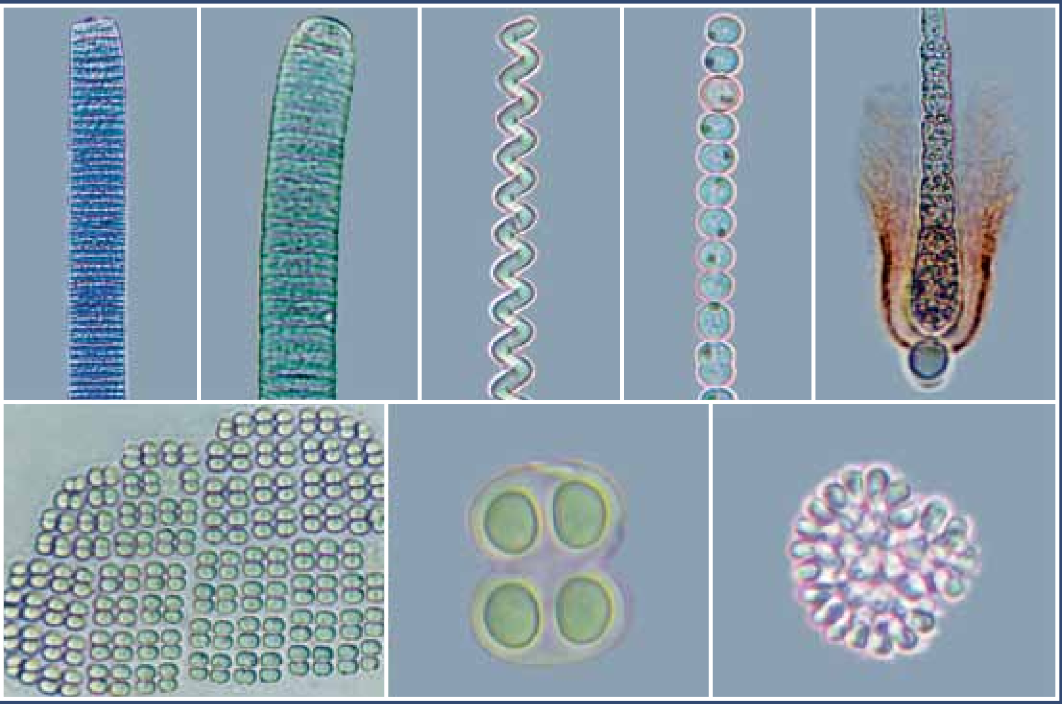
Algal Flora of Nepal

Vol. 1
Cyanobacteria



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National Herbarium and Plant Laboratories
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Cover photo: © Shiva Kumar Rai. *Gloeotrichia raciborskii* var. *kashiense*, *Oscillatoria princeps*, *Dolichospermum affinis*, *Oscillatoria sancta*, *Spirulina princeps*, *Chroococcus minutus*, *Gomphosphaeria aponina*, *Merismopedia elegans*

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Foreword

I take great pleasure in writing the foreword to this book, "Algal Flora of Nepal: 1. Cyanobacteria". In this book, a total of 315 algal taxa reported, covering collection from different parts of Nepal by different researchers in time to time. This book was developed to address issues related to the total number of cyanobacteria in Nepal and keys for the identification of these taxa.

As for the academic studies, this book will fill a gap in this field owing to the fact that the non-vascular lower groups of plants including algal flora library is poor with references dealing with higher plants. Another factor that leads to the development of this book is the continuously growing number of exploration of cyanobacteria. Algal flora represents sources of many significant ecological roles in aquatic ecosystems, and publication of the first volume of this book is very important effort for the advancement of science in our country.

I hope publications of furthermore series of this book which will help to achieve the department's aim of publishing the complete algal flora of the country.

