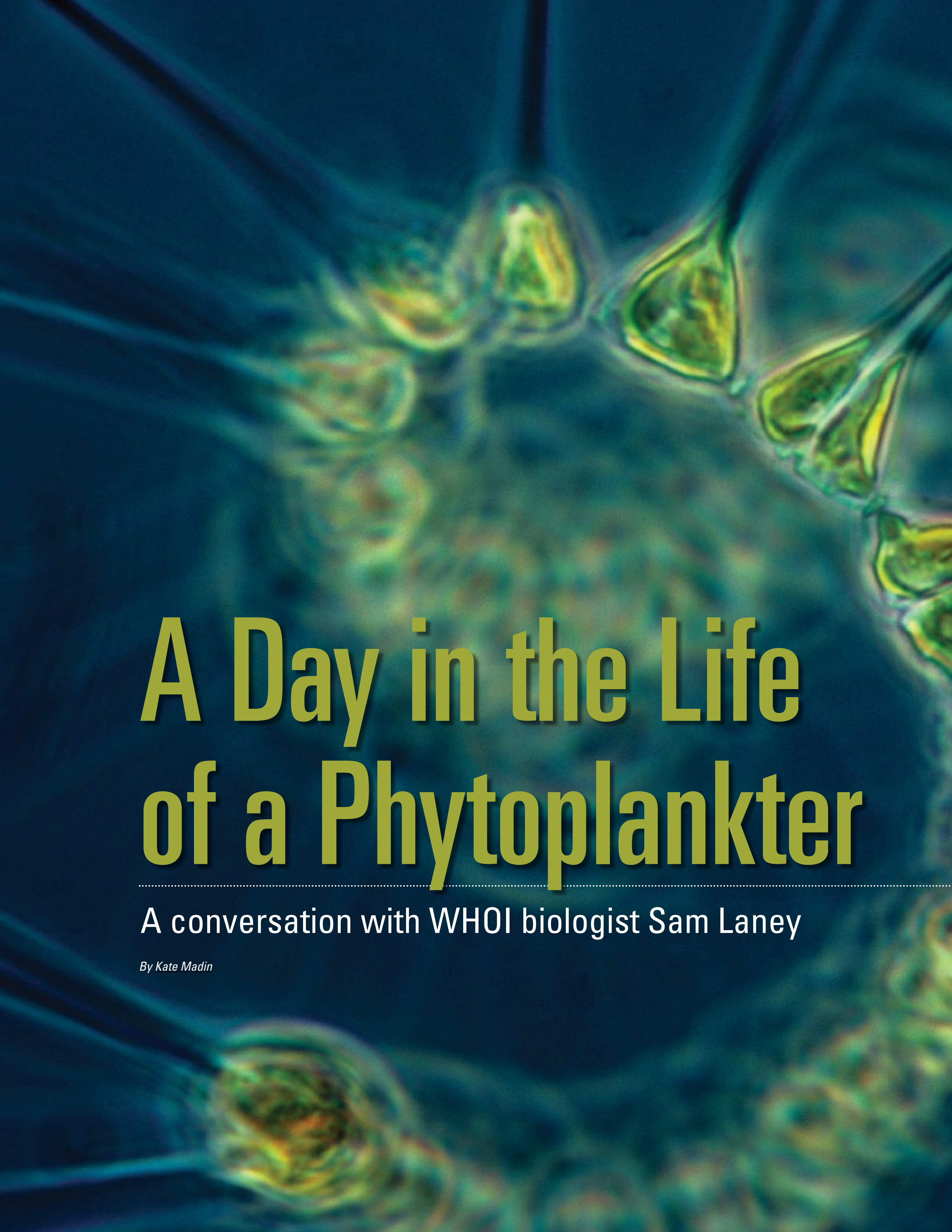
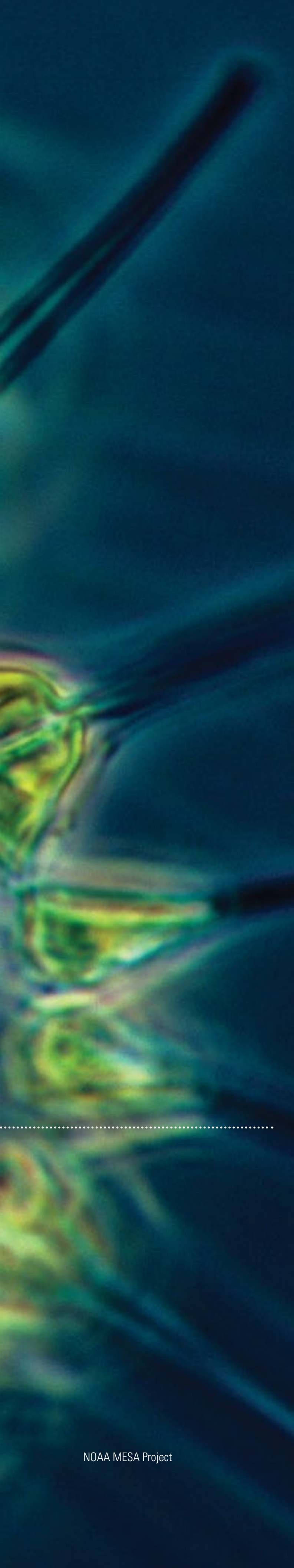


