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Stemming the Tide

Killer technologies target invading stowaways

Ben Harder

Zebra mussels. Green crabs. Sea lampreys. Ruffe and round gobies. These are just a few of the troubles that have swum forth from the bellies of oceangoing ships. Those species and scores of other once-foreign aquatic organisms now besiege U.S. ports and waterways. These unwanted immigrants have found passage to the New World by stowing away in ships' ballast tanks, each a potential Pandora's box of ecological perils.

The problem has been growing since the 1980s, and interim measures have proven inadequate. Even so, research and development into technologies to replace existing practices is only now beginning to show promise.

ALIEN MENACE. Like many of the dozens of alien species that have invaded the Great Lakes, the round goby hitched a ride from Europe in a ship's ballast tank.
D. Jude/U. Michigan Center for Great Lakes and Aquatic Sciences

Ironically, it's ships' need for stability on the seas that has destabilized aquatic ecosystems around the world. When it offloads cargo, a ship may flood its ballast tanks with seawater to maintain a consistent weight; when it takes on freight, it may flush out ballast water.

Large vessels on transoceanic voyages may carry the equivalent of a small lake—more than 100,000 tons of ballast water—for thousands of miles. They also carry a host of organisms that enter the tanks along with the water. After these organisms are flushed into the novel environment of a port or waterway, some of them may begin to crowd out native species and disrupt local ecosystems.

"Ballast water is by far the most significant vector" for the spread of aquatic invasive species, says David F. Reid of the National Oceanic and Atmospheric Administration's Great Lakes Environmental Research Laboratory in Ann Arbor, Mich. In all, the Coast Guard estimates, the nation loses more than $7.3 billion per year to problems arising from invasive aquatic species. Worldwide, aquatic and terrestrial invasive species are together regarded as the second-leading cause of species extinctions, and they may soon eclipse habitat destruction as the largest factor.

To date, at least 162 nonindigenous aquatic species have colonized the Great Lakes—North America's most susceptible entry point for biological interlopers. The most economically significant aquatic invader to have hit the continent is the zebra mussel (*Dreissena polymorpha*), an import in 1988 from the Black Sea that has become an ecological and economic disaster, marine scientists say.

Inedible to most of North America's indigenous species, the mussels proliferate into massive colonies that strangle native ecosystems. They also clog water pipes of industrial plants, causing them to reduce or suspend operations. From its Great Lakes beachhead, this invader has extended its range north to Quebec City, south to New Orleans, and as far west as Oklahoma. Zebra mussels cost the United States about $5 billion each year in economic losses and control efforts, according to a Coast Guard report issued on March 4.

As the zebra mussel infestation progressed in the early 1990s, ecologists and officials devised a strategy for limiting the risk posed by ballast water. If ships while they were still in oceanic waters exchanged any freshwater ballast they'd taken on overseas, it was believed, the freshwater species within would perish at sea. The saltwater organisms that replaced them would fare equally badly when they got dumped into freshwater destinations.

That apparently tidy solution encouraged Congress to pass legislation that since 1993 has required ships carrying ballast water from foreign ports to exchange it with mid-ocean seawater before entering the Great Lakes. An exception theoretically exists for ships operating a Coast Guard-approved treatment system for ballast water. But nearly a decade after the act took effect, the Coast Guard has yet to specify the criteria it would use to approve such a system, and no potential systems have been submitted for consideration.

No water is too much

The shipping industry has shown a reasonably high degree of compliance with U.S. and Canadian ballast-water exchange policies, says Christopher Wiley of Fisheries and Oceans Canada in Sarnia, Ontario. Nevertheless, aquatic invaders keep coming.

In late 1998, for example, the fishhook water flea (*Cercopagis pengoi*) appeared for the first time in Lake Ontario. Within a year, this minute native of Eastern Europe had spread to both ends of Lake Michigan and occupied at least half a dozen of the Finger Lakes in New York (SN: 11/13/99, p. 308: http://www.sciencenews.org/sn_arc99/11_13_99/fob1.htm). These water fleas compete for food with the young fry of many fish species and, because they form dense, cohesive masses by interlocking their hooked tails, they tangle anglers' fishing lines and are difficult for larger fish to eat.

What's gone wrong? For starters, ballast-water exchange doesn't seem to be as effective at killing freshwater stowaways as some had hoped it would be. Midocean exchange leaves about one in every thousand organisms alive. That still leaves enough organisms to seed an invasion, says Hugh J. MacIsaac at the University of Windsor in Ontario. His team's work will appear in an upcoming *Canadian Journal of Fisheries and Aquatic Sciences.*

Furthermore, although 90 percent of ships from foreign ports declare that they carry no ballast, they aren't quite as harmless as they would seem. The nozzle that sucks ballast water from each tank and pumps it from the ship hangs far into the tank but above the actual floor. A few inches of inextricable water always remain beneath the nozzle. Sediments that settle out of ballast water also stay behind.

