Should Oceanographers Pump Iron?

Companies and countries are planning a series of controversial experiments to help determine if seeding the ocean with iron can mitigate global warming.

Ambling down to the winch room after a midday nap, German oceanographer Victor Smetacek realized immediately that the instruments aboard the RV Polarstern were registering something important. The water hundreds of meters below a massive algal bloom that Smetacek was monitoring was surprisingly turbid, with particles clumping up everywhere. A handful of samples revealed that the clumps consisted of dead algae.

The phenomenon surprised the 50 scientists on the European Iron Fertilization Experiment operating in the Southern Ocean 2000 km off the Antarctic coast. Six weeks earlier, the participants in the 2004 cruise had dumped nearly 3 metric tons of iron into the frigid sea. The algal bloom from the iron was expected. But Smetacek’s excitement soon gave way to frustration: The EIFEX team was focused on the surface plankton bloom and lacked instruments to measure what was happening deep underwater or to collect more than a few samples. “We were not prepared for what we saw,” says Smetacek. Next time, he vowed, that wouldn’t happen.

He may soon get another chance. Last month, scientists from the National Institute of Oceanography in Goa, India, visited Smetacek’s lab at the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, Germany. The Indian team is planning a 2009 cruise to explore the impact of a fertilization experiment on krill stocks and to determine how much of the algae’s carbon actually reaches the depths without being recycled through the food web. Dubbed LOHAFEX—loha means iron in Hindi—the cruise is one of a new generation of iron fertilization experiments (see table, p. 1370).

Earlier projects like EIFEX confirmed that iron fertilization stimulates algal blooms. The new experiments will explore what happens to those blooms and whether they can be carbon sinks for atmospheric carbon dioxide. There’s a lot scientists don’t know, including why some blooms fall so rapidly, how much of them are devoured by microbes and other sea life on the way down, and which locations and plankton species do the best job of sequestering carbon. Larger experiments could more effectively track carbon that makes it to the deep and help to quantify the impact of the technique on climate.

The strong interest of commercial companies and governments is driving academic experiments like LOHAFEX. Companies are hoping to make money by selling credits for carbon sequestered, using the Kyoto international climate system, smaller trading schemes, or voluntary ones. On 6 November, a ship leased by one company, Foster City, California–based Planktos, set sail from Florida toward an undisclosed area in the equatorial Atlantic that it plans to fertilize. (The secrecy is due to threats from environmental activists to disrupt the mission.) Climos, a competitor based in San Francisco, California, says on its Web site that the technique has “the highest greenhouse gas mitigation potential of all available methods.”

These plans are generating a backwash of concerns. Scientists have been divided for years about not only whether large-scale
ocean fertilization is feasible but also whether it should be done at all. One worry is that such ocean engineering could disrupt ocean food webs. Another is that jump-starting ocean ecosystems with an iron jolt could lead to emissions of methane and N₂O, both potent greenhouse gases that could limit the total climate benefit of a big uptake in carbon. At a recent meeting at Woods Hole Oceanographic Institution (WHOI) in Massachusetts, several scientists questioned whether large-scale fertilization could ever provide the data needed for a credible credits program. And earlier this month, the parties to the international antidumping London Convention declared that “given the present state of knowledge regarding ocean fertilization, such large-scale operations are currently not justified.” (Experts say that the treaty may be easy to circumvent, however, and that it’s not clear iron fertilization is even a form of “dumping.”)

Location, location

Behind the current buzz about ocean fertilization is one of the biggest oceanographic discoveries of the past 50 years, namely, that iron from terrestrial dust controls the growth of extensive marine ecosystems. Scientists had long puzzled over why huge swaths of surface oceans lacked phytoplankton, the plants that form the foundation of global ocean ecosystems, despite relatively high levels of two important nutrients—nitrate and phosphate. In 1990, biogeochemist John Martin of Moss Landing Marine Laboratories in California proposed an answer: Iron is the limiting factor in determining the abundance of life in the ocean, and those marine deserts contained too little of it.

