaputra Valley flood plains of Assam. In total, they isolated 47 N₂-fixing cyanobacterial taxa belonging to 20 genera under 8 families. Among them, 12 were heterocystous, including *Scytonema rivulare*.

According to the research by Venkataraman (1972), Brock (1973), and Gowda (2006), cyanobacteria normally grow best in a pH range of neutral to alkaline. Nonetheless, reports of their existence in extremely acidic pH settings exist. Acidic rice field soils in Kerala were found to include nitrogen-fixing cyanobacteria such as *Aulosira* sp., *Calothrix* spp., and *Scytonema* spp. Anand and Hopper (1987, 1995) and Madhusoodanan and Dominic (1996) reported these findings.

A systematic study was undertaken by Suresh et al. (2012) on the microalgal flora of Western Ghats and other parts of Eastern Ghats. A total of 97 species were recorded including *Scytonema schmidtii* and *Scytonema myochrous*. The physicochemical nature of water samples was studied and correlated with the total microalgal diversity. Their study showed a positive relationship with dissolved oxygen, salinity, and nutrients and a negative relationship with temperature and humidity. The species diversity index, species richness, and species evenness were also analyzed. Due to the high soil pH, high temperature, and high UV exposure, microalgae species were abundantly distributed in high-altitude regions (Whitton and Potts 2000). Cyanobacteria can withstand extremely tolerant environments including high exposure to sunlight, and UV radiation, thereby successfully colonizing in high-altitude and high-latitude environments (Sinha and Hader 2002).

The diversity of the cyanobacterial flora was studied by Philip et al. (2016) in Nelliampathy, Kerala. Their studies concentrate on the taxonomic identification of cyanobacteria at the species level and the exploration of that particular field. According to their investigation, Nelliampathy Ghats are rich in cyanobacterial diversity including the Scytonemataceae family. Geethu and Shamina (2021)

investigated filamentous cyanobacteria from the Western Ghats of northern Kerala, India. A total of 18 cyanobacterial taxa were identified. Filamentous heterocystous forms showed maximum diversity with 10 species followed by non-heterocystous forms with 8 species. They also reported *Scytonema Pascheri* belonging to the family Scytonemataceae. Ram and Shamina (2016) conducted a study on the biodiversity of epilithic cyanobacteria in Kerala, India. They found a total of 37 species from 6 different families. Scytonemataceae was the most common family with 9 species, which were *S. rivulare*, *S. stuposum*, *S. hofmannii*, *S. pascheri*, *S. bohneri*, *S. millei*, *S. coactile*, *S. simplex*, and *S. ocellatum*. Sebastian and Joseph (2013) investigated the diversity of filamentous algae in a minor stream of the Thodupuzha River, Kerala and their study recorded nine species of cyanobacteria including *Scytonema cincinnatum*. John and Francis (2013) investigated the algal flora of the Idukki District in Kerala, India, and found 50 cyanobacterial species, including *Scytonema* species. Research revealed that the cyanobacterial flora was dominated by unicellular rather than filamentous forms.

Joishi (2014) investigated the occurrence, distribution, species richness, and diversity of cyanobacteria with the water chemistry in four different rivers of the Western Ghats region, Karnataka. *Scytonema* represented one of 16 genera and 41 species recorded. Based on their research, it was found that cyanobacteria thrive at an ideal temperature, a slightly alkaline pH, and a higher concentration of dissolved oxygen. Additionally, the occurrence, growth, and richness of cyanobacteria may be favored by the high nitrate and phosphate contents of the river water (Dey and Hazra 2005).

Madhumathi et al. (2012) studied the diversity of cyanobacteria from the Scytonemataceae family that are found in alkaline rice field soils in Tamil Nadu, India. Similarly, *Scytonema* species, such as *Scytonema bohneri*, *Scytonema hofmannii*, and *Scytonema simplex*, are prevalent in the rice fields of Bongaigaon area in Assam (Das and Sarma 2010). From the acidic rice fields in the upper Brahmaputra Valley (Assam), India, Hazarika et al. (2012) reported five different species of *Scytonema*.

Blue-green algae have been documented by various researchers from different regions of Maharashtra (Ashtekar and Kamat 1980; Auti and Pingle 2006; Barhate and Tarar 1983; Bhoge and Ragothaman 1986; Kamat 1962, 63, 64, 68; Mahajan and Mahajan 1988, 89; Nandan 2010; Sardeshpande and Goyal 1981). Many investigations on cyanobacteria have been carried out in the Western Ghats region of Maharashtra, although the majority of the studies have been undertaken in fresh water and paddy fields (Balakrishnan and Chougule 2002; Kolte and Goyal 1985). Priyadarshani et al. (2014) investigated the biodiversity of blue-green algae from the Western Ghats of Maharashtra. They taxonomically enumerated 127 species from 36 genera including *Scytonema* species such as *Scytonema saleyeriense*, *Scytonema burmanicum*, *Scytonema julianum*, *Scytonema cincinnatum*, and *Scytonema amplum*.

Dhanya and Ray (2015) conducted a field investigation on the ecology and diversity of cyanobacteria from the rice fields in Kuttanadu, Kerala, India. Their work represents the first assessment of the blue-green algal population in Kuttanadu in connection to various soil regions, seasons, and crop growth stages. According to their research, the wetland paddy soils in Kuttanadu are highly varied in terms of blue-green algae. They found that 38% of the species present were those of Oscillatoriales. The research also revealed that species richness and the number of species positively correlate with crop seasons. The Lower Kuttanadu soil region observed the highest values for all the ecological parameters, whereas the Upper Kuttanadu soils recorded the lowest values for all of the parameters. The algal diversity of the region is noted to be at its highest during monsoon season. The Lower Kuttanadu soils had the highest species richness, and the Kayal lands had the lowest.

Li et al. (2016) evaluated the diversity and distribution of microbial communities, including *Scytonema* species, collected from the Lingyin and Kaihua temples located in Hangzhou, China. They also examined how environmental factors, such as atmospheric humidity, light intensity, temperature, and concentrations of NO₂ and SO₂, influenced the distribution and diversity of these microbial communities. Their

findings indicated that the presence of phototrophic microorganisms was correlated with levels of light and humidity.

In the eastern Himalayan foothills, one of the world's richest regions of biodiversity, Das and Keshri (2017) assessed the diversity of cyanobacteria. They concentrated on the N₂ fixing group, the Nostocales of Koch Bihar, a district of West Bengal located at the base of the Eastern Himalayas. They reported a total of 25 taxa of Nostocales during their examination. The first records of *Scytonema pascheri* Bharadwaja and *Scytonema javanicum* Bornet ex Bornet and Flahault were reported from West Bengal.

Tagad (2016) investigated the algal diversity of the Nostocaceae, Scytonemataceae, and Rivulariaceae families in the Pune district of Maharashtra. They included 42 species from the 12 genera and 3 families of the class Cyanophyceae. Three genera and 11 species were reported from the family Scytonemataceae. The main *Scytonema* species were *Scytonema cincinnatum*, *Scytonema crustaceum*, *Scytonema geitleri*, *Scytonema mirabile*, *Scytonema pseudohofmanni*, *Scytonema pseudopunctatum*, and *Scytonema schmidtii*. Tagad (2016) recorded *Scytonema mirabile* from Junnar Taluk of Pune district, India. Ray et al. (2018) observed it from Ri-Bhoi district, Meghalaya, and Luz et al. (2022) recorded it from Azores Island, Archipelago.

Banerjee et al. (2020) explored the heterocytous morphotypes of cyanobacteria from a wide range of habitats throughout West Bengal. Sampling was carried out both in rice fields as well as terrestrial locales of different areas of the state. A total of 19 genera and 35 heterocytous species, mostly from Nostocaceae, followed by Scytonemataceae, Rivulariaceae, Microchaetaceae, and Hapalosiphonaceae, were reported. Eight species of *Scytonema* were reported. Additionally, West Bengal provided the first record of *Brasilonema octagenerum*.

Romanenko et al. (2020) studied the morphological and molecular characterizations of the *Brasilonema* genus, which was first identified in a tropical greenhouse in Kyiv, Ukraine. Researchers looked at the morphological features of this newly

discovered cyanobacteria in both culture and natural material samples from greenhouses. A comparison of the original data with descriptions of the known *Brasilonema* species revealed that the Kyiv population shares morphological and ecological traits with several species, of which *B. octagenarum* (Aguiar et al. 2008) is the one to which it is most closely related. Analysis of the 16S-23S ITS region's nucleotide sequence and the secondary structure of its most informative helices confirmed the closest proximity of the Kyiv material to *Brasilonema octagenarum* which itself is likely a complex of species whose taxonomic separation is eventually conceivable.

Morales et al. (2017) conducted a study on cyanobacteria found in various tropical regions of Costa Rica. Their research focused on both the morphological identification and molecular characterization of these cyanobacteria. The strains were cultured using BG0-11 media and were then examined and classified at the genera level using a light microscope. Based on the phenotypic characteristics observed, the researchers identified four genera of Nostocales: *Calothrix* spp., *Tolypothrix* spp., *Scytonema* spp., and *Nostoc* sp. The study also explored potential biotechnological applications of these cyanobacteria.

The qualitative and quantitative effects of PAR and PAR+UV-B on the formation of mycosporine-like amino acids in *Scytonema geitleri* were examined by Mishra et al. (2014). According to their research, *Scytonema geitleri* can synthesize MAAs to shield itself from the harmful effects of increased UV-B radiation, changing radiation, and enhanced heat. Cyanobacteria have created mitigation defensive mechanisms, which can be broadly categorized into four types: avoidance (Bebout and Garcia-Pichel 1995; Castenholz 1997), screening, quenching, and repair. Avoidance by mat formation, gliding, and extracellular polysaccharide formation, and screening via MAA and Scytonemin formation (Garcia-Pichel et al. 1992; Singh et al. 2010) repair of UV-induced DNA damage or quenching of reactive oxygen species by enzymatic and non-enzymatic antioxidant molecules (Sinha and Hader 2002) and UV-sensitive protein resynthesis.

Kumar et al. (2016) conducted a study on the molecular phylogeny and diversity of cyanobacteria present in the biological crusts of arid soils in Eastern India. The researchers isolated a total of 15 cyanobacteria species from the soil crusts of Santiniketan and Salbani in West Bengal, as well as Bhubaneswar in Odisha. These species were identified as belonging to the genera *Scytonema*, *Tolypothrix*, *Nostoc*, and *Lyngbya*. The study revealed that the dominant component in the Biological Soil Crusts of India was the cyanobacteria species with a thick sheath layer around their trichome under the genera *Scytonema*, *Tolypothrix*, and *Lyngbya*.

Rai et al. (2018) used a culture-based approach to analyze both the molecular and morphological diversity of cyanobacteria along a rural-urban gradient. They found that the diversity of cyanobacteria decreased gradually from rural to urban areas due to changes in soil properties. The soils along the gradient varied in phosphorous, nitrogen, organic carbon, pH, micro-nutrient composition, and bulk density, resulting in changes in the texture, moisture content, and microbial biomass of the soil. The researchers also recorded the occurrence of heterocystous-filamentous cyanobacteria, specifically *Scytonema hofmanni* and *Scytonema ocellatum* f. *minor* from the order Nostocales.

The traditional taxonomic description of the genus *Scytonema* was compiled by Geitler (1932), Desikachary (1959), Starmach (1966), Bourrelly (1970), and Komarek and Anagnostidis (1988), but the modern revision based on polyphasic approach. Palinska and Surosz (2014) evaluated the current scenario of cyanobacterial taxonomy, describing older, classical, and recent taxonomic approaches as well as future trends, emphasizing methodology advancements as key drivers for this field's advancement. The use of multiple criteria, such as molecular and ultrastructural, in addition to the morphological, known as the "Polyphasic approach," has been proven to be effective in identifying and characterizing various taxa of cyanobacteria. Several researchers, including Flechtner et al. 2002; Gonzalez-Resendiz et al. 2013; Komarek 2010; Vaccarino and Johansen 2011, 2012, have used the term "Polyphasic" in this sense. The results of several studies, including those by Wilmotte and Golubic (1991) and Komarek (2006, 2010)

demonstrated a clear link between the morphology and DNA sequences of different genes within cyanobacteria, particularly the 16S rRNA. Geitler's (1932) classification of traditional cyanobacterial genera has been supported by DNA sequencing.

Taxonomic classification is complicated in photosynthetic prokaryotic, phylogenetically old cyanobacteria, because of their structural diversity. Komarek (2016) investigated the polyphasic approach, which combines modern molecular, cytomorphological, and ecological methods for cyanobacterial classification. The usage of this combined approach is considered to be the most recent technique for acquiring precise data on taxonomical identification and classification of cyanobacteria.

The taxonomy of cyanobacteria has been significantly changed by new taxonomical paradigms and the development of molecular techniques, resulting in the definition of new genera and species based on genetic and morphological research. Additionally, several previously identified cyanobacteria taxa, including some based on morphological and ecological characteristics, have been verified by molecular tools. A new species of *Brasilonema* (Scytonemataceae) from Tolantonga, Hidalgo, Central Mexico was reported by Becerra-Absalon et al. (2013). Based on morphological and molecular analyses, scientists believe the Tolantongo strain to be a new species, which they refer to as *Brasilonema tolantongensis* after the location where it was discovered.

Maree et al. (2018) provided the first report of the cyanobacterium *Petalonema alatum* (Borz ex Bornet and Flahault) Correns (Cyanobacteria, Scytonemataceae) in Africa. This species is known for forming thick biofilm mats with dense clusters. The morphology of *Petalonema alatum*, including the filaments, cells, and heterocytes, is consistent with the range of previous morphological descriptions provided in the literature by John et al. (2002), Uher (2010), Komarek (2013), and Wehr et al. (2015). The structure of the sheath, cell size, heterocyte shape and position, and branching patterns are among the important features used for species identification, as described by Komarek (2013). The sheaths of *Petalonema alatum*

are usually colorless in the early stages, but later turn yellow to brown, according to Wehr et al. (2015). *Petalonema alatum* has only been recorded in the northern hemisphere, except for Brazil (Sant'Anna et al. 2011) and the small island of New Caledonia, located east of Australia (Coute et al. 1999). Several researchers, including Borzi (1879), Correns (1898), Kosinskaja (1926), Jaag (1945), John et al. (2002), Uher (2010), and Wehr et al. (2015), have provided detailed descriptions, line drawings, and photographs of this species.

Several species of *Petalonema* have been studied and described in different regions of India. *Petalonema alatum* has been reported from Shembaganur, Tamil Nadu (Fremy 1942), Alibag, Maharashtra (Kamat 1968), Kolkata, West Bengal (Gupta 2012), and Sirsi taluk, Uttara Kannada, Karnataka. Rao (1944) described *Petalonema alatum* var. *indicum* which was collected near Chakrata, Dehra Dun Road, Uttarakhand. Gupta (2012) discovered another species of *Petalonema*, *Petalonema crassum*, from Kolkata, West Bengal. Biswas (1934) described *Petalonema crustaceum* from Cherrapunji, Meghalaya, which was initially collected by Agharkar 1925. Singh and Singh (2019) also studied *Petalonema crustaceum* from Sirsi taluk, Uttara Kannada, Karnataka. Kamat (1963) discovered *Petalonema densum* from Takala, Kolhapur, Maharashtra, and Gupta (2012) also found it in Kolkata, West Bengal. Jackson and Panikkar (2015) described *Petalonema incrustans* from Punnathala, Thangasserry (Kollam), Kerala. Meshram (2021) studied the taxonomic details of three species of the genus *Petalonema* collected from Maharashtra, India. Among these, *Petalonema alatum* and *Petalonema densum* were rediscovered after decades in Maharashtra, while *Petalonema crassum* is a newly reported cyanobacterium in the state.

Philip (2020) conducted a study on the cyanobacterial diversity of the Western Ghats forests of Kerala, India. In their study, they reported a total of 204 cyanobacterial species, including 10 species of *Scytonema* and 4 species of *Petalonema*, representing 50 genera and 16 families. The major species of the family Scytonemataceae include *Scytonema coactile* var. *minor*, *Scytonema crispum*, *Scytonema javanicum*, *Scytonema millei*, *Scytonema myochrous*, *Scytonema*

pseudoguyanense, *Scytonema stuposum*, *Scytonema caldarium*, *Scytonema torulosum*, *Scytonema schmidtii*, *Petalonema alatum*, *Petalonema pulchrum*, *Petalonema velutinum*, *Petalonema involvens*. Ram (2022) investigated the ecology and diversity of mangrove-associated cyanobacteria in Southern Kerala, India. A total of 89 species were recorded from various habitats within the mangrove ecosystems. This included 6 species of *Scytonema*, such as *Scytonema millei*, *Scytonema javanicum*, *Scytonema coactile*, *Scytonema tolypothrichoides*, *Scytonema bohneri*, and *Scytonema varium* were recorded.

Sarma et al. (2023) conducted a study on the diversity and morpho-taxonomy of the genus *Scytonema* in Tripura, India. Their study focused on the diversity and distribution pattern of the genus *Scytonema*, and they reported ten species of the genus *Scytonema* from the family Scytonemataceae. These species include *Scytonema bivaginatam*, *Scytonema chengii*, *Scytonema coactile*, *Scytonema hormocystum*, *Scytonema millei*, *Scytonema ocellatum*, *Scytonema praegnans*, *Scytonema pseudohofmannii*, *Scytonema twymanianum*, and *Scytonema zellerianum* found in different habitats of Tripura. All ten species are new additions to the flora of Tripura, India.

Novel genus and species

Scytonema pachmarhiense, a novel species belonging to the genus *Scytonema*, was named by Saraf et al. (2018) in the Pachmarhi Biosphere Reserve, India. They used a polyphasic approach to characterize a cyanobacterial strain that was collected from a freshwater body of the Pachmari Biosphere. Morphological analysis of the collected strain revealed similarities with the genus *Scytonema* because of having a false branching character. The strain's comprehensive morphological, molecular, and phylogenetic characterization together with the use of 16S rRNA gene phylogeny made it abundantly evident that it was distinct from other *Scytonema* species. According to the International Code of Nomenclature for Algae, Fungi, and Plants, they describe it as a new species of *Scytonema* with the aid of phylogenetic evidence, and they suggested the name *Scytonema pachmarhiense* for the new species.

Iningainema pulvinus gen nov., sp nov., a newly discovered nodularin-producing benthic cyanobacterium from a freshwater ambient spring wetland in tropical, northeastern Australia, was described by McGregor (2017). Their study was the first report of nodularin synthesis by cyanobacterial members of the Scytonemataceae family. *Iningainema* shares its morphology most closely with *Scytonematopsis Kiseleva* and *Scytonema* Agardh ex Bornet and Flahault. The isopolar filaments in all three genera are enveloped by a firm, often layered, and colourful sheath; false branching is typically geminate and less commonly single. *Iningainema pulvinus* distinguishes itself by having a false branching ontogeny and a typically spherical to discoid colony development. *Iningainema pulvinus* distinguishes itself by having a false branching ontogeny and a typically spherical to discoid colony development. A new species of cyanobacteria from the *Iningainema* genus has been discovered and described by Maltsev et al. (2021) by the International Code of Nomenclature for Algae, Fungi, and Plants. The newly discovered species, named *Iningainema sahyadrensis* sp. nov., was found in the Western Ghats (Sahyadri mountain range) in India. The description of the new species is based on its morphological characteristics and a phylogenetic analysis of the partial 16S rDNA gene. The results of the analysis indicate that *Iningainema sahyadrensis* belongs to the *Iningainema* clade, which is part of the Scytonemataceae family. The new strain of cyanobacteria established a solidly supported monophyletic lineage with strains of the type species of *Iningainema*, *Iningainema pulvinus*.

In the genus *Scytonema*, a new species was reported by Singh et al. (2017). A false-branching cyanobacterium was discovered during their research in a freshwater body in Bilaspur (Chhattisgarh, India). The strain showed significant differences from the closely related strains *Scytonema bilaspurensis* and *Scytonema hofmannii*, according to the morphological, ecological, molecular, and phylogenetic evidence. *Scytonema singhii* varies from closely related species in that it has a thin, textured sheath throughout the entire length of the trichome, as well as differences in the shape and dimensions of the vegetative cells and heterocytes. It has a close genetic affinity with *Scytonema bilaspurensis* and *Scytonema hofmannii* based on the 16S rRNA, *rbcl*, and *psbA* genes, however, phylogenetic analysis showed that *Scytonema*

singhii is distinct from those two species. Based on morphological, ecological, and genetic considerations, they concluded that the strain they identified, *Scytonema singhii*, was a new species of the genus *Scytonema*.

Sant' Anna et al. (2011) studied the subgeneric diversity of *Brasilonema*. A unique species of cyanobacterium was discovered in the Mata Atlantica tropical and subtropical rain forests of southeast Brazil. It grows on aerophytic wooden, stony, and iron substrates and resembles the genus *Scytonema* phenotypically, with erect fascicles and rare false branching. The researchers concluded that this species was distinct and different from *Scytonema* and was recognized as *Brasilonema* and placed in a separate generic entity according to both Bacteriological and Botanical nomenclature rules as noted by Fiore et al. (2007). According to their findings, the genus currently consists of seven taxa each of which can be distinguished by differences in morphological and ecological traits.

According to Villanueva et al. (2018), *Brasilonema lichenoides* sp. nov. is the first *Brasilonema* species to be isolated from a lichen thallus. According to Fiore et al. (2007), the Scytonemataceae family includes the type species *Brasilonema bromeliae*, which is isolated from subaerophytic environments in tropical and subtropical Brazil. On the Hawaiian island of Oahu, Vaccarino and Johansen (2012) discovered a novel filamentous cyanobacterial species called *Brasilonema angustatum* sp.nov. Several epilithic, epiphytic, aerophytic *Brasilonema* species have been reported from Hawaii, central Mexico (Rodarte et al. 2014). Six were identified as being native to Brazil: *Brasilonema bromeliae* (Fiore et al. 2007), *Brasilonema octagenarum* (Aguiar et al. 2008), *Brasilonema epidendron*, *Brasilonema ornatum*, *Brasilonema terrestre*, and *Brasilonema sennae* (Sant' Anna et al. 2011). Initially identified as *Camptylonemopsis sennae* (Komarek 2003), *Brasilonema sennae* has since been reclassified as *Brasilonema* (Aguiar et al. 2008; Sant' Anna 2011). Whereas *Brasilonema roberti-lamii*, which was first identified as *Tolypothrix roberti-lamii* in the Antilles (Bourrelly and Manguin 1952), which was later transferred to the genus *Shmidleinema* by Komarek (1989) and recently moved to *Brasilonema* (Sant' Anna et al. 2011). Rodarte et al. (2014) investigated the

morphological as well as molecular characterization of the cyanobacterium *Brasilonema roberti-lamii* from populations found in Central Mexico. They studied the morphological, morphometric, and ecological characteristics of the populations and their findings support the transference of *Tolypothrix roberti-lamii*, which was made based only on morphological criteria, to *Brasilonema*.

A filamentous cyanobacterium from Bilaspur, Chhattisgarh, India was recorded as a new species of the polyphyletic genus *Scytonema* by Singh et al. (2016). The presence of a distinctively textured sheath along the entire length of the trichome, variations in the shape and size of the vegetative cells, and heterocysts all served as reliable morphological signals that the strain was distinct from the rest of the closely related species. The strain was subjected to phenotypic, molecular, and phylogenetic analyses, and the results validated the strain's position as a novel species. The name *Scytonema bilaspurensis* was proposed for the strain.

Scytonematopsis contorta, a new species, was described by Vaccarino and Johansen (2011) based on morphological and molecular evidence from the Hawaiian island of Oahu. Its ability to produce a spirally contorted trichome within a single filament sets it apart from other species. The phylogenetic placement of the genus is unclear. Based on its isopolar growth, *Scytonematopsis* was placed in the Scytonemataceae by Anagnostidis and Komarek (1989), however, it is associated with species of *Rivularia* and *Calothrix* in the Rivulariaceae, which is distant from the Scytonemataceae. In India, the *Scytonematopsis* genus has three representatives. *Scytonematopsis ghazipurensis* Pandey and Mitra (1972) is found in soils of rice paddy fields whereas *Scytonematopsis kashyapii* (Bharadwaja) Geitler (1935) is observed on submerged water plants in small lakes, pools, and ponds. *Scytonematopsis woronichinii* Kiseleva (1931) was observed in the rice fields.

Komarek et al. (2013) conducted a study to explore the phenotypic characteristics of fourteen morphotypes of the cyanobacterial species *Scytonema*, which is ecologically significant. The research focussed on the state of Sao Paulo and the Atlantic Rainforest in Southeast Brazil. They used a polyphasic strategy to analyze 28 populations from natural samples, mostly from aerophytic habitats, and also 7

isolated strains. Their findings led them to recognize 13 *Scytonema* species including *Scytonema guyanense*, *Scytonema javanicum*, *Scytonema arcangelii*, *Scytonema hyalinum*, *Scytonema ocellatum*, *Scytonema crispum*, *Scytonema bohneri*, *Scytonema stuposum*, *Scytonema sp.*, *Scytonema schmidtii*, *Scytonema longiarticulatum*, *Scytonema papillicapitatum* and *Scytonema chorea*. The names *Scytonema papilli-capitatum* Sant' Anna et Komarek and *Scytonema chora* Sant'Anna et Komarek are used to designate two new species from the subgenus *Myochrotes*.

A new genus *Chakia* was identified in Belize, Central America, based on the genetic sequencing of 16S rRNA from four strains isolated from two alkaline marshes (Komarkova et al. 2013). The description of this new genus was completed by documenting the characteristic morphological features of thalli from both natural and cultivated environments. *Chakia* was established as a new genus based on both molecular sequencing and morphological characteristics. *Chakia* and other genera belonging to Scytonemataceae do not differ morphologically in many ways, however, the ends of vegetative filaments are never as narrow as they are at *Scytonematopsis*. Whole trichomes are narrow in comparison to the most closely related species of *Scytonema*. Cells vary in shape, sometimes being short and cylindrical, elongated, or barrel-shaped. The type species, *Chakia ciliosa*, found in natural samples, often formed hormocytes, which are not found in other species of Scytonemataceae. (Komarek 2013).

Scytonema santannae, a novel morphospecies of cyanobacteria from the Atlantic rainforest in southeast Brazil, was described by Hentschke and Komarek (2014). Due to their mosaic-ornate sheaths and typical epiphytic development like mosses on wooden surfaces, the new morphospecies set themselves apart from previous *Scytonema* species that have been identified. Only *Brasilonema ornatum* Sant' Anna et al. (2011) and *Scytonema stuposum* sensu Sant'Anna et al. (1983) reported mosaic-ornate sheaths. However, the type described by Sant' Anna et al. (1983) also demonstrates biseriate trichome sections, which suggests that it belongs to a distinct taxon than *Scytonema*. Despite having the same type of sheath, *Scytonema*

santannae and *Brasilonema ornatum* differ in diagnostic traits at the generic level, such as the existence of parallel filaments in *Brasilonema ornatum* that are untangled in *Scytonema santannae*.

A novel species of *Scytonema*, named *Scytonema foetidum* sp. nov., has been described by Tawong et al. (2022) based on both morphological and genetic evidence. Two clonal strains of this new species were isolated from a wet soil sample collected from the Khek River in northern Thailand. This species closely resembles *S. hofmanii* but can be distinguished by its smaller filament width, conically rounded apical cells, and the presence of a sheath that extends along the entire trichome. Phylogenetic analysis using 16S ribosomal RNA (rRNA), *rbcLX*, and *nifH* sequences revealed that *S. foetidum* forms a unique cluster within the *Scytonema sensu stricto* clade. Additionally, it shows low sequence similarity (<98.4%) in 16S rRNA with phylogenetically related taxa, supporting its classification as a separate species. The 16S–23S rRNA internal transcribed spacer (ITS) sequences of *S. foetidum* also exhibit unique secondary structures in the D1–D1', Box B, and V3 helices, further differentiating this species from other known *Scytonema* species. Moreover, *S. foetidum* is capable of producing the odoriferous compound geosmin.

Bohunicka et al. (2024) isolated 76 strains from tropical, subtropical, and temperate regions (Central Africa, North, Central, and South America, South and East Asia, and Europe). They employed a polyphasic approach to species delineation. All taxa were investigated morphologically initially, and then their relationships were examined using the standard 16S rRNA gene sequence together with three additional markers (*nifD*, *rpoC1*, and *rbcLX*). Their research revealed the discovery of 24 new *Brasilonema* species as well as new populations of established species. In addition, a full review of the genus and descriptions of new species were provided. These species are *Brasilonema amethysteum* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema bambusae* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema bambusicola* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema brancoi* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema calcareum* M. Bohunicka et J.R.

Johansen sp. nov., *Brasilonema corcovadense* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema epiphyllum* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema elegans* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema fatamorganum* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema incudis* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema mombasense* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema palmarum* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema muscicola* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema verawerneriae* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema calidum* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema cataractarum* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema cubense* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema elongatum* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema hortense* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema kauaiense* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema komarekii* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema mata-atlanticum* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema ohuense* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema villosum* M. Bohunicka et J.R. Johansen sp. nov.

Ecological and economic significance of Scytonemataceae

Rajeshwari and Rajashekhar (2011) attempted to the biochemical contents of seven species of cyanobacteria including *Scytonema bohneri* isolated from various aquatic habitats of Western Ghats, Southern India. The biochemical elements were examined regarding total protein, total carbohydrates, total free amino acid, total lipid, fatty acid, and mineral contents. The investigation indicated the greatest quantity of total carbohydrates in *Scytonema bohneri*. Moreover, a total of 12 types of fatty acids were observed, with lauric acid having the highest abundance across all seven species. Nickel was observed maximum in *Scytonema bohneri*. Sfriso et al. (2014) addressed several aspects of biochemistry such as phycocyanin, phycoerythrin, chlorophyll-a, carotenoids, carbohydrates, proteins, fatty acids, exopolysaccharides, and DNA profiling as more reliable approaches for characterization of cyanobacteria.

In a paddy field in the Fujian Province of China, Song et al. (2005) assessed the biodiversity and seasonal variation of the cyanobacterial assemblage during the rice growth season and after harvest. By considering both soil depth and time, seasonal change in the cyanobacterial populations could be shown. This finding indicated that the deeper soil fraction had a greater cyanobacterial diversity than the upper soil fraction. Additionally, the highest diversity was discovered in the middle of the growth season and the lowest after harvest. Furthermore, their research revealed that temperature, light intensity, and water availability are significant and may be the primary factors controlling cyanobacterial populations.

Cyanobacteria produce a wide range of pigments. Chlorophylls (Chls a, b, d, and f), carotenoids (β carotene, lutein, lycopene, astaxanthin, fucoxanthin), phycobiliproteins (phycoerythrin, phycocyanin, and allophycocyanin), and scytonemin are the pigments which exhibit diverse colours. Lutein, fucoxanthin, and phycocyanin have medicinal value and hence are used to treat cataracts, cardiovascular and renal diseases, and cancerous cell chemotherapy. In addition to serving as an antioxidant, β carotene is necessary for the biosynthesis of vitamins and rhodopsin (retina) and vitamins (Mandal et al. 2020). Scytonemin, a mostly UV-A photoprotective pigment from *Scytonema javanicum*, was reported by Proteau et al. (1993). Scytonemin has a significant ability to absorb UV radiations (UV-C, UV-B, and UV-A) and may be used as a sunscreen. The usage of scytonemin as sunscreen has an advantage over synthetic sunscreen compounds since they are evolved through the selection process which makes them appropriate for human applications (Gao and Garcia-Pichel 2011). Mishra et al. (2015) worked on the characterization of cyanobacterial pigments and the most current developments regarding the use of scytonemin, a UV-protective chemical found in cyanobacteria. Scytonemin can inhibit the proliferation of human fibroblasts, endothelial cells (Stevenson et al. 2002), and tumor cells (McInnes et al. 2005; Zhang et al. 2007; Duan et al. 2010) and can be employed as anti-inflammatory and antiproliferative medication in addition to antioxidant activity (Takamatsu et al. 2003; Ninomiya et al. 2011; Matsui et al. 2012).

Cyanobacteria from the rice field soil of Irongmara, Barak Valley, Assam were documented by Rout and Dey (1999). Deb et al. (2015) isolated *Scytonema tolypothrichoides* from acidic rice field soil from the Dholai region of the Cachar district in Assam, North-East India for its biochemical profile and antibacterial activities. The research shows the usefulness of integrated morphological and biochemical investigations in the characterization of cyanobacterial species as a component of the polyphasic approach. The isolated species was discovered to have a greater phycocyanin concentration compared to other phycobiliprotein pigments. The high carbohydrate and protein content observed in this alga contributes to the nutritional value of the species. The chosen microbial strain also showed a considerable nitrogen fixation capacity and antibacterial activity.

Nehul (2021) focused on the antibacterial properties of *Scytonema schmidtii*, isolated from various locations in Ahmednagar district of Maharashtra. Anonymous (1996) evaluated the antibacterial activity of *Scytonema schmidtii* using the disc diffusion method. Six hazardous bacteria, including *Escherichia coli*, *Pseudomonas aeruginosa*, *Micrococcus flavus*, *Staphylococcus aureus*, *Bacillus subtilis*, and *Proteus mirabilis* were utilized to assess the antibacterial activity of *Scytonema schmidtii* extracts. The extraction was carried out using water, methanol, hexane, and chloroform. Every bacterial strain worked out demonstrated activity against the methanol extract of *Scytonema schmidtii*. Several culture media, such as BG-11, Fogg's medium, Allen and Arnon medium, Zarrouk's medium, and CFTRI medium, were employed to produce biomass. The technique outlined by Bennett and Bogorad was used to measure phytobilins. The BG-11 medium, which has a greater phycobilin content than the Allen and Arnon medium, was shown to be the most successful of the culture media effective in supporting the growth of *Scytonema schmidtii*.

Scytonema javanicum was isolated from the biological crusts of the desert, and Hu et al. (2014) investigated the physiological and biochemical characteristics of the organism under salinity stress. Phycocyanin and chlorophyll content were reduced due to salinity, according to pigment analysis, but carotenoid concentration

increased in low salinity and dropped in high salinity. Additionally, salinity inhibited the rate of CO₂ assimilation and the photosynthetic oxygen evolution in this cyanobacterium.

According to research by Venkataraman (1972), and Brock (1973), cyanobacteria normally grow best in a pH range of neutral to alkaline. Nonetheless, there have been accounts of their existence in extremely high pH environments. Anand and Hopper (1987, 1995) and Madhusoodanan and Dominic (1996) reported nitrogen-fixing cyanobacteria in acidic rice field soils in Kerala, including *Aulosira* spp., *Calothrix* spp., and *Scytonema* spp.

In the freshwater bodies of the Peterhof fountains in Saint-Petersburg, Russia, Rodina et al. (2021) conducted research on the cyanobacterial communities associated with carbonate sediments. This study contributes to our understanding of the roles played by several cyanobacteria, such as *Scytonema ocellatum* and *Scytonema jullianum*, in the biomineralisation of carbonates. Additionally, the study demonstrated that cyanobacteria play significant roles in the biofilm community by forming their mucous matrix, which in turn affects the production of carbonate sediment. Research has demonstrated that cyanobacterial species belonging to the Oscillatoriaceae family have a considerable impact on carbonate biomineralization.

The characterization of cyanobacteria isolated from biofilms on stone monuments at Santiniketan, India, was studied by Keshari and Adhikary (2013). The results of the analysis revealed that the main constituents of the biofilms on the monuments are cyanobacteria from the genera *Scytonema* and *Tolypothrix*. Numerous investigations have also demonstrated that cyanobacterial species from the genera *Tolypothrix* and *Scytonema*, along with the associated species from the genera *Nostoc*, *Lyngbya*, *Gloeocapsa*, *Asterocapsa*, and *Plectonema*, all of which have either an abundance of mucilage or a distinct sheath around their trichomes, were the dominant organisms in biofilms on several stone temples and monuments (Roy et al. 1997; Pattanaik and Adhikary 2002). The extracellular sheath layers of cyanobacteria are made of polysaccharides that are capable of holding moisture, allowing them to thrive in extremely dry environments (Gloaguen et al. 1995; Adhikary 1998; Bertocchi et al.

1990; Cappitelli et al. 2012; Rossi et al. 2012). To develop and carry out effective conservation measures, Popovic et al. (2018) researched the diversity of cyanobacterial species colonizing several stone monuments in Serbia. They also documented their potential significance in biodeterioration processes. Four different substrata (carbonate rock, sandstone, lime mortar, and granite) on six cultural heritage sites with visible indications of biological colonization and deterioration were sampled for subaerial biofilm-forming cyanobacteria. There were 18 different cyanobacterial taxa found. On carbonate rock substrates, cyanobacteria from the genera *Scytonema*, *Nostoc*, *Hassallia*, *Gloeocapsa*, *Gloeotheca*, and *Gloeocapsopsis* were discovered. Carbonate rock has the most diversity observed because carbonate substrates are more porous and maintain a pH level that is ideal for biological processes over an extended time, and is the ideal environment for the growth of cyanobacteria (Warscheid and Braams 2000; Whitton 2012). Cyanobacteria thrive best in environments with significant CaCO₃ concentrations and a suitable pH, which is consistent (Warscheid and Braams 2000; Cuzman et al. 2011). The most optimal substrate for cyanobacterial colonization, according to Macedo et al. (2009), is carbonate rocks like marble. According to Vazquez-Nion et al. (2018), higher porosity of materials is related to greater water absorption via capillary forces, which is crucial for the formation of biofilms. The surfaces of rocks can provide a potential habitat for the growth and activity of cyanobacteria. Many researchers have carried out studies on the rock surfaces in Goa, Karnataka, Kerala, and Tamil Nadu. These studies are conducted by Pereira and Almeida (2012), Suresh et al. (2012), Singh and Singh (2019), and Philip and Radhakrishnan (2020). Apart from rocks, the surfaces of bark, concrete structures, and monuments were also investigated for the presence of cyanobacteria by Adhikary (2000), Pereira and Almeida (2012), and Singh and Singh (2019).

Tirkey and Adhikary (2005) investigated the occurrence of cyanobacteria in the biological soil crust of India. Biological crusts play a crucial ecological role by protecting soils from wind erosion and acting as a mechanism for moisture and water absorption. This process creates favorable conditions for the germination of flowering plant seeds. According to their findings, certain species of *Scytonema*

such as *Scytonema ocellatum*, *Scytonema rivulare*, *Scytonema schimidtii* and *Scytonema varium* are the dominant components of soil crusts in different regions of India.

Antonopoulou et al. (2005), worked out to establish data on the biological activity of the glycolipids of *Scytonema julianum*. Based on their research, novel bioactive compounds found in cyanobacteria have biological activity remarkably similar to that of platelet-activating factor (PAF) and may have a significant role in the development of allergic skin irritation and allergic asthma, following exposure to cyanobacteria. Notably, this study is the first to report the presence of compounds with PAF-like activity in cyanobacteria. However, there is limited information available on the lipid composition of *Scytonema julianum* (Reshef et al. 1997; Golecki and Drews 1982).

The first report on the toxicity of cyanobacteria *Scytonema javanicum* and *Scytonema ocellatum* LPS to microglia, an immune cell type involved in neuroinflammation and neurotoxicity in the central nervous system, was reported by Klemm et al. (2018). The cyanobacterial genus *Scytonema* has been found to produce various toxins, including tolytoxin, a member of the polyketide-derived macrolides scytophycins that exhibited cytotoxic and antifungal properties (Carmeli et al. 1990; Smith et al. 1993; Patterson and Bolis 1994). Scytovirin, a potent novel anti-HIV protein was also been identified in *Scytonema varium* (Bokesch et al. 2003). Scytoscalarol, an antibacterial sesterpene has also been identified (Mo et al. 2009). Additionally, the cyclic peptides scytonemides A and B, which have 20S proteasome inhibitory activity have been discovered in cyanobacterium *Scytonema hoffmanii* (Krunic et al. 2010). The first report of saxitoxin production by a species of freshwater benthic cyanobacterium, *Scytonema* Agardh was also published (Smith et al. 2011) and the alkaloid saxitoxins, which are quick-acting neurotoxins, that block sodium channels, have been studied in *Scytonema cf crispum* (Harland et al. 2015).

In the littoral zone of recreational lakes in Canterbury, New Zealand, Smith et al. (2012) undertook a survey of *Scytonema* (Cyanobacteria) and associated saxitoxins.

This was the first time these cyanobacterial saxitoxin variants had been reported in New Zealand. According to Sivonen and Jones (1999), some freshwater cyanobacteria and some marine dinoflagellates produce saxitoxins, which are neurotoxins. Human poisonings caused by eating seafood, especially shellfish, that contain saxitoxin have been frequently documented (Llewellyn 2006). The discovery of saxitoxins in drinking water sources in Australia, Brazil, and New Zealand's Waikato River (Kouzminov et al. 2007), as well as Hoeger et al. (2004) and Molica et al. (2004), revealed a further route for saxitoxin exposure in humans. Smith et al. (2011) conducted a study that confirmed the presence of a cyanobacterium in New Zealand capable of producing saxitoxin, which is a dangerous neurotoxin. The researchers found saxitoxin (STX) in a unialgal culture of *Scytonema cf. crispum* (C. Agardh), Bornet (strain UCFS10) obtained from the Groyne, a recreational reserve in Christchurch. While *Scytonema* spp. has been found in other parts of New Zealand, the distribution of *Scytonema cf. crispum* was largely unknown. Recently, *Scytonema cf. crispum* has been found in a pretreatment drinking water reservoir in the South Island of New Zealand, which highlights the need for further research to determine its distribution in the country's waterways.

Comprehensive research has been conducted on the biotechnological potential of cyanobacteria (Mends 2003; Meyer and Hamann 2005; Spolaore et al. 2006). Ananya et al. (2014) have reviewed cyanobacteria and their novel applications. Zahra et al. (2020) have compiled a summary of the potential applications of cyanobacteria in various scientific and developmental fields. Their research focuses on the use of these bacteria for producing biofuels and other co-products that are valuable in industry. Additionally, they have also examined the challenges that hinder the industrial development of these applications and suggested ways to overcome such obstacles. An assessment of the literature on the pharmacological, toxicological, and other possible uses of cyanobacteria was provided by Rishi and Aswathi (2015). Numerous cyanobacteria metabolites have been found as antialgal agents, in the sense they prevent the growth and development of various algal species. Cyanobactericin from *Scytonema hoffmanii* is one of these metabolites (Abarzua et al. 1999). Numerous cyanobacterial species are known to produce

unique chemicals that exhibit strong antiviral action against a range of viral pathogen, including HIV. The ability of cyanobacteria to combat a wide range of viruses is widely recognized (Damonte et al. 2004; Meyer and Hamann 2005;). Scytovirin, isolated from *Scytonema varium* has been shown that scytovirin binds to the HIV envelope glycoprotein, inactivating the virus and making it useful for treating AIDS (Boyd et al. 1997; Loya et al. 1998; Bokesch et al. 2003). Numerous cyanobacteria species have been isolated from different deep-sea and coastal marine environments and have shown to be a major source of numerous chemical classes of natural products that have anti-cancer, and anti-proliferative qualities. Moore (1981) identified the first anticancer substance, called "Tolytoxin," from cyanobacteria. According to Pattenden and Thom (1993), modified cytotoxic peptides of *Scytonema mirabile* are known as tantazoles and mirabazoles.

A global overview of the presence of algae and cyanobacteria in phytotelmata was published by Ramos and Moura (2019). Among these groups, cyanobacteria (Cyanophyceae) is quite commonly found in phytotelmata. About 37 species of cyanobacteria have been reported in phytotelmata, with the majority being found in bromeliad tanks. The studies carried out by Bermudes and Benzing (1991) in Ecuador suggest that cyanobacteria play a crucial ecological role in phytotelmata. These microorganisms secrete nitrogenous substances that are taken up by the trichomes of bromeliads, which benefits the symbiosis of other organisms. Another study was performed by Fiore et al. (2007), where they described the genus *Brasilonema* from polyphasic studies in material collected in bromeliad tanks of Sao Paulo.

Butel-Ponce et al. (2004) conducted a study on new pigments extracted from *Scytonema* species, a terrestrial cyanobacterium that grows on the Mitaraka Inselberg in French Guyana. The researchers discovered three new pigments derived from the scytoneman skeleton of scytonemin, namely tetramethoxy scytonemin, dimethoxy scytonemin, and scytonine. Scytonemin is a yellow-brown pigment that is known for its potent ultraviolet-absorbing properties. It is found in the

extracellular polysaccharide sheath of some cyanobacteria and was first described by Proteau et al. (1993).

Cyanobacteria can release several biologically active substances, including carbohydrates, vitamins, proteins, polysaccharides, amino acids, and phytohormones. These substances act as elicitor molecules, which help promote plant growth and enhance the plant's ability to fight against biotic and abiotic stress. Singh (2014) reviewed the role of cyanobacteria elicitor molecules in enhancing plant growth and providing tolerance against biotic or abiotic stress. Cyanobacteria play a crucial role in maintaining overall soil health. They not only perform biological nitrogen fixation but also produce polysaccharides and other bioactive compounds that stimulate plant growth. These substances are crucial for enhancing soil quality and preventing soil erosion.

Cyanobacteria are known to thrive in salt-affected soils, indicating their natural tolerance to salt stress (Apte and Bhagwat 1989; De Philippis et al. 1998; Singh and Dhar 2010). Their colonization in these soils has been shown to release various biologically active metabolites in the rhizosphere, which can induce systemic responses in plants to combat stress and promote growth. One such study conducted on cyanobacterium *Scytonema hofmanni* revealed its positive effect on the growth of rice seedlings in salt-stress conditions. Extracellular products of *Scytonema hofmanni* were found to partially or completely reverse many of the adverse effects of NaCl on growth, as well as the biochemical alterations of rice seedlings, including 5-aminolevulinate dehydratase activity, total free porphyrin, and pigment content (Rodriguez et al. 2006).

Silva et al. (2020) conducted a study on the niche partitioning of the three most common biocrust heterocystous cyanobacteria. They used enrichment cultivation and determined the growth responses to temperature in 30 representative isolates, including 12 *Scytonema* spp. The study found that *Scytonema* spp. isolates were the most thermotolerant, typically growing up to 40°C, while only those of *Tolypothrix* spp. grew at 4°C. *Nostoc* spp. strains showed good growth responses at intermediate temperatures. Their findings suggest that these cyanobacteria exhibit different

thermophysiological patterns in culture and have consistent worldwide distributions in nature. This suggests that they may have different sensitivities to global warming, which could result in microbial replacement that biocrusts will face in future climate change scenarios.

Scytonema foetidum sp. nov. was described by Tawong et al. (2022) based on both morphological and genetic evidence. Two clonal strains of this new species were isolated from a wet soil sample collected from the Khek River in northern Thailand. *S. foetidum* can produce the odoriferous compound geosmin, known for its earthy smell in soil. Geosmin is a well-known volatile compound and plays a significant role in biotechnology; however, the pleasant scent associated with soil can lead to off-flavors in water, wine, and freshwater fish products, which producers often find challenging to eliminate.

With this background, the present study has been attempted with the above-cited objectives.

MATERIALS AND METHODS

The present study has been carried out to assess the diversity, distribution, habitat preferences, and seasonality of occurrence of the members of the family Scytonemataceae in selected districts adjoining the Western Ghats of Kerala. The details of the sampling locations, together with other attributes undertaken for the study, are detailed below.

3.1 The Western Ghats

The Western Ghats are a range of mountains that run parallel to the western coast of India, stretching from Gujarat to Tamil Nadu. The mountain range covers the states of Maharashtra, Goa, Karnataka, and Kerala and spans an area of around 160,000 km² in a 1,600 km long stretch. The Ghats are known as the Great Escarpment of India and have been recognized as a UNESCO World Heritage site. The Western Ghats are renowned for their exceptional biological diversity and endemism. They are also recognized as one of the World's eight hottest hotspots. The western Ghats are a region of immense global importance for the conservation of biological diversity as well as containing areas of high geological, cultural, and aesthetic values. Moreover, they significantly impact the ecological and physical processes across the entire Indian peninsula and also impact the country's monsoon weather patterns. The Western Ghats are highly regarded for their contribution to the conservation of biological diversity and are recognized as a vital ecological asset.

Kerala, an Indian state in the south-western side, has not been extensively studied for cyanobacteria, especially the Scytonemataceae family, from the Western Ghats region of Kerala. The literature on cyanobacterial taxa having members of the Scytonemataceae family in Kerala is scarce. Initial investigations on the cyanobacteria of Western Ghats produced astounding findings, indicating that the cyanobacteria in these regions are extremely diversified. Thus, an in-depth analysis of the diversity and ecology is necessary to understand the distribution of the

Scytonemataceae family in the Western Ghats region. In this perspective, the current study was planned and carried out.

3.2 Study areas

The present study was carried in Palakkad, Malappuram, Kozhikode, and Wayanad districts of Kerala State (latitudes 8°18' and 12°48' and longitudes 74°52' and 77°22'), which are adjoining the Western Ghats. Details of the sampling locations, including place names, location code and the geographic coordinates are detailed below (Table 3.1). Maps concerning the 52 sampling locations are prepared using Arc GIS software and are depicted as Figs.3.5-3.10. The habitats of Palakkad, Malappuram, Kozhikode, and Wayanad districts are illustrated in the figures 3.1-3.4).

