A LIVING CARBON RESERVOIR

Sequestering carbon in the sea

No matter how much some politicians may try to deny it, the evidence for global warming is overwhelming. Yet while we humans are busy pumping heat-trapping carbon into the atmosphere, our oceans are teeming with microscopic algae that consume carbon during photosynthesis. Scientists and politicians alike have begun to wonder if it might be possible to harness the earth's oceans as a carbon reservoir. James Bishop of UC Berkeley's Department of Earth and Planetary Science and the Lawrence Berkeley National Laboratory is deploying remote-controlled robots to find out if stimulating phytoplankton growth could reduce the amount of carbon in the earth's atmosphere.

Marine phytoplankton are the primary producers of the ocean. As phytoplankton photosynthesize, they convert dissolved inorganic carbon into organic carbon, thereby sequestering it within their cells. Some phytoplankton inevitably sink deep into the ocean, taking their particulate organic carbon (POC) with them. POC lost from the ocean surface is replaced by carbon from the atmosphere, and the whole system forms a biological carbon pump that lowers the amount of CO_2 in the atmosphere.

Scientists have long suspected that they could increase the flux through the pump by increasing phytoplankton activity. The question was, how could phytoplankton productivity be enhanced on a large scale?

The answer resided within the Pacific Ocean, in regions that are famous for being high in nutrients such as nitrogen and phosphorous, but mysteriously low in

Collecting data in the stormy South Pacific is dangerous work, so Berkeley scientists are deploying remote-controlled robots that can continuously monitor carbon levels for months at a time. (Photo: LBNL)

phytoplankton. For years, scientists debated the nutrients that might be limiting phytoplankton growth in these areas. In the late 1990s, a ship carrying ten tons of iron sulfate sailed to a high nutrient/low phytoplankton region in the South Pacific, south of Tasmania. There, scientists dumped their cargo of iron into the sea, triggering a massive algal bloom a few days later. Space satellites that monitor chlorophyll fluorescence could detect the bloom for almost two months following fertilization. The answer to ocean fertilization, it seemed, was iron.

But this experiment was only the beginning, and much more must be learned about the ocean's carbon cycle before we begin filling our oceans with iron. In the past, data collection was limited by a reliance upon manned research voyages that were prohibitively expensive and often dangerous. Furthermore, each voyage could last only a few months at a time, and could easily miss sporadic natural events. Bishop and his team decided it was time to switch tactics and designed remote-controlled robots called Carbon Explorers.

The neutrally buoyant Carbon Explorers can move from the surface of the ocean to depths of 1,000 meters, measuring POC concentrations along the way. Active for the greater part of a year, these robots can monitor the ocean continuously and quickly relay their findings to researchers via satellite. They send frequent emails to Bishop, who admits, "It's like being addicted to a computer program." The Carbon Explorers are also incredibly cost effective: building one Carbon Explorer and operating it for many months costs about $25,000—that's roughly equivalent to operating an oceanographic ship for one day.

For their first deployment, two Carbon Explorers were released in a high nutrient/low phytoplankton region of the North Pacific, approximately 1,000 miles west of Vancouver Island, British Columbia. On April 7, 2001, NASA satellites detected a large dust storm originating near the Gobi desert. The powerful storm churned up debris over land and then traveled out over the Pacific Ocean, depositing iron-rich dust in its wake. When the dust storm passed over the Carbon Explorers on April 12, high winds and seas prevented the Carbon Explorers from communicating with satellites.

A few days later, the storm had died down and the Carbon Explorers were again transmitting data. Although communications were temporarily interrupted during the storm, data collection had continued smoothly. Five days after the storm passed overhead, the robots detected large increases in POC. Several days later, POC levels hit their peak, at nearly double the pre-storm levels.

On their first mission out, Bishop's Carbon Explorers had made a tremendous discovery. They had detected a completely natural iron fertilization experiment, and provided the first direct evidence for ocean fertilization by natural storms—a phenomenon that would have been very difficult to observe by manned research voyages.

While these results make iron fertilization seem like an easy solution to global warming, Bishop makes it clear that this field is "still in the realm of science" and not yet at the level of practical application. In 2002, the Carbon Explorers were involved in iron fertilization experiments in the South Pacific. These experiments showed that adding iron can increase phytoplankton productivity, but the response is not always consistent. "The results demonstrate that there is a lot to learn yet from the ocean," says Bishop.

Many aspects of the ocean's carbon cycle are unknown, and whether this method would be effective on a large scale remains an open question. Furthermore, no one knows what consequences global climate engineering may hold. While there may be good outcomes, negative repercussions for ocean ecology are easy to imagine. Algal blooms have a terrible reputation, and sometimes trigger massive fish kills and perturbations in the food chain. "Ocean fertilization will be a global decision," says Bishop, "after a lot of people think of the consequences and outcomes."

But the consequences cannot be fully understood until scientists discover more about the ocean's carbon cycle. Bishop's Carbon Explorers are still out there, now exploring the North Atlantic, the North Pacific, and the Southern Ocean, and investigating other aspects of phytoplankton productivity and the ocean's carbon cycle. "We are still trying to understand how the ocean behaves naturally," says Bishop. "Once we have a predictive basis, we will be able to predict the outcome of an ocean fertilization experiment." And even if ocean fertilization is ruled out, Bishop's experiments provide the basis for understanding how the natural carbon cycle will be affected as the oceans respond to climate change. "Each time the floats go out," says Bishop, "they find something different. And that's very exciting." ■

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Want to know more?

Robotic observations of dust storm enhancement of carbon biomass in the North Pacific. JKB Bishop et al., *Science* (2002); Vol. 298, pages 817–821.

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TWO WAYS TO SIX LEGS

Creepy crawlies will never be the same

It turns out that not every six-legged creepy crawly is an insect. Lawrence Berkeley Laboratory and University of Siena researchers have made the unexpected discovery that collembolans, a type of primitive arthropod long thought to be closely related to insects, are actually only distant relatives.

Collembolans are commonly referred to as springtails, due to an appendage on their abdomen that propels them through the air. They are small, wingless, and harmless, although they can seem alarming when they mob moist places like floor drains and damp basements. Collembolans and insects are traditionally grouped together in the subphylum Hexapoda ("six feet"). Like crustaceans, spiders, and many-legged creatures such as centipedes and millipedes, hexapods are members of the phylum Arthropoda. Hexapods are characterized by the presence of three main body regions (head, thorax, and abdomen), a pair of antennae, and, of course, three pairs of legs.

Scientists have found it difficult to determine how hexapods are evolutionarily related to other types of arthropods. For many years, hexapods were thought to have diverged most recently from centipedes and millipedes. But recent genetic and developmental analyses show that hexapods are actually more closely related to crustaceans such as shrimp and lobsters. Still, it was believed that all hexapods developed from a single common ancestor. However, recent work by LBL scientist Jeffrey Boore and University of Siena collaborator Francesco Nardi challenges the common-ancestor model, and provides strong evidence that acquisition of the hexapod body plan occurred independently in the insects and the collembolans. In fact, genomic analysis of mitochondria (cellular organelles that contain their own DNA) reveals that collembolans may have split from the future insect lineage even before insects split from crustaceans.

Collembolans are an ancient group of arthropods, dating back 400 million years. To the untrained eye, they resemble wingless insects. But collembolans have only six abdominal segments whereas "true" insects have 11. Previous work by