MICROBIAL ECOLOGY

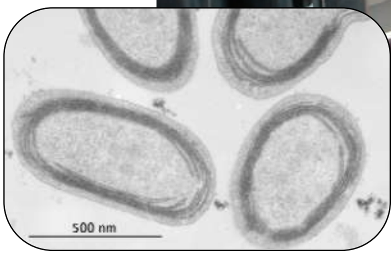
How a Marine Bacterium Adapts To Multiple Environments

Ahab chased a giant sperm whale through the seas for years. Sallie Chisholm has spent much of her professional career tracking far smaller denizens of the ocean: photosynthetic bacteria called *Prochlorococcus*. A marine microbiologist at the Massachusetts Institute of Technology (MIT), Chisholm helped discover these microbes 20 years ago. Now, she and her colleagues have charted the distribution of *Prochlorococcus* across the Atlantic Ocean and found that various strains congregate at different depths and places.

In a Research Article on page 1737 of this issue of *Science*, Chisholm's team describes how water temperature and other environmental factors determine which strains thrive at particular places. And in a Report on page 1768, she and her colleagues reveal newly discovered "guest" genes in two strains that may help each strain survive in particular ocean environments. The studies "give us a rare glimpse into the population genetics of a native population," says Stephen Giovannoni, a marine microbiologist at Oregon State University in Corvallis.

With 1700 genes, *Prochlorococcus* has the smallest genome known for a free-living, photosynthetic organism. Yet, in low-nutrient environments typical of deep oceans, it outnumbers all other marine microbes and can account for up to 48% of net primary production there. Moreover, although all *Prochlorococcus* strains are quite closely related—at least according to traditional comparisons of their ribosomal RNA gene—Chisholm and her colleagues found a diversity of physiologically distinct strains, or ecotypes. For example, some grow best in dim light, whereas others require four times as much sunshine as their low-light–adapted peers.

In 2003, Zackary Johnson, Chisholm's postdoctoral fellow, surveyed the ocean distribution of these ecotypes during a research cruise from Europe to the tip of South America. He and another postdoc, Erik Zinser, used the polymerase chain reaction to identify which ecotypes lived where. They also measured the biomass of *Prochlorococcus* and the amount of photosynthesis at specific depths at each sampling site. "This is the first [extensive] study about *Prochlorococcus* distributions at the ecotype level," says Jakob Pernthaler, a microbial ecologist at the University of Zurich, Switzerland. "It's an impressive data set."



Hot on the trail. Erik Zinser searches for the cyanobacterium *Prochlorococcus* (*inset*).

CREDITS: ZACKARY JOHNSON/MIT; (INSET) CLAIRE C. TING/WILLIAMS COLLEGE

On the trip, water temperatures ranged from 5°C to 29°C, and nitrate, phosphate, silicate, and other nutrients utilized by *Prochlorococcus* were more abundant in the southern reaches. At certain sampling sites, two of the light-loving strains populated the surface in about equal numbers. And at depths of 50 meters, a low-light–adapted strain typically appeared, its abundance increasing with depth until about 75 meters down. Deeper down, a second low-light–adapted strain would take over. However, these distributions varied by latitude. Close to the equator, one low-light–adapted strain was as common at the surface as a high-light–adapted one. Together, these data provide "an ocean snapshot of *Prochlorococcus* biogeography" that will aid the understanding of this organism's ecology and role in the environment, says Eugene Madsen, a microbial ecologist at Cornell University.

Edward DeLong, a microbiologist at MIT, also recently found stratification of the *Prochlorococcus* strains, but through a slightly less direct method (*Science*, 27 January, p. 496). His team, which included Chisholm and her postdoc Matthew Sullivan, sampled all the DNA in a water column from 10 meters to 4000 meters down, at a monitoring station off Hawaii. They then used a sophisticated computer program to assemble the bits of DNA into sequences large enough to identify genes and to get a read on which organisms were present. For example, that work showed that genes from high-light–adapted and low-light–adapted *Prochlorococcus* strains had different abundances at various depths.

DeLong's group also discovered high concentrations of bacterial viruses called phages at ocean depths where *Prochlorococcus* lives; the greatest concentrations were at a depth of 70 m. The second study by Chisholm's team indicates that such phages are key to the adaptability of *Prochlorococcus*. Chisholm says that the viruses have inserted "islands" of genes into this bacterium, helping to create the various ecotypes she and others have found. In each strain, the islands are located in about the same place on the bacteria's chromosome, but the genes they contain vary from strain to strain. "These are hot spots in the genomes that appear to be very dynamic," says Chisholm.

When Chisholm's graduate student Maureen Coleman looked at these islands in two high-light–adapted strains growing in the lab, she found genes important for photosynthesis and for proteins for coping with stress, such as phosphorus deficiencies. Some of the islands' genes were the same in all strains. But not always: *Prochlorococcus* collected from the Mediterranean had a gene likely to be important for nitrogen scavenging, but this gene was lacking in another strain. Thus, the island genes may enable various strains to thrive at particular depths, light intensities, nutrient content, and temperatures. "The case is very strong that the islands and their variations play a role in [*Prochlorococcus*] evolution," says Madsen.

Pathogenic bacteria often have phage-delivered islands of DNA that contain genes for increased virulence or drug resistance, so it's not unexpected that similar islands enhance *Prochlorococcus*'s survival, says Xabier Irigoyen of AZTI-Tecnalia in Pasaia, Spain. Nonetheless, Pernthaler notes, "it's a great piece of science that will inspire follow-up for other marine bacteria."

–ELIZABETH PENNISI