Table 3.1

Details of sampling locations

Sl. No	Location	Location Code	Coordinates
Palakkad District			
1	Nelliyampathy	P1a	N10°31.623' - E076°38.748'
2	Nelliyampathy	P1b	N10°31.625' - E076°38.747'
3	Minnampara	P2a	N10°32.356' - E076°42.877'
4	Minnampara	P2b	N10°31.680' - E076°43.198'
5	Mattumala	P3	N10°31.750' - E076°43.173'
6	Meenvallam	P4	N10°55.381' - E076°33.685'
7	Attapady	P5	N11°02.847' - E076°32.349'
8	Pothundy dam	P6	N10°31.128' - E076°37.744'
Malappuram District			
1	Adyanpara	M1a	N11°21'17.73" - E076°12'11.86"
2	Adyanpara	M1b	N11°21'19.74" - E076°12'11.85"
3	Adyanpara	M1c	N11°17'95" - E076°12'11.92"
4	Kozhipara Waterfalls	M2a	N11°21'14.51" - E076°06'30.40"
5	Kozhipara Waterfalls	M2b	N11°21'17.51" - E076°06'31.37"
6	Kozhipara Waterfalls	M2c	N11°21'14.67" - E076°06'28.84"
7	Valillapuzha	M3a	N11°16'25.83" - E076°02'05.19"
8	Valillapuzha	M3b	N11°16'26.07" - E076°02'05.40"
9	Koonorkandy	M4	N11°16'26.04" - E076°02'05.46"
10	Nadukani churam	M5	N11°24'38.23" - E076°22'31.72"

11	Arimbra hills	M6	N11°05'.950"-E076°00'.990"
12	Cheruppadimala	M7a	N11°06'.542"-E075°59'.504"
13	Cheruppadimala	M7b	N11°06'.536"-E075°59'.542"
14	Cheuppadimala	M7c	N11°07.068'-E075°59.354"
Kozhikode District			
1	Thonikadavu	K1a	N11°32'11.22"-E075°53'39.88"
2	Thonikadavu	K1b	N11°32'12.80"-E075°53'40.86"
3	Thonikadavu	K1c	N11°32'12.98"-E075°53'59.66"
4	Koorachundu	K2	N11°31'34.98"-E075°49'27.84"
5	Muthappanpuzha	K3a	N11°26.948'-E076°06.022'
6	Muthappanpuzha	K3b	N11°26.715'-E076°05.292"
7	Muthappanpuzha	K3c	N11°27.156'-E076°05.983
8	Thamarassery churam	K4a	N11°30'45.96"-E076°01'08.52"
9	Thamarassery churam	K4b	N11°30'38.01"-E076°01'09.48"
10	Urumi dam	K5	N11°22'22.73"-E076°03'32.30"
11	Kuliramutty	K6	N11°21'28.01"-E076°02'46.61"
12	Thalayad	K7	N11°30'37.65"-E075°53'19.85"
13	Thalayad 26 mile	K8	N11°30'56.55"-E075°53'21.05"
14	Kariyathumpara	K9	N11°32'26.31"-E075°53'33.58"
15	Thechi	K10	N11°28'31.84"-E075°53'47.28"
16	Kalpini	K11a	N11°20'01.15"-E076°03'49.82"
17	Kalpini	K11b	N11°20'02.04"-E076°03'53.55"
Wayanad District			
1	Edakkal	W1a	N11°37'47.52"-E076°13'44.12"
2	Edakkal	W1b	N11°37'47.79"-E076°13'40.58"
3	Edakkal	W1c	N11°37'20.12"-E076°13'42.71"
4	Edakkal	W1d	N11°37'18.97"-E076°13'44.92"
5	Phantom rock	W2a	N11°38'08.55"-E076°12'11.61"
6	Phantom rock	W2b	N11°38'09.96"-E076°12'14.27"
7	Govindamoola Chira	W3	N11°37'41.96"-E076°14'30.07"
8	Ambukuthi 19	W4	N11°37'01.80"-E076°14'06.19"
9	Meppadi	W5	N11°33'28.3" E076°07'55.2"
10	Rippon	W6	N11°32'25.02"-E076°08'10.94"
11	Thirunelli	W7a	N11°30'41.79"-E076°14'30.21"
12	Thirunelli	W7b	N11°54'49.33"-E075°59'39.29"
13	Kanthanpara	W8	N11°31'41.35"-E076°09'25.75"

3.2.1 Station 1: Palakkad

Palakkad is a district in Kerala, India, located centrally and ranked as the second largest district in the state after Idukki. The district headquarters is in the city of

Palakkad, which is known as "The Granary of Kerala". Serving as the gateway to Kerala, Palakkad is notable for the Palakkad Gap in the Western Ghats. The district's highest elevation point is Anginda Peak, which stands at 2,383 meters (amsl) and lies on the border of Palakkad, Nilgiris, and Malappuram districts within Silent Valley National Park. The district covers 4,480 km² (1,730 sq mi), making it Kerala's largest district, accounting for 11.5% of the state's total land area. Forests represent 1,360 km² (530 sq mi) of the total land area. The majority of the district is in the midland region, with average elevations ranging from 75 to 250 m, except the hilly Nelliampathy-Parambikulam area in the Chittur taluk in the south and the Attappadi-Malampuzha area in the north, with elevations exceeding 250 m. The Attappadi valley of Palakkad district, along with the Chaliyar valley of the neighbouring Nilambur region (Eastern Eranad region) in the Malappuram district, is renowned for natural gold fields, which can also be found in other parts of the Nilgiri Biosphere Reserve.

3.2.2 Station 2: Malappuram

Malappuram district is the third-largest district in Kerala, encompassing 3,554 square kilometers, occupying 9.13% of the State's total area. The district is located within the geographic coordinates of 75°E - 77°E longitude and 10°N - 12°N latitude. Being the most populous district in Kerala, Malappuram constitutes around 13% of the state's total population. The district borders the Arabian Sea to the west, the Nilgiri Hills to the east, the Palakkad district to the southeast, the Thrissur district to the southwest, and the Kozhikode district to the northwest. Malappuram has a coastal region or lowland that borders the Arabian Sea, a midland in the centre, and a hilly region or highland which forms part of the Western Ghats. The midland area of the district, however, has a lot of mountainous regions, which is not typical of other districts in Kerala.



Fig. 3.1: Habitat of Palakkad district



Fig. 3.2: Habitat of Malappuram district

3.2.3 Station 3: Kozhikode

Kozhikode district is bordered by the Malappuram district to the south, Kannur district to the north, Wayanad district to the east, and the Arabian Sea to the west. Kozhikode city, popularly referred to as Calicut, serves as the district's headquarters and is the third-largest urban agglomeration in Kerala. Kozhikode is topographically divided into three distinct regions: the lateritic midland, the sandy coast, and the rocky highlands which is a mountainous section of the Western Ghats. The highlands cover approximately 637.65 square kilometers of the overall 2344 square kilometers. The sandy coastal belt and lateritic midlands cover 362.85 square kilometers and 1343.5 square kilometers, respectively. The climate of the district is typically humid, with a highly hot season from March to May. The South West Monsoon, which begins in the first week of June and lasts through September, brings in the year's rainfall. From the second half of October into November, there is a North East Monsoon. The average annual rainfall is 3,266 millimetres, or 129 inches.

3.2.4 Station 4: Wayanad

The Wayanad district is located in the north-eastern part of the state of Kerala. It covers an area of the Western Ghats and is situated on the southernmost extremity of the Deccan plateau. The district shares its western border with the Kozhikode district, and this region is mostly covered by dense forests of the Western Ghats. The district has an area of 885.92 km² and is mostly covered with forests. The administrative headquarters is Kalpetta. Wayanad is the only plateau in Kerala, which is situated at an altitude of 700 to 2100 meters above sea level. Connecting the Eastern and Western Ghats, it is the southern portion of the Deccan Plateau. The Wayanad plateau is an extension of the Mysore plateau and is situated at a high altitude in the Western Ghats. The highest point in the district is Vellari Mala, a hill that is 2,240 meters (7,349 ft) high. It is located at the intersection of Wayanad, Malappuram, and Kozhikode districts. Wayanad district borders Karnataka (Kodagu, Chamarajnar, and Mysore districts) to the north and north-east, Tamilnadu (Nilgiris districts) to the south-east, Malappuram to the south, Kozhikode to the south-west, and Kannur to the north-west.



Fig. 3.3: Habitat of Kozhikode district

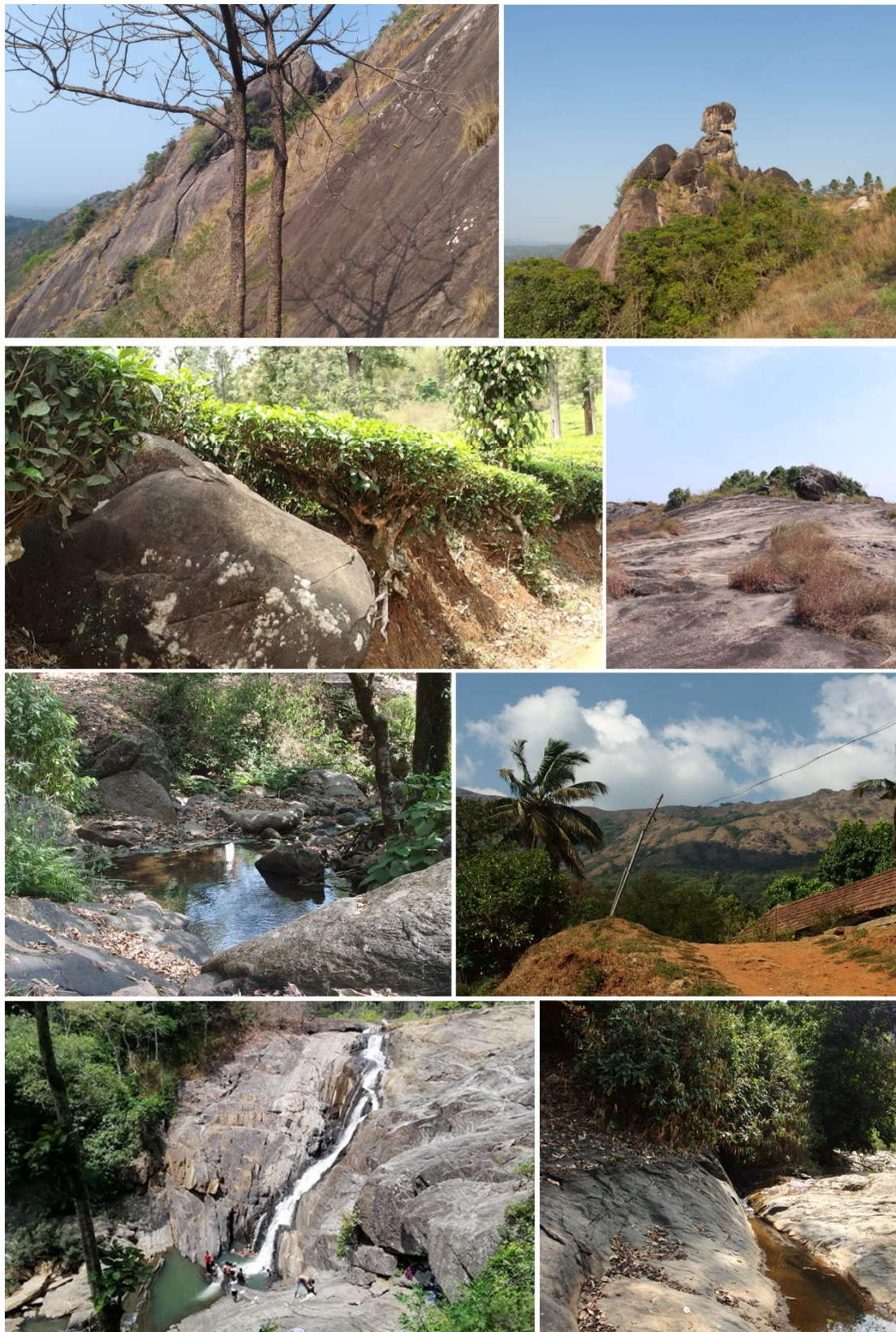


Fig. 3.4: Habitat of Wayanad district

The district of Wayanad is surrounded by a network of protected areas that host various biological reserves. These include the Malabar Wildlife Sanctuary in the west, the Mudumalai National Park in the south, the Bandipur National Park in the east, the Nagarhole National Park in the northeast, the Brahmagiri Wildlife Sanctuary in the north, and the Ariram Wildlife Sanctuary in the northwest, which is connected to the Wayanad Wildlife Sanctuary. These protected areas support a wide variety of flora and fauna, creating a distinctive ecology in the Wayanad district.

Wayanad enjoys a pleasant climate throughout the year, with an average rainfall of 2322 m. Lakkidi, Vythiri, and Meppadi receive the highest amount of rainfall, ranging between 3,000 to 4,000 mm each year. During March and April, dry winds blow, while high-velocity winds are common during the southwest monsoon. High-altitude areas experience extreme cold. The relative humidity in the region can reach up to 95% during the southwest monsoon season. The year is divided into four seasons: cold weather (December-February), hot weather (March-May), southwest monsoon (June-September), and northeast monsoon (October-November). The valley of Lakkidi, tucked away among the hills of Vythiri taluk, receives the highest average rainfall in Kerala.

3.3 Cyanobacterial Sampling

Specimens were collected on a seasonal basis (pre-monsoon, monsoon, and post-monsoon) from 52 sites of the Western Ghats, adjoining Palakkad, Malappuram, Kozhikode, and Wayanad districts. The sampling co-ordinates were marked with an Etrex 20X Garmin GPS. Also, the cyanobacterial patches were collected from different rock surfaces at various sampling sites by scraping with sterile scalpels and were kept in collection bottles. Additionally, habit and habitat characteristics of patches were identified and recorded. Each specimen was given a voucher number for identification. Microclimatic parameters associated with the habitat, such as atmospheric temperature (Divinext digital Thermometer), surface temperature (Metravi AVM-08 IR Thermometer), humidity (Divinext digital Hygrometer), and wind velocity (Prova AVM -01 Anemometer) were recorded. Diurnal temperature and relative humidity data were acquired from Google Earth Pro (2022). Moisture percentage has been assessed by taking uniformly sized patch and estimating its fresh weight and dry weight by following standard procedures.

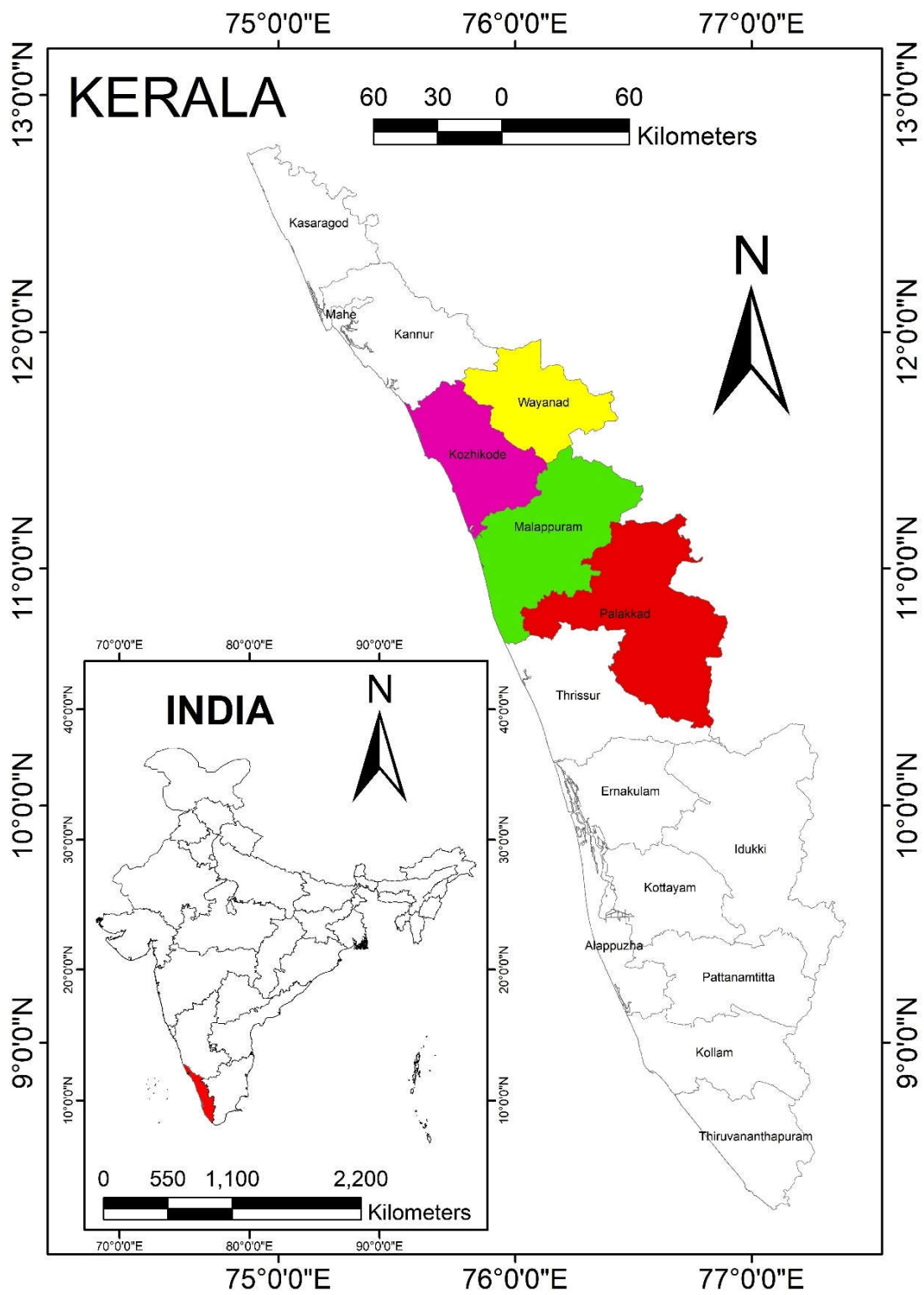


Fig. 3.5: Map of the study area

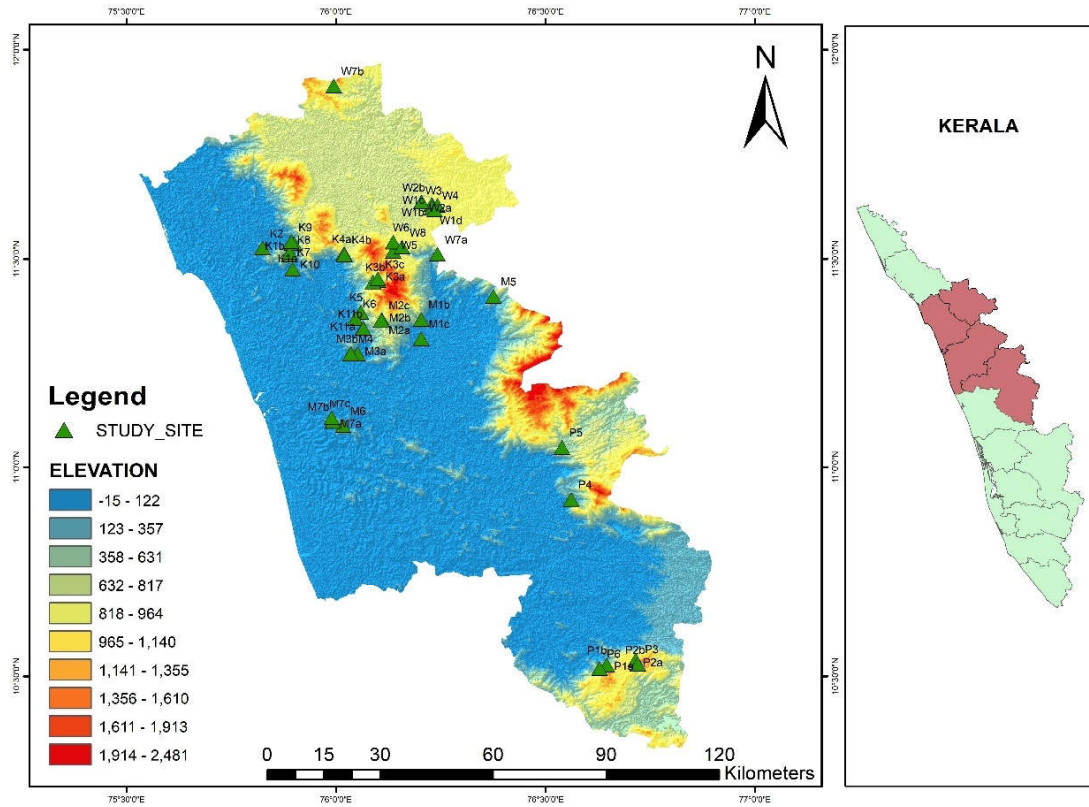


Fig. 3.6: Map of the study area showing sampling sites at different elevations (meters)

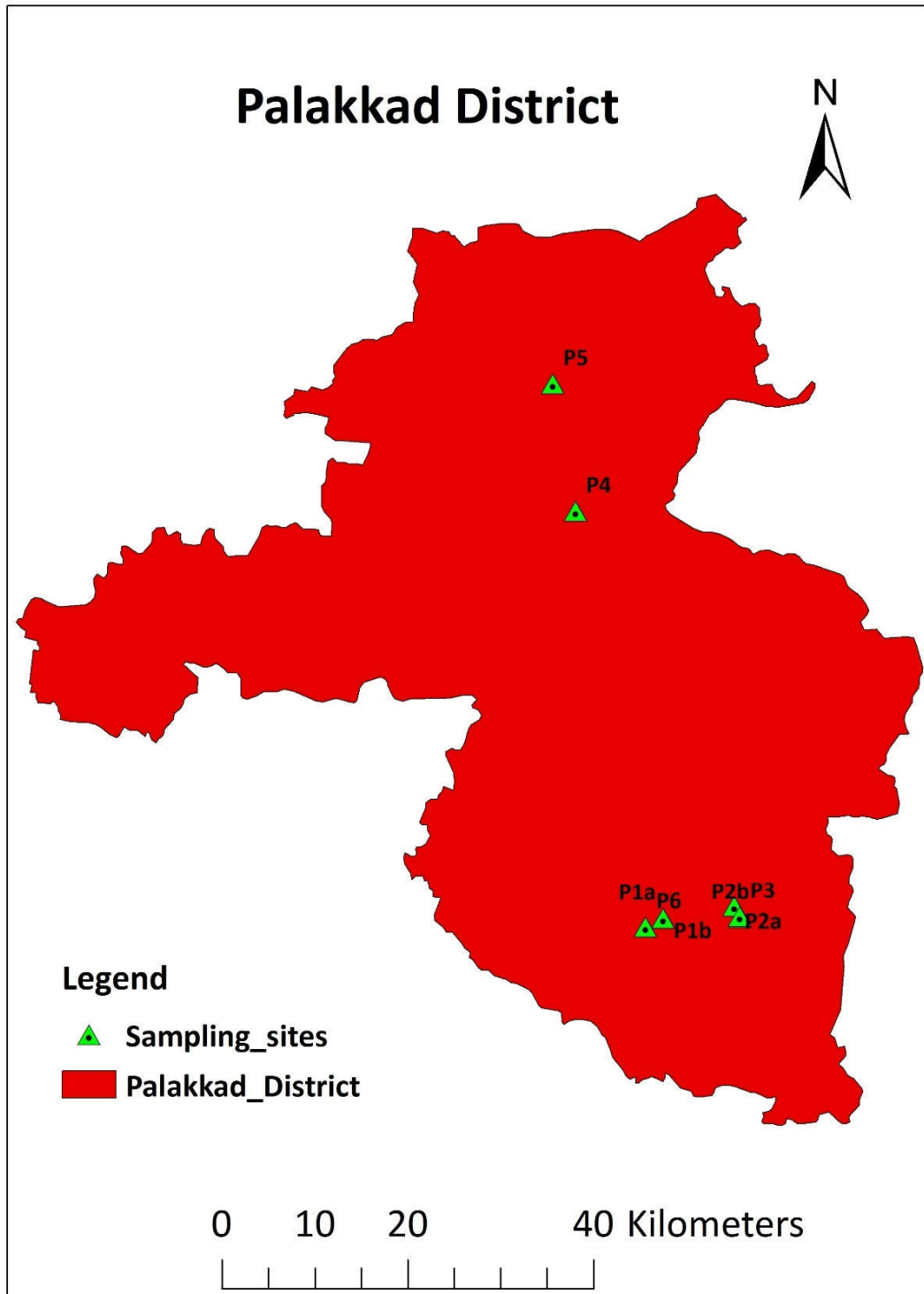


Fig. 3.7: Sampling location: Palakkad district

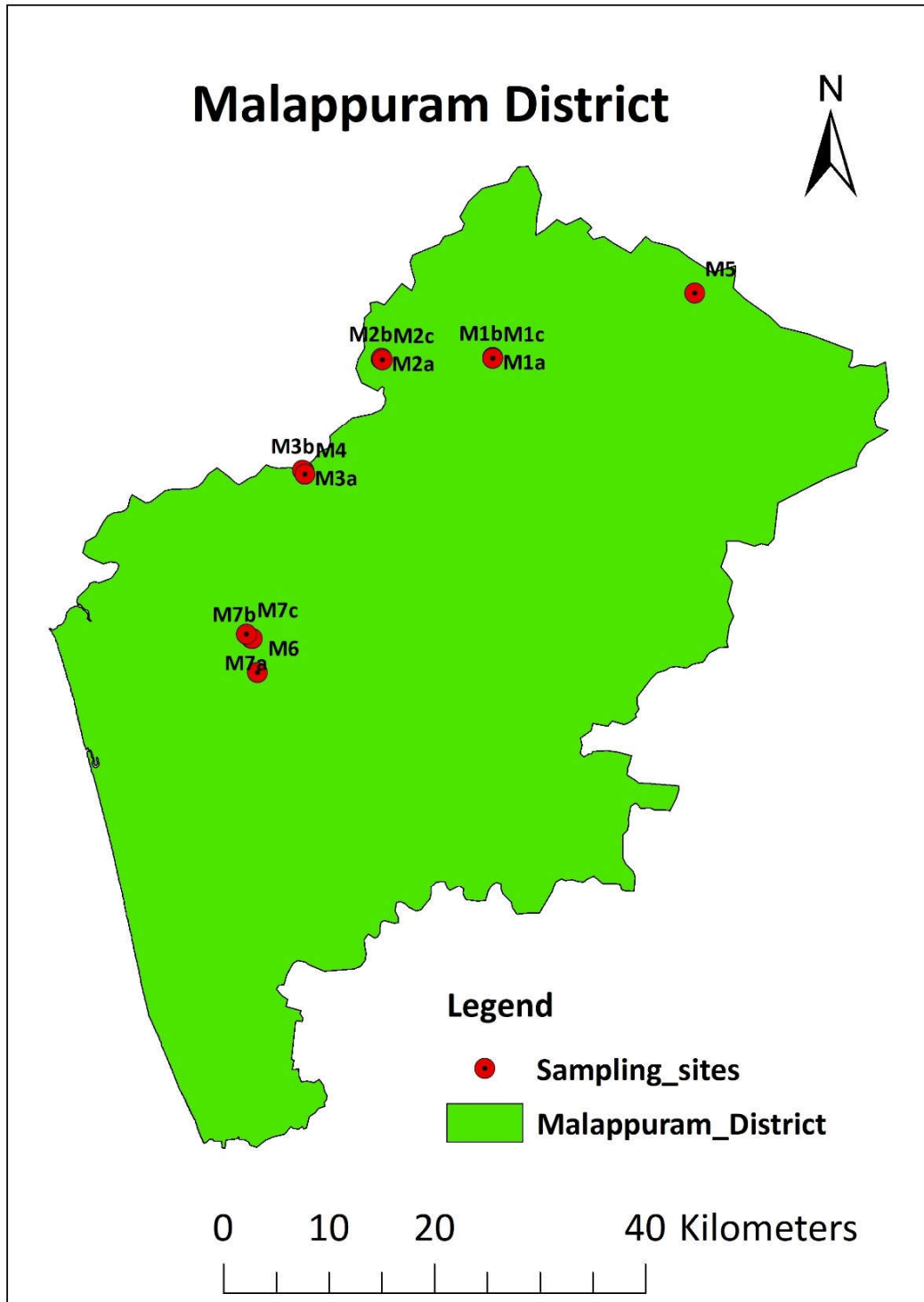


Fig. 3.8: Sampling location: Malappuram district

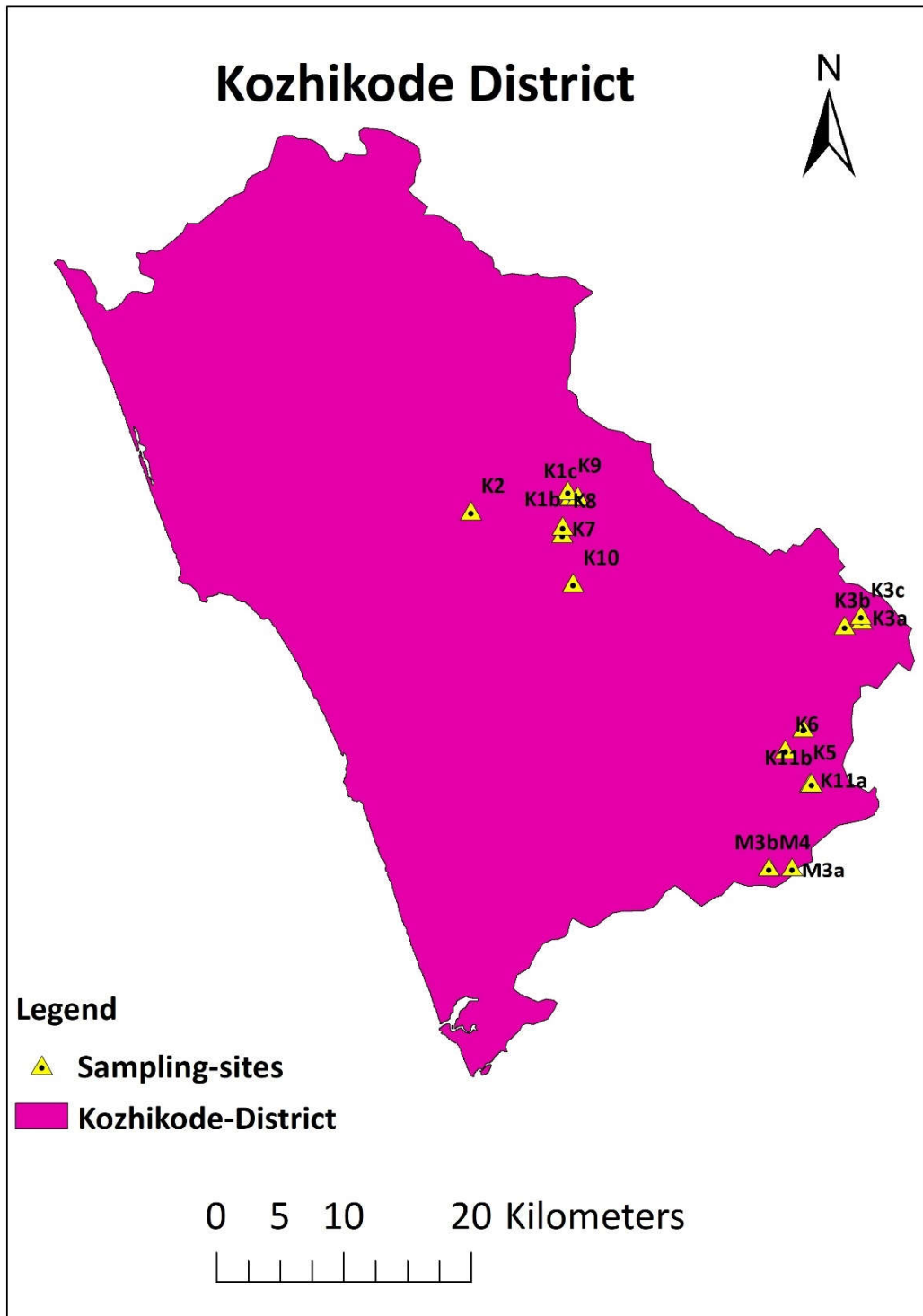


Fig. 3.9: Sampling location: Kozhikode district

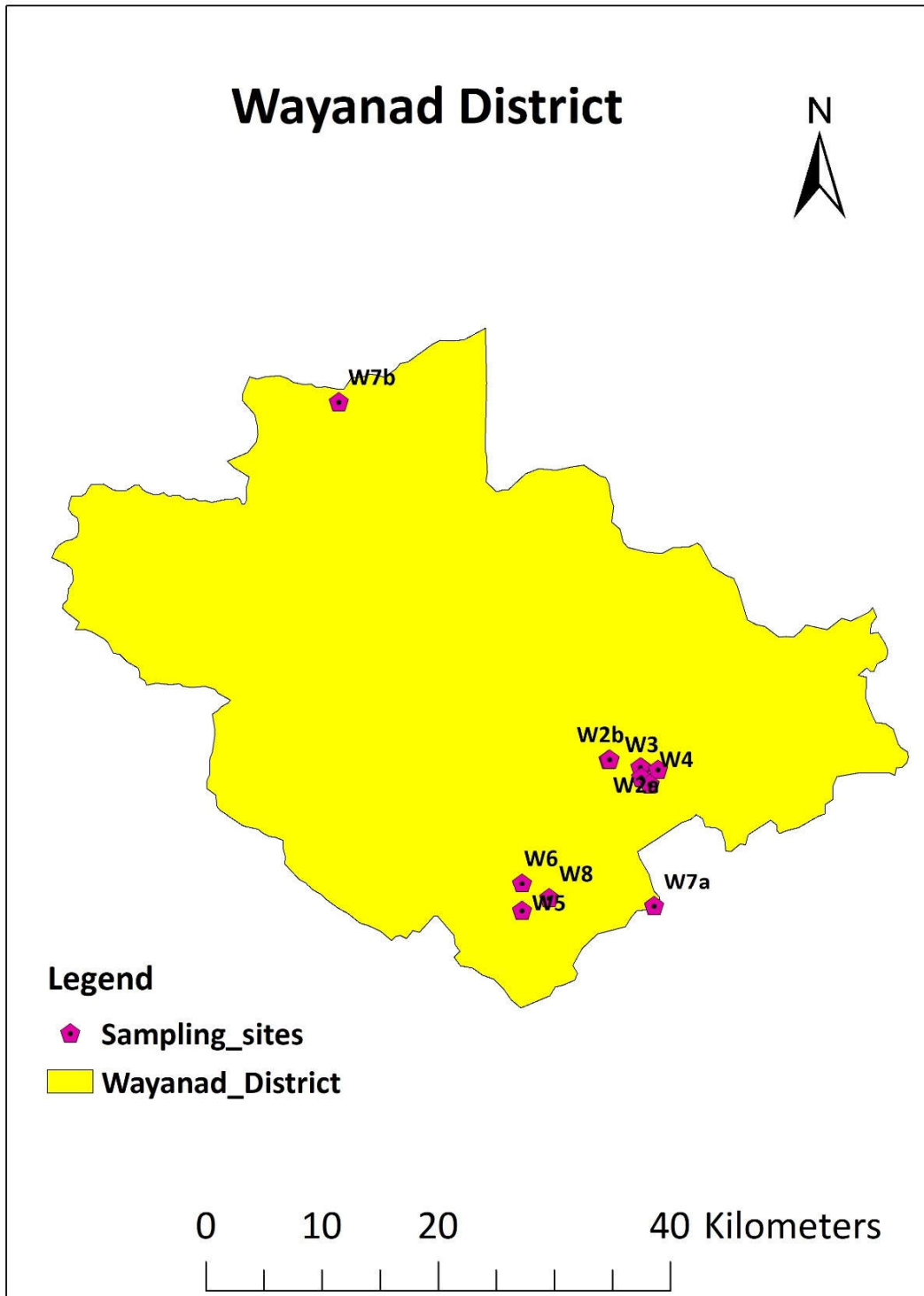


Fig. 3.10: Sampling location: Wayanad district



Fig. 3.11: Habitat of cyanobacteria (Family Scytonemataceae) found attached to rock surfaces

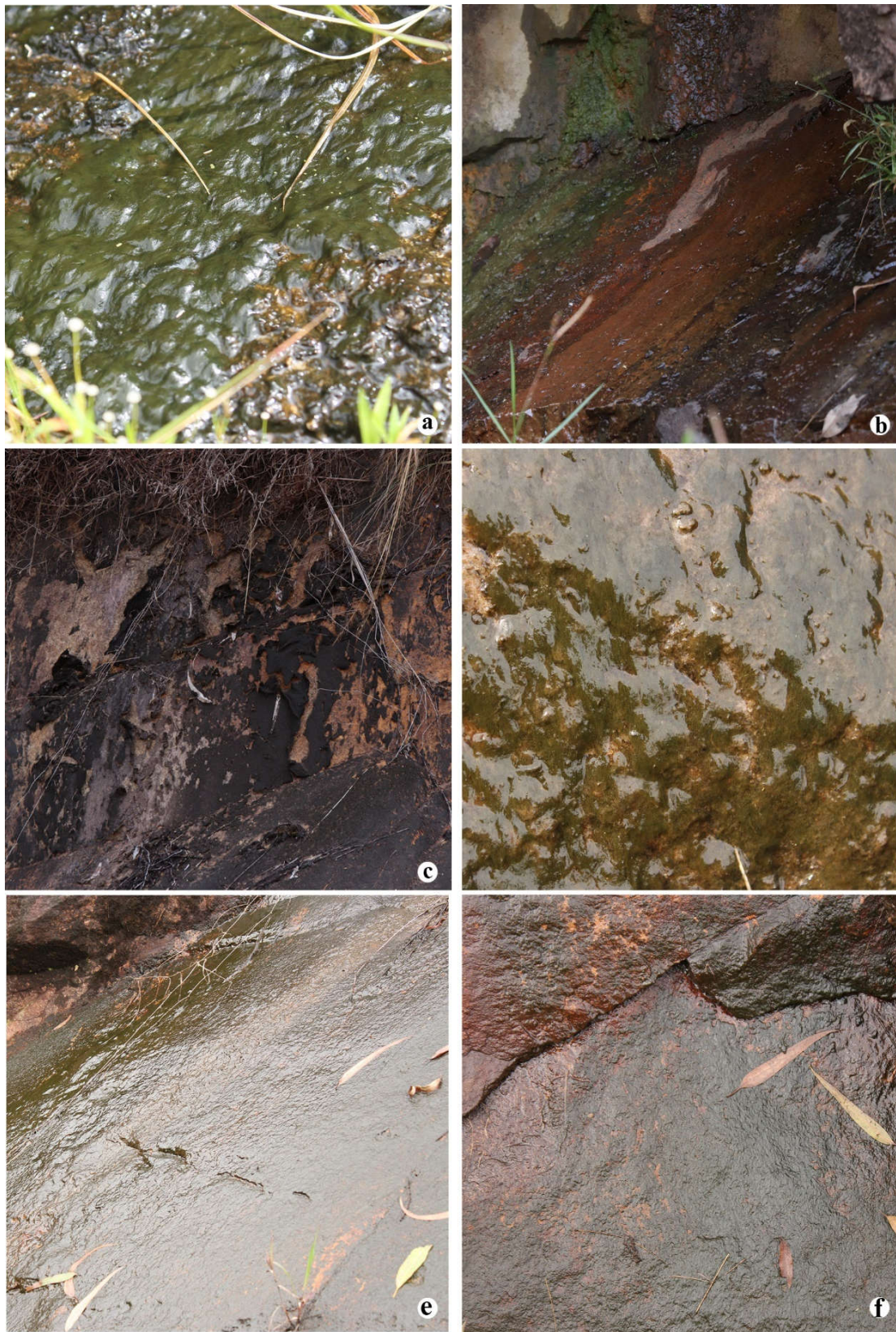


Fig. 3.12: Habitat of cyanobacteria (Family Scytonemataceae) found attached to rock surfaces

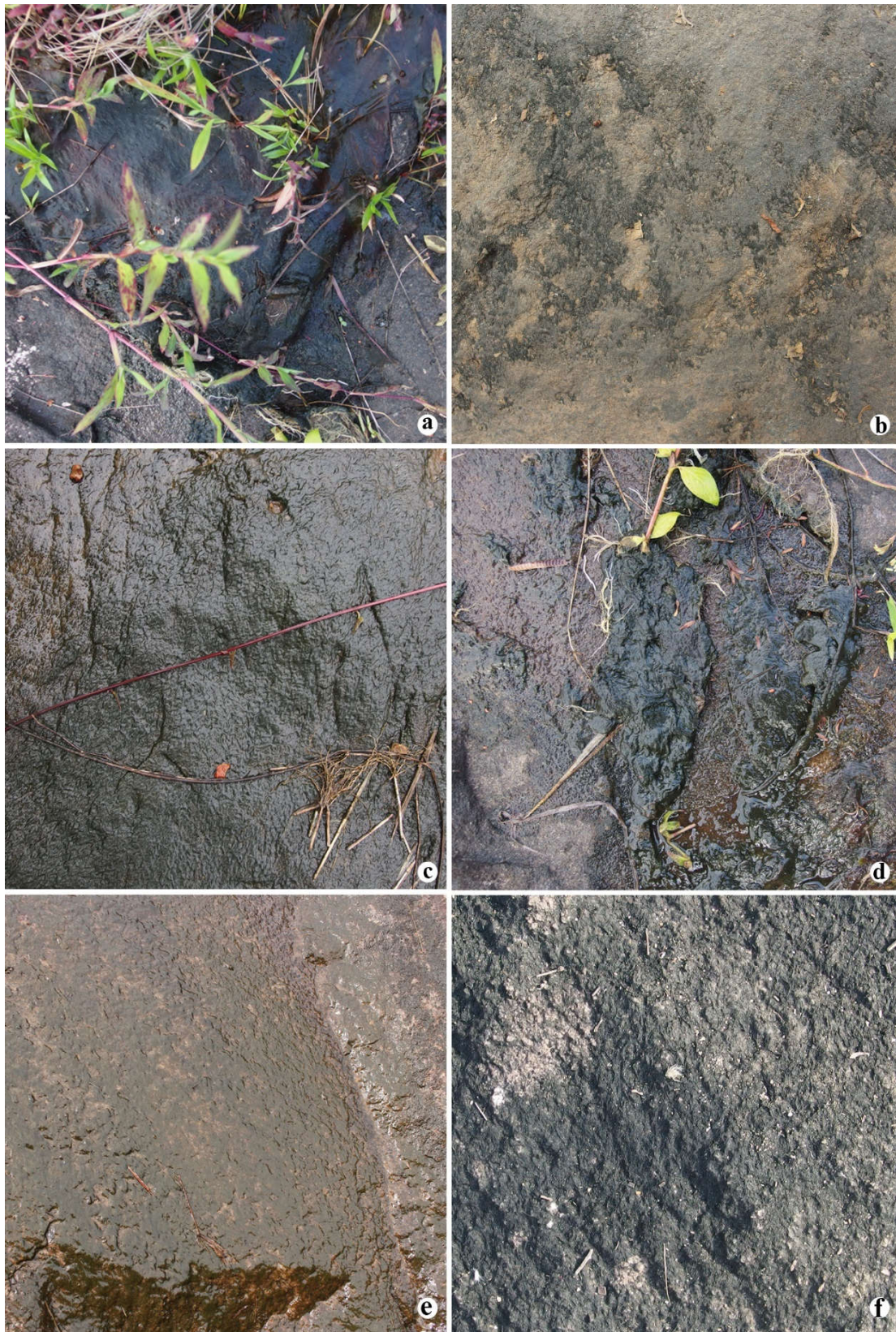


Fig. 3.13: Habitat of cyanobacteria (Family Scytonemataceae) found attached to rock surfaces

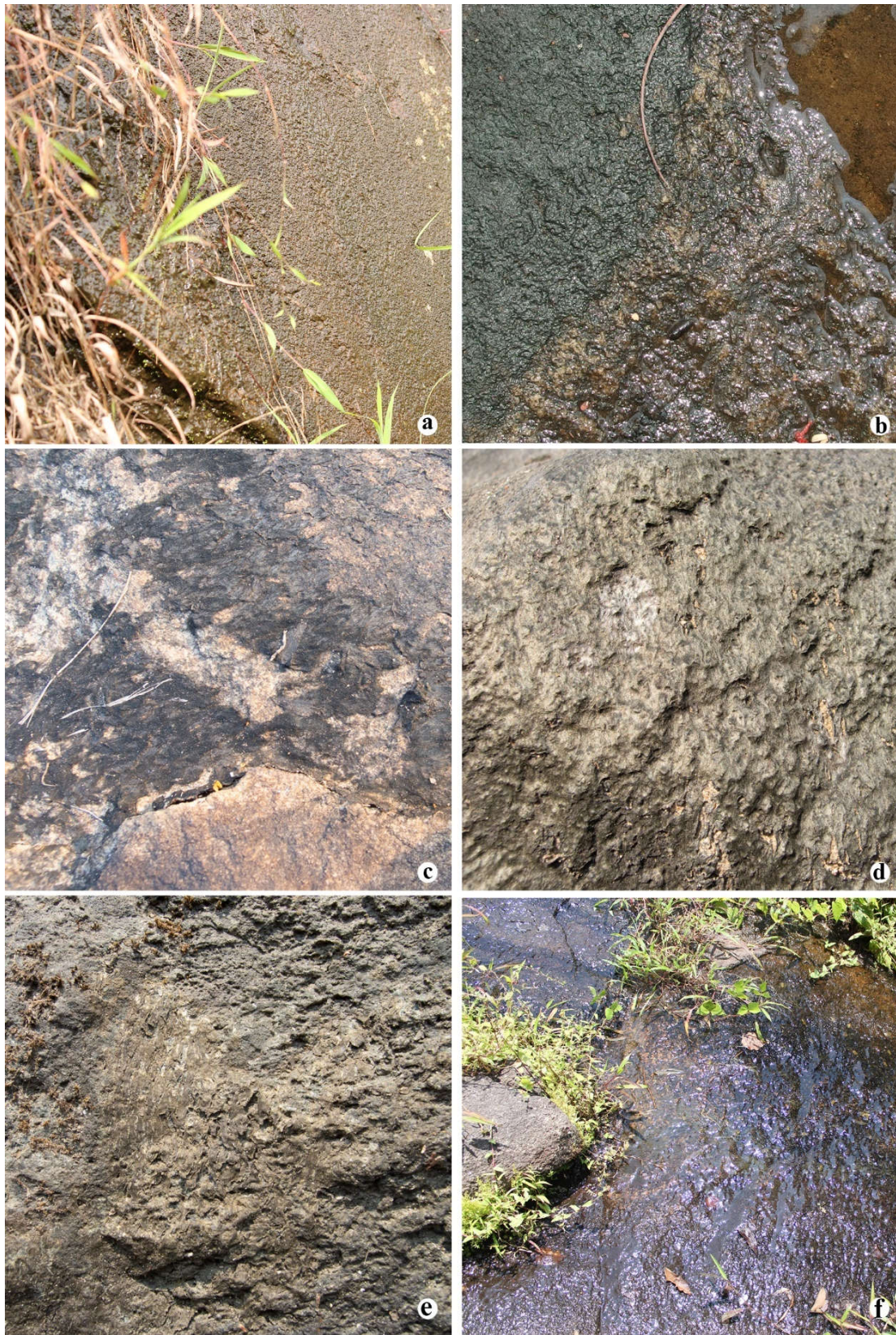


Fig. 3.14: Habitat of cyanobacteria (Family Scytonemataceae) found attached to rock surfaces

3.4 Culturing and Identification of Family Scytonemataceae

Two sets of cyanobacterial specimens were collected and brought to the laboratory for further studies. To get rid of any debris and impurities, the samples were first cleansed with distilled water. They were then cultured in BG-11 medium, which is a nitrogen-free medium prepared without Sodium nitrate (Table 3.2). The pH of the medium was adjusted to 7.4 using a digital pH meter and autoclaved at 121°C for 20 minutes. The cleaned samples were transferred to conical flasks containing the culture medium under a Laminar air flow chamber. The specimens were then kept at a temperature of $25 \pm 2^\circ\text{C}$ and 3000 lx illumination by altering light/dark periods of 16:8 hours. The other set of samples were preserved in 4% (v/v) formaldehyde and deposited in the germplasm collection of cyanobacteria at the laboratory, Division of Environmental Science, Department of Botany, University of Calicut.

Table 3.2

BG11 medium composition (Rippka et al. 1979)

Ingredients	g/L
NaNO ₃	1.5
K ₂ HPO ₄ .3H ₂ O	0.04
MgSO ₄ .7H ₂ O	0.075
CaCl ₂ .2H ₂ O	0.036
Citric acid	0.006
Ferric ammonium citrate	0.006
EDTA	0.001
Na ₂ CO ₃	0.02
Trace metal Solution	1ml
Distilled water	1000 ml

Composition of Trace metal Solution (Rippka et al. 1979)

Ingredients	g/L
H ₃ BO ₃	: 2.86
MnCl ₂ .4H ₂ O	: 1.81
ZnSO ₄ .7H ₂ O	: 0.222
Na ₂ MoO ₄ .2H ₂ O	: 0.390
CuSO ₄ .5H ₂ O	: 0.079
Co (NO ₃) ₂ .6H ₂ O	: 0.049

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

For the identification purpose of cyanobacteria, microscopic analysis was done in live conditions. The collected specimens were examined and Photomicrographs were taken using a Leica DM6B compound microscope. Morphometric analyses were carried out based on the nature and size of the filament; the size and colour of the trichomes; the colour and size of the sheath; and the nature and size of the heterocysts and their colour. The Standard taxonomic manuals by Desikachary (1959) and Komarek (2013) were used for the identification of cyanobacterial species, and recent literature was also referred for the confirmation of identified taxa. Morpho-taxonomic identification was carried out up to the species level using all available information. The entity of the taxonomically accepted species was verified as per Algaebase (<https://www.algaebase.org/>) (Guiry and Guiry 2024).