I express my sincere thanks to Dr. Shiva Kumar Rai, Professor Department of Botany, Post Graduate Campus, Tribhuvan University, Biratnagar and Sajita Dhakal, Research Officer of National Herbarium and Plant Laboratories for their efforts to prepare the manuscript of this book. I am thankful to Mr. Mohan Dev Joshi, Deputy Director General, of the DPR, and Mr. Subhash Khatri, Chief of the National Herbarium and Plant Laboratories, Godawari for their valuable suggestions and help in managing the publications of this volume.

Mr. Dhananjaya Paudyal
Director General
Department of Plant Resources
Kathmandu

Preface

It was in 2007, when I had just completed my Ph.D. on freshwater algae of Eastern Nepal, that I ran for the last time into Dr. Viswanath Prasad, one of the great phycologists of Nepal in T.U. Guest House, Balkhu. He said to me, “you are the first person to study the taxonomy of Algae in Nepal. Why don’t you start writing books on algae of Nepal?” That was what inspired me to embark on this book. The need for a book on Cyanobacteria dealing with the species reported from Nepal has been felt for a long time. During my research on algae, I was struck by the lack of literatures on algae of Nepal, and I wished there were consolidated documents about Nepal’s algae.

The opportunity for writing this book came when a meeting was held with S.K. Rai, then the Director General of Department of Plant Resources (DPR), Thapathali, Kathmandu, on June 1, 2018, and I was assigned this project. “Algal Flora of Nepal: 1. Cyanobacteria” is the first volume in fulfillment of that assignment, and the next volumes will appear successively in coming years.

We are happy that this book has come out after almost two years of hard work. This is the first book ever written in the history of algal flora of Nepal that explores the species with illustrations in detail. We also feel proud that we had an opportunity to write the first monographic book on algae of Nepal.

In this book, all the cyanobacteria reported by various phycologists so far from different places of Nepal have been incorporated and presented systematically. The text covers the morphology, habitat and distribution with illustrations of all the cyanobacteria in detail, using the recently developed molecular based polyphasic approach of classification.

This book can be very useful for algae researchers, especially in identifying cyanobacteria. It can also serve as teaching material in universities.

We would like to thank Prof. Dr. Sasinath Jha, Former Head, Department of Botany, P.G. Campus, Biratnagar for reviewing this book. We owe thanks to Prof. Dr. Krishna Mohan Mishra, Department of English, Ohio State University, USA, for his help with the grammar. We are grateful to National Herbarium and Plant Laboratories, Department of Plant Resources (DPR), Ministry of Forests and Environment, Godawari, Lalitpur, Nepal for taking the responsibility to publish this book. We express our gratitude for the photographs and illustrations taken from various sources, viz., Desikachary (1959), Hauer (2008), Hirano (1963, 1969, 1971), Iliev et al. (2006), Jha & Kargupta (2001, 2006, 2012), Kant et al. (2005), Komárek & anagnostidis (2005), Komárek & Watanabe (1990, 1998), Komárek et al. (2013a), Komárek (2005, 2008), McGregor (2013, 2018), Naz et al. (2004), Sant’anna et al. (2004), Skinner & Entwisle (2001), Subba Raju & Suxena (1979), Waner & Laughinghouse (2009), Watanabe & Komárek (1989, 1994, 1988), and Watanabe (1995). I must thank all my family members for their moral support throughout my writing phase. Finally, thanks to Mr. Mahesh Maharjan for laying out and printing this book.

We welcome any comments or suggestions to improve this book.

Shiva Kumar Rai
Biratnagar, Nepal

This book is dedicated to Dr. Vishwanath Prasad (1954-2012)

Contents

Introduction

Cyanobacteria (Myxophyceae, Blue-green algae, Cyanophyta, Cyanoprokaryotes) are the largest, most diverse, and widely distributed group of photosynthetic prokaryotes. They are found in all sorts of habitats where life is possible and distributed throughout the world in marine, freshwater and terrestrial habitats. It is considered that the total number of cyanobacterial species in the world is 2698 (Nabout et al., 2013). Their sizes range from simple microscopic unicells to multiseriate, true branching thalli. In natural habitats, their colour range from dirty yellow, through various shades of blue-green to brown or black. It is mainly due to their pigments like phycobiliprotein and mucilage.

