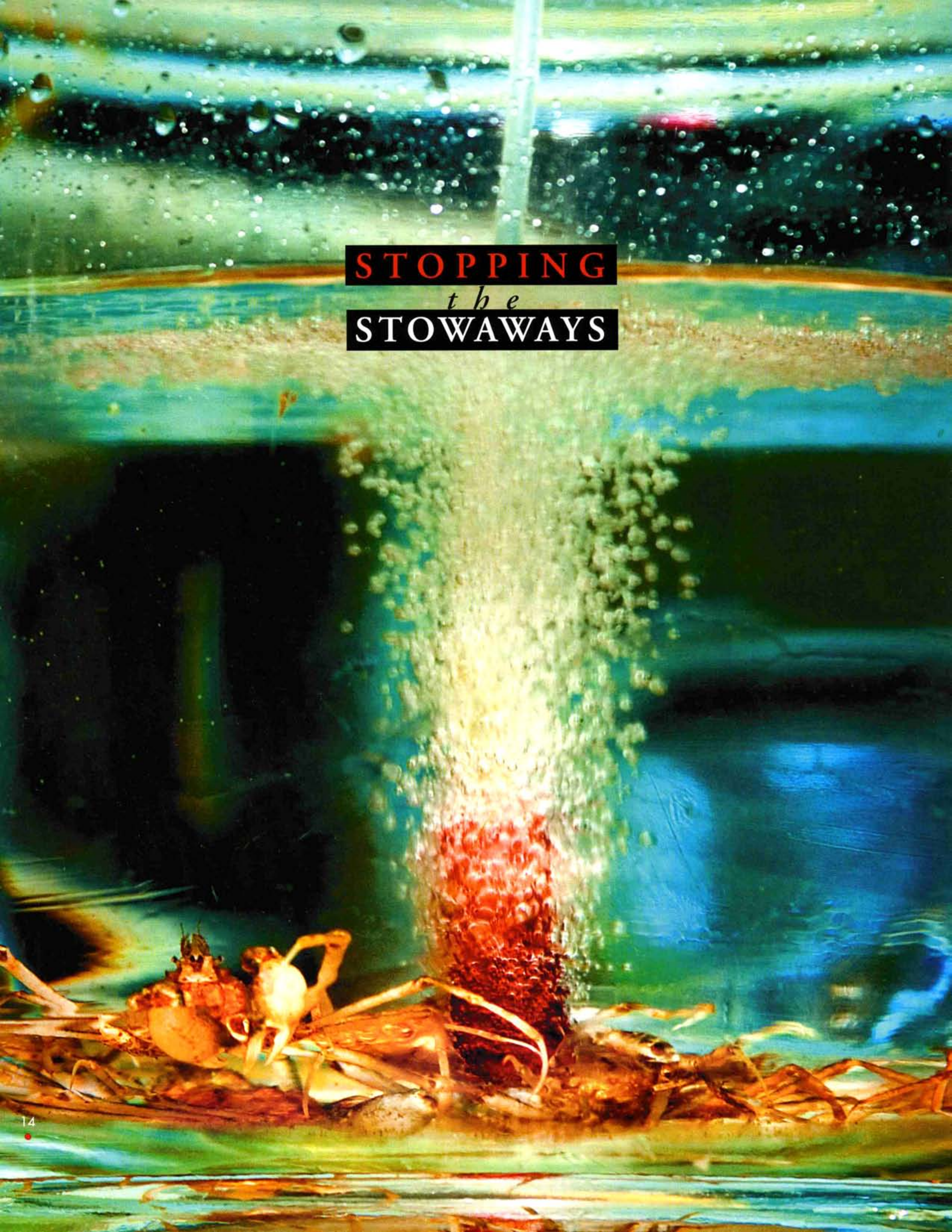


STOPPING *the* STOWAWAYS

Scripps's Horst Felbeck, an expert on marine invertebrates such as these crabs from San Diego waters, records the durations required to kill a host of creatures ranging from phytoplankton to small fishes.