The first successful test of this “iron hypothesis” was carried out in 1993—just months after Martin’s death—by oceanographers on a cruise southwest of the Galápagos Islands in the Pacific. Since then, nearly a dozen experiments in the southern, equatorial, and northern Pacific and South Atlantic oceans have shown that iron, dissolved into seawater, could catalyze algal blooms. Some blooms were so huge, they were visible by satellite.

Oceanographers don’t understand exactly how iron influences the blooms. But ice cores suggest that the oceans have taken up as much as 100 billion tons of carbon during a series of ice ages. Smetacek calls the quest to understand how the oceans took in so much carbon “the Holy Grail” of paleoceanography because of its significance for the history of Earth’s climate.

But iron fertilization experiments have not simply opened a window into the past, he says. They have also given researchers the unique ability to perturb an ocean ecosystem with small amounts of a single chemical and then watch the effects. “All the rest [of oceanography] are simple observations,” says Smetacek. “This is the way to really understand the system.”

Can that system be used to fight global warming? The first order of business, according to oceanographer Philip Boyd of the University of Otago in Dunedin, New Zealand, is to get a better handle on where to conduct such experiments. “Location, location, location,” Boyd said at the Woods Hole meeting. The key is to find ocean sites that are fertile enough to grow algae on the surface but that offer the environmental, ecological, and physical traits needed for the carbon to sink quickly to the deep and stay there.

Planktos later plans to take advantage of warm waters and nutrients in the equatorial Pacific in hopes of spurring rapid algal growth. Russ George of Planktos says the company will be looking for areas that feature the best nutrient cycling. But WHOI marine geochemist Ken Buesseler questions whether it would be appropriate to sell credits based on work at the site. “It’s quick and easy [there] to get a quick green patch,” he says. But nutrients from the deep are recycled infrequently in those areas, he adds, and those nutrients “would have been used anyway” by carbon-sipping plants growing naturally.

To avoid that potential problem, the India-funded team is focusing on the Southern
Ocean. Although the cold and seasonally dark conditions are less conducive to algal growth, its surface nutrients are more regularly replenished by upwelling. That allows successive iron-fertilized blooms to take in carbon using nutrients that would have otherwise returned to the deep.

Larger experiments of longer duration could make it easier to track the human-made blooms, which get stretched and diluted by currents, downwelling, and storms. During a 12-day experiment in 1999, says Boyd, “we invested about half our time just keeping track of where [the patch] is.” Scientists have calculated that the next generation of experiments should be bigger by a factor of 10 and occur within a relatively enclosed, recirculating area called an eddy to keep the fertilized area intact.

**Counting the carbon**

The trick to sequestering carbon is to have it fall below what oceanographers call the 100-year horizon. That’s the point, starting at 500 m, beyond which the water will not come into contact with the surface for a century. That duration is the international standard for commercial carbon-storage projects. As much of the carbonaceous material grown on the surface falls, microorganisms and animals called zooplankton below invariably eat it, creating, among other things, CO₂, that eventually returns to the surface within a year. By getting more carbon beyond the 100-year line, fertilization buffers hope to bypass that process.

Scientists don’t know exactly why some of the dead algae clumps and falls, and only three of the 11 experiments to date have shown evidence of carbon being transported below the surface. It’s possible that the experiments were too short or too small for scientists to measure the amount of carbon transported. A more ambitious effort should, many scientists think, send more carbon to the deep. Researchers also need better measurements to quantify how much carbon is gone for good after a bloom dies or gets eaten up. Climos plans to deploy devices, called sediment traps, just below the 100-year horizon to catch that harvest.

To know where the magic line is, says oceanographer Andrew Watson of the University of East Anglia in Norwich, U.K., modelers need a better understanding of how water moves within their ocean models. “The physics is as important as the biology,” he says. Another task is to monitor more accurately the potent greenhouse gases produced by microbes in such an altered ocean ecosystem. Although only two of the 11 experiments thus far have detected nitrous oxide and none methane, any company that hopes to claim carbon credits from a fertilization project must first measure these gases and subtract their impact.

