Barge ahead. A new research barge will screen ballast water treatment technologies.

INVASIVE SPECIES

Researchers Set Course To Blockade Ballast Invaders

As U.S. regulations loom, scientists are working to test new devices that can remove potentially invasive organisms from ships' ballast water

BALTIMORE, MARYLAND—Standing aboard one of the newest research vessels in the United States, Mario Tamburri looks more like a plumber than a marine ecologist. Blame it on the pipes: Bright red, blue, and green tubes twist and turn across the deck of the repurposed barge. Tamburri, who is based in Solomons and directs the Maritime Environmental Resource Center (MERC), part of the University of Maryland Center for Environmental Science, points to a narrow outlet. It's here, he says, that researchers can tap into the barge's precious scientific cargo: its ballast water and the organisms that live in it.

Ballast is crucial to balancing the weight of giant cargo ships as they ply the world's oceans. But as these ships pump millions of liters of ballast in and out of their hulls, they also help spread sometimes microscopic stowaways, including invasive shellfish and algae that have damaged marine ecosystems and local economies worldwide. Blocking these invasions is the goal of Tamburri's science barge, officially christened the *Mobile Ballast Water Treatment Test Platform*. Recently, he and his colleagues began using it to test ship-based technologies—including mechanical filters and chemical weapons—capable of removing most organisms from ballast water. The experiments are part of a larger international effort to prevent ship-borne invasions. Earlier this year, for example, the United States adopted new rules that limit how many ballast organisms commercial ships can release into coastal waters and require ship owners to install proven water-treatment systems. It's not clear, however, which technologies will meet the new standards—or how researchers can validate the effectiveness of various devices. That's where MERC's barge, and several other floating laboratories like it, come in: "We're here to provide unbiased, independent data to regulators [and] shipbuilders," Tamburri says.

The stakes are high for ecosystems and shippers. Big cargo ships dock in U.S. waters an estimated 90,000 times each year and unload nearly 200 million tons of ballast. Even relatively isolated ports, such as those in the Great Lakes, "are connected to almost every other port on the planet through four or five ship voyages," says David Lodge, an ecologist at the University of Notre Dame in South Bend, Indiana. Those linkages have enabled some organisms to travel far from home: Roughly one-half of the 59 invasive species known to have colonized the Great Lakes since the late 1950s, for instance, likely arrived in ballast tanks, according to a 2007 report to the U.S. National Academy of Sciences's Transportation Research Board. Those invaders include the now-pervasive zebra mussel (*Dreissena polymorpha*), which has clogged industrial pipes and displaced native animals. Overall, such invasions cost about $130 million annually in the Great Lakes alone, Lodge and colleagues estimated in a February 2011 study in the journal *Ecosystems*. And saltwater habitats haven't fared much better. Researchers suspect that ballast tanks carried troublesome Asian shore crabs (*Hemigrapsus sanguineus*) to the Northeast coast of the United States, and Asian clams (*Potamocorbula amurensis*) to San Francisco Bay—although it's possible that some invaders simply hitched a ride on the outer hulls of ships (see sidebar, p. 665).

For the past decade, U.S. regulations required most ships entering U.S. waters to flush and refill ballast tanks far offshore, where waters are less likely to harbor organisms that might take hold in coastal seas. But many environmental groups are pressing the government to set tighter standards. In 2011, the U.S. National Research Council asked scientists to examine just how tight such standards would need to be: In other words, how many ballast organisms does it take to start an invasion? The answer, says panelist Gregory Ruiz, a zoologist at the Smithsonian Environmental Research Center (SERC) in Edgewater, Maryland, depends on a number of factors, from the saltiness of the water to the presence of predators. But one thing is certain: "The lower you go, the lower the risk."

That's the thinking behind new U.S. Coast Guard regulations published on 23 March. The rules—which echo standards proposed or adopted by the United Nations' International Maritime Organization and the U.S. Environmental Protection Agency (EPA)—require most ships built after December 2013 and planning to enter U.S. waters to install

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an approved, onboard ballast-treatment system. The aim is to thin, but not necessarily eliminate, the aquatic herds living in ballast water. The rules require culling the biggest hitchhikers—such as most mussel larvae and crustaceans—down to nine living individuals or fewer per cubic meter of water.

The rules don't specify which treatment systems ship owners must use. But the best candidates rely on a combination of approaches, according to a 2011 EPA report. Many start with brute force, using mesh screens to filter out bigger organisms or even spinning the water to flush them out. Then the systems typically go for the kill, using a toxic chemical such as chlorine to poison survivors. Other systems bombard organisms with damaging ultraviolet rays (UV) or suffocate them by removing oxygen. Whatever the approach, ballast-cleaning equipment is expected to be expensive, costing from $1 million to $3 million per ship. As a result, shippers and regulators want to find out which technologies really work—a task that has fallen to scientists such as Tamburri. "There's going to be a real push" for rigorous testing, he says.