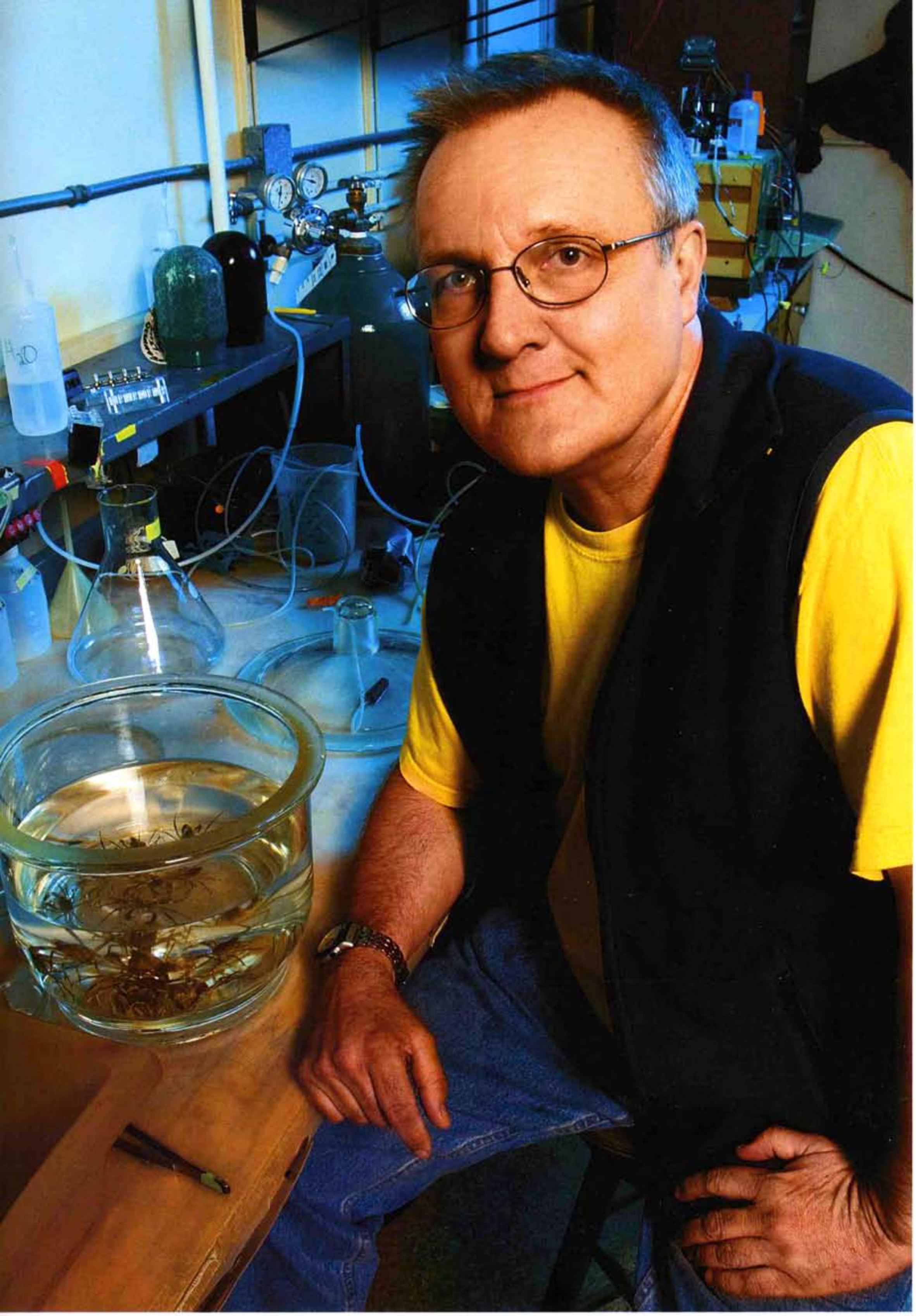
Around the world, biological invaders have caused port and waterway authorities as well as private vessel owners billions in repair and remediation expenditures. In 2000, researchers reporting in the journal *BioScience* put the cost of dealing with all invasive species at $137 billion a year in the United States alone. For comparison, a recent calculation of the known costs of all major oil spills in the United States between 1984 and 1997—including the Exxon *Valdez* spill off Prince William Sound—totaled just under $13 billion. The International Maritime Organization's (IMO) "Top 10 Most Wanted" list includes a North American jellyfish now clogging the Black Sea and a strain of cholera bacteria blamed for human deaths near Peruvian seaports.

Nonnative creatures have also created one of the most pressing threats to marine biodiversity around the world. The elimination of native populations can create a secondary set of problems ranging from additional stresses on endangered species to die-offs of commercially important fish. Unlike pollution or oil spills, habitat invasions are nearly irreversible once an introduced species takes hold.