Cyanobacteria are considered to be the most primitive and ancient group of organism and it is evident from their fossil records that they have had a long evolutionary history which extends to at least 3500 Ma ago (Whitton and Potts, 2000). They were most abundant in the fossil record of the Proterozoic Era (2500-470 Ma) so this Era is also called as "Age of Cyanobacteria" (Schopf and Walter, 1982). The earliest cyanobacteria were unicellular having coccoid or ellipsoidal or short rod shaped structure and lived in terrestrial or freshwater environments (Baracaldo et al., 2005). Later, they acquired many more complex traits like extracellular sheaths, filamentous growth, motility, thermophily, nitrogen fixation, and sulphide tolerance that made them able to colonize in brackish, marine, and hypersaline environments. These traits were important to develop dense microbial mats early in the Earth's history.

Cyanobacteria having complex traits such as hormogonia, akinetes and heterocytes are derived from a common ancestor. Within nostocales, hormogonia and heterocytes evolved first then followed by akinetes (Baracaldo et al., 2005). They are thought to have converted the early reducing atmosphere (oxygen poor or anaerobic atmosphere) of the earth into an oxidizing atmosphere (aerobic atmosphere) and changed the life forms on the earth. During the course of evolution, the eukaryotic cell organelles (chloroplasts, mitochondria, etc.) have evolved through symbiosis of cyanobacterial cell which is popularly known as 'endosymbiotic theory'. So, the cell organelles in the present eukaryotic cells were once prokaryotic cyanobacteria.

General Characteristics

Cyanobacteria have the following features.

1. Prokaryotic cell: Lack of organized membrane bound cell organelles, i.e., absence of mitochondria, nucleus, chloroplast, golgi apparatus, endoplasmic reticulum and true vacuoles. Presence of unstacked thylakoids.
2. Protoplasm: Differentiated into peripheral pigmented 'chromoplasm' and central colourless 'centroplasm'.
3. Photosynthetic pigments: Chlorophyll a, xanthophylls (myxoxanthin, myxoxanthophyll, etc.), carotenoids, and three types of phycobilisomes or phycobiliproteins (i.e., phycocyanin c, allophycocyanin, and phycoerythrin c).
4. Reserve food: Cyanophycean starch, cyanophycian granules, polyphosphate granules, polyhedral bodies and poly-B-hydroxybutyric acid.
5. Cell wall is made up of murein (peptidoglycan) and cells secrete mucilage.

6. Flagella and locomotion: Cyanobacteria have no flagella but they show certain types of movement (Hormogomia- gliding movement, *Oscillatoria* filaments- waving or rotation and back and forth oscillation) by the action of mucilage and phototaxis.
7. Photosynthetic products: Sugar and glycogen.
8. Thallus organization: Unicellular, colonial, filamentous, and sometimes simple parenchymatous forms. Branching of filaments are of two types, i.e., true branching (e.g., *Hapalosiphon*) and false branching (e.g., *Scytonema*).
9. Heterocytes: It is a thick-walled, usually translucent structure, present either basally (terminal) or intercalary or sometimes laterally in the filament, developed from vegetative cells under nitrogen limiting conditions. It contains enzyme 'nitrogenase' that is able to fix atmospheric nitrogen into ammonia in it. Heterocytes also act as reproductive cells, organs of attachment, and regulators for akinete formation. It is present in heterocystous cyanobacteria, e.g., *Nostoc*, *Anabaena*, *Calothrix*, etc.
10. Enzymes: Presence of few enzymes, i.e., invertase, lipase, and catalase.
11. Akinete (spore): It is a thick-walled, large-sized resting spore develops in adverse environmental conditions and can remain viable for a long period. Akinetes are formed singly or in chain in specific position in relation to the position of heterocytes. It is resistant to harsh environment (high temperature, desiccation) and also helps in reproduction. It is found in heterocystous cyanobacteria, e.g., *Nostoc, Rivularia*, etc.
12. Gas vacuole: Cyanobacteria lack true vacuoles but gas vacuoles are present which help to maintain buoyancy as well as upward and downward movement in the water.
13. Reproduction: Sexual reproduction is not known but transfer of genes by transformation and conjugation processes occurs. They reproduce vegetatively by cell division, fragmentation, hormogonia, etc., and asexually by formation of asexual spores like akinetes, endospores, exospores, nanocytes, baeocytes, hormospores, pseudo-hormogones, etc. The most common mode of reproduction is by hormogonia which is a small piece of trichome with one to many uniform cells and shows motility (e.g., *Oscillatoria*). The hormogonium when enclosed in a thick lamellated and pigmented sheath, then it is called hormocysts or pseudo-hormogonia (e.g., *Westiella*). Endospores are small spores, usually naked and formed endogenously within a mother cell (sporangium) by rapid successive division in three planes (e.g., *Dermocarpa*). Exospores are formed in sporangia by successive transverse division and detached one by one like budding which released out serially from the open ends of sporangia (e.g., *Chamaesiphon*). The repeated and successive division of cells without any enlargement forms a group of very small cells in the parent cell is called nanocytes (e.g., *Gloeocapsa*). Other special vegetative structures found in cyanobacteria are necridium, calyptra, hairs, etc.