A Day in the Life of a Phytoplankter

A conversation with WHOI biologist Sam Laney

By Kate Madin



NOAA MESA Project

Earth's oceans teem with innumerable microscopic plants that make the fertility and abundance of the Grain Belt in the United States look like, well, a drop in the ocean. Sam Laney, a biologist at Woods Hole Oceanographic Institution (WHOI), has a unique perspective of these "grasses of the sea."

Why are phytoplankton so important?

Just like plants on land, phytoplankton do photosynthesis: They suck up carbon dioxide and exhaust oxygen. About half of the oxygen on the planet comes from phytoplankton, so every other breath you take is phytoplankton air. Moreover, phytoplankton are the base of marine food webs. Tuna fish or squid ultimately exist because earlier in the food chain, somebody ate some phytoplankton.

Your approach seems a little more personal.

Most oceanographers think about phytoplankton as a big biomass of plants. They think of them as a population, or crop, or conduits for large-scale biogeochemical processes. Which is fine. But they're individuals, too. I'm interested in them as individual beings.

So, what is life like for an individual phytoplankton cell—a phytoplank*ter*? If you were a phytoplankton cell, how would you see your environment? What things are important to you? What situations would you experience over your short life span, and what can you do in response?"

How do you explore the lives of individual cells in the ocean?

That's always been one of the challenges of phytoplankton ecology: You can look under a microscope and see *a cell*. But you can't track it over its lifespan or through its history. Terrestrial ecologists have it easy—they can tag a lion, for example. We oceanographers cannot tag a phytoplankter and follow it around in the ocean. It's hard to see the world the way a phytoplankter does.

I try to get around this by looking at things a phytoplankton cell can change about itself within a day or two, because that would be its life span. If I can tell you how a single diatom—a type of phytoplankton—can respond to a passing cloud, then I can tell you how diatom *populations* respond to passing clouds.

How does a phytoplankter's life story begin?

A cell and its sister are formed when their parent cell divides in two. Then the name of the game is absorbing enough nutrients and energy to grow large enough that you can divide—and to do that *quickly*, because somebody is trying to eat you.

People can eat burgers and get both energy and nutrition out of the one meal, but phytoplankton have to get theirs in two separate servings. They get energy from absorbing sunlight, but they have to absorb dissolved nutrients to get their nutrition. In the open ocean, the nutrients near the surface are coming from below, but the sunlight is coming from above. If you're a phytoplankton cell and you're too high in the water column, you get lots of light but no nutrients, and if you're too low, you get plenty of nutrients but not a lot of light. The best place to live is in a sweet spot in the middle. That's one way a phytoplankter sees the world: It's looking in two directions for the two important things that it needs.

It seems like an uncertain existence.

