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THE BIOLOGICAL CARBON PUMP: CLIMATE CHANGE WARRIOR

BY MADALYN MILES

Imagine a cold, windy day out on the open ocean, and your robot just got chewed up by a shark.

For Jim Bishop, a professor of Marine Science at UC Berkeley, conducting research at sea comes with risks such as these. But a bigger challenge is the well-being of the biochemical mechanism that his team is studying beneath the waves. This biochemical mechanism is called the "Biological Carbon Pump," and it may help calm the crisis of global warming. The Pump naturally sinks as much carbon to ocean depths as is found in the atmosphere, but as humans continue to emit greenhouse gases, can the Pump keep up?[1] Professor Bishop and PhD student Hannah Bourne are studying the Pump's process of carbon sequestration, hoping that by understanding its pathways, they may be able to help the Pump help us.

THE BIOLOGICAL CARBON PUMP: THE BASICS

The Pump's traditionally understood salt-shaker mechanism is relatively simple. Picture a vertical sequestration of carbon through a marine food chain. Phytoplankton, such as coccolithophores, take up carbon into their shells. Then, they are preyed on by larger organisms and sink to the bottom of the ocean as feces to be buried via deep-sea sedimentation. On a molecular level, carbon starts as carbon dioxide in the atmosphere. Most winds up in the bodies of phytoplankton through the movement of three dissolved organic compounds: carbonic acid (H_2CO_3), bicarbonate (HCO_3^-), and carbonate (CO_3^{2-}).[2] First, atmospheric carbon dioxide is absorbed in the upper euphotic layer of the ocean and mixes with water molecules to form carbonic acid.[3] Second, H_2CO_3 discards its hydrogen atoms one by one to become HCO_3^-, and then a CO_3^{2-} ion, which coccolithophores will use to form their calcium carbonate ($CaCO_3$) plates on their shells (Fig. 1a). Once these plated primary producers are consumed by larger organisms such as zooplankton (Fig. 1b-c), they become ballast-like fecal pellets that rain down like salt towards the deep sea (Fig. 1d).[4]

Scientists may reasonably understand this traditional salt-shaker mechanism, but understanding what controls the Pump's rate of carbon flux is more complicated. Twenty years and six research papers later, Professor Bishop and his research team have been convinced that primary productivity in the ocean and the rate of carbon flux vary across space and time.

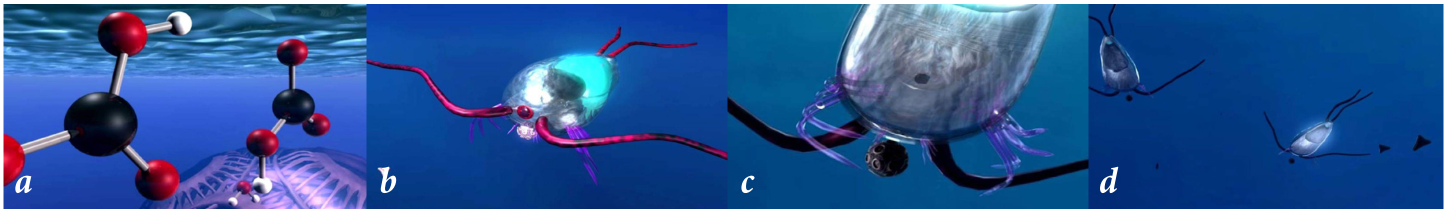

Figure 1: *The steps of the ocean's Biological Carbon Pump.*

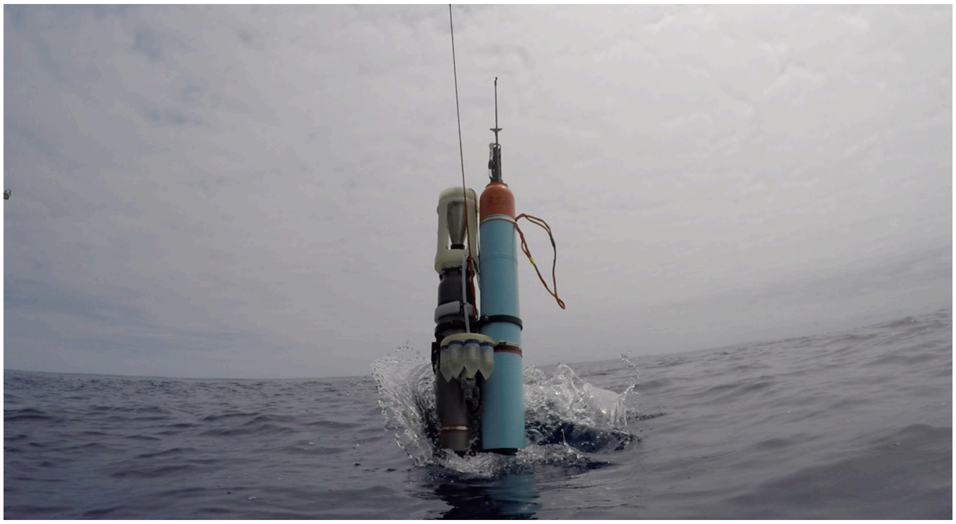

Figure 2: *A CFE robot breaks the surface of the ocean as it is launched. It is ready to monitor how much carbon the Pump is sending downwards.*

VARIATION ACROSS TIME

Professor Bishop observed the seasonal variations of primary productivity back in 1996. While at the Lawrence Berkeley National Lab, he launched the first set of ocean profiling robots called the Carbon Flux Explorers (CFEs) in the North Pacific, just off Canada's west coast, in order to measure the concentrations of carbon particles in the ocean. Within weeks, nature delivered a dust storm that swept from Asia across the North Pacific, dusting and fertilizing the sea with iron. Bishop, along with two other scientists from the Scripps Institution of Oceanography in La Jolla, California, hypothesized that an increase in iron, a limiting nutrient for phytoplankton, would stimulate primary productivity, and therefore carbon flux.[5,6]

"Sure enough, we got a signature of the stimulation of the biology as a result of the deposition of dust iron," Professor Bishop says of the 1996 experiment. "But the effect only lasted for three weeks!"

