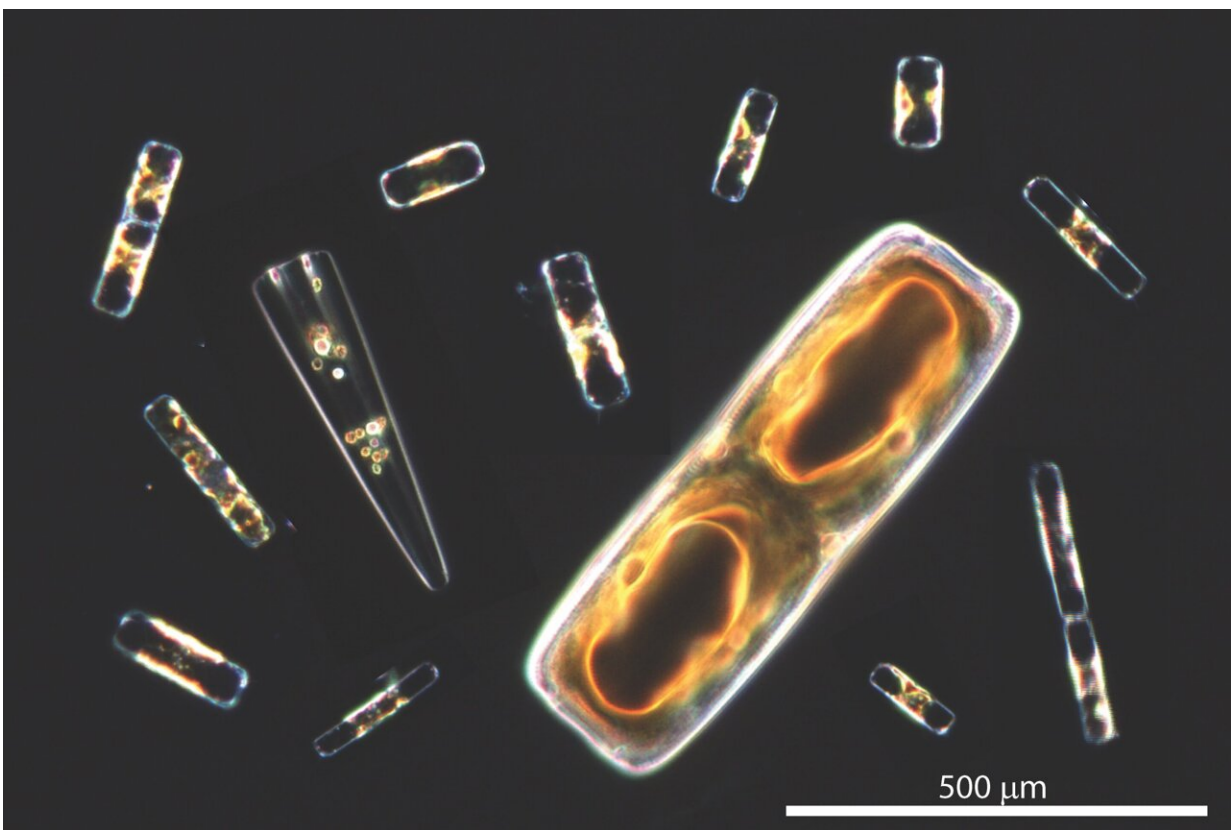


# Phenomenal phytoplankton: Scientists uncover cellular process behind oxygen production

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A composite image of diatoms, single-celled algae famous for their ornamental cell walls made of silica. Credit: Daniel Yee

Take a deep breath. Now take nine more. According to new research, the

amount of oxygen in one of those 10 breaths was made possible thanks to a newly identified cellular mechanism that promotes photosynthesis in marine phytoplankton.

Described as "groundbreaking" by a team of researchers at UC San Diego's Scripps Institution of Oceanography, this previously unknown process accounts for between 7% to 25% of all the oxygen produced and carbon fixed in the ocean. When also considering photosynthesis occurring on land, researchers estimated that this mechanism could be responsible for generating up to 12% of the oxygen on the entire planet.

Scientists have long recognized the significance of phytoplankton—microscopic organisms that drift in aquatic environments—due to their ability to photosynthesize. These tiny oceanic algae form the base of the aquatic food web and are estimated to produce around 50% of the oxygen on Earth.

The new study, published in *Current Biology*, identifies how a proton pumping enzyme (known as VHA) aids in global oxygen production and carbon fixation from phytoplankton.

"This study represents a breakthrough in our understanding of [marine phytoplankton](#)," said lead author Daniel Yee, who conducted the research while a Ph.D. student at Scripps Oceanography and currently serves as a joint postdoctoral researcher at the European Molecular Biology Laboratory and University of Grenoble Alpes in France.