A vessel that's considered free of ballast water, therefore, typically contains about 150 tons of residual water and mud. Even in dry portions of tanks, organisms can often survive within tiny, hardy cysts called resting eggs, says Reid. When the tanks are next flooded, the eggs may hatch and then be dumped in the next port.

Working with Reid, MacIsaac and several of his colleagues at the University of Windsor recently collected residual water from ballast tanks on 20 ships, ostensibly not carrying ballast water, that had entered the Great Lakes after transoceanic voyages. They found live invertebrates in all the tanks they examined, with as many as 39 species present in a single vessel's tanks and 48 species identified during the study.

Many of these specimens were eggs buried in sediments at the bottoms of tanks. In their laboratory, the researchers were able to hatch the eggs in water drawn from the Great Lakes, so the eggs were viable.

Zapping the next alien

Help could be on the way. Research institutions, private firms, and government agencies are working to develop ballast-water treatment standards and technologies. Such tools could enable ships' crews to destroy potentially devastating cargoes of organisms before they invade vulnerable new ecosystems.

One tack is to filter ballast water to remove organisms. Mesh barriers or sieves can screen out anything larger than a certain size from incoming water. Unfortunately, even with self-cleaning components, such filters tend to quickly clog with flow-slowing objects and organic matter. Under the best circumstances, screen filtration would require large ships to install expensive equipment to keep up with their ballasting rates of several thousand tons per hour. Researchers now are preparing to test the technique on a small vessel.

Another leading design for removing organisms relies on centrifugation. In this process, incoming ballast water is spun rapidly to extract denser particles, which are then pumped back into the water outside. While potentially effective at barring sediments and some organisms from ballast tanks, centrifugation doesn't work well against most aquatic creatures, which have body densities almost the same as water's.

In a Coast Guard-funded effort, researchers at the University of Miami have recently tested several technologies in a custom-built dockside facility in Miami, Fla., that simulates conditions on a large tanker. Thomas Waite and his colleagues are using the facility to compare the effectiveness of self-cleaning screens, centrifugation, and a filtration system composed of fine-grain sand.

Preliminary data suggest that screens, despite their limitations, are the most practical and promising filtration method, says Waite.

The Miami team is also looking at a system that passes incoming water through a curtain of ultraviolet radiation that has enough energy to kill small organisms on even brief exposure. The team's unpublished data show that UV treatment is more effective than filtration at eliminating microorganisms, such as bacteria, that are as small as 10 micrometers in diameter. However, filtration seems more effective at screening large organisms.

Those results suggest that the best approach may be screening used in tandem with UV radiation or another process that targets small organisms. The benefits of such a two-stage battery compound because filtration clarifies the water by removing sediments and debris, thereby enabling UV rays to penetrate the incoming stream more completely, Waite says.

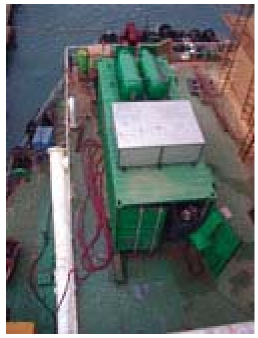
Such hardware-intensive procedures, however, are simply not practical for large ships because they can't efficiently process several tons of water a minute while tanks are being emptied or filled, argues David Wright of the University of Maryland's Center for Environmental Science in Solomons, Md. In tests on a ship docked in Baltimore Harbor, he found a disinfectant, or biocide, that's more promising and less expensive than UV treatment.

PILOT TRIAL. The oil tanker Tonsina has been outfitted with an experimental system to treat ballast water. If new technologies prove effective, they may phase out current practices, which have failed to stop an onslaught of aquatic invaders.
Stubblefield/ENSR International

Even when diluted in ballast water to concentrations as low as 2 part per million, vitamin K serves as a biocide and kills 90 to 95 percent of the minute animals that drift in the sea, Wright reported at the Aquatic Invasive Species conference in Alexandria, Va., on February 27.

Chemical disinfectants such as chlorine are also quite effective at killing transoceanic hitchhikers, but treated ballast water that's released at the destination also may be sufficiently toxic to kill the port's natural aquatic flora and fauna. In contrast, vitamin K would be relatively harmless to release once it has had time to do its work and then break down, Wright finds. The half-life of this compound in water is 18 to 24 hours, according to the company that is producing it as a biocide, SeaKleen, and that partially funds Wrights work.

One way around the environmental problems that may be posed by biocides is to find a simpler agent that breaks down or dissipates rapidly. The gases ozone and nitrogen are most promising in this category.



OZONE ON BOARD. A container on the deck of the Tonsina (above) houses canisters of ozone (below). Mueller/Nutech-03; Stubblefield/ENSR International

Already used to control bacteria in some pools and aquariums, ozone gas causes oxidizing reactions that damage tissue. Its reactivity has another benefit: "Because it reacts rapidly with materials in the water, ozone tends to break down," says William Stubblefield of ENSR International in Fort Collins, Colo. "When it does, it's no longer toxic."

