PHYTOPLANKTON PIGMENTS

Characterization, Chemotaxonomy and Applications in Oceanography

Pigments act as tracers to elucidate the composition and fate of phytoplankton in the world's oceans and are often associated with important biogeochemical cycles related to, for example, carbon dynamics in the oceans. They are increasingly used in *in situ* and remote-sensing applications, detecting algal biomass and major taxa through changes in water colour (associated with changes in algal pigments).

This book is a follow-up to the 1997 volume *Phytoplankton Pigments in Oceanography*, edited by Jeffrey, Mantoura and Wright (UNESCO Press). Since then, there have been many advances and discoveries concerning phytoplankton pigments and it is widely recognized – as concluded by a recent meeting supported by the Scientific Committee on Oceanic Research (SCOR) – that these should be brought together in a new book to update the user community. This book includes recent discoveries on several new algal classes, particularly for the picoplankton, and on new pigments. It also includes many advances in methodologies, including liquid chromatography-mass spectrometry (LC-MS) and developments and updates on the mathematical methods used to exploit pigment information and extract the composition of phytoplankton communities. The book includes seven sections: (1) Algal chlorophylls and carotenoids, (2) Methodology guidance, (3) Water-soluble 'pigments', (4) Selected pigment applications in oceanography, (5) Future perspectives, (6) Aids for practical laboratory work, and (7) Phytoplankton pigments data sheets. Electronic versions of the data sheets, plus extra and extended Appendices, are also available online at www.cambridge.org/phytoplankton.

The book is invaluable primarily as a reference for students, researchers and professionals in aquatic science, biogeochemistry and remote sensing.

SUZANNE ROY is a Professor of biological oceanography at the Institut des Sciences de la Mer of the Université du Québec à Rimouski (Canada) and a member of Québec-Océan. Over the last 20 years, Professor Roy has developed an expertise in the ecology and physiology of marine and estuarine phytoplankton, focusing on various aspects such as population dynamics of harmful algae, environmental impacts of aquaculture and ozone-related ultraviolet radiation effects. She also runs an analytical laboratory for the HPLC determination of algal pigments and UV-screening compounds. Her current research interests include the combined influence of climate warming and enhanced UV on phytoplankton communities, photoprotection and cell mortality in Arctic phytoplankton, and the transport of non-indigenous dinoflagellates in ships' ballast tanks. Several of these projects are part of Canada's major NSERC Research Networks such as CAISN and CFL. Professor Roy is a member of the Scientific Committee for the international Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB) programme.

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This volume is dedicated to Dr S. W. Jeffrey, a pioneer in the development of tools and knowledge on pigments in ocean environments, and an inspiration and great help in the production of the present volume.

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Preface

In 1997, the Scientific Committee on Oceanic Research (SCOR) (with support from the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the editors' institutions) sponsored a volume on phytoplankton pigments entitled *Phytoplankton Pigments in Oceanography*: *Guidelines to Modern Methods*. This volume was edited by Drs S. W. Jeffrey, R. F. C. Mantoura and S. W. Wright and resulted from the activities of SCOR Working Group 78. The 1997 volume went out of print a few years after publication (about 2000 copies were sold), which prompted UNESCO Publishing to print another 500 copies in 2005.

In April 2006, SCOR sponsored a workshop of pigment specialists from around the world to examine updates in this field. This workshop was hosted by Dr R. Fauzi C. Mantoura and the International Atomic Energy Agency's Marine Environmental Laboratory in Monaco. The updates that were identified include new advances in the taxonomy of marine phytoplankton (several new algal groups have been described since 1997), improved analytical techniques (notably HPLC-linked mass spectrometry, not generally used for pigment analysis before 1997), and new applications for pigments. The outcome of this meeting was a consensus that an update of the original 1997 volume was urgently needed, and a new editorial team was nominated. The present volume is the result of this update. Two of the three former editors of the 1997 volume contributed to the present volume (S. W. Jeffrey and S. W. Wright). Their collaboration ensures a smoother transition between the two volumes and prevents repetition, focusing instead on developments since the 1997 volume.

Recent discoveries on several new algal classes particularly for the picoplankton category (smallest sized algae) and on new pigments are outlined in Chapter 1 of the present volume. These discoveries have benefited from improvements in culturing, microscopic and molecular methods. In particular, molecular methods have contributed to the recent advances in our understanding on the biosynthetic pathways for both chlorophylls and carotenoids (see Chapters 2 and 3). The present volume also includes overviews on water soluble 'pigments' used more extensively in oceanography, namely phycobiliproteins (Chapter 9) and mycosporine-like amino acids (Chapter 10).

The many recent advances in methodologies examined in the present volume include wider application of HPLC (Chapter 4), liquid chromatography-mass spectrometry (Chapter 7) and developments and updates on the mathematical methods used to exploit pigment information and extract the composition of phytoplankton communities (Chapter 6). The importance of high-quality chromatographic data for pigment determinations is highlighted in Chapter 5, particularly when pigments are used for remote-sensing applications and algorithm development. Mathematical tools have also been developed to extract information from absorption or fluorescence spectra without prior separation of the various pigments by a chromatographic technique – some applications are reviewed in Chapter 8.

A few selected applications in oceanography are included, notably on the use of pigments to provide information on the status of photoacclimation, through changes in photoprotective pigments (Chapter 11), as well as a review on the use of pigment labelling to infer rates of algal growth or the rate of grazing on algae, with highlights on the importance of microzooplankton in oceans (Chapter 12).