MAKING SHIPS LESS HOSPITABLE

In 2002 the ballast-water transport dilemma became an offshoot of another exercise: containing oil spills. The U.S. Navy had commissioned Mo Husain to undertake the latter problem. Husain is president of MH Systems, a naval architectural firm in San Diego. While he was developing a negative-pressure system that could stanch the flow of oil from a tanker's ruptured hull, a U.S. Coast Guard acquaintance persuaded him to consider taking on the problem of stowaway organisms in ballast tanks.

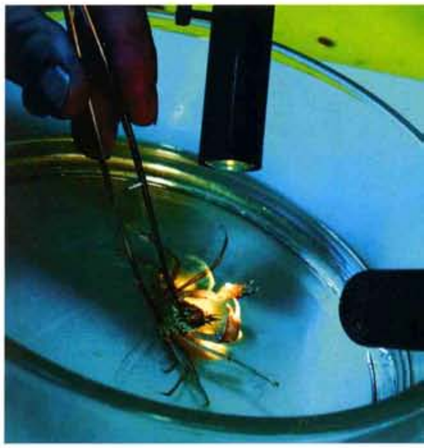
In the past decade, the maritime community has considered a number of mitigation measures of dubious value and occasionally high risk. Current IMO guidelines call for voluntary cooperation measures among vessel operators. Control techniques at their disposal include discharging ballast water only at treatment facilities, refraining from releasing it at all or only minimally, and exchanging ballast water on the high seas. The principle behind the last measure is that organisms that are suited to harbors cannot survive



dumping detergent into the harbor of a foreign port.

Instead, Husain modified a ballast-water treatment method developed in the mid-1990s. To test its effectiveness in killing would-be invaders, he approached Scripps and was eventually directed to Felbeck at the Marine Biology Research Division. In 2003, the two began attempts to bubble inert gas—a mixture of nitrogen, carbon dioxide, and a very small amount of oxygen—into simulated ballast tanks, attempting to suffocate marine invaders in transit before they ever reached distant shores. Inert gas is generated by burning oil or other organic fuels in a controlled ratio with air. The exhaust gas produced is then cleaned and put to use. Already oil tankers replace the small amount of air left when a tank is filled with oil or gas with inert gas so that a random spark does not cause a catastrophic explosion.

Husain's design involves bubbling inert gas through perforated pipes at the bottom of



Left, *Horst Felbeck in the lab.* **Above**, *After inert gas is cycled through sample water, dead specimens are examined.*

the radically different environment of deep seas and vice versa for the pelagic creatures that would be discharged at a port. The exchange process, however, can quickly turn hazardous if it causes a sudden balance shift on rough waters.

Additionally, said Felbeck, efforts to kill the creatures in transit by means of radiation or poisoning cause different problems: effectiveness is difficult to demonstrate and the by-products themselves might pose a danger. Imagine

THE TEN LEAST WANTED

A SAMPLING OF SOME OF THE WORLD'S MOST DAMAGING INVASIVE SPECIES INTRODUCED INTO NEW LOCATIONS VIA SHIPPING TRAFFIC

1. CHOLERA
Native to: Various strains found worldwide.
Introduced to: South America and Gulf of Mexico.
Impacts: One epidemic apparently associated with ballast water began at three separate ports in Peru in 1991 and spread around South America, killing 10,000 by 1994.

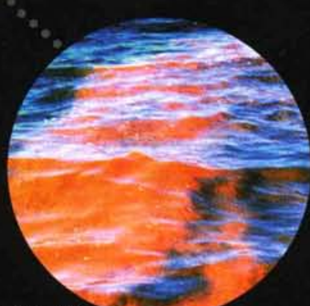
2. EUROPEAN GREEN CRAB
Native to: European Atlantic coast.
Introduced to: Australia, South Africa, United States, and Japan.
Impacts: Competes with and displaces native crabs and becomes a dominant species in invaded areas.

3. CLADOCERAN WATER FLEA
Native to: Black and Caspian seas.
Introduced to: Baltic Sea.
Impacts: Large populations dominate native zooplankton communities and clog fishing nets and trawls.

4. ASIAN KELP
Native to: Northern Asia
Introduced to: Australia, New Zealand, and United States.
Impacts: Displaces native algae and marine life. Alters ecosystems and food webs. May damage commercial shellfish stocks through space competition.