Talk about extreme environments! If you're a tree that lives for years, you can bank on having decent light levels over your life. But if you're a phytoplankter that lives only a few days, you might have decent light one day, but then a current pushes you down in the ocean so tomorrow you've got little to no light.

WHOI biologist Sam Laney

Passing clouds also cause fluctuations in sunlight. Clouds are intermittent over the ocean, so a phytoplankter experiences dim light, then bright light, then dim again. When the sun rises in the morning, how does a phytoplankter plan ahead? It has to be very flexible in its responses to good, bad, and changing light conditions.

How do phytoplankton harness light energy?

Photosynthesis starts with absorbing sunlight, which is done by chlorophyll and other pigments. Chlorophyll is inside structures called chloroplasts where individual chlorophyll molecules are packaged into little bundles called "reaction centers." [See next page.] The reaction centers absorb photons of light and shovels that energy into energy-storing or electron-storing molecules such as ATP (adenosine triphosphate) and NADPH (nicotinamide adenine dinucleotide phosphate). The cell uses ATP and NADPH in reactions to make compounds the cell needs: sugars, lipids, amino acids, and DNA. This energy also goes to repairing cell damage, swimming (if you can swim), and, of course, for reproduction.

It sounds like an assembly line in a factory.

Yes, keeping a smooth flow of energy through its reaction centers is really important to plants. If the reaction center has to wait too long between photons, the assembly line is sitting idle. That's inefficient.

When a chlorophyll molecule absorbs a photon, it rings like a bell—it actually starts resonating. But a chlorophyll molecule can only deal with a certain amount of energy at a time. If it gets two photons' worth of energy at once, it can break.

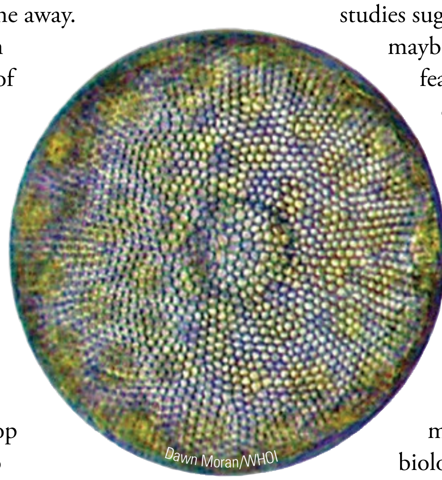
What can a phytoplankter do to respond to changing light conditions?

That's something I'm investigating. In lower light, it can make more chlorophyll, but that takes many hours and costs a lot of energy. You can't use that response to adjust to rapid changes in sunlight caused by intermittent clouds. You need other, faster responses to keep feeding chlorophyll *just the right amount* of energy: enough so that they're not idle, but not so much that they get overexcited and break.

So phytoplankton have evolved other types of special pigments, including ones called xanthophylls. In land plants, these are the yellow-colored pigments that remain in leaves in autumn after the green chlorophyll has gone away.

Some xanthophylls help phytoplankton absorb light, but others help them get rid of excess light. They act like sunscreen. Some xanthophylls actually do both: They can quickly shift from being a helper pigment to being a protective pigment. Shifts in light ultimately cause tiny shifts in the structure of the xanthophyll molecules—to make them either feed light to chlorophyll, or shunt light away. That maintains a smooth flow of light energy through the reaction centers.

These xanthophyll pigments can flip-flop within *minutes* to convert from helper into protector pigments. That's a pretty amazing little trick for a microbe.



Diatoms are plankton that live in transparent silica shells.

I've also looked at photosynthetic responses to natural cloud variability in the ocean off Hawaii. Most days have some cloud cover. People had thought that these pigments flip-flopping back and forth don't really boost photosynthetic performance much in the real world. But from what I see, I think it can change phytoplankton's overall efficiency by 25 percent

That's not a trivial amount.

Yeah, exactly—would you take a 25 percent pay cut?

A 25-percent enhancement over 30 minutes might be enough to matter ecologically—it could make the difference between being able to reproduce today, or having to wait until tomorrow. And while you're standing by overnight waiting for the sun to come up, you are prey!

What are some other reasons to study phytoplankton as individuals?

