Evolutionary Physiology of Algae and Aquatic Plants

Photosynthetic organisms have an enormous influence on our environment through their effects on the development of other life on Earth and the way they alter the planet's geology and geochemistry. This book takes a unique approach by examining the evolutionary history of the major groups of aquatic photoautotrophs in the context of the ecophysiological characteristics that have allowed them to adapt to the challenges of life in water and thrive under past and present environmental conditions. The important role played by aquatic photoautotrophs on a planet undergoing unprecedented anthropogenic change is also highlighted, in chapters on their critical function in mitigating environmental change through their physiological processes and on the role of algae in biotechnology. This invaluable resource will be appreciated by researchers and advanced students interested in the biodiversity and evolutionary physiology of the full range of aquatic photoautotrophs, and their interaction with the environment.

Mario Giordano (1964–2019) was Professor of Plant Physiology at the Università Politecnica delle Marche (UNIVPM), Ancona, Italy, where he founded a plant and algae physiology laboratory focussing on the acquisition and metabolism of carbon, nitrogen and sulfur by algae. He was Professor at the Academy of Science of the Czech Republic and an associate researcher at the Institute of Marine Sciences of the Italian National Research Council, Venice. Mario was Director of the Joint Algal Research Center between the University of Shantou in China and UNIVPM. He published over 120 journal articles and book chapters and received the Luigi Provasoli Award from the Phycological Society of America (2002). Shortly before his untimely death, he had been appointed scientific attaché at the Italian Embassy in Beijing.

John Beardall is Emeritus Professor at the School of Biological Sciences, Monash University, Clayton, Australia. He is also Distinguished Visiting Professor at the Faculty of Applied Sciences, UCSI University, Kuala Lumpur, Malaysia, and Visiting Professor at the State Key Laboratory of Marine Environmental Science, College of Ocean & Earth Sciences, Xiamen University, China. His research has centred on the physiology of algae, focussing on the acquisition of inorganic carbon and the effects of climate change. He has published over 300 papers and book chapters and received the Luigi Provasoli Award (2002) and the PSA Award of Excellence (2018) from the Phycological Society of America.

John A. Raven (1941–2024) was Emeritus Professor at the Division of Plant Science, University of Dundee, UK. He was also Adjunct Professor at the School of Biology, University of Western Australia, and Visiting Professor at the University of Technology, Sydney. His research focussed on the functioning of photosynthetic organisms, particularly aquatic photosynthetic organisms, in relation to their environment. He published over 500 peer-reviewed papers and book chapters and was elected Fellow of the Royal Society of Edinburgh (1981) and Fellow of the Royal Society, London (1990).

Stephen C. Maberly is a Fellow of the UK Centre for Ecology & Hydrology, Lancaster, UK. His research has included ecological studies of inland waters and their response to ecological pressures, and physiological experiments on the carbon acquisition mechanisms of their phytoplankton and macrophytes and also those of marine algae and seagrasses. He has published 180 papers and book chapters and 130 publications or reports for the general public and environmental managers. He received the Luigi Provasoli Award from the Phycological Society of America (1992).

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Edited by

MARIO GIORDANO
Università Politecnica delle Marche (UNIVPM)

JOHN BEARDALL
Monash University

JOHN A. RAVEN
University of Dundee

STEPHEN C. MABERLY
UK Centre for Ecology & Hydrology

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Contributors

John Beardall
School of Biological Sciences, Monash University, Clayton, Australia
Faculty of Applied Sciences, UCSI University, Kuala Lumpur, Malaysia
State Key Laboratory of Marine Environmental Science, College of Ocean & Earth Sciences, Xiamen University, Xiamen, China

Michael A. Borowitzka
Algae R&D Centre, School of Veterinary and Life Sciences, Murdoch University, Murdoch, Australia
OzAlgae, Cygnet, Australia

Anita G. J. Buma
University of Groningen, Faculty of Science & Engineering, Energy & Sustainability, Groningen, Netherlands

Olivier De Clerck
Department of Biology, Ghent University, Ghent, Belgium

Kevin J. Flynn
Plymouth Marine Laboratory, Plymouth, UK

Mario Giordano†
Dipartimento di Scienze della Vita e dell’Ambiente, Università Politecnica delle Marche (UNIVPM), Ancona, Italy

E. Walter Helbling
Photobiology Station Playa Unión (EFPU), Chubut, Argentina
National Scientific and Technical Research Council (CONICET), Buenos Aires, Argentina

Catriona L. Hurd
Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Australia

Ulf Karsten
Institute of Biological Sciences, University of Rostock, Rostock, Germany

Stephen C. Maberly
Lake Ecosystems Group, UK Centre for Ecology & Hydrology, Lancaster, UK

Aditee Mitra
School of Earth and Environmental Sciences, Cardiff University, Cardiff, UK

Ondřej Prášil
Institute of Microbiology, The Czech Academy of Sciences, Trebon, Czech Republic

Antonietta Quigg
Department of Marine Biology, Texas A&M University at Galveston, Galveston, USA

