On ice. The icebreaker RV *Nathaniel B. Palmer* crunched through winter pack ice to reach open water in Antarctica's frozen Ross Sea for algae studies.

NEWS

Sailing the Southern Sea

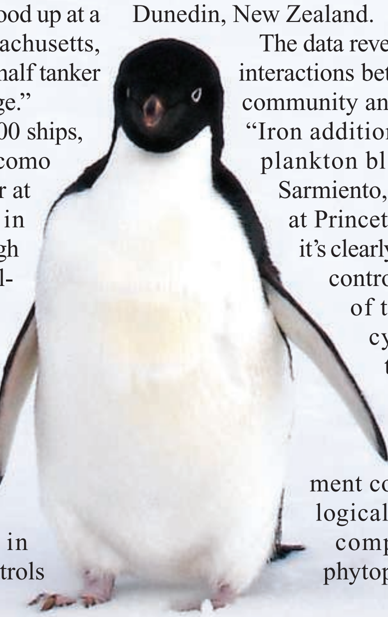
An international project sorts out the dynamics of climate and nutrient fluxes in this polar ocean community

The spirit of John Martin still seems to haunt oceanography 14 years after his death from cancer. When he was a researcher at Moss Landing Marine Laboratories in California, Martin proposed that massive blooms of photosynthetic plankton in the frigid Southern Ocean around Antarctica and other nutrient-rich but iron-starved waters could be an antidote to global warming. By pulling carbon dioxide out of the atmosphere to build their tiny bodies and then sequestering that carbon as they die and drift to the bottom of the ocean, these microscopic algae could reduce greenhouse gases and cool Earth. The only thing holding them back, Martin argued, was a dearth of iron, a necessary part of their photosynthetic machinery. To drive the point home, he once stood up at a conference in Woods Hole, Massachusetts, and said half-jokingly, "Give me a half tanker of iron, and I will give you an ice age."

It was an idea that launched 1000 ships, "or certainly hundreds," says Giacomo (Jack) DiTullio, an oceanographer at Hollings Marine Laboratory in Charleston, South Carolina. Although Martin did not live to see it, his colleagues at Moss Landing and others confirmed that lack of iron does limit growth: In a 1995 experiment, spreading dissolved iron over a 64-km^2 patch of ocean near the Galápagos Islands caused a temporary, 30-fold boost in phytoplankton biomass.

DiTullio has also followed in Martin's wake. As head of the Controls on Ross Sea Algal Community Structure (CORSACS) project, he and his colleagues are sorting out what—in addition to iron—makes plankton communities tick in the Ross Sea, the southernmost part of the Southern Ocean. It is one of the biggest potential hot spots for the phytoplankton blooms Martin envisioned.

The CORSACS researchers have looked at half a dozen environmental parameters—iron, light, carbon dioxide, temperature, and several trace nutrients—not only individually but also in combination. Doing so is "both novel and necessary" for understanding how this community can contribute to climate change, says Philip Boyd, an oceanographer at the University of Otago in Dunedin, New Zealand.



The data reveal a tangled web of interactions between the plankton community and its environment. "Iron addition works" to spark plankton blooms, says Jorge Sarmiento, a climate modeler at Princeton University, but it's clearly not the only factor controlling this key part of the global carbon cycle. In addition, the study indicates that changes in the Southern Ocean environment could shift the ecological balance between competing species of phytoplankton and, consequently, alter the contribution of phytoplankton to the carbon cycle. Such shifts could in turn exert "a very large impact on the air-sea balance of carbon dioxide," says Sarmiento. CORSACS's challenge is to nail down these complexities so they can be built into climate models.

Probing a complex soup

The Ross Sea is a tough place to work. Its thick blanket of ice covers all but a France-sized pool, or polynya, where sunlight allows phytoplankton to flourish. For two cruises (December 2005 to January 2006 and then again November to December 2006), the researchers worked there around the clock, often with wet and freezing hands, while their shipboard laboratory pitched wildly beneath their feet. Although satellite data, easily collected from the comfort of one's office chair, can provide information about plankton densities and environmental conditions, "there's just no other way to answer the kind of questions we're after," says DiTullio. To predict how the phytoplankton community will react to a changing environment, the researchers had to survey conditions in real time and test samples onboard to avoid confounding factors introduced by shipping them to labs on land.

The team dangled sampling devices that tracked iron and other nutrient concentrations, as well as light, temperature, and pH at various depths throughout the cruises. At the same time, they studied the species composition, biomass, and photosynthetic activity. As Martin predicted, the survey data "consistently demonstrated iron limita-

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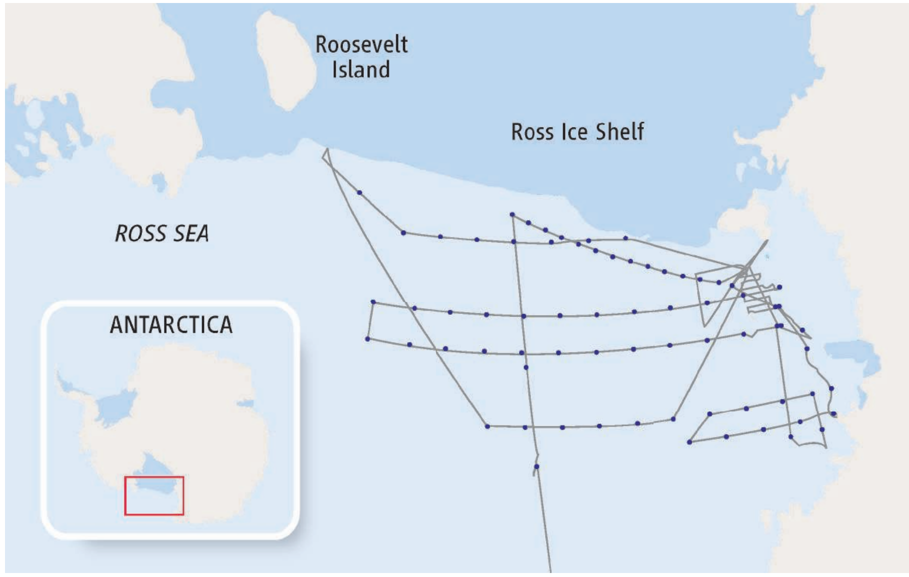
tion of growth," says DiTullio. Wherever iron was available—blown in as dust or transported in water upwelling from the deep—the plankton multiplied, but only as long as the iron lasted. Several experiments onboard the ship showed the same phenomenon: Adding iron boosts growth until the metal is gone.