> "By understanding its pathways, scientists] may be able to help the Pump help us."

The reason the effect was so short-lived is that the Pump's turnover time is lightning quick. While landlocked carbon cycles circulate on a time scale of over two dozen years; for example, the marine carbon cycle circulates in as few as two weeks, according to Professor Bishop.[7] This rapid turnover time is due to the radically different growth cycles of phytoplankton and land plants—many coccolithophores live for merely a week, according to Professor Bishop, before being absorbed into the food chain and excreted as ballast-like fecal pellets, while land plants have far less turnover. "You cannot go out on ships every three months and do a seasonal study on this ocean biological pump, because that is equivalent to sitting here in my office at UC Berkeley, closing the blinds, leaving them closed, and opening them once every 240 years," Jim says.

VARIATION ACROSS SPACE

This reality drove Professor Bishop and colleagues to deploy their CFEs again the following year, this time while studying the Pump in the Southern Ocean.[8] The team knew that diatoms, another important phytoplankton that accounts for nearly 40% of marine primary productivity, prefer cold water.[9] Their hypothesis was that iron fertilization would have a minimal effect in the higher latitude control group while a "massive sedimentation event" would occur in the colder, lower latitude, waters—a diatom's paradise.

But the results were unexpected. "To the surprise of everyone, the place that was not supposed to have a response to iron, did!" says Professor Bishop. This clued marine scientists into the possibility that primary productivity is not the only predictor of the Pump's success.

Fifteen years later, after observing an phytoplankton bloom in the California Current during summer of 2017, Bourne made her own observation that, while chlorophyll—a sign of primary productivity—was over 30 times higher in concentration closer to shore, carbon flux rate was the same onshore as in the deeper, offshore location of the plume.

ZEROING IN ON AN EXPLANATION WITH MULTIPLE PATHWAYS

Professor Bishop and his colleagues made two overarching observations from their respective research voyages. First, they observed that enhancing primary productivity by raining down limiting nutrients, like iron, over the euphotic zone does not guarantee carbon flux increase. Second, they observed that temperature cannot necessarily predict primary productivity and flux rate either. Thus, the traditional salt-shaker pathway cannot be the Biological Carbon Pump's only mechanism. "We are actually finding out that this biological

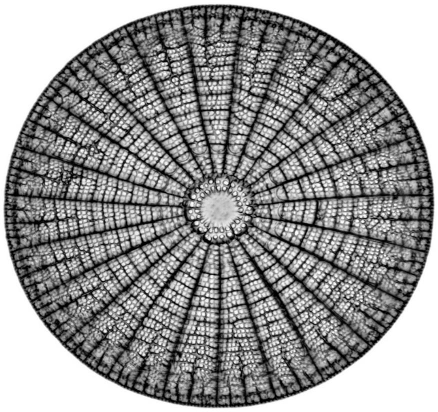

Figure 3: *Diatom, a phytoplankton that can play an important role in the Biological Carbon Pump.*

***Figure 4:** Undergraduate Sylvia Targ, PhD student Hannah Bourne, and Professor Jim Bishop.*

carbon pump is just not simply a monolithic process," Professor Bishop explains, "and there are multiple [biological] pathways by which carbon sinking can be enhanced."

As part of her PhD thesis, Hannah Bourne has come up with two hypotheses that explain the following observation: more phytoplankton present in the euphotic zone does not necessarily mean increased carbon flux. One is that an active organism can swim from depth to the surface, feed, and then swim back down and excrete feces. The other is that sediments from shallow shelves can flow into the interior, and the filter-feeders will then harvest the material. The latter scenario would explain the high fluxing at depths that Bourne observed in some locations in the California Current.

Bourne and Professor Bishop still have much to discover. But by actually observing carbon aggregates, or particulate organic carbon, at different places, they are piecing together a puzzle of how the Pump works. "It is a bit like how by going through garbage cans you can tell how people live," Jim says. "We can actually see how [respective] ecosystems are functioning to transport carbon."

To Bourne, this project is very exciting. "What I really love about our research is we put these robotic instruments out, and then they come back with large series of images of what is sinking down through the water column," says Bourne. "It is completely different [from the] things I see in my daily life back on land, and it is cool to see this completely different part of the Earth," she says.

HORIZONS FOR FUTURE EXPLORATION

What is next for these UC Berkeley marine scientists studying the Pump? "I think we should learn as much as we can now so we can predict how it might change as climate is changing," Bourne says.

And they are getting closer. Bourne and Professor Bishop's summer 2017 voyage revealed that the robots are even more effective at calculating carbon flux than the team had supposed, which makes Professor Bishop all the more eager see them in action at full capacity.[10]

Next, Professor Bishop is anxious to start observing these changes on the proper time and space scale to eventually give the public a full picture of the Pump's pathways. He believes that proactive use of these robots is the key to unlocking the secrets of the Biological Pump's variations across time and space. "We have three robots and there is a big ocean out there!" Bishop says. "Let's put thirty or forty of them out in the California Current in an upwelling system and let them go! Let's go to area where we did SOFeX and let them go south of Tasmania, and they'll go a third of the way around the world in a year!"

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