3.5 Statistical analysis

For analysing the diversity of Family Scytonemataceae, diversity indices such as the Simpson index (Simpson 1949), Shannon and Weiner index (Shannon and Weiner 1949), Evenness index (Pielou 1975), Brillouin index (Brillouin 1956), Menhinick's index (Whittaker 1977), Margalef index (Margalef 1968), and Berger-Parker index (Berger & Parker 1970) were performed. These diversity indices were done by using PAST 4.03 statistical software (Hammar et al. 2001). The environmental parameters associated with cyanobacterial diversity were assessed using the 'R' statistical software. Also, the Pearson correlation coefficient matrix and Principal Component Analysis (PCA) were employed to identify relationships among variables, simplifying complex datasets and aiding in interpreting results. Additionally, the logistic regression models and generalized linear model were also performed.



Fig. 3.15: Collection and Culturing of cyanobacteria

RESULTS AND DISCUSSION

Cyanobacteria are the largest and most diverse group of oxygen-producing photosynthetic microorganisms. They have a wide range of applications in Biotechnology, Pharmacology, and Agriculture. Kerala is one of the least-explored regions concerning cyanobacterial studies. The Western Ghats, located in the eastern part of the state, is famous for its rich ecology and biodiversity, particularly due to its diverse habitats. The Scytonemataceae family, among various groups of cyanobacteria, is particularly significant because of its ecological and economic importance. This family is recognized for its taxonomic diversity and varied distribution. However, research focussed especially on the Scytonemataceae family, has been limited in this area.

The present study aims to explore the diversity and ecology of the Scytonemataceae family from four districts (Palakkad, Malappuram, Kozhikode, and Wayanad) falling part of the Western Ghats in Kerala, South India. The research focuses on various aspects, including diversity, spatiotemporal patterns, seasonality, habitat characteristics, and the factors influencing the members of the family in selected locations. Understanding the ecological and economic significance of these life forms is crucial for their conservation. Protecting their natural habitats and promoting sustainable practices are vital for ensuring that these microorganisms continue to contribute to Earth's ecosystems. This study is intended to provide the first comprehensive information on the cyanobacterial diversity of family Scytonemataceae in this region. Details of the 52 sampling locations together with the seasonality of the collection are depicted in previous chapters. The systematic account of the family and the species collected are detailed below.

4.1 Systematic Account

Order Nostocales

Family Scytonemataceae Rabenhorst ex Bornet et Flahault 1887

Heterocytous, uniseriate filamentous cyanobacteria with obligate false branching. Thallus usually prostrate, in the form of flat or woolly mats, less frequently forming

erect fascicles. Filaments isopolar, branching starts usually in trichomes between vegetative cells or between two slightly distant heterocytes. Trichomes always monoseriate, isopolar, cylindrical or widened or narrowed at both ends. Sheaths usually thick, firm or gelatinizing, often lamellated, colourless or coloured with sheath-pigments. Heterocytes initially sometimes basal, intercalary, mostly single. Reproduction by disintegration of the thallus or by hormogonia.

Key to the genera

- 1. Filaments free from thallus 2
- 1. Filaments joined into thallus *Brasilonema*
- 2. Sheaths lamellated and coloured *Petalonema*
- 2. Sheaths usually colourless, rarely lamellated *Scytonema*

1. *Brasilonema* Fiore et al. 2007

Filaments joined into a thallus, attached to solid substrates, forming macroscopic, velvet-like strata or mats, usually composed from densely arranged, erect fascicles; filaments ensheathed, intensely and \pm parallelly fasciculated, long, mostly (7) 10-26 μm wide, cylindrical, of the same width along the whole length, usually with false branching, with branches single or in pairs, mainly in upper parts of filaments. Branches of the same width and morphology as the main filaments. Sheaths thin or slightly thickened, sometimes slightly lamellated, colourless or yellow brown. Trichomes cylindrical, not or slightly constricted at cross-walls, not attenuated or widened towards ends. Cells usually cylindrical, with blue-green or slightly violet content; apical cells morphologically identical with other vegetative cells. Heterocytes solitary, intercalary, discoid up to cylindrical and longer than wide. Akinetes absent. Reproduction by hormogonia.

Key to the Species

- 1. Thallus macroscopic, trichomes constricted at the cross walls 2
- 1. Thallus macroscopic, trichomes not constricted at the cross walls *B. terrestre*
- 2. Thallus parallelly fasciculate *B. epidendron*
- 2. Thallus irregularly fasciculate *B. bromeliae*

1. *Brasilonema bromeliae* Fiore et al. 2007

Komarek, 2013, vol.19, pp. 107-108, fig.88.

Description: Thallus irregularly fasciculated. Filaments joined to flat macroscopic, velvet, blackish green to blackish violet mats, densely fasciculate, more or less creeping on the substrate, slightly irregularly coiled, 10-21 μ m wide, later joined in dense, erect fascicles. Branches rare. Sheaths firm, thin, colourless to yellow-brown. Trichomes cylindrical, 8-18 μ m wide, not or very slightly constricted at cross-walls. Cells 1.8-16 μ m long greyish-green, olive-green, brownish violet, Heterocyst solitary, intercalary, discoid or cylindrical 4-19 \times 15-16.8 μ m.

Distribution: Central America: Costa Rica (Bohunicka et al. 2024), Caribbean Islands: Puerto Rico (Bohunicka et al. 2024), S. America: Brazil Brazil (Fiore 2007, Werner 2010), Asia: Nepal (Bohunicka et al. 2024).

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of India.

Specimen Examined: INDIA: Kerala; Kozhikode district, Thalayad 26 mile, N11°30'56.55"- E075°53'21.05", Environmental Science Division, University of Calicut, CU No: 163876. Wayanad district, Edakkal, N11°37'20.12"- E076°13'42.71", Environmental Science Division, University of Calicut, CU No:173146. **(Fig. 4.1).**

2. *Brasilonema epidendron* Sant'Anna et al. 2011

Komarek, 2013, vol.19, pp. 108, fig.89.

Description: Thallus macroscopic, composed from parallelly fasciculated, erect filaments, irregularly arranged, dark green to blackish. Filaments 7-10.9 \times 12 (14) μ m wide, very rarely branched. Sheaths thin, firm. Trichomes 5.5-8.2-10 (11) μ m wide, cylindrical not constricted at cross-walls, not attenuated towards ends. Cells cylindrical or shortened. Heterocytes barrel-shaped to cylindrical, (7)8-10 (11.5) \times 7-9 μ m.



Fig. 4.1: a-c. *Brasilonema bromeliae*; d-f. *Brasilonema epidendron*

Distribution: No distribution information is available at present.

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of India.

Specimen Examined: INDIA: Kerala; Kozhikode district, Thalayad 26 mile, N11°30'56.55"-E075°53'21.05", Environmental Science Division, University of Calicut, CU No: 173189. Wayanad district, Meppadi, N 11° 30' 41.93" - E076° 0'56.8", Environmental Science Division, University of Calicut, CU No:173134, Phantom rock, N11°38'09.96"-E076°12'14.27", Environmental Science Division, University of Calicut, CU No: 163859. **(Fig. 4.1).**

3. *Brasilonema terrestre* Sant'Anna & J. Komarek 2011

Komarek, 2013, vol.19, pp. 113, fig.94.

Description: Thallus macroscopic, composed from very irregularly fasciculated, partly erect filaments. Filaments cylindrical, 12-17µm wide. Sheaths thin, firm, colourless to yellow brown. Trichomes cylindrical, 9-15µm wide, not constricted at crosswalls. Cells ± isodiametric, shorter towards the ends, greyish-green or bluegreen. Heterocytes short barrel-shaped to cylindrical, 6-17×13-14 µm.

Distribution: No distribution information is available at present.

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of India.

Specimen Examined: INDIA: Kerala; Kozhikode district, Thonikadavu, N11°32'12.80"- E075°53'40.86", Environmental Science Division, University of Calicut, CU No: 173195. Wayanad district, Edakkal, N11°37'47.52"- E076°13'44.12", Environmental Science Division, University of Calicut, CU No: 173144. **(Fig. 4.2).**

2. *Petalonema* Berkeley ex Correns 1889

Filaments free, in clusters or irregular mats, irregularly coiled, creeping or erect, at first heteropolar with apical growth, subapical meristematic zones, falsely branched with single or branches in pairs, later becoming isopolar. Trichomes usually uniseriate, cylindrical, sometimes widened at the ends and narrowed in the middle parts. Constricted or unconstricted at the cross walls. Sheaths prominent, firm, delimited, extremely wide, mostly highly lamellated and funnel like divergent at the ends. Usually coloured, yellow, yellowish brown in colour; cells cylindrical, barrel shaped or spherical in shape. Heterocysts intercalary, sometimes at the bases of branches; usually branches arise between two heterocysts; spherical, oval, barrel shaped up to cylindrical, usually found as solitary, rarely in pairs. Akinetes unknown. Reproduction by hormogonia and disintegration of filaments.

Key to the Species

- 1. Mucilaginous, single branch, 25-46 μm wide*P. crassum*
- 1. Mucilaginous, branches geminate, up to 22 μm wide*P. crustaceum*

1. *Petalonema crassum* (Nageli ex Bornet & Flahault) Migula 1905

Kutzing] Migula 1907

Komarek, 2013, vol.19, pp. 146-148, fig.138.

Description: Thallus woolly, an expanding cushion like on moist rocky substratum, spongy tomentose, blackish green; Filaments in widely prostrate, grass like, mucilaginous, olivegreen or blackish-green mats, 25-46 μm wide, entangled. Branches usually single, less frequently in pairs, erect or situated parallelly to the main filament. Sheaths with numerous divergent layers, inside yellow up to brown (in the middle of filaments), more pale in external parts. Trichomes cylindrical, constricted at cross-walls. Cells cylindrical, in apical parts distinctly shorter than wide, in older parts up to isodiametric, 9-15 (20) μm wide. Heterocysts barrel-shaped up to cylindrical, intercalary or basal, usually single.

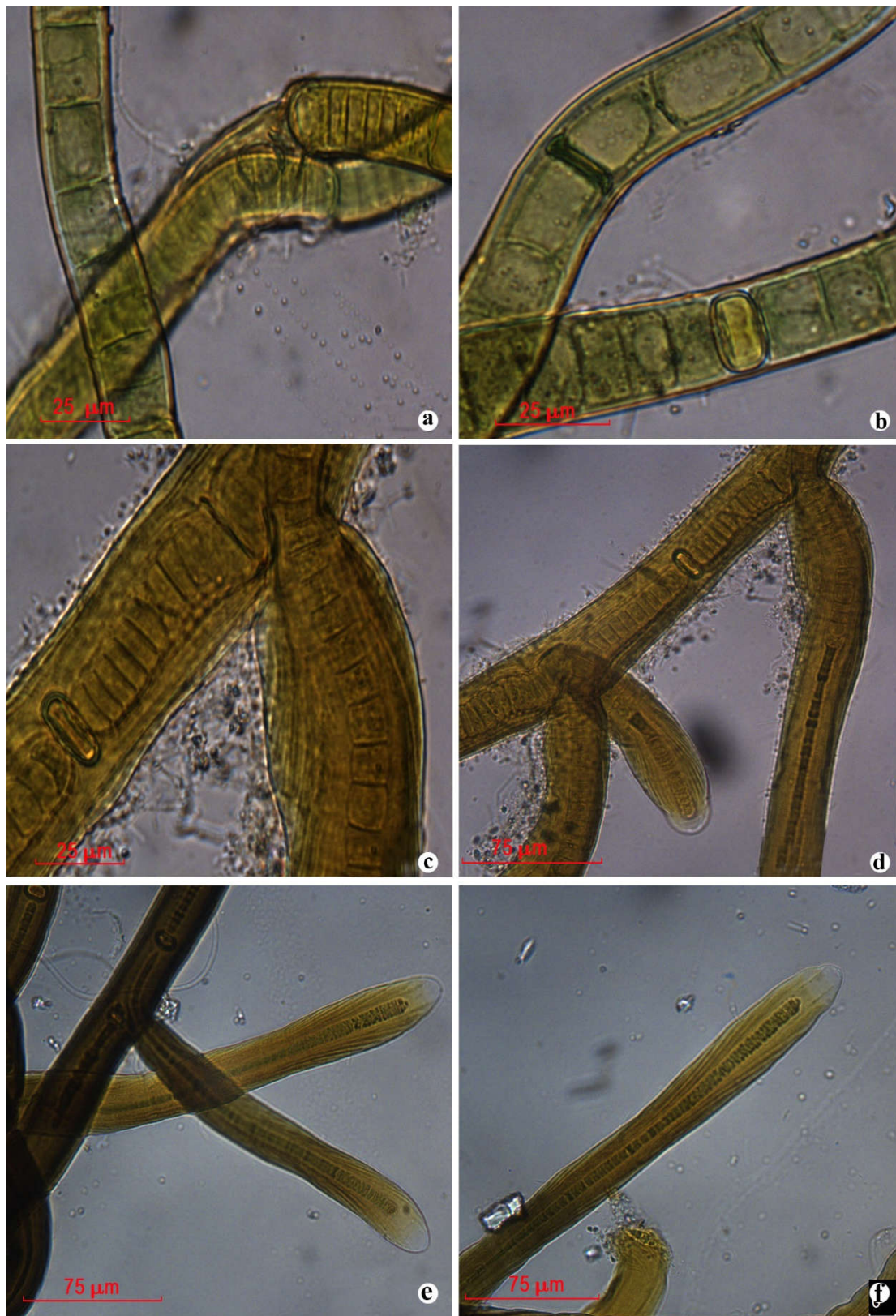


Fig. 4.2: a-b. *Brasilonema terrestre*; c-d. *Petalonema crassum*; e-f. *Petalonema crustaceum*

Distribution: Brazil (Budel, Weber, Porembski and Barthlott 2002), India (Gupta 2012), Maharastra (Meshram 2021); Indonesia (Koster 1939), China (Chu et al. 2007)

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of Kerala.

Specimen Examined: INDIA: Kerala; Palakkad district, Mattumala, N10°31.750'-E076°43.173', Environmental Science Division, University of Calicut, CU No: 163803. (Fig. 4.2).

2. *Petalonema crustaceum* (Thuret ex Bornet & Flahault) Kirchner 1900

Komarek, 2013, vol.19, pp. 150, fig.144.

Description: Thallus crusty, blackish or dark brown. Filaments (13) 18-22 µm wide, partly up to 30 µm wide, sometimes densely entangled, richly and repeatedly branched. Branches common, usually in pairs near the base of thallus, in erect parts mainly solitary: paired branches usually grow in parallel at the point of branching, later divergent. Sheaths yellow-brown to dark brown, with fine or oblique lamellation. Trichomes cylindrical, not constricted at the cross-walls. Cells mostly shorter than wide, 4.5-7×(6-8)-12µm, rarely up to quadratic cylindrical. Heterocytes flattened spherical to barrel-shaped, 5.7-8 µm in diameter, rarely elliptical - cylindrical.

Distribution: Arctic (Patova, Davdov and Andreeva 2015), Russia (Davydov 2018), Svalbard (Spitsbergen) (Davydov 2021), Germany (Stutz et al. 2018), Scandinavia (Karlason et al. 2018).

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of Kerala.

Specimen Examined: INDIA: Kerala; Palakkad district, Nelliampathy, N10°31.623' - E076°38.748', Environmental Science Division, University of Calicut,

CU No: 163804. Wayanad district, Phantom rock, N11°38'08.55"- E076°12'11.61", Environmental Science Division, University of Calicut, CU No: 163812, Thirunelli, N11°30'41.79"-E076°14'30.21", Environmental Science Division, University of Calicut, CU No: 163852. (Fig. 4.2).

3. *Scytonema* Agardh ex Bornet et Flahault 1887

Filaments- solitary branched filaments or mats on the substrate. 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. Filaments are enveloped always with firm, colourless or coloured sheaths; layers of sheaths have parallel lamina or are slightly divergent towards ends. 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.

Key to the Species

1. Thallus macroscopic, trichomes widened towards the end2
1. Thallus macroscopic, trichomes not widened towards the end 10
2. Filaments more than 13 µm wide3
2. Filaments less than 13 µm wide*S. drilosiphon*

3. Filaments more than 30 μm wide	4
3. Filaments up to 30 μm wide	5
4. Trichomes narrower, slightly constricted	<i>S. variabile</i>
4. Trichomes wider, not constricted	<i>S. myochrous</i>
5. Sheath firm, lamellated	6
5. Sheath firm, non-lamellated	9
6. Sheath parallelly lamellated	7
6. Sheaths obliquely lamellated	<i>S. brunneum</i>
7. Heterocyst cylindrical in shape	8
7. Heterocyst ellipsoidal in shape	<i>S. pascheri</i>
8. Trichomes up to 10 μm wide	<i>S. papilli-capitatum</i>
8. Trichome more than 10 μm wide	<i>S. praegnans</i>
9. Thallus dark green, heterocyst spherical	<i>S. torulosum</i>
9. Thallus brown, heterocyst cylindrical	<i>S. longiarticulatum</i>
10. Filaments long, up to 15 μm wide	11
10. Filaments long, more than 15 μm wide	14
11. Filaments densely entangled or coiled	12
11. Filaments straight and smooth	<i>S. hyalinum</i>
12. Trichomes constricted at the cross walls	13
12. Trichomes not constricted at the cross walls	<i>S. javanicum</i>
13. Thallus gelatinous, sheaths colourless	<i>S. sanpaulense</i>
13. Thallus woolly, sheaths yellowish brown	<i>S. schmidtii</i>
14. Heterocyst cylindrical or barrel-shaped	15
14. Heterocyst not cylindrical or barrel-shaped	26
15. Thallus woolly or flocculent	16
15. Thallus fruticose or thin	24
16. Sheaths lamellated	17

16. Sheaths non-lamellated	22
17. Filaments more than 16 μm wide	18
17. Filaments less than 16 μm wide	21
18. Trichomes constricted at the cross walls	19
18. Trichomes not constricted at the cross walls	20
19. False branches same as the main filament	<i>S. millei</i>
19. False branches smaller than main filament	<i>S. malaviyanense</i>
20. Usually single branched	<i>S. masonianum</i>
20. Usually geminate branched	<i>S. pseudoguyanense</i>
21. Filaments coiled	<i>S. tolypothrichoides</i>
21. Filaments straight	<i>S. caldarium</i>
22. Sheath pigmented or coloured	23
22. Sheath not pigmented or colourless	<i>S. arcangelii</i>
23. Sheath yellowish in colour	<i>S. coactile</i>
23. Sheath brown in colour	<i>S. spirulinoides</i>
24. Filaments with thick sheath	25
24. Filaments with thin sheath	<i>S. tenellum</i>
25. Trichomes constricted at the cross walls	<i>S. chiastum</i>
25. Trichomes not constricted at the cross walls	<i>S. polycystum</i>
26. Trichomes more than 10 μm wide	27
26. Trichomes less than 10 μm wide	29
27. Filaments coiled, more than 18 μm wide	28
27. Filaments straight, less than 18 μm wide	<i>S. twymanianum</i>
28. Heterocyst short barrel-shaped	<i>S. ocellatum</i>
28. Heterocyst spherical	<i>S. cincinnatum</i>
29. Heterocyst sub-rectangular, 8-12 μm	<i>S. bivaginatam</i>
29. Heterocyst cylindrical, 18-22 μm	<i>S. fritschii</i>

1. *Scytonema arcangelii* Bornet et Flahault 1887

Komarek, 2013, vol.19, pp. 83, fig.49.

Description: Thallus pillow-like, olive green. Filaments 12-17µm wide. False branching usually geminate, branches long and bent usually of the same morphology as the main filaments. Sheaths distinct, thin, firm, colourless. Trichomes green, cylindrical along the whole length, not attenuated or widened at the ends, 9.5-14.5 µm wide, not constricted at crosswalls. Cells in the middle of trichomes cylindrical, quadratic, rarely indistinctly barrel-shaped. Heterocytes quadratic or slightly longer or shorter than wide, 6-14.5 µm long.

Distribution: N. America: Laurentian Great Lakes (Prescott 1962), Quebec (QC) (Poulin et al. 1995), Brazil (Werner 2010, Azevedo, Nogueira and Sant'Anna 1996, Bicudo, Necchi and Chamixaes 1995), Iraq (Maulood et al. 2013), India (Gupta 2012), China (Chu et al. 2007), Nepal (Rai et al. 2010) Russia (Medvedeva and Nikulina 2014), Australia and New Zealand: Northern Territory (Day et al. 1995), Hawaiian Islands (Sherwood 2004).

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of India.

Specimen Examined: INDIA: Kerala; Kozhikode district, Koorachundu, N11°31'34.98"- E075°49'27.84", Environmental Science Division, University of Calicut, CU No: 173164.

Wayanad district, Ambukuthi 19, N11°37'01.80"-E076°14'06.19", Environmental Science Division, University of Calicut, CU No: 163819, Meppadi, N 11° 30' 41.93" - E076° 0'56.8",

Environmental Science Division, University of Calicut, CU No: 163810. (**Fig. 4.3**).

2. *Scytonema bivaginatum* H. Welsh 1965

Komarek, 2013, vol.19, pp. 85, fig.53.

Description: Thallus woolly, dark brown. The main filaments up to 30 μm wide, rarely geminate, false branches about 12 μm wide. Sheaths firm, smooth, usually hyaline with thin, about 2-3 μm thick, yellow layer next to trichome and a wider, colourless outerpart, about 10 μm thick. In young branches sheaths are only homogeneous and hyaline. Trichomes in main filaments 6-7 μm wide, in branches 3.5-5 μm wide, cylindrical, not constricted at cross-walls, sometimes with granular content. Cells 3-8 \times 6-7 μm in old parts, 10-15 \times \pm 3.5 μm in branches. Heterocytes intercalary, subrectangular, \pm 12 \times 8.5 μm .

Distribution: No distribution information is available at present.

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of India.

Specimen Examined: INDIA: Kerala; Malappuram district, Kozhipara waterfalls, N11°21'14.51"-E076°06'30.40", Environmental Science Division, University of Calicut, CU No: 173129. Kozhikode district, Kalpini, N11°20'02.04"-E076°03'53.55", Environmental Science Division, University of Calicut, CU No: 173173. Wayanad district, Edakkal, N11°37'18.97"-E076°13'44.92", Environmental Science Division, University of Calicut, CU No: 163818. (**Fig. 4.3**).

3. *Scytonema brunneum* Schmidle 1901

Komarek, 2013, vol.19, pp. 116, fig.95.

Description: Thallus flat, brownish. Filaments straight, 14-24 μm wide, in lower parts creeping on the substrate. False branching rare, usually solitary, rarely branches in pairs. Sheaths wide, obliquely lamellated, yellow-brown. Trichomes brown, at the ends rarely blue-green, cylindrical, in middle parts without constrictions, towards ends widened and constricted at cross-walls. Cells in the middle of trichomes longer than wide, cylindrical, near the ends barrel-shaped, isodiametric up to distinctly shorter than wide. Heterocytes usually cylindrical, elliptical, solitary.

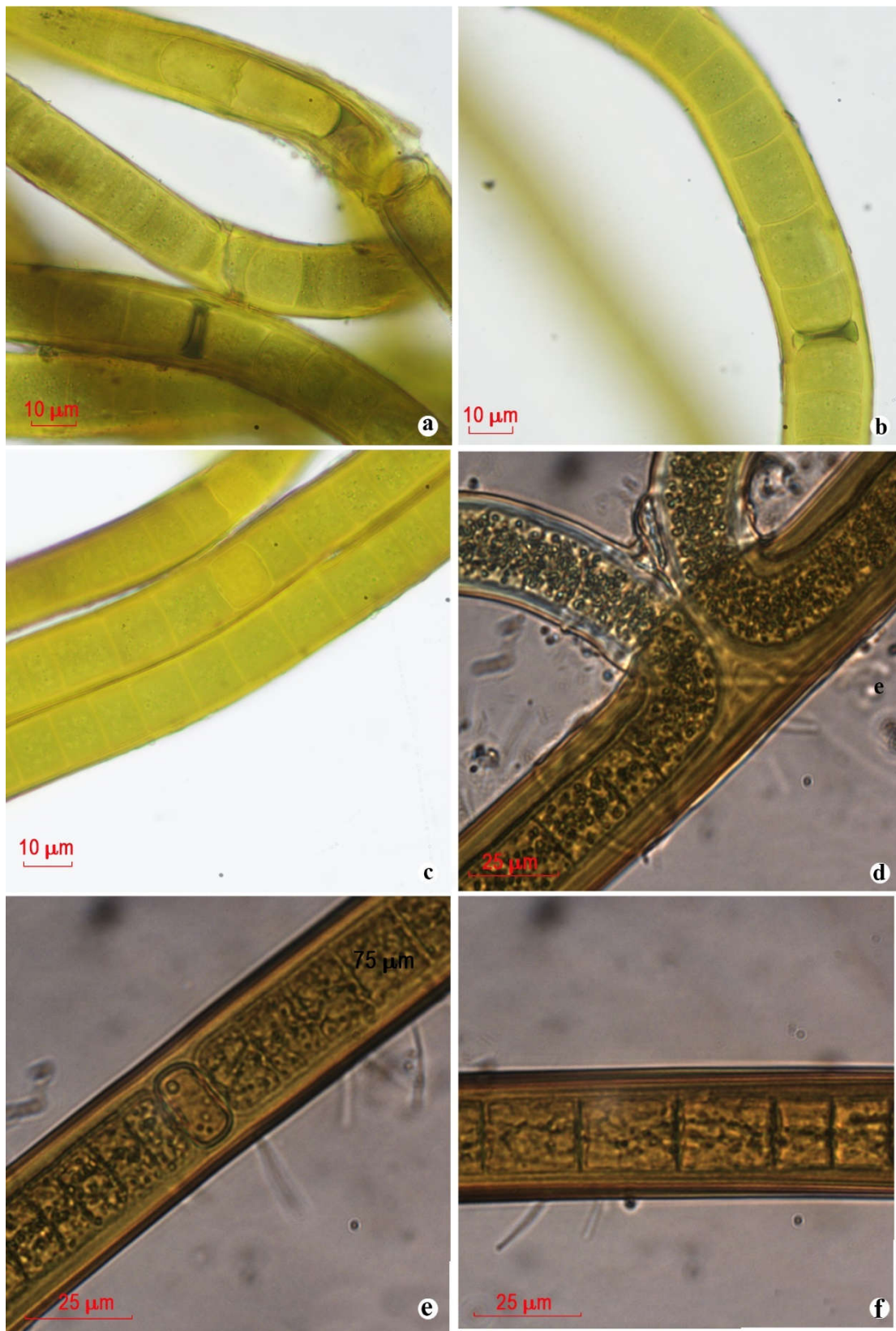


Fig. 4.3: a-c. *Scytonema arcangelii*; d-f. *Scytonema bivaginatatum*

Distribution: Europe: Latvia (Skuja 1934).

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of India.

Specimen Examined: INDIA: Kerala; Palakkad district, Attappady, N11°02.847'-E076°32.349', Environmental Science Division, University of Calicut, CU No: 163884. Wayanad district, Edakkal, N11°37'20.12"-E076°13'42.71", Environmental Science Division, University of Calicut, CU No: 163816, Rippon, N11°32'25.02"-E076°08'10.94", Environmental Science Division, University of Calicut, CU No: 163854. (Fig. 4.4).

4. *Scytonema caldarium* Setchell 1899

Komarek, 2013, vol.19, pp. 125, fig.107.

Description: Thallus expanded, flocculent, Filaments 12-16 µm in diameter, with paired or single false branches. Sheaths firm, Parallely lamellated, in young parts colourless, in old filaments golden-brown. Trichomes cylindrical and narrow with long cells, not constricted cross-walls, olive-green or yellowish. Cells usually longer than wide, 6.9-18.4 µm long, 4-9 µm wide, in meristematic regions shorter; terminal cells rounded. Heterocytes cylindrical, longer than wide.

Distribution: Brazil (Fonseca et al. 2019).

Habitat: Epilithic.

Specimen Examined: INDIA: Kerala; Malappuram district, Adyanpara, N11°21'19.74"-E076°12'11.85", Environmental Science Division, University of Calicut, CU No: 163829. Wayanad district, Phantom rock, N11°38'08.55"-E076°12'11.61", Environmental Science Division, University of Calicut, CU No: 173139. (Fig. 4.4).

5. *Scytonema chiastum* Geitler 1925

Desikachary, 1959, pp. 453, pl. 90, fig.1; Komarek, 2013, vol.19, pp. 82, fig.45.

Description: Thallus fruticose with many filaments densely arranged, olive-green or brown. Filaments nearly straight, 20-25 µm broad, with common geminate, rarely

single false branching, false branches often growing in the direction of main filaments, long, usually narrower than the main filaments, mostly 20 µm wide. Older filaments encrusted by calcareous precipitates. Sheaths thick, firm, parallelly lamellated, colourless, later brown. Trichomes cylindrical, slightly constricted at the cross-walls, Cells cylindrical to barrel shaped, olive-green or bluegreen. Heterocytes solitary, intercalary, quadratic rounded up to almost spherical.

Distribution: Brazil (Dunck et al. 2018), Iraq (Maulood et al. 2013), India (Gupta 2012), China (Chu et al. 2007), New Zealand (Smith et al. 2012), Pacific Islands/Pacific Ocean: Hawaiian Islands (Sherwood 2004).

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of Kerala.

Specimen Examined: INDIA: Kerala; Malappuram district, Cheruppadimala, N11°06'.536"-E075°59.542", Environmental Science Division, University of Calicut, CU No: 173183, Kozhipara waterfalls, N11°21'14.67"-E076°06'28.84", Environmental Science Division, University of Calicut, CU No: 163900. Kozhikode district, Muthappanpuzha, N11°26.948'-E076°06.022', Environmental Science Division, University of Calicut, CU No: 173118. **(Fig. 4.5).**

6. *Scytonema cincinnatum* Thuret ex Bornet et Flahault 1886

Desikachary, 1959, pp. 453-455, pl. 93, fig.1; Komarek, 2013, vol.19, pp. 82, fig.47.

Description: Thallus caespitose, wooly, olivaceous to brownish green. Filaments slightly coiled, (16) 18.5-24.5 (36) µm wide, cylindrical with solitary or geminate false branches. Sheaths not very thick, firm lamellated, smooth on the outside. Trichomes cylindrical, 14.5-22 µm wide, of the same width along the whole length, distinctly constricted at cross-walls. Cells shortly barrel-shaped. Heterocytes spherical or slightly elongated and oval of the same width as vegetative cells.

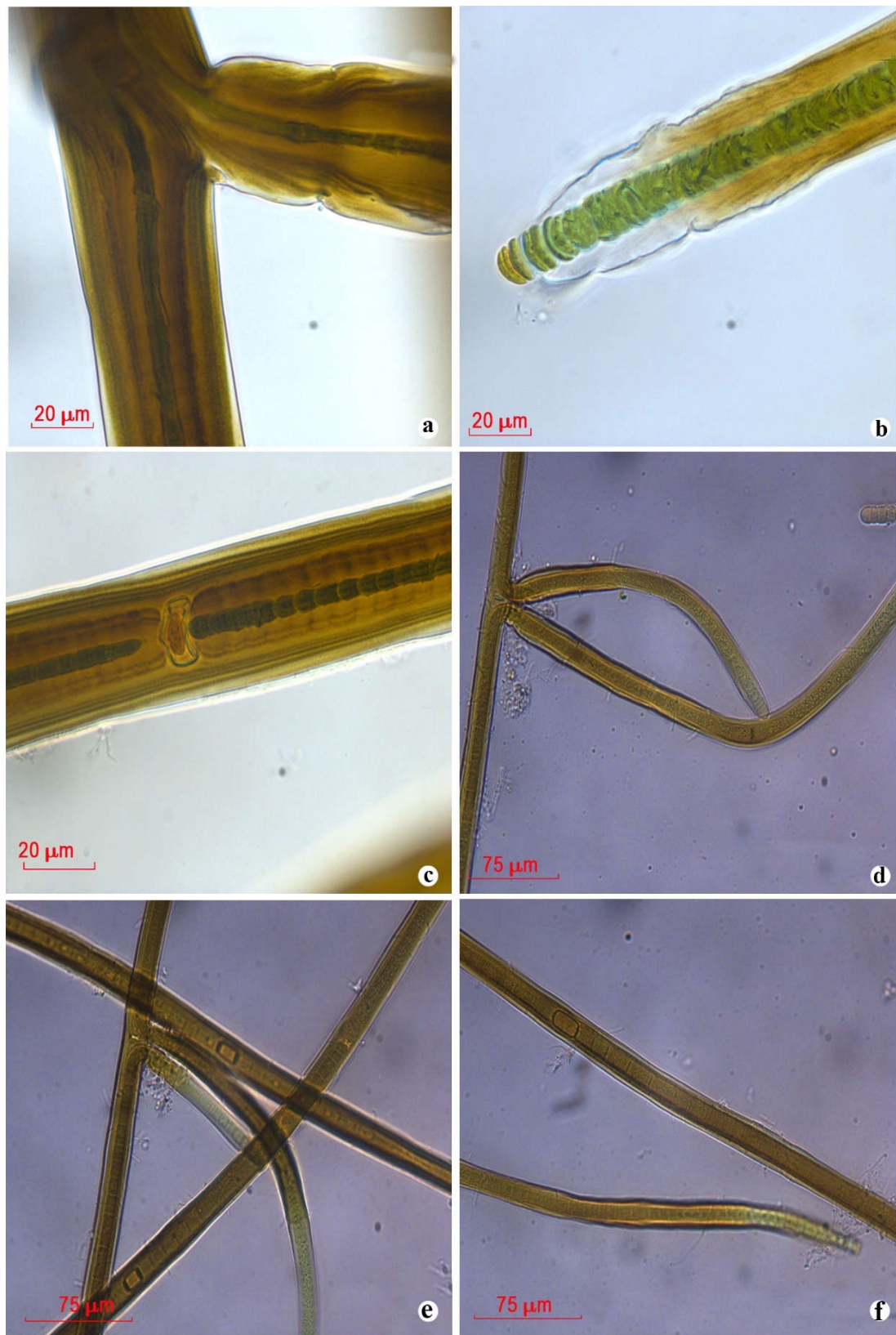


Fig. 4.4: a-c. *Scytonema brunneum*; d-f. *Scytonema caldarium*

Distribution: Europe: Bulgaria (Stoyneva-Gartner et al. 2015), N. America: Quebec (QC) (Poulin et al.1995) Iraq (Maulood et al.2013), Bangladesh (Siddiqui et al. 2009), India (Gupta 2012), Jharkhand (Gupta 2021), Karnataka (Gupta and Das 2019), Rajasthan (Jain 2018). China (Chu et al. 2007), Australia: Queensland (Day et al. 1995).

Habitat: Epilithic.

Specimen Examined: INDIA: Kerala; Malappuram district, Valillapuzha, N11°16'25.83"-E076°02'05.19", Environmental Science Division, University of Calicut, CU No: 173125. Kozhipara, N11°21'14.51"-E076°06'30.40", Environmental Science Division, University of Calicut, CU No: 163821. **(Fig. 4.5).**

7. *Scytonema coactile* Montagne ex Bornet & Flahault 1886

Desikachary,1959, pp. 455-457, pl. 90, fig.2; Komarek, 2013, vol.19, pp. 78, fig.40.

Description: Thallus brush-like, caespitose, woolly, green or blue-green. Filaments (14) 16.5-24 µm wide. False branching usually geminate, branches sometimes erect, usually widely divaricated from the main filaments, but morphologically identical. Sheaths firm, colourless or yellowish, up to 4.8 µm wide. Trichomes cylindrical along the whole length, not constricted at the cross-walls, (7) 10-18 µm wide, olive-green, bluegreen. Cells isodiametric, longer than wide. Heterocytes solitary, intercalary, cylindrical, 11.8-23×12-16.5 µm.

Distribution: Ukraine (Barinova and al. 2019), Arkansas (Smith 2010), Laurentian Great Lakes (Prescott 1962), Quebec (QC) (Poulin and al. 1995), Cuba (Comas 2009), Brazil (Werner 2010), Iraq (Maulood and al. 2013), Turkey (Sahin and Akar 2019), Bangladesh (Siddiqui and al. 2009), India (Gupta 2012), Kerala (Arulmurgan and al. 2016), Odisha (Kumari Samad, Rath and Prasad Adhikary 2008), Myanmar (Burma) (Skuja 1949), China (Hu and Wei 2006, Chu and al. 2007), Russia (Far East) (Medvedeva and Nikulina 2014), Tajikistan (Barinova and Niyatbekov 2018), NewZealand (Broady and Merican 2012), French Polynesia (Pari and N'Yeurt 1999, Vieira and al. 2023), Hawaiian Islands (Sherwood 2004).

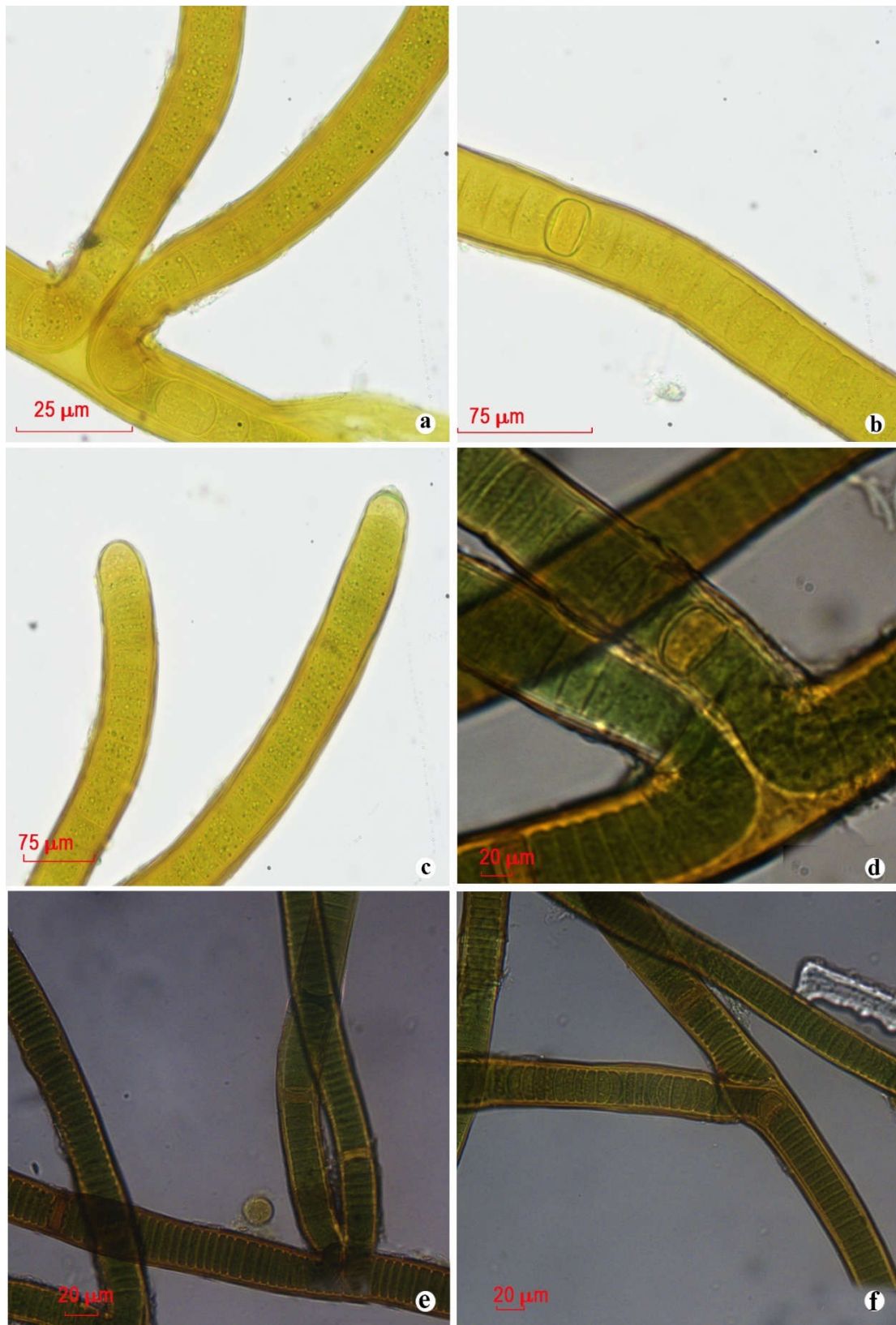


Fig. 4.5: a-c. *Scytonema chiastum*; d-f. *Scytonema cincinnatum*

Habitat: Epilithic.

Specimen Examined: INDIA: Kerala; Palakkad district, Minnampara, N10°31.680'-E076°43,198', Environmental Science Division, University of Calicut, CU No: 163890. Malappuram district, Adyanpara, N11°21'17.73"-E076°12'11.86", Environmental Science Division, University of Calicut, CU No: 163826. Kozhikode district, Thonikadavu, N11°32'11.22"-E075°53'39.88", Environmental Science Division, University of Calicut, CU No: 173160, Muthappanpuzha, N11°27.156'-E076°05.983, Environmental Science Division, University of Calicut, CU No: 163883. Wayanad district, Edakkal, N11°37'20.12"-E076°13'42.71", Environmental Science Division, University of Calicut, CU No: 163864. **(Fig. 4.6).**

8. *Scytonema drilosiphon* Elenkin & V.I.Poljansky 1922

Komarek, 2013, vol.19, pp. 73, fig.33.

Description: Thallus woolly, up to 1-3 mm thick, grey or pale greyish blue-green, sometimes slightly up to densely covered by CaCO₃- precipitates. Filaments intertwined ± in bundles, 7-13µm wide, with sparse geminate or single false branching. Sheaths firm, thin, not lamellated, colourless or slightly yellowish. Trichomes blue-green, cylindrical, at the ends sometimes slightly widened, not constricted at cross-walls, 5.5-10 µm wide. Cells cylindrical, in the middle of trichomes isodiametric, 2.5-12 µm long; terminal cells rounded. Heterocytes elliptical to quadratic, 8-12 (14) × 7-9µm.

Distribution: Czech Republic (Gadea et al. 2013), Germany (Stutz et al. 2018), Poland (Nowicka-Krawczyk et al. 2014), Russia (Popkova et al. 2019), Serbia (Cvijan and Blazencic1996), Abkhazia (Popkova and Mazina 2019, Fedorov et al.2023), Poland (Nowicka-Krawczyk) Israel (Vinogradova et al. 2000, Barinova and Smith 2022), Bangladesh (Siddiqui et al. 2009). West Bengal (Banerjee et al. 2020)

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of Kerala.

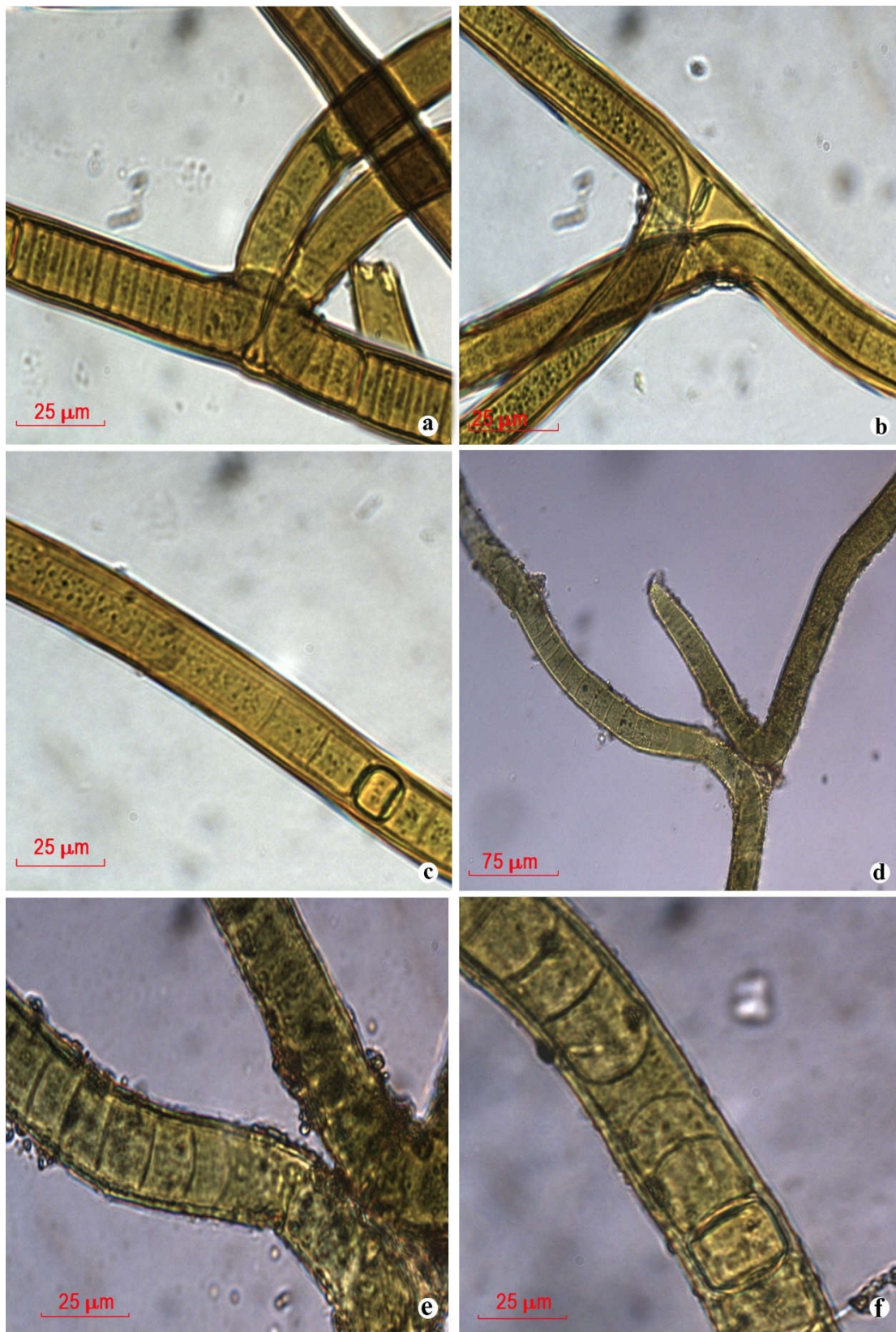


Fig. 4.6: a-c. *Scytonema coactile*; d-f. *Scytonema drilosiphon*

Specimen Examined: INDIA: Kerala; Kozhikode district, Urumi dam, N11°22'22.73"-E076°03'32.30", Environmental Science Division, University of Calicut, CU No: 163840. Wayanad district, Thirunelli, N11°30'41.79"-E076°14'30.21", Environmental Science Division, University of Calicut, CU No:163831. **(Fig. 4.6).**

9. *Scytonema fritschii* S.L. Ghose 1924

Desikachary, 1959, pp. 458, pl. 95, fig. 1; Komarek, 2013, vol. 19, pp. 89, fig. 58.

Description: Thallus flocculose, greenish brown or blue green. Filaments thin, long, (14.7)15-20 (21) μm wide, mostly with geminate pseudobranches; branches of the same width as the main filaments. Sheaths firm, colourless. Trichomes 7-8 (10) μm wide, cylindrical not constricted at cross-walls. Cells mostly longer than wide. Heterocytes intercalary, cylindrical 18-22 μm .

Distribution: Brazil (Werner 2010), India (Gupta 2012), Rajasthan (Jain 2018) China (Chu et al. 2007), New Zealand (Smith et al. 2012), Pacific Islands/Pacific Ocean: Hawaiian Islands (Sherwood 2004).

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of Kerala.

Specimen Examined: INDIA: Kerala; Palakkad district, Mattumala, N10°31.750'-E076°43.173', Environmental Science Division, University of Calicut, CU No: 163892. Kozhikode district, Kalpini, N11°20'01.15"-E076°03'49.82", Environmental Science Division, University of Calicut, CU No: 173172. **(Fig. 4.7).**

10. *Scytonema hyalinum* N.L. Gardner 1927

Komarek, 2013, vol. 19, pp. 90, fig. 61.

Description: Thallus in form of indefinite, flocculent masses, clustering. Filaments relatively straight and smooth, (12)13-15 μm wide, moderately false branched, with

mostly geminate. Branches of the same width as the main filaments. Sheaths thin, colourless, not lamellated, homogeneous, always hyaline. Trichomes cylindrical, not constricted at cross-walls, (7) 11-13 μm wide. Cells quadratic pale olive-green, pale blue-green. Heterocytes cylindrical-rounded, intercalary, 6-10 (18) μm long.

Distribution: Europe: Ural Mountains (Patova et al. 2023), N. America: Tennessee (Johansen et al. 2007), S. America: Chile (Jung et al. 2019), Africa: Sierra (Alfinito 2011), China (Chu et al. 2007).

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of India.

Specimen Examined: INDIA: Kerala; Malappuram district, Adyanpara, N11°17'95"-E076°12'11.92", Environmental Science Division, University of Calicut, CU No: 163830. Wayanad district, Kanthanpara, N11°31'41.35"-E076°09'25.75", Environmental Science Division, University of Calicut, CU No: 163856. (Fig. 4.7).

11. *Scytonema longiarticulatum* N.L. Gardner 1927

Komarek, 2013, vol.19, pp. 130, fig.116.

Description: Thallus flat, brown. Filaments 15-18 μm wide, almost straight, falsely branched. Sheaths at first hyaline, and when old, completely brown. Trichomes cylindrical, not constricted at cross-walls, with long cells, narrow 5-8 μm wide, towards ends slightly widened and 9-11 μm wide. Cells in old parts 18-25 (35) μm long, near ends isodiametric olive-green. Heterocytes cylindrical, solitary, intercalary.

Distribution: No distribution information is available at present.

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of India.

