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Genome Watch

Microbial adaptability in changing environments

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This Genome Watch article highlights the recent use of large-scale monitoring of natural microbiomes to examine feedback between environmental change and microbial adaptation.

The network of interacting microbial species inhabiting an environment — the microbiome — is often inextricably intertwined with environmental processes. But this is not a static relationship. Microorganisms harbour enormous capacity for evolutionary change, and alterations in the environment can cause rapid adaptive shifts in microbiome composition, intraspecies variation and overall function. A microbiome can thus be swept into a tight feedback loop, whereby microbiome adaptation impacts key aspects of its environment, which in turn changes selective pressures on the microbiome itself. Understanding and accounting for these dynamics is crucial for predicting long-term environmental trajectories. While controlled single-species laboratory experiments have long been used to study microbial adaptation, until recently, little was known about how these findings translate to the complex communities and ever-changing environments found in the wild. New studies are using high-throughput tracking of real-world ecosystems to tackle this challenge at scale.

An arena that has been a major focus of such studies is the soil microbiome and its push–pull relationship with biogeochemi cal cycling[1]. A recent study[2] hypothesized that the scenario in which a potential rise in temperatures leads to increased carbon emissions by soil microbiome decomposers, which in turn exacerbates warming, could be mitigated if microorganisms were concurrently adapting to the new environmental conditions. To examine the likelihood of this hypothesis, the authors collected soil samples from 72 different European locations spanning a wide swath of mean average temperatures. For each location, they measured how the growth and respiration rates of sampled bacteria responded to temperature shifts. They found that rather than following a single global trend, the temperature sensitivity of these two microbial traits varied systematically across samples, from the southern reaches of Spain to the Arctic chill of northern Sweden. Microorganisms sampled from warmer environments had lower respiration rates than their coldadapted counterparts when tested at the same temperature. This suggests that the adaptive capacity of soil microorganisms could mitigate some of the worst-case climate change predictions.

Interestingly, another recent study[3] found largely concordant results, but in a completely different setting — the oceans. Marine micro biomes are a critical component of ocean ecosystems, constituting both a food source and a driver of nutrient cycling. Using broad sampling across a similar latitudinal gradient of European marine sediments, researchers found that the average temperature of the sampled environment predicted the optimal temperature at which multiple classes of microbial enzymes were most active. Temperature variability also shaped the proteome composition, with the most stable proteins sampled from environments with a history of substantial temperature fluctuations, adding a new wrinkle to predictions of microbiome resilience in a changing world.

A different study[4] of soil microbiomes investigated the adaptive strategies used by microorganisms living in serpentine soils, environments known for their toxic levels of heavy metals. The authors not only reported strong evidence of microbial adaptation but also linked the observed patterns to horizontal gene transfer of a specific genomic island with hallmarks of mobile genetic element machinery. This suggests that a key microbial strategy may involve sharing adaptive variants between unrelated strains. Moreover, allelic variation within the identified genomic island was associated with different levels of metal tolerance and closely tracked with metal concentrations in the environment, potentially constituting a mechanism for refining the adaptive response.

Researchers have long recognized the potential for adaptation-driven microbiome impact on the environment. Our ability to deeply profile complex microbiomes over time and space has finally begun to yield the data needed to integrate these dynamics into more accurate predictions of our future.

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