Environmental Microbiology

Second Edition

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Raina M. Maier
Department of Soil, Water and Environmental Science
University of Arizona
Tucson, Arizona

Ian L. Pepper
Department of Soil, Water and Environmental Science
University of Arizona
Tucson, Arizona

Charles P. Gerba
Department of Soil, Water and Environmental Science
University of Arizona
Tucson, Arizona

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Cover photos:
(left) Adenovirus, copyright Russell Kightley Media, with permission. (middle) A fluorescent in situ hybridization (FISH) image of bacterial colonization of a *Buchloe dactyloides* (buffalograss) root grown in mine tailings with 5% compost. The universal probe EUB338-mix labeled with Cy5 was used to label the bacteria and the image was taken with a Zeiss confocal scanning laser microscope. Image courtesy Sadie L. Iverson, University of Arizona, Tucson, AZ. (right) *Prosopis juliflora* (mesquite) root colonized by the mycorrhizal fungus *Glomus intraradices*, showing spores and hyphae. The sample was stained with trypan blue and imaged with at 40X. Image courtesy Fernando A. Solis-Dominguez

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It takes a village—thanks to my family, especially Mom, Dad and my daughter Claire.

Raina M. Maier

This book is dedicated to microbes—they're everywhere and I believe they are smarter than we think.

Ian L. Pepper

This book is dedicated to my wife and sons Peter and Phillip for all their support.

Charles P. Gerba

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Preface

Historically, environmental microbiology can be traced to studies of municipal waste treatment and disposal. In the first Edition of Environmental Microbiology, we recognized that this field had expanded to the study of earth, water, and air systems, including the interaction of indigenous microbes with organic and inorganic pollutants, behavior of pathogens introduced into these systems, and the discovery and application of new microbes and their products to benefit human health and welfare. In the intervening years since, there has been a virtual explosion of knowledge on microbial diversity and communities in various environments. As a result, in the second edition of Environmental Microbiology we have added chapters on extreme environments, as well as microbial communities and communication among microorganisms. Similarly, in recognition of ever-increasing human population pressures and climate change, we have added chapters on domestic microbiology, bioterrorism, and the impact of global change on microbial infectious disease.

Microbes are everywhere, all over the world and in every imaginable environment. For example in soil, just one gram contains billions of microorganisms and all their associated activities. Imagine the challenge of studying all the major groups of microbes found in each of earth's biomes given the magnitude of their immense diversity. Imagine then the challenge of developing strategies to harness and manipulate their activities. That is what environmental microbiology is about. We invite you to use this text to begin the exciting adventure of understanding microorganisms in their many environments.

This text has eight subject areas presented in a logical progression: (i) foundation chapters to provide an adequate background for the advanced material presented in subsequent chapters; (ii) chapters on microbial environments, including earth, aquatic, and atmospheric; (iii) chapters on detection and quantitation of microbial activity, including cultural, microscopic, physiological, molecular, and immunological approaches; (iv) chapters on microbial interactions with their environment from element cycling to microbial communication to development and movement of bacterial communities, (v) chapters on microbial remediation of organic and metal pollutants, (vi) chapters on water and food-borne pathogens, (vii) chapters on waste treatment and drinking water, and finally, (viii) chapters on urban issues including domestic and indoor microbiology, bioterrorism, and risk assessment. This textbook is designed for a senior-level undergraduate class or a graduate-level class in environmental microbiology and to serve as a reference for scientists and engineers interested in this field. The overall objectives of the text are to define the important microbes involved in environmental microbiology, the nature of the different environments in which the microbes are situated, and the methodologies used to monitor the microbes and their activities and, finally, to evaluate the effects of these microbes on human activities. This book represents a joint effort led by three authors who have diverse yet complementary backgrounds in environmental microbiology. The authors are close colleagues at the University of Arizona and all have large and active research programs. They have worked together extensively on a variety of practical problems using advanced, interdisciplinary approaches. Examples include microbiology of extreme environments, biotechnology applications of microbial surfactants, molecular detection of emerging pathogens, transport of microbes and DNA through soil, and microbial risk assessment. Their extensive research programs have provided a number of the examples used in this text to illustrate important learning points. Key contributions to this text were also made by eleven colleagues who collaborate with the authors at the University of Arizona. This group has worked closely together, resulting in a textbook that has continuity in depth and style, and that is state-of-the-art at the time of press.