Cell Structure

Cyanobacterial cells (also filaments, and colonies) are covered with a hygroscopic mucilaginous layer known as sheath. Sheath is made up of pectic substances and its nature, colour and thickness depend upon the outer environmental conditions. It keeps the cell moist and protects from adverse environmental conditions and also helps in gliding movement. The cell wall is composed of four layers interconnected by plasmodesmata and is perforated by numerous mucilage passage pores. Chemically cell wall is usually made up of muramic acid, glucosamine and di-amino-pamelic acids. The cell cytoplasm is differentiated into two regions, the central colourless region called centroplasm which contains granular nuclear material, and peripheral densely pigmented region called chromoplasm which contains flattened vesicular thylakoids. The characteristic blue-green colour of cyanobacteria is due to the presence of phycocyanin c and allophycocyanin (blue), and phycoerythrin-c (red) pigments. All these pigments are collectively called as Phycobiliproteins. Cyanobacterial cells lack membrane bounded cell organelles and possess naked DNA. Cell inclusions are mainly gas vacuoles, cyanophycian granules, polyphosphate bodies, carboxysomes and lipid droplets.

Thallus Organization

Cyanobacteria show wide range of variation in thallus organization.

1. Unicellular form: The unicells are either spherical, oval or cylindrical in shape with or without sheath, e.g., *Anocystis, Chroococcus, Gloeocapsa*, etc.
2. Colonial form: The cells after division remain attached together in a common mucilaginous sheath and form a colony. Cell divisions in more than one plane form either spherical (e.g., *Gomphosphaeria*), squarish (e.g., *Merismopedia*), cubical (e.g., *Eucapsis*) or irregular (e.g., *Microcystis*) colonies. The colony with hollow sphere is found in *Coelosphaerium, Gomphosphaera*, etc.
3. Filamentous form: The regular and repeated cell divisions in one plane forms a single row of cells known as trichomes, and the trichome covered with sheath is called a filament. A filament may contain single trichome or more than one trichomes enclosed by a common sheath. The filaments may be
   - Unbranched: Filament simple, without branching, tapered or untapered, with heterocytes or without heterocyete, e.g., *Oscillatoria, Lyngbya*, etc.
   - False branched: The death of a cell or formation of a separation disc cause breaking of trichome and the cells on one or either sides of the dead cell continue to divide transversely forming a false branch, e.g., *Calothrix, Scytonema*, etc. False branching may be single or geminate (paired).
   - Truly branched: Here trichome does not break. A cell in main trichome divides longitudinally and outer daughter cell further divides into a true branch. The branches remain connected with the main filaments. True branching is three types, i.e., lateral branching, dichotomous branching, and reverse V-shaped branching. e.g., *Hapalosiphon, Stigonema*, etc.
   - Heterotrichous: Differentiated into horizontal prostrate and vertical erect system with true branching, e.g., *Mastigocladus*, *Pulvinaria*, etc.

