

PERSPECTIVE

Unveiling the microbial world: Single-cell techniques in environmental microbiology

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Microorganisms are ubiquitous, playing pivotal roles in diverse ecosystems ranging from soil and water to extreme environments like deep-sea vents and polar ice caps. Traditional microbiological methods have provided valuable insights into microbial communities; however, they often overlook the inherent heterogeneity within these communities. Single-cell techniques have revolutionized environmental microbiology by allowing researchers to explore microbial diversity, function and interactions at the individual cell level. This article delves into the significance of single-cell techniques in environmental microbiology, their methodologies and applications. Microbial diversity encompasses the range of microorganisms present in a given environment, including bacteria, archaea, fungi, protists and viruses.

Keywords: Microorganisms, Single-cell techniques, Diversity, Pests.

Introduction

Microorganisms are found everywhere and are essential to a wide variety of habitats, from water and soil to harsh settings like polar ice caps and deep-sea vents. Conventional microbiological techniques have shed important light on microbial communities, but they frequently ignore the intrinsic variability that exists within these populations. Single-cell techniques have revolutionized environmental microbiology by allowing researchers to explore microbial diversity, function and interactions at the individual cell level. This paper explores the role, methods and applications of single-cell techniques in environmental microbiology (Lane, N. 2015). Microbial diversity encompasses the range of microorganisms present in a given environment, including bacteria, archaea, fungi, protists and viruses.

Single-cell techniques, such as Fluorescence *In Situ* Hybridization (FISH) and single-cell genomics, offer unprecedented insights into microbial diversity by directly visualizing and analyzing individual cells. FISH utilizes fluorescently labeled nucleic acid probes to target specific microbial taxa within complex communities, enabling the identification and quantification of microbial populations in their natural habitat. Single-cell genomics involves the isolation and genomic analysis of individual microbial cells, providing insights into their genetic composition, metabolic potential and evolutionary relationships (Hugerth, L. W., et al., 2017). Microbial communities drive essential biogeochemical processes, including nutrient cycling, pollutant degradation and carbon sequestration.

Description

Single-cell techniques facilitate the elucidation of microbial functionality by assessing metabolic activities, gene expression patterns and physiological states at the single-cell level. For instance, single-cell Raman spectroscopy enables non-destructive chemical profiling of individual cells, revealing their metabolic activities and interactions within complex microbial consortia. Additionally, single-cell transcriptomics allows the characterization of gene expression profiles in individual cells, shedding light on microbial

responses to environmental stimuli and community dynamics (Fraser, C. M., et al., 2000). Microbial interactions, such as symbiosis, competition and predation, profoundly influence community structure and ecosystem functioning.

Single-cell techniques provide unique opportunities to study microbial interactions and ecological niches with unprecedented spatial and temporal resolution. Microfluidic devices coupled with microscopy enable the observation of microbial interactions in controlled microenvironments, elucidating dynamic processes such as biofilm formation and microbial predation (Bell, T., et al., 2005). Moreover, single-cell stable isotope probing allows researchers to track the metabolic activities of individual cells within complex communities, elucidating nutrient fluxes and trophic interactions in diverse ecosystems. Single-cell techniques find applications across various environmental settings, including soil, aquatic environments, extreme habitats and engineered systems

In soil microbiology, single-cell techniques have revealed the diversity and functional roles of soil microorganisms in nutrient cycling, plant-microbe interactions and soil remediation processes. In aquatic environments, single-cell techniques have been instrumental in studying microbial communities in marine, freshwater and wastewater ecosystems, elucidating their roles in biogeochemical cycling and pollutant degradation. Moreover, single-cell techniques have facilitated the exploration of microbial life in extreme habitats such as deep-sea hydrothermal vents, permafrost and acidic hot springs, offering insights into the limits of microbial adaptation and survival. Despite their transformative potential, single-cell techniques pose several challenges, including sample contamination, cell lysis and data analysis complexities (Singh, B. K., et al., 2010).

Conclusion

Improvements in sample preparation protocols, instrument sensitivity and bioinformatic tools are essential to overcome these challenges and maximize the utility of single-cell techniques in environmental microbiology. Future research directions include the integration of multi-omics approaches, development of high-throughput single-cell platforms and application of machine learning algorithms for data interpretation. By addressing these challenges and embracing technological advancements, single-cell techniques hold promise for further unraveling the complexities of microbial communities and their ecological significance in diverse environmental systems. Single-cell techniques have revolutionized environmental microbiology by offering unprecedented insights into microbial diversity, functionality and interactions at the individual cell level. From unraveling microbial diversity in complex ecosystems to elucidating metabolic activities and ecological interactions, single-cell techniques have transformed our understanding of microbial communities and their roles in environmental processes. As technology continues to advance and interdisciplinary collaborations flourish, single-cell techniques are poised to drive innovative discoveries and address pressing environmental challenges in the years to come.

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Conflict of Interest

The authors declare no conflict of interest.

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