But there is more to life than iron. Mak Saito, an oceanographer at the Woods Hole Oceanographic Institution in Massachusetts, wondered how vitamin B-12, another necessary nutrient, might affect algal growth. Only prokaryotic organisms such as bacteria are capable of making the molecule from scratch. In most ecosystems, there are more than enough bacteria to go around. "But the polar environments are unique," says Saito, because these bacteria can be so rare there that B-12 might limit community growth. To test that idea, he took samples of plankton from three locations—ranging from low to high bacterial concentrations—and incubated them for a week in bottles with or without a supplement of the vitamin.

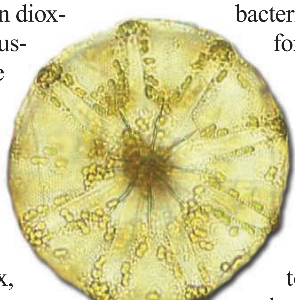
Sure enough, adding B-12 boosted the algae's growth in bottles with sparse bacteria, whereas it had no effect when plenty of bacteria were present. An input of iron may be necessary for the phytoplankton to grow, says Saito, but so is access to vitamin B-12.

CORSACS researcher Phillipe Tortell, an oceanographer at the University of British Columbia in Vancouver, Canada, wanted to know what increased carbon dioxide concentrations might do to the productivity of the Ross Sea. Tortell incubated samples of algae in bottles with a range of carbon dioxide concentrations, from preindustrial levels up to more than twice current levels. As one would expect for photosynthesizers, higher carbon dioxide led to higher metabolic rates and faster reproduction. But a surprise was that increased carbon dioxide changed the species mix, causing one group of diatoms, known as *Chaetoceros*, to dominate the rest. This result sounds like good news for climate-change buffering, as these particular diatoms form long chains of cells that sink efficiently, making them adept carbon sequesterers.

But the story is not that simple, says Tortell.



A broad sampling. The CORSACS team crisscrossed the Ross Sea (*above*) to understand what gives some plankton species, like this diatom (*below*), an edge over others.



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Algal politics

Tortell's carbon dioxide experiments highlight the dynamic nature of the Ross Sea ecosystem. The Southern Ocean is home to a diversity of species that compete for resources using different life strategies. In the Ross Sea, the diatoms and *Phaeocystis*, a green-brown, single-celled photosynthesizer that forms mucus-covered colonies, compete to be the top-dog alga. And the dominant species can vastly change the community's impact on the carbon cycle. Thus, understanding what gives one group of plankton an edge over another is key to predicting how the Ross Sea community will evolve in response to climate change, says Tortell.

Saito has made a start. His group has discovered dense clusters of bacteria thriving within the mucus of *Phaeocystis* colonies. The bacteria may provide B-12 in exchange for a free ride in the mucus's carbohydrate-rich environment. And the mucus may benefit both species by acting as a sponge for iron. Because of this symbiosis, "*Phaeocystis* may outcompete diatoms," says Saito.

This interplay between bacteria and algae and between the algae themselves is occurring against a backdrop of the many environmental changes associated with global warming. For instance, the atmosphere is likely to become dustier due to increased droughts and soil degradation—potentially delivering more iron to the Southern Ocean. Warmer surface waters could also shift the ocean's ecological balance. And increased precipitation and ice melt will decrease the salinity of surface waters, which in turn will slow down mixing with saltier, lower levels. Less mixing means more time spent near the surface, says DiTullio, which is effectively "an increase in the average light level experienced by phytoplankton."

To test how these changes may act in concert on algal growth, a team led by David Hutchins, an oceanographer at the University of Southern California in Los Angeles, grew cultures of plankton during both cruises while tweaking temperature, light, and carbon dioxide and iron concentration simultaneously. Models of the Ross Sea based on field observations have "typically assumed that high light and high iron would favor diatom communities," says Hutchins. But under high light and high iron concentrations in his experiments, *Phaeocystis* thrived whereas diatoms lagged.

These dynamics make the Southern Sea a devilishly complex environment for climate researchers to model. Whatever ecological shifts wait over the horizon, says Hutchins, they will alter "the efficiency of the biological pump" for pulling carbon dioxide out of the atmosphere. And what sign will be attached to that change—positive or negative—is still anyone's guess.

At this point, the CORSACS cruises have generated more questions than answers. In April, the researchers will gather in South Carolina to analyze the data. But one thing is already clear, says Boyd: "They indicate that climate change will simultaneously impact a wide range of ocean properties in Antarctica." The big question is what those changes will mean for global climate in the coming decades—an unplanned experiment on a far grander scale than anything Martin ever imagined.

–JOHN BOHANNON