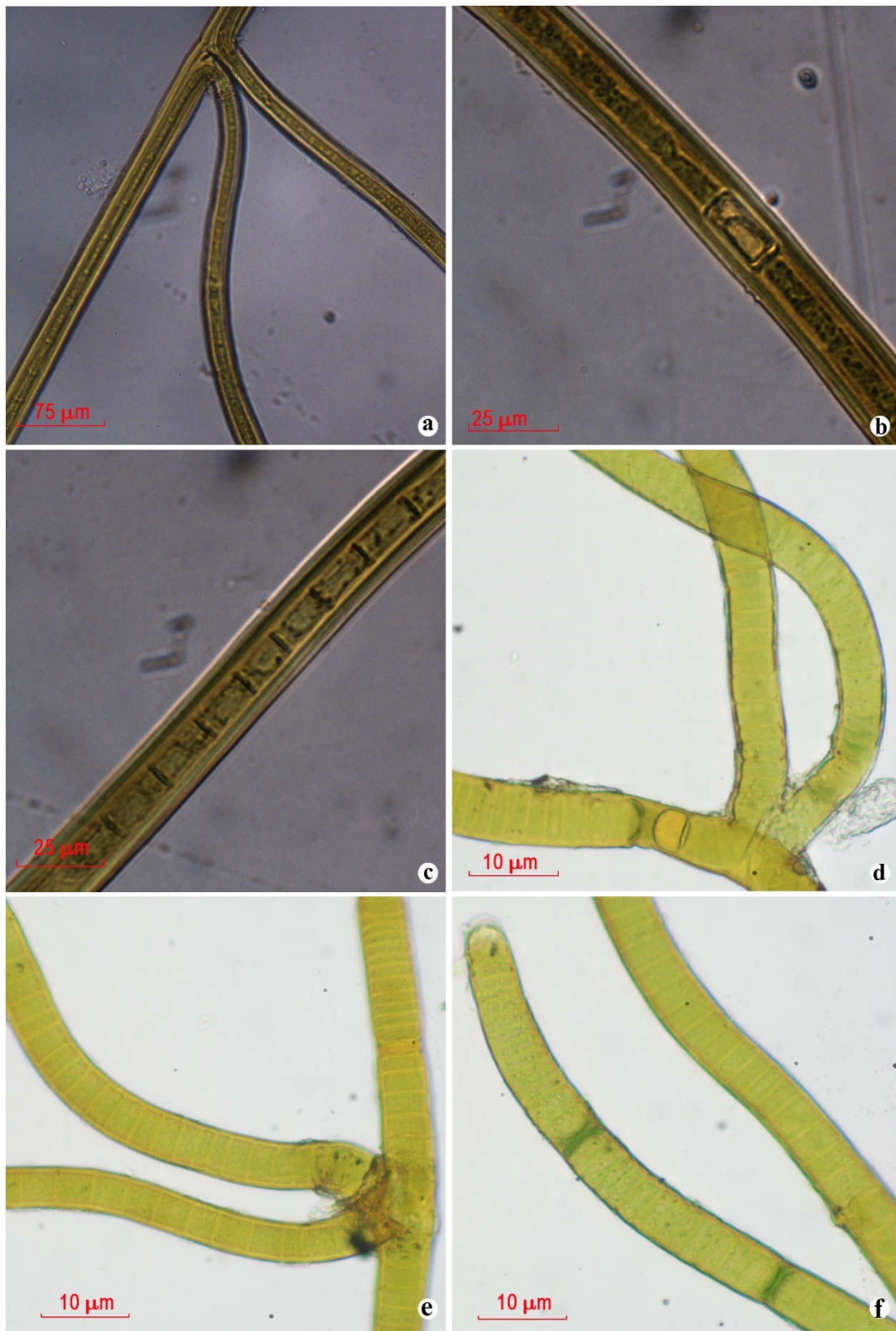


Fig. 4.7: a-c. *Scytonema fritschii*; d-f. *Scytonema hyalinum*

Specimen Examined: INDIA: Kerala; Palakkad district, Attappady, N11°02.847'-E076°32.349', Environmental Science Division, University of Calicut, CU No: 163807. Malappuram district, Valillapuzha, N11°16'26.07"-E076°02'05.40", Environmental Science Division, University of Calicut, CU No: 163835. Kozhikode district, Thonikadavu, N11°32'12.98"-E075°53'59.66", Environmental Science Division, University of Calicut, CU No: 163878. **(Fig. 4.8).**

12. *Scytonema javanicum* Kutzing ex Bornet & Flahault 1886

Desikachary, 1959, pp. 461, pl. 100, fig.4; Komarek, 2013, vol.19, pp. 76, fig.38.

Description: Thallus prostrate, thin, yellow-brownish, blue-green. Filaments coiled, creeping later up to erect, 12-15(19) µm wide. False branches mostly common, long flexuous, usually geminate or aggregated, sometimes shortly joined together at the base, also coiled and arcuated, of the same morphology as the main filaments, but sometimes slightly narrower. Sheath thin, firm, colourless or yellow. Trichomes cylindrical, not constricted at the cross-walls, not widened or narrowed towards ends, 7-12 (14) µm width, olive-green, brownish. Cells cylindrical, mostly quadratic or shorter than wide, 7-13.8 µm long in the middle, 3.4-7 µm long at the ends. Heterocytes cylindrical, mostly quadratic or hemispherical.

Distribution: Europe: Romania (Caraus 2017), Spain (Penalta Rodriguez and Lopez Rodriguez 2004, Alvarez Cobelas and Gallardo 1988), Brazil (Azevedo, Nogueira and Sant'Anna 1996), Israel (Vinogradova et al. 2000, Barinova and Smith 2022), Bangladesh (Siddiqui et al. 2009), India (Gupta 2012), Rajasthan (Jain 2018), China (Liu 2008, Xia 2017, Chu et al. 2007), Nepal (Rai, Rai and Jha 2010) Russia (Medvedeva and Nikulina 2014).

Habitat: Epilithic.

Specimen Examined: INDIA: Kerala; Palakkad district, Pothundi dam, N10°31.128'-E076°37.744', Environmental Science Division, University of Calicut, CU No: 163893. Malappuram district, Adyanpara, N11°21'17.73"-E076°12'11.86",

Environmental Science Division, University of Calicut, CU No: 173121, Arimbra hills, N11°05'.950"-E076°00'.990", Environmental Science Division, University of Calicut, CU No: 163851. Kozhikode district, Thamarassery churam, N11°30'38.01"-E076°01'09.48", Environmental Science Division, University of Calicut, CU No: 163825, Thalayad, N11°30'37.65"-E075°53'19.85", Environmental Science Division, University of Calicut, CU No: 173187. **(Fig. 4.8).**

13. *Scytonema malaviyanense* Bharadwaja 1930

Desikachary, 1959, pp. 483; Komarek, 2013, vol.19, pp. 94, fig.86.

Description: Thallus thick, felt like spongy, bluish green. Filaments flexuous, interwoven, young 8-10 µm, old 16.8-20.2 µm wide, up to 4mm long. False branches only geminate, 6.5 -8.5 µm wide, up to 14-16 µm wide in older parts. Sheaths firm, at first thin, hyaline or slightly yellow, later thick, lamellated and yellowish-brown, brown to dark brown, 1.4-4 µm thick. Trichomes bluish-green, with older trichomes slightly constricted at cross-walls. Cells isodiametric. Heterocytes absent in young filaments, but present in old ones, intercalary, quadratic, 11.2-15.4 × 9.8-15.4 µm.

Distribution: India (Gupta 2012), China (Chu et al. 2007), West Bengal (Banerjee et al. 2020) **Habitat:** Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of Kerala.

Specimen Examined: INDIA: Kerala; Palakkad district, Minnampara, N10°31.680'-E076°43,198', Environmental Science Division, University of Calicut, CU No:163802, Nelliampathy, N10°31.623' - E076°38.748', Environmental Science Division, University of Calicut, CU No: 163895. Wayanad district, Kanthanpara, N11°31'41.35"-E076°09'25.75", Environmental Science Division, University of Calicut, CU No:173138. **(Fig. 4.9).**

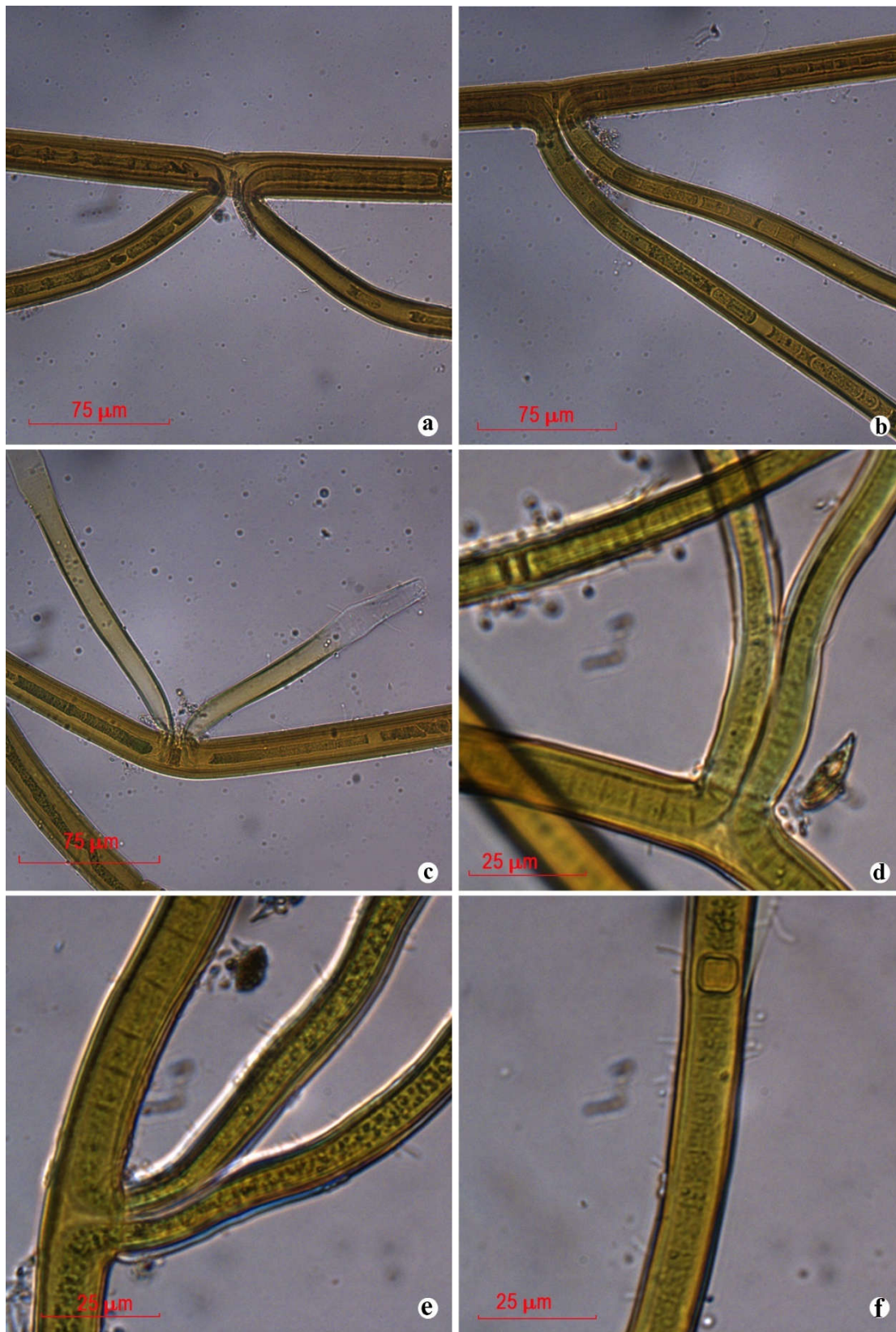


Fig. 4.8: a-c. *Scytonema javanicum*; d-f. *Scytonema longiarticulatum*

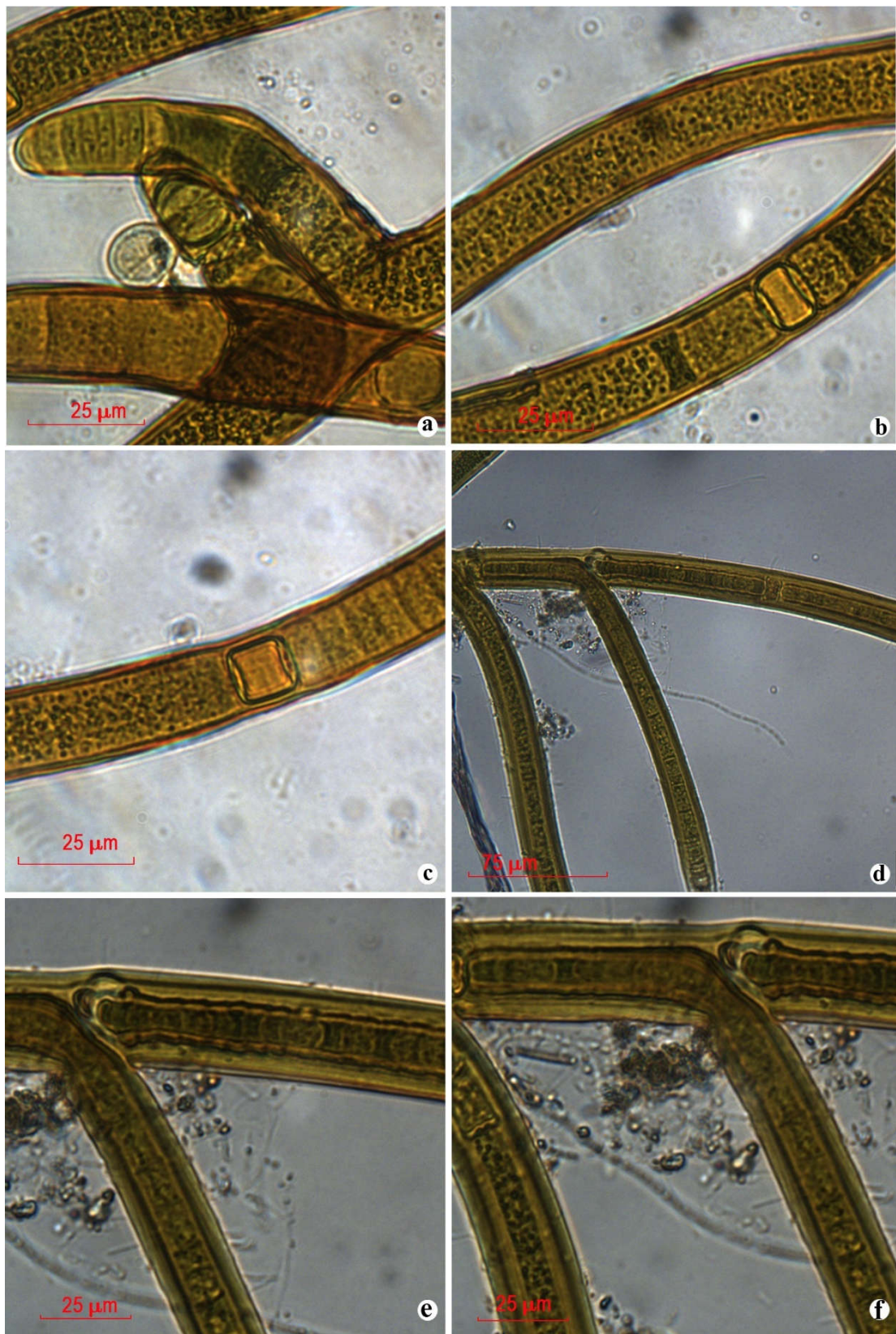


Fig. 4.9: a-c. *Scytonema malaviyanense*; d-f. *Scytonema masonianum*

14. *Scytonema masonianum* H. Welsh 1963

Komarek, 2013, vol.19, pp. 94-95, fig.67.

Description: Thallus floccose, dark green to brownish. Old filaments intricately intertwined, about 20 µm wide, younger parts of filaments and branches about 13 µm wide; filaments false branched, branches infrequent, V-formed or lateral, commonly single, rarely geminate. Sheaths well developed, straight, firm, parallelly and faintly, but distinctly lamellated or diffluent, especially in older parts, 2-4 µm thick, greenish-yellow towards ends hyaline. Trichomes brownish-yellow, not constricted at cross-walls. Cells 4-12 µm long. Heterocytes not numerous, intercalary, rectangular.

Distribution: No distribution information is available at present.

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of India.

Specimen Examined: INDIA: Kerala; Malappuram district, Cheruppadimala, N11°06'.542"-E075°59'.504", Environmental Science Division, University of Calicut, CU No: 163849. Kozhikode district, Muthappanpuzha, N11°26.715'-E076°05.292", Environmental Science Division, University of Calicut, CU No: 173192. Wayanad district, Phantom rock, N11°38'09.96"-E076°12'14.27", Environmental Science Division, University of Calicut, CU No: 173142. (**Fig. 4.9**).

15. *Scytonema millei* Bornet ex Bornet et Flahault 1886

Desikachary, 1959, pp. 460, pl. 93, fig. 2,3; Komarek, 2013, vol.19, pp. 94, fig.68.

Description: Thallus woolly, widely prostrate and expanded, dark green to brown. Filaments 15-21 µm wide, flexuous, entangled, with divaricated, erect false branches, which are of the same width as main filaments. Sheaths firm, brown, parallelly lamellated, particularly in old parts. Trichomes cylindrical, constricted at cross-walls, 10-15 µm wide. Cells shortly barrel-shaped usually shorter than wide. Heterocytes shortly barrel-shaped, brown, intercalary, solitary, sometimes slightly wider than vegetative cells.

Distribution: Bangladesh (Siddiqui et al. 2009), India (Gupta 2012), Karnataka (Gupta and Das 2019), Punjab (Singh et al. 2022), Rajasthan (Jain 2018), West Bengal (Kumar et al. 2019, Keshari and Adhikary 2013, Sen et al. 2015, Banerjee et al. 2020), Meghalaya (Kharkongor and Ramanujam 2014), Assam (Saha et al. 2007). Orissa (Dash et al. 2011), China (Chu et al. 2007), Japan (Hirose, Yamagishi and Akiyama 1977)

Habitat: Epilithic.

Specimen Examined: INDIA: Kerala; Palakkad district, Nelliampathy, N10°31.623'-E076°38.748' Environmental Science Division, University of Calicut, CU No:173107. Malappuram district, Valillapuzha, N11°16'26.07"-E076°02'05.40", Environmental Science Division, University of Calicut, CU No:173126. Kozhikode district, Muthappanpuzha, N11°26.715'-E076°05.292", Environmental Science Division, University of Calicut, CU No: 163881. **(Fig. 4.10).**

16. *Scytonema myochrous* C. Agardh ex Bornet & Flahault 1886

Desikachary, 1959, pp. 487, pl. 90, fig. 3; Komarek, 2013, vol. 19, pp. 119, figs. 99, 100.

Description: Thallus flat-hemispherical to expanded, leathery, crusty, brown-black or blackish-green. Filaments entangled, (10-14) 18-36 (40) μm wide, with usually common false branching; branches usually in pairs, rarely solitary, long. Sheaths dark yellow, yellow-brown, rarely pale yellow, with distinctly divergent layers. Trichomes cylindrical, sometimes slightly wider at the ends, not constricted at cross-walls, only slightly constricted at the ends of trichomes in branches. Cells cylindrical, blue-green or olive-green, in older parts of trichomes quadratic or slightly longer or shorter than wide (4-14 μm long), rarely up to 2 \times longer than wide, 6-12 μm (rarely up to 23 μm) wide, towards ends sometimes shortened and up to slightly short barrel-shaped (as short as 3.5 μm long); end cells rounded, 12-13 μm wide. Heterocytes cylindrical, rarely spherical or shortly obliquely elliptic, isodiametric-rounded or elongated elliptical, usually 8-10 μm wide.

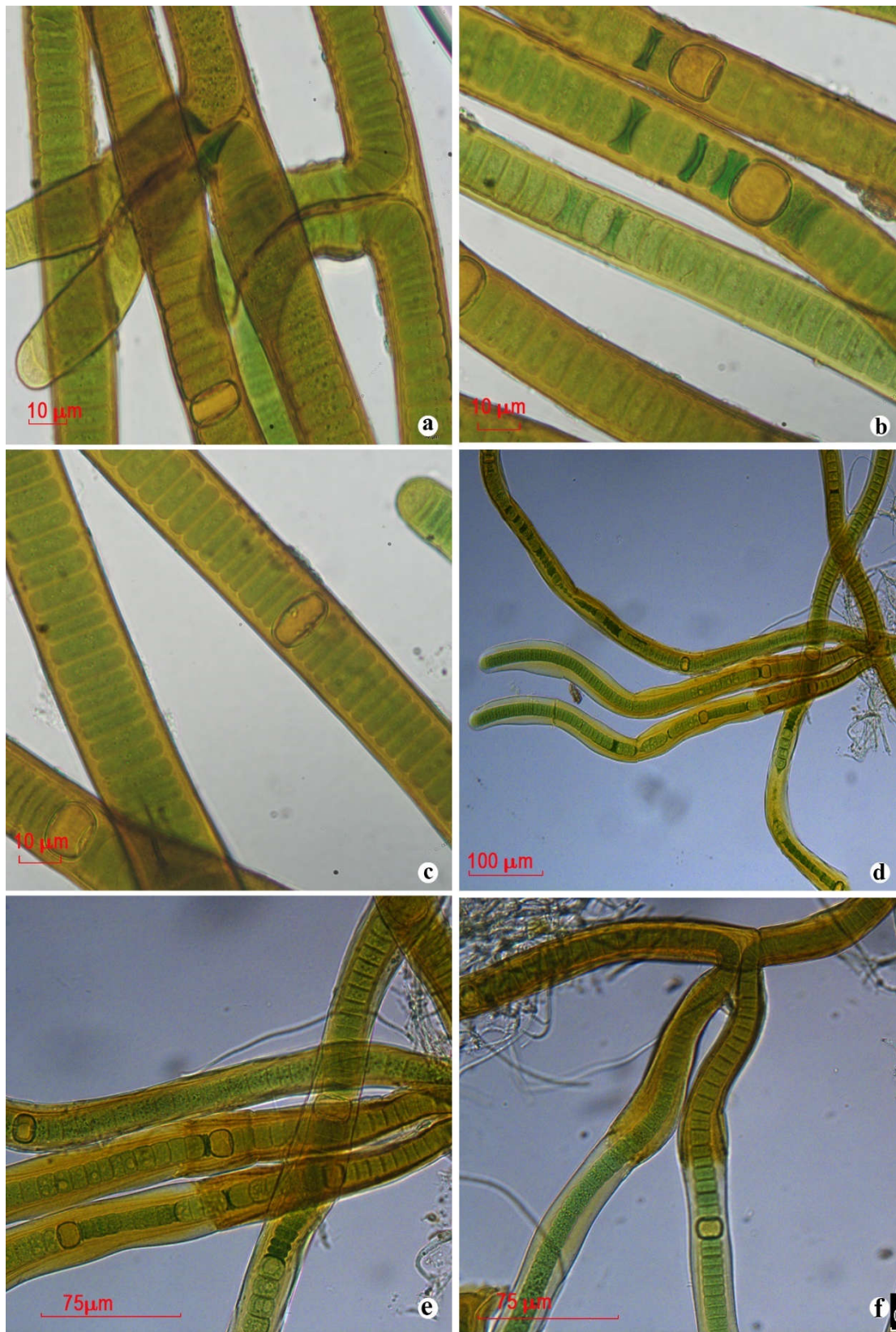


Fig. 4.10 a-c. *Scytonema millei*; d-f. *Scytonema myochrous*

Distribution: Arctic: Svalbard (Spitsbergen) (Skulberg 1996, Davydov 2014, Davydov 2021), E. Greenland (Borgesen 1910), Iceland (Hallgrimsson 2007). Britain (Pentecost and Haworth 2021), Britain and Ireland (Whitton et al. 2003, John et al. 2011), Czech Republic (Gadea et al. 2013, Kastovsky et al. 2018), Germany (Tauscher 2011, Stutz et al. 2018), Greece (Gkelis et al. 2016), Ireland (Adams 1908), Romania (Caraus 2017), Saxony (Germany) (Doege et al. 2022), Scandinavia (Kallason et al. 2018), Slovakia (Hindak and Hindakova 2016), Spain (Aboal 1989, Aboal 1988, Alvarez-Cobelas and Gallardo 1988), Ukraine (Barinova et al. 2019), N. America: Alaska (Saunders 1901), Laurentian Great Lakes (Prescott 1962), Northwest Territories (NT) (Sheath and Steinman 1982), Quebec (Poulin et al. 1995), Virginia (Forest 1954), S. America: Argentina (Tell 1985), Brazil (Budel, Weber, Porembski and Barthlott 2002), Colombia (Taylor 1935), Israel (Barinova and Smith 2022), Turkey (Taskin et al. 2019). Bangladesh (Siddiqui et al. 2009), India (Gupta 2012), Jharkhand (Gupta 2021), Karnataka (Gupta and Das 2019), Myanmar (Burma) (Skuja 1949), China (Hu and Wei 2006, Chu et al. 2007), Japan (Hirose, Yamagishi and Akiyama 1977), Nepal (Rai, Rai and Jha 2010), Tajikistan (Barinova and Niyatbekov 2018), Australia and New Zealand: New South Wales (Day et al. 1995), New Zealand (Broady and Merican 2012, Chapman, Thompson and Segar 1957), Queensland (Day et al. 1995, Phillips 2002, Bostock and Holland 2010). Pacific Islands/Pacific Ocean: Federated States of Micronesia (Lobban and Tsuda 2003), Hawaiian Islands (Sherwood 2004), Marshall Islands (Taylor 1950, Dawson 1957).

Habitat: Epilithic.

Specimen Examined: INDIA: Kerala; Palakkad district, Pothundy dam, N10°31.128'-E076°37.744', Environmental Science Division, University of Calicut, CU No: 163806. Kozhikode district, Kalpini, N11°20'01.15"-E076°03'49.82", Environmental Science Division, University of Calicut, CU No: 163837. Wayanad district, Kanthanpara, N11°31'41.35"-E076°09'25.75", Environmental Science Division, University of Calicut, CU No: 163811, Ambukuthi 19, N11°37'01.80"-E076°14'06.19", Environmental Science Division, University of Calicut, CU No: 163855. (**Fig. 4.10**).

17. *Scytonema ocellatum* Lyngbye ex Bornet & Flahault 1886

Desikachary, 1959, pp. 467, pl. 92, fig. 3; Komarek, 2013, vol. 19, pp. 82-83, fig. 48.

Description: Thallus cushion-shaped, blackish or greyish blue. Filaments cylindrical, entangled, and intricately intertwined, 10-19 μm wide, falsely branched with both geminate and singular branches. Branches relatively short, of the same morphology as the main trichomes. Sheaths firm, thin, initially colourless, later brownish to yellow brown. Trichomes cylindrical 6-15 μm wide, not constricted at cross-walls, not attenuated towards ends. Cells shorter than wide. Heterocytes short barrel-shaped up to quadratic or slightly longer than wide, yellowish.

Distribution: Arctic: Arctic (Patova, Davdov & Andreeva 2015), Russia (Arctic) (Davydov 2018, Shalygin 2012), Svalbard (Spitsbergen) (Davydov 2014, Skulberg 1996, Davydov 2021). Europe: Britain (Pentecost & Haworth 2021), Britain & Ireland (Whitton & al. 2003, John & al. 2011), Czech Republic (Czechia) (Gadea & al. 2013), Ireland (Adams 1908), Romania (Caraus 2017), Russia (Europe) (Stenina & Patova 2007, Patova & Novakovskaya 2018), Saxony (Germany) (Doege & al. 2022), Scandinavia (Karlason & al. 2018), Serbia (Cvijan & Blazencic 1996), Slovakia (Das & al. 2020, Hindák & Hindáková 2016), Spain (Alvarez-Cobelas & Gallardo 1988), Ukraine (Barinova & al. 2019), Ural Mountains (Patova & al. 2023). N. America: Channel Islands, California (Ramos *et al.* 2014), Florida (Taylor 1928), Missouri (Gier & Johnson 1954), North America (Wehr & al. 2015), North Carolina (Whitford & Schumacher 1969), Québec (QC) (Poulin & al. 1995), Tennessee (Johansen & al. 2007), Virginia (Forest 1954). S. America: Brazil (Büdel, Weber, Porembski & Barthlott 2002, Oliveira Filho 1977), Venezuela (Ganesan 1990). Africa: Libya (Compère 1986). Middle East: Georgia (Barinova & Kukhaleishvili 2017, Barinova & Kukhaleishvili 2014). South-west Asia: Himachal Pradesh (Singh & al. 2023), India (Gupta 2012), Jharkhand (Gupta 2021), Kerala (Jose & Xavier 2022), Punjab (Singh & al. 2022), Rajasthan (Jain 2018). Southeast Asia: Myanmar (Burma) (Skuja 1949), Viet Nam (Nguyen *et al.* 2013). Asia: China (Chu & al. 2007, Hu & Wei 2006), Japan (Hirose, Yamagishi & Akiyama 1977), Nepal (Rai, Rai & Jha 2010), Russia (Far East) (Medvedeva & Nikulina 2014),

South China Sea (Phang & al. 2016), Tajikistan (Barinova & Niyatbekov 2018). Australia and New Zealand: Queensland (Phillips 2002, Bostock & Holland 2010). Pacific Islands/Pacific Ocean: French Polynesia (Vieira & al. 2023, Pari & N'Yeurt 1999), Hawaiian Islands (Sherwood 2004), Marshall Islands (Taylor 1950).

Habitat: Epilithic.

Specimen Examined: INDIA: Kerala; Palakkad district, Nelliampathy, N10°31.625'-E076°38.747', Environmental Science Division, University of Calicut, CU No: 163896. Malappuram district, Nadukani, N11°24'38.23"-E076°22'31.72", Environmental Science Division, University of Calicut, CU No: 173198, Cheruppadimala, N11°07.068'-E075°59.354", Environmental Science Division, University of Calicut, CU No: 163848. Kozhikode district, Thamarassery churam, N11°30'45.96"-E076°01'08.52", Environmental Science Division, University of Calicut, CU No: 163887. Wayanad district, Govindamoolachira, N11°37'41.96"-E076°14'30.07", Environmental Science Division, University of Calicut, CU No: 163820, Edakkal, N11°37'18.97"-E076°13'44.92", Environmental Science Division, University of Calicut, CU No: 163865. **(Fig. 4.11).**

18. *Scytonema papilli-capitatum* C.L. Sant'Anna and J. Komarek 2013

Komarek, 2013, vol.19, pp. 130-131, fig.120;

Description: Thallus in the form of dirty green mass with entangled filaments. Filaments cylindrical, flexuous, sometimes slightly, continually widened towards ends, 13-16 µm wide; Well-developed filaments have hemispherical, cup-shaped cell wall formation with terminal, finger-like processus. Sheaths firm, slightly widened, parrallely lamellated yellow to yellow-brown, at the ends sometimes (old) with hyaline. Trichomes cylindrical, narrow in older parts, 2-3 µm wide, widened towards ends of branches and there up to 5-8 µm wide, not constricted at the cross walls. Cells in older trichomes long cylindrical, up to 5× longer than wide, cylindrical to barrel-shaped. Heterocytes intercalary, solitary, sometimes slightly wider than trichomes, cylindrical, 10-15×6-6.5 µm.

Distribution: SE Brazil (Komarek, 2013)

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of India.

Specimen Examined: INDIA: Kerala; Palakkad district, Meenvallam, N10°55.381'-E076°33.685', Environmental Science Division, University of Calicut, CU No: 163808 (**Fig. 4.11**).

19. *Scytonema pascheri* Bharadwaja 1934

Desikachary, 1959, pp. 463, pl. 89, fig.3; Komarek, 2013, vol.19, pp. 132, fig.122.

Description: Thallus thick, brownish green. Filaments irregularly curved and densely entangled, 18.9-22.1 µm wide, with false branches, which are long, usually geminate. Sheaths firm, thick, pigmented, with parallel layers, up to 5.8 µm wide. Trichomes ± cylindrical, not constricted at cross-walls, 9.4-10.5 µm wide, but at the ends up to 11.5 µm wide. Cells in old parts cylindrical, ± isodiametric, and quadratic, more commonly distinctly shorter. Heterocytes few, single, intercalary, quadratic, or ellipsoidal, 10.4-18.9 (21.0) × 9.4-12.6 (13.6) µm.

Distribution: South-west Asia: Bangladesh (Siddiqui et al. 2009), India (Gupta 2012), Karnataka (Gupta and Das 2019), Rajasthan (Jain 2018), Asia: China (Chu et al.2007).

Habitat: Epilithic.

Specimen Examined: INDIA: Kerala; Palakkad district, Minnampara, N10°32.356'-E076°42.877', Environmental Science Division, University of Calicut, CU No: 163891. Kozhikode district, Urumi dam, N11°22'22.73"-E076°03'32.30", Environmental Science Division, University of Calicut, CU No: 173177. (**Fig. 4.12**).

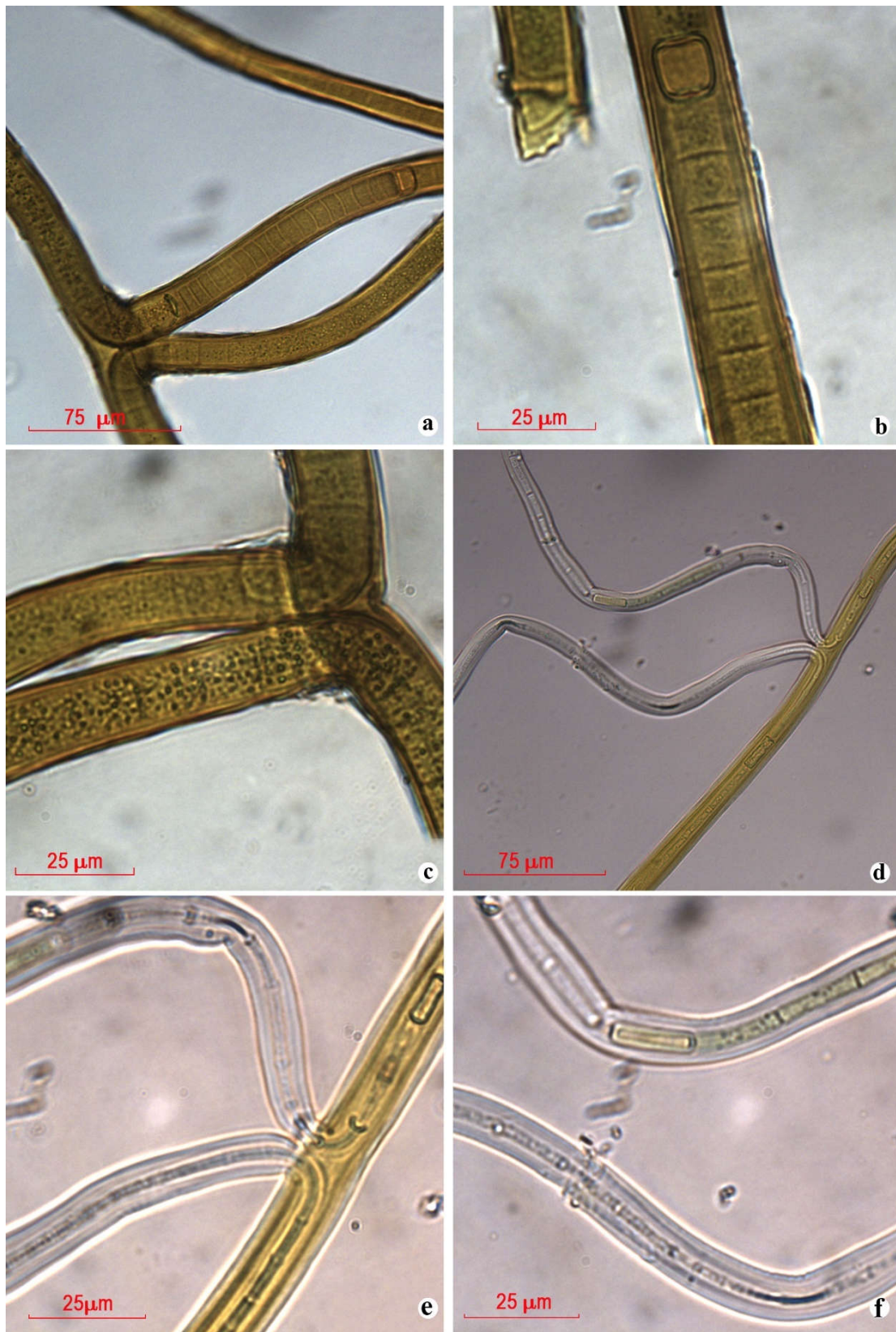


Fig. 4.11: a-c. *Scytonema ocellatum*; d-f. *Scytonema papilli-capitatum*

20. *Scytonema polycystum* Bornet et Flahault 1886

Komarek 2013, vol.19, pp. 96, fig.70.

Description: Thallus cluster-like, greyish-green. Filaments entangled, 14-24 μm wide, scarcely falsely branched. Branches of the same morphology as the main filaments, geminate or single. Sheaths thin up to 3 μm thick, not lamellated. Trichomes cylindrical, 10-15 (20) μm wide, not attenuated towards ends, not constricted at cross-walls. Cells cylindrical, 3-6 μm long; terminal cells rounded. Heterocytes 7-21 μm long, cylindrical.

Distribution: Europe: Greece (Gkelis et al. 2016), Caribbean Islands: Caribbean (Littler and Littler 2000), Indian Ocean Islands: Mauritius (Silva and Pienaar 2000), Asia: Chin (Liu 2008, Xia 2017), Korea (Lee and Kang 1986), Australia and New Zealand: Queensland (Phillips 2002, Bostock and Holland 2010), Pacific Islands/Pacific Ocean: Central Polynesia (Tsuda and Walsh 2013), Federated States of Micronesia (Lobban and Tsuda 2003), French Polynesia (Pari and N'Yeurt 1999, Vieira et al. 2023), Marshall Islands (Dawson 1957), Wallis and Futuna Is. (N'Yeurt and Payri 2004).

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of India.

Specimen Examined: INDIA: Kerala; Palakkad district, Meenvallam, N10°55.381'-E076°33.685', Environmental Science Division, University of Calicut, CU No: 163886. Malappuram district, Kozhipara, N11°21'17.51"-E076°06'31.37", Environmental Science Division, University of Calicut, CU No: 163899. Kozhikode district, Thonikadavu, N11°32'11.22"-E075°53'39.88", Environmental Science Division, University of Calicut, CU No: 173190, Muthappanpuzha, N11°26.948'-E076°06.022', Environmental Science Division, University of Calicut, CU No: 163882. Wayanad district, Phantom rock, N11°38'09.96"-E076°12'14.27", Environmental Science Division, University of Calicut, CU No: 163813. **(Fig. 4.12).**

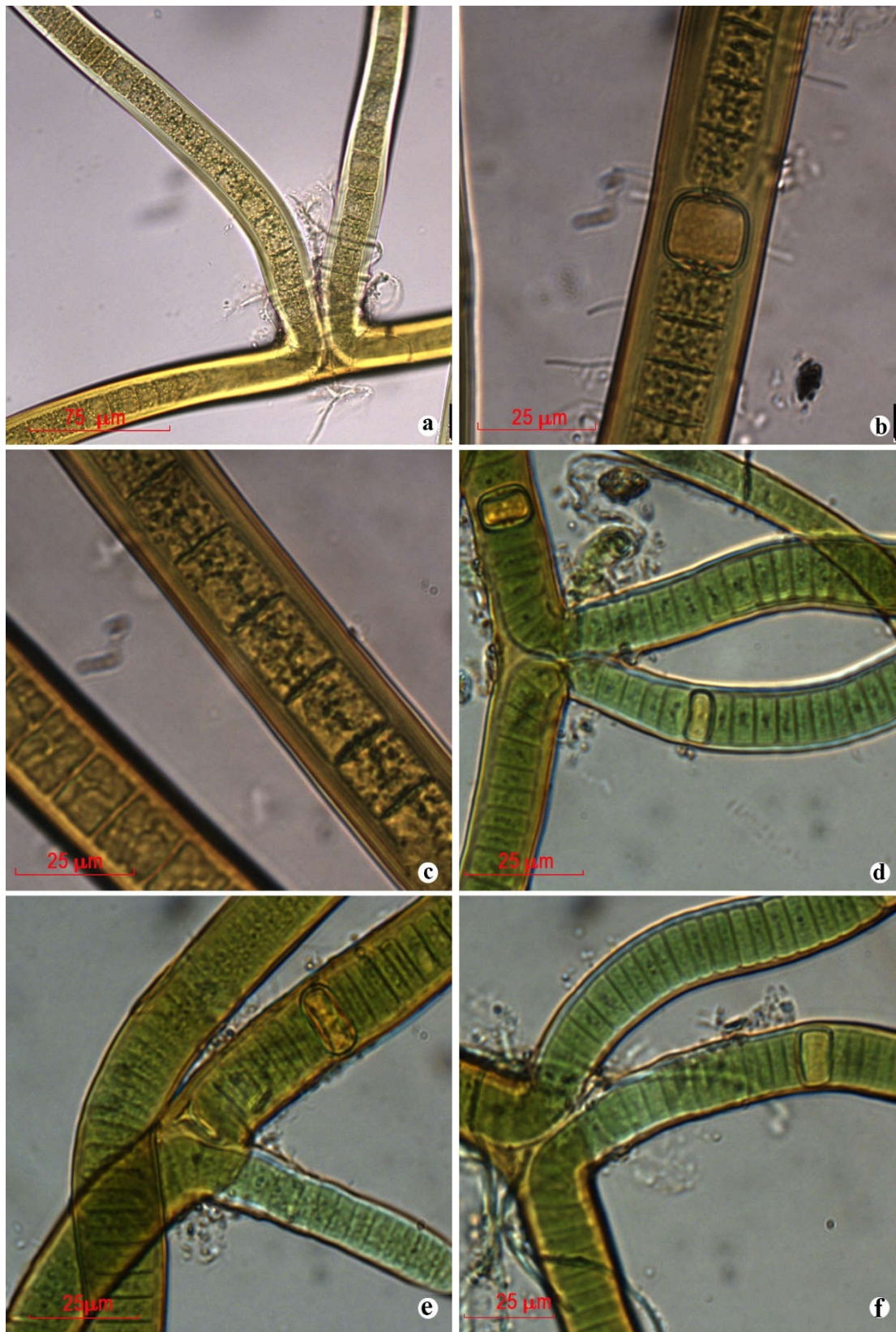


Fig. 4.12: a-c. *Scytonema pascheri*; d-f. *Scytonema polycystum*

21. *Scytonema praegnans* Skuja 1937

Komarek, 2013, vol.19, pp. 96, fig.73.

Description: Thallus expanded, flocculent. Filaments 19-30µm wide, slightly falsely branched with single or paired branches, which are slightly thinner than main filaments. Sheaths firm, parallel lamellated, sometimes in apical parts slightly divergent, colourless or inside yellowish or yellow-brown. Trichomes 11-21µm wide, constricted at crosswalls. Cell content greyish or olive green. Heterocytes rounded cylindrical or disciform, longer or shorter than wide, slightly wider than vegetative cells up to 24 µm wide.

Distribution: China (Chu et al. 2007)

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of India.

Specimen Examined: INDIA: Kerala; Malappuram district, Kozhipara Waterfalls, N11°21'17.51"-E076°06'31.37", Environmental Science Division, University of Calicut, CU No:163822. Kozhikode district, Thonikadavu, N11°32'12.80"-E075°53'40.86", Environmental Science Division, University of Calicut, CU No:173162. (**Fig. 4.13**).

22. *Scytonema pseudoguyanense* Bharadwaja 1934

Desikachary, 1959, pp. 472, pl. 89, fig.2; Komarek, 2013, vol.19, pp. 132, fig.121.

Description: Thallus in form of a thick cushion, with long erect threads, brownish green. Filaments irregularly curved and densely entangled, 15.7-18.9 (23.1) µm wide, with numerous false branches which are invariably slightly narrower than the main filaments, forming secondary branches at an early stage; branching usually geminate and sometimes (young) arising in characteristic loops. Sheaths firm, pigmented with parallel stratification, 3.1 (4.5) µm wide, in old filaments up to 7.3 µm wide, in young branches only narrowed to 2.1 µm. Trichomes cylindrical, not

constricted at cross-walls, 8.4-9.5 (10.5) μm , in old parts only 5.2 μm wide. Cells almost quadratic, in old parts of filaments cylindrical, up to 4 \times longer than broad, at the ends shortened and flattened. Heterocytes cylindrical, quadratic, or ellipsoidal, rarely longer or shorter than wide, 7.3-18.6 (21) \times 10.5-12.6 μm .

Distribution: India (Gupta 2012), Jharkhand (Gupta 2021), China (Chu et al. 2007).

Habitat: Epilithic.

Specimen Examined: INDIA: Kerala; Malappuram district, Cheruppadimala, N11°06'536"-E075°59.542", Environmental Science Division, University of Calicut, CU No: 163847. Kozhikode district, Urumi dam, N11°22'22.73"-E076°03'32.30", Environmental Science Division, University of Calicut, CU No: 173133, Kariyathanpara, N11°32'26.31"-E075°53'33.58", Environmental Science Division, University of Calicut, CU No: 173200, Thonikadavu, N11°32'12.80"-E075°53'40.86", Environmental Science Division, University of Calicut, CU No: 163879. Wayanad district, Rippon, N11°32'25.02"-E076°08'10.94", Environmental Science Division, University of Calicut, CU No: 163809, Meppadi, N 11° 30' 41.93" - E076° 0'56.8", Environmental Science Division, University of Calicut, CU No: 163857. (**Fig. 4.13**).

23. *Scytonema sanpaulense* Sant' Anna 1988

Komarek, 2013, vol.19, pp. 100, fig.77.

Description: Thallus gelatinous. Filaments entangled, 10-15 μm wide, with single or paired branches. Sheaths homogeneous, colourless or yellowish. Trichomes constricted at the cross-walls, 4-10 μm wide. Cells 4-15 μm long with blue-green or violet content, quadratic or slightly shorter or longer than wide. Heterocytes quadratic or rounded, intercalary, 10-15 \times 4-9 μm .

Distribution: No distribution information is available at present.

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of India.

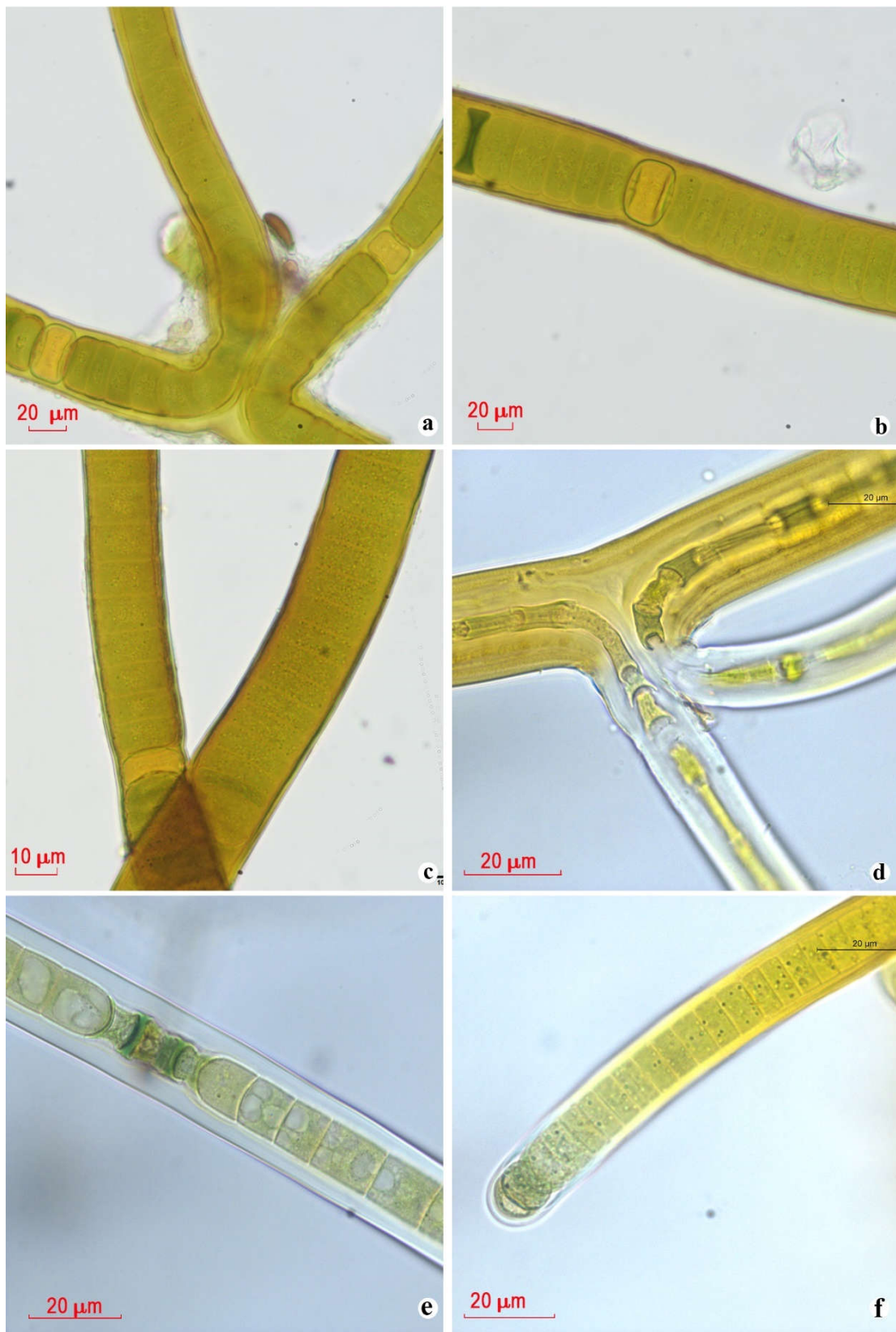


Fig. 4.13: a-c. *Scytonema praeagnans*; d-f. *Scytonema pseudoguyanense*

Specimen Examined: INDIA: Kerala; Malappuram district, Adyanpara, N11°21'19.74"-E076°12'11.85", Environmental Science Division, University of Calicut, CU No: 173122, Koonorkandy, N11°16'26.04"-E076°02'05.46", Environmental Science Division, University of Calicut, CU No: 173178. Kozhikode district, Koorachundu, N11°31'34.98" E075°49'27.84", Environmental Science Division, University of Calicut, CU No: 163880. **(Fig. 4.14).**

24. *Scytonema schmidtii* Gomont 1901

Desikachary, 1959, pp. 459-460, pl. 92, fig.1; Komarek, 2013, vol.19, pp. 100, fig.78.