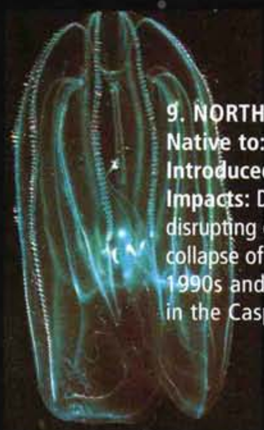
5. ROUND GOBY
Native to: Black and Caspian seas.
Introduced to: Baltic Sea and North America.
Impacts: Competes for food and habitat with commercially important native fishes and preys on their young. Can survive even in poor water quality.

6. ZEBRA MUSSEL
Native to: Black Sea.
Introduced to: Western Europe and North America.
Impacts: Displaces native aquatic life. Causes severe fouling problems on marine infrastructure and vessels. Blocks water-intake pipes and irrigation ditches.

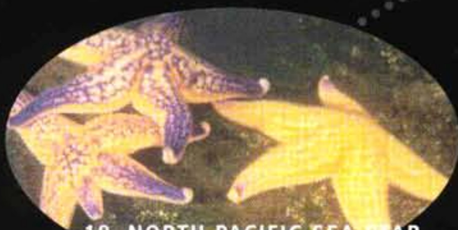


7. TOXIC ALGAE
Native to: Various species found worldwide.
Introduced to: Transferred to new areas around the world in ballast water.
Impacts: Kills native marine life through oxygen depletion and release of toxins. Can curtail tourism activities in coastal areas. Can cause illness or death of in people who eat contaminated shellfish.

8. MITTEN CRAB
Native to: Northern Asia.
Introduced to: Western Europe, Baltic Sea, and North America.
Impacts: Burrows into river banks and dykes, causing erosion. Preys on native fish and invertebrate species, causing local extinctions. Interferes with fisheries.



9. NORTH AMERICAN COMB JELLY
Native to: United States.
Introduced to: Black and Caspian seas.
Impacts: Depletes zooplankton stocks, disrupting ecosystems. Contributed to collapse of fisheries in the Black Sea in 1990s and is now threatening fisheries in the Caspian Sea.



10. NORTH PACIFIC SEA STAR
Native to: North Pacific Ocean.
Introduced to: Australia.
Impacts: Feeds on commercially important scallop, oyster, and clam species.

Far left, *Horst Felbeck (left) with Mo Husain of San Diego's MH Systems.* **Left,** *Scripps marine technician Eddie Kisfaludy and undergraduate student Craig Marelshagen collect plankton samples off La Jolla for testing.*

ballast tanks. The resulting product is too harsh for organisms to withstand. Husain estimates that his system could deoxygenate ballast tanks and eliminate the $137-billion problem at a cost of four cents per ton of ballast water.

"We are eager to go ahead with it, but we have to scale up," Felbeck said, "The gassing works, we know that, but MH Systems now has to design equipment that works on ships."

Teams from MH Systems and Felbeck's lab hope to test the concept in a simulated ballast tank built on a scale close to the real thing or possibly outfit an existing ship for their equipment. The anticipated Office of Naval Research grant to pay for such a venture was withdrawn last year to accommodate increased Defense Department spending in Iraq, said Husain.

In the meantime, Felbeck and Husain have been testing the inert-gas method on smaller scales. The mini–ballast tank simulators have progressed from what might have been the world's most elaborately engineered beer keg to the simple Erlenmeyer flasks of Felbeck's lab. There Felbeck has been studying the effects of various gas mixtures on marine organisms he collects in the waters off La Jolla—plankton, small kelp crabs, rockfish larvae, tiny crustaceans called isopods, and other creatures small enough to find their way into a ballast tank.

In the simulated ballast tanks, inert gas bumps up carbon dioxide levels to 12 percent compared to the .03 percent concentration in the air we breathe. Larger organisms like shrimp and crabs die within a few minutes. The survival of smaller creatures, like phytoplankton spores, is more difficult to determine.

"The nonmoving ones are little green balls no matter whether they are alive or dead," Felbeck said.

Felbeck and Husain feel confident that their method will meet a standard proposed by the U.S. Congress calling for a 95-percent reduction in transport of living marine creatures through ballast water. Now it's a matter of engineering and allocation of federal dollars. Husain is asking for $1 million to $1.5 million to proceed with testing.

"There's no question in my mind that it's going to work on a large scale," he said. "It's simple. You just blow bubbles."

LOST IN TRANSIT: Using inert gas to clean ballast water