There’s also the problem of tracing carbon that doesn’t make it past the 100-year line, says John Cullen of Dalhousie University in Halifax, Canada. The water below the surface moves turbulently and gets mixed up, so any N₂O generated later could turn up far from the original. “There could be ill effects we simply could not see,” says Cullen. “It’s a legitimate concern,” agrees Margaret Leinen of Climos.

**A Growing Field**

<table>
<thead>
<tr>
<th>The Players</th>
<th>Their Plans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planktos</td>
<td>This public U.S. company plans six seeding experiments, the largest 31,000 km². Its ship left Florida on 6 November for an undisclosed location in the equatorial Atlantic.</td>
</tr>
<tr>
<td>Climos</td>
<td>This private U.S. company is funded by Silicon Valley tycoon Dan Whaley; his mother, oceanographer Margaret Leinen, is leading development of a scientific plan. It’s released a draft code of conduct for the field.</td>
</tr>
<tr>
<td>China</td>
<td>Scientists aboard its research icebreaker, Xuelong, are headed to the Southern Ocean to perform small-scale studies. The government is also seeking collaborations with U.S. experts.</td>
</tr>
<tr>
<td>India</td>
<td>Scientists plan to carry out experiments in the Southern Ocean in 2009 aboard the Polarstern, Germany’s research icebreaker.</td>
</tr>
<tr>
<td>GreenSea Ventures</td>
<td>This private U.S. company owns several of the original patents on the fertilization technique. But it has not announced any plans to conduct experiments.</td>
</tr>
</tbody>
</table>

But she believes that observational data suggesting a problem with N₂O levels are “equivocal” and that modeling studies show that only a portion of the positive impact of the bloom would be offset by the additional levels of the potent greenhouse gas.

**A sea of unknowns**

Scientists must find a way of linking specific downstream impacts to specific experiments. Otherwise, says Buesseler, once several companies begin working in the same region, “it starts to get very difficult to work out who’s responsible for some of these effects.”

Those consequences could be considerable. The next generation of experiments must improve monitoring of nitrate and phosphate to measure whether an algal bloom could deplete these nutrients from the site of the experiments or adjacent areas. Overfished bacteria, for instance, can create dead zones that could deplete fish stocks. So the next experiments need better technology to track nutrients and oxygen levels indicative of dead zones. Right now, the error bars are too large. The problem is “somewhere between trivial and bad,” says Climos adviser Anthony Michaels of the University of Southern California in Los Angeles. Researchers are also on the lookout for toxic algae strains from blooms.

Leinen says “a mix of indicators” on robots and boats could help track the algal blooms. It would be a big improvement over the first generation of experiments, she says, which had little ability to monitor their blooms over a broad tract. The increasing variety of buoys, undersea gliders, and autonomous samplers can now follow a bloom and report data to satellites at regular intervals. But the tools are still limited. Remote sensors can’t yet measure N₂O and have limited battery life. The thousands of buoys needed to keep an eye on greenhouse gases returning to the surface for roughly a year would be prohibitively expensive, notes Watson.

Even if individual projects could account for the carbon that they’re sequestering, says oceanographer James Bishop of the University of California, Berkeley, their combined impact could alter the carbon uptake of the world’s oceans in ways that are very hard to quantify. That could stymie efforts to balance the terrestrial, atmospheric, and ocean segments of the global carbon budget, he says, and make it harder for policymakers “to know if carbon management is working.”

Despite considerable reservations, a growing number of oceanographers expect ocean fertilization to be among the proposed solutions to global warming. “China has 500 years of coal and intends to burn it at 3 cents a kilowatt hour,” Brian Von Herzen of the Climate Foundation said at the Woods Hole conference. In response, he says, “as a community, we can do nothing. Or [we can] play an active role by exploring this second generation of [fertilization] experiments.”

Cullen predicts that scientists will be unable to quantify the greenhouse impacts of fertilization but that policymakers will want to use the method anyway. Before that happens, Cullen says, scientists should have collected as much data as possible. “It’s the only ocean we have,” he says. “Society needs clearer answers on what the risks are.”

--ELI KINTISCH