We tend to assume that when single-celled organisms divide asexually, they produce two identical daughter cells. But when diatoms divide, they produce one daughter cell that is slightly smaller than its sister.

Is there any difference other than size between two diatom daughter cells, and if so, which daughter cell does better? For organisms that give birth to twins, there are a lot of studies about whether the older or younger twin does better. These are obvious questions to ask about dogs or monkeys or people. Sometimes it surprises me how we've gotten this far without asking these same types of questions about phytoplankton.

How did you investigate this and what have you found?

I did an experiment with my WHOI colleagues Rob Olson and Heidi Sosik where I made time-lapse movies of diatom cells dividing, generation after generation. I wrote software to keep track of individual cells in these movies.

We showed that the smaller of the two diatom daughters inherits more cellular material (or cytoplasm) from its parent, and subsequently grows faster and divides sooner than its larger sister. It looks like diatoms "favor" the smaller daughters somehow.

This is the first time this has been shown in diatoms. Other studies suggest it's true in bacteria as well, and so maybe this type of favoritism is a more universal feature in microbes. That could have significant ecological implications.

How did you arrive at this area of research?

I've got an engineering degree and a biology degree. I used to think that the engineering degree was useful because it allowed me to build things. But now I'm beginning to think that the engineering degree is valuable because it allows me to apply "engineering-style thinking" to biological systems.

By "engineering-style thinking," do you mean thinking about phytoplankton cells as machines?

Exactly! You can look at a machine in a physical sense, with gears and a motor and wires. A phytoplankton cell is like that: There's stuff inside that does certain jobs, and these things are connected to one another, so that the whole cell acts as a coordinated gadget. A mechanical engineer will get it when you describe a phytoplankton cell in this way.

But you can also look at machines in a more abstract sense—as a coordinated network of individual items linked together that, as a whole, does a certain thing—in the case of phytoplankton, to grow and reproduce. This might be the way it's seen by operations engineers who do factory design and care about the flow of things through a large complex system.

For instance, think about how you might plan for a factory that makes iPads: You have to get different raw materials, and then you have to process these through a factory so that iPads come out the other end. You need to optimize the flow so there are no bottlenecks, so that everything is working smoothly from where the ore for materials is mined to where you buy your iPad in Boston.

When I first started thinking of phytoplankton from an engineering perspective, I thought about them as little computers, asking questions such as: What's their algorithm for dealing with changes in life? Now it's more like phytoplankton as "dynamical systems," which is how an operations engineer might think of this problem of keeping light energy flowing smoothly through a cell.

Describe this dynamical systems approach.

Presumably people at Apple build their systems so they don't end up with an idle assembly line and an iPad shortage if a supplier can't provide a necessary material. They have sophisticated software at their disposal to tackle *dynamical* questions such as: "How do you plan for the future when something critical to you might not be always available?" That's a tough mathematical problem.

In my case, it's the flow of light through a plant, and what happens if the flow of light is disrupted. It's pretty phenomenal, the complexity of the phytoplankton organism, given how supposedly simple it is. It's not a tree, it's not a Venus flytrap, it's a microbe. It doesn't look complicated compared with bigger plants, but it displays complex behavior.

You have a philosophical approach.

That's because I spent the first two years of college studying political philosophy!

Do you recommend that?

Yep! All science students should study a little philosophy, especially the philosophy of science. A lot of people know how to pose a scientific question and address it, but that doesn't necessarily mean they've got a big picture or appreciate the limits to knowledge. Anybody who has studied the philosophy of science will tell you that you can never *prove* anything; you can at best only *disprove* something.