"Over millions of years of evolution, these small cells in the ocean carry out minute chemical reactions, in particular to produce this mechanism that enhances photosynthesis, that shaped the trajectory of life on this planet."

Working closely with Scripps physiologist Martín Tresguerres, one of his

co-advisors, and other collaborators at Scripps and the Lawrence Livermore National Laboratory, Yee unraveled the complex inner workings of a specific group of phytoplankton known as diatoms, which are single-celled algae famous for their ornamental cell walls made of silica.

## Understanding the 'proton pump' enzyme

Previous research in the Tresguerres Lab has worked to identify how VHA is used by a variety of organisms in processes critical to life in the oceans. This enzyme is found in nearly all forms of life, from humans to [single-celled algae](#), and its basic role is to modify the pH level of the surrounding environment.

"We imagine proteins as Lego blocks," explained Tresguerres, a study co-author. "The proteins always do the same thing, but depending on what other proteins they are paired with, they can achieve a vastly different function."

In humans, the enzyme aids kidneys in regulating blood and urine functions. Giant clams use the enzyme to dissolve [coral reefs](#), where they secrete an acid that bores holes in the reef to take shelter.

Corals use the enzyme to promote photosynthesis by their symbiotic algae, while deep-sea worms known as Osedax use it to dissolve the bones of marine mammals, such as whales, so they can consume them. The enzyme is also present in the gills of sharks and rays, where it is part of a mechanism that regulates blood chemistry. And in fish eyes, the proton pump helps deliver oxygen that enhances vision.

Looking at this previous research, Yee wondered how the VHA enzyme was being used in phytoplankton. He set out to answer this question by combining high-tech microscopy techniques in the Tresguerres Lab and

[genetic tools](#) developed in the lab of the late Scripps scientist Mark Hildebrand, who was a leading expert on diatoms and one of Yee's co-advisors.

Using these tools, he was able to label the proton pump with a fluorescent green tag and precisely locate it around chloroplasts, which are known as "organelles" or specialized structures within diatom cells. The chloroplasts of diatoms are surrounded by an additional membrane compared to other algae, enveloping the space where carbon dioxide and light energy are converted into organic compounds and released as oxygen.

"We were able to generate these images that are showing the protein of interest and where it is inside of a cell with many membranes," said Yee. "In combination with detailed experiments to quantify photosynthesis, we found that this protein is actually promoting photosynthesis by delivering more [carbon dioxide](#), which is what the chloroplast uses to produce more complex carbon molecules, like sugars, while also producing more oxygen as a by-product."

## **Connection to evolution**

Once the underlying mechanism was established, the team was able to connect it to multiple aspects of evolution. Diatoms were derived from a symbiotic event between a protozoan and an algae around 250 million years ago that culminated into the fusing of the two organisms into one, known as symbiogenesis.

The authors highlight that the process of one cell consuming another, known as phagocytosis, is widespread in nature. Phagocytosis relies on the proton pump to digest the cell that acts as the food source. However, in the case of diatoms, something special occurred in which the cell that was eaten didn't get fully digested.

"Instead of one cell digesting the other, the acidification driven by the proton pump of the predator ended up promoting photosynthesis by the ingested prey," said Tresguerres. "Over evolutionary time, these two separate organisms fused into one, for what we now call diatoms."

Not all algae have this mechanism, so the authors think that this [proton pump](#) has given diatoms an advantage in photosynthesis. They also note that when diatoms originated 250 million years ago, there was a big increase in oxygen in the atmosphere, and the newly discovered mechanism in algae might have played a role in that.

The majority of fossil fuels extracted from the ground are believed to have originated from the transformation of biomass that sank to the ocean floor, including diatoms, over millions of years, resulting in the formation of oil reserves.

The researchers are hopeful that their study can provide inspiration for biotechnological approaches to improve photosynthesis, carbon sequestration, and biodiesel production. Additionally, they think it will contribute to a better understanding of global biogeochemical cycles, ecological interactions, and the impacts of environmental fluctuations, such as climate change.

"This is one of the most exciting studies in the field of symbiosis in the past decades and it will have a large impact on future research worldwide," said Tresguerres.

**More information:** Daniel P. Yee et al, The V-type ATPase enhances photosynthesis in marine phytoplankton and further links phagocytosis to symbiogenesis, *Current Biology* (2023). [DOI: 10.1016/j.cub.2023.05.020](https://doi.org/10.1016/j.cub.2023.05.020)  
[www.cell.com/current-biology/f ... 0960-9822\(23\)00615-2](https://www.cell.com/current-biology/fulltext/S0960-9822(23)00615-2)

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