Raina Maier, Ian Pepper and Charles Gerba

Acknowledgments

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The Authors

All three authors are professors in the Department of Soil, Water and Environmental Science at the University of Arizona.

Raina M. Maier Ph.D., Rutgers University, 1988. Currently, Professor of Environmental Microbiology and Associate Director of the University of Arizona NIEHS Superfund Basic Research Program. Dr. Maier's research is focused on developing a basic understanding of how to evaluate and control microbial activity in disturbed and extreme environments ranging from mine tailings to cave environments to the Atacama Desert, Chile. She is known for using an interdisciplinary approach to study the interaction microorganisms with both biotic and the abiotic components of their environment. Dr. Maier has earned an international reputation for her work on microbial surfactants (biosurfactants) a class of fascinating secondary metabolites with possible uses in remediation, biological control, surface coatings, and the cosmetic and pharmaceutical industries

"Environmental microbiology remains one of the relatively unexplored and extremely exciting frontiers of science. So little is yet known about environmental microbes—partially because they quickly become lab rats when taken out of their environment—that the possibilities for new discoveries are limitless."

Ian L. Pepper Ph.D., The Ohio State University, 1975. Currently, Professor of Environmental Microbiology. Dr. Pepper's diverse research interests are reflected in the fact that he is Fellow of The American Association for the Advancement of Science, The American Academy of Microbiology, the Soil Science Society of America, and the American Society of Agronomy. He is also Director of the National Science Foundation Water Quality Center at the University of Arizona. Dr. Pepper has been active in the area of soil molecular ecology as well as waste utilization including biosolids and effluent reuse. More recently he pursues research on real-time monitoring of microbial contaminants in potable water, and "smart water distribution systems."

"Microbes are in the air we breathe, the water we drink and the food we eat. In fact there are more microbes within our bodies than mammalian cells. On this basis alone, microbes are fascinating, and when you study environmental microbes, it takes your breath away."

Charles P. Gerba Ph.D., University of Miami, 1973. Currently, Professor of Microbiology. Dr. Gerba is a Fellow of the American Academy of Microbiology. He is receipent of the A. P. Black Award from the American Water Works Assoication for outstanding contributions to Water Science, and the McKee Award from the Water Environment Federation for outstanding contributions to groundwater protection. He has an international reputation for his methodologies for pathogen detection in water and food, pathogen occurrence in households, and risk assessment.

"My interest in microbiology was sparked by Paul DeKruf's inspiring tales of the scientific achievements of early microbiologists in the book The Microbe Hunters *and my mother's error in giving me a microscope for Christmas instead of the chemistry set I wanted. In my first summer job out of college, I was introduced to environmental microbiology by studying sewage disposal. Later, I examined the fate of viruses in sewage discharged into the ocean. These beginnings led me to an exciting and adventurous career in environmental microbiology where every day brings a new problem to be addressed."*

Contributing Authors

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Scot E. Dowd Ph.D. Microbiologist, USDA ARS Livestock Issues Research Unit, Lubbock, TX.

Marilyn J. Halonen, Professor of Pharmacology, University of Arizona

Christopher Y. Choi, Professor of Agricultural and Biosystems Engineering, University of Arizona

Elizabeth M. Marlowe Ph.D. Assistant Director of Microbiology-Molecular Testing, Southern California Permanente Medical Group

David C. Herman Ph.D. in Microbiology, University of Arizona

Deborah T. Newby Ph.D. Idaho National Laboratory

Leland S. Pierson III Professor of Plant Pathology, University of Arizona

Christopher Rensing Associate Professor of Microbiology, University of Arizona

Kelly A. Reynolds Associate Professor of Public Health, University of Arizona

Timberley M. Roane Associate Professor of Microbiology, University of Colorado, Denver

Todd R. Sandrin Associate Professor of Microbiology, University of Wisconsin, Oshkosh