For me, science isn't for answering questions; my job is to *make* questions! As a scientist, you're on the frontier of knowledge. There is nothing ahead of you but empty space, until you start putting ideas into it. Some of the best scientists are the ones who are comfortable looking into the black, where nothing is known. They realize how *much* is unknown, and are still willing to take that step forward. ▲

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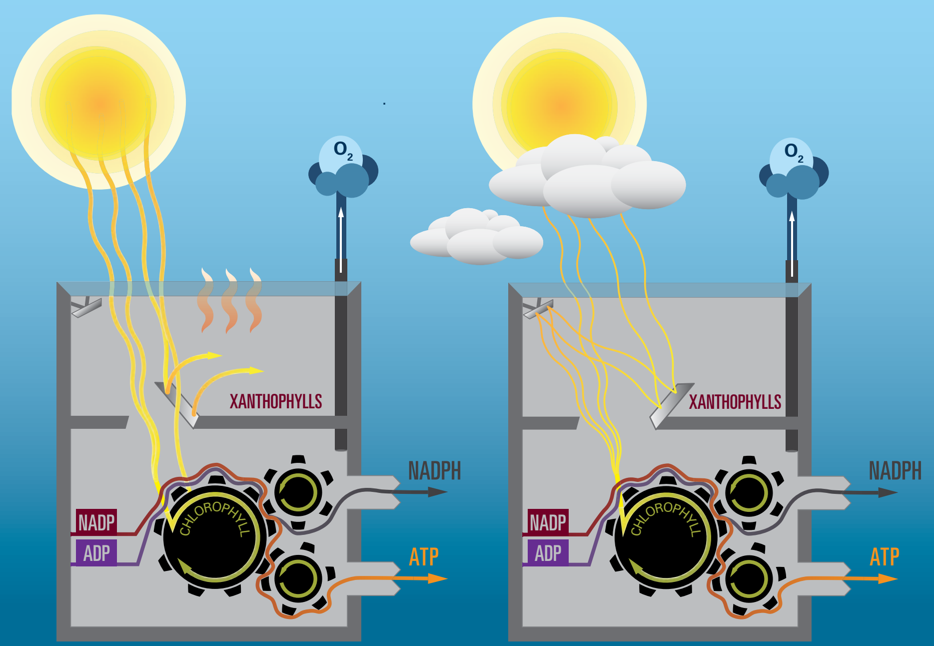
Let the sun shine in

Single-celled phytoplankton carry out photosynthesis inside organelles called chloroplasts containing the green pigment chlorophyll. Acting like little factories, chloroplasts take in energy (sunlight) and raw materials (carbon dioxide) and create products (sugars) and waste products (oxygen).

To cope with widely fluctuating light levels, many phytoplankton have certain red accessory pigments called xanthophylls that act like gatekeepers. As light levels change, their structures alter to send more or less light energy to chloroplasts.

FIRST-STAGE LIGHT REACTIONS



High light levels can damage chlorophyll, so xanthophylls absorb excess light and burn it off as heat.

Low light doesn't provide enough energy for sugar production, so xanthophylls absorb more light to relay to chlorophyll.

Chlorophyll absorbs light energy that fuels the production of two important molecules, ATP and NADPH. Oxygen is a byproduct of the process.

SECOND-STAGE DARK REACTIONS

In the second stage of photosynthesis, different cellular "machinery" takes in carbon dioxide and uses ATP and NADPH to produce sugars that are used for growth, repair, and reproduction.

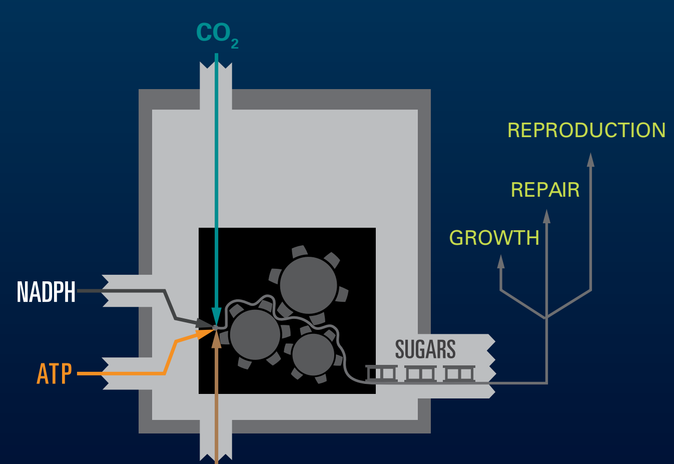


Illustration: Amy Caracappa-Qubec/WHOI