Regulating Earth's climate with micro-organisms

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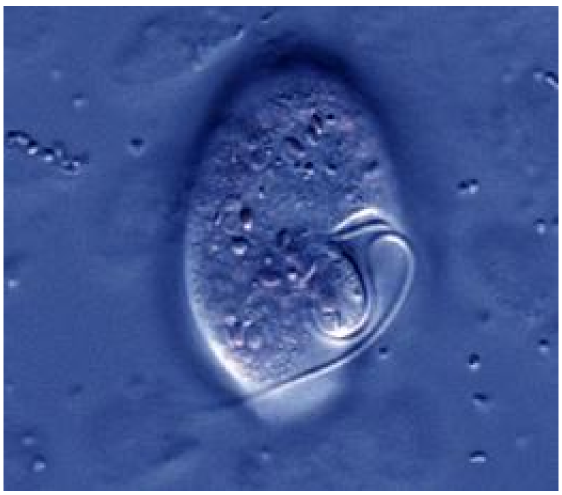

An image of the ventral face of Oxyrrhis marina, a micro-organism whose behavior was studied by an international team of scientists led by Professor Roman Stocker of the MIT Department of Civil and Environmental Engineering. Image: David Patterson/micro*scope

Scientists have sought to learn more about how the Earth's oceans absorb carbon dioxide and generally exchange gases with the atmosphere so they can better understand the corresponding effects on climate. To that end, many researchers are turning their attention to the microscopic organisms that help recycle carbon, nitrogen, sulfur and other elements through the oceans. Finding out exactly how and to what degree they do that is an ongoing scientific challenge, and scientists may first have to learn more about how the microbes interact with their environment at the scale of the individual microbe.

In recent work, an international team of scientists led by Professor Roman Stocker of the MIT Department of Civil and Environmental Engineering opened a window into that microbial world. The team studied how certain strains of marine microbes find and use sulfur, an element vital to many of them. Some microbes ingest the sulfur, convert it and pass it back into the ocean in altered form, keeping the chemical moving through Earth's sulfur cycle.

Using video microscopy, the scientists captured digital images of the single-celled microbes swimming toward two forms of sulfur: dimethylsulfide (DMS), the chemical responsible for the slightly sulfuric smell of the sea, and its precursor dimethylsulfoniopropionate (DMSP), which can be converted to DMS by the microbes. DMS is known to influence climate; when it moves from the ocean to the atmosphere as a gas, it oxidizes, forming cloud condensation nuclei which promote cloud formation over the ocean. These clouds reflect sunlight rather than allowing it to heat the Earth's surface.

Stocker, Justin Seymour, a former postdoctoral fellow at MIT who is now a research fellow at the University of Technology Sydney, Professor Rafel Simó of the Institute for Ocean Sciences in Barcelona, and MIT graduate student Tanvir Ahmed reported this research — which was funded by the Australian Research Council, the Spanish Ministry of Science and Innovation, La Cambra de Barcelona, the Hayashi Fund at MIT, and the National Science Foundation — earlier this year in the journal *Science*.

"It had been previously demonstrated that DMSP and DMS draw coral reef fish, sea birds, sea urchins, penguins and seals, suggesting that these chemicals play a prominent ecological role in the ocean. Now we know that they also attract microbes," said Stocker. "But this is not simply adding a few more organisms to that list. The billions of microbes in each liter of seawater play a more important role in the ocean's chemical cycles than any of the larger organisms."

Marine microcosm

Stocker has pioneered the use of microfluidic technology to study the behavior of marine microbes in the laboratory. He re-creates a microcosm of the ocean environment using a device about the size of a flash drive, made of clear rubbery material engraved with minuscule channels into which he injects ocean water, microbes and food in the form of dissolved organic matter. Then, using a camera attached to a microscope, he records the microbes' response. In the past few years, he has recorded microbes as they use their whip-like flagella to swim toward food, a finding that contradicts the traditional view of marine microbes as passive feeders.

In the latest research, the scientists injected different chemicals into the channels of the device in a way that mimicked the bursting of a microbial cell after a viral infection — a common event in the ocean. Although they performed the tests using several substances, including DMS, the scientists focused primarily on DMSP, which is produced by some phytoplankton and released into the water when a cell explodes. That DMSP can dissolve in the water or be transformed by other microbes into DMS, which also dissolves in the water before being released as a gas into the atmosphere.

The research indicates that the chemical's odor does draw microbial predators, much as its smelly cousin DMS does at larger scales. This is the first such study to make a visual record of microbial behavior in the presence of DMSP.

The team selected seven microbial species that are roughly analogous to plants, herbivores and predators in the animal kingdom: three photosynthetic microbes (phytoplankton), two heterotrophic bacteria that feed off the carbon produced by other microbes, and two microzooplankton that prey on other microbes.

Six of the seven microbial species tested were attracted to the DMSP in the microfluidic device; only one species — a phytoplankton — ignored it. Some of the species displayed the strongest swimming responses among any of the 100 or so cases yet tested by Stocker and Seymour in their research projects. This, Stocker said, is a clear indication that DMSP acts as a powerful chemical cue.

The researchers also found that some marine microbes, including bacteria, are attracted to DMSP because they feed on it, while others, the microzooplankton, are drawn to the chemical because it signals the presence of prey. This challenges previous theories that DMSP might deter predators. "Our observations clearly show that, for some plankton, DMSP acts as an attractant towards prey rather than a deterrent," said Simó.

Farooq Azam of the Scripps Institution of Oceanography, one of the first scientists to recognize the importance of microbes in the ocean food chain, agrees. "The findings of this study are exciting and unexpected in showing how broadly distributed throughout the microbial food web is the ability to sense DMSP and to behaviorally respond to it. In view of the significance of DMSP and DMS in global climate, these results should stimulate future research to understand how the potentially complex microbial interactions are reflected in the regulation of the fluxes of DMS and DMSP."

Azam also said that the study "adds substantial weight to the emergent view that understanding how microbes control the grand cycles of elements in the ocean and global climate" will require study at the scale of the individual microbe.

The researchers are now working on a system to replicate their experiments on oceanographic ships using bacteria collected directly from the ocean, rather than lab-cultured microbes. This will allow them to use microfluidics to create a virtual microbe aquarium at sea.

“We’re doing for microbes what ecologists have done with larger organisms for a long time,” said Stocker. “We’re observing them in order to better understand their behavior.”

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