Climate Change and Microbial Ecology

Current Research and Future Trends (Second Edition)

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Cover Illustration

Photomicrographs of cyanobacteria (the illustration is derived from Chapter 1, Fig. 1.2).

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Preface to the 1st edition

When I was asked by the publisher some time ago, whether I was willing to edit a book on *Climate Change and Microbial Ecology*, I agreed because I felt that it was timely to have a comprehensive overview on the advancements in this field. I thought that it was appropriate to summarize the current knowledge on how the microorganisms on earth are affected by global climate change and vice versa how they themselves affect the development of global climate change, - by viewing from the perspective of the different groups of microorganisms like bacteria including cyanobacteria, fungi, and protozoa, also viruses, as well as by looking in detail on the different ecosystems on earth like oceans, inland waters with rivers, lakes, and groundwater, and soil. Thus I am happy that a broad range of renowned scientists provided their expertise demonstrating not only the actual status but also the imminent need to increase our knowledge on the role of microbial communities with respect to global climate change.

The reader will observe that the style of the chapters is not always consistent between the different authors. Some of the chapters are short and concentrated, whereas other chapters go into great detail. However, I decided the differences to be maintained in order to allow the authors to present these review papers using their personal preferences. Unfortunately, there are a few gaps in this book, which prohibits the presentation of a complete suite of the major aspects within the general topic of "Climate Change and Microbial Ecology", mainly because the manuscripts from a few authors were not received within an acceptable time frame.

Nevertheless, I am convinced that the list of contributions to this book covers most of the important areas from the book's title *Climate Change and Microbial Ecology: Current Research and Future Trends* and that the volume will be helpful not only for every microbial ecologist from the PhD student to the experienced scientist, but also for every one interested in the field of global climate change.

Finally, I would like to express my thanks to all the authors for their kind cooperation. They did a great job in presenting a timely overview on topics of climate change and microbial ecology in their special fields of expertise. I am also indebted to Dr Thomas Horvath (University of Koblenz-Landau, Landau, Germany) who improved some manuscripts prepared by authors who were not native English speakers, and also to the publisher who was especially patient with the many delays occurring through the preparation of this volume.

Jürgen Marxsen, Giessen, Germany

Preface to the 2nd edition

Climate change is continuing unabated. I think there can be no doubt. Thus I am very happy to be able to present now to the scientific community and everybody who is interested an enlarged and updated book on *Climate Change and Microbial Ecology: Current Research and Future Trends*. The first edition of the book appeared in 2016, and I was surprized that the publisher asked me very soon to prepare a new edition. This meant to me that the interest of readers in the book and its topic could not have been minor, and I enjoyed agreeing. Now, about five years after the book had appeared for the first time, we are able to present this new edition containing now even four more chapters. Many of the authors revised and updated or even expanded their chapters, only few chapters had to be printed unchanged. With the assistance of renowned colleagues who entered the project and prepared new chapters it was possible to close at least some of the gaps from the first edition although not all. So this new edition covers more of the important fields from the book's title and hopefully will be even more helpful for the audience addressed.

Let me again express my thanks to all the authors for their kind cooperation and for their great engagement in preparing new or revised contributions with timely overviews on topics of climate change and microbial ecology in their field of expertise. Also warmest thanks to the publisher who encouraged me to start working on the preparation of the new edition and as I am firmly convinced, will produce this new edition with the same high standard as the first one.

Jürgen Marxsen, Giessen, Germany

Introduction

The structure of microbial communities and their functions play a crucial role for the flow of matter in the Earth's biogeochemical cycles. Effects of microbial communities on the carbon and nitrogen cycles are particularly important for producing climate gases such as CO_2, CH_4, or N_2O, thus enhancing or hampering global climate change. However, the biogeochemical cycles are reversely impacted by global climate change themselves, for example by increasing temperature, increasing CO_2 concentration, or changing soil humidity. Microbes may respond differently to human-caused climate change. They may act as potent amplifiers, but may also dampening human-caused effects on climate. Nevertheless, understanding of microbial ecology in the different ecosystems on Earth, such as soil, oceans, inland waters, is essential for our ability to assess the importance of biogeochemical cycles–climate feedbacks (Bardgett et al., 2008). Unfortunately microbial communities are extremely complex in structure and function and can be affected by climate and other global changes in many ways, which impedes our ability to draw reliable conclusions.

