

Editorial overview: Environmental Biotechnology

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According to the late philosopher Thomas Kuhn in his classic book *The Structure of Scientific Revolutions* [1], science advances by breakthrough disruptions that change the existing consensus with so-called paradigm shifts. Over the last two decades, the cultivation-independent paradigm [2] within a dynamic molecular view of evolution and phylogeny [3] has been firmly established in environmental microbiology. This revolution is enabled in no small measure by the unprecedented power of high-throughput ‘omics’ technologies and computational methodologies. And while the omics toolbox is having a remarkable influence on how we (re)formulate basic scientific questions in environmental biotechnology, the holistic framework of systems biology is serving to integrate this massively accumulating molecular information toward a fuller functional understanding and a more sustainable management of ecosystems and their services. Beyond this new methodology and epistemology brought by new generation molecular technology platforms, our perceptions of environmental and host-associated microbiomes and the benefits they can provide to society are markedly changing. Traditional wastewater treatment plants (WWTPs) that aimed at removing pollution are now viewed as water resource recovery facilities (WRRFs) that can supply energy and other valuable resources [4]. The new scientific consensus about the human gut microbiome is another example of paradigm shift that now regards human-associated microorganisms as a major driver of immunity and resistance to pathogens instead of enemy or simple food digesters. In this respect, the adoption of the human resource management metaphor from the social sciences has given us a fresh perspective on microbial resource management (MRM, [5]) to steer the potential of microorganisms and their assemblages in our favor.

Thus, environmental biotechnology is now emerging as a composite but increasingly integrated discipline, which relies on a detailed understanding of microbial biodiversity in both its natural and its anthropogenic context to help us engineer large-scale systems for environmental quality and, more generally, introduce innovation and prosperity in human society in all the areas affected by microbial life, from the global elemental cycles influencing our climate to the quality and abundance of our food to the health of our gut.

The increasing availability of genes, genomes, and metagenomes as well as the growing understanding of their functionalities are without any doubt supported by the more classical yet solid considerations of microbial physiology, biochemistry, genetic regulation and engineering in pure strains or defined communities for implementation in bioremediation scenarios. In addition, the environmental context that defines the boundary conditions affecting the outcome of such scenarios can only be understood by integrating and quantifying physicochemical and biological interactions. In a conceptual extension of pollutant bioremediation, more and more types of industrial residues and effluents instead of being slated for treatment as pollutants can now be viewed as feedstocks that can be converted by appropriately managed microbial strains or consortia into bio-based fine chemicals, materials, and fuels.

In this issue we have tried to capture the excitement of current and emerging research in environmental biotechnology through 25 outstanding opinion articles that reflect several of the above considerations and offer fresh insights.

The power and promise of meta-omics to understand in-depth and to manage sustainably key operations in WWTPs are vividly shown by Sales and Lee and by Carballa et al. The microbial community dynamics in enhanced biological phosphorus removal (EBPR) processes for tertiary water treatment and in organic carbon transformation to methane through anaerobic wastewater treatment are now manageable. In the same vein, Stenuit and Agathos give an overview of the current conceptual and experimental tools to study microbial community robustness and to develop predictive models for biological robustness engineering. Also, de los Reyes III et al. provided a methodological framework that can guide experimental design, and discussed specific issues that can affect how researchers generate and use data to elucidate the relationships between bacteria. Sewer networks are now considered as an integral part of an urban water system. Odor and corrosion problems are still a challenge, which can be managed in a cost efficient way, as described by Jiang et al. Finally, flow cytometry is one of the most promising high throughput techniques to analyze microbial communities very fast, even online. Proctor and Hammes show how these new techniques can be used for the microbial management in drinking water microbiomes.

Outside of mainstream, well-studied environments, microorganisms display fascinating, multifaceted physiological features that can be both a source of new fundamental insights into universal evolution and adaptation mechanisms and also can constitute a springboard for practical applications of their catabolic potential. Thus, Oren gives an exciting overview of the ecological significance and technological potential of mostly unculturable halophilic prokaryotes which are becoming 'visible' thanks to high-throughput sequencing. Zhang et al. synthesize the emerging physiological features of marine piezophilic prokaryotes and their adaptive mechanisms as revealed by a combination of omics and high-pressure cultivation technology. The marine environment should constitute fertile ground for metagenomic bioexplorations in search of novel biosurfactants of potential utility in combatting oil spills, hence it is of interest to ponder the insights offered by Jackson et al. in this area which has not yet lived up to its full potential. Microorganisms also can be used to overcome the supply risk of PGMs and REEs by biometallurgical technology development. Zhuang et al. identified waste streams with low metal concentrations which are potential niches for biometallurgy. The interactions of microorganisms with conductive surfaces, such as electrodes are the core elements of bioelectrochemical systems (BESs). Guo et al. suggest future optimization of these microbe-electrode interactions is key to maximize BES performances. Finally, Okshevsky et al describe the ecological role of extracellular DNA (eDNA) in biofilms and how this knowledge can be used to obtain a better biofilm treatment.

Research on the fate of environmental chemicals is enriched with studies addressing less studied compounds with increasingly widespread applications, such as quaternary ammonium compounds (QAC) and manufactured nanoparticles (NP). Tezel and Pavlostathis describe the emerging mechanisms of microbial degradation, adaptation and resistance to widely used

QAC disinfectants while suggesting ways to mitigate adverse effects and develop greener technologies. On the NP front, Van Aken gives an overview of their effects on plants and bacteria and he charts out the implications of such interactions for human health and for the environment at large. The biodegradation of equally recalcitrant pollutants that have been studied over a longer period of time, such as polycyclic aromatic hydrocarbons (PAHs), can still offer valuable new insights as pointed out by Vila et al. They suggest a fruitful integration of omics with community structure/function studies after properly curating the ever-augmenting databases and, together with an appreciation of emerging co-metabolic networks, this knowledge should ultimately help predict the outcome of in situ bioremediation. These and other xenobiotics and their analogs in an environmental setting are also examined by Parales et al. They offer a beguiling look at strategies used by bacteria to sense these molecules via signaling pathways often coordinately regulated with biodegradation pathways and the challenges in understanding the functions of the multiple chemoreceptors expressed by catabolically versatile soil bacteria. Zanaroli et al. discuss the fate and remediation of a group of very recalcitrant molecules, organohalides, and how the activity of dehalogenating microbes may contribute, if properly stimulated, to the in situ bioremediation of marine and estuarine contaminated sediments. The micropollutants, recalcitrant molecules present at low concentrations, are the challenge for the 21st century. Helbling describes the new methods and models to determine and steer biodegradation kinetics at these low concentrations.

An intriguing viewpoint on the biodegradation mechanisms of both well-known and emerging aromatic pollutants is presented by Ricken et al. who suggest that many transformations into intermediates involve *ipso*-substitution events without being generally recognized as such. These authors suggest the fruitful exploration of this and analogous unusual mechanisms, especially in the context of the transformations of emerging pollutants. Contrary to bacteria either as isolated strains or as consortia, fungi have been studied less extensively as agents of environmental management. To fill this void and capture the increasing research and development activities in this area, the versatility of fungal enzymes alone in the form of immobilized biocatalyst formulations or in the context of whole cell fungal bioaugmentation is explored in a synthetic overview by Kües. Finally, another lower eukaryote, the model yeast *Saccharomyces cerevisiae*, is the subject of a timely review by dos Santos and Sá-Correia who draw our attention to the importance of the physiological genomic approaches to describe the response to chemical stress in yeast and the usefulness of post-genomic approaches for environmental toxicology using yeast as a model.

Four contributions address the intriguing features of phototrophic microorganisms which have a global environmental significance as primary producers while being actively considered as potential bio-economy actors for biofuels and high-value ingredients. Kouzuma and Watanabe review the fascinating complexity of algal-bacterial interactions that are mediated by signaling compounds, have the potential to affect global nutrient cycling and can also be harnessed for water treatment and energy conversion. Microalgae from algal ponds coexist with bacteria, viruses and other planktonic microbiota in aerosol droplets emitted in the atmosphere through mechanisms whose understanding can shed light on these bio-aerosols' ecological impact as described by Sialve et al. The current trends in mathematically modeling the nonstandard lifestyle of microalgae are surveyed by Baroukh et al. who draw our attention to the complexities of permanently fluctuating environments for the production of biofuels, while Jeffryes et al. offer an intriguing smorgasbord of possibilities to manufacture sustainably high-value bionanomaterials from photosynthetic microorganisms.

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Vitae



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