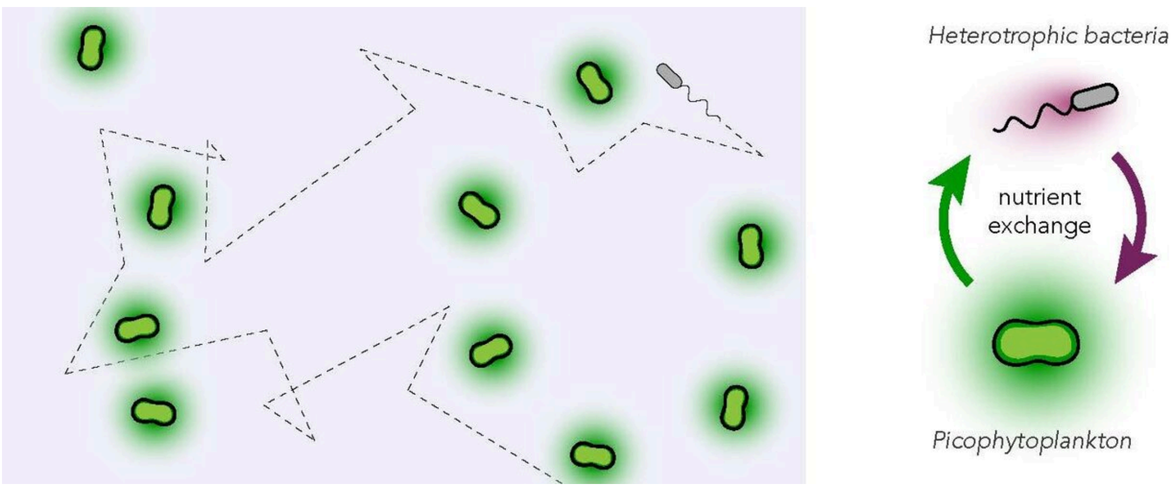
Fleeting interactions between the smallest phytoplankton and bacteria help to shape global ocean productivity

February 9 2023, by Dr Douglas R. Brumley



Chemotactic bacteria can swim towards the nutrient-rich water around picophytoplankton, but they don't stay long. Credit: Dr Douglas R. Brumley

Microorganisms, or microbes, are the engines driving large-scale ecological and biogeochemical processes in the ocean.

They process light and nutrients at a massive scale and represent the base of the marine food web.

While microbial activity in the ocean has typically been studied at large scales to understand things like global oxygen production and CO_2 sequestration, there's increasing evidence that the intricate small-scale movement of individual cells plays a major role in shaping the productivity of the ocean.

Bacteria swim towards large phytoplankton

Two types of microbes dominate in the ocean, phytoplankton and bacteria.

Phytoplankton are the tiny 'plants' of the open ocean, soaking up sunlight and using this energy to create food and oxygen. The exchange of nutrients between phytoplankton and bacteria regulates ocean productivity.

Under the microscope, marine bacteria (around one micrometer, or 1/1000th of a millimeter wide) are often seen clustering around large phytoplankton cells (like diatoms, which are approximately 0.5 to one millimeter in size), feeding from nutrients that seep into the environment.

Nutrient-rich areas around phytoplankton, referred to as phycospheres, attract bacteria, which home in on them using a process called chemotaxis.

However, phytoplankton come in a vast array of shapes and sizes, and the most abundant are also some of the smallest.

Picophytoplankton like Synechococcus (which are a form of photosynthetic bacteria called a cyanobacterium) can be hundreds of times smaller than diatoms.

Because of their tiny size—just a few micrometers wide—the prevailing view has been that cell-to-cell interactions between picophytoplankton and other bacteria are not possible. The chances of bumping into one another to share nutrients seemed incredibly slim, like needles finding other needles in a haystack.

Follow the [chemical] money

In collaboration with colleagues in the Climate Change Cluster at the University of Technology Sydney and around the world, we devised a series of experiments and mathematical models—published in *Nature Microbiology*—to test if and how swimming and navigation can help bacteria find these picophytoplankton 'needles in the haystack.'

To test if nutrients were being transferred between these different organisms, we grew the bacteria and picophytoplankton separately with different forms of nitrogen and carbon (called stable isotopes), and then grew them together for three hours in the lab.

Next, our team measured the nitrogen and carbon composition of individual cells and found that some of these nutrients had indeed transferred between the two types of organisms.

How important is bacterial movement?

For the experiment, we used bacteria that were chemotactic—they could swim towards food. But is swimming important for this nutrient exchange, and in fact, for cells in the ocean that are so small, is there any point at all in swimming?

To find out, we repeated these experiments with two different types of bacteria: bacteria that could swim but not navigate towards food and bacteria that could not swim at all.

The exchange of nutrients with the picophytoplankton was much lower in each case.

This demonstrated that the prevailing view was wrong. Bacterial swimming behavior is key in exchanging nutrients and using chemotaxis; bacteria can indeed home in on their nutrient-rich picophytoplankton targets.

Mathematical modeling shows us how it's done

Although bacterial sensing and movement are complex, their behavior can be very accurately captured by simplified mathematical models.

And the great thing about a good mathematical model is it does not just reproduce the experimental data but provides new insights into the system that are difficult or impossible to see in other ways.

Our mathematical model directly simulates the motion of thousands of bacteria swimming within a small droplet of seawater.

The model backed up our experimental findings that swimming enhances nutrient uptake from picophytoplankton. It also allowed us to follow individual bacterial cells and calculate how far from a food source they were—at all times.

A new type of symbiosis

We discovered that bacteria capable of performing chemotaxis will swim towards the picophytoplankton hotspots, but will frequently get 'lost' and move away.

Their targets are so small and the signal so weak that even with very precise navigation, it's impossible for them to reside indefinitely near a picophytoplankton cell. Their swimming movement will inadvertently take them away from the cell, and they then have to find their way back, or to another cell, a quite laborious process for these tiny bacteria.

This seems a very inefficient way to get nutrients but, in the same way that the casino house always wins in the end, the chemotactic cells gain up to 160 percent more nutrients than those that can't navigate.

This is because these bacteria spend a little more time in the very narrow nutrient-rich environment surrounding each hotspot.

The effect of visiting nutrient pulses more often and for slightly longer results in a significantly higher growth rate over time.

Our team's findings represent a new form of symbiosis, in which significant two-way exchanges occur between organisms, but over fleeting timescales of a few seconds. These results are in contrast to typical symbioses, which involve organisms sitting in close proximity to one another indefinitely.

Microscale movement is key

The main finding of our work is that cell behavior has a tremendous role in shaping metabolic partnerships between microorganisms.

Even though the cells are extremely small, the fine-scale movement of individual cells provides conspicuous advantages, which ultimately scale up to enhanced growth rates and help to shape overall ocean productivity.

Beyond the ocean, this work also shows that chemotaxis may play an unexpected role in the metabolic exchanges between individual cells across a whole range of other environments.

More information: Jean-Baptiste Raina, Chemotaxis increases metabolic exchanges between marine picophytoplankton and heterotrophic bacteria, *Nature Microbiology* (2023). DOI: 10.1038/s41564-023-01327-9.
www.nature.com/articles/s41564-023-01327-9

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