Stubblefield and his colleagues outfitted two of about a dozen tanks on the oil tanker *Tonsina* with an ozonation system developed by a private company. They treated the experimental tanks with varying concentrations of ozone or with compressed air containing little ozone. To evaluate the system's efficacy, they sampled the water in each tank for plankton and microbes. They also placed fish, shrimp, and mud-dwelling organisms in each tank and monitored their condition.

"Ozone has very high control rates on bacteria and smaller organisms," but it is less effective against adult crustaceans and fish, Stubblefield concludes. It may still be useful because eggs and larval forms of these organisms are of more concern than the mature forms, he says.

Mario N. Tamburri of the Monterey Bay (Calif.) Aquarium Research Institute and his colleagues have experimented with another approach. First, they simulated conditions in a ballast tank containing larvae of zebra mussels and two other aquatic invaders. Then, the researchers bubbled nitrogen gas through the tank, thereby lowering oxygen concentrations. The exotic organisms died within 3 days, the researchers report in the January *Biological Conservation.* As the nitrogen naturally bubbles out, the oxygen concentration returns to normal, and the sterilized ballast water can be released harmlessly.

BURSTING THEIR BUBBLES. Bubbling

The finding amounts to an interesting "proof of concept" for nitrogen-mediated deoxygenation, says Reid. Although the method's too expensive to use solely for killing invasive species, it could prove economical because of a secondary benefit, Tamburri says. Removing oxygen from the water also prevents the iron in ships' hulls from rusting. In fact, that's the purpose for which Japanese industry originally developed the technology.

ozone through water kills fish.

Undefined mission

It's difficult to say which treatment methods work best when no standards exist, says Waite. The lack of regulations or clearly stated goals presents a major impediment to further progress.

For example, the dearth of scientific data on the threats posed by microorganisms and viruses has stalled development of a government directive. Screen filters with holes 50 micrometers across, Waite says, would strain most aquatic animals from incoming ballast water. However, that sieve would fail to keep out phytoplankton and bacteria, which might also be dangerous invaders. If miniscule viruses represent serious threats, screens might not be practical at all.

In addition to these biological questions, regulations will need to address concerns of the shipping industry. It's unclear, for example, whether ships will be regulated differently according to size or travel distance, which is a consideration because short routes permit less time to process ballast water. Another question is whether older ships will be required to undergo expensive retrofitting procedures for state-of-the-art ballast-treatment equipment.

Regulating ballast-water management in the era of global trade and transport, furthermore, poses considerable political challenges that require multinational coordination. A government acting unilaterally could be judged in violation of free-trade agreements.

Yet, while an international consensus remains elusive, a foreign marine organism is introduced to a new environment somewhere in the world approximately every 9 weeks, says Adnan Awad of the United Nations' International Maritime Organization.

In an effort to stem that unending tide of invaders, the organization will convene next year to consider ballast-water management on a global scale. By that time—if development of ballast-treatment technologies proceeds apace—the delegates might have some new tools at their disposal.

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References and Sources for this Article

References:

Coast Guard, Department of Transportation. 2002. Standards for living organisms in ship's ballast water discharged in U.S. waters. *Federal Register* 67(March 4):9632–9638. Text.

Tamburri, M.N., K. Wasson, and M. Matsuda. 2002. Ballast water deoxygenation can prevent aquatic introductions while reducing ship corrosion. *Biological Conservation* 103(March):331–341.

Further Readings:

Harder, B. 2001. Fierce invader steals nests from a native fish. *Science News* 160(Sept. 15):166. Available to subscribers at http://www.sciencenews.org/20010915/fob6.asp.

Helmuth, L. 1999. Feds plan battle against aliens. *Science News* 155 (Feb. 13):103.

Raloff, J. 2000. Infectious stowaways. *Science News* 158(Nov. 11):348.

______. 1999. New flea imperils fish, fouls gear. *Science News* 156 (Nov. 13):308. Available at http://www.sciencenews.org/sn_arc99/11_13_99/fob1.htm.

______. 1999. Fisheries don't welcome this whelk. *Science News Online* (Oct. 9). Available at http://www.sciencenews.org/sn_arc99/10_9_99/food.htm.

______. 1999. Invading gobies conquer Great Lakes. *Science News* 156(July 31):68. Available at http://www.sciencenews.org/sn_arc99/7_31_99/fob1.htm.

______. 1998. European crab leaps to Pacific prominence. *Science News* 153(June 13):373. Available at http://www.sciencenews.org/sn_arc98/6_13_98/fob2.htm.

______. 1992. From tough ruffe to quagga. *Science News* 142(July 25):56–58.

Information about the 11th International Conference on Aquatic Invasive Species, held in Alexandria, Va., Feb. 25–March 1, 2002, can be found at http://www.aquatic-invasive-species-conference.org/.

An interactive, animated map showing the spread of the zebra mussel across the United States can be found at http://www.nationalatlas.gov/zmussels1.html (requires a Shockwave plug-in for your browser).

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