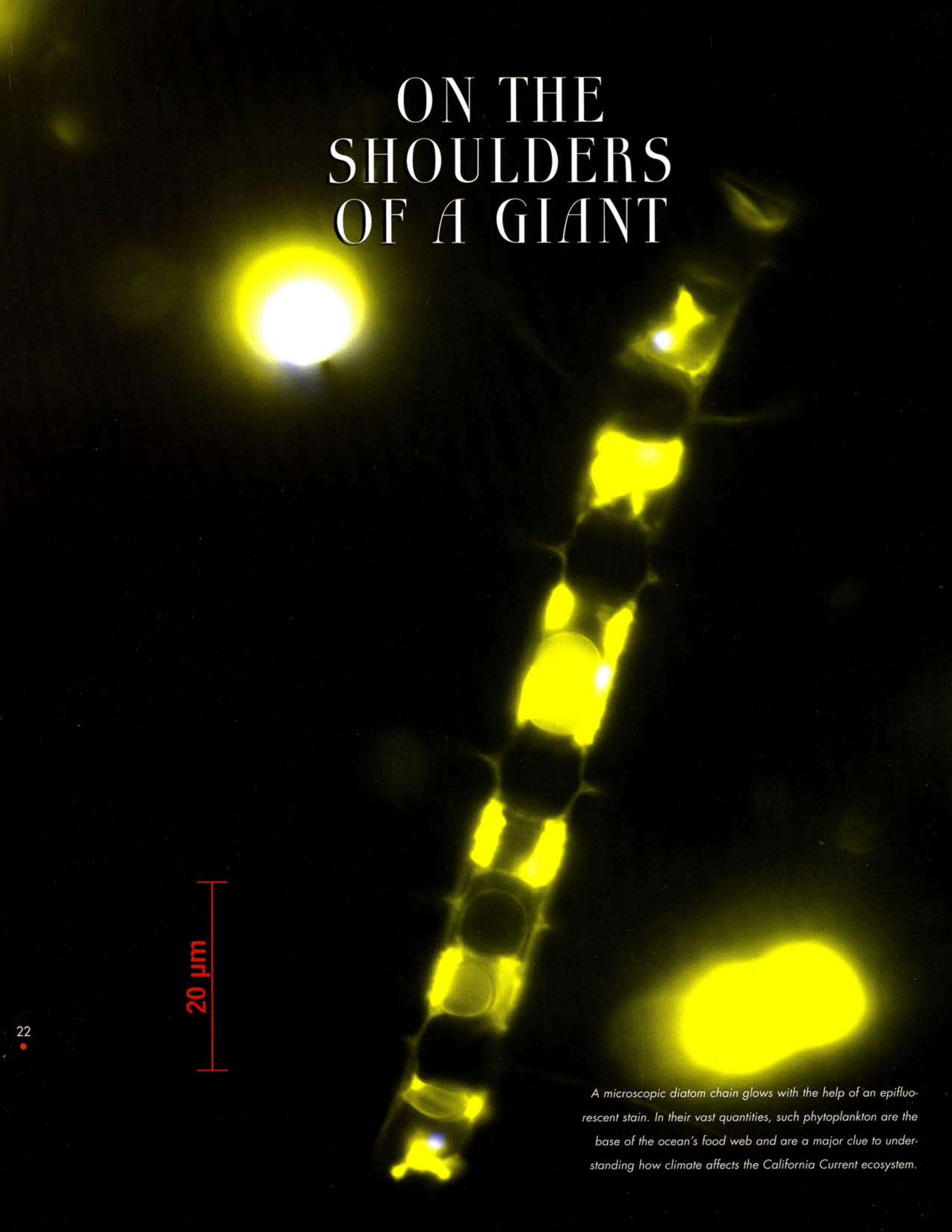
ON THE SHOULDERS OF A GIANT



A microscopic diatom chain glows with the help of an epifluorescent stain. In their vast quantities, such phytoplankton are the base of the ocean's food web and are a major clue to understanding how climate affects the California Current ecosystem.

A Classic Science Program Gives New Field Study a 56-Year Head Start

By Robert Monroe

FOR THE TIME OF YEAR, it wasn't at all what Annie Douglas expected to see.

The leader of a marine mammal survey team from Cascadia Research, Douglas had observed hundreds of dolphins off the California coast during a November research cruise aboard the Scripps research vessel *Roger Revelle*. But off the starboard bow observers had alerted her to a humpback whale arching as it surfaced south of Ventura.

That a humpback whale had appeared at all was noteworthy. Surveyors from Cascadia, a nonprofit research organization based in Olympia, Washington, have seen a sharp drop in humpback sightings here since the El Niño season of 1997–98. Douglas's whale should have been headed to Mexico by now for breeding season. Yet by the end of the cruise, 14 such humpback sightings would take place.

"It's November and they're still feeding," Douglas noted with wonder.

Perhaps the aberration she saw from R/V *Revelle*'s deck was to be explained in a laboratory two levels down, where a Scripps research team was estimating the abundance of the krill that humpbacks eat in the area. Maybe an answer was to be found in the ocean-water-temperature readings and current measurements being made during this cruise, the first for

Bongo nets sample phytoplankton in a collection procedure little changed since the 1940s.

"We have to be able to understand the natural sources of variability and tease those apart from anthropogenic causes."

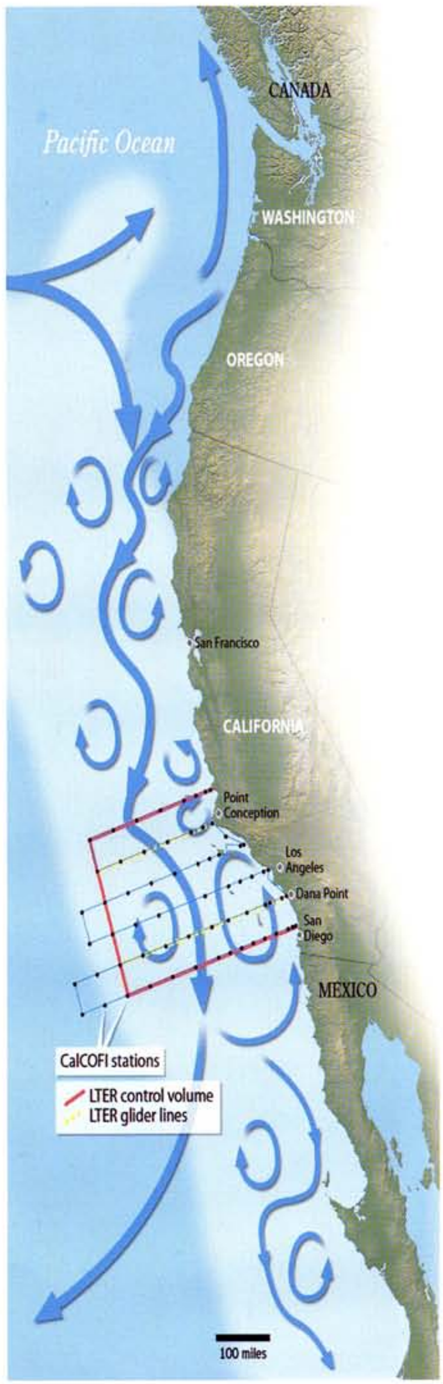
—LTER PRINCIPAL SCIENTIST MARK OHMAN

a program taking an unprecedented look at the relationship between the forces of nature and the food web in the California Current, one of the most economically important ocean regions in the world.

The expedition was the result of Scripps becoming the newest member of the National Science Foundation's (NSF) Long-Term Ecological Research (LTER) network, a collection of 26 field-study sites across the country and in Antarctica. California's marine ecosystem joined surveys taking place in forests, grasslands, estuaries, and other representative habitats, mostly located in the United States. At all of the LTER sites, intensive studies are aiming to tease apart the slowly evolving dynamics of nature. The benefits of this research will extend well beyond the network to non-LTER observational groups like Cascadia (one of several unrelated research teams sharing space on this *Revelle* cruise) and a host of other end users worldwide.

The Scripps group, which includes scientists from five other research institutions, received nearly $5 million to carry out experiments over six years in the California Current, a predominantly southward flow of water from the Washington–Oregon border to Baja California.

This maiden Scripps LTER cruise had a symbolic as well as practical significance, piggybacking on the 56-year-old California Cooperative Oceanic Fisheries Investigations (CalCOFI) program. The November voyage was a regularly scheduled survey of basic physical and biological conditions off southern California conducted by CalCOFI. The cruises take place four times a year and include the CalCOFI regulars—the plankton counters, fish-egg surveyors, nutrient quantifiers, and oxygen measurers whose consistent measurements have made the ocean off California the most intensely studied ocean region in the world.



The cubical region of water off the California coast that comprises LTER's control volume permeates the core of the California Current, a predominantly southward flow accompanied by smaller eddies and lesser flows.

IN SEARCH OF THE BIG PICTURE

A better understanding of the California Current could enable scientific advancements such as improved weather forecasting for the western United States and the implementation of measures to ensure the survival of key marine populations in the region. The marine creatures living here are a bellwether when it comes to climate-change effects. The tip-off that indicates a major shift in ocean temperature or circulation might be a sudden drop in the population of a certain species of zooplankton, the rapid swelling in numbers of a certain type of seabird, or the migration of a fish species. The LTER scientists want to test a variety of theories that explain how these physical changes play out.

Opposite page, top right, *LTER coprincipal scientist Ralf Goericke aboard R/V* Roger Revelle. **Right,** *Larvae and plankton collected in a bongo net.*

"The California Current is intrinsically interesting but also extremely important for marine resources," said Mark Ohman, Scripps's LTER principal scientist. "In order to properly manage marine ecosystems in the long term, we have to be able to understand the natural sources of variability and tease those apart from anthropogenic causes."

Phillip Taylor, the NSF program director whose scientists recommended the California Current site for inclusion in the LTER network, said Scripps's project is in the mold of long-term field studies taking place in Hawaii and Bermuda. In those places, the benefits of comprehensive data gathering have exceeded expectations.

"When we study things over longer terms and at higher frequencies, we are continually surprised at the way things happen," he said.

This LTER network site will take the form of a hypothesis-driven series of experiments that complement the team's ongoing observations of changes in the ocean ecosystem. For the timeseries studies, California Current Ecosystem investigators will draw heavily from CalCOFI, an expansive observation program in its seventh decade.

The mystery of vanishing sardines initially launched CalCOFI, which exposed much of the climatic subtext of ecosystem change that fascinates the LTER team today. CalCOFI survey runs began in 1949, a decade after the beginning of one of the most profound industry collapses in the country's history. Fishing fleets, canneries, and wholesalers on the West Coast all reeled

from the inexplicable loss of a fish species thought to be in limitless supply.

An early and obvious culprit was overfishing. But as CalCOFI proved over the ensuing decades, placing blame on the sardine industry wasn't that simple. The collapse had come at a time when fishing methods were becoming too efficient for their own good, but there was another cause, a far subtler trend playing out in the ocean itself. A climate signal called the Pacific Decadal Oscillation (PDO) was entering its negative phase, a fluctuation marked by generally colder ocean temperatures and lower sea-surface heights in the eastern Pacific Ocean.

The altered set of physical conditions set in motion a corresponding set of biological conditions. The cold water allowed certain species of zooplankton to thrive while concentrations of others diminished. The change worked its way through the food web, affecting the success of larger predators to find food and reproduce. The PDO cold phase lasted until the mid-1970s, ushered out by some of the driest years in southern California history. Strict catch limits for fishermen and the returning pendulum of nature eventually saw a return of sardine populations after a warm PDO phase began.