The MERC team, for instance, plans to use funding from private and public sources to screen about three privately developed treatment systems per year aboard their barge. Last month, the researchers installed their first prototype, a system that pairs filtration with UV rays. Over the next month, the researchers will see how it cleans nearly 300 metric tons of ballast water that the barge can store in one of its dual deck tanks. The results may determine whether the equipment receives the Coast Guard's approval for wider use. And later this year, a tugboat is scheduled to push the barge around the Chesapeake Bay, where the scientists will test how the equipment treats water with a range of salinities, including brackish and fresh water. "The more sources you can pull water from, the more confident you are that water from around the world can be treated successfully," says Nick Welschmeyer, who studies plankton at Moss Landing Marine Laboratories in California. He also serves as chief scientist of the Golden Bear Facility, a similar testing platform based in San Francisco Bay. A third U.S. effort, called the Great Ships Initiative, operates in the Great Lakes.

All three U.S. facilities and their European counterparts, however, face sizable technical obstacles. One of the most fundamental is that larvae and algae aren't easy to count. To get a sample representative of an entire ballast tank, for instance, technicians need to tally tiny organisms living in as much as 7 cubic meters of water (about the volume of seven average-sized hot tubs), Tamburri and colleagues reported in 2011 in *Environmental Science & Technology*. Welschmeyer says the process can be "so cumbersome it hurts."

That pain was on display recently aboard the MERC barge. Darrick Sparks, a member of the SERC team, sat in a cramped trailer peering at dozens of small animals called rotifers through a microscope. To determine if the creatures were alive or dead, he used an ice pick–like instrument to poke idle rotifers to see whether they moved.

Scientists like Welschmeyer and Tamburri are working on tricks to make the process easier. For instance, measuring how much chlorophyll, a pigment common in many photosynthesizing organisms, is in a water sample can give officials a reasonable guess of the abundance of algae. It's the "whoa, that is way too green" to meet regulations approach, Tamburri says.

Such techniques may be critical if the U.S. government follows some states in further tightening ballast standards. California, for example, has adopted tougher rules that are slated to enter into full force in 2020, and environmentalists want the U.S. and other nations to follow suit.

But many in the shipping industry are pushing back, citing a 2011 EPA report that concluded that no current ship-based technology can meet California's tighter standards. The struggle highlights the need to think ahead, says Thom Cmar, an attorney with the Natural Resources Defense Council in Chicago, which is pushing for tighter limits. The technologies shipbuilders choose could stay on vessels for decades, he notes, so "the time is really now, before the vessels have started installing those systems, to get it right."

–DANIEL STRAIN

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A Foul Problem

Not all potential invaders lurk inside cargo ships. Many live in plain sight, clinging to vessels' outer hulls. From mussels to barnacles to algae, studies suggest that such "hull-fouling" organisms could pose an invasion threat that is "equally strong if not stronger" than that from ballast creatures, says zoologist Gregory Ruiz of the Smithsonian Environmental Research Center in Edgewater, Maryland.

So far, however, regulators haven't addressed the hull-fouling issue, in part because it's not clear how boats can effectively get rid of their clinging hitchhikers. Researchers are also still trying to understand which hull organisms can withstand long sea journeys that are fraught with extreme swings in temperatures and salinities.

To replicate such stresses, Louise McKenzie, a postdoctoral researcher in Ruiz's laboratory, has been subjecting small clutches of hull-fouling animals, including blue mussels (*Mytilus edulis*) and tunicates called sea grapes (*Molgula manhattensis*), to simulated voyages.

First, she places the organisms in rows of tanks. Then over hours or days, she changes the temperature and salinity of the water, replicating the fluctuating conditions at sea. She recently took her passengers on a faux voyage from New York to Melbourne, Australia; to simulate passing through the Panama Canal, McKenzie plunged the animals into fresh water, then back again into a salty solution. Sometimes, McKenzie says, the toll of such shifts is obvious just by sniffing the air in her laboratory: "It can be a bit smelly if a few things have died."

Researchers hope that McKenzie's study and others like it will help them identify shipping routes with a high risk of carrying organisms overseas. Others, meanwhile, are developing new tools to keep creatures off hulls, such as nonstick surfaces and improved cleaning methods. But one thing is clear, says Mario Tamburri, director of the University of Maryland's Maritime Environmental Resource Center in Solomons: "We're only solving half of the problem with ballast-water treatment." **–D.S.**

Cling-ons. Divers survey marine organisms (*inset*) clinging to a vessel's hull.

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