Ecology

Cyanobacteria are ubiquitous and cosmopolitan in distribution (Kumar, 1999). They are the most successful group of microorganisms found in almost all lotic and lentic environments, freshwater and saline waters, clean and polluted waters, paddy fields, above or below the soil, on tree barks, on rocks, on brick walls, on flower pots, etc., or almost on all moist environments. They grow as planktonic, benthic, aerial, subaerial, epiphytic, endophytic, epizoic, endozoic, epilethic, etc., on different substrata. Many species of cyanobateria also form symbiotic relationships with a broad range of eukaryotic hosts including plants (bryophytes *Anthoceros punctatus* - *Nostoc*, pteridophytes *Azolla* - *Anabaena azollae*, cycads

Encephalartos - *Nostoc commune*, and angiosperms *Gunnera* - *Nostoc punctiforme*), fungi (lichen, *Geosiphon pyriformis* - *Nostoc* sp.), and animals (corals, sponges, sea anemones) (Adams and Duggan, 2008). Cyanobacteria have a great adaptability to variations of environmental factors thus can grow in adverse and harsh environments. They thrive well even in extremes of temperature, light intensity, desiccation and high and low concentration of nutrients (Kumar, 1999). *Phormidium* and *Mastigocladus* species growing in hot springs can tolerate up to 75°C of temperature whereas *Calothrix parietina* can tolerate very low temperature of the Polar Regions (Vincent, 2007).

Economic Importance

1. Nitrogen fixation: Some heterocyte bearing cyanobacteria (e.g., *Anabaena*, *Anabaenopsis*, *Aulosira*, *Calothrix*, *Nostoc*, *Scytonema*, etc.) can fix atmospheric nitrogen into ammonia, nitrites or nirates under anaerobic condition and enrich the soil fertility. Heterocyte is the site for nitrogen fixation and enzymes nitrogenase produced in it is responsible for this process.
2. Land reclamation: After rains, species of *Anabaena*, *Microcoleus*, *Nostoc*, *Scytonema*, etc., grow on disturbed or burned land forming a thick substratum that checks soil erosion and retain water. Extensive growth of blue-green algae on alkaline usar land increases the nitrogen content and ultimately makes the soil fertile.
3. Bioremediation: Cyanobacteria are used for bioremediation of heavy metals (Cd, Pb, Se, As, etc.) and organic pollutants (pesticides, PCBs, DDT, etc.) accumulated in aquatic ecosystem which otherwise can cause serious problems on environment and aquatic organisms and can also cause difficulties for animals and human health, e.g., *Agmenellum quadruplicatum*, *Anabaena flos-aquae, Nostoc linckia, N. spongiaeforme, Oscillatoria laete-virens, Phormidium bohneri* (for Chromium metal), *Spirulina platensis*, etc.
4. Food chain: As the major primary producers of aquatic ecosystems, they support food webs and maintain CO_2 and O_2 balance.
5. Health food: *Spirulina* (taxonomically *Arthrospira platensis* and *Aphanizomenon flos-aquae*) is widely marketed as a health food (Spolaore et al., 2006). *Nostoc flageliforme* is boiled and taken as soup in western China (Roney et al., 2009).
6. Algal bloom: Sometimes cyanobacteria like *Microcystis*, *Nodularia*, etc., grow profusely and reproduce explosively forming macroscopic and quite apparent bodies called algal bloom. Algal bloom stops sun light to penetrate into the water so that aquatic plants fail to perform photosynthesis. Hence, concentration of carbon dioxide increases and oxygen decreases that may cause death of aquatic animals.
7. Cyanotoxins: Some cyanobacteria also produce poisonous toxins (neurotoxins, cytotoxins, endotoxins, hepatotoxins, microcystin) in the water making the latter unsuitable for aquatic animals. *Microcystis aeruginosa* produces a toxin which causes death of fishes, shellfishes, and other aquatic animals.
8. Water supply: The luxuriant growth of cyanobacteria in water reservoirs for domestic water supply sometimes produce bad tastes and foul odour to the drinking water and make it unhygienic for human consumption. They also interfere with the filtration process of water, e.g., *Nostoc, Anabaena, Microcystis* and *Oscillatoria*.
9. Some species of cyanobacteria may damage building plasters, stones, glasses, etc. Spraying of $CuSO_4$ and sodium arsenate can prevent it.