If it hadn't been for CalCOFI's steady measure-

Below, *Research associate Sue Reynolds and fourth-year graduate student Brian Hopkinson from the Barbeau Lab at Scripps retrieve a seawater sample from ocean depths where chlorophyll concentration is highest. Members of the Barbeau Lab are exploring the effect of diminishing iron concentrations on phytoplankton survival.* **Left,** *Dave Wolgast, CalCOFI research associate.*

Below, *A wayward Leach's storm petrel is prepared for release. LTER participant Point Reyes Bird Observatory will explore the response of "sentinel" seabird species to ecosystem changes.*

ments throughout the course of the entire cycle, scientists would have had a much harder time understanding the connections between overfishing and the natural phase of decline of the sardines as the marine ecosystem changed. The California Current LTER project intends to augment the basic measurements of CalCOFI with detailed experiments. Instead of merely estimating the abundance of certain marine phytoplankton, for instance, researchers will fashion experiments to plot the rate at which grazers selectively consume that type of phytoplankton.

"We have key hypotheses that we've been able to develop from distilling decades of research, and we now intend to test those hypotheses," Ohman said.

Think of climate trends like the PDO, El Niño, and human-caused warming as the gas powering the California Current. Now LTER scientists want to look inside the engine compartment to see which physical forces control biological responses to that power.

"It's been a dream to look at the whole system," said Ralf Goericke, coprincipal scientist. "Ever since I came to Scripps 11 years ago, I've wanted to be part of a group that could take the whole ecosystem and study its components together."

UNDERSTANDING THE BASICS

Researchers know that physical properties of the ocean affect the biology of the California Current, but which ones are most important and when? The main physical parameters studied in most of the LTER experiments will be factors like ocean currents, the amount of thermal stratification between warm surface and cool deeper layers in the water column, and the rate of upwelling of deep, nutrient-rich waters toward the surface. These processes alter the types and growth rates of phytoplankton (primary producers), whose fluxes have a ripple effect through the rest of the food web.

Specifically, says Ohman, researchers want to know the relative effects of four basic processes—the main flow of the California Current, the cross-shore flows between the coast and the deep ocean, the rate of supply of nutrients from deep waters, and the top-down pressures that come from predators. In an unknown combination, these factors cause shifts in the composition of small organisms at the base of the food web.

To understand these mechanisms, LTER oceanographers are developing new, sophisticated data-gathering abilities. Goericke and biological oceanographer Mike Landry are able to more rapidly identify and quantify particular types of plankton using techniques of flow cytometry and high-performance liquid chromatography. Satellite remote-sensing specialists, Greg Mitchell and Mati Kahru, are developing new computer algorithms to obtain high-resolution images of phytoplankton blooms from space. Biological oceanographer David Checkley is using a laser optical plankton counter to rapidly assess the size, composition, and vertical distribution of zooplankton. Biochemist Katherine Barbeau's lab is testing the possibili-

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Above center, *Cruise mascot Ophelia.*
Above right, *Research associate Jennifer Sheldon unloads a CTD rosette containing water samples from several depths.*

A MODEL ECOSYSTEM

CREATING COMPUTER MODELS of ocean physics isn't exactly a breeze. At Scripps Institution of Oceanography and other research institutions, physical oceanographers like Art Miller spend years trying to design accurate simulations of the internal motion of the ocean. Armed with a long-term oceanic time series of temperature, salinity, current speed, and wind speed, as well as some serious computer memory, they set out to model past ocean activity and predict how the ocean might behave in the future.

Now Miller and former Scripps graduate student Emanuele Di Lorenzo are embarking on a new quest to create even more sophisticated models for the California Current portion of the Long-Term Ecological Research (LTER) project led by Scripps. In addition to the myriad variables that need to be taken into account to model major currents, eddies, and upwellings of cold water from the deep ocean to the surface, the new models will also include biological variables such as phytoplankton aggregations, grazing rates, and infusions of nutrients into given areas.