The *IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels* (2018) emphasized that climate change continues unabated. "Emissions of greenhouse gases due to human activities, the root cause of global warming, continue to increase, year after year." (IPCC 2018) This underlines the importance of the main objective of this book, to present in its 2nd edition again a timely overview of advancements in the field of climate change and microbial ecology. Individual chapters cover the various types of ecosystems, the role of different groups of microorganisms, and the complex effects on and interrelationships with the various cycles of matter. A few special chapters cover applied aspects such as land-use and geoengineering.

The volume starts in its initial chapters with contributions on the different microbial groups occurring in the Earth's ecosystems.

Hans W. Paerl (Chapter 1) shows the impact of climate change on the Earth's oldest oxygenic phototrophs, the cyanobacteria. Their long evolutionary history was of special advantage for adapting to recent anthropogenic modifications of their environment, such as eutrophication, water diversion, withdrawal, and salinization. Harmful cyanobacterial blooms were promoted worldwide by eutrophication, but manifestations of climate change, particularly temperature rise, play synergistic roles in promoting blooms of cyanobacteria, as Paerl can demonstrate in his revised and extended chapter.

Ingrid Brettar, Manfred G. Höfle, Carla Pruzzo, and Luigi Vezzulli (Chapter 2) present a paper on climate change effects on bacteria in aquatic environments - with the focus on marine planktonic communities, because very little is known about climate change effects on inland water as well as on sediment communities in both, inland and marine systems. Beside effects of climate change on bacterial growth and community composition, the authors consider effects on bacteria-mediated biogeochemical cycling and potential hazards by increased abundance of pathogenic bacteria.

The new contribution of Felipe Bastida, Alfonso Vera, Marta Díaz, Carlos García, Antonio Ruíz-Navarro, and José Luis Moreno (Chapter 3) is focusing on soil microbial communities in semiarid and arid environments. Climate change strongly impacts the diversity of soil microbial communities and their ecosystem functioning, but agricultural activities may enhance the effects of climate change. The maintenance of productivity often requires the application of nutrients (organic amendments and fertilizers) and alternative water sources for irrigation, which can be accompanied by contamination. The current impacts and perspectives of these practices, together with climate change, on microbial communities in semiarid and arid soils are described in this chapter.

Heterotrophic protozoans play a key role in marine and freshwater microbial food chains. The major effects of increased temperature on free-living heterotrophic protists are summarized by Hartmut Arndt and Mar Monsonís Nomdedeu (Chapter 4, updated and extended), who also illustrate the complexity of temperature impact on the background of complex microbial food web interactions.

Irina Sidorova and Elena Voronina completely revised and substantially enlarged the chapter on terrestrial fungi (Chapter 5). They give a review on different groups of saprotrophic, mycorrhizal, and pathogenic fungi addressing direct and indirect effects of climate change including responses to warming, extreme weather events, elevated carbon dioxide, and nitrogen concentrations. Although a huge variety across taxa and functional guilds occurs, the authors discuss possible mechanisms underlying climate change effects observed or predicted.

Aquatic hyphomycetes are important components of heterotrophic food webs in woodland streams as pioneer colonizers of submerged leaf litter from the surrounding environment. They mineralize litter carbon and nutrients and convert dead organic matter into biomass, establishing the link between basal resources and higher trophic levels. Verónica Ferreira (Chapter 6) addresses direct and indirect effects of climate change on their community composition, growth, reproduction, metabolism, and decomposing activity and discusses the consequences for the functioning of woodland streams.

The current knowledge on potential climate-related consequences for viral assemblages, virus-host interactions, and virus functions, and in turn viral processes contributing to climate change is synthesized by Rui Zhang, Markus G. Weinbauer, and Peter Peduzzi in a revised and extended contribution (Chapter 7). They show that viruses have the potential to significantly influence carbon and nutrient cycles as well as food webs in aquatic ecosystems and that viruses are clearly needed to be incorporated into future ocean and inland water climate models.

Biofilms are complex and dynamic assemblages of microorganisms, important particularly in many aquatic ecosystems. How they are affected through warming and desiccation is reviewed by Anna M. Romaní, Stéphanie Boulêtreau, Verónica Díaz Villanueva, Frédéric Garabetian, Jürgen Marxsen, Helge Norf, Elisabeth Pohlon, and Markus Weitere (Chapter 8). Commonly observed effects of warming on biofilms include changes in the autotrophic and heterotrophic community composition and extracellular polymeric substances. Photosynthesis, respiration, denitrification, and extracellular enzyme activity show different sensitivity to temperature. However desiccation may produce more permanent changes, more on the biofilm microbial structure than on activities.

The second part of the book is focussed on climate change and its effect on microbes in biogeochemical cycles.