10. Many species produce biologically active compounds which are of both great interest and potential concern to human beings.

Classification

Cyanobacteria have been classified and revised time to time by various phycologists. Due to the absence of sexual reproduction and sexual reproductive structures in cyanobacteria, the earlier classifications were based almost entirely upon their morphological features. Morphological characters such as growth form (unicellular, colonial, filamentous), colony (shape, compactness), filament (true branching - uniseriate/multiseriate, and false branching - non-geminate/geminate), polarity (isopolar and anisopolar, tapering), cell differentiation (heterocytes and akinetes), sheath (absence/presence, and thickness), shape and dimensions of cells, heterocytes, akinetes, calyptras, etc., were considered for the classification (Roger, 1982). The mode of reproduction, ecology especially the types of habitats, and pigmentation were other important taxonomic features for classification.

The first taxonomic monographs on cyanobacteria was written by Thuret in 1875 (Palinska and Surosz, 2014). Some of the important taxonomic revisions and classifications on cyanobacteria were given by Gomont (1892), Bornet and Flahault (1886-1888), Geitler (1925), Frémy (1929a), Elenkin (1936), Fritsch (1945), Smith (1950), Papenfuss (1955), Desikachary (1959), Prescott (1962), Bourrelly (1970), Rippka et al. (1979), and others. Frémy (1929b) recognized three orders, viz., Chroococcales, Chamaesiphonales, and Hormogonales (Desikachary, 1959). Geitler (1942) classified cyanobacteria into four orders, viz., Chroococcales, Dermocarpales, Pleurocapsales and Hormogonales (Desikachary, 1959). Desikachary (1959) followed Fritsch's (1945) classification and classified cyanobacteria into five orders (Chroococcales, Chamaesiphonales, Pleurocapsales, Nostocales, and Stigonematales) under single class cyanophyceae. Later, Frémy's (1929b) system was followed by Prescott (1962) and Desikachary's (1959) system was followed by Bourrelly (1970). On the basis of bacteriological characters, Rippka et al. (1979) classified cyanobacteria into five subsections instead of orders, viz., I (= Chroococcales), II (= Pleurocapsales), III (= Oscillatoriales), IV (= Nostocales) and V (= Stigonematales) (Komárek et al., 2014).

The recent trend in classification of cyanobacteria is polyphasic approach which combines both genotypic and phenotypic properties (Palinska and Surosz, 2014). It can evaluate evolutionary and phylogenetic relationships based on gene sequencing and determine taxonomic position. Some of the recent molecular methods used for taxonomic and phylogenic studies of cyanobacteria are: DNA-DNA hybridization (Wilmotte et al., 1997), fingerprinting based upon PCR with primers from short and long tandemly repeated elements (Rasmussen and Svenning, 1998), classification of clone cultures based upon 16S rRNA sequences from the variable regions V6, V7 and V8 (Rudi et al., 1997) and amplified ribosomal DNA restriction analysis of the internally transcribed spacer (Scheldeman et al., 1999). Woese (1987) introduced a phylogenetic classification based on sequence similarities of the 16S rRNA gene as molecular taxonomic marker (Drews, 2011). The 16S rRNA gene sequences is the most common genetic marker that has been using widely so far to study bacterial phylogeny and taxonomy (Johnson et al., 2019). The reasons for its wide use are: its presence in almost all cyanobacteria, its function has not changes over time, and it is large enough (1,500 b) for informatics purposes (Janda and Abbott, 2007). Recently, Komárek et al. (2014) have published a summary of modern taxonomic system for cyanobacteria which includes the status of all currently used families, review of results of molecular taxonomic studies, description of new orders and new families and the elevation of a few subfamilies to family level.