"No one's ever tried this before, so understanding complexity and trying to model it is the key issue," Miller said.

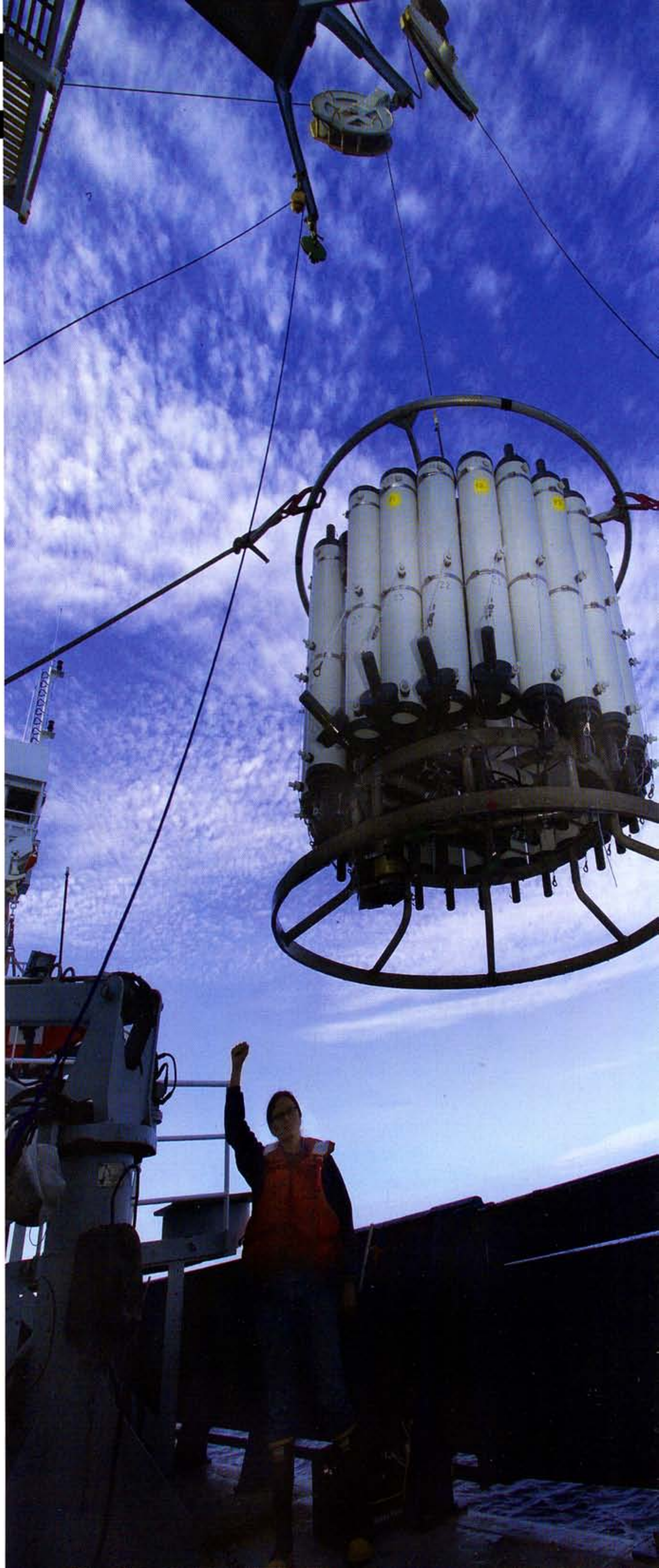
Computer modelers tend to represent biological activity as simply as possible in their simulations, content to let a condition like phytoplankton abundance in a parcel of ocean be represented by generalized characteristics. LTER biologists hope to provide Miller and Di Lorenzo with much more specific parameters describing biological processes to plug into their models.