Description: Thallus extensive, prostrate, blackish-brown, woolly. Filaments elongated, densely entangled, 10-12 (16) μm wide, richly and repeatedly falsely branched with divaricated geminate branches. Sheaths not lamellated, in old parts thick, yellowish-brown. Trichomes cylindrical, distinctly constricted at cross-walls, 9-12 μm wide. Cells shorter than wide, rarely up to quadratic. Heterocytes quadratic, cylindrical or up to distinctly shortened end shortly barrel-shaped.

Distribution: Iraq (Maulood et al. 2013), Israel (Vinogradova et al. 2000), India (Gupta 2012), Karnataka (Gupta and Das 2019), Rajasthan (Jain 2018), Nepal (Rai, Rai and Jha 2010), Australia and New Zealand: Queensland (Phillips 2002, Bostock and Holland 2010).

Habitat: Epilithic.

Specimen Examined: INDIA: Kerala; Malappuram district, Cheruppadimala, N11°07.068'-E075°59.354", Environmental Science Division, University of Calicut, CU No: 173184, Adyanpara, N11°17'95"-E076°12'11.92", Environmental Science Division, University of Calicut, CU No: 163872, Valillapuzha, N11°16'25.83"-E076°02'05.19", Environmental Science Division, University of Calicut, CU No: 163834. Wayanad district, Thirunelli, N11°06'.536"-E075°59.542", Environmental Science Division, University of Calicut, CU No: 163853. **(Fig. 4.14).**

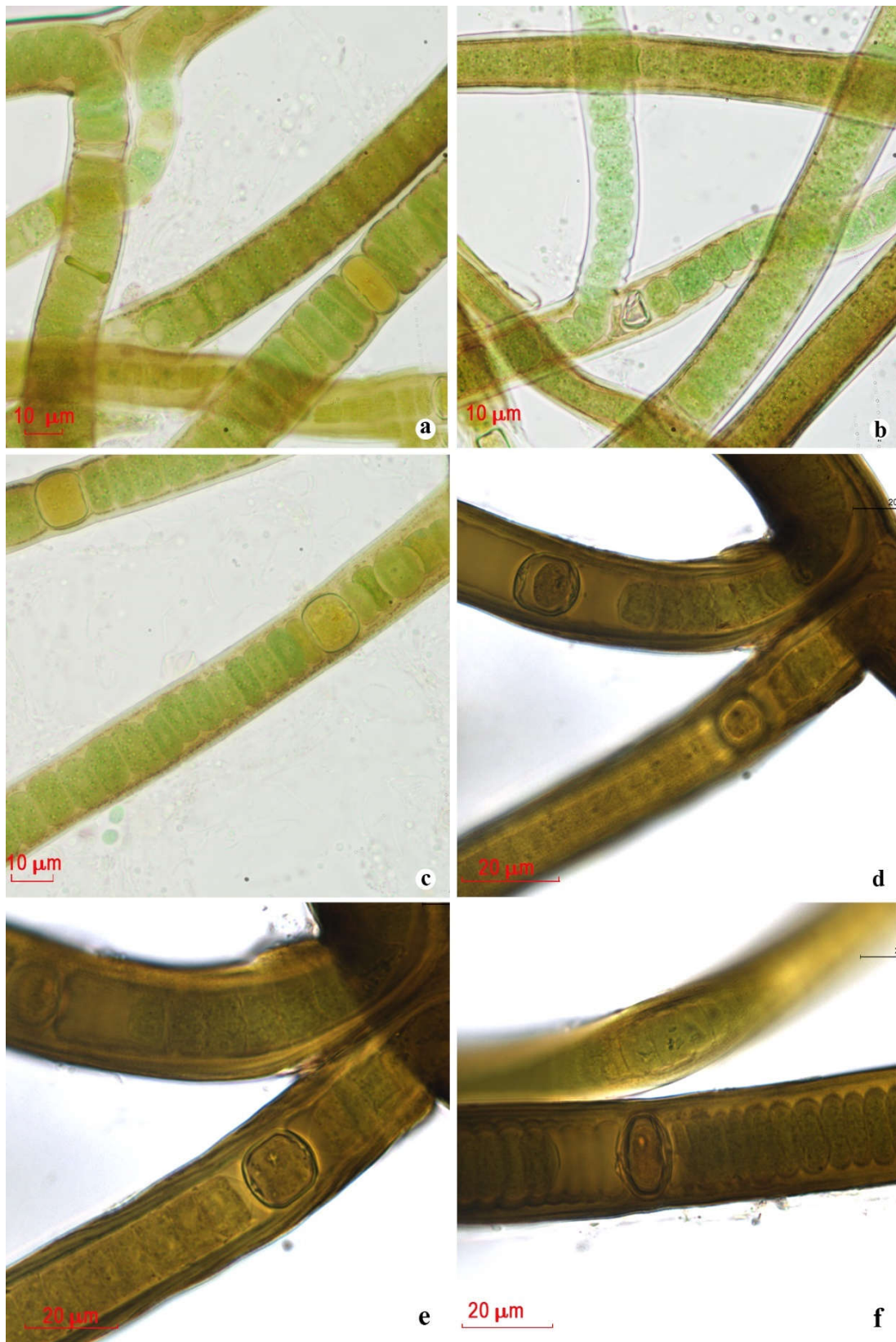


Fig. 4.14: a-c. *Scytonema sanpaulense*; d-f. *Scytonema schmidtii*

25. *Scytonema spirulinoides* N.L. Gardner 1927

Komarek 2013, vol.19, pp. 133, fig.125.

Description: Thallus flocculent. Filaments curved and spirally coiled, 15-20 µm wide, usually geminate branching, Sheaths thick, homogeneous, without lamellation, dark brown. Trichomes cylindrical, not constricted at cross-walls, in old parts distinctly narrower than towards ends, 10-12 µm wide. Cells cylindrical, isodiametric towards ends shortened. Heterocytes cylindrical, of the same shape and size as the cells.

Distribution: Switzerland (Mian 2002)

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of India.

Specimen Examined: INDIA: Kerala; Palakkad district, Nelliampathy, N10°31.625'- E076°38.747', Environmental Science Division, University of Calicut, CU No: 163805. Malappuram district, Kozhipara waterfalls, N11°21'17.51"-E076°06'31.37" Environmental Science Division, University of Calicut, CU No: 173130, Arimbra hills, N11°05'.950"-E076°00'.990", Environmental Science Division, University of Calicut, CU No: 173185. Kozhikode district, Koorachundu, N11°31'34.98"-E075°49'27.84", Environmental Science Division, University of Calicut, CU No: 173191, Thamarassery churam, N11°30'38.01"-E076°01'09.48", Environmental Science Division, University of Calicut, CU No: 163888. Wayanad district, Govindamoolachira, N11°37'41.96"-E076°14'30.07", Environmental Science Division, University of Calicut, CU No: 173149, Edakkal, N11°37'47.52"-E076°13'44.12", Environmental Science Division, University of Calicut, CU No: 163814. **(Fig. 4.15).**

26. *Scytonema tenellum* N.L. Gardner 1927

Komarek, 2013, vol.19, pp. 101-102, fig.82.

Description: Thallus thin. Filaments flexuous or densely intertwined, erect, 12-16µm wide. Branching geminate, branches perpendicular to gently curved. Sheaths thin, smooth, homogeneous not lamellated. Trichomes cylindrical, not tapering towards the ends, very slightly constricted at the crosswalls, 10-14 µm wide. Cells shorter than wide, pale olive or bluegreen. Heterocytes numerous, golden yellow of the same shape and size as vegetative cells, or quadratic.

Distribution: No distribution information is available at present.

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of India.

Specimen Examined: INDIA: Kerala; Palakkad district, Meenvallam, N10°55.381'-E076°33.685', Environmental Science Division, University of Calicut, CU No: 173109. Kozhikode district, Thonikadavu, N11°32'12.98"-E075°53'59.66", Environmental Science Division, University of Calicut, CU No: 173163. Wayanad district, Thirunelli, N11°54'49.33"-E075°59'39.29", Environmental Science Division, University of Calicut, CU No: 163832. **(Fig. 4.15).**

27. *Scytonema tolypothrichoides* Kutzing ex Bornet & Flahault 1886

Desikachary, 1959, pp. 479, pl. 91, fig. 1; Komarek, 2013, vol.19, pp. 75, fig.36.

Description: Thallus caespitose, floating, flake or tuft-like, green or brownish, up to 3cm in diameter, with radially arranged, coiled filaments. Filaments 10-17 µm wide, 5-6mm long. Sheath initially colourless, later yellow or orange-brown, sometimes slightly parallelly striated with divergent layers towards ends; sometimes with slight development of ferric precipitates. Trichomes cylindrical, not constricted at the crosswalls, sometimes narrowed or widened towards ends in narrowed or widened sheaths. Heterocytes barrel-shaped, almost spherical up to elongated cylindrical, 6-16 µm long.

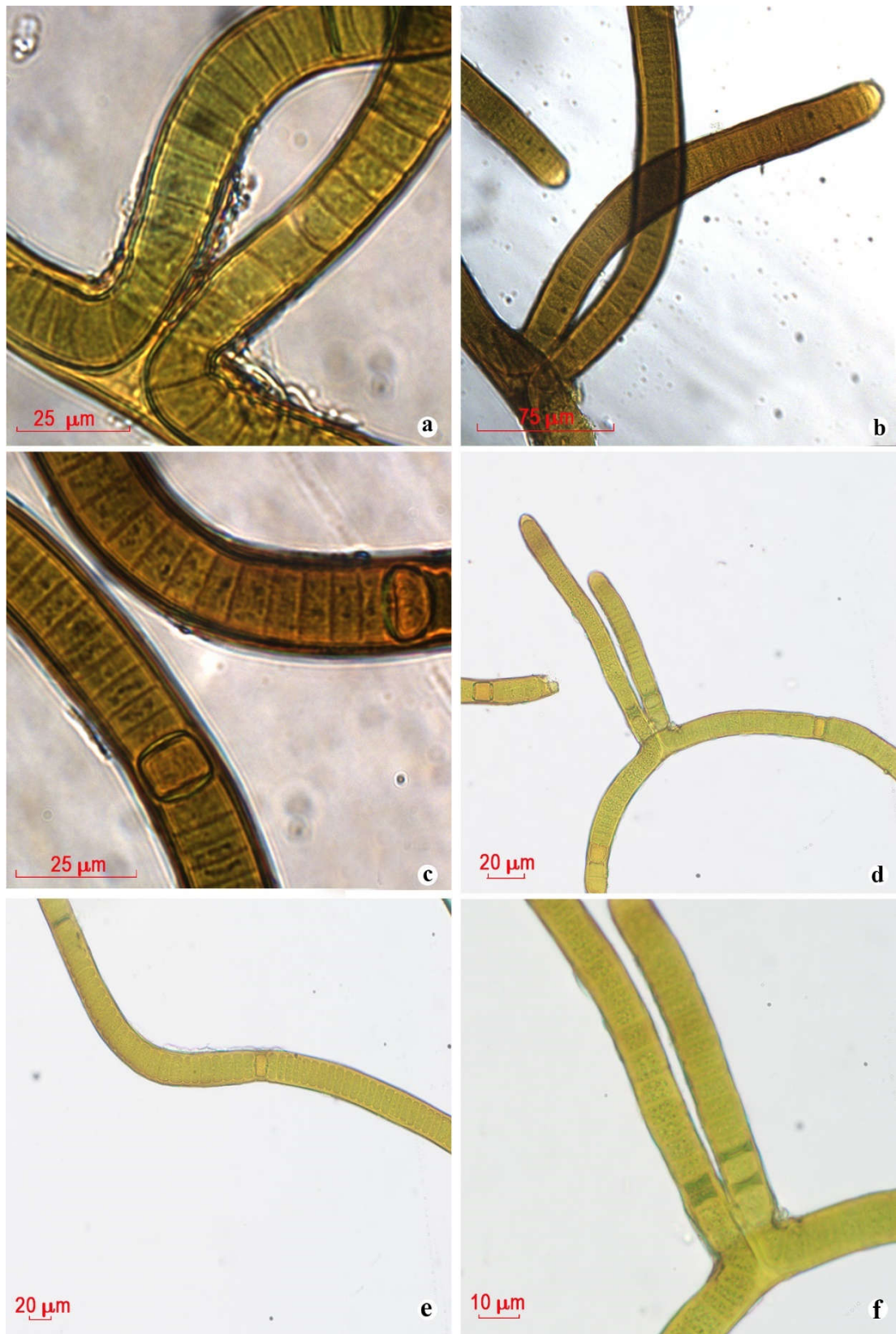


Fig. 4.15: a-c. *Scytonema spirulinoides*; d-f. *Scytonema tenellum*

Distribution: Arctic: Svalbard (Skulberg 1996, Davydov 2021), Iceland (Hallgrímsson 2007), Czech Republic (Gadea et al. 2013), Ireland (Adams 1908), Romania (Caraus 2017), Scandinavia (Karlason et al. 2018), Ukraine Barinova et al. 2019, N. America: Arkansas (Smith 2010), Laurentian Great Lakes (Prescott 1962), Quebec (QC) (Poulin et al. 1995), Tennessee (Johansen et al. 2007), Bangladesh (Siddiqui et al. 2009), India (Gupta 2012), Jharkhand (Gupta 2021), Kerala (Arulmurgan et al. 2016), Khandesh (Jaiswal 2017), Punjab (Singh et al. 2022), Rajasthan (Jai 2018), China (Chu et al. 2007), New Zealand (Chapman 1956, Broady and Merican 2012), Queensland (Day et al. 1995), Hawaiian Islands (Sherwood 2004).

Habitat: Epilithic.

Specimen Examined: INDIA: Kerala; Palakkad district, Mattumala, N10°31.750'-E076°43.173', Environmental Science Division, University of Calicut, CU No: 173110. Malappuram district, Valillapuzha, N11°16'25.83"-E076°02'05.19", Environmental Science Division, University of Calicut, CU No: 173171, Nadukani, N11°24'38.23"-E076°22'31.72", Environmental Science Division, University of Calicut, CU No: 163873. Kozhikode district, Kuliramutty, N11°21'28.01"-E076°02'46.61", Environmental Science Division, University of Calicut, CU No: 173193. Wayanad district, Edakkal, N11°37'47.79"-E076°13'40.58", Environmental Science Division, University of Calicut, CU No: 173145. **(Fig. 4.16).**

28. *Scytonema torulosum* C.-C. Jao 1940

Komarek, 2013, vol.19, pp. 158-160, fig.159.

Description: Thallus thin, dark green, or brownish green. Filaments densely entangled, commonly false branched, (13) 17-28 µm wide. Branches solitary or in pairs. Sheaths distinctly or obliquely stratified, yellow-brown. Trichomes cylindrical, distinctly constricted at cross-walls, not attenuated or widened towards ends. Cells barrel-shaped, cylindrical or quadrate, shorter than wide, 3.6-6.3×7-10 µm. Heterocytes intercalary, spherical, 4.5-10.8×9.9-12.6 µm.

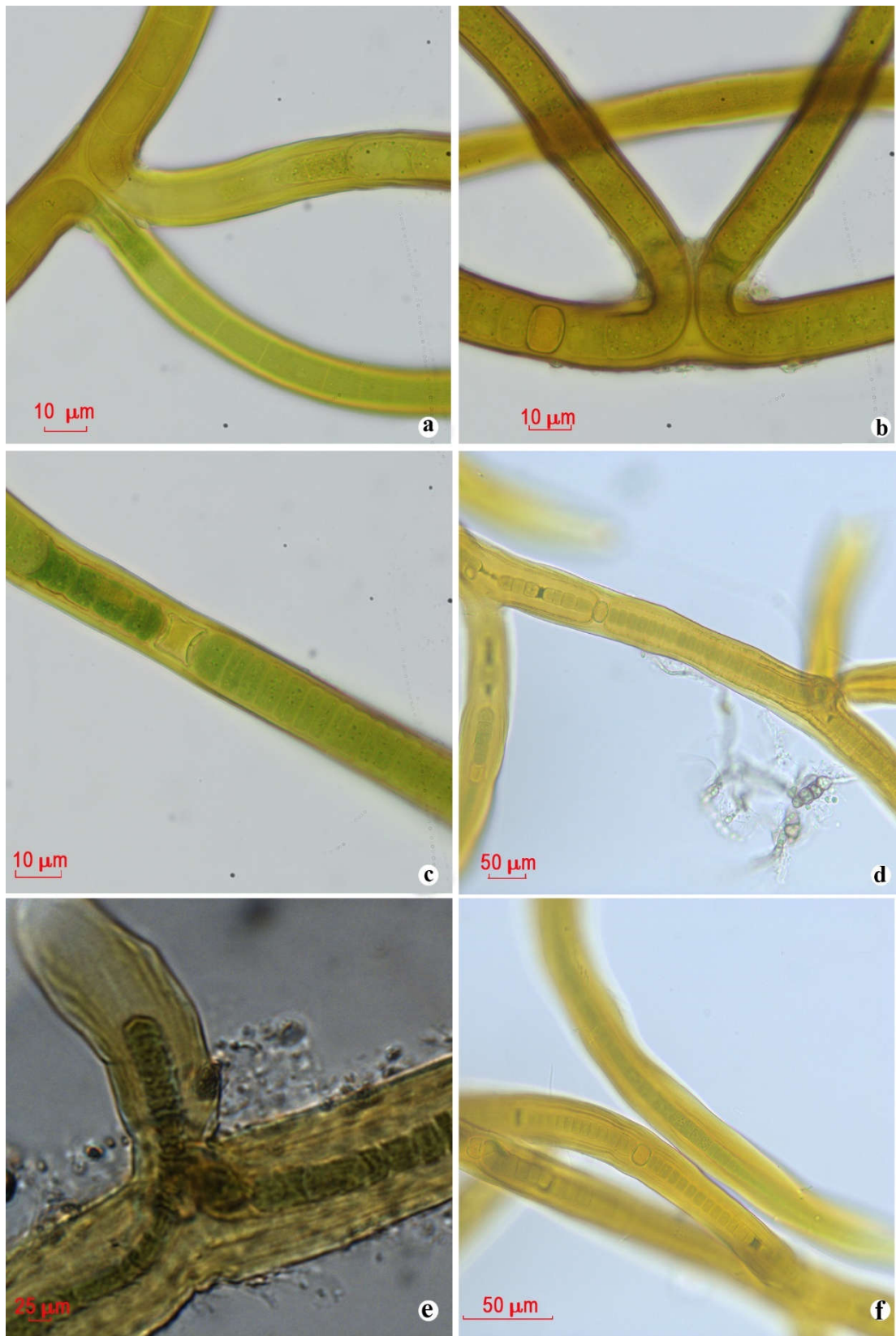


Fig. 4.16: a-c. *Scytonema tolypothrichoides*; d-f. *Scytonema torulosum*

Distribution: China (Chu et al. 2007)

Habitat: Epilithic.

Specimen Examined: INDIA: Kerala; Palakkad district, Minnampara, N10°32.356'-E076°42.877', Environmental Science Division, University of Calicut, CU No: 163801. Malappuram district, Adyanpara, N11°21'19.74"-E076°12'11.85", Environmental Science Division, University of Calicut, CU No: 163870. Kozhikode district, Kuliramutty, N11°21'28.01"-E076°02'46.61", Environmental Science Division, University of Calicut, CU No: 173131. **(Fig. 4.16).**

29. *Scytonema twymanianum* Welsh 1966

Komarek, 2013, vol.19, pp. 101, fig.83.

Description: Thallus macroscopic, very dark olive-green, caespitose, erect. Filaments densely agglutinated in basal parts, straight and parallelly or densely interwoven, yellowish-green to bluish-green, 10-17 µm wide. Sheath firm, rather thin 1-2 µm thick colourless, in older parts yellowish, mostly not lamellate. Trichomes at the base 10-15 µm wide, constricted at the crosswalls, especially in older parts. Heterocytes common intercalary, solitary, subquadrate to subglobose 10-14×8-12 µm.

Distribution: No distribution information is available at present.

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of Kerala.

Specimen Examined: INDIA: Kerala; Malappuram, Koonorkandy, N11°16'26.04"-E076°02'05.46", Environmental Science Division, University of Calicut, CU No: 173127, Cheruppadimala, N11°06'.542"-E075°59'.504", Environmental Science Division, University of Calicut, CU No: 173182. Kozhikode district, Thonikadavu, N11°32'12.98"-E075°53'59.66", Environmental Science Division, University of Calicut, CU No: 173196, Thalayad, N11°30'37.65"-E075°53'19.85", Environmental Science Division, University of Calicut, CU No:163875. **(Fig. 4.17).**

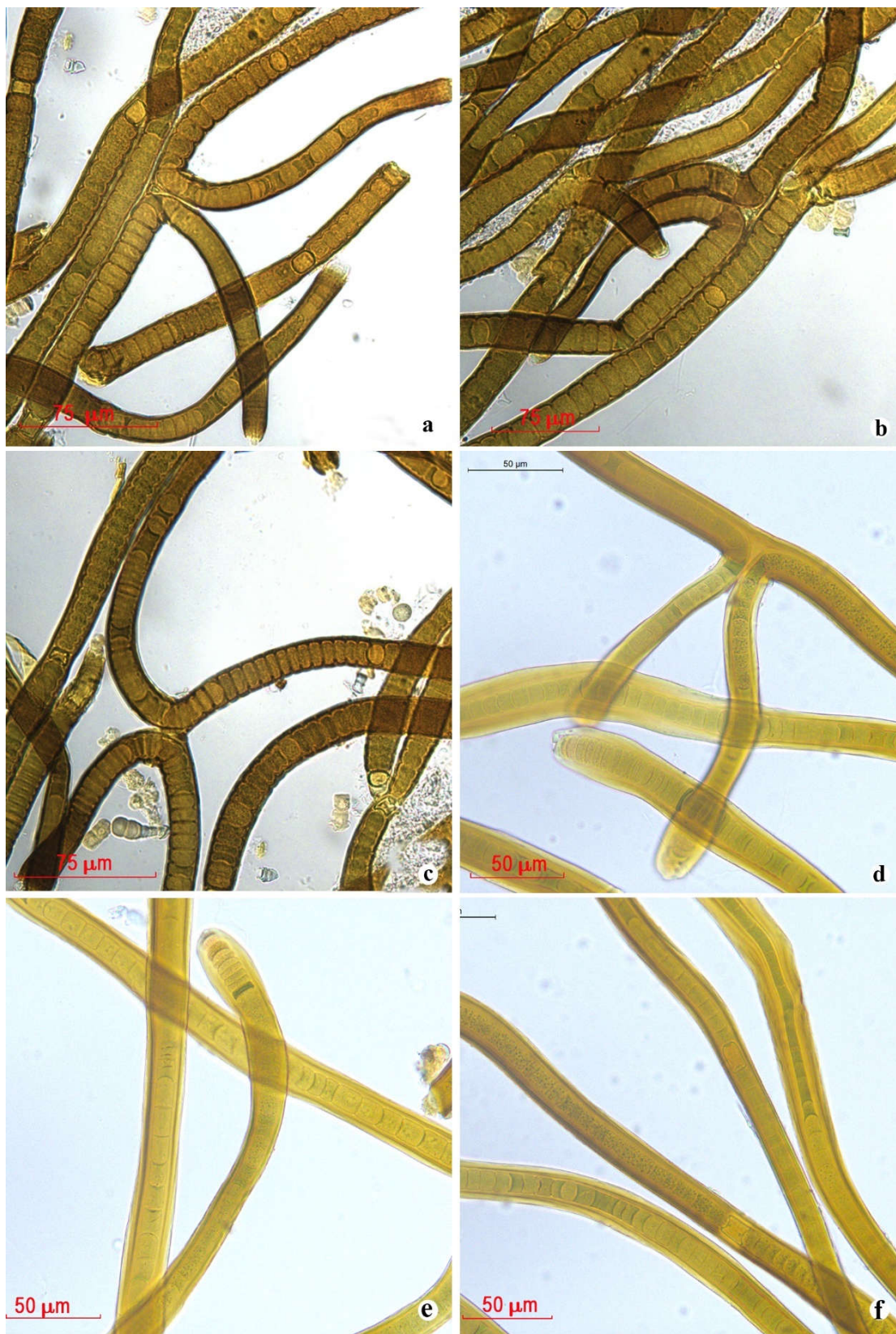


Fig. 4.17: a-c. *Scytonema twymanianum*; d-f. *Scytonema variabile*

30. *Scytonema variabile* N.L. Gardner 1927

Komarek, 2013, vol.19, pp. 133, fig.128.

Description: Thallus in the form of thick layer. Filaments mostly straight, sparsely branched with both single or geminate branches; main filaments 34-42 µm wide, branches thinner, all filaments very variable in width in different parts. Sheaths hyaline to yellowish-brown, 6-12 µm thick, homogeneous or with a few divergent layers, subgelatinous. Trichomes very variable in width, distinctly narrower in older parts and slightly constricted at crosswalls, widened toward ends up to 25 µm and there constricted distinctly. Cells cylindrical, bright blue-green, in older segments of trichomes long cylindrical and up to 2x longer than wide, towards ends widened, short barrel-shaped; terminal cells widely rounded. Heterocytes cylindrical, of the same size and shape like the vegetative cells.

Distribution: No distribution information is available at present.

Habitat: Epilithic.

Comments: New record to the Western Ghats Cyanobacterial flora of India.

Specimen Examined: INDIA: Kerala; Malappuram district, Kozhipara, N11°21'14.51"-E076°06'30.40", Environmental Science Division, University of Calicut, CU No: 163898. Kozhikode district, Thechi, N11°28'31.84"-E075°53'47.28", Environmental Science Division, University of Calicut, CU No: 173199. Wayanad district, Edakkal, N11°37'18.97"-E076°13'44.92", Environmental Science Division, University of Calicut, CU No: 173147. **(Fig. 4.17).**

Scytonema was initially described by Bornet and Flahault (1886) and is regarded as one of the oldest genera among Cyanoprokaryotes. It has since been confirmed that this genus comprises over 300 species (Komarek 2013). In general, *Scytonema* is considered cosmopolitan, comprising numerous species that exist endemically in tropical and ecologically distinct habitats, such as dripping rocks and reservoirs with water vegetation (Komarek et al. 2013). The genus *Scytonema* was summarized by Geitler (1932), Desikachary (1959), Starmach (1966), Bourrelly (1970), and

Komarek and Anagnostidis (1998). Nevertheless, more recent revisions relying on the polyphasic method have indicated that this genus is polyphyletic (Komarek 2013). Molecular evidence (Boyer et al. 2002; Berrendero et al. 2008; Zapomelova et al. 2011) has shown its heterogeneity and polyphyly, leading to the division of the genus into various generic units (Bohunicka et al. 2012). *Scytonema sensu stricto* is based on the type species *Scytonema hofmannii* C. Agardh ex Bornet et Flahault (1888), which is morphologically characterized by cylindrical trichomes along its whole length, more or less quadratic cells in the main trichomes, and relatively narrow sheaths (Anagnostidis and Komarek 1988). Of the genus *Scytonema*, Desikachary (1959) reported a total of 41 species, whereas Komarek (2013) identified 131 species. Taxonomically, the database now has 121 accepted species names, 30 accepted varieties, and 12 accepted formae for the genus *Scytonema*. 64 species names, 6 variety names, and 11 formae names are recognised worldwide in synonymy and are included in the Algae Base (Guiry and Guiry 2024).

Previously, fifteen species of *Brasilonema*, comprising both recently discovered species and those that were formerly categorized in other genera, have been described. These species are *B. bromeliae* Fiore et al. (Fiore et al. 2007), *B. octagenarum* Aguiar et al. (Aguiar et al. 2008), *B. epidendron* Sant'Anna et Komarek, *B. ornatum* Sant'Anna et Komarek, *B. roberti-lamyi* (Bourelly) Sant'Anna et Komarek, *B. sennae* (Komarek) Sant'Anna et Komarek, *B. terrestre* Sant'Anna et Komarek (all in Sant'Anna et al. 2011), *B. angustatum* Vaccarino et Johansen (Vaccarino and Johansen 2012), *B. tolantongense* Becerra–Absalon et Montejano (Becerra-Absalon et al. 2013), *B. burkei* Miscoe, Pietrasiak et Johansen in Miscoe et al. (2016), *B. lichenoides* Villanueva, P. Hasler et Casamatta (Villanueva et al. 2018), *B. geniculatum* Villanueva et Casamatta (Villanueva et al. 2019), *B. fioreae* D.E. Berthold et al., *B. santannae* D.E. Berthold et al., and *B. wernerae* D.E. Berthold et al. (Barbosa et al. 2021). Bohunicka et al. (2024) reported the discovery of 24 new *Brasilonema* species as well as new populations of existing species. Moreover, a thorough review of the genus along with descriptions of novel species were given.

Bohunicka et al. (2024) isolated 76 strains from tropical, subtropical, and temperate environments (North, Central, and South America, South and East Asia, Central Africa, and Europe). They used polyphasic approach to their species delineation and they reported the finding of 24 new *Brasilonema* species as well as new populations of known species. Furthermore, a comprehensive assessment of the genus and descriptions of noval species were provided. These species are *Brasilonema amethysteum* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema bambusae* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema bambusicola* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema brancoi* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema calcareum* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema corcovadense* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema epiphyllum* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema elegans* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema fatamorganum* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema incudis* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema mombasense* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema palmarum* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema muscicola* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema verawerneriae* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema calidum* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema cataractarum* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema cubense* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema elongatum* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema hortense* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema kauaiense* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema komarekii* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema mata-atlanticum* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema ohuense* M. Bohunicka et J.R. Johansen sp. nov., *Brasilonema villosum* M. Bohunicka et J.R. Johansen sp. nov.

The filamentous, falsely branching cyanobacterium *Petalonema* Berkeley ex Correns 1889 belongs to the family Scytonemataceae and the order Nostocales. While *Petalonema* and *Scytonema* share similar morphology, some distinguishing features set them apart, such as irregular false branching, incredibly thick and broad lamellated sheaths surrounding the trichomes, a sheath that is several times broader than the trichomes, and funnel-shaped divergent sheaths at the ends. Currently, only

nine species in this genus have been reported globally: *P. alatum*, *P. crassum*, *P. crustaceum*, *P. densum*, *P. fluminale*, *P. incrustans*, *P. involvens*, *P. pulchrum*, and *P. velutinum* (Guiry and Guiry 2024). Although most *Petalonema* species are terrestrial, they have also been documented in some aquatic environments, including calcareous lakes, ponds, and limestone springs (Kukk et al. 2001; Komarek 2013; Maree et al. 2018). They grow naturally on calcareous wet rocks, on stones, dripping walls, and on wet soils. Taxonomically, there are 9 accepted species names and 3 accepted varieties in the database at present.

Cyanobacteria are a diverse group of oxygenic, gram-negative, photosynthetic microorganisms that thrive in almost all habitats. While cyanobacteria are common in Kerala, the region is renowned for its rich ecology and biodiversity, especially in the Western Ghats, which are considered as one of the most diverse regions. Nevertheless, little research has been done in this field on cyanobacteria, particularly the family Scytonemataceae. Previous studies on cyanobacterial diversity in Kerala have mainly focused on coastal and agricultural areas, with lesser focus on the Western Ghats region. The minimal availability of literature highlights the importance of studying and identifying cyanobacterial strains. This study examines the diversity of family Scytonemataceae in selected districts adjoining the Western Ghats region of Kerala. It will provide comprehensive information on cyanobacterial diversity, marking the first-time approach in this region. The present study recorded 35 species from the selected Western Ghats region of Kerala.

The Cyanobacteria, also known as Cyanoprokaryota or Cyanophyta, are the largest, most diverse, and widely distributed group of photosynthetic prokaryotes. They can be found in various environments, including extreme climatic conditions and oxic and anoxic environments (Whitton and Potts 2000; Thajuddin and Subramanian 2005). The present study focuses on the diversity of the Scytonemataceae family in the Western Ghats region of Kerala. Current research observed that these cyanobacteria are abundant on rock surfaces. The surfaces of rocks have the potential to provide a habitat for the growth and activity of cyanobacteria. Various researchers have studied rock surfaces in Goa, Karnataka, Kerala, and Tamil Nadu

(Pereira and Almeida 2012; Suresh et al. 2012; Singh and Singh 2019; and Philip and Radhakrishnan 2020; Swetha and Harilal 2024). Cyanobacteria have been found in rocky environments in the Arctic and Antarctic regions. Based on their spatial locations, they are categorized as endolithic (in rock pore spaces), hypolithic (under rocks), chasmoendolithic (in rock cracks and crevices), and cryptoendolithic (in spaces between the grains of porous rocks) (Vincent 1988; Nienow and Friedmann 1993; Hughes and Lawley 2003; Cockell and Stokes 2004; Omelon et al. 2007; Omelon 2008).

Cyanobacteria adhere to rock surfaces by producing and secreting mucilaginous substances, such as extracellular polymeric substances. The extracellular sheath layers of cyanobacteria are composed of polysaccharides that can retain moisture, which enables them to withstand severe droughts (Gloaguen et al. 1995; Adhikary 1998; Bertocchi et al. 1990; Cappitelli et al. 2012; Rossi et al. 2012). Furthermore, rocky environments protect cyanobacterial species from environmental stresses such as high UV irradiation, extreme temperatures, desiccation, and physical removal by wind (Vincent 1988; Hughes and Lawley 2003).

The Scytonemataceae family is renowned for its taxonomic diversity and widespread distribution. The genus *Scytonema* has a wide ecological range, with species found in soils, marine, and freshwater environments across various ecosystems (Komarek 2013). The current study observed that this family is abundantly seen on rock surfaces in the Western Ghats region of Kerala. In Indian ecosystems, cyanobacteria from the Scytonemataceae family are mainly represented by species of the genus *Scytonema* (Maltsev et al. 2021). Among the representatives of the genus, *Scytonema schmidtii* is widely found in tropical Asia up to the Himalayas on dripping rocks and wet soils (Gomont 1901). Turkey and Adhikary (2005) reported the occurrence of *Scytonema schmidtii* in the biological soil crust of India. Tagad (2016) recorded it from Junnar Taluk of Pune district, India. Suresh et al. (2012) observed them from Western Ghats and other parts of Eastern Ghats. Komarek et al. (2013) from Atlantic Rainforest in Southeast Brazil. Sebastian and

Joseph (2013) identified from minor stream of Thodupuzha river, Kerala. Priyadarshani et al. (2014) from Western Ghats of Maharashtra. Nehul (2021) isolated from various locations in Maharashtra's Ahmednagar district. Philip (2021) documented it in Bonacaud, Thiruvananthapuram, Kerala. In the present study, *Scytonema schmidtii* was recorded from Cheruppadimala, Adyanpara and Valillapuzha of Malappuram district and Thirunelli, of Wayanad district in the Western Ghats region of Kerala.

Scytonema chiastum was previously reported by Silambarasan et al. (2012) from a mangrove environment on the Tamil Nadu coast, Southeast coast of India. Keshari and Adhikary (2013) isolated from biofilms on stone monuments at Santiniketan, India, Tagad (2016) investigated the taxonomic diversity of planktonic algae in Junnar Taluk of Pune district, India and they reported *Scytonema chiastum*. Kumar et al. (2016) recorded from biological soil crust in the eastern region of India. The present study reveals the occurrence of the species *Scytonema chiastum* on rock surfaces in Cheruppadimala, Malappuram and Muthappanpuzha, Kozhikode district.

The presence of *Scytonema myochrous* was documented on rock surfaces in Kalpini, Kozhikode; Ambukuthi 19, Kanthanpara, Wayanad districts; and Pothundi dam, Palakkad district. This observation is consistent with findings by various researchers. Suresh et al. (2012) recorded *Scytonema myochrous* from the Western Ghats and Eastern Ghats of India. In tropical environments, Budel (1999) observed on moist rock, Popovic et al. (2018) confirmed its existence on selected monuments in Serbia. Philip (2021) recorded its presence in Eravikulam National Park, Idukki, Kerala. Saber et al. (2021) reported *Scytonema myochrous*, a cyanobacterium, as a new record for the Egyptian algal inventory.

Scytonema tolypothrichoides was previously reported by Nikam et al. (2010) from the Western Ghats region of Maharashtra. Deb et al. (2015) isolated from acidic rice field soil from the Dholai region of the Cachar district in Assam, North-East India. Kumar et al. (2016) recorded from biological soil crust in the eastern region of India. Ram (2022) observed from Sakthikulangara, Kollam. The present study confirmed

its presence in Mattumala, Palakkad; Valillapuzha, Malappuram; Kuliramutty, Kozhikode and Edakkal, Wayanad district of Western Ghats region of Kerala.

Komarek et al. (2013) reported *Scytonema arcangelii* from Atlantic Rainforest in Southeast Brazil. Aguiar Caires et al. (2019), recorded from tropical marine environments of Bahia State, Northeastern Brazil. The present study documented its existence on rocks in Koorachundu, Kozhikode and Ambukuthi 19, Wayanad districts. Das and Keshri (2017) observed *Scytonema pascheri* from the Eastern Himalayas-III foothills, Ram and Shamina (2016) noted on the rock surfaces of Kerala, India. Geethu and Shamina (2021) from the Western Ghats of northern Kerala, India. The present study documented its occurrence in Minnampara, Palakkad district, and Urumi dam sites, Kozhikode district, in the Western Ghats region of Kerala.

Earlier reports on *Scytonema millei* were reported from biofilms on stone monuments at Santiniketan, India, Keshari and Adhikary (2013). Ram and Shamina (2016) from rock surfaces of Kerala, India, Banerjee et al. (2020) from West Bengal, India. Philip (2021) recorded from Peppara WLS, Thiruvananthapuram, Kerala. Ram (2022) recorded from Kumbalam, Ernakulam. Sarma et al. (2023) reported *Scytonema millei* from Tripura, India, adding a new species to the region's flora. The current study observed the species in Nellyampathy, Palakkad; Valillapuzha, Malappuram, and Muthappanpuzha, Kozhikode district.

Scytonema javanicum Bornet ex Bornet and Flahault had previously been observed in Costa Rica's rain forest (Freiberg 1998). Hu et al. (2002) from the soil in the Tengger desert, Ningxia, China. Komarek et al. (2013) from Atlantic Rainforest in Southeast Brazil, Hu et al. (2014) isolated from desert biological crusts. Das and Keshri (2017) from the Eastern Himalayas-III foothills. Philip (2021) recorded from Muthanga, Wayanad. Ram (2022) from Kumbalam, Ernakulam, Kerala. Luz et al. (2022) from Azores Island, Archipelago. In the Present Study, *Scytonema javanicum* was observed in Pothundi dam, Palakkad, Adyanpara of Malappuram and Thamarassery churam of Kozhikode district.

The species *Scytonema pseudoguyanense* Bharadwaja (1934) has been found in various locations. Adhikary et al. (2015) observed them in stone temples of Bhubaneswar, India. Samad and Adhikary (2008) confirmed their presence on the walls of Parasurameswar temple, Bhubaneswar, Orissa. Mahanandia and Singh (2023) documented their existence on monuments and exterior surfaces of building facades of Odisha state, India. Dasgupta et al. (2017) reported from suburban waterbodies of Lucknow, Uttarpradesh. Philip (2021) recorded from Karapuzha, Wayanad, Kerala. In the current study, the same species were noted on the moist rock in Cheruppadimala, Malappuram; Urumi, Kariyathanpara, and Thonikadavu of Kozhikode; Rippon, Meppadi of Wayanad district.

Keshari and Adhikary (2013) isolated *Scytonema coactile* from biofilms on stone monuments at Santiniketan, India. Ram and Shamina (2016) noted from rock surfaces of Kerala, India. Sarma et al. (2023) reported from Tripura, India, and the species were new addition to the flora of Tripura, India. The current study demonstrates their distribution in Minnampara, Palakkad; Adyanpara, Malappuram; Thonikadavu, Thamarassery churam, Muthappanpuzha of Kozhikode and Edakkal of Wayanad district.

In a study by Komarek et al. (2013), *Scytonema hyalinum* was reported in the Atlantic Rainforest in Southeast Brazil. As part of our current research, we observed *Scytonema hyalinum* in Adyanpara, Malappuram, and Kanthanpara, Wayanad in the Western Ghats region of Kerala. This discovery marks a new record of this species within the Scytonemataceae family in the Western Ghats region of Kerala, India. Komarek et al. (2013) reported *Scytonema papilli-capitatum* from Atlantic Rainforest in Southeast Brazil. The current study reports its existence in Meenvallam, Palakkad district in the western Ghats region of Kerala. This discovery represents a new record of this species within the Scytonemataceae family in the Western Ghats region of Kerala, India.

Komarek et al. (2013) reported *Scytonema ocellatum* from Atlantic Rainforest in Southeast Brazil. Philip (2021) recorded from Pazhassi dam, Kannur, Kerala. In the current observation, this species was noted in Nelliampathy, Palakkad; Nadukani,

and Cheruppadimala, Malappuram; Muthappanpuzha, Thamarassery churam, Kozhikode and Govindamoolachira and Edakkal, Wayanad, in the Western Ghats region.

Komarek et al. (2013) reported *Scytonema longiarticulatum* from Atlantic Rainforest in Southeast Brazil. In the present study, this species was observed in Attappady, Palakkad; Valillapuzha, Malappuram; and Thonikadavu, Kozhikode. Nowicka-Krawczyk et al. (2014) reported *Scytonema drilosiphon* from historical buildings in the former Auschwitz II-Birkenau concentration camp, Poland. Banerjee et al. (2020) reported *Scytonema drilosiphon* from West Bengal, India. The current study demonstrates the presence of this species in Urumi dam, Kozhikode; Thirunelli, Wayanad district in the Western Ghats region of Kerala.

Sarma et al. (2023) reported *Scytonema twymanianum* from Tripura, India and the species were new additions to the flora of Tripura, India. Banerjee et al. (2020) reported from West Bengal, India. The current study recorded the presence of this species in Koonorkandy and Cheruppadimala, Malappuram; Thonikadavu, Thalayad, Kozhikode; Edakkal, Wayanad district in the Western Ghats region of Kerala. Werner (2010) recorded *Scytonema fritschii* from Brazil. India: (Gupta 2012), Rajasthan (Jain 2018) China (Chu et al. 2007), New Zealand (Smith et al. 2012), and Hawaiian Islands (Sherwood 2004). The present investigation reported its occurrence in Mattumala, Palakkad; Kalpini, Kozhikode district in the Western Ghats region of Kerala. Philip (2021) recorded *Scytonema caldarium* from Karappuzha, Wayanad, Kerala. The current research recorded its presence in Adyanpara, Malappuram; Phantom rock, Wayanad district in the Western Ghats region of Kerala.

Scytonema torulosum was previously recorded by Philip (2021) from Kanjirappuzha, Palakkad, Kerala. The present research demonstrates its occurrence in Minnampara, Palakkad; Adyanpara, Malappuram; Kuliramutty, Kozhikode. *Scytonema malaviyanense* Bharadwaja (1930), was observed on the bark of trees. Banerjee et al. (2020) reported it from West Bengal, India. The current investigation

reported its presence in Minnampara, and Nelliampathy, Palakkad; Kanthanpara, Wayanad district in the Western Ghats region of Kerala.

Gkelis et al. (2016) reported the presence of *Scytonema polycystum* in Greece. It has also been documented in the Caribbean (Littler and Littler 2000), Mauritius (Silva and Pienaar 2000), China (Liu 2008, Xia 2017), Korea (Lee and Kang 1986), Queensland in Australia (Phillips 2002, Bostock and Holland 2010), Central Polynesia (Tsuda and Walsh 2013), Federated States of Micronesia (Lobban and Tsuda 2003), French Polynesia (Pari and N'Yeurt 1999, Vieira et al. 2023), Marshall Islands (Dawson 1957), and Wallis and Futuna Islands (N'Yeurt and Payri 2004). As a part of current investigation, this particular species was recorded in Meenvallam, Palakkad; Kozhipara, Malappuram; Thonikadavu, and Muthappanpuzha, Kozhikode; Phantom rock, and Edakkal, Wayanad.

Sarma et al. (2023) reported *Scytonema bivaginatum* from Tripura, India, and the species were new additions to the flora of Tripura, India. The present work confirmed their presence in Kozhipara, Malappuram; Thonikadavu, Kozhikode; Edakkal, Wayanad district. *Scytonema praegnans* was previously reported by Sarma et al. (2023) from Tripura, India and the species were new additions to the flora of Tripura, India. The current study documented its existence on rocks in Kozhipara, Malappuram; Thonikadavu, and Kariyathanpara, Kozhikode district in the Western Ghats region.

Species of *Brasilonema* Fiore, Sant' Anna, de Paiva Azevedo, Komarek, Kastovsky, Sulek and Lorenzi, and *Petalonema* Berkeley ex Correns are less frequently occurring and therefore more difficult to characterize (Maltsev et al. 2021). Fiore et al. (2007) isolated *Brasilonema bromeliae* from subaerophytic environments in tropical and subtropical Brazil. Sant' Anna et al. (2011) reported *Brasilonema epidendron* and *Brasilonema terrestre* from Brazil. The current investigation reported the presence of *Brasilonema terrestre* in Thonikadavu, Kozhikode, and Edakkal in Wayanad district, in the Western Ghats region of Kerala. The species *Brasilonema epidendron* were recorded in Thalayad 26 mile, Kozhikode, Meppadi, and Phantom rock, Wayanad. This study demonstrates the occurrence of

Brasilonema bromeliae in Thalayad 26 mile, Kozhikode, and from Edakkal, Wayanad district, in the Western Ghats region of Kerala. Gupta (2012) recorded *Petalonema crassum* from Kolkata, West Bengal. In this study, this species distribution was observed in Mattumala, Palakkad. Biswas (1934) described *Petalonema crustaceum* from Cherrapunji, Meghalaya, originally collected by Agharkar 1925. Singh and Singh (2019) also described *Petalonema crustaceum* from Sirsi taluk, Uttara Kannada, Karnataka. In the current investigation, the occurrence of this species was observed in Nelliampathy, Palakkad; Phantom rock, and Thirunelli, Wayanad district in the Western Ghats region of Kerala.

4.2 Dominant Genera

The study was conducted at 52 sampling sites in the Western Ghats, covering Palakkad, Malappuram, Kozhikode, and Wayanad districts (Table 4.1). A total of 35 species were identified across the four districts (Table 4.2). Among the 3 recorded genera, the genus *Scytonema* was the most dominant with 30 species, followed by *Brasilonema* (3 species) and *Petalonema* (2 species). In detail, the genus *Scytonema* is represented by 18 species in Palakkad district, 21 species in Malappuram district, 23 species in Kozhikode district, and 15 species in Wayanad district (Table 4.3, 4.4, 4.5, 4.6). The genus *Brasilonema* was the second dominant, represented with 3 species each in Kozhikode and Wayanad districts, while the genus *Petalonema* was the least represented with 2 species in Palakkad and 1 species in Wayanad.

4.3 Study sites having dominant Species

The number of cyanobacterial species belonging to the family Scytonemataceae (individual species) was higher in the Kozhikode district (39 species) followed by Malappuram district (35 species), Wayanad district (35 species), and Palakkad district (18 species). The present study also revealed that the most common species found in the four districts include *Scytonema ocellatum*, *Scytonema coactile*, *Scytonema polycystum* and *Scytonema spirulinoides*. The frequent occurrence of these *Scytonema* species in the districts of Palakkad, Malappuram, Kozhikode, and Wayanad can be attributed to their shared ecological traits. These regions show

favorable climatic conditions, water availability, habitat similarity, and the ability of these cyanobacterial species to adapt to the local environments.

4.4 Site-specific/ Area-specific species distribution

Certain species of cyanobacteria from the Scytonemataceae family were found to be specific to particular sites or areas (Table Table 4.3, 4.4, 4.5, 4.6). For instance, *Scytonema papilli-capitatum* Sant'Anna and Komarek 2013 was observed exclusively in Meenvallam of the Palakkad district. While *Petalonema crassum* (Nageli ex Bornet & Flahault) Migula 1905 was recorded only in Mattumala of the Palakkad district. Additionally, the species *Scytonema cincinnatum* Thuret ex Bornet et Flahault 1887 was identified only in the Malappuram district the site includes Valillapuzha and Kozhipara. Each of these species was unique only to the mentioned districts.

This exclusive presence can be attributed to a combination of factors such as habitat specificity, moisture retention, nutrient availability, ecological interactions, and localized adaptations. These factors create unique environments that are conducive to the growth of these cyanobacterial species, underscoring the significance of specific ecological conditions in shaping their distribution. Both species are well-suited for growth on rock surfaces, which provide a stable substrate for attachment and growth. The physical characteristics of the rocks, including texture and mineral composition, in these regions may play a vital role in facilitating the colonization of these cyanobacteria (Reboah et al. 2023). Additionally, the ability of rock surfaces to retain moisture creates a microhabitat supportive of cyanobacterial growth (Tripathy et al. 1999).

The local climate and environmental conditions in Palakkad, such as humidity and rainfall patterns, may increase moisture availability, which is essential for the survival of these organisms (*Scytonema papilli-capitatum* and *Petalonema crassum*). Ecological interactions involve nutrient availability (Reboah et al. 2023). The specific nutrient dynamics of the rock surfaces in these locations may support their growth, particularly through nitrogen fixation capabilities that enable them to utilize

atmospheric nitrogen. Symbiotic relationships play a pivotal role in the ecology and life cycle of many cyanobacteria. These cyanobacteria may establish symbiotic relationships with other organisms, such as fungi or plants, which can promote their survival and growth on rock surfaces. Such interactions can provide additional nutrients or protection from environmental stressors. The restricted distribution of these species is likely due to biogeographic factors that limit their spread. For instance, natural barriers and specific climatic conditions in the Palakkad district may have led to the evolution of localized populations that are adapted to their respective environments. Furthermore, the distinctive environmental conditions of Meenvallam and Mattumala, including light exposure, temperature variations, and rock chemistry, may have contributed to the specialization of these cyanobacteria (*Scytonema papilli-capitatum* and *Petalonema crassum*) in these areas. This pattern of restricted distribution of the species also applies to the other districts under study, where similar environmental factors create unique ecological niches that facilitate the establishment and proliferation of these cyanobacterial species in their respective habitats.

In Palakkad district, 18 different species were reported. Each of these species was observed once across various sites, except for *Scytonema malaviyanense*, which was found in both Minnampara and Nelliampathy in Palakkad district. Other species observed include *Scytonema millei* Bornet ex Bornet & Flahault 1886 from Nelliampathy, *Scytonema tolypothrichoides* Kutzing ex Bornet & Flahault 1886 from Mattumala, *Scytonema tenellum* Gardner 1927 from Meenvallam, *Scytonema torulosum* C.-C.Jao 1940 from Minnampara, *Scytonema longiarticulatum* N.L.Gardner 1927 from Attappady, *Petalonema crassum* (Nageli ex Bornet & Flahault) Migula 1905 from Mattumala, *Scytonema papilli-capitatum* C.L.Sant'Anna & J.Komarek 2013 from Meenvallam, *Petalonema crustaceum* (Thuret ex Bornet & Flahault) Kirchner 1900 from Nelliampathy, *Scytonema myochrous* C.Agardh ex Bornet & Flahault 1886 from Pothundi dam, *Scytonema spirulinoides* Gardner 1927 from Nelliampathy, *Scytonema ocellatum* [Agardh] Bornet 1889 from Nelliampathy, *Scytonema fritschii* S.L.Ghose 1924 from Mattumala, *Scytonema brunneum* Schmidle 1901 from Attappady, *Scytonema*

pascheri Bharadwaja 1934 from Minnampara, *Scytonema coactile* Montagne ex Bornet & Flahault 1886 from Minnampara, *Scytonema javanicum* Bornet ex Bornet & Flahault 1886 from Pothundi dam, and *Scytonema polycystum* Bornet & Flahault 1886 from Meenvallam.

In Malappuram district, 11 species were observed once across various sites. These include *Scytonema millei* Bornet ex Bornet & Flahault 1886 found only in Valillapuzha, *Scytonema coactile* Montagne ex Bornet & Flahault 1886 in Adyanpara, *Scytonema caldarium* Setchell 1899 in Adyanpara, *Scytonema praegnans* Skuja 1937 in Kozhipara, *Scytonema hyalinum* Gardner 1927 in Adyanpara, *Scytonema pseudoguyanense* Bharadwaja 1934 in Cheruppadimala, *Scytonema polycystum* Bornet et Flahault 1887 in Kozhipara, *Scytonema variabile* N.L.Gardner 1927 in Kozhipara, *Scytonema torulosum* C.-C.Jao 1940 in Adyanpara, *Scytonema masonianum* H.Welsh 1963 in *Scytonema longiarticulatum* N.L. Gardner 1927 in Cheruppadimala. Species observed in two sites each consist of *Scytonema sanpaulense* Sant' Anna 1988 found in both Adyanpara and Koonorkandy, *Scytonema cincinnatum* Thuret ex Bornet & Flahault 1886 in Valillapuzha and Kozhipara, *Scytonema javanicum* Bornet ex Bornet & Flahault 1886 in Adyanpara and Arimbra hills, *Scytonema bivaginatum* H.Welsh 1965 in Kozhipara and Valillapuzha, *Scytonema twymanianum* Welsh 1966 in Koonorkandy and Cheruppadimala, *Scytonema spirulinoides* N.L. Gardner 1927 in Kozhipara and Arimbra hills, *Scytonema ocellatum* Lyngbye ex Bornet & Flahault 1886 in Nadukani and Cheruppadimala, *Scytonema tolypothrichoides* Kutzing ex Bornet & Flahault 1886 in Valillapuzha and Nadukani, *Scytonema chiastum* Geitler 1925 in Cheruppadimala and Kozhipara, while *Scytonema schmidtii* Gomont 1901 was observed in three sites including Cheruppadimala, Adyanpara, and Valillapuzha.

In Kozhikode district, 19 species were observed once across various sites. These species include *Scytonema arcangelii* Bornet & Flahault 1886 found in Koorachundu, *Scytonema chiastum* Geitler 1925 in Muthappanpuzha, *Scytonema torulosum* C.-C.Jao 1940 in Kuliramutty, *Scytonema tenellum* N.L.Gardner 1927 in Thonikadavu, *Scytonema javanicum* Bornet ex Bornet & Flahault 1886 in Thalayad,

Scytonema masonianum H.Welsh 1963 in Muthappanpuzha, *Scytonema variabile* N.L. Gardner 1927 in Thechi, *Scytonema tolypothrichoides* Kutzing ex Bornet & Flahault 1886 in Kuliramutty, *Brasilonema terrestre* Sant'Anna & J.Komarek 2011 in Thonikadavu, *Brasilonema epidendron* Sant'Anna et al. 2011 in Thalayad 26 mile, *Scytonema fritschii* S.L.Ghose 1924 in Kalpini, *Scytonema pascheri* Bharadwaja 1934 in Urumi, *Scytonema bivaginatum* H.Welsh 1965 in Thonikadavu, *Scytonema millei* Bornet ex Bornet & Flahault 1886 in Muthappanpuzha, *Scytonema myochrous* C.Agardh ex Bornet & Flahault 1886 in Kalpini, *Brasilonema bromeliae* Fiore et al. 2007 in Thalayad 26 mile, *Scytonema longiarticulatum* N.L.Gardner 1927 in Thonikadavu, *Scytonema sanpaulense* Sant'Anna 1988 in Koorachundu, *Scytonema drilosiphon* Elenkin & V.I.Poljansky 1922 in Urumi. Species observed in two sites each consist of *Scytonema praegnans* Skuja 1937 found both in Thonikadavu and Kariyathanpara, *Scytonema ocellatum* Lyngbye ex Bornet & Flahault 1886 in Muthappanpuzha and Thamarassery, *Scytonema twymanianum* Welsh 1966 in Thonikadavu and Thalayad, *Scytonema spirulinoides* N.L.Gardner 1927 in Koorachundu and Thamarassery, *Scytonema polycystum* Bornet & Flahault 1886 in Thonikadavu and Muthappanpuzha. In addition, species observed in three sites each consist of *Scytonema pseudoguyanense* Bharadwaja 1934 in Urumi, Kariyathumpara and Thonikadavu, *Scytonema coactile* in Montagne ex Bornet et Flahault 1886 Thonikadavu, Thamarassery and Muthappanpuzha.

In Wayanad district, 11 species were observed once across various sites. These species include *Brasilonema bromeliae* Fiore et al. 2007 found in Edakkal, *Brasilonema terrestre* Sant'Anna & J.Komarek 2011 in Edakkal, *Scytonema caldarium* Setchell 1899 in Phantom rock, *Scytonema masonianum* H.Welsh 1965 in Phantom rock, *Scytonema malaviyanense* Bharadwaja 1930 in Kanthanpara, *Scytonema variabile* N.L.Gardner 1927 in Edakkal, *Scytonema tolypothrichoides* Kutzing ex Bornet & Flahault 1886 in Edakkal, *Scytonema drilosiphon* Elenkin & V.I.Poljansky 1922 in Thirunelli, *Petalonema crustaceum* (Thuret ex Bornet & Flahault) Kirchner 1900 in Thirunelli, *Scytonema bivaginatum* H.Welsh 1965 in Edakkal, and *Scytonema tenellum* N.L.Gardner 1927 in Thirunelli. Species observed in two sites each consist of *Brasilonema epidendron* Sant'Anna et al. 2011

found in both Meppadi and Phantom rock, *Scytonema spirulinoides* N.L.Gardner 1927 in Govindamoolachira and Edakkal, *Scytonema ocellatum* Lyngbye ex Bornet & Flahault 1886 in Govindamoolachira and Edakkal, *Scytonema pseudoguyanense* Bharadwaja 1934 in Meppadi and Rippon, *Scytonema myochrous* C.Agardh ex Bornet & Flahault 1886 in Kanthanpara and Ambukuthi 19, *Scytonema arcangelii* Bornet & Flahault 1886 in Ambukuthi 19 and Meppadi, *Scytonema brunneum* Schmidle 1901 in Edakkal and Rippon, *Scytonema polycystum* Bornet & Flahault 1886 in Edakkal and Phantom rock.

The current study shows that all cyanobacteria belonging to the family Scytonemataceae were found only on rock surfaces in the Western Ghats region of Kerala. This limited distribution may be due to several factors that make these rock surfaces unique habitats for these organisms. In conclusion, the distinctive ecological conditions of the rock surfaces in Kerala, such as moisture retention, temperature, nutrient availability, symbiotic relationships, and geographic isolation, create an ideal habitat for the growth and proliferation of these cyanobacteria. The exclusive presence of *Scytonema*, *Petalonema*, and *Brasilonema* on these rock surfaces underscores the significance of specific environmental factors in shaping the distribution of these organisms. Further research could offer a more profound understanding of the specific interactions and environmental factors that sustain these populations.

4.5 New records/ New additions to the cyanobacterial flora

The family Scytonemataceae includes 35 species, observed from the Western Ghats region of Kerala. The occurrence of these 23 species, *Scytonema chiastum* Geitler 1925, *Scytonema malaviyanense* Bharadwaja 1930, *Scytonema fritschii* S.L.Ghose 1924, *Petalonema crassum* (Nageli ex Bornet & Flahault) Migula 1905, *Scytonema twymanianum* Welsh 1966, *Scytonema brunneum* Schmidle 1901, *Scytonema variabile* N.L. Gardner 1927, *Scytonema arcangelii* Bornet & Flahault 1886, *Scytonema hyalinum* N.L.Gardner 1927, *Scytonema polycystum* Bornet & Flahault 1886, *Scytonema praegnans* Skuja 1937, *Scytonema sanpaulense* Sant' Anna 1988, *Scytonema spirulinoides* N.L.Gardner 1927, *Scytonema tenellum* N.L.Gardner 1927,

Scytonema drilosiphon Elenkin & V.I. Poljansky 1922, *Scytonema bivaginatatum* H. Welsh 1965, *Scytonema papilli-capitatum* C.L.Sant'Anna & J. Komarek 2013, *Scytonema masonianum* H.Welsh 1963, *Scytonema longiarticulatum* N.L.Gardner 1927, *Brasilonema bromeliae* Fiore et al. 2007, *Brasilonema terrestre* Sant'Anna & J.Komarek 2011, *Brasilonema epidendron* Sant'Anna et al. 2011, *Petalonema crustaceum* (Thuret ex Bornet & Flahault) Kirchner 1900 was considered new additions to the cyanobacterial flora of Western Ghats region of Kerala, while out of these 23 species 16 species are new record for cyanobacterial flora of India. These species include, *Scytonema brunneum* Schmidle 1901, *Scytonema variabile* Gardner N.L.1927, *Scytonema arcangelii* Bornet & Flahault 1886, *Scytonema hyalinum* N.L.Gardner 1927, *Scytonema polycystum* Bornet & Flahault 1886, *Scytonema praegnans* Skuja 1937, *Scytonema sanpaulense* Sant' Anna 1988, *Scytonema spirulinoides* N.L.Gardner 1927, *Scytonema tenellum* N.L.Gardner 1927, *Scytonema bivaginatatum* H.Welsh 1965, *Scytonema papilli-capitatum* C.L.Sant'Anna & J.Komarek 2013, *Scytonema masonianum* H.Welsh 1963, *Scytonema longiarticulatum* N.L.Gardner 1927, *Brasilonema bromeliae* Fiore et al. 2007, *Brasilonema terrestre* Sant'Anna & J.Komarek 2011, and *Brasilonema epidendron* Sant'Anna et al. 2011 was regarded as a new record for cyanobacterial flora of India.

Table 4.1.*List of Species across the four districts*

('+' indicates Presence and '-' indicates Absence)

Sl.No.	Species	Palakkad	Malappuram	Kozhikode	Wayanad
1	<i>Scytonema cincinnatum</i>	-	+	-	-
2	<i>Scytonema ocellatum</i>	+	+	+	+
3	<i>Scytonema chiastum</i>	-	+	+	-
4	<i>Scytonema drilosiphon</i>	-	-	+	+
5	<i>Scytonema tolypothrichoides</i>	+	+	+	-
6	<i>Scytonema javanicum</i>	+	+	+	-
7	<i>Scytonema coactile</i>	+	+	+	+
8	<i>Scytonema pascheri</i>	+	-	+	-
9	<i>Scytonema twymanianum</i>	-	+	+	+
10	<i>Scytonema brunneum</i>	+	-	-	+
11	<i>Scytonema variabile</i>	-	+	+	+
12	<i>Scytonema myochrous</i>	+	-	+	+
13	<i>Scytonema pseudoguyanense</i>	-	+	+	+
14	<i>Scytonema arcangelii</i>	-	-	+	+
15	<i>Scytonema caldarium</i>	-	+	-	+
16	<i>Scytonema schmidtii</i>	-	+	-	+
17	<i>Scytonema hyalinum</i>	-	+	-	+

Sl.No.	Species	Palakkad	Malappuram	Kozhikode	Wayanad
18	<i>Scytonema malaviyanense</i>	+	-	-	+
19	<i>Scytonema polycystum</i>	+	+	+	+
20	<i>Scytonema praegnans</i>	-	+	+	-
21	<i>Scytonema sanpaulense</i>	-	+	+	-
22	<i>Scytonema spirulinoides</i>	+	+	+	+
23	<i>Scytonema tenellum</i>	+	-	+	+
24	<i>Scytonema torulosum</i>	+	+	+	-
25	<i>Scytonema bivaginatam</i>	-	+	+	+
26	<i>Scytonema papilli-capitatum</i>	+	-	-	-
27	<i>Scytonema masonianum</i>	-	+	+	+
28	<i>Scytonema millei</i>	+	+	+	-
29	<i>Scytonema fritschii</i>	+	-	+	-
30	<i>Scytonema longiarticulatum</i>	+	+	+	-
31	<i>Brasilonema bromeliae</i>	-	-	+	+
32	<i>Brasilonema epidendron</i>	-	-	+	+
33	<i>Brasilonema terrestre</i>	-	-	+	+
34	<i>Petalonema crassum</i>	+	-	-	-
35	<i>Petalonema crustaceum</i>	+	-	-	+

Table 4.2.*List of identified species*

Sl. No	Name of Species
1	<i>Brasilonema bromeliae</i> Fiore et al. 2007
2	<i>Brasilonema epidendron</i> Sant'Anna et al. 2011
3	<i>Brasilonema terrestre</i> Sant'Anna & J. Komarek 2011
4	<i>Petalonema crassum</i> (Nageli ex Bornet & Flahault) Migula 1905
5	<i>Petalonema crustaceum</i> (Thuret ex Bornet & Flahault) Kirchner 1900
6	<i>Scytonema arcangelii</i> Bornet & Flahault 1886
7	<i>Scytonema bivaginatium</i> H. Welsh 1965
8	<i>Scytonema brunneum</i> Schmidle 1901
9	<i>Scytonema caldarium</i> Setchell 1899
10	<i>Scytonema chiastum</i> Geitler 1925
11	<i>Scytonema cincinnatum</i> Thuret ex Bornet & Flahault 1886
12	<i>Scytonema coactile</i> Montagne ex Bornet & Flahault 1886
13	<i>Scytonema drilosiphon</i> Elenkin & V.I. Poljansky 1922
14	<i>Scytonema fritschii</i> S.L. Ghose 1924
15	<i>Scytonema hyalinum</i> N.L. Gardner 1927
16	<i>Scytonema javanicum</i> Bornet ex Bornet & Flahault 1886
17	<i>Scytonema longiarticulatum</i> N.L. Gardner 1927
18	<i>Scytonema malaviyanense</i> Bharadwaja 1930
19	<i>Scytonema masonianum</i> H. Welsh 1963
20	<i>Scytonema millei</i> Bornet ex Bornet & Flahault 1886
21	<i>Scytonema myochrous</i> C. Agardh ex Bornet & Flahault 1886
22	<i>Scytonema ocellatum</i> Lyngbye ex Bornet & Flahault 1886
23	<i>Scytonema papilli-capitatum</i> C.L. Sant'Anna & J.Komarek 2013
24	<i>Scytonema pascheri</i> Bharadwaja 1934
25	<i>Scytonema polycystum</i> Bornet & Flahault 1886
26	<i>Scytonema praegnans</i> Skuja 1937
27	<i>Scytonema pseudoguyanense</i> Bharadwaja 1934
28	<i>Scytonema sanpaulense</i> Sant'Anna 1988
29	<i>Scytonema schmidtii</i> Gomont 1901
30	<i>Scytonema spirulinoides</i> N.L. Gardner 1927
31	<i>Scytonema tenellum</i> N.L. Gardner 1927
32	<i>Scytonema tolypothrichoides</i> Kutzing ex Bornet & Flahault 1886
33	<i>Scytonema torulosum</i> C.-C. Jao 1940
34	<i>Scytonema twymanianum</i> Welsh 1966
35	<i>Scytonema variabile</i> N.L. Gardner 1927

Table 4.3.

List of species distributed at different sites in Palakkad district.

('+' indicates Presence and '-' indicates Absence)

Sl.No.	Species	Palakkad							
		P1a	P1b	P2a	P2b	P3	P4	P5	P6
1	<i>Scytonema millei</i> Bornet ex Bornet & Flahault 1886	+	-	-	-	-	-	-	-
2	<i>Scytonema tolypothrichoides</i> Kutzing ex Bornet & Flahault 1886	-	-	-	-	+	-	-	-
3	<i>Scytonema tenellum</i> N.L. Gardner 1927	-	-	-	-	-	+	-	-
4	<i>Scytonema torulosum</i> C.-C. Jao 1940	-	-	+	-	-	-	-	-
5	<i>Scytonema longiarticulatum</i> N.L. Gardner 1927	-	-	-	-	-	-	+	-
6	<i>Petalonema crassum</i> (Nageli ex Bornet & Flahault) Migula 1905	-	-	-	-	+	-	-	-
7	<i>Scytonema papilli-capitatum</i> C.L. Sant'Anna & J. Komarek 2013	-	-	-	-	-	+	-	-
8	<i>Petalonema crustaceum</i> (Thuret ex Bornet & Flahault) Kirchner 1900	+	-	-	-	-	-	-	-
9	<i>Scytonema myochrous</i> C. Agardh ex Bornet & Flahault 1886	-	-	-	-	-	-	-	+
10	<i>Scytonema spirulinoides</i> N.L. Gardner 1927	+	-	-	-	-	-	-	-
11	<i>Scytonema malaviyanense</i> Bharadwaja 1930	+	-	-	+	-	-	-	-
12	<i>Scytonema ocellatum</i> Lyngbye ex Bornet & Flahault 1886	-	+	-	-	-	-	-	-
13	<i>Scytonema fritschii</i> S.L. Ghose 1924	-	-	-	-	+	-	-	-
14	<i>Scytonema brunneum</i> Schmidle 1901	-	-	-	-	-	-	+	-
15	<i>Scytonema pascheri</i> Bharadwaja 1934	-	-	+	-	-	-	-	-
16	<i>Scytonema coactile</i> Montagne ex Bornet & Flahault 1886	-	-	-	+	-	-	-	-
17	<i>Scytonema javanicum</i> Bornet ex Bornet & Flahault 1886	-	-	-	-	-	-	-	+
18	<i>Scytonema polycystum</i> Bornet & Flahault 1886	-	-	-	-	-	+	-	-

Table 4.4.

List of species distributed at different sites in Malappuram district.
 ('+' indicates Presence and '-' indicates Absence)

Sl. No.	Species	Malappuram													
		M1a	M1b	M1c	M2a	M2b	M2c	M3a	M3b	M4	M5	M6	M7a	M7b	M7c
1	<i>Scytonema sanpaulense</i> Sant'Anna 1988	-	+	-	-	-	-	-	-	+	-	-	-	-	-
2	<i>Scytonema cincinnatum</i> Thuret ex Bornet & Flahault 1886	-	-	-	+	-	-	+	-	-	-	-	-	-	-
3	<i>Scytonema javanicum</i> Bornet ex Bornet & Flahault 1886	+	-	-	-	-	-	-	-	-	-	+	-	-	-
4	<i>Scytonema bivaginatum</i> H. Welsh 1965	-	-	-	+	-	-	-	+	-	-	-	-	-	-
5	<i>Scytonema millei</i> Bornet ex Bornet & Flahault 1886	-	-	-	-	-	-	-	+	-	-	-	-	-	-
6	<i>Scytonema twymanianum</i> Welsh 1966	-	-	-	-	-	-	-	-	+	-	-	+	-	-

7	<i>Scytonema spirulinoides</i> N.L. Gardner 1927	-	-	-	-	+	-	-	-	-	-	+	-	-	-
8	<i>Scytonema coactile</i> Montagne ex Bornet & Flahault 1886	+	-	-	-	-	-	-	-	-	-	-	-	-	-
9	<i>Scytonema caldarium</i> Setchell 1899	-	+	-	-	-	-	-	-	-	-	-	-	-	-
10	<i>Scytonema schmidtii</i> Gomont 1901	-	-	+	-	-	-	+	-	-	-	-	-	-	+
11	<i>Scytonema praegnans</i> Skuja 1937	-	-	-	-	+	-	-	-	-	-	-	-	-	-
12	<i>Scytonema ocellatum</i> Lyngbye ex Bornet & Flahault 1886	-	-	-	-	-	-	-	-	-	+	-	-	-	+
13	<i>Scytonema hyalinum</i> N.L. Gardner 1927	-	-	+	-	-	-	-	-	-	-	-	-	-	-

14	<i>Scytonema tolypothrichoides</i> Kutzing ex Bornet & Flahault 1886	-	-	-	-	-	-	+	-	-	+	-	-	-	-
15	<i>Scytonema chiasmum</i> Geitler 1925	-	-	-	-	-	+	-	-	-	-	-	-	+	-
16	<i>Scytonema pseudoguyanense</i> Bharadwaja 1934	-	-	-	-	-	-	-	-	-	-	-	-	+	-
17	<i>Scytonema polycystum</i> Bornet & Flahault 1886	-	-	-	-	+	-	-	-	-	-	-	-	-	-
18	<i>Scytonema variabile</i> N.L. Gardner 1927	-	-	-	+	-	-	-	-	-	-	-	-	-	-
19	<i>Scytonema torulosum</i> C.-C. Jao 1940	-	+	-	-	-	-	-	-	-	-	-	-	-	-
20	<i>Scytonema masonianum</i> H. Welsh 1963	-	-	-	-	-	-	-	-	-	-	-	+	-	-
21	<i>Scytonema longiarticulatum</i> N.L. Gardner 1927	-	-	-	-	-	-	-	+	-	-	-	-	-	-

Table 4.5.

List of species distributed at different sites in Kozhikode district.

(‘+’ indicates Presence and ‘-’ indicates Absence)

Sl. No.	Species	Kozhikode																
		K1a	K1b	K1c	K2	K3a	K3b	K3c	K4a	K4b	K5	K6	K7	K8	K9	K10	K11a	K11b
1	<i>Scytonema arcangelii</i> Bornet & Flahault 1886	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
2	<i>Scytonema chiastum</i> Geitler 1925	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
3	<i>Scytonema praegnans</i> Skuja 1937	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
4	<i>Scytonema pseudoguyanense</i> Bharadwaja 1934	-	+	-	-	-	-	-	-	-	+	-	-	-	+	-	-	-
5	<i>Scytonema torulosum</i> C.-C. Jao 1940	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
6	<i>Scytonema tenellum</i> N.L. Gardner 1927	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	<i>Scytonema coactile</i> Montagne ex Bornet & Flahault 1886	+	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-
8	<i>Scytonema javanicum</i> Bornet ex Bornet & Flahault 1886	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
9	<i>Scytonema masonianum</i> H. Welsh 1963	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
10	<i>Scytonema variabile</i> N.L. Gardner 1927	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-

	<i>Scytonema ocellatum</i>																	
11	Lyngbye ex Bornet & Flahault 1886	-	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-
	<i>Scytonema tolypothrichoides</i>																	
12	Kutzing ex Bornet & Flahault 1886	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
	<i>Brasilonema terrestre</i>																	
13	Sant'Anna & J. Komarek 2011	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	<i>Brasilonema epidendron</i>																	
14	Sant'Anna et al. 2011	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
	<i>Scytonema fritschii</i> S.L.																	
15	Ghose 1924	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
	<i>Scytonema pascheri</i>																	
16	Bharadwaja 1934	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
	<i>Scytonema twymanianum</i>																	
17	Welsh 1966	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-
	<i>Scytonema spirulinoides</i> N.L.																	
18	Gardner 1927	-	-	-	+	-	-	-	-	+	-	-	-	-	-	-	-	-
	<i>Scytonema polycystum</i> Bornet & Flahault 1886																	
19		+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	<i>Scytonema bivaginatum</i> H.																	
20	Welsh 1965	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	<i>Scytonema millei</i> Bornet ex Bornet & Flahault 1886																	
21		-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
	<i>Scytonema myochrous</i> C.																	
22	Agardh ex Bornet & Flahault	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+

	1886																	
23	<i>Brasilonema bromeliae</i> Fiore et al. 2007	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
24	<i>Scytonema longiarticulatum</i> N.L. Gardner 1927	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	<i>Scytonema sanpaulense</i> Sant'Anna 1988	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
26	<i>Scytonema drilosiphon</i> Elenkin & V.I. Poljansky 1922	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-

Table 4.6.*List of species distributed at different sites in Wayanad*

('+' indicates Presence and '-' indicates Absence)

Sl. No	Species	Wayanad												
		W1a	W1b	W1c	W1d	W2a	W2b	W3	W4	W5	W6	W7a	W7b	W8
1	<i>Brasilonema bromeliae</i> Fiore et al. 2007	-	+	+	-	-	-	-	-	-	-	-	-	-
2	<i>Brasilonema epidendron</i> Sant'Anna et al. 2011	-	-	-	-	-	+	-	-	+	-	-	-	-
3	<i>Brasilonema terrestre</i> Sant'Anna & J. Komarek 2011	+	-	-	-	-	-	-	-	-	-	-	-	-
4	<i>Scytonema spirulinoides</i> N.L. Gardner 1927	+	-	-	-	-	-	+	-	-	-	-	-	-
5	<i>Scytonema caldarium</i> Setchell 1899	-	-	-	-	+	-	-	-	-	-	-	-	-
6	<i>Scytonema masonianum</i> H. Welsh 1963	-	-	-	-	-	+	-	-	-	-	-	-	-
7	<i>Scytonema malaviyanense</i> Bharadwaja 1930	-	-	-	-	-	-	-	-	-	-	-	-	+
8	<i>Scytonema variabile</i> N.L. Gardner 1927	-	-	-	+	-	-	-	-	-	-	-	-	-
9	<i>Scytonema tolypothrichoides</i> Kutzing ex Bornet & Flahault 1886	-	+	-	-	-	-	-	-	-	-	-	-	-
10	<i>Scytonema drilosiphon</i> Elenkin & V.I. Poljansky 1922	-	-	-	-	-	-	-	-	-	-	+	-	-

11	<i>Scytonema ocellatum</i> Lyngbye ex Bornet & Flahault 1886	-	-	-	+	-	-	+	-	-	-	-	-	-
12	<i>Petalonema crustaceum</i> (Thuret ex Bornet & Flahault) Kirchner 1900	-	-	-	-	-	-	-	-	-	-	+	-	-
13	<i>Scytonema pseudoguyanense</i> Bharadwaja 1934	-	-	-	-	-	-	-	-	+	+	-	-	-
14	<i>Scytonema myochrous</i> C. Agardh ex Bornet & Flahault 1886	-	-	-	-	-	-	-	+	-	-	-	-	+
15	<i>Scytonema bivaginatatum</i> H. Welsh 1965	-	-	-	+	-	-	-	-	-	-	-	-	-
16	<i>Scytonema arcangelii</i> Bornet & Flahault 1886	-	-	-	-	-	-	-	+	+	-	-	-	-
17	<i>Scytonema tenellum</i> N.L. Gardner 1927	-	-	-	-	-	-	-	-	-	-	-	+	-
18	<i>Scytonema brunneum</i> Schmidle 1901	-	-	+	-	-	-	-	-	-	+	-	-	-
19	<i>Scytonema polycystum</i> Bornet & Flahault 1886	+	-	-	-	-	+	-	-	-	-	-	-	-

4.6 Issues and challenges in cyanobacterial taxonomy and identification

The heterocytous cyanobacteria with false branching have been categorized into four families: Scytonemataceae, Rivulariaceae, Godleyaceae, and Tolypothrichaceae (Komarek et al. 2014). The Scytonemataceae family is renowned for possessing isopolar filaments with frequent false branching and comprises various taxa such as *Scytonema*, *Brasilonema*, *Petalonema*, *Chakia*, *Iningainema*, and *Ewamiania*. Nevertheless, the classification system no longer includes the division known as sect. *Myochrotes* (Komarek et al. 2014; Hauer and Komarek 2021). The classification of the Scytonemataceae family has been revised multiple times, with the addition of new genera and the transfer of existing ones to other established or new families (Mishra et al. 2021). For instance, *Kyrtuthrix*, which was initially considered part of Scytonemataceae, was later moved to Rivulariaceae based on phylogenetic analyses (Leon-Tejera et al. 2016). Recent studies have revealed that the Scytonemataceae family is highly polyphyletic. Furthermore, the lack of molecular information for *Scytonematopsis*, *Ophiothrix*, and *Petalonema* has made the taxonomic complexity of the family even more complex. Revisionary efforts have started to address the phylogenetic complexities of the Scytonemataceae family, resulting in the formation of the Heteroscytonemataceae family (Sendall and McGregor 2018).

Scytonema Agardh ex Bornet et Flahault (1887), the type genus of the Scytonemataceae family, is also polyphyletic, according to multiple findings (Vaccarino and Johansen 2012; Komarek et al. 2013; Saraf et al. 2018). The establishment of *Scytonema sensu stricto* by Komarek et al. (2013) was a major step towards the taxonomic resolution of the *Scytonema* genus. Based on a recent investigation, Saraf et al. (2018) concluded that *Scytonema* is a highly polyphyletic genus and recommended genus-level taxonomic modifications to account for *Scytonema*-like taxa that cluster outside of *Scytonema sensu stricto*. There have also been reports of phylogenetic complexity in other taxa within the Scytonemataceae family (McGregor and Sendall 2017a, b; Saraf et al. 2018). Several studies have repeatedly demonstrated that *Petalonema* and *Scytonematopsis* cluster distantly from

the other Scytonemataceae family members (Vaccarino and Johansen 2011; Komarek et al. 2013, 2014; McGregor and Sendall 2017 a, b; Saraf et al. 2018). Saraf et al. (2018) have noted that the genus *Iningainema* appears to cluster distantly from the other Scytonemataceae family members. Remarkably, *Chakia* is consistently shown to cluster closely with *Scytonema* and *Brasilonema* despite having a very different morphology from the other Scytonemataceae family members (Komarkova, Zapomelova and Komarek 2013; Saraf et al. 2018). There are significant phylogenetic inconsistencies within the Scytonemataceae family and its members overall, and recent research indicates that taxonomic revisions at the family and genus levels may occur in the future (Vaccarino and Johansen 2011, 2012; Komarek et al. 2013; Komarek et al. 2014; McGregor and Sendall 2017a; Sendall and McGregor 2018; Saraf et al. 2018).

The phylogenetic status of the family Scytonemataceae has been the subject of ongoing debate in recent years, with numerous studies reporting its polyphyletic nature (Vaccarino and Johansen, 2011; Komarek et al. 2013, 2014; McGregor and Sendall, 2017a, b). Modern cyanobacterial taxonomy primarily relies on the polyphasic approach (Johansen and Casamatta 2005; Komarek 2010), where molecular sequencing and phylogenetic comparisons are fundamental techniques. Unfortunately, species of the genus *Scytonema* and many other cyanobacterial genera often show resistance to being isolated into pure cultures. Consequently, it can be difficult to establish monospecific cultures from the populations studied, limiting the ability to support taxonomic decisions with molecular sequencing in only a few cases. The phylogeny and relationships among species within the genus remain largely unclear due to challenges in isolating these organisms and the scarcity of molecular data (Hentschke and Komarek 2014).

4.7 Measuring the diversity indices: Statistical analysis

Biodiversity is a multifaceted aspect of natural systems that is challenging to measure due to the numerous indices available for this purpose. Understanding diversity is crucial for comprehending the structure and dynamics of communities. However, it is particularly challenging for microorganisms, as no single index fully

encapsulates the concept (Hurlbert 1971; Purvis and Hector 2000). In environmental microbiology, assessing microbial diversity and distribution is a significant focus. Biodiversity is measured using mathematical functions called diversity indices, which enable comparisons across different spatial regions, time intervals, species, functional groups, and trophic levels. They are crucial for ecological monitoring, conservation, and efforts to study and address the biodiversity crisis. Alpha (α) diversity examines the variation within a single community or sample, incorporating evenness and species richness to summarize species abundance distribution. Essentially, it measures the overall heterogeneity of the community. On the other hand, beta (β) diversity measures the differences or similarities among different communities (samples) by considering the number of shared species. Common alpha diversity indices include the Shannon index, Simpson's index, and species richness (The use and types of Alpha-Diversity Metrics in Microbial NGS, 2016).

4.7.1 Spatio-temporal diversity of Family Scytonemataceae

Understanding the spatiotemporal variations in microbial populations with environmental parameters is essential for gaining insights into microbial ecology, as it reveals the distribution of microorganisms and their responses to environmental changes (Chapin et al. 2000; Fuhrman et al. 2006; Andersson et al. 2010). The spatial and temporal variations of cyanobacteria belonging to the family Scytonemataceae along the Western Ghats were analyzed and compared to identify the key influencing factors.

In the current study, the specimens were collected on a seasonal basis (pre-monsoon, monsoon, and post-monsoon) from 52 sites. Cyanobacterial patches were taken as the unit for diversity analysis. Our study, (Table 4.7) indicates that the highest number of species were observed during monsoon season (35) followed by post-monsoon (30), and pre-monsoon (22) seasons. Additionally, it was revealed that the highest number of patches were found during monsoon (216) followed by post-monsoon (53) and the least was present during the pre-monsoon (30) season.

4.7.2 Diversity Analysis

Table 4.7.

Diversity analysis: Diversity indices of Scytonemataceae among different seasons

Items	Pre-monsoon	Monsoon	Post monsoon
Number of species	22	35	30
No. of Patches	30	216	53
Dominance (D)	0.0503	0.03698	0.0464
Simpson (1-D)	0.9497	0.963	0.9536
Shannon (H)	3.045	3.435	3.232
Evenness	0.954	0.886	0.8447
Brillouin	2.25	2.73	2.594
Menhinick	4.315	4.854	4.243
Margalef	6.445	8.605	7.413
Berger-Parker	0.07692	0.07692	0.08

4.7.2.1 Dominance (D) index analysis

The Dominance Index measures the extent to which certain species predominate an ecosystem. In the present study, the Dominance Index values were highest for the pre-monsoon season (0.0503), followed by the post-monsoon season (0.0464), and the monsoon season (0.0369). The D value of the Dominance Index ranges between 0 and 1. A higher value suggests that a few species dominate the community, while a lower value implies a more even distribution of species. A low Dominance Index (close to 0) indicates that no single species dominates the community, which means high diversity and an even distribution of individuals among different species. A value of zero signifies infinite diversity. Conversely, a high Dominance Index (close to 1) indicates that one or a few species dominate the community, resulting in low diversity because a large proportion of total individuals belong to a small number of species and a dominance index value of 1 signifies no diversity. The Dominance

Index is influenced by the diversity value, where a higher diversity value corresponds to a lower dominance value, and vice versa.

4.7.2.2 Simpson index

The Simpson index is a popular method to measure habitat biodiversity. This index considers both the number of species present and their abundance. It is commonly used to evaluate the degree of homogeneity or diversity within communities. The Simpson index ranges from 0 to 1, where 0 indicates maximum homogeneity or absence of diversity, and 1 indicates maximum heterogeneity or diversity. Guajardo (2015) suggested interpreting the Simpson index in further detail, with a score of 0.00 indicating a complete absence of diversity or homogeneity, 0.01-0.40 indicating a low degree of diversity or heterogeneity, 0.41-0.60 indicating a moderate degree of diversity or heterogeneity, 0.61-0.80 indicating a moderately high degree of diversity or heterogeneity, 0.81-0.99 indicating a high degree of diversity or heterogeneity, and 1.00 indicating absolute or perfect diversity or heterogeneity.

The values of the Simpson diversity index were between 0.949-0.963. According to Guajardo (2015), all three seasons possess a high degree of cyanobacterial diversity, whereas the comparatively highest value was reported during the monsoon season (0.963) followed by post-monsoon (0.9536) and the lowest was during pre-monsoon (0.9497). A higher index value indicates greater diversity.

4.7.2.3 Shannon-Wiener index

The Shannon-Wiener index is a widely used metric for assessing biodiversity. It considers both species richness (the number of different species) and species evenness (the distribution of individuals among these species). Higher values of the index signify greater diversity, indicating a higher number of species and a more even distribution of individuals among those species. Lower values suggest lower diversity, indicating either fewer species or a less even distribution of individuals among species. Typically, the index value ranges from 0 to 4.5, and it considers both the species richness and the evenness of their distribution. According to Shanthala et al. (2009), a Shannon-Weiner index value of 3.00-4.50 indicates high diversity,

2.00-3.00 indicates moderate diversity, 1.00-2.00 indicates less diversity, and 0.00-1.00 indicates very low diversity.

The values of the Shannon Diversity Index ranged from 3.045 to 3.435, which indicates that the habitat structure is stable, as the values were above 3.0 (Shanthala et al. 2009). The highest value (3.435) was recorded during the monsoon season, followed by the post-monsoon season (3.232) and the pre-monsoon season (3.045). A higher index value indicates greater sample diversity, meaning that the monsoon season had the highest diversity, while the pre-monsoon season had comparatively the lowest cyanobacterial diversity.

4.7.2.4 Pielou's Evenness index

Pielou's Evenness index measures how evenly individuals are distributed among different species within a community. This measurement provides insights into the structure of a community and helps ecologists understand the impact of environmental changes on biodiversity. The evenness value ranges from 0 to 1, where 0 indicates a highly uneven distribution, with values close to 0 suggesting that one or a few species dominate the community, reflecting low evenness. A value of 1 indicates that taxa are evenly distributed across the community. When the evenness value is close to 1, individuals are evenly spread among species or categories. Hussain et al. (2012) subdivided the evenness value into three categories: balanced (>0.8-0.9), semi-balanced (>0.5-0.8), and unbalanced (≤ 0.5).

In this study, values of evenness ranged from 0.8447 to 0.9548. The highest value of 0.9548 was observed during the pre-monsoon season, followed by the monsoon season with a value of 0.8863, and the lowest value of 0.8447 was recorded during the post-monsoon period. The study revealed that the species in the community are evenly distributed. While the value of 0.954 (pre-monsoon) indicates the highest level of evenness among the three, all values are sufficiently high to suggest a well-balanced community, with low dominance by any single species and high species evenness.

4.7.2.5 Brillouin index

The Brillouin index is a precise measure of biodiversity that is particularly useful for complete and non-random samples. It considers evenness and species richness providing a comprehensive view of community diversity. Higher index values indicate greater diversity with a more even distribution of individuals among species, while lower values suggest lower diversity with one or a few dominating species. Pielou (1975) recommends using this index in all situations where a collection is made, sampling is non-random, or the full composition of the community is known. Comparing Brillouin index values across different studies and ecosystems helps understand biodiversity patterns and environmental changes' effects on species distribution. In contrast, the Shannon-Wiener Index assumes random sampling and it is often used for larger, random samples, while the Brillouin index does not rely on random sampling and is exact for known populations. Simpson's index measures the probability that two randomly selected individuals from a sample belong to the same species. It focuses on dominance and is less sensitive to species richness compared to the Brillouin index.

In this study, values of the Brillouin index were between 2.25 - 2.73. The lowest value (2.25) was recorded for the pre-monsoon season, followed by 2.594 for the post-monsoon season, and the highest value (2.73) for the monsoon season. To put it another way, the monsoon season exhibits high diversity, while the pre-monsoon season shows very low cyanobacterial abundance.

4.7.2.6 Menhinick index

The Menhinick index is a valuable tool for evaluating species richness in ecological studies based on the number of individuals. It offers a standardized measure that facilitates meaningful comparisons across various habitats and sample sizes. Higher values indicate greater species richness relative to the number of individuals, suggesting a more diverse community. Conversely, lower values suggest lower species richness relative to the number of individuals, indicating less diversity. By

understanding and interpreting Menhinick index values in the context of other research, insights into biodiversity patterns and the effects of environmental changes on species diversity can be gained. According to Kanieski et al. (2018), a Menhinick diversity index value of <1.96 indicates high diversity, $0.80-1.96$ indicates medium diversity, and >0.80 indicates low diversity.

In the current study, values of the Menhinick diversity index ranged from 4.243 to 4.854. The highest value of 4.854 was observed during the monsoon season, followed by the pre-monsoon season with a value of 4.315. The comparatively lowest value of 4.243 was recorded during the post-monsoon period. Since higher values indicate greater species richness relative to the number of individuals, suggesting a more diverse community, the study revealed that all three seasons exhibit higher species richness.

4.7.2.7 Margalef index

The Margalef index is used in ecological studies to measure species richness in a community and assess biodiversity. It offers a simple and practical approach for comparing species diversity across several habitats or the impact of environmental changes on biodiversity over time. Higher values of the Margalef index indicate greater diversity and richness of species, while lower values imply lesser levels of these attributes. Based on the interpretations by Yeom and Kim (2011) and Kanieski et al. (2018), a value of greater than 4 indicates high diversity, $2.05-3.99$ represents medium diversity, and less than 2.05 signifies low diversity.

In this study, Margalef diversity index values ranging from 6.445 to 8.605 were recorded. The highest value (8.605) was observed during the monsoon season, followed by the post-monsoon season. The lowest value (6.445) was recorded during the pre-monsoon season. This suggests that all three seasons exhibit high cyanobacterial richness. Since higher values of the Margalef index indicate greater diversity and richness of species.

4.7.2.8 Berger-Parker index

The Berger-Parker index can be used to measure species dominance in an ecological community. It considers the proportion of the most abundant species with the total number of individuals in the sample. This index indicates the extent to which a community is dominated by a single species. Higher values mean a higher dominance by a single species, indicating lower diversity. A value of 1 indicates the total dominance of a single species. Lower values imply a more even distribution of individuals among species, meaning higher diversity. At the minimum, the value hovers around 0, suggesting that no single species is too dominant. The Berger-Parker index only considers the dominance of the most abundant species, whereas the Shannon-Wiener index considers both evenness and species richness. The Berger-Parker index provides a direct measure of dominance in contrast to Simpson's index, which takes a different approach to dominance by calculating the probability that two randomly chosen individuals from a sample will belong to the same species. In contrast, Pielou's index measures the evenness of species distribution, and the Berger-Parker index directly quantifies the effect of the most dominant species. According to Magurran (1988), the ecological significance of the Berger-Parker index was not well established. The Berger-Parker index has been shown by Caruso et al. (2007) to be a useful tool for monitoring biodiversity. Because of its simplicity and focus on species dominance, they found it especially helpful in biodiversity assessments.

The Berger-Parker index ranges from 0.0769 to 0.08. A lower index value signifies higher richness. The lowest value (0.0769) was recorded for the pre-monsoon and monsoon seasons, while the comparatively highest value of (0.08) was observed for the post-monsoon season. The study revealed that all three seasons demonstrate higher cyanobacterial diversity and high species evenness within the community.

4.7.3 Seasonal Variation in Patch Numbers

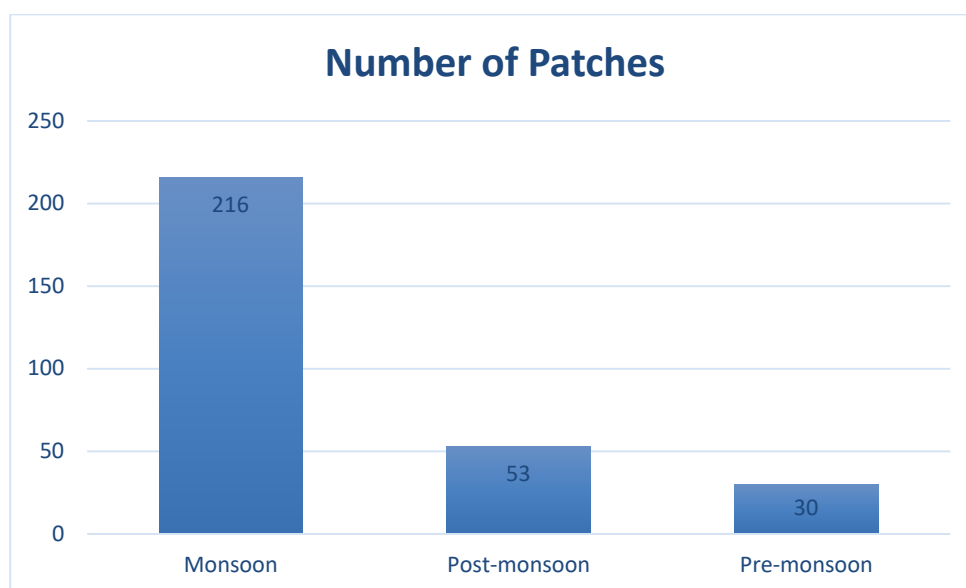


Fig. 4.18 Patch number across different seasons

The above data (Table 4.7; Fig 4.18) shows that the highest number of patches were observed during the monsoon season (216), followed by Post monsoon season (53). The least were found during the Pre-monsoon season (30). The remarkable increase in cyanobacterial patches during the monsoon season can be attributed to several environmental conditions that induce cyanobacterial growth, including increased rainfall, nutrient inflow, and water level fluctuations. Pre-monsoon seasons usually have lower nutrient inflow and less favourable hydrological conditions, which limit cyanobacterial presence to the lowest observed levels. However, post-monsoon seasons also facilitate cyanobacterial proliferation because they frequently involve stable water conditions and residual nutrient levels that sustain cyanobacterial growth.

Analysis showing seasonal variation in patch numbers across different sites during three seasons was done (Figs. 4.19, 4.20, 4.21; Table 4.8). The highest mean patch numbers were observed during the monsoon season. The mean patch number is less during the post-monsoon followed by pre-monsoon. During monsoon season, the highest mean patch number is observed in the Palakkad district.