There is an increasing recognition of the impact that environmental change has on biological productivity, biodiversity and microbial cycling in the ocean. Knowledge on pigments in the aquatic environment is critical to understanding these fundamental aspects and is also a key complement to the rapidly advancing fields of remote sensing of pigments from space and environmental monitoring, particularly for coastal regions. Monitoring is particularly important for the study of phytoplankton bloom dynamics in general and harmful algal blooms (HABs). These often toxic blooms are a growing problem in many coastal regions of the world, for reasons that are not entirely clear, but which may be related to eutrophication, ballast transport, aquaculture, climate change, etc. Chapter 13 provides the background information on bio-optical properties of pigments, necessary for understanding the recently developed tools that make use of these properties, and Chapter 14 provides an outlook on the use of pigments for *in situ* and remote-sensing detection of phytoplankton blooms (including HABs) in coastal regions, with an Appendix containing information on pigments found in harmful algae (Appendix 14A). The final chapter, Chapter 15 presents a collection of perspectives on future directions for pigment research. The book also has further materials available online at www.cambridge.org/phytoplankton. Electronic versions of the data sheets in the book are supplied for easy reference, plus an extra Appendix on specific absorption coefficients, and an extended version of Appendix 14A.

The 1997 volume was considered an extremely useful handbook by most users. The book was not developed as a textbook for university students; it was addressed rather to aquatic scientists interested in analysing and using pigments to trace algae in their study systems, for example, in relation to environmental monitoring, climate change, remote sensing, biogeochemical, ecological and biodiversity studies. Our aim is the same with this present volume, making it an indispensable tool for professionals and students who wish to analyse and research all areas in relation to aquatic pigments. We hope you will find it useful.

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Abbreviations and symbols

The abbreviations shown below are common across several chapters. More specific abbreviations can be found in their respective chapters.

Pigment names

Allo	alloxanthin
Anth	antheraxanthin
APC	allophycocyanin
Aph	aphanizophyll
Asta	astaxanthin
ββ-Car	β,β-carotene (trivial name = β-carotene)
βε-Car	β,ε-carotene (trivial name = α-carotene)
βψ-Car	β,ψ-carotene (trivial name = γ-carotene)
BChl(s)	bacteriochlorophyll(s)
But-fuco	19′-butanoyloxyfucoxanthin
c_2-MGDG [14/14]	Chl c_2-monogalactosyldiacylglycerol [14:0/14:0] ester
c_2-MGDG [14/18]	Chl c_2-monogalactosyldiacylglycerol [14:0/18:4] ester
Calo	caloxanthin
Cantha	canthaxanthin
Car	carotene(s)
Chl	chlorophyll
Chl c_1+c_2	unresolved Chl $c_1 + c_2$
Chl c_{2Pg}	chlorophyll c_2-like *Pavlova gyrans*-type
Chlide	chlorophyllide
Cryp	cryptoxanthin
Diadino	diadinoxanthin
Diato	diatoxanthin
Dino	dinoxanthin
DV	divinyl
Echin	echinenone

Fuco	fucoxanthin
Gyr-de	gyroxanthin diester
Hex-fuco	19′-hexanoyloxyfucoxanthin
Hex-kfuco	19′-hexanoyloxy-4-ketofucoxanthin (also known as 4-keto-19′-hexanoyloxyfucoxanthin)
Kfuco	4-ketofucoxanthin
Kmyxo	4-ketomyxoxanthophyll
Kmyxoe	4-ketomyxoxanthophyll ester
Lut	lutein
MgDVP	Mg-2,4-divinyl pheoporphyrin a_5 monomethyl ester
MV	monovinyl
Myxo	myxoxanthophyll
Neo	neoxanthin
Oscil	oscillaxanthin
PC	phycocyanin
PCB	phycocyanobilin
PChlide	protochlorophyllide
PE	phycoerythrin
PEB	phycoerythrobilin
PEC	phycoerythrocyanin
Peri	peridinin
Pheide	pheophorbide
Phe	pheophytin
PPC	photoprotective carotenoids
Pras	prasinoxanthin
PSC	photosynthetic (light harvesting) carotenoids
PUB	phycourobilin
PVB	phycoviolobilin (also known as phycobiliviolin)
Siph	siphonaxanthin
Siph-e	siphonaxanthin ester (siphonein)
TChl	total chlorophyll (sum of Chl, allomers, epimers and Chlide)
Uri	uriolide
Vauch	vaucheriaxanthin
Viola	violaxanthin
XC	xanthophyll cycle
Zea	zeaxanthin

Other common abbreviations and symbols

CDOM	chromophoric dissolved organic matter
DAD	diode array detection
DIC	dissolved inorganic carbon
DNA	deoxyribonucleic acid

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More information

DOM	dissolved organic matter
ε	molar absorption coefficient
E	irradiance
HPLC	high performance liquid chromatography
MAAs	mycosporine-like amino acids
Me	methyl
MeOH	methanol
MS	mass spectrometry
NASA	National Aeronautics and Space Administration
NMR	nuclear magnetic resonance
PAR	photosynthetically active radiation, 400–700 nm
PS	photosystem
RC	photosynthetic reaction centre
SCOR	Scientific Committee on Oceanic Research
UV	ultraviolet radiation
Vis	visible range of wavelengths (400–700 nm)