Plant Life and Environment Dynamics

Prateek Srivastava
Ambrina Sardar Khan
Jyoti Verma
Shalini Dhyani *Editors*

Insights into the World of Diatoms: From Essentials to Applications

Springer

About this book

This edited book provides a comprehensive and a reliable source of information on all major areas of diatom research. It addresses research advances in the key areas of diatom biology, morphology, systematics, phylogeny and ecology along with their interdisciplinary applications. Diatoms are the world's most diverse group of algae populating the freshwater and marine ecosystems of the world. They are unicellular, photosynthetic, eukaryotes having ornate silicified cell walls. Diatoms contribute around 25% of annual global carbon fixation, which is more than all of the terrestrial rainforests combined. Diatoms underpin major aquatic food webs and drive global biogeochemical cycles and have several ecological and interdisciplinary applications. This book targets a wide range of audience including researchers, academicians, teachers and students of varied disciplines such as biology, environmental sciences, ecology, evolution, nanotechnology and other related disciplines. It is useful read for beginners as well as advanced researchers.

Keywords

Diatoms · Biogenic Silica · Environmental indicators · Diatom nanobiotechnology · Novel materials · Biofuels · Biogeography · Biomonitoring · Climate change and diatoms

Prateek Srivastava • Ambrina Sardar Khan •
Jyoti Verma • Shalini Dhyani
Editors

Insights into the World of Diatoms: From Essentials to Applications

Springer

Editors
Prateek Srivastava
Department of Botany
University of Allahabad
Prayagraj, Uttar Pradesh, India

Ambrina Sardar Khan
Amity Institute of Environmental Sciences
Amity University
Noida, Uttar Pradesh, India

Jyoti Verma
Department of Zoology
CMP Degree College, University of Allahabad
Prayagraj, Uttar Pradesh, India

Shalini Dhyani
CSIR-National Environmental Engineering Research Institute (CSIR-NEERI)
Nagpur, Maharashtra, India

ISSN 2730-6755 ISSN 2730-6763 (electronic)
Plant Life and Environment Dynamics
ISBN 978-981-19-5919-6 ISBN 978-981-19-5920-2 (eBook)
https://doi.org/10.1007/978-981-19-5920-2

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Foreword

The diatoms are algal forms that are known for creating a castle of glass. They have a unique type of cell wall composed of silica. But for Leeuwenhoek, who devised a model of microscope with 300-fold magnification, it would not have been possible to see these minute organisms and their beautiful ornamentation. These ubiquitous organisms are the major primary producers in all aquatic ecosystems and moist places, and hence form the base of food web on which the higher trophic levels are dependent. They are well-known surrogate for the past climatic events because they settle at the bottom of lakes and oceans after death and remain intact because cell walls are readily preserved well along with their intricate microscopic details owing to their siliceous nature. As consumers of 20–25% of the global CO_2 they are important for the study of present climate.

Of recent, the science around diatoms has been concentrated mostly in Europe, Russia, North America, and Japan. As more and more samples were examined the workers left reference slides, material and publications as a record of their work. These are preserved in museums and institutions around the world. Major collections from the nineteenth century can be found in Philadelphia, Vienna, Berlin, Antwerp, Stockholm, Edinburgh and London. Diatom flora and taxonomy has been the major area of interest In India. Other perspectives have received scarce attention.

The initiative Diatoms: Biology and Applications is indeed an effort to generate interest in this less explored organism. This volume contains valuable information on the fundamentals of diatom biology and its multifarious applications to current as well as general issues. The included chapters throw a panoramic view of the world of diatoms touching upon biological aspects such as pigment composition and ecological and environmental facets such as climate change, ocean acidification and impact assessments. The book also takes into account varied applications of diatom research prevalent around the world such as nanobiotechnological utilization and forensic applications. I congratulate the editors for their collective wisdom in selecting a suitable theme for this volume. The information emerging from this volume will create interest in the young minds pursuing research as a career in national and international research institutes, universities and colleges. It will also attract research laboratories looking for fresh areas of research or unique organism models. It will be equally handy for planners, policymakers and managers of water for domestic and industrial use, be it rivers, lakes, lagoons and reservoirs.