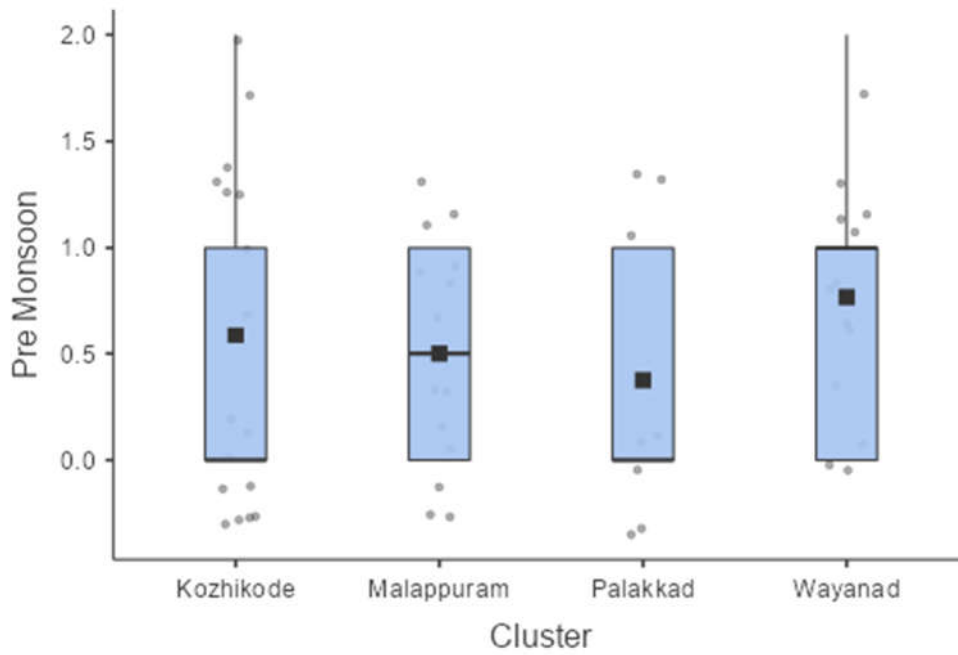


Fig. 4.19 Box plots showing seasonal variations in Patch numbers across different sites during pre-monsoon

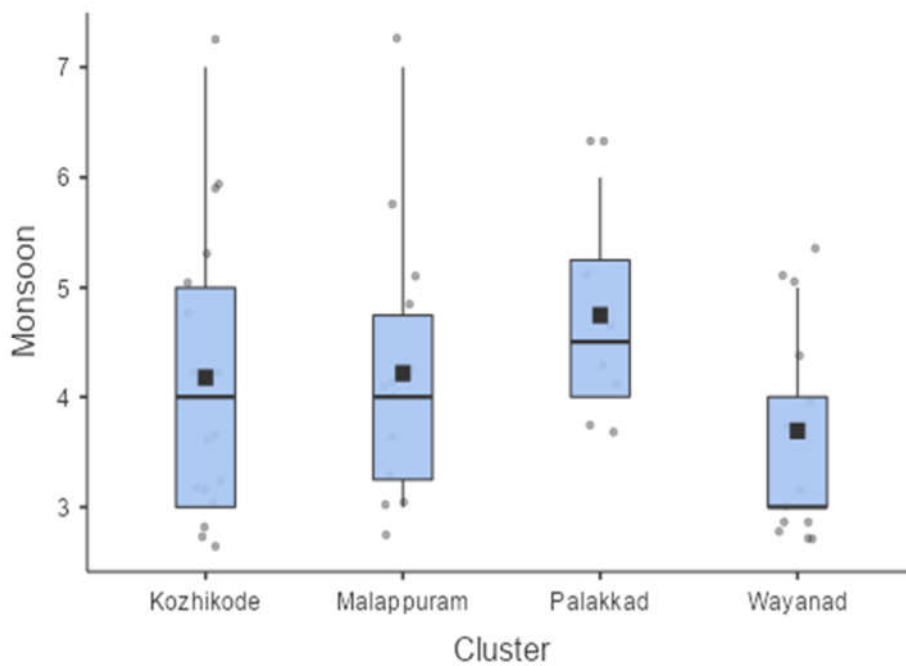


Fig. 4.20 Box plots showing seasonal variations in Patch numbers across different sites during monsoon

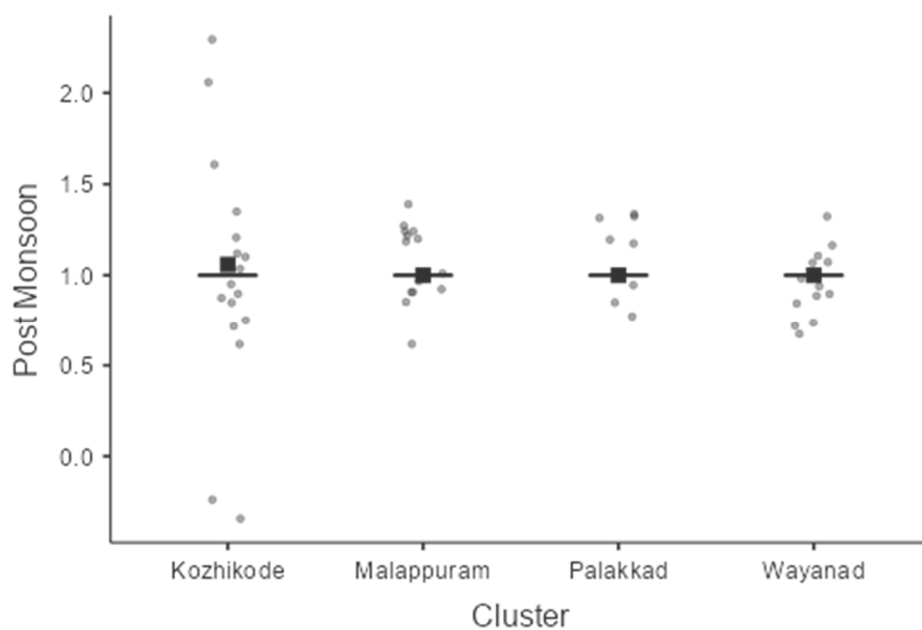


Fig. 4. 21 Box plots showing seasonal variations in Patch numbers across different sites during post monsoon

Table 4.8.

Analysis showing seasonal variation in Patch numbers across different sites and Mean values

Season	Districts	Mean
Pre-monsoon	Palakkad	0.375±0.518
	Malappuram	0.500±0.519
	Kozhikode	0.588±0.712
	Wayanad	0.769±0.599
Monsoon	Palakkad	4.75±0.886
	Malappuram	4.21±1.19
	Kozhikode	4.18± 1.29
	Wayanad	3.69±0.855
Post-monsoon	Palakkad	1.00±0.00
	Malappuram	1.00±0.00
	Kozhikode	1.06±0.556
	Wayanad	1.00±0.00

Several researchers conducted similar investigations on cyanobacterial seasonal variation, species diversity, and distribution patterns. Species diversity and seasonal variation of the cyanobacterial assemblage were carried out in different habitats, namely, temple ponds (Joishi 2009). Joishi (2014) studied the annual variation in the species diversity of cyanobacteria in four rivers located in the Western Ghats. Sharathchandra and Rajashekhar (2013) studied the cyanobacterial distribution pattern in the Kaiga region of Karnataka's Western Ghats. Seasonal occurrence of cyanobacteria in four artificial tanks of the Western Ghats of Karnataka was documented by Sharath Chandra and Rajashekhar (2016) and they revealed that the monsoon season had greater species diversity and richness than in other seasons.

The current study shows that cyanobacterial diversity appeared to be maximum during the monsoon season, which is in confirmation of the earlier findings of Vijayan and Ray (2015). This trend is the opposite of that reported by Mondal et al. (2022), in which cyanobacterial diversity was maximum during summer and lowest in the monsoon season. Consistent with the findings of Sharath Chandra and Rajashekhar (2016) the present study found that cyanobacterial species richness was maximum during the monsoon season followed by pre-monsoon, where it was minimal during the post-monsoon season.

4.7.4 Elevation/Altitude VS Patch Size

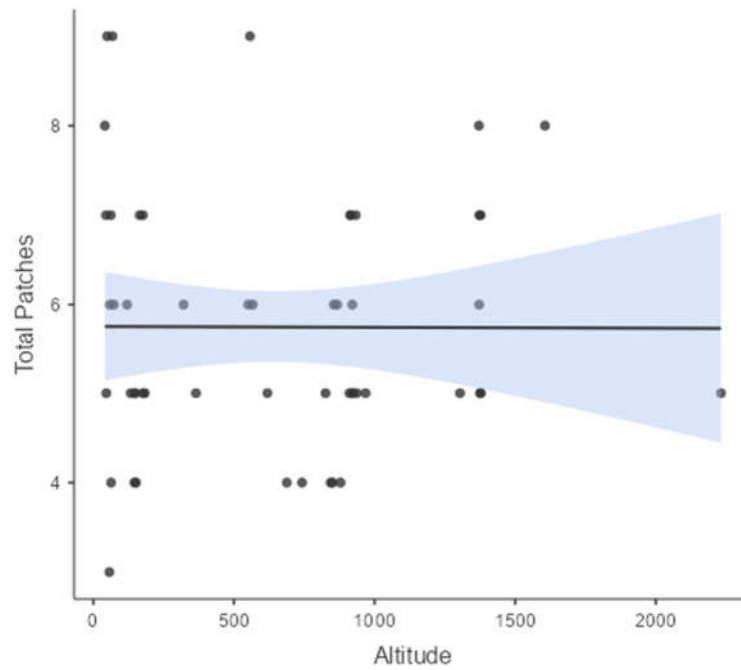


Fig. 4.22 Plot showing Total patches and altitude

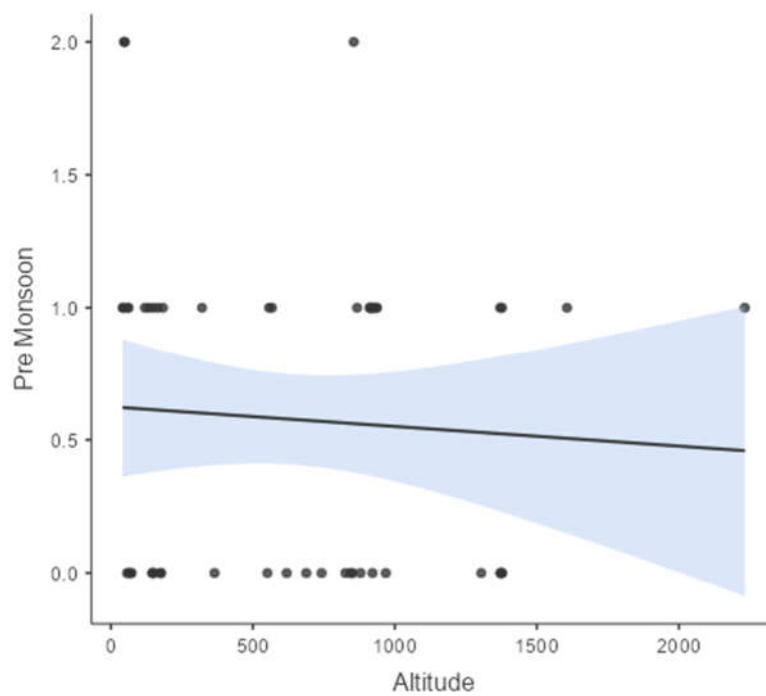


Fig. 4.23 Plot showing Patch size and altitude during Pre-monsoon season

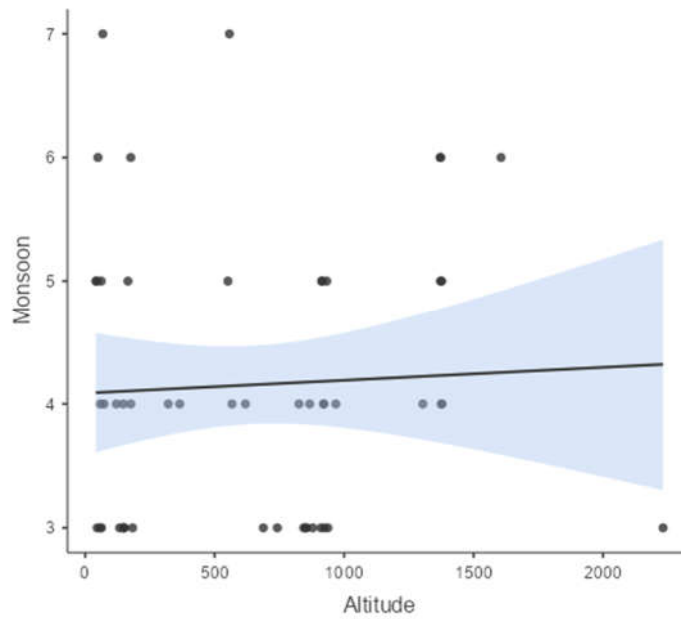


Fig. 4.24 Plot showing Patch size and altitude during Monsoon season

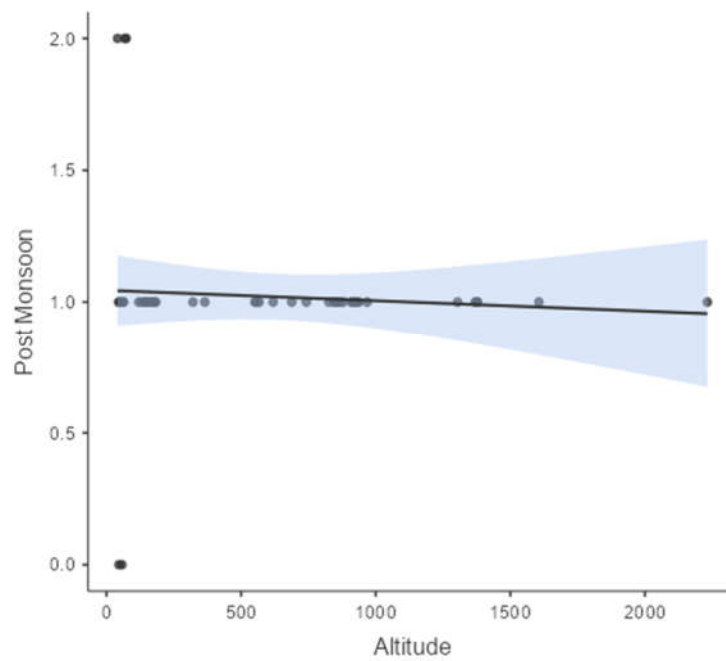


Fig. 4.25 Plot showing Patch size and altitude during Post-monsoon season

Table 4.9.*Pearson correlation among three seasons*

Season	Pearson correlation r value	p value (0.05)
Pre-monsoon	-0.064	0.651
Monsoon	0.049	0.732
Post- monsoon	-0.067	0.637
Total patches	-0.004	0.980

Pearson correlation was worked out to know whether there is any significant correlation between elevation and patch size (Table 4.9; Figs. 4.22, 4.23, 4.24, 4.25). Results show that there is no correlation between elevation and patch size. To put it another way, there is no consistent pattern in the size of the cyanobacterial patches, as elevation increases or decreases. The absence of correlation indicates that elevation might not be a significant factor influencing the size of these patches, or that other factors have a greater influence on patch size. Suresh et al. (2012) conducted a study on microalgae in high-altitude environments. Their research in the Western and Eastern Ghats confirmed that species composition was strongly influenced by altitude. This finding contradicts our data, which shows no correlation between elevation and cyanobacterial growth.

Diversity across Districts**Table 4.10.***Diversity across Districts during pre-monsoon Season*

Items	Palakkad	Malappuram	Kozhikode	Wayanad
Taxa_S	3	7	7	9
Dominance_D	0.3333	0.1429	0.1429	0.1111
Simpson_1-D	0.6667	0.8571	0.8571	0.8889
Shannon_H	1.099	1.946	1.946	2.197
Evenness_e^H/S	1	1	1	1
Brillouin	0.5973	1.218	1.218	1.422
Menhinick	1.732	2.646	2.646	3
Margalef	1.82	3.083	3.083	3.641
Berger-Parker	0.3333	0.1429	0.1429	0.1111

Table 4.11.*Diversity across Districts during Monsoon season*

Items	Palakkad	Malappuram	Kozhikode	Wayanad
Taxa_S	8	14	17	13
Dominance_D	0.125	0.07143	0.05882	0.07692
Simpson_1-D	0.875	0.9286	0.9412	0.9231
Shannon_H	2.079	2.639	2.833	2.565
Evenness_e^H/S	1	1	1	1
Brillouin	1.326	1.799	1.971	1.735
Menhinick	2.828	3.742	4.123	3.606
Margalef	3.366	4.926	5.647	4.678
Berger-Parker	0.125	0.07143	0.05882	0.07692

Table 4.12.*Diversity across Districts during Post-monsoon season*

Items	Palakkad	Malappuram	Kozhikode	Wayanad
Taxa_S	8	14	15	13
Dominance_D	0.125	0.07143	0.06667	0.07692
Simpson_1-D	0.875	0.9286	0.9333	0.9231
Shannon_H	2.079	2.639	2.708	2.565
Evenness_e ^{H/S}	1	1	1	1
Brillouin	1.326	1.799	1.86	1.735
Menhinick	2.828	3.742	3.873	3.606
Margalef	3.366	4.926	5.17	4.678
Berger-Parker	0.125	0.07143	0.06667	0.07692

Diversity indices were carried out to know the pattern of distribution of members of the family Scytonemataceae across four districts during the three seasons (Tables 4.10, 4.11, & 4.12). During the pre-monsoon season, most regions, except Palakkad, exhibit low dominance values, which indicates a relatively even distribution of species. Palakkad stands out with the highest dominance value of 0.3333, suggesting a less uniform distribution of species than other regions. On the other hand, Wayanad, with the lowest dominance value, has the most evenly distributed species community. Wayanad has the highest species diversity, with a Simpson's Index value of 0.8889, indicating the most diverse ecosystem among the four regions. Malappuram and Kozhikode also show high levels of diversity, suggesting balanced and rich ecosystems. In contrast, Palakkad exhibits the lowest species diversity with a Simpson's Index of 0.6667, indicating a least diverse community. The different regions display varying levels of species diversity. Palakkad has the lowest diversity, with a Shannon Index value of 1.099, while Wayanad has the highest

species diversity, with a Shannon Index value of 2.197. Malappuram and Kozhikode exhibit similarly high levels of diversity, indicating balanced and rich ecosystems. The distribution of individuals among species in all four districts (Palakkad, Malappuram, Kozhikode, and Wayanad) is perfectly even, with an evenness value of 1. This indicates that there is no single dominating species, suggesting a well-balanced community structure across all regions. The Wayanad district exhibits the highest Brillouin index, which indicates the greatest biodiversity among the four regions. This suggests a high number of species or a more even distribution of species. Both Malappuram and Kozhikode have the same Brillouin index value of 1.218 each, showing considerable and equal biodiversity. They have lower biodiversity compared to Wayanad but higher than Palakkad. Palakkad has the lowest Brillouin index, 0.5973, indicating the lowest biodiversity among the four districts. Wayanad has the highest species richness with a Menhinick's Index value of 3.000, indicating the richest species community. Malappuram and Kozhikode also have high species richness, reflecting diverse and species-rich ecosystems. Palakkad has the lowest species richness with a Menhinick's Index value of 1.732, indicating fewer species compared to the number of individuals sampled. The Margalef index indicates that Palakkad district has the lowest species richness during the pre-monsoon period compared to the other districts. Malappuram and Kozhikode have similar species richness levels, both higher than Palakkad but lower than Wayanad. Wayanad has the highest species richness with a Margalef index value of 3.641. The Berger-Parker index measures dominance in an ecosystem, with lower values denoting higher diversity and higher values indicating lower diversity. Wayanad has the highest species diversity with the least species dominance, followed by Malappuram and Kozhikode with similar levels of diversity and dominance. Palakkad has the highest species dominance (0.3333) and the lowest diversity.

During the monsoon season, (Table 4.11.) Palakkad has the highest species dominance and lowest species diversity with a dominance index value of 0.125. Malappuram and Wayanad show relatively high diversity and low dominance. Furthermore, Kozhikode has the highest species diversity with the lowest species dominance. According to Simpson's Diversity Index, Kozhikode shows (0.9412) the

highest species diversity and evenness, suggesting a very healthy and balanced ecosystem. Close to Kozhikode, Malappuram also shows a high level of biodiversity which points to a healthy ecosystem, supporting a variety of species with relatively even abundance. Despite having the lowest index among the four, Palakkad still shows a relatively diverse ecosystem. The Index value in Palakkad (0.875) suggests relatively lower cyanobacterial diversity compared to the other regions. Though still diverse, it indicates that fewer species or less even distribution of cyanobacteria is present compared to the other regions. The high Shannon Diversity Index values in Kozhikode (2.833) indicate the highest species diversity and evenness, showing a very healthy and balanced ecosystem. Wayanad also exhibits high species diversity and evenness, slightly lower than Kozhikode, but still suggesting a diverse ecosystem. This is followed by Malappuram and then Palakkad. In all four districts (Palakkad, Malappuram, Kozhikode, and Wayanad), there is perfect evenness, with an evenness value of 1 indicating that the distribution of individuals among species is completely even within each region, without any single species dominating the others, suggesting a well-balanced community structure across all regions. The Brillouin index values indicate the diversity of species during the monsoon season in each district. Higher values represent greater diversity. The current data suggests that Kozhikode has the highest cyanobacteria diversity with a value of 1.971. Malappuram also exhibits relatively high diversity, while Wayanad shows a moderate level of diversity. Palakkad has the lowest diversity among the four districts with a value of 1.326. On the other hand, Menhinick index values indicate the species richness of cyanobacteria during the monsoon season in each district. Higher values represent greater richness. Present data shows that Kozhikode has the highest species richness of cyanobacteria (4.123). Malappuram also has a relatively high richness, while Wayanad has moderate richness. Palakkad has the lowest richness among the other regions (2.828). The Margalef index values indicate the species richness of cyanobacteria. Higher values represent greater richness. Kozhikode has the highest species richness of cyanobacteria with a value of 5.647. Malappuram also exhibits relatively high richness, while Wayanad has moderate richness. Palakkad has the lowest richness among the four districts (3.366).

Conversely, the Berger-Parker Index value is 0.05882, indicating that Kozhikode has the lowest dominance value, suggesting the even distribution of cyanobacteria species. Malappuram also exhibits a relatively low dominance value, whereas Wayanad has a moderate dominance value. Palakkad has the highest dominance value (0.125), indicating the least even distribution of cyanobacteria species among the four districts during the monsoon season.

In the post-monsoon season (Table 4.12.), Kozhikode shows the lowest Dominance value of 0.06667, indicating a more even distribution of cyanobacteria species. Malappuram also exhibits a relatively low dominance value while Wayanad has a moderate dominance value. Palakkad, on the other hand, has the highest dominance value (0.125), suggesting the least even distribution of cyanobacteria species among the four districts. The Simpsons index value of 0.9333 in Kozhikode indicates the highest diversity, showing that species are well-distributed with no single species dominating the community, suggesting a rich and balanced ecosystem. Malappuram also demonstrates a high diversity value, indicating a healthy ecosystem that supports a variety of species with relatively even abundance. Wayanad follows with a slightly lesser but remains high diversity value of 0.9231, reflecting a diverse community while Palakkad has the lowest index among the four, with a value of 0.875, but it still shows a significant level of biodiversity. This value indicates that even though some species may be dominant, overall biodiversity is still noteworthy. The Shannon Diversity Index value shows that Kozhikode has the highest species diversity (2.708) among the four districts. Malappuram also has high species diversity, slightly lower than Kozhikode, followed by Wayanad with slightly lower diversity than Malappuram. Palakkad exhibits the lowest species diversity among the listed regions. The distribution of individuals among species in all four districts (Palakkad, Malappuram, Kozhikode, and Wayanad) is perfectly even, with an evenness value of 1. This indicates that there is no single dominating species, suggesting a well-balanced community structure across all regions. The Brillouin Index shows that Kozhikode has the highest species diversity with a value of 1.86 during the post-monsoon season, followed by Malappuram and Wayanad. Palakkad has the lowest species diversity according to the Brillouin Index. According to the

Menhinick Index, Kozhikode has the highest species richness with a value of 3.873, followed by Malappuram and Wayanad. Palakkad exhibits the lowest species richness among the listed regions. Kozhikode has the highest species richness according to the Margalef Index (5.17), followed by Malappuram, Wayanad, and Palakkad districts. This result is in line with the findings of the Brillouin, Menhinick, and Shannon Diversity Indexes, where all show that Kozhikode has the highest diversity. The Berger-Parker Index indicates that Kozhikode demonstrates the lowest dominance by a single species, suggesting a more even distribution of individuals among species. Malappuram also displays relatively low dominance, while Wayanad and Palakkad show higher levels of species dominance, with Palakkad exhibiting the highest dominance. This implies that Kozhikode has the most balanced ecosystem based on the distribution of species, whereas Palakkad has a more significant presence of a dominant species.

4.7.5 Seasonal Variation in Patch Size

Seasonal variations in patch size were analyzed (Table 4.13, Fig. 4.26). The highest patch size was observed during the monsoon season. The mean patch size during monsoon season was 34.8 ± 9.65 followed by post-monsoon. The lowest patch size was found during the pre-monsoon (1.79 ± 2.33). The size of cyanobacterial patches varies by season, depending on environmental conditions. During the monsoon and post-monsoon seasons, larger patches are observed due to increased nutrient availability, favorable temperature and light conditions, and hydrological changes that support cyanobacterial growth. In contrast, during the pre-monsoon season, lower nutrient levels and less favorable environmental conditions result in smaller patch sizes. This suggests that there is less moisture and rainfall during the pre-monsoon season. Upon consolidation, our data suggests that cyanobacteria thrive more during wet seasons, leading to fewer and smaller patches during dry periods.

Table 4.13.

Analysis showing Seasonal variations in Patch size

Season	Patch size
Monsoon	34.8±9.65
Post monsoon	3.24±2.40
Pre-monsoon	1.79±2.33

Patch size vs season

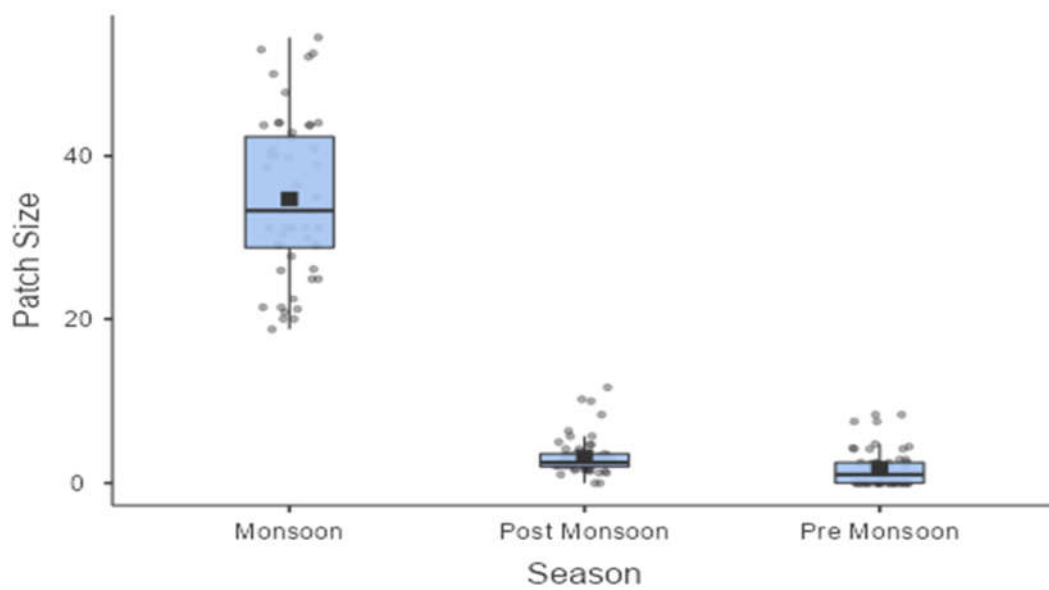


Fig. 4.26 *Analysis showing Seasonal variations in Patch size*

SPATIO-TEMPORAL DISTRIBUTION MAP

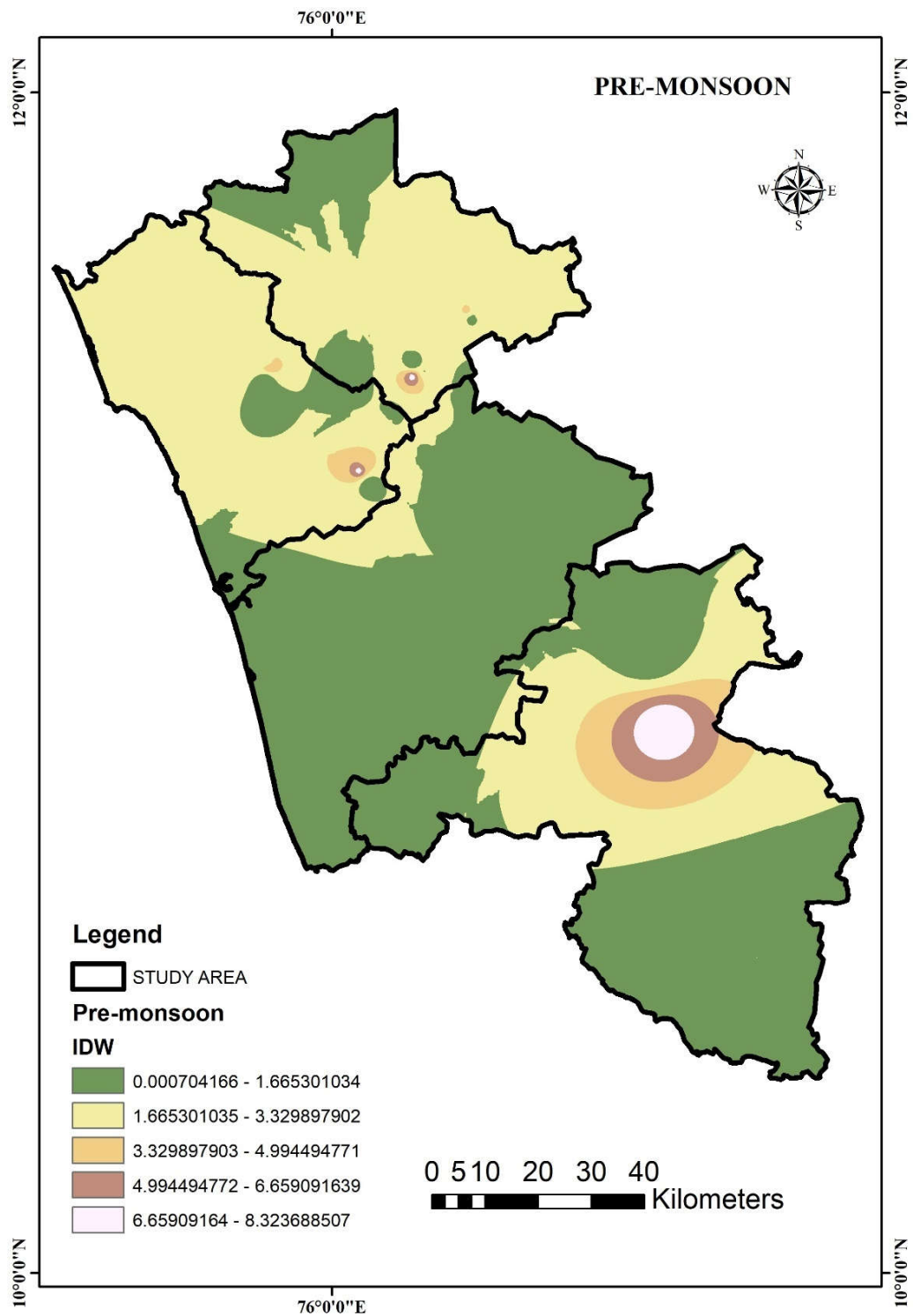


Fig. 4.27: Spatio-temporal distribution map during Pre-monsoon season

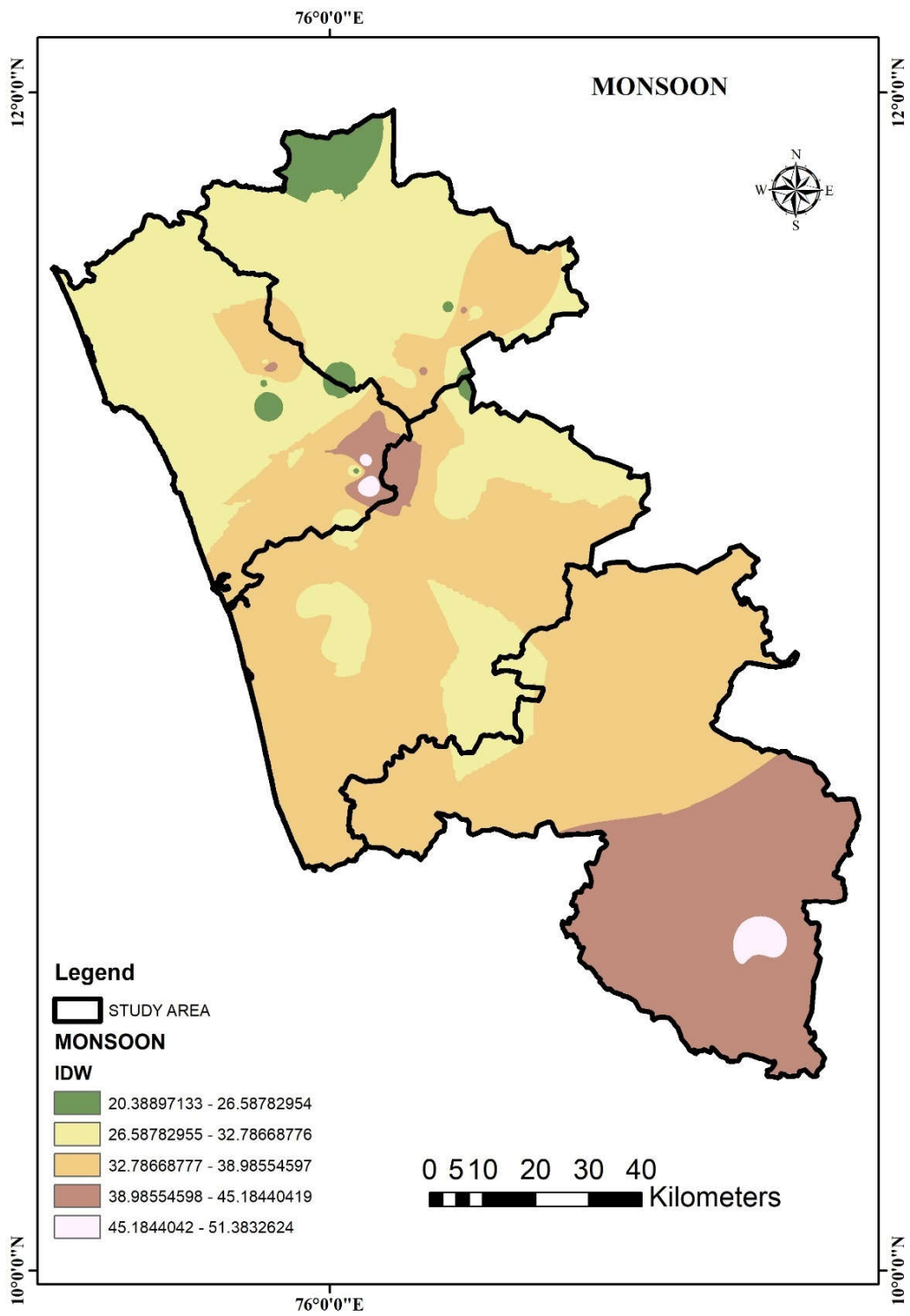


Fig. 4.28: Spatio-temporal distribution map during Monsoon season

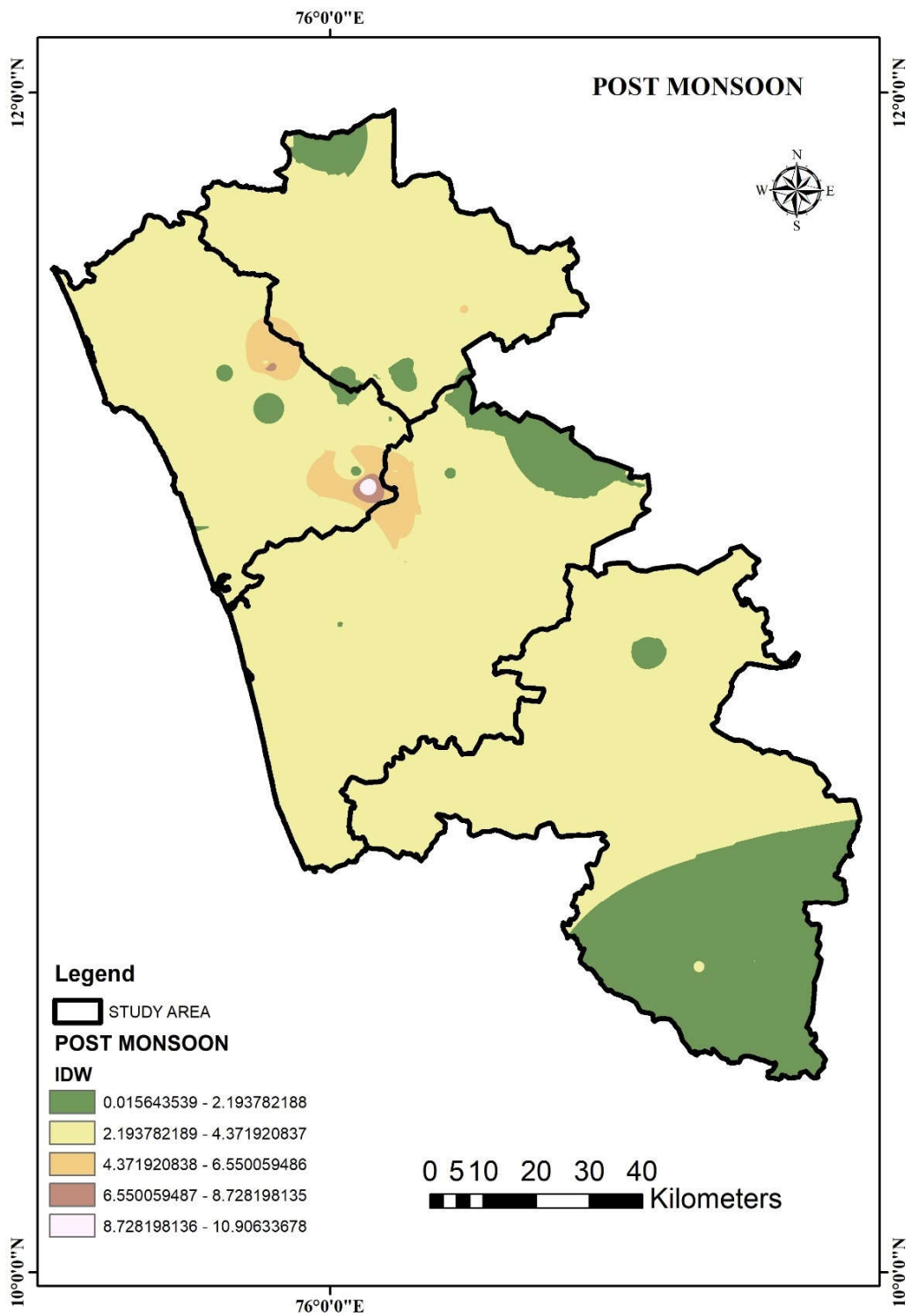


Fig. 4.29: Spatio-temporal distribution map during Post-monsoon season

The maps illustrate the spatio-temporal distribution of cyanobacterial patches across the Palakkad, Malappuram, Kozhikode, and Wayanad districts during the pre-monsoon, monsoon, and post-monsoon seasons, utilizing the Inverse Distance Weighting (IDW) interpolation technique. During pre-monsoon season (Fig. 4.27), The highest cyanobacterial patches were observed in Palakkad, followed by Kozhikode and Wayanad. In the monsoon season (Fig. 4.28), the highest concentration of patch was again found in Palakkad, with notable patches also occurring in Kozhikode and Malappuram. By the post-monsoon season (Fig. 4.29), the most extensive patches were recorded in Kozhikode, along with regions in Malappuram and near the Wayanad border. These findings highlight a distinct spatial pattern in the distribution of cyanobacterial patches, with variations across seasons but a consistent recurrence in specific districts.

4.8 Ecological Analysis

To analyze the habitat preferences of the members of the family Scytonemataceae, various environmental parameters such as atmospheric temperature, surface temperature, diurnal temperature, relative humidity, moisture, altitude, and wind speed were assessed and have been calculated based on Pearson Correlation Matrix and multivariate analysis.

4.8.1 Pearson Correlation Matrix

The habitat preferences of the family Scytonemataceae were analyzed by assessing various environmental parameters which include atmospheric temperature, surface temperature, diurnal temperature, relative humidity, moisture, altitude, and wind speed (Tables 4.14, 4.15, 4.16 and 4.17). From an ecological perspective, it is crucial to analyze the inter-relationships of environmental parameters within a habitat to determine any connections between the patch size of cyanobacteria of the family Scytonemataceae in the Western Ghats region. The correlation coefficient matrix can help establish the relationships between environmental variables or use these relationships to make predictions. The present study used Pearson correlation to understand how patch size was related to different environmental parameters. The correlation matrix of seasonal variations of different environmental parameters is

represented in Tables 4.18, 4.19, and 4.20. Some environmental parameters were noted to have statistically significant correlations with each other, indicating a close association. The correlation coefficient value ranges from -1 to +1. From this study, it was observed that during the pre-monsoon season, moisture, atmospheric temperature, surface temperature, and diurnal temperature exhibited a significant correlation with patch size. These same environmental parameters also displayed a significant correlation with patch size during the monsoon season. That is during monsoon season, data observed that moisture, atmospheric temperature, surface temperature, and diurnal temperature revealed significant correlations with patch size. During post-monsoon season moisture, atmospheric temperature, surface temperature, diurnal temperature, and relative humidity exhibited significant correlation with patch size.

The current study shows that environmental factors are strong determinants in the growth of family Scytonemataceae during all seasons. The Pearson correlation table shows that moisture ($r=0.921$, *** $p < .001$), atmospheric temperature ($r=0.407$, ** $p < .01$), surface temperature ($r=0.702$, *** $p < .001$) and diurnal temperature ($r=0.491$, *** $p < .001$) are positively correlated with patch size during Pre-monsoon season in a significant level; moisture ($r=0.849$, *** $p < .001$), atmospheric temperature ($r=0.774$, *** $p < .001$), surface temperature ($r=0.715$, *** $p < .001$) and diurnal temperature ($r=0.693$, *** $p < .001$) and altitude ($r=0.287$, * $p < .05$) are positively correlated during monsoon season in a significant way; and moisture ($r=0.749$, *** $p < .001$), atmospheric temperature ($r=0.673$, *** $p < .001$), surface temperature ($r=0.747$, *** $p < .001$) and diurnal temperature ($r=0.579$, *** $p < .001$), relative humidity ($r=0.486$, *** $p < .001$) are significantly correlated during post-monsoon season. In all seasons, moisture, atmospheric temperature, surface temperature, and diurnal temperature are positively related to the patch size of species of the Scytonemataceae family. However, relative humidity significantly correlated with patch size in post-monsoon. It is also noted that there is no significant relationship between wind speed/wind velocity and patch size of members of the Scytonemataceae family in all three seasons.

Reboah et al. (2023) performed Pearson correlation analyses between various independent meteorological variables, such as relative humidity, temperature to identify the factors influencing the occurrence of cyanobacteria. The results suggest a strong correlation between cyanobacteria concentration and relative humidity, aligning with our findings. However, the correlation with temperature is found to be negative in contrast to our results. In the present study, we observed a positive correlation with temperature and moisture across all three seasons: pre-monsoon, monsoon, and post-monsoon. The current study agrees with the findings of Bi et al. (2022), stating that temperature is a crucial environmental factor for the growth of bacterial communities.

Table 4.14.*Different environmental parameters across various sites of Palakkad district among three seasons*

Sl. No.	Location details		Pre-monsoon						Monsoon						Post-Monsoon					
	Location code	Elevation (m)	Atm. Temp. (°C)	Surface temp. (°C)	Humidity (%)	RH (%)	Wind speed (km/hr)	Diurnal temp (°C)	Atm. Temp. (°C)	Surface temp. (°C)	Humidity (%)	RH (%)	Wind speed (km/hr)	Diurnal temp (°C)	Atm. Temp. (°C)	Surface temp. (°C)	Humidity (%)	RH (%)	Wind speed (km/hr)	Diurnal temp (°C)
1	P1a	1371	36	27.8	31	64.25	14.3	10.82	22.2	37.8	71	89.07	16.9	7.925	34.6	30.3	22	87.14	5.4	9.3
2	P1b	1372	32.2	17.8	22	64.25	13.2	10.82	22.3	32.7	72	89.07	17.8	7.925	38.3	30.7	21	87.14	3.4	9.3
3	P2a	4720	25.7	0	26	64.25	16.9	10.82	26.5	97.6	64	89.07	18.5	7.925	31.3	30.4	24	87.14	25.1	9.3
4	P2b	4217	25.8	0	25	64.25	16.7	10.82	26.3	95.8	63	89.07	17.8	7.925	29.1	26.8	24	87.14	24.8	9.3
5	P3	4249	24.7	21.3	26	64.25	21	10.82	25.5	42.7	65	89.07	23.2	7.925	32.8	39.5	29	87.14	23.3	9.3
6	P4	320.8	40.3	58.7	30	66.65	1.3	10.82	25.1	63.8	64	90.03	3.7	7.925	40.1	57.7	36	82.595	2.3	9.3
7	P5	1304	33	0	55	66.65	1.4	12.3	21.7	47.9	74	90.03	4.6	8.05	35.3	32.6	34	82.595	5.2	10.675
8	P6	968	37.9	0	31	64.25	3.5	10.82	21.7	37.8	73	89.07	10.3	7.925	32.1	31.3	31	87.14	3.2	9.3
	Mean	2315.2	32.425	29.23	30.75	64.85	10.95	4.526	23.91	57.01	68.25	89.31	14.1	41.56	34.38	34.91	27.625	86.003	11.58	2.24
	STDEV	1762.1	6.847	16.87	10.30	1.110	7.727	3.302	2.126	26.22	4.652	0.444	7.073	5.628	4.025	9.884	5.680	2.103	10.670	0.857

Atm temp-Atmospheric temperature, Surface temp-Surface temperature, Hmdty - Humidity, Relative hum -Relative humidity, Diurnal temp -Diurnal temperature

Table 4.15.*Different environmental parameters across various sites of Malappuram district among three seasons*

Sl. No.	Location details		Pre-monsoon						Monsoon						Post Monsoon					
	Location code	Elevation (m)	Atm. Temp. (°C)	Surface temp. (°C)	Humidity (%)	RH (%)	Wind speed (km/hr)	Diurnal temp (°C)	Atm. Temp. (°C)	Surface temp. (°C)	Humidity (%)	RH (%)	Wind speed (km/hr)	Diurnal temp (°C)	Atm. Temp. (°C)	Surface temp. (°C)	Humidity (%)	RH (%)	Wind speed (km/hr)	Diurnal temp (°C)
1	M1a	148	38.5	25.2	40	65.11	1.3	10.12	31.5	53.1	52	90.04	5.8	6.775	36.7	59.3	41	41	5.2	9.225
2	M1b	183	37.8	26.3	41	65.11	1.2	10.12	33.7	51.6	47	90.04	7.9	6.775	34	38.7	43	43	5.4	9.225
3	M1c	152	37.4	0	40	65.11	1.4	10.12	35.8	50.2	47	90.04	3.7	6.775	39.7	56.6	37	37	5.5	9.225
4	M2a	567	33.6	33.8	49	65.11	3.2	10.12	31.8	84.6	56	90.04	6.2	6.775	40.3	45.2	30	30	12.3	9.225
5	M2b	557	38.8	48.5	44	65.11	3.1	10.12	33.3	82.8	63	90.04	4.7	6.775	40.1	44.5	31	31	8.7	9.225
6	M2c	551	34.7	0	46	65.11	3.3	10.12	32.8	89.6	63	90.04	1.7	6.775	40.3	48.5	30	30	8.9	9.225
7	M3a	62	29.7	24.1	68	65.11	2.2	10.12	30.1	92.8	70	90.04	1.9	6.775	31.2	49.7	58	58	0.8	9.225
8	M3b	58	31.7	30.8	69	65.11	2.8	10.12	30.7	93.3	68	90.04	3.7	6.775	33.4	64.6	57	57	0.7	9.225
9	M4	120	30.3	37.5	60	65.11	3.4	10.12	28.7	72.9	73	90.04	4.1	6.775	31.5	51.8	52	52	1.7	9.225
10	M5	365	33.4	0	44	65.11	4.7	10.12	30.3	68.7	60	90.04	6.2	6.775	37.3	58.3	32	32	5.6	9.225
11	M6	825.7	36.3	0	35	66.65	7.5	10.12	32.1	93.8	60	90.03	1.4	6.775	34.8	34.8	49	49	2.1	9.225
12	M7a	176	35.4	0	33	66.65	6.6	8.1	38.8	86.4	61	90.03	3.1	5.55	32.6	40.2	56	56	1.2	8.4
13	M7b	742	35.3	0	34	66.65	6.2	8.1	32.3	90.2	63	90.03	8.9	5.55	32.4	40.1	55	55	1.2	8.4
14	M7c	176	35.7	0	33	66.65	6.4	8.1	32.7	78.4	57	90.03	5.8	5.55	32.1	42.3	56	56	1.3	8.4
	Mean	334.47	34.9	32.31	45.42	65.55	3.807	2.120	32.47	77.74	60	90.03	4.65	33.56	35.49	49.18	44.78	44.78	4.328	2.637
	STDEV	262.63	2.885	8.637	12.15	0.721	2.120	1.418	2.522	15.99	7.785	0.004	2.277	7.371	3.571	8.931	11.15	11.15	3.665	1.160

Atm temp-Atmospheric temperature, Surface temp-Surface temperature, Hmdty - Humidity, Relative hum -Relative humidity, Diurnal temp -Diurnal temperature

Table 4.16.*Different environmental parameters across various sites of Kozhikode district among three seasons*

Sl. No.	Location details		Pre-monsoon						Monsoon						Post Monsoon					
	Location code	Elevation (m)	Atm. Temp. (°C)	Surface temp. (°C)	Humidity (%)	RH (%)	Wind speed (km/hr)	Diurnal temp (°C)	Atm. Temp. (°C)	Surface temp. (°C)	Humidity (%)	RH (%)	Wind speed (km/hr)	Diurnal temp (°C)	Atm. Temp. (°C)	Surface temp. (°C)	Humidity (%)	RH (%)	Wind speed (km/hr)	Diurnal temp (°C)
1	K1a	49	35.3	87.2	45	70.29	12.1	9.25	28.3	93.3	71	88.32	14.3	5.775	34.1	40.4	46	78.04	4.1	8.9
2	K1b	45	34.8	98.1	44	70.29	11.7	9.25	28.3	102.8	70	88.32	13.8	5.775	34	41.8	46	78.04	3.9	8.9
3	K1c	41	34.8	101.3	42.20	70.29	10.6	9.25	29.2	107.5	70.00	88.32	12.8	5.775	33.6	47.6	44.00	78.04	3.5	8.9
4	K2	133	35.8	118	42	70.29	3.1	9.25	27.3	72.6	68	88.32	1.5	5.775	36.1	49.3	37	78.04	3.5	8.9
5	K3a	2232	32	25.94	42	65.11	1.5	10.12	23.8	66.1	70	90.04	1.1	6.775	35	32.2	37	83.82	5.1	9.225
6	K3b	1606	29.1	30.8	40	65.11	1.2	10.12	23.7	72.1	71	90.04	1.1	6.775	35.1	32.1	38	83.82	4.3	9.225
7	K3c	2129	31.2	0	40	65.11	1.2	10.12	23.6	67.2	70	90.04	1.2	6.775	35.4	32.4	39	83.82	4.1	9.225
8	K4a	688	33.1	0	48	65.11	2.6	11.47	25.3	72.7	52	90.04	1.3	7.025	30.3	41	35	83.82	1.2	9.9
9	K4b	619	33.8	0	44	65.11	1.6	11.47	25.7	23.2	62	90.04	1.3	7.025	30.7	39	62	83.82	1.3	9.9
10	K5	165	34.8	40.6	52	65.11	2.8	10.12	33.1	89.2	67	90.04	1.7	6.775	32.5	34.8	54	83.82	0.5	9.225
11	K6	46	33.9	31.2	50	65.11	2.4	10.12	32.3	93.7	61	90.04	1.1	6.775	32.5	39.17	51	83.82	1.2	9.225
12	K7	146	33.1	0	51	70.29	3.2	9.25	27.7	80.1	74	88.32	1.6	5.775	31.5	31.6	53	78.04	3.5	8.9
13	K8	147	34.3	0	50	70.29	2.2	9.25	28.7	71.8	75	88.32	1.7	5.775	32.4	31.8	52	78.04	1.1	8.9
14	K9	63	33.4	0	39	70.29	3.7	9.25	30.3	68.7	63	88.32	4.8	5.775	30.8	32.7	54	78.04	3.1	8.9
15	K10	57	31.4	0	53	70.29	3.8	8.1	29.1	56.4	59	88.32	5.2	5.55	30.4	33.4	53	78.04	1.2	8.4
16	K11a	68	32.8	0	47	65.11	2.4	10.12	33.1	126.8	54	90.04	3.5	6.775	36.3	48.8	53	83.82	1.6	9.225
17	K11b	73	33.6	0	45	65.11	1.8	10.12	33.2	97.4	55	90.04	1.3	6.775	33.8	25.9	49	83.82	2.5	9.225
	Mean	488.64	33.36	66.64	45.54	67.54	3.994	4.275	28.39	80.09	65.41	89.23	4.076	35.10	33.20	37.17	47.23	81.1	2.688	4.629
	STDEV	750.17	1.701	38.03	4.478	2.666	3.659	2.390	3.280	23.35	7.150	0.884	4.739	12.34	2.007	7.028	7.806	2.973	1.438	3.691

Atm temp-Atmospheric temperature, Surface temp-Surface temperature, Hmdty - Humidity, Relative hum -Relative humidity, Diurnal temp -Diurnal temperature

Table 4.17.

