Zebra Mussel Invasion Threatens U.S. Waters

Damage estimates soar into the billions for the zebra mussel, just one of many invaders entering U.S. waters via ballast water

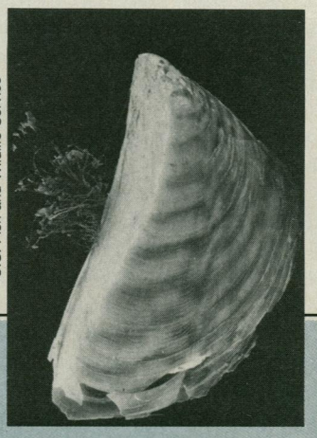
SOMETIME IN 1986, A SHIP probably taking on cargo in the St. Clair River dumped its ballast water, releasing billions of organisms that it had picked up in freshwater ports in Europe. Most of the species that had hitched a ride across the Atlantic perished. But at least one, *Dreissena polymorpha,* or the zebra mussel, survived—and, for reasons that no one fully understands, the population exploded with a vengeance. Indeed, some biologists are predicting that this tiny mollusk, a mere inch and a half long, could turn out to be the most destructive and expensive biological invader yet to hit the Great Lakes.

In just a few years in Lake Erie, the hardest hit area, the zebra mussel has fouled water intake pipes at municipal and industrial plants, disrupted municipal water supplies, and altered the ecosystem in still unknown ways. Rough damage estimates for the Great Lakes run to $4 billion over the next decade. And no one expects the intruder to stop there. "The zebra mussel has the potential to colonize almost all of the United States and a good part of southern Canada," says John Gannon of the Fish and Wildlife Service's National Fisheries Research Center–Great Lakes. Already, there are unconfirmed spottings in Tennessee lakes. "The zebra mussel may be one of the greatest biological invaders in North America, ranking up there with the gypsy moth and the starling," predicts James Carlton, director of the Maritime Studies Program at Williams College in Mystic, Connecticut.

As Great Lakes biologists scramble to understand the biology and ecology of the zebra mussel—and, with any luck, to find its Achilles' heel—they and others are warning that this is not an isolated invasion. "The zebra mussel is the most spectacular example of a whole slew of introductions happening all over the world, the result of ballast water," says Peter Moyle, a freshwater ecologist at the University of California, Davis.

Since trade opened with the People's Republic of China, a host of exotic species have colonized the San Francisco Bay, says Moyle. In the 3 or 4 years since it was introduced, the Asian clam has already become one of the most abundant organisms in the entire estuary system. "In some places it literally coats the bottom, with a density of 10,000 to 20,000 per square meter," says Moyle, with unknown effects. American comb jelly are showing up in the Black Sea in force. Australia has also been hard hit with ballast water stowaways, including Japanese dinoflagellates, an algae that causes red tide, and a variety of fish and shrimp.

Exactly why ballast-borne invasions are on the rise is a puzzle, because ships have used ballast water, which is carried in a series of tanks beneath the hull for balance and weight, since the 1880s. Carlton suspects that some combination of the larger volume of water carried and the higher speeds of today's ocean-going vessels may have breached a biological barrier that had previously held ballast-related invasions in check.



U.S. Fish and Wildlife Service

The invader. *The zebra mussel clamps onto just about anything with hundreds of byssal threads. It has now been sighted throughout the Great Lakes: in Duluth, Thunder Bay, Alpena, Kenosha, and Gary.*

Nor does anyone know why some invaders rapidly expand in their new environment while others never become a problem (see box, p. 1371). Ironically, what seems to have given the zebra mussel an opportunity to colonize a new continent is that both the Great Lakes and the freshwater ports in Europe have been cleaned up in the past 10 years, providing an ideal habitat for the mollusk—and other invaders as well. "That's what's really got us concerned. What's next?" asks FWS's Gannon.

But for now, Gannon and other Great Lakes biologists have their hands full just dealing with the zebra mussel. The intruder was not detected until 1 June 1988, when two students working with Canadian biologist Paul Hebert plucked one of the pretty striped creatures out of Lake St. Clair. By that time, the zebra mussