Exploring the Mysteries of Marine Microorganisms: AI-Assisted Development and Application of Marine Microbial Resources

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Abstract

Marine microorganisms, including bacteria, viruses, microalgae, and fungi, play essential roles in biogeochemical cycles and strongly influence climate change, ecosystem sustainability, and environmental health. They drive key processes such as carbon sequestration, nitrogen fixation, and sulfur cycling, while also supporting food webs, degrading pollutants, and providing valuable biotechnological applications. However, most marine microorganisms remain uncultivated and unidentified, forming what is known as "microbial dark matter." Our laboratory has investigated microbial communities from the surrounding waters of Taiwan, host-associated environments, and Arctic ecosystems. We found that most dominant microbial taxa in these environments represent potentially novel species, with relative abundances reaching 70–80%. For example, in the Yin-Yang Sea area, eight of the top ten dominant bacterial taxa were potentially novel species, highlighting the great potential of these microbial resources for further exploration and application. To advance this field, we developed a Microbial Community-Guided Cultivation Strategy (MCGCS) integrated with portable Oxford Nanopore Technologies for rapid sequencing. By combining MCGCS with metagenome-assembled genomes (MAGs), we can predict microbial growth requirements, optimize culture media, and improve cultivation efficiency. Furthermore, through artificial intelligence and machine learning, we developed the Microbe-Mon and Microbe-G2C platforms to more precisely predict the growth requirements and cultivation conditions of uncultivated microorganisms directly from MAGs. Using these platforms, we are further expanding microbial dark matter research toward novel applications, such as discovering antifreeze substances from Arctic microorganisms for food preservation and microbial strain cryopreservation. With AI-assisted exploration, we can accelerate the discovery, cultivation, and application of novel marine microbial resources, contributing to biotechnology, environmental sustainability, and marine conservation.