John A. Raven†
Division of Plant Science, University of Dundee at the James Hutton Institute, Dundee, UK
School of Biological Science, University of Western Australia, Crawley, Australia
Climate Change Cluster, University of Technology, Sydney, Australia

Michael Y. Roleda
Diliman Marine Science Institute, University of the Philippines, Quezon City, Philippines

Patricia Sánchez-Baracaldo
School of Geographical Sciences, University of Bristol, Clifton, UK

Diane Stoecker
Horn Point Laboratory, University of Maryland Centre for Environmental Science, Cambridge, USA

Prachi Varshney
Shannon Applied Biotechnology Centre, Technological University of the Shannon: Midlands Midwest, Limerick, Ireland

Heiko Wagner
Department of Algal Biotechnology (SenProf), Institute of Biology, Leipzig University, Leipzig, Germany

Christian Wilhelm
Department of Algal Biotechnology (SenProf), Institute of Biology, Leipzig University, Leipzig, Germany
German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany

Preface

Photosynthetic organisms have had an enormous influence on our environment. They have not only affected the development of other life on Earth but have also altered the geology and geochemistry of the planet. Early photosynthetic organisms (invariably bacteria) used light energy to drive assimilation of inorganic carbon into organic matter, using electrons from highly reduced compounds such as hydrogen, hydrogen sulfide or ferrous iron. The evolution, in cyanobacteria (or their progenitors), of the capacity to split water as a source of electrons, starting around 2.8 billion years ago, changed this situation dramatically since water splitting results in the release of oxygen. The Great Oxidation Event from ~2.4 billion years ago saw large increases in atmospheric oxygen levels resulting from organic carbon burial. The oxygen in the atmosphere reacted with ultraviolet (UV) radiation from the sun to form ozone in the stratosphere, and this ozone layer has since then shielded us from much of the more damaging UV in solar radiation. Oxygen also resulted in changes in the oxidation state and availability of elements such as iron and other metals as well as other important nutrients such as nitrogen and sulfur. These changes, and their consequences for photosynthetic organisms, are discussed in Chapters 1–3.

The original oxygenic photolithotrophs were cyanobacteria. Through endosymbiosis, a cyanobacterium was incorporated into a eukaryote to form chloroplasts of the Archaeplastida, that is glaucophyte, red and green algae. Further endosymbiosis of red and of green algae yielded the rest of the micro- and macro-eukaryotic algae. In turn, charophyte green algae gave rise to terrestrial plants, and it is from these that the remaining group of aquatic phototrophs, the aquatic embryophytes, evolved. The evolutionary history of these major groups of aquatic photolithotrophs, and some of the physiological challenges they face, are discussed in Chapters 4–6.

Aquatic oxygenic photolithotrophs play a critical role in the functioning of the planet today. The cyanobacteria, algae and aquatic embryophytes in freshwater and marine ecosystems account for half of the global primary productivity and play critical roles in biogeochemical cycles. These organisms function under a range of environmental factors that pose physiological challenges in present-day situations. How they operate under these different conditions is discussed in Part II of the book that covers physiological responses to factors such as visible radiation, UV radiation, desiccation, salinity and nutrient availability (Chapters 7–11). There are also chapters discussing alternative metabolic strategies such as photo-phago-mixotrophy (Chapter 12) and the impacts of pollutants (Chapter 13). Some environmental challenges can be considered extreme, and the ability of algae and cyanobacteria to function in unusual and extreme situations is discussed in Chapter 14.

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Our planet is experiencing a period of unprecedented change associated with anthropogenic causes. This book therefore closes with chapters dealing with physiological processes of aquatic photolithotrophs on a planet undergoing considerable changes in its climate, UV radiation levels and nutrient availability (Chapters 15–17) as well as a consideration of the role of algae in biotechnology (Chapter 18).

We are very grateful to the many people who contributed chapters to this book. These have allowed us to put together what we consider a careful and thorough discussion of the physiology of aquatic photolithotrophs in the context of evolutionary, present-day and future environments.

The book was the brainchild of our friend and colleague, Mario Giordano, who enlisted the other three co-editors to his cause. Sadly, Mario passed away far too prematurely, in December 2019, without seeing this project come to fruition. His untimely passing also slowed down progress by the remaining editors, so the production of this volume has been drawn out for far longer than intended – we are grateful to the contributing authors (and indeed our publishers, Cambridge University Press) for their forbearance in the light of our tardy progress.

Mario Giordano doing one of the things he loved: diving in the sea

John A. Raven

Professor John A. Raven FRS, FRSE sadly passed away in May 2024 just after the book proofs had been finalized. The scope and depth of his knowledge and insight were extraordinary and are evident in the range of his various contributions to this book. We are grateful for his friendship and collaboration over many years and for his input into the production of this book.

This book is dedicated to the memory of Mario and John.

Acknowledgments

We are grateful to Cambridge University Press for the opportunity to compile this book and to our many colleagues who agreed to contribute chapters. For various reasons, this book has had a long gestation, and we thank everyone involved for their patience. Chris Beardall read through entire drafts of the book and made many useful suggestions to improve clarity, grammar and punctuation.