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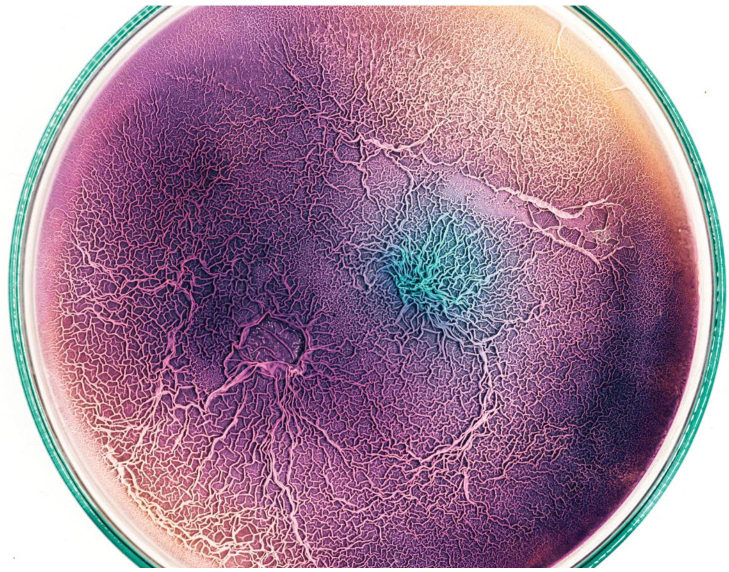
Microbes in a warming world

Microorganisms and their activities are as integrated in climate change science as they are in the world around us, playing key roles related to the causes, impacts and perhaps even some solutions of climate change.



A recent estimate suggests that the Earth contains approximately 10^{30} living cells (P. W. Crockford et al., *Curr. Biol.* **33**, P4741–4750.E5; 2023). While some of these cells are wrapped into larger, visible forms of plants, animals and fungi, a vast amount exist as microorganisms. This informal group of 'small things' includes organisms from all domains of life, inhabiting all of Earth — from inside other organisms to extreme environments — and providing services related to resource cycling, health and agriculture. Unsurprisingly, they are also key in our understanding of the inputs and impacts of climate change.

In marine realms, microbes define global nutrient cycles and fix about half of the Earth's carbon. On land, microbes in soil regulate soil carbon storage directly while further influencing the growth and productivity of plant life. The fact that microbes play such diverse roles in both sequestering and producing greenhouse gases — the latter being exemplified in settings such as flooded rice paddies and the gastrointestinal tracts of animals — raises concerns for the impacts of changing climate on the microbe-mediated carbon source–sink balance. Microbe-associated processes can be linked to both high uncertainty and high risk: as a key example, microbial decomposition of previously frozen carbon in high-latitude permafrost can lead to the release of huge amounts of carbon dioxide and methane, which could trigger warming–carbon feedback loops. Beyond carbon budgets, recent years have also seen increasing concern about the impacts of change on microorganisms linked to human, plant and animal health, as well as a push for further investigation into the role microbes can play in various climate solutions.

In this issue of *Nature Climate Change*, Sáez-Sandino and colleagues investigate warming effects on soil microbial respiration, a factor that remains a major source of uncertainty in carbon–land feedback projections. Using soil from 332 sites across all major biomes, they show that while factors such as substrate quantity and biochemical recalcitrance do play a role, the varying response of soil respiration to warming is largely governed by the biomass, richness and composition of the microbial community. In light of these findings, Sáez-Sandino and colleagues urge for increased action to both monitor and conserve soil microbiomes.

Also in this issue, two other works touch on the world of microbes. Hudiburg and colleagues review carbon dynamics and recovery under wildfire and highlight the requirement for a deeper understanding of microbial taxonomy, function and stress response to adequately map ecosystem recovery and carbon responses to fire, noting the dearth of studies in this space. Ryu and colleagues' Brief Communication describes a rice variety that shows reduced soluble sucrose accumulation in its roots, which leads to reduced abundance of methanogens and fermentation-inducing microbes at certain growth stages, ultimately limiting methane production.

These three works show just a fraction of the roles and responses of microbes in the context of climate change. Recent years and technological advances have seen increased understanding of how terrestrial and aquatic microorganisms produce and sequester greenhouse gases, as well as how warming will impact the survival of the organisms themselves and their interactions — from symbiotic to pathogenic — with other organisms.

Research efforts in the field are increasing, but more still needs to be done. In 2019, scientists issued a warning to humanity on the topic of microorganisms and climate change (R. Cavicchioli et al., *Nat. Rev. Microbiol.* **17**, 569–586; 2019). The consensus statement urged for increased awareness and focus on microorganisms in climate change studies and long-term monitoring, incorporation of their processes into Earth system models, development of microbial technologies as potential solutions, and consideration in the development of policy and action. More than four years later, these calls still hold true. Microbes might remain largely unseen in the literal sense, but increased visibility is required to push forward global change science.

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