The Cells That Rule the Seas

The ocean's tiniest inhabitants, notes biological oceanographer Sallie W. Chisholm, hold the key to understanding the biosphere—and what happens when humans disturb it   By STEVE NADIS

An unseen "forest" of microscopic beings fills the upper 200 meters of ocean, exerting an influence on this planet every bit as profound as the forests on land. The diverse phytoplankton species inhabiting the ocean's surface waters—which mainly consist of single-celled cyanobacteria, diatoms and other kinds of algae—form the base of the marine food web. They account for roughly half the photosynthesis on the earth, remove nearly as much carbon dioxide from the atmosphere as all land plants, and supply about half the oxygen we breathe. Without the activities of these free-floating plantlike organisms, atmospheric carbon dioxide levels would triple.

SALLIE ("PENNY") CHISHOLM: SEEING SMALL

- Discovered *Prochlorococcus* in 1988. The microbe's minute size enables it to capture sunlight efficiently (there is less self-shading).
- *Prochlorococcus* is responsible for roughly half the photosynthesis in the oceans. A drop of seawater contains up to 20,000 cells.
- On promoting phytoplankton growth with iron: "Even if you fertilized the entire ocean, it wouldn't make much of a dent on global warming—at best postponing the inevitable by about five years."

That phytoplankton could accomplish so much with so little recognition from the general public is surprising [see "The Ocean's Invisible Forest," by Paul Falkowski; SCIENTIFIC AMERICAN, August 2002]. Even more remarkable, scientists had no idea which microbial species performed the bulk of these vital functions until 15 years ago, when Sallie W. Chisholm of the Massachusetts Institute of Technology, Robert J. Olson of the Woods Hole Oceanographic Institution and other collaborators discovered marine cyanobacteria from the genus they later named *Prochlorococcus*. They are the smallest and most numerous photosynthetic organisms known and arguably the most plentiful species on the earth, responsible at times for more than half the photosynthesis in the seas. Cyanobacteria such as *Prochlorococcus* were the planet's first oxygen-producing creatures and are, in a broad sense, the ancestors of all higher plants.

Chisholm and Olson made their discovery by sampling ocean water with a flow cytometer—an instrument common in life sciences laboratories but one that had never been taken to sea before. The device helps to characterize single cells as they move past a laser beam. By measuring the scattering of laser light by seawater, the researchers saw hints of tiny cells. After isolating and culturing these cells, Chisholm's team named them *Prochlorococcus*, believing they were related to cyanobacteria called prochlorophytes—a supposition that later proved incorrect. Next, the team documented the abundance of *Prochlorococcus*. The microbe's dominance of the seas shocked the oceanography community. "It's hard to believe we'd overlooked something so important for so long," says Richard T. Barber of the Duke University Marine Laboratory. Chisholm considers the discovery "a lesson in humility, showing just how little we know about nature." This past April she was elect-

PHOTOGRAPH BY KATHLEEN DOOHER, WOODS HOLE, MASS.

ed to the National Academy of Sciences, largely for her role in the discovery and subsequent investigation of *Prochlorococcus*.

Despite its size—just 0.5 to 0.7 micron wide—*Prochlorococcus* has a major impact on climate because of its sheer abundance, up to 20,000 cells per drop of seawater. That's not nearly as dense as soil microbes, which may reach concentrations more than 1,000 times as high. But among photosynthesizers, tiny *Prochlorococcus* is huge. "People had assumed that much bigger organisms were fixing carbon," notes Scripps oceanographer Farooq Azam. "Penny's work has focused attention on the role of the small." (Chisholm is known as Penny to friends and colleagues—a childhood nickname that she adopted to avoid confusion with her mother and grandmother, both also named Sallie.)

Although the 56-year-old Chisholm has indeed kept her gaze on the smallest marine creatures, her career might easily have taken a different turn. In college chemistry experiments more than 30 years ago, she measured manganese concentrations in an upstate New York lake. Every water sample she inspected was filled with specks of phytoplankton. She became fascinated with these organisms and soon jettisoned plans for graduate study in chemistry.

PROLIFIC *Prochlorococcus* might be the most abundant species on the planet.

Instead Chisholm has made *Prochlorococcus* her chief research interest, guided by the conviction that "this organism could open doors for us. The reason to study it is its global importance. Whatever we learn, the multiplier is enormous." Chisholm and her colleagues have identified about 35 *Prochlorococcus* species and strains and have categorized two general classes that inhabit different subsurface layers, adapted to high and low light conditions. The team has subdivided the genus into six additional categories, based on an analysis of the ribosomal RNA gene. But Chisholm hopes to go much further and obtain complete genomes for all known species so that more thorough comparisons can be made.

This past August researchers unveiled complete genomes for three *Prochlorococcus* strains plus a strain of *Synechococcus,* a close relative. Chisholm participated in the analysis of two strains, one having the smallest genome—1.7 million base pairs and 1,700 genes—of any known oxygen-producing photosynthesizer. By seeing which genes a strain possesses—such as a gene to utilize nitrate, nitrite or cyanate—scientists can learn which nutrients are significant and what parameters govern an organism's abundance. This approach can reveal environmental factors that have not been appreciated before.

Her ultimate goal is to determine the biosphere's vital components: "What regulates them, how much we have to preserve for them to function properly, and what pushes them beyond their limits," Chisholm states. That knowledge can only come by studying the system as a whole and piece by piece. Until we understand how the biosphere works, she adds, we can't gauge the extent to which human activities disturb its functions.

What would happen, for instance, if we tried to offset global warming by pouring large quantities of iron into the oceans? The idea, sometimes called the "Geritol" solution, is to add the mineral to iron-poor ocean regions, thereby stimulating phytoplankton growth. The proliferating organisms would then remove carbon dioxide from the air. Although Chisholm has criticized this concept since it was advanced in the late 1980s, she has participated in experiments to test the hypothesis, starting in 1993 with the IRONEX experiment in the eastern equatorial Pacific. On a small scale, iron fertilization can be a powerful research tool, Chisholm maintains.

Yet she is equally convinced that large-scale fertilization would be a mistake. "How can we manipulate this system when we don't know what's in it?" she asks. "The oceans are performing all kinds of functions we don't understand." If the approach works at all—still an open question—it will inevitably alter the food web, promoting the growth of larger cells such as diatoms at the expense of smaller ones such as *Prochlorococcus,* with unknown effects rippling through the trophic levels.

By no means an activist, Chisholm rarely joins causes or signs petitions, but on this issue she feels obliged to speak out. "I didn't spend my life studying how aquatic ecosystems work only to have this fundamental knowledge ignored," she says.

Most ocean scientists agree with Chisholm about iron fertilization. Nevertheless, she observes, "this idea just won't go away." Every year she hears of a different patent filed, a new commercial venture or some other fertilization scheme. Part of the problem is the profit motive, but Chisholm also holds scientists responsible. Although it is essential to clarify iron's role as a limiting nutrient, she says, this research is commonly justified by tying it to ocean fertilization. "Somehow we must evolve to the point where people accept the importance of studying how the biosphere works—what regulates the flow of energy and cycling of elements—in its own right."

Chisholm is similarly irritated by claims that *Prochlorococcus* can be genetically engineered to draw down more carbon, thereby making it "useful" to humans. "These guys are already useful to humans," she says of her favorite cells. "They're out there doing their job in planetary maintenance, helping to regulate the biogeochemical cycles of the biosphere." The job for Chisholm and other humans is to figure out precisely what these organisms do and how they do it. SA

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