Different environmental parameters across various sites of Wayanad district among three seasons

Sl. No.	Location details		Pre-monsoon						Monsoon						Post Monsoon					
	Location name with code	Elevation (m)	Atm. Temp. (°C)	Surface temp. (°C)	Humidity (%)	RH (%)	Wind speed (km/hr)	Diurnal temp (°C)	Atm. Temp. (°C)	Surface temp. (°C)	Humidity (%)	RH (%)	Wind speed (km/hr)	Diurnal temp (°C)	Atm. Temp. (°C)	Surface temp. (°C)	Humidity (%)	RH (%)	Wind speed (km/hr)	Diurnal temp (°C)
1	W1a	933	29.2	103.8	37	65.11	4.3	11.47	29.4	96.4	59	90.04	3.4	7.025	34	40.4	59	83.82	2.8	9.9
2	W1b	913	35.2	108.2	39	77.62	9	11.47	28.7	88.9	59	91.12	1.9	7.025	35.3	37.9	48	78.88	3.2	9.9
3	W1c	915	33.7	112.8	39	65.11	4.2	11.47	29.7	88.5	54	90.04	3.1	7.025	35.7	37.8	48	83.82	1.8	9.9
4	W1d	921	34.1	117.2	37	65.11	3.8	11.47	29.9	70.9	58	90.04	4.1	7.025	29.9	37.8	52	83.82	2.4	9.9
5	W2a	924	32.6	121.6	41	65.11	1.4	11.47	30.2	84.3	58	90.04	1.5	7.025	30.9	34.6	26	83.82	1.8	9.9
6	W2b	911	35.0	123.8	37	65.11	8.9	11.47	30.1	90.5	59	90.04	1.4	7.025	31.8	31.2	36	83.82	1.7	9.9
7	W3	937	30.7	87.3	38	65.11	1.2	11.47	28.3	84.3	63	90.04	1.2	7.025	33.3	34.9	45	83.82	1.6	9.9
8	W4	921	33.8	0	35	65.11	3.4	11.47	27.6	92.3	66	90.04	1.7	7.025	32.6	31.1	34	83.82	1.4	9.9
9	W5	855	30.4	86.1	51	65.11	2.3	11.47	31.8	96.3	55	90.04	7.9	7.025	34.3	24.4	34	83.82	4.5	9.9
10	W6	844	30.4	0	52	65.11	4.8	11.47	33.2	108.6	59	90.04	2.6	7.025	33.3	28.8	31	83.82	2.8	9.9
11	W7a	851	32.3	0	42	65.11	5.00	11.47	29.8	89.3	54	90.04	4.7	7.025	31.8	33.7	44	83.82	3.2	9.9
12	W7b	879	33.7	0	41	59.8775	3.8	9.25	29.2	88.7	55	88.28	4.2	5.775	31.2	49.9	46	83.34	1.8	8.9
13	W8	867	33	119	43	65.11	6.8	11.47	32.5	90	48	90.04	1.9	7.025	31.3	27.1	36	83.82	2.4	9.9
	Mean	897.76	32.62	108.86	40.92	65.66	4.530	3.171	30.030	89.92	57.46	89.98	3.046	31.41	32.72	34.58	41.46	83.40	2.123	3.026
	STDEV	33.48	1.908	14.06	5.219	3.870	2.464	1.969	1.613	8.502	4.464	0.593	1.871	8.370	1.771	6.568	9.412	1.365	0.983	1.402

Atm temp-Atmospheric temperature, Surface temp-Surface temperature, Hmdty - Humidity, Relative hum -Relative humidity, Diurnal temp -Diurnal temperature

Table 4.18.*Correlation Matrix (Pre-monsoon)*

		Patch size	Moisture	Atm_temp	Surface_temp	RH	Diurnal	Altitude	wind_speed
Patch size	Pearson's r	—							
	p-value	—							
Moisture	Pearson's r	0.921 ***	—						
	p-value	<.001	—						
Atm_temp	Pearson's r	0.407 **	0.395 **	—					
	p-value	0.003	0.004	—					
Surface_temp	Pearson's r	0.702 ***	0.712 ***	0.404 **	—				
	p-value	<.001	<.001	0.003	—				
RH	Pearson's r	0.263	0.233	0.503 ***	0.207	—			
	p-value	0.060	0.097	<.001	0.140	—			
Diurnal	Pearson's r	0.491 ***	0.448 ***	0.216	0.425 **	0.217	—		
	p-value	<.001	<.001	0.124	0.002	0.122	—		
Altitude	Pearson's r	-0.147	-0.114	-0.007	0.060	0.014	-0.025	—	
	p-value	0.299	0.421	0.963	0.672	0.922	0.858	—	
wind_speed	Pearson's r	-0.000	-0.058	-0.081	0.196	-0.147	0.118	0.547 ***	—
	p-value	0.999	0.681	0.566	0.164	0.298	0.405	<.001	—

Note. * $p < .05$, ** $p < .01$, *** $p < .001$

Atm temp-Atmospheric temperature, Surface temp-Surface temperature, RH -Relative humidity, Diurnal -Diurnal temperature

Table 4.19.*Correlation Matrix (Monsoon)*

		patch size	moisture	Wind_speed	Atm_Temp	Surface_Temp	Diurnal	RH	Altitude
patch size	Pearson's r	—							
	p-value	—							
moisture	Pearson's r	0.849***	—						
	p-value	<.001	—						
Wind_speed	Pearson's r	0.241	0.134	—					
	p-value	0.086	0.342	—					
Atm_Temp	Pearson's r	0.774***	0.699***	0.193	—				
	p-value	<.001	<.001	0.170	—				
Surface_Temp	Pearson's r	0.715***	0.575***	0.177	0.541***	—			
	p-value	<.001	<.001	0.209	<.001	—			
Diurnal	Pearson's r	0.693***	0.606***	0.160	0.498***	0.546***	—		
	p-value	<.001	<.001	0.258	<.001	<.001	—		
RH	Pearson's r	0.273	0.233	0.165	0.462***	0.189	0.109	—	
	p-value	0.050	0.096	0.243	<.001	0.179	0.443	—	
Altitude	Pearson's r	0.287*	0.315*	-0.244	0.193	0.162	-0.041	0.086	—
	p-value	0.039	0.023	0.082	0.171	0.251	0.773	0.547	—

Note. * p < .05, ** p < .01, *** p < .001

Atm temp-Atmospheric temperature, Surface temp-Surface temperature, RH -Relative humidity, Diurnal-Diurnal temperature

Table 4.20.*Correlation Matrix (Post Monsoon)*

		Patch size	Moisture	Wind speed	Atm_temp	Surface_temp	Diurnal	RH	Altitude
Patch size	Pearson's r	—							
	p-value	—							
Moisture	Pearson's r	0.749***	—						
	p-value	<.001	—						
Wind speed	Pearson's r	-0.103	-0.073	—					
	p-value	0.468	0.606	—					
Atm_temp	Pearson's r	0.673***	0.552***	-0.051	—				
	p-value	<.001	<.001	0.720	—				
Surface_temp	Pearson's r	0.747***	0.603***	-0.199	0.515***	—			
	p-value	<.001	<.001	0.162	<.001	—			
Diurnal	Pearson's r	0.579***	0.409**	-0.144	0.362**	0.427**	—		
	p-value	<.001	0.003	0.309	0.008	0.002	—		
RH	Pearson's r	0.486***	0.315*	0.001	0.382**	0.425**	0.333*	—	
	p-value	<.001	0.023	0.994	0.005	0.002	0.016	—	
Altitude	Pearson's r	-0.251	-0.182	0.808***	-0.105	-0.263	-0.192	-0.012	—
	p-value	0.072	0.197	<.001	0.460	0.062	0.172	0.935	—

Note. * $p < .05$, ** $p < .01$, *** $p < .001$

Atm temp-Atmospheric temperature, Surface temp-Surface temperature, RH -Relative humidity, Diurnal -Diurnal temperature

In an investigation by Li et al. (2016), they found an association between the diversity and distribution of microbial communities and various environmental factors such as humidity and light intensity. They noted that the presence of cyanobacteria was closely linked to both light intensity and humidity. Our research aligns with their findings, showing a positive correlation with relative humidity during the post-monsoon season.

4.8.2 Multivariate Statistical Analysis

4.8.2.1 Principal Component Analysis (PCA)

In the current study, Principal Component Analysis (PCA) was performed among the three seasons to know the environmental parameters that are influencing the patch size. The results of the PCA were represented by two main components, PC1 and PC2. It is comprised of environmental parameters such as moisture, atmospheric temperature, surface temperature, relative humidity, diurnal temperature, altitude, and wind speed.

Principal component analysis depicted in statistical Table 4.21, for the pre-monsoon season, shows Eigenvalue as 4.16104 and 3.04696 for PC1 and PC2 respectively. The two principal components explained 90.1 % of the variability in the data. The effective loading score of patch size was observed in PC 2 and the value for the same was observed as 0.5624 in the pre-monsoon. The table shows that during the pre-monsoon season, it is observed that, moisture, atmospheric temperature, and diurnal temperature are the influencing factors of patch size.

The eigenvalue is 5.17959 for PC1 and 1.64404 for PC2 during the monsoon season (Table 4.22), and the data shows 85.29 variabilities. The effective loading score of patch size was observed in PC 1 and the value for the same was observed as 0.40574 in the monsoon season. The above data suggests that during the monsoon season, moisture, atmospheric temperature, relative humidity, and altitude are the influencing factors of patch size. During post-monsoon season, Eigenvalue shows 5.97381 and 1.43657 for PC1 and PC2 respectively. The effective loading score of patch size was observed in PC 2 and the value for the same was observed as 0.62011

in the post-monsoon season. The table also shows that moisture, relative humidity, and surface temperature are the influencing factors of patch size (Table 4.23). The results are graphically represented in (Figs. 4.30, 4.31 and 4.32).

Table 4.21.

Principal Component Analysis- Loading scores of Pre-monsoon

Sl. No.	Parameters	PC 1	PC 2
1	Eigenvalue	4.16104	3.04696
2	% variance	52.013	38.087
3	Patch size	0.005477	0.5624
4	Moisture	-0.3292	0.41057
5	Atmospheric temperature	0.37307	0.37
6	Surface temperature	0.41024	0.024246
7	RH	0.30703	-0.29881
8	Diurnal	0.13673	0.52921
9	Altitude	0.48375	0.068114
10	Wind speed	0.48697	-0.06051

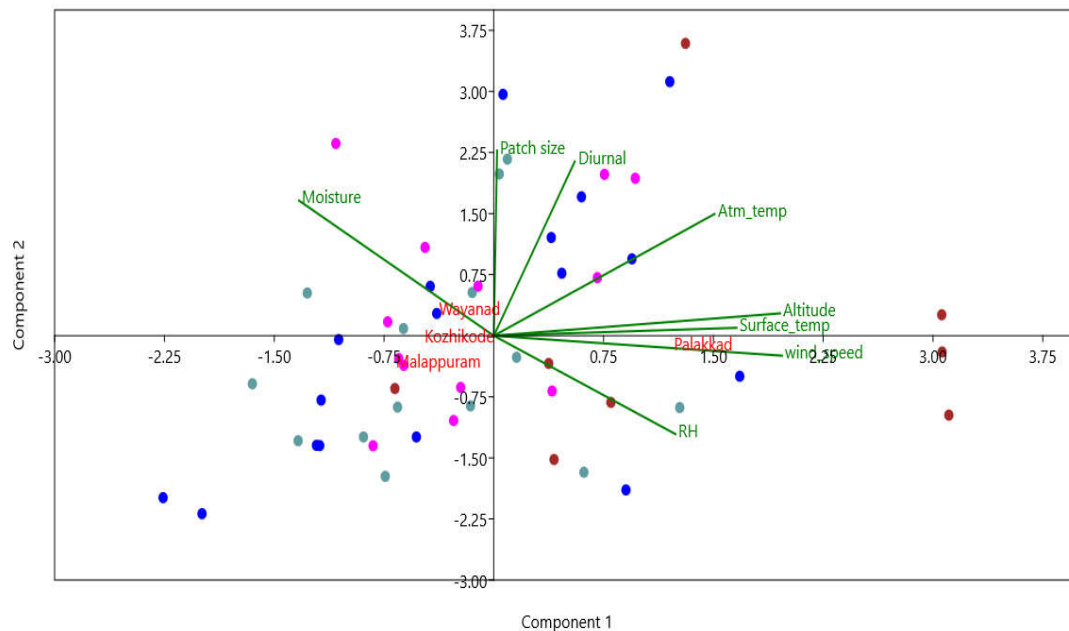


Fig. 4.30: *The results of Principal Component Analysis during Pre-monsoon*

Table 4.22.*Principal Component Analysis -Loading scores of Monsoon*

Sl. No	Parameters	PC 1	PC 2
1	Eigenvalue	5.17959	1.64404
2	% variance	64.745	20.55
3	Patch size	0.40574	0.29256
4	Moisture	0.40537	0.30016
5	Wind speed	-0.2558	0.61372
6	Atmospheric temperature	0.41622	0.2458
7	Surface temperature	0.32439	-0.39798
8	Diurnal	0.10934	-0.47594
9	RH	0.37499	0.02998
10	Altitude	0.41783	-0.03779

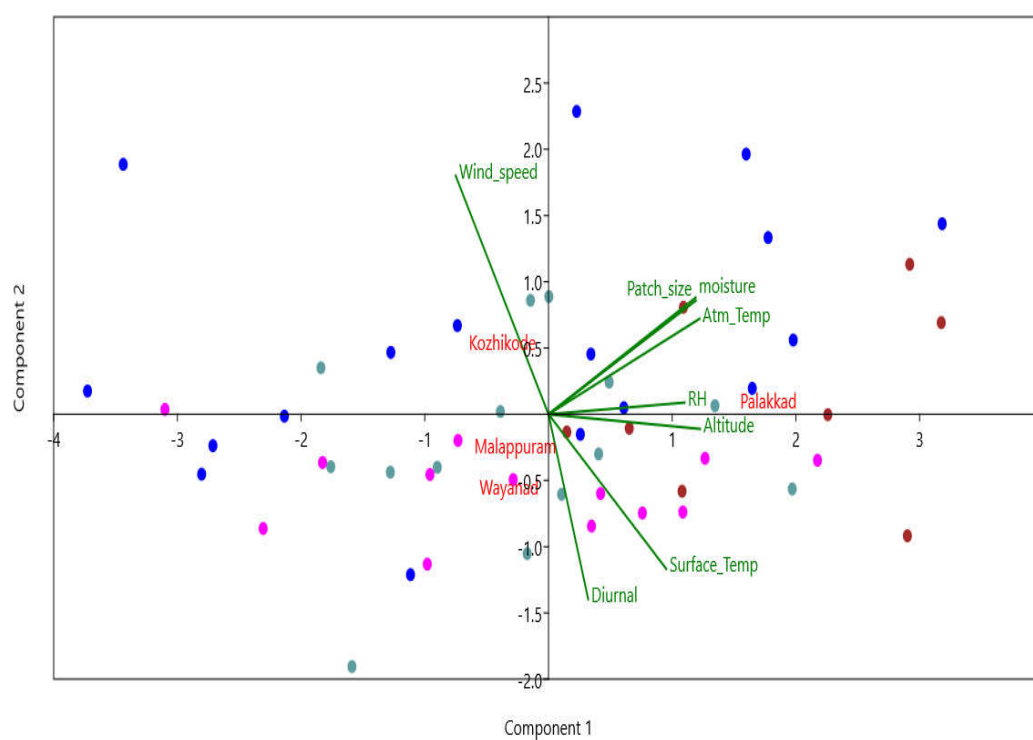
**Fig. 4.31:** *The results of Principal Component Analysis during Monsoon*

Table 4.23.

Principal Component Analysis -Loading scores of Post-monsoon

Sl. No	Parameters	PC 1	PC 2
1	Eigenvalue	5.97381	1.43657
2	% variance	74.673	17.957
3	Patch size	0.2723	0.62011
4	Moisture	0.37404	0.30045
5	Wind speed	-0.37064	-0.07827
6	Atmospheric temperature	0.3765	-0.31724
7	Surface temperature	0.39769	0.032264
8	Diurnal	0.33113	-0.13882
9	RH	-0.26795	0.63037
10	Altitude	-0.40892	-0.02749

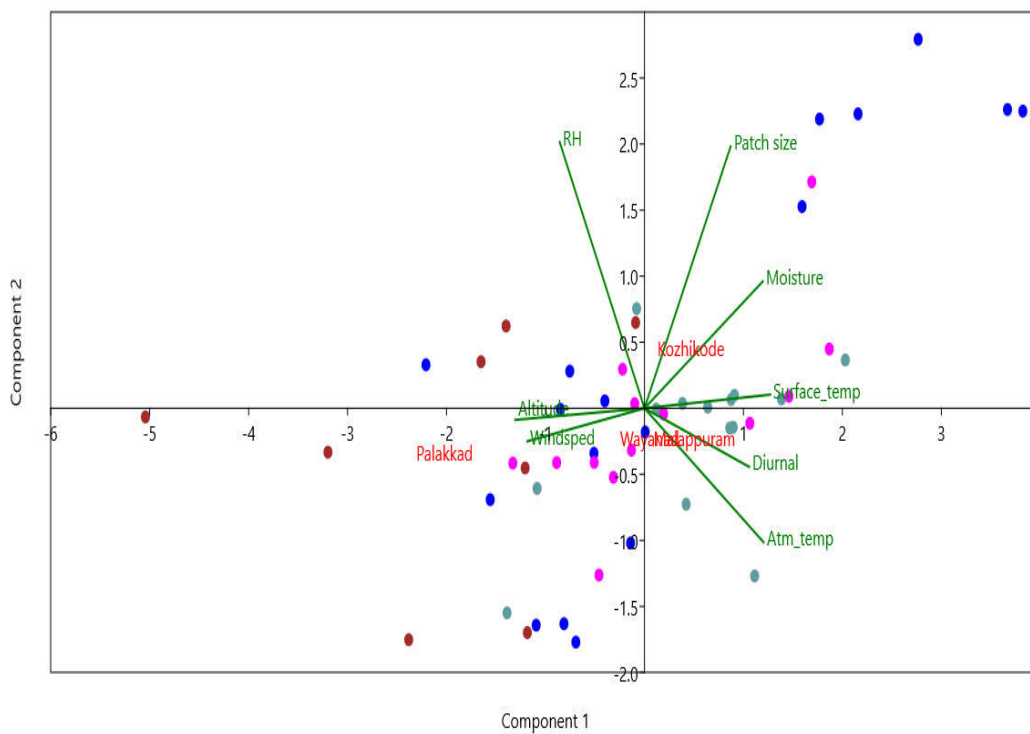


Fig. 4.32: *The results of Principal Component Analysis during Post-Monsoon*

Popovic et al. (2020) employed the PCA to investigate the seasonal diversity of cyanobacteria and its ecological attributes. Their findings corroborated our findings that all cyanobacterial groups exhibited a positive connection with relative humidity and water content. Consistent with the findings of Lin et al. (2013) we found that moisture content plays a very important role in the diversity and distribution of microalgae. In line with Hakkoum et al. (2020), the analysis revealed that humidity is the key environmental factor influencing the distribution of cyanobacterial communities.

4.8.2.2 Generalized Linear Model

Generalized Linear Models (GLMs) are regression models used to depict various relationships between a response variable and predictor variables. They offer a clear interpretation of the relationship between the response and predictor variables like, how predictor variables affect the response variable. GLMs are an advanced statistical modeling technique and are extensively used in ecology and environmental science for Species Distribution Modeling, which involves predicting species presence or abundance based on environmental variables as well as evaluating how suitable different habitats are for various species. They also enable the assessment of the effects of environmental changes, such as climate change, or pollution on biodiversity.

The Generalized Linear Model was performed among three seasons to know how different environmental parameters effect the patch size in different sites (Tables 4.24, 4.25, and 4.26). For this model, environmental parameters such as altitude, windspeed, diurnal temperature, atmospheric temperature, relative humidity, surface temperature, and moisture were assessed. It was observed that, during pre-monsoon, a significant effect was shown by the diurnal temperature. This single environmental parameter determines the effect of patch size while, other environmental parameters such as altitude, wind speed, atmospheric temperature, surface temperature, relative humidity, and moisture do not have significant effects on patch size (all p-values > 0.05). For the monsoon season, a significant effect was shown by wind speed, surface temperature, and moisture. Other environmental parameters such as altitude, atmospheric temperature, relative humidity, and diurnal temperature do not show

significant effects. During post-monsoon season, a significant effect is shown by atmospheric temperature and moisture. The environmental parameters such as altitude, wind speed, surface temperature, relative humidity, and diurnal temperature variation do not have significant effects on patch size (all p-values > 0.05).

Table 4.24.

Generalized Linear Model during Pre-monsoon Season

Parameter Estimates

Names	Estimate	SE	exp(B)	z	p
(Intercept)	0.42493	0.21208	1.529	2.004	0.050
Altitude	-9.23e-4	7.01e-4	0.999	-1.317	0.195
Wind_speed	0.06046	0.05147	1.062	1.175	0.246
Atm_temp	0.04672	0.05972	1.048	0.782	0.438
Surface_temp	0.00174	0.00668	1.002	0.261	0.795
Relative_hum	0.03266	0.06150	1.033	0.531	0.598
Diurnal_temp	0.63104	0.31913	1.880	1.977	0.050
Moisture	-0.29177	0.29318	0.747	-0.995	0.325

Table 4.25.

Generalized Linear Model during Monsoon Season

Parameter Estimates

Names	Estimate	SE	exp(B)	z	p
(Intercept)	3.51901	0.02090	33.751	168.404	<.001
Altitude	-7.69e-5	5.87e-5	1.000	-1.309	0.197
Wind_speed	0.01578	0.00535	1.016	2.950	0.005
Atm_temp	-0.00625	0.00950	0.994	-0.659	0.514
Surface_temp	0.00276	0.00112	1.003	2.457	0.018
Relative_hum	0.08522	0.05364	1.089	1.589	0.119
Diurnal_temp	-0.01774	0.04946	0.982	-0.359	0.721
Moisture	0.24429	0.02641	1.277	9.251	<.001

Table 4.26.*Generalized Linear Model during Post-monsoon Season*

Parameter Estimates					
Names	Estimate	SE	exp(B)	z	p
(Intercept)	1.04470	0.05852	2.843	17.8516	< .001
Altitude	-2.89e-4	1.77e-4	1.000	-1.6339	0.110
Wind speed	-0.00369	0.01149	0.996	-0.3216	0.749
Atm_temp	0.04262	0.02008	1.044	2.1223	0.040
Surface_temp	-0.00535	0.00752	0.995	-0.7113	0.481
Relative humidity	0.00137	0.02481	1.001	0.0552	0.956
Diurnal_temp	0.21342	0.14422	1.238	1.4799	0.146
Moisture	0.66110	0.07936	1.937	8.3301	< .001

4.8.2.3 Logistic regression models

Logistic regression is a statistical technique used for modeling the relationship between a dependent binary variable and one or more independent variables. Logistic regression, a specific type of GLM, is particularly effective for modeling binary outcomes and is widely used in microbial ecology. It helps predict species presence and assess the effects of environmental factors, allowing researchers to examine the impact of environmental changes or interventions on microbial communities. Additionally, logistic regression helps identify key environmental factors or conditions affecting the presence or absence of specific microbial species. Its ability to manage multiple predictors and provide interpretable results makes it a valuable tool for ecological studies.

The research conducted performed logistic regression models to predict the best climatic niche for the family Scytonemataceae based on various environmental parameters during all three seasons. Based on the data, the best-fit model during the pre-monsoon season consists of moisture and altitude, which account for 63% of the weightage. This model shows the lowest AICc, indicating the best fit among the tested models. The cumulative weights suggest that the top two models encompass 85% of the probability, implying that moisture and altitude, possibly with some contribution from wind speed, are the most influential factors in predicting patch

size during pre-monsoon season. Meanwhile, during the monsoon season, the best model with the lowest AICc incorporates moisture, altitude, wind speed, atmospheric temperature, surface temperature, and relative humidity. The cumulative weights indicate that the top two models account for 66% of the probability. This suggests that moisture, altitude, wind speed, atmospheric temperature, and surface temperature are the most influential factors, with relative humidity perhaps having a small impact. Finally, during the post-monsoon season, the best model comprises moisture and altitude, which represents 61% of the weightage. The cumulative weights indicate that the top two models account for 82% of the probability, suggesting that moisture and altitude, along with possible minor influences from wind speed and atmospheric temperature, are the most influential factors in predicting the patch size for the family Scytonemataceae during the post-monsoon season. (Tables 4.27, 4.28 and 4.29). Based on this data, we can conclude that a combination of environmental parameters such as moisture, altitude, wind speed, atmospheric temperature, surface temperature, and relative humidity plays a significant role in determining the best climatic niche for the family Scytonemataceae. For example, during the pre-monsoon season, factors like moisture and altitude promote the growth of the Scytonemataceae family, making it the best model for observing their flourishing during that particular season. This is similarly true for all other seasons, where the ideal combination of environmental parameters leads to cyanobacterial flourishing.

Table 4.27.

Logistic regression model during Pre-monsoon season

Sl. No	Model-Pre-monsoon	K	AICc	Δ AICc	AICcWt	Cum.Wt	LL
1	ps~mst+alt	4	242.03	0.00	0.63	0.63	-116.59
2	ps~mst+alt+ws	5	244.11	2.08	0.22	0.85	-116.40
3	ps~mst+alt+ws+at	6	245.93	3.90	0.09	0.94	-116.03
4	ps~mst+alt+ws+at+st	7	247.91	5.88	0.03	0.97	-115.68
5	ps~mst+alt+ws+at+st+rh+dt	9	249.03	7.01	0.02	0.99	-113.37
6	ps~mst+alt+ws+at+st+rh	8	250.28	8.25	0.01	1.00	-115.47

(ps-patch size, mst-moisture, alt-altitude, ws-windspeed, at-atmospheric temperature, st-surface temperature, rh-relative humidity, dt-diurnal temperature)

Table 4.28.*Logistic regression model during Monsoon season*

Sl. No	Model-Monsoon	K	AICc	Δ AICc	AICcWt	Cum.Wt	LL
1	ps~mst+alt+ws+at+st	7	328.56	0.00	0.36	0.36	-156.01
2	ps~mst+alt+ws+at+st+rh	8	328.92	0.37	0.30	0.66	-154.79
3	ps~mst+alt+ws	5	330.34	1.78	0.15	0.81	-159.52
4	ps~mst+alt+ws+at+st+rh+dt	9	331.74	3.18	0.07	0.88	-154.73
5	ps~mst+alt+ws+at	6	331.74	3.18	0.07	0.96	-158.94
6	ps~mst+alt	4	332.77	4.22	0.04	1.00	-161.96

(ps-patch size, mst-moisture, alt-altitude, ws-windspeed, at-atmospheric temperature, st-surface temperature, rh-relative humidity, dt-diurnal temperature)

Table 4.29.*Logistic regression model during Post-monsoon season*

Sl. No	Model-Post monsoon	K	AICc	Δ AICc	AICcWt	Cum.Wt	LL
1	ps~mst+alt	4	202.57	0.00	0.61	0.61	-96.86
2	ps~mst+alt+ws+at	6	204.78	2.22	0.20	0.82	-95.46
3	ps~mst+alt+ws	5	204.98	2.42	0.18	1.00	-96.84

(ps-patch size, mst-moisture, alt-altitude, ws-windspeed, at-atmospheric temperature, st-surface temperature, rh-relative humidity, dt-diurnal temperature)

Microclimatic and microhabitat characteristics play a pivotal role during the colonization and temporal development processes. Species diversity is influenced by moisture and tends to increase as moisture levels rise (Casamatta et al. 2002; Dayner and Johansen 1991; Ress and Lowe 2013). From various studies, it is well recognized that several environmental conditions like the availability of water, light intensity, and temperature, have an impact on the distribution and abundance of cyanobacteria (song et al. 2005). The present results show that environmental parameters such as moisture, atmospheric temperature, surface temperature, and diurnal temperature have a significant correlation with patch size during all three seasons. In addition to those parameters, relative humidity displayed a positive correlation to patch size during post-monsoon season.

The availability of moisture is crucial for the growth of cyanobacteria, especially those living on rocks in dry environments. Studies conducted by Budel et al. (1997) have shown that hydration cycles have a significant impact on the activity of cyanobacteria on rocks. Species of cyanobacteria that are resistant to drying out can survive drought periods without water and quickly resume growth once they are rehydrated. The surface features of rocks, such as micro-cracks and porous textures, can affect water retention and therefore influence the growth of cyanobacteria by creating niches where moisture is retained for longer periods (Belnap 2003). The current study revealed that moisture is the key factor determining the growth of the cyanobacterial population, and hence their full flourishing can be seen during the wet season. Our findings are in agreement with those of Singh et al. (2008), who reported that the cyanobacteria are more frequently seen in wet seasons and less frequently in dry ones. Our findings are further supported by Broady (1979), stating that the availability of water mostly influences the abundance of algae. Since there was less moisture and rainfall available during the pre-monsoon, it is evident from the current study that there were fewer and smaller patches of cyanobacteria during that time of the year. This finding supports the idea that cyanobacteria can thrive more vigorously during wet seasons.

Seeping water or liquid is essential for the development of cyanobacterial biofilms (Mulec et al. 2008). The presence of seeping water allows microorganisms within biofilms to remain hydrated for longer periods due to extracellular polymeric substances (EPS), which help retain water. Biofilms with higher levels of EPS can remain hydrated for longer periods compared to biofilms with lower levels of these polysaccharides, which rely more on the presence of liquid water for hydration. Seeping water not only hydrates cells but also brings inorganic and organic particles, dust, minerals, and nutrients into the biofilm. Additionally, it can introduce spores of other microorganisms and other microorganisms that become temporarily or permanently trapped in the biofilm. These microorganisms may originate from different areas of the rock or entirely different environments (Pipan and Culver 2013). Consequently, microorganisms typically found in soil or freshwater can inhabit rock biofilms. The sticky nature of EPS allows biofilms, especially gelatinous

ones, to trap various particles and microorganisms. Even thinner biofilms, such as those containing mosses, can retain microorganisms. Thus, the continuous presence of seeping water, which carries various microbes (Ogorek et al. 2014), can influence the diversity of microorganisms at specific sampling points. Popovic et al. (2020) suggested that the presence of seeping water at certain times of the year could lead to variations in the diversity of phototrophic organisms from month to month, resulting in a lower number of overlapping species and a high number of species-specific to only one season. A variety of taxa were only present during specific seasons, likely due to differences in microclimatic and microhabitat conditions at sampling sites, as well as variations in the presence of seeping water throughout the year (Popovic et al. 2020).

According to Dodds and Castenholz (1990), the rate of photosynthesis in cyanobacteria is directly impacted by light intensity. Excessive light can cause photoinhibition, while insufficient light can restrict photosynthesis. For instance, Garcia-Pichel et al. (1992) discovered that certain cyanobacterial species can alter their pigmentation to enhance light absorption under varying light levels. Research by Castenholz (1973) indicates that different cyanobacteria species have specific temperature preferences for growth. Most cyanobacteria thrive in warm temperatures, typically ranging from 20-30°C. Hosmani (2010) observed that the diversity of cyanobacterial species was high at a temperature range between 30 and 34.0°C. Additionally, cyanobacteria can survive in extreme temperatures, such as the thermophilic cyanobacteria found in hot springs can grow at temperatures exceeding 70°C (Ward and Castenholz 2000). The population dynamics of microalgal flora are directly influenced by light and temperature conditions (Suresh et al. 2012). Research has identified a moderate temperature of 20-40°C as optimal for the luxurious growth of cyanobacterial taxa (Khare 2007). In line with their research, we found that the temperature in the present study ranged from 22.2-40.3°C.

The presence of nutrients, especially nitrogen and phosphorus, is crucial for the growth of cyanobacteria. In environments with low nutrient levels, such as nutrient-

poor rocks, cyanobacteria face challenges in thriving. However, cyanobacteria can extract nitrogen from the atmosphere, which gives them an advantage in environments where nitrogen is scarce. Studies conducted by Fay (1992) have demonstrated that nitrogen-fixing cyanobacteria can effectively colonize nutrient-poor rocks. Additionally, research by Whitton and Potts (2000) has shown that the availability of phosphorus can also limit the growth of cyanobacteria. To address this limitation, cyanobacteria can exhibit adaptations, such as producing phosphatases to release phosphorus from organic compounds present on rock surfaces.

A complex interplay of environmental factors influences the growth of cyanobacteria on rocks. Factors such as light availability, temperature, moisture, nutrient levels, relative air humidity, and substrate characteristics (Pentecost and Whitton 2012) play significant roles in determining the viability and proliferation of these organisms in different habitats. According to Macedo et al. (2009), water availability is the most important factor for the development of all microorganisms. Sufficient water availability combined with moderate temperature allows for the growth of a variety of cyanobacteria, despite their high resistance to desiccation (Ortega-Morales et al. 2019). The colonization of cyanobacteria has been correlated with air humidity and light intensity (Li et al. 2016). Other environmental factors, such as temperature, light intensity, and pH, influence the distribution of microorganisms (Ortega-Calvo et al. 1995). Understanding these factors is essential for predicting the distribution of cyanobacteria and its ecological impact in natural environments. Further research into how these factors interact and affect different cyanobacterial species will provide greater insights into their ecological dynamics and potential applications in biotechnology and environmental management.

SUMMARY AND CONCLUSION

Cyanobacteria, the oldest group of prokaryotic organisms on Earth, play a significant role in photosynthesis and have a major impact on global ecosystems. Around three billion years ago, their photosynthesis caused the "oxygen revolution," which led to changes in the Earth's atmosphere and its biota. They have become increasingly important due to their applications in Agriculture, Biotechnology, and Pharmacology. Their recent use in wastewater treatment, aquaculture, fertilizers, food, and the production of secondary metabolites, including exopolysaccharides, vitamins, toxins, enzymes, and pharmaceuticals, is widely accepted. In-depth knowledge of their diversity, distribution, growth, and physiology serves as a strong basis for exploring their applications in Biotechnology.

The family Scytonemataceae is unique with a false branching phenotype and contains ecologically and economically important species contributing significantly to nitrogen fixation, making them promising candidates for agricultural and biotechnological applications. These forms are normally identified and categorized based on their morphological traits, such as cell dimensions, colour, shape, sheath characteristics, type of branching, and cell contents. However, this family has not been extensively studied.

The Western Ghats represents a unique ecosystem and is recognized as one of the world's eight 'hottest hotspots' of biological diversity. Given the promising potential of the family Scytonemataceae, a detailed ecological analysis considering environmental factors is crucial to understanding the diversity and distribution of Scytonemataceae in the Western Ghats. This study was therefore designed and implemented to explore the diversity and distribution of the family Scytonemataceae in selected districts adjoining the Western Ghats in greater detail.

Fifty-two study areas were chosen from four districts (Palakkad, Malappuram, Kozhikode, and Wayanad) to explore the diversity, distribution, and ecology of cyanobacteria belonging to the family Scytonemataceae. The study analyzed the species diversity, habitat characteristics, spatial and temporal variations, seasonality, and the impact of environmental factors on the diversity and distribution of the members of the family Scytonemataceae.

Samples were collected across different seasons (Pre-monsoon, Monsoon, and Post-monsoon). A total of 35 species were identified, in which the dominant genus was *Scytonema*, represented by 30 species, followed by *Brasilonema* with 3 species and *Petalonema* with 2 species. The study also noted that all species from the Scytonemataceae family were present only on rock surfaces. The distinct ecological conditions of the rock surfaces, such as light exposure, moisture retention, temperature variation, nutrient availability, ecological interactions, successional stages, and geographic isolation, create an optimal environment for the growth and proliferation of these cyanobacteria. The exclusive presence of *Scytonema*, *Petalonema*, and *Brasilonema* on these rock surfaces highlights the importance of specific environmental factors in shaping the distribution of these organisms. Further research is likely to provide a deeper understanding of the specific interactions and environmental factors that support these populations.

New records or additions to the Cyanobacterial flora of the Western Ghats region of Kerala include the Twenty-three species listed below:

1. *Scytonema chiastum* Geitler 1925
2. *Scytonema malaviyanense* Bharadwaja 1930
3. *Scytonema fritschii* S.L. Ghose 1924
4. *Petalonema crassum* (Nageli ex Bornet & Flahault) Migula 1905
5. *Scytonema twymanianum* Welsh 1966
6. *Scytonema brunneum* Schmidle 1901
7. *Scytonema variabile* N.L. Gardner 1927
8. *Scytonema arcangelii* Bornet et Flahault 1887
9. *Scytonema hyalinum* Gardner 1927
10. *Scytonema polycystum* Bornet & Flahault 1886
11. *Scytonema praegnans* Skuja 1937
12. *Scytonema sanpaulense* Sant' Anna 1988
13. *Scytonema spirulinoides* N.L. Gardner 1927
14. *Scytonema tenellum* N.L. Gardner 1927
15. *Scytonema drilosiphon* Elenkin & V.I. Poljansky 1922
16. *Scytonema bivaginatatum* H. Welsh 1965
17. *Scytonema papilli-capitatum* C.L. Sant' Anna & J. Komarek 2013

18. *Scytonema masonianum* H. Welsh 1963
19. *Scytonema longiarticulatum* N.L. Gardner 1927
20. *Brasilonema bromeliae* Fiore et al. 2007
21. *Brasilonema terrestre* Sant'Anna & J. Komarek 2011
22. *Brasilonema epidendron* Sant'Anna et al. 2011
23. *Petalonema crustaceum* (Thuret ex Bornet & Flahault) Kirchner 1900

The present study also documents new additions to the cyanobacterial flora of India. Out of the 23 cyanobacterial species belonging to the family Scytonemataceae listed above, 16 are new records of the cyanobacterial flora of India.

1. *Scytonema brunneum* Schmidle 1901
2. *Scytonema variabile* N.L. Gardner 1927
3. *Scytonema arcangelii* Bornet & Flahault 1886
4. *Scytonema hyalinum* N.L. Gardner 1927
5. *Scytonema polycystum* Bornet & Flahault 1886
6. *Scytonema praegnans* Skuja 1937
7. *Scytonema sanpaulense* Sant'Anna 1988
8. *Scytonema spirulinoides* N.L. Gardner 1927
9. *Scytonema tenellum* N.L. Gardner 1927
10. *Scytonema bivaginatatum* Welsh 1965
11. *Scytonema papilli-capitatum* C.L. Sant'Anna & J. Komarek 2013
12. *Scytonema masonianum* H. Welsh 1963
13. *Scytonema longiarticulatum* N.L. Gardner 1927
14. *Brasilonema bromeliae* Fiore et al. 2007
15. *Brasilonema terrestre* Sant'Anna & J. Komarek 2011
16. *Brasilonema epidendron* Sant'Anna et al. 2011

It is critical to understand the spatiotemporal variations in populations with environmental parameters to have a better understanding of their ecology. This understanding provides insights into the distribution of species and their responses to changing environmental conditions. The present study analyzed and compared the spatial and temporal variations of cyanobacteria belonging to the family Scytonemataceae along the Western Ghats to identify the predominant factors influencing them. Specimens were collected seasonally (pre-monsoon, monsoon, and

post-monsoon) from 52 sites, with cyanobacterial patches being used as the unit for diversity analysis.

The study conducted a diversity analysis across three seasons, revealing that the monsoon season had the highest cyanobacterial diversity, followed by the post-monsoon season. In contrast, the pre-monsoon season exhibited relatively lower cyanobacterial diversity. Regarding evenness, the highest value was observed during the pre-monsoon season, followed by the monsoon, while the lowest value was recorded during the post-monsoon. The pre-monsoon season showed the highest level of evenness among the three seasons, indicating a well-balanced community with low dominance by any single species and high species evenness. Overall, the study concluded that the species in the community are evenly distributed. The study observed the highest species richness during the monsoon season, followed by the pre-monsoon season, with the lowest value recorded during the post-monsoon period. The higher values indicate a greater species richness relative to the number of individuals, suggesting a more diverse community in all three seasons. In the study, the Dominance Index values were highest for the pre-monsoon season, followed by the post-monsoon, and the monsoon. The Simpson index, which considers both the number of species present and their abundance, showed that all three seasons possess a high degree of cyanobacterial diversity, with the highest value reported during the monsoon season, followed by post-monsoon, and the lowest during pre-monsoon. In general, the greater the index value, the higher the diversity.

The study also examined the diversity in four districts - Palakkad, Malappuram, Kozhikode, and Wayanad during the pre-monsoon, monsoon, and post-monsoon seasons. The findings revealed that Wayanad district showed the highest diversity during the pre-monsoon season, followed by Malappuram and Kozhikode, which had similar diversity values, while Palakkad exhibited the least diversity. In the monsoon season, Kozhikode had the highest diversity, followed by Malappuram, with Palakkad showing the least diversity. Similarly, Kozhikode district had the highest diversity during the post-monsoon season, followed by Malappuram, and Palakkad exhibited the least diversity. Consistently, Palakkad district showed the lowest diversity across all three seasons.

The study examined the number of patches over different seasons and found that the highest number of patches occurred during the monsoon season, followed by the

post-monsoon season. The lowest number of patches was observed during the pre-monsoon season. The increase in cyanobacterial patches during the monsoon season can be attributed to environmental conditions such as increased rainfall, nutrient inflow, and water level fluctuations. The pre-monsoon season had lower nutrient inflow and less favorable hydrological conditions, leading to the lowest levels of cyanobacterial presence. Conversely, the post-monsoon season provides stable water conditions and residual nutrient levels that support cyanobacterial growth. An analysis was conducted to demonstrate the seasonal variation in patch numbers across different sites over three seasons. The highest mean patch numbers were observed during the monsoon season, while the mean patch number was lower during the post-monsoon season followed by the pre-monsoon season. It was noted that the highest mean patch number was observed in the Palakkad district during the monsoon season.

The study analyzed the variation in patch sizes throughout the year. It was found that the highest patch sizes occurred during the monsoon, with the highest mean patch size observed during the same period followed by the post-monsoon season. Conversely, the smallest patch sizes were found during the pre-monsoon season. The size of cyanobacterial patches varied by season, depending on environmental conditions. During the monsoon and post-monsoon seasons, larger patches were observed due to increased nutrient availability, favorable temperature and light conditions, and hydrological changes that supported cyanobacterial growth. In contrast, smaller patch sizes were observed during the pre-monsoon season, likely due to lower nutrient levels and less favorable environmental conditions, which suggested lower moisture and rainfall during this period. Overall, the findings suggested that cyanobacteria thrived more during wet seasons, leading to fewer and smaller patches during dry periods.

The Pearson correlation was undertaken to assess if there is a significant correlation between elevation and patch size. The results indicated that there is no correlation between elevation and patch size. In other words, there is no consistent pattern in the size of the cyanobacterial patches as elevation changes. The lack of correlation suggests that elevation may not be a significant factor influencing the size of these patches, or that other factors may have a greater influence on patch size. The study also employed Pearson correlation to examine the relationship between patch size and various environmental parameters. The findings revealed that, during the pre-monsoon

season, moisture, atmospheric temperature, surface temperature, and diurnal temperature were significantly correlated with patch size. During the monsoon season, significant correlations were observed between patch size and moisture, atmospheric temperature, surface temperature, diurnal temperature, and altitude. In the post-monsoon season, moisture, atmospheric temperature, surface temperature, diurnal temperature, and relative humidity showed notable correlations with patch size. Throughout all seasons, moisture, atmospheric temperature, surface temperature, and diurnal temperature were positively associated with the patch size of species belonging to the Scytonemataceae family. However, relative humidity only exhibited a significant correlation with patch size during the post-monsoon season. Moreover, it was found that wind speed did not have a significant relationship with patch size in any of the three seasons. This study underscores the importance of environmental factors as strong determinants in the growth of the Scytonemataceae family across all seasons.

In the present study, Principal Component Analysis was conducted across three seasons to identify the environmental parameters that influence patch size. The PCA plot indicated that during the pre-monsoon season, moisture, atmospheric temperature, and diurnal temperature are the key factors affecting patch size. In the monsoon season, the influencing factors are moisture, atmospheric temperature, relative humidity, and altitude. In the post-monsoon season, the influencing factors are noted to be moisture, relative humidity, and surface temperature.

The Generalized Linear Model was undertaken across three seasons to assess how different environmental parameters affect the patch size in various sites. It was found that during the pre-monsoon season, the diurnal temperature had a significant effect on patch size. This single environmental parameter determines the effect of patch size while other environmental factors such as altitude, wind speed, atmospheric temperature, surface temperature, relative humidity, and moisture content do not have significant effects. During the monsoon season, wind speed, surface temperature, and moisture showed significant effects on patch size. In the post-monsoon season, variations in atmospheric temperature and moisture had significant effects on patch size, while altitude, wind speed, surface temperature, relative humidity, and diurnal temperature did not have significant effects.

The research employed logistic regression models to predict the best climatic niche for the family Scytonemataceae based on various environmental parameters across

all three seasons. The findings indicated that the best-fit model for the pre-monsoon season includes moisture and altitude, which together account for 63% of the weightage. In the monsoon season, the best model characterized by the lowest AICc incorporates moisture, altitude, wind speed, atmospheric temperature, surface temperature, and relative humidity. Finally, during the post-monsoon season, the best model comprises moisture and altitude, representing 61% of the weightage. Overall, these results suggest that a combination of environmental factors, such as moisture, altitude, wind speed, atmospheric temperature, surface temperature, and relative humidity, significantly influences the ideal climatic niche for the family Scytonemataceae.

In conclusion, the research examined the diversity, spatio-temporal patterns, seasonality, habitat characteristics, and other factors influencing the Scytonemataceae family in selected locations of the Western Ghats region of Kerala state, India. The study revealed that in terms of temporal scale, seasonal variation had the most significant effect on the cyanobacteria belonging to the family Scytonemataceae, with the highest diversity during the monsoon season, followed by the post-monsoon and pre-monsoon seasons. From the Spatial perspective, environmental factors such as moisture, atmospheric temperature, surface temperature, and diurnal temperature were identified as strong determinants of the growth of the Scytonemataceae family throughout all seasons. The research indicates that seasonal variations and specific environmental conditions strongly influence the diversity of the family Scytonemataceae.

Apart from the ecological roles being played, the members of the family Scytonemataceae produce bioactive compounds that contribute to Pharmacology, Biotechnology, and Agriculture. This highlights the need for the conservation of their natural habitats, especially that of the Western Ghats. Cyanobacterial communities face significant threats due to habitat loss from construction, quarrying, deforestation, and other developmental activities. In recent times, altered rainfall patterns, rising temperatures, pollution, and climate change-related issues are adversely affecting their diversity and distribution, worldwide. Frequent monitoring of their populations and the adoption of measures for the conservation of their habitats are immediate steps required in this direction.

RECOMMENDATIONS

- ▲ Investigate the microbial communities associated with *Scytonema* species to gain insights into potential mutualistic or competitive interactions that could influence habitat preference.
- ▲ Investigate the nitrogen fixation abilities of family Scytonemataceae to evaluate its potential as a biofertilizer for sustainable agriculture, particularly in arid regions.
- ▲ Monitoring and assessment of water and soil quality parameters on the diversity and distribution of cyanobacteria.
- ▲ Molecular and phylogenetic analysis cyanobacteria from epiphytic habitats of Kerala, India.
- ▲ Examine the potential of family Scytonemataceae to produce bioactive compounds for pharmaceutical or agricultural applications. Identifying strains with novel compounds could open pathways for biotechnological applications.

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