I am quite convinced that the effort will spark and ignite minds when it reaches the bookshelves and e-books of individuals and libraries. It is a beginning to reach out and probe the scientific minds.

Aquatic Biodiversity Unit, Department of Zoology, Hemwati Nandan Garhwal University (A Central University), Srinagar-Garhwal, Uttarakhand, India

Prakash Nautiyal

Preface: The World of Diatoms

We often come across partially or completely submerged rocks in streams and rivers covered by golden brown slimy films. These biofilms are composed of microscopic eukaryotic organisms commonly known as the diatoms. These wonderful organisms though are not only restricted to streams and rivers but are abundant in most aquatic ecosystems such as lakes, ponds, wetlands, oceans and even in soils with adequate moisture content.

The word diatom comes from the Greek dia, meaning "through", and temnein, implying "to cut", literally meaning "cut in half", as they consist of two overlapping and interlocking units of their frustules. Diatoms are eukaryotic, unicellular and autotrophic organisms which are characterized by unique cell walls made up of silica (hydrated silicon dioxide). The frustules of diatoms are intricately sculptured and ornate. It is due to their enchanting beauty of their cell walls that these organisms have been labelled as "jewels of the sea". They have been systematically placed in the stramenopile clade of the SAR supergroup and are recognized as members of Bacillariophyceae or Bacillariophyta.

The chloroplasts of diatoms contain chlorophylls a and c along with carotenoids such as fucoxanthin: the pigment responsible for the characteristic golden brown colour. These tiny organisms are the major component of the phytoplankton communities of the oceans and constitute approximately half of the organic material found in the oceans. They are responsible for the production of roughly 25–30% of oxygen globally which equals the contribution of the rainforests combined. They are known to be more energy efficient than their counterparts with organic cell walls. Moreover marine diatoms essentially sequester considerable amount of carbon dioxide from the atmosphere.

Fossil evidences trace back the origin of diatoms to early Jurassic Period though molecular clocks indicate the appearance of diatoms to Triassic period. The emergence of diatoms caused a major shift in the ocean carbon cycle with increased carbon locking in dead diatom cells. Genome sequencing of diatoms such as *Thalassiosira pseudonana* and *Phaeodactylum tricornutum* has thrown light on the unique secondary endosymbiotic origin of diatoms. These genomic studies also revealed several biochemical features of diatoms which are similar to that of organisms of the animal kingdom.

Diatoms have been extensively used in the water quality estimation of aquatic ecosystems such as lakes, rivers, wetlands, etc. and also in paleolimnological reconstructions. They are robust ecological monitors and have been used in assessment purposes throughout the world. The Water Framework Directive has recommended the utilization of diatoms in water quality monitoring programmes. The widespread use of diatoms for ecological health assessment of ecosystems has led to the generation of indicator and sensitivity value of several diatom species. Diatom indices are increasingly being used to evaluate the state of aquatic ecosystems. Recently the potential of terrestrial diatoms for ecological monitoring has also been explored.

Commercial applications of diatoms have a long history. Diatomaceous earth, the fossilized remains of diatoms, has been used in explosives, filtration systems, pest control, agriculture, etc. The unique way of deposition of silica by diatoms in their frustules has widespread applications in nanotechnology such as biosensors, bioimaging, drug delivery, etc. Diatoms have been extensively used in forensics and biofuel production.

The domain of diatom research has tremendous potential. From unravelling secrets of evolution to climate change mitigation, insights into the world of diatoms are expected to uncover evolutionary enigmas and enhance their commercial applications.