One aspect of Miller's LTER work will be to develop models that fabricate a physical and climatic context in which to understand measurements made over the last seven decades as part of the CalCOFI. As a first step, plans are under way to have Di Lorenzo, now at the Georgia Institute of Technology, take data from this year's initial LTER cruises and create models from them, fine-tuning the models until they match actual ocean conditions observed during the current cruises.

Far from previous representations of organisms in physical ocean models, which acknowledged their presence and little more, Miller said the new models will account for processes such as the grazing rates of microzooplankton on phytoplankton and develop competition scenarios when two or more plankton species inhabit the same parcel of ocean.

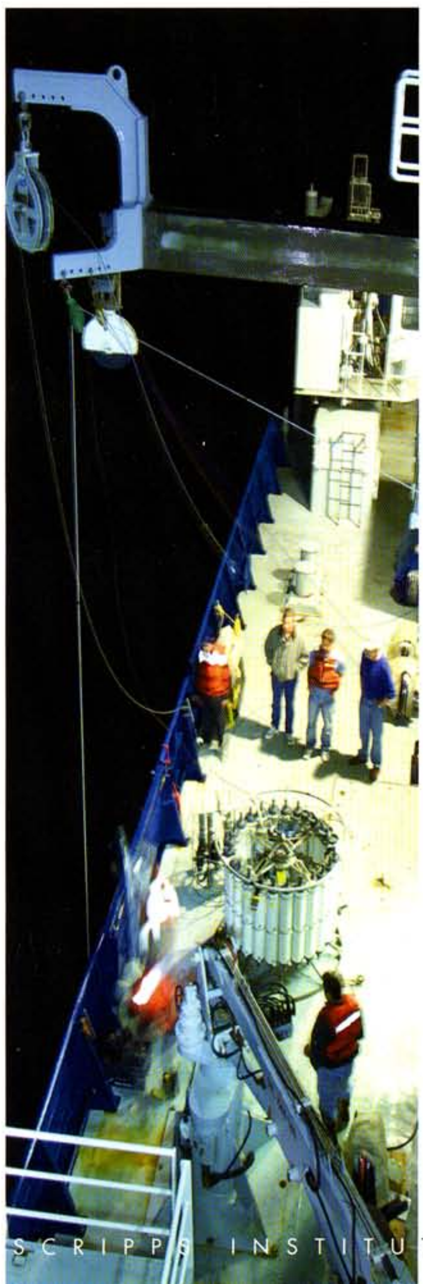
Sound complex? It is, said Miller, acknowledging the challenge.

"By constructing these models, we'll be able to determine the level of complexity needed to explain the observations," he said, "or know whether it is even possible to build a model that can explain them—or is the biology way too complicated?"



Opposite page, *A CTD rosette is prepared for deployment.* **Above,** *Marine geochemist Lihini Aluwihare, with student Roman de Jesus (below), studies the role of dissolved organic matter in the California Current.*

ty that phytoplankton become iron-starved as newly upwelled water begins to age. And marine geochemist Lihini Aluwihare's group is trying to understand the complex organic compounds that constitute the large reservoir of dissolved organic matter in the California Current. The Spray glider developed at Scripps will send continuous robotic observations of the current back to Scripps via satellite. Amassing all of these data will be computer modelers who will attempt to simulate the mechanics of the California Current and estimate what changes occur under different climate scenarios. (*See "A Model Ecosystem," p. 28.*)



As your stockbroker will tell you, past performance is no guarantee of future results, and so it goes with the waters off California's coast, which have experienced a steady anthropogenic temperature increase over the course of CalCOFI's long history. Ohman notes that no one knows yet what will happen during the next climatic perfect storm, the "triple-positive" year in which the PDO and El Niño peak at the same time while superimposed on an ever-warming ocean.

"When El Niño next occurs in the positive phase of the PDO, following decades of ocean warming, will it have the same consequences El Niño had in a positive phase of the PDO 50 years earlier when the whole background state of the ocean was cooler?" Ohman asked. "We probably have better prospects of sorting out such questions here in the California Current than anywhere in the ocean because of the excellent foundation of CalCOFI observations."