The importance of microbial responses for the balance of soil carbon loss and storage under future temperature and precipitation conditions is examined by Timothy H. Keitt, Colin Addis, Daniel Mitchell, Andria Salas, and Christine V. Hawkes (Chapter 9). The authors propose four classes of response mechanisms allowing for a more general understanding of microbial climate responses. They find that moisture has large effects on predictions for soil carbon and microbial pools.

Soil microbes play a central role in the global carbon cycle; they metabolize organic matter, thereby releasing more than 60 Pg C annually. The composition and activity of microbial communities are strongly influenced by environmental conditions. Thus, global climate change may provoke climate-microbial feedbacks to accelerate or alleviate greenhouse gas emission. Lei Qin, Hojeong Kang, Chris Freeman, Juanita Mora-Gómez, and Ming Jiang (Chapter 10; updated and extended) review the effects of elevated CO_2 concentrations, temperature increase, and precipitation changes on soil microbial community composition and metabolism. They further suggest topics important to be addressed for better understanding the implications of microbial feedback to climate change.

The contribution of Benckiser (Chapter 11) is an updated and extended review of the current knowledge about N cycling in terrestrial and aquatic environments, beginning with the introduction by N_2-fixation followed by the uptake of NH_4 into cells and its transformation, the oxidation to NO_3^-, and the energy conserving reduction of NO_3^- to N_2O and N_2. The author discuss how a less N_2O polluted atmosphere could be achieved under the aspect of climate change perspectives via less N overloaded agri- and aquaculture systems and less nitrate polluted groundwaters, particularly in the industrialized world.

Giulia Gionchetta, Aline Frossard, Luis Bañeras, and Anna Maria Romaní (Chapter 12) provide a new chapter, which reviews the responses and strategies of streambed and soil microbes to changes in precipitation patterns. Such communities contribute greatly to global biogeochemical cycles and thus it is crucial to understand their response mechanisms to increasing dryness. The authors regard the responses to different organizational levels, from cells to whole communities and emphasize the importance of habitat heterogeneity in support of microbial resistance and resilience against intensification of dry-wet extreme episodes.

Alice Retter, Clemens Karwautz, and Christian Griebler, in another new contribution (Chapter 13), summarize actual and expected impacts of climate change on subsurface ecosystems, the earth largest reservoir of freshwater. Significant increase in temperature and serious consequences from extreme hydrological events already observed are altering the composition of the specialized microbiome and fauna and endangering important ecosystems functions such as the cycling of carbon and nitrogen in the typically vulnerable groundwater systems. Retter et al. emphasize that understanding the interplay of biotic and abiotic drivers is required to anticipate future effects of climate change to groundwater resources and habitats.

Ecosystem respiration is typically the dominant process in river networks because of the fuelling by organic carbon from the terrestrial environment. Vicenç

Acuña, Anna Freixa, Rafael Marcé, and Xisca Timoner (Chapter 14) outline in their updated and extended contribution that the mineralization of organic carbon within river networks will be highly sensitive to global climate change because of major increases in the extent of non-flowing periods as well as in flood frequency and magnitude. The alterations in flow regime will increase organic carbon export, whereas temperature rise will increase organic carbon mineralization rates.

The final two chapters discuss selected applied aspects of the topic "Climate Change and Microbial Ecology". One contribution regards the combined impacts of land-use and climate change; the other one presents an example of how our knowledge on microbial ecology could be used for climate engineering.

Together with climate change, land-use is among the most important drivers impacting soil microbial communities and several microbially mediated biogeochemical processes. Stephen A. Wood, Krista McGuire, and Jonathan E. Hickman (Chapter 15) found evidence that both climate change and land-use change have strong impacts on the composition and functioning of tropical microbial communities, potentially amplifying the effects of climate change. The authors suggest research priorities which could improve our understanding of microbial responses to climate and land-use change including these drivers' interactions.

Christian Dunn, Nathalie Fenner, Anil Shirsat, and Chris Freeman (Chapter 16) propose that the "enzymic latch" in the breakdown of organic matter, particularly by inhibitory effects of phenolic compounds, could be used for a number of peatland based geoengineering schemes maximizing their abilities to store and capture carbon. Peatlands contain more than twice as much carbon that is contained in the Earth's forests. As with all geoengineering approaches, peatland geoengineering is not a 'magic bullet' to reverse the effects of climate change, but it has numerous advantages over other proposed schemes. The authors illustrate in their revised and updated chapter that peatland geoengineering offers a realistic concept (as "Plan B") for saving the Earth from the outcomes of anthropogenic climate change.

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