The taxonomic arrangement of cyanobacteria in this book is as follows.

Order 1. Synechococcales
- (*Coccoid Synechococcales*)
- Family 1. Synechococcaceae
  - Genera: *Lemmermanniella*, *Rhabdogloea*, *Synechococcus*
- Family 2. Merismopediaceae
  - Genera: *Aphanocapsa*, *Eucapsis*, *Limnococcus*, *Mantellum*, *Merismopedia*, *Microcrocis*, *Pannus*, *Synechocystis*
- Family 3. Coelosphaeriaceae
  - Genera: *Coelomoron*, *Coelosphaerium*, *Snowella*, *Woronichinia*
- Family 4. Chamaesiphonaceae
  - Genera: *Chamaesiphon*, *Clastidium*
- (*Filamentous Synechococcales*)
- Family 5. Pseudanabaenaceae
  - Genera: *Arthronema*, *Jaaginema*, *Pseudanabaena*
- Family 6. Leptolyngbyaceae
  - Genera: *Leibleinia*, *Leptolyngbya*, *Phormidesmus*, *Planktolyngbya*, *Trichocoleus*
- Family 7. Heteroleibleiniaceae
  - Genera: *Heteroleibleinia*, *Tapinothrix*
- Family 8. Schizotrichaceae
  - Genus: *Schizothrix*

Order 2. Spirulinales (*All filamentous form*)
- Family 1. Spirulinaceae
  - Genus: *Spirulina*

Order 3. Chroococcales (*All coccoid form*)
- Family 1. Microcystaceae
  - Genus: *Microcystis*
- Family 2. Aphanothecaceae
  - Genera: *Aphanothece*, *Gloeothece*
- Family 3. Cyanobacteriaceae
  - Genus: *Cyanobacterium*
- Family 4. Chroococcaceae
  - Genera: *Chondrocystis*, *Chroococcus*, *Cyanosarcina*, *Dactylococcopsis*, *Gloeocapsa*, *Gloeocapsopsis*, *Nephrococcus*
- Family 5. Gomphosphaeriaceae
  - Genus: *Gomphosphaeria*
- Family 6. Entophysalidaceae
  - Genera: *Chlorogloea*, *Entophysalis*

Order 4. Pleurocapsales (*All coccoid form*)

- Family 1. Xenococcaceae
  - Genus: *Xenococcus*

Order 5. Oscillatoriales

- (*Coccoid Oscillatoriales*)
- Family 1. Cyanothecaceae
  - Genus: *Cyanothece*
- (*Filamentous Oscillatoriales*)
- Family 2. Coleofasciculaceae
  - Genera: *Anagnostidinema*, *Geitlerinema*
- Family 3. Microcoleaceae
  - Genera: *Arthrospira*, *Hydrocoleum*, *Kamptonema*, *Microcoleus*, *Oxynema*, *Planktothrix*, *Symploca*, *Symplocastrum*, *Tychonema*
- Family 4. Oscillatoriaceae
  - Genera: *Blennothrix*, *Limnoraphis*, *Lyngbya*, *Microseira*, *Oscillatoria*, *Phormidium*, *Plectonema*, *Potamolinea*

Order 6. Nostocales (*All filamentous form*)

- Family 1. Scytonemataceae
  - Genus: *Scytonema*
- Family 2. Rivulariaceae
  - Genera: *Calothrix*, *Microchaete*, *Rivularia*
- Family 3. Tolypothrichaceae
  - Genera: *Coleodesmium*, *Tolypothrix*
- Family 4. Hapalosiphonaceae
  - Genera: *Fischerella*, *Hapalosiphon*, *Nostochopsis*, *Westiellopsis*
- Family 5. Stigonemataceae
  - Genus: *Stigonema*
- Family 6. Fortieaceae
  - Genera: *Aulosira*, *Fortiea*
- Family 7. Gloeotrichiaceae
  - Genus: *Gloeotrichia*
- Family 8. Aphanizomenonaceae
  - Genera: *Anabaenopsis*, *Cyanospira*, *Dolichospermum*, *Nodularia*, *Raphidiopsis*, *Sphaerospermopsis*
- Family 9. Nostocaceae
  - Genera: *Anabaena*, *Cylindrospermum*, *Desmonostoc*, *Macrospermum*, *Nostoc*, *Trichormus*

About the Authors

Dr. Shiva Kumar Rai:

He is professor of Botany in the Phycology Research Lab of the Botany department of Post Graduate Campus, Tribhuvan University, Biratnagar. His major field of interest is taxonomy and diversity of freshwater algae. He earned his Ph.D. from the University of Lucknow, India, in 2007. His PhD thesis is titled "Studies on freshwater algal diversity of eastern Nepal".

He joined Central Campus of Technology, Hattisar, Dharan, as teaching assistant on the 16th of November 1996. Then he moved to Post Graduate Campus in Biratnagar as assistant professor on the 2nd of June 1997. He was promoted to associate professor on the 26th of June 2009, and to professor on the 24th of July 2015. He worked as assistant campus chief of Post Graduate Campus from 19h August 2014 to 1st October 2017.

He was conferred the Young Science and Technology Award 2064/2065 by Nepal Academy of Science and Technology (NAST), Khumaltar, Lalitpur for identification of varieties of algae from eastern Nepal and investigation of ethnomedicinal plants used by Meche people of Jhapa District. He received Nepal Vidhya Bhusan-Ka from Ministry of Education, Government of Nepal for his successful completion of Ph.D. degree.

He is a life member as well as a member of the advisory committee of the Botanical Society of Nepal (BSON), Kathmandu; general secretary of the Nepal Biological Society (NBS) Biratnagar; and secretary of the Nature Conservation and Health Care Council, Biratnagar.

He has published about a dozen scientific papers in international journals, fifty in national journals, and about a dozen articles in various local newspapers. In collaboration with O. Necchi Jr., São Paulo State University, Brazil and his team, Prof. Rai reported two red algae, viz., *Sheathia dispersa* and *S. indonepalensis* as nova species from Nepal.

He has conducted eight national and international research projects as principal investigator granted by the Third World Academy of Science (TWAS), Italy; University Grants Commission (UGC), Nepal; Nepal Academy of Science and Technology (NAST); and Institute of Science and Technology, T.U. He is currently working as an executive editor of *Our Nature, an International Biological Journal* and *Nepalese Journal of Biosciences*.

He was a co-convener of National Conference on Integrating Biological Resources for Prosperity, which was held 6-7, February 2020 in Biratnagar. In another national conference entitled "Modern Trends in Science and Technology," held 28-29 December 2012 in the same city, he had the chance to perform as organizing secretary. He has worked as facilitator or expert in more than twelve workshops and trainings and has participated in about three dozen national and international conferences, workshops, and trainings. He has supervised the dissertations of about two dozen M.Sc. students.

Mrs. Sajita Dhakal:

She is a Research Officer in National Herbarium and Plant Laboratories (KATH) under the Department of Plant Resources (DPR), Ministry of Forests and Environment. She received her M.Sc. degree (botany) from Tribhuvan University in 2017. She has been working in Cryptogams Section (Algae, Fungi, Lichen) in KATH since 2018. She has gathered a great deal of experience by being involved in many +2 colleges in Kathmandu valley. She has published research articles in national and international journals.

About the book

- Describes the exploration history and present status of cyanobacteria in Nepal as well as in the provinces, ecological regions, and development regions of Nepal.
- Provides a list of 315 cyanobacteria of Nepal belonging to 90 genera, 29 families and 6 orders including 19 new species.
- Describes generic characters and provides 'key' to the species.
- Describes each cyanobacteria with the taxonomic character, dimension, habitat and distribution in Nepal.
- Includes a list of previous as well as recently accepted names of cyanobacteria.
- Consists of a total of 459 cyanobacteria illustrations.
- Helps algae researchers identifying cyanobacteria.

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