Prayagraj, Uttar Pradesh, India — Prateek Srivastava
Noida, Uttar Pradesh, India — Ambrina Sardar Khan
Prayagraj, Uttar Pradesh, India — Jyoti Verma
Nagpur, Maharashtra, India — Shalini Dhyani

Acknowledgements

Coming up with this book on diatoms would not have been possible without the contributions of our hardworking and dedicated authors. It was due to their willingness to contribute even after being engaged with their tight academic schedules. We wish to extend a deep sense of gratitude to all our authors. We profoundly appreciate and deeply acknowledge several eminent persons from the academia such as scientists, scholars and teachers who extracted time from their otherwise busy schedules, critically reviewed the manuscripts and provided us with their precious comments which led to a substantial enhancement in quality. We truly appreciate their cooperation and good understanding in meeting our rather strict paper submissions and review deadlines. We deeply admire the invaluable suggestions of Professor Prakash Nautiyal, HNB Garhwal University, for improving the content of our chapters. His distilled vision throughout the compilation of this book alleviated our challenges. Fundamental questions on the subject matter raised by Dr. Durgesh Kumar Tripathi, Amity University, during the book compilation deserve special appreciation. We are in praise of our research scholars who have worked relentlessly to check for typological errors and formatting issues. We wish to complement the production team members of the publication house for guiding us throughout the compilation of the book. Dr. Akanksha Tyagi and Mr. Jayesh Kalleri, Springer Publications, need special mention for allowing us operational flexibility in several areas. In spite of the fact that we have put in our best efforts to avoid any mistakes, there is a possibility of residual errors. Each chapter included in this book was finalized with primary responsibility of author and co-authors. The editors have gone through all the chapters included and reviewed them meticulously following international standards including ethics of publication. We are open to receive critical comments from readers for the improvement of our book. Last, but in no way the least, we wish to thank our family members from the core of our hearts for their understanding, patience and support for completion of this enormous task.

Prateek Srivastava
Ambrina Sardar Khan
Jyoti Verma
Shalini Dhyani

Contents

1 Photosynthetic Pigments in Diatoms 1
Abhishek Sharma, Prishita Singh, and Prateek Srivastava

2 Impact Assessment: Diatom Flora of Free-Flowing and Fragmented Stretches of Serially Impounded Bhagirathi River (Indian Himalayan Region) 21
Sandeep Kumar and Prakash Nautiyal

3 Use of Multivariate Techniques for Quick Assessment of Hydropower Impacts on the Producer Community in Himalayan Rivers with a Note on Required Sample Size 37
Prakash Nautiyal and Tanuja Bartwal

4 Alpine Lake Environments and Psychrophile Diatoms Around the World with a Particular Emphasis on Turkish Glacial Lakes 45
Cüneyt Nadir Solak, Paul Hamilton, Łukasz Peszek, Małgorzata Bąk, Elif Yilmaz, Korhan Özkan, and Nesil Ertorun

5 Ocean Acidification Conditions and Marine Diatoms 103
Sarah H. Rashedy

6 Diatom Algae for Carbon Sequestration in Oceans 113
Bhaskar Venkata Mallimadugula and Adeela Hameed

7 Diatoms: A Potential for Assessing River Health 121
Shikha Sharma, Kartikeya Shukla, Arti Mishra, Kanchan Vishwakarma, and Smriti Shukla

8 Terrestrial Diatoms and Their Potential for Ecological Monitoring 131
Saleha Naz, Sarika Grover, Ambrina Sardar Khan, Jyoti Verma, and Prateek Srivastava

9 Role of Diatoms in Forensics: A Molecular Approach 143
S. K. Pal, Nitika Bhardwaj, and A. S. Ahluwalia

10 Diatoms in Forensics: Adding New Dimension to the Growing Relevance of Diatoms in Improving Lives 165
Shalini Dhyani and Kavita Bramhanwade

11 Diatom Silica a Potential Tool as Biosensors and for Biomedical Field 175
Raunak Dhanker, Parul Singh, Drishti Sharma, Priyanka Tyagi, Mithlesh Kumar, Richa Singh, and Suraj Prakash

12 Diatoms in Biomedicines and Nanomedicines 195
Rishabh Agrahari, Khushboo Iqbal, Jaagriti Tyagi, Naveen Chandra Joshi, Smriti Shukla, Kartikeya Shukla, Ajit Varma, and Arti Mishra

13 Recent Advances in Biomedicine: Diatomaceous Applications 211
Vivek Narkhedkar and Kavita Bramhanwade

14 Perspectives on the Ecosystem Services and Need for Conservation of Diatomite and Diatomaceous Earth Landscapes for India 225
Harini Santhanam

15 Biofuels from Diatoms: Potential and Challenges 237
Jyoti Verma, Akriti, Hemlata Pant, and Ambrina Sardar Khan

16 Potential Industrial Application of Diatoms for a Greener Future 255
Kavita Bramhanwade, Vivek Narkhedkar, and Shalini Dhyani

17 The Mechanism of Ecosystem Restoration and Resilience of Present-Day Coastal Lagoons by Coastal Diatoms and Their Implications for the Management of Successional Diatomite Landscapes 269
Harini Santhanam and Anjum Farooqui

Editors and Contributors

About the Editors

Prateek Srivastava received a PhD in Botany from the University of Allahabad. His research areas are freshwater ecology and phycology. He has been awarded several research projects from reputed funding agencies of India viz. Ministry of Science & Technology, Ministry of Environment and Climate Change and Science and Engineering Research Board, most of which have focused on diatoms and other river algae. Two students have been awarded with the PhD degree under his guidance. He has been teaching ecology, biodiversity and phycology to UG and PG students since 2008. He has worked as an assistant professor in Amity University, Noida, from 2010 to 2017 and is presently working in the Department of Botany, University of Allahabad. He has more than 35 publications to his credit which include research papers in peer-reviewed international and national journals, book chapters, conference proceedings, etc. He has organized and attended several national and international seminars and workshops.

Ambrina Sardar Khan has completed her PhD in Environmental Science from the University of Allahabad in the year 2010. Since then, she has been working as an Assistant Professor in Amity University, Uttar Pradesh, and is engaged in UG and PG teaching. She taught various subjects like Geo-environmental and meteorological Sciences, Environmental Law, audit and policies, Disaster management and planning and Environmental pollution to the students of Master's in Environmental Sciences and M.Tech Environmental Engineering. Her areas of interest are Air and water quality monitoring, ecotoxicology, Nutritional and health risk assessment and Sustainable urban development. She had published two books namely *Disaster Management and Preparedness* with CBS publication and *Health & Environment: Key Factors for Sustainable Urban Development: Changing cities with challenging issues* with Lambert Publication. She is actively engaged in R&D and has published several research papers in various reputed journals.

Jyoti Verma is working as an Assistant Professor, Department of Zoology, CMP PG College, University of Allahabad. She has worked with Indian Institute of Technology, Kanpur, as a Project Scientist in GRBMP, World Bank project, and Biodiversity expert in E-FLOW Project of World Wildlife Fund India supported by HSBC. She has also completed many Environmental Impact assessment reports of Northeastern states. She has completed a research project on diatoms of Indian subcontinent funded by Indian Government Agencies. Presently she is working on a UGC Start-up grant project on Diatom Biodiversity of Ken-Betwa Rivers. She has received UGC-Women PDF Fellowship Award 2011, CSIR-International Travel Fellowship 2012, Young Scientist award in Oral Presentation 2016, International Travel Fellowship DST 2018, Young Indian Diatomist 2018 and Young Environmental Scientist Award 2018 at JNU, New Delhi.

She has published more than 35 publications in peer-reviewed international and national journals, 7 book chapter and 10 reports. She has attended and presented more than 30 research papers in national and international seminars and 12 workshops. She has visited many countries as a recourse person and young researcher (Germany, Thailand, Malaysia and Nepal). She is a member and fellow of many national and international prestigious societies. She is a reviewer and member of the editorial boards of national and international journals. She has supervised a PhD student of Amity University as a Co-Supervisor (awarded) and one student enrolled for PhD under her supervision.

Shalini Dhyani is Senior Scientist with Critical Zone Group of Water Technology and Management Division in CSIR-NEERI, India. She is South Asia Regional Chair for IUCN CEM (Commission on Ecosystems Management) (2017–2020). She is IPBES Lead Author Global thematic assessment on Sustainable Use of Wild Species (2018–2021) and was lead author for IPBES Asia Pacific regional assessment of biodiversity and ecosystem services in Asia Pacific (2015–2018). She did her doctoral work from Forest Research Institute, Dehradun. Presently, she is involved in a multidisciplinary long-term Critical Zone research for understanding the functioning and impact of groundwater-dependent ecosystems and APN-IGES, Japan project on developing plausive alternate scenarios for Bhitar kanika, India. Dr. Shalini has worked on Biodiversity Inclusive impact assessment of important developmental projects across India and has also contributed to many NGT and Judiciary projects. Her work in Upper Ganga catchment focuses on understanding the role of riparian buffers for ensuring river health and role of phytochemicals in giving special property to river water. She has worked in Indo-EU projects on decontamination of soil and water using techno-ecological solutions. She was jury member for innovation prize programme on climate change adaptation (CCA) at scale (A@S) 2019 by IMC, UK, for Nepal. Dr. Shalini was awarded "IUCN-CEM Chair Young Professional Award" at World Parks Congress 2014 in Sydney, Australia, for her excellent research on Himalayan ecosystems. Dr. Shalini is a recipient of various national as well as international financial grants viz. UNEP, UNESCO, GIZ, FAO, IUCN, UNU, European Union-LEANES, Rufford SGP, DST, APN, etc. She has more than 60 national and international publications and many invited popular science talks to her credit.

Contributors

Rishabh Agrahari Amity Institute of Microbial Technology, Amity University, Noida, Uttar Pradesh, India

A. S. Ahluwalia Department of Botany, Eternal University, Baru Sahib, Himachal Pradesh, India

Akriti Department of Zoology, CMP College, University of Allahabad, Prayagraj, Allahabad, India

Małgorzata Bąk Institute of Marine and Environmental Sciences, University of Szczecin, Szczecin, Poland

Tanuja Bartwal Aquatic Biodiversity Unit, Department of Zoology, HNB Garhwal University, Srinagar-Garhwal, Uttarakhand, India

Nitika Bhardwaj Department of Institute of Forensic Science and Criminology, Panjab University, Chandigarh, India

Kavita Bramhanwade CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, Maharashtra, India

Raunak Dhanker Department of Basic and Applied Sciences, School of Engineering and Sciences, GD Goenka University, Gurugram, Haryana, India

Shalini Dhyani CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur, Maharashtra, India

Nesil Ertorun Department of Biology, Science Faculty, Eskişehir Technical University, Eskişehir, Turkey

Anjum Farooqui Birbal Sahni Institute of Paleosciences (BSIP), Lucknow, Uttar Pradesh, India

Sarika Grover Amity Institute of Environmental Sciences, Amity University Uttar Pradesh, Noida, Uttar Pradesh, India

Adeela Hameed Jammu and Kashmir Policy Institute, Srinagar, Jammu and Kashmir, India

Paul Hamilton Research Division, Canadian Museum of Nature, Ottawa, ON, Canada

Khushboo Iqbal Amity Institute of Microbial Technology, Amity University, Noida, Uttar Pradesh, India

Naveen Chandra Joshi Amity Institute of Microbial Technology, Amity University, Noida, Uttar Pradesh, India

Mithlesh Kumar Department of Basic and Applied Sciences, School of Engineering and Sciences, GD Goenka University, Gurugram, Haryana, India

Sandeep Kumar Aquatic Biodiversity Unit, Department of Zoology, Hemwati Nandan Garhwal University (A Central University), Srinagar-Garhwal, Uttarakhand, India

Bhaskar Venkata Mallimadugula Kadambari Consultants Pvt Ltd, Hyderabad, India

Arti Mishra Amity Institute of Microbial Technology, Amity University, Noida, Uttar Pradesh, India

Vivek Narkhedkar Department of Botany, Mahatma Jyotiba Fule Commerce, Science and Vitthalrao Raut Arts College, Amravati, Maharashtra, India

Prakash Nautiyal Aquatic Biodiversity Unit, Department of Zoology, Hemwati Nandan Garhwal University (A Central University), Srinagar-Garhwal, Uttarakhand, India

Saleha Naz Department of Botany, CMP College, University of Allahabad, Prayagraj, Uttar Pradesh, India

Korhan Özkan Institute of Marine Sciences, Middle East Technical University, Mersin, Turkey

Surender Kumar Pal Biology and Serology, Directorate of Forensic Services, Junga, Shimla Hills, Himachal Pradesh, India

Hemlata Pant Amity Institute of Environmental Science, Amity University, Noida, Uttar Pradesh, India

Łukasz Peszek Department of Agroecology, Institute of Agricultural Sciences, Land Management and Environmental Protection, University of Rzeszów, Rzeszów, Poland

Suraj Prakash Department of Basic and Applied Sciences, School of Engineering and Sciences, GD Goenka University, Gurugram, Haryana, India

Sarah H. Rashedy National Institute of Oceanography and Fisheries (NIOF), Cairo, Egypt

Harini Santhanam Department of Public Policy, Manipal Academy of Higher Education (MAHE), Bengaluru, Karnataka, India
Commission for Ecosystem Management, International Union for Conservation of Nature (IUCN), Gland, Switzerland

Ambrina Sardar Khan Amity Institute of Environmental Sciences, Amity University, Noida, Uttar Pradesh, India

Abhishek Sharma Department of Botany, CMP College, University of Allahabad, Prayagraj, Uttar Pradesh, India

Drishti Sharma Department of Basic and Applied Sciences, School of Engineering and Sciences, GD Goenka University, Gurugram, Haryana, India

Shikha Sharma Amity Institute of Environmental Sciences, Amity University, Noida, Uttar Pradesh, India

Kartikeya Shukla Amity Institute of Environmental Sciences, Amity University, Noida, Uttar Pradesh, India

Smriti Shukla Amity Institute of Environmental Toxicology, Safety and Management, Amity University, Noida, Uttar Pradesh, India

Parul Singh Department of Basic and Applied Sciences, School of Engineering and Sciences, GD Goenka University, Gurugram, Haryana, India

Prishita Singh Department of Botany, CMP College, University of Allahabad, Prayagraj, Uttar Pradesh, India

Richa Singh Department of Basic and Applied Sciences, School of Engineering and Sciences, GD Goenka University, Gurugram, Haryana, India

Cüneyt Nadir Solak Faculty of Arts and Science, Department of Biology, Dumlupınar University, Kütahya, Turkey

Prateek Srivastava Department of Botany, University of Allahabad, Prayagraj, Uttar Pradesh, India

Jaagriti Tyagi Amity Institute of Microbial Technology, Amity University, Noida, Uttar Pradesh, India

Priyanka Tyagi Department of Basic and Applied Sciences, School of Engineering and Sciences, GD Goenka University, Gurugram, Haryana, India

Ajit Varma Amity Institute of Microbial Technology, Amity University, Noida, Uttar Pradesh, India

Jyoti Verma Department of Zoology, CMP Degree College, University of Allahabad, Prayagraj, Uttar Pradesh, India

Kanchan Vishwakarma Amity Institute of Microbial Technology, Amity University, Noida, Uttar Pradesh, India

Elif Yilmaz Faculty of Arts and Science, Department of Biology, Dumlupınar University, Kütahya, Turkey
Institute of Marine and Environmental Sciences, University of Szczecin, Szczecin, Poland

Abbreviations

β-car	β carotene
βTCP	β-tricalcium phosphate
AD	Alzheimer's disease
aDDS	Advanced drug delivery systems
AEAPTMS	3-aminopropyl trimethoxysilane
AMD	Age-related macular degeneration
APTES	3-aminopropyl triethoxysilane
Ax	Antheraxanthin
BQE	Biological quality elements
Chl a	Chlorophyll a
Chl b	Chlorophyll b
Chl c	Chlorophyll c
Chls	Chlorophylls
CWM	Conjunctive water management
Cx	β-cryptoxanthin
CxE	β-cryptoxanthin-epoxide
DD	Diadinoxanthin
Ddx	Diadinoxanthin
DE	Diatomaceous earth
DMAPP	Dimethylallyl diphosphate
DOX	Doxorubicin
DPOR	Dark operated protochlorophyllide oxidoreductase
DSNs	Diatomite silica nanoparticles
Dt	Diatoxanthin
Dtx	Diatoxanthin
FCP	Fucoxanthin-chlorophyll-protein
FTIR	Fourier transform infrared
Fx	Fucoxanthin
GGPP	Geranylgeranyl pyrophosphate
HEP	Hydroelectric projects
hMSCs	Human pluripotent stromal cells

HPQR	High-pressure rapid release
HTL	Hydrothermal liquefaction
HTU	Hydrothermal treatment
IDE/S	Index of Saprobity Eutrophication
IDG	Generic Diatom Index
IPCC	Intergovernmental Panel on Climate Change
IPP	Isopentenyl pyrophosphate
IPS	Specific Pollution Index
LHC	Light harvesting proteins
LPOR	Light operated protochlorophyllide oxidoreductase
LSPR	Localized surface plasmon resonance
MEP	Methylerythritol phosphate
MEV	Mevalonate
MG63	Hypotriploid human cell line
MGNREGS	Mahatma Gandhi National Rural Employment Guarantee Scheme
NPQ	Non-photochemical quenching
NPs	Nanoparticles
Nx	Neoxanthin
PDS	Phytoene desaturase
PEG	Polyethylene glycol
PH	Powerhouse
PL	Photoluminescence
PSY	Phytoene synthase
PTX	Paclitaxel
SDGs	Sustainable Development Goals
SERS	Surface-enhanced Raman spectroscopy
siRNA	Small interfering RNA
SLA	Sustainable Livelihoods Approaches
SPU	Signal processing unit
TDI	Trophic Diatom Index
TEMPO	2,6,6-tetramethylpiperidine-*N*-oxyl
USEPA	U.S. Environmental Protection Agency
VDE	Vx de-epoxidases
VOCs	Volatile organic compounds
Vx	Violaxanthin
WFD	Water Framework Directive
WHO	World Health Organization
ZEP	Zx epoxidases
Zx	Zeaxanthin

Chapter 8
Terrestrial Diatoms and Their Potential for Ecological Monitoring

Saleha Naz, Sarika Grover, Ambrina Sardar Khan, Jyoti Verma, and Prateek Srivastava

Abstract Diatoms have long been utilized as robust ecological indicators for aquatic ecosystems. Ecological data of aquatic diatoms have been well documented. Autecological and biotic indices have extensively used for ecoassessment of water bodies throughout the world. In spite of the fact that diatoms are quite abundant in terrestrial environments and respond quickly to soil environment fluctuations, ecological studies on these entities are substantially lacking as compared to their aquatic counterparts. Of late researchers have investigated certain aspects of soil diatom ecology from some parts of the world. Terrestrial diatoms have been found to be quite responsive to soil environmental conditions, anthropogenic disturbances and agricultural practices. This review attempts to assemble the diverse findings associated with the terrestrial diatoms and their response towards various stressors and explores the future prospects of soil diatom ecology.

Keywords Terrestrial diatoms · Soil microbiome · Agricultural practices

The diatoms are ubiquitous, highly successful microalgae (heterokonts) and constitute one of the most diverse groups on organisms on our planet. They are unique in possessing a highly ornamented cell wall made up of silica (frustules). Diatoms are unicellular eukaryotes mostly occurring as solitary cells, but colonial forms are common as well. An estimated 100,000–200,000 species are known with new species continuously added every year by scientists (Armbrust 2009; Mann and

S. Naz
Department of Botany, CMP College, University of Allahabad, Prayagraj, Uttar Pradesh, India

S. Grover · A. S. Khan
Amity Institute of Environmental Sciences, Amity University, Noida, Uttar Pradesh, India

J. Verma
Department of Zoology, CMP Degree College, University of Allahabad, Prayagraj, Uttar Pradesh, India

P. Srivastava (✉)
Department of Botany, University of Allahabad, Prayagraj, Uttar Pradesh, India

P. Srivastava et al. (eds.), *Insights into the World of Diatoms: From Essentials to Applications*, Plant Life and Environment Dynamics,
https://doi.org/10.1007/978-981-19-5920-2_8

Vanormelingen 2013). The frustule's morphology has formed the backbone of diatom taxonomy and systematics.

The pigment composition of diatoms is quite distinct as along with chlorophyll a and c; they contain a group of carotenoid pigments which are photoprotective in nature (Demmig-Adams and Adams 2000; Kuczynska et al. 2015; Fernandes et al. 2018). They are highly important photosynthetic organisms which account for approximately 20–25% of global oxygen produced via the process of photosynthesis (Field et al. 1998; Sarthou et al. 2005; Scarsini et al. 2019). By virtue of the fact that diatoms are highly sensitive to various environmental variables, these heterokonts have served as highly robust ecological indicators of aquatic ecosystems and have been extensively used in estimation of their ecological health for long (Dixit et al. 1992; Prygiel and Coste 1993; Van Dam et al. 1994; Prygiel et al. 1999; Datta et al. 2019; Maurya et al. 2020; Foets et al. 2020a, b). Ecological tolerance and sensitivity values of most of the abundant diatom taxa have been established, and several diatom indices have been developed throughout the world for assessment of freshwaters which have yielded promising and effective results (Lecointe et al. 1993; Prygiel and Coste 1993; Kelly et al. 1995; Rakowska and Szczepocka 2011; Tan et al. 2017; Antonelli et al. 2017).

As diatom biotic indices are extensively used worldwide for assessment, the ecological amplitudes of aquatic diatoms have been mapped comprehensively. A plethora of literature exists which take into account the tolerance of aquatic diatoms to environmental fluctuations and their environmental requirements (Watson and Kalff 1981; Peters 1983; Sprules and Munawar 1986; Cattaneo 1987; Tremblay et al. 1997; Cattaneo et al. 1997; Duarte et al. 2000; Vidal and Duarte 2000; Tsuda et al. 2003; Lavoie et al. 2006; Jones et al. 2014; Carayon et al. 2019; Passy 2007). In spite of the fact that diatoms are quite abundant in terrestrial environments, ecological studies on these entities are substantially lacking as compared to their aquatic counterparts (Falkowski et al. 1998). This could be attributed to the fact that diatom indices dedicated exclusively for soil assessments are completely lacking (Barragán et al. 2018). However, soil diatoms have exhibited considerable potential with respect to soil ecosystem assessments (Johansen et al. 2010; Zhang et al. 2020). Soil diatoms not only contribute significantly to organic carbon enrichment of soil ecosystems but also have a pivotal role in the soil formation and augmentation of stability in soil aggregates (Shein et al. 2016).

8.1 Soil Microbiomes

Soil microbiomes are one of the richest and most diverse communities of microorganisms on our planet (Jansson and Hofmockel 2018). These microbiomes consist of complex interactions of bacteria, viruses, fungi, archaea, and protists. These interactions have an array of consequences on nutrient cycling, determination of fertility of soil, and carbon sequestration (Prescott et al. 2019). Diatoms are an integral part of the soil microbiome and contribute significantly by enhancing organic carbon concentrations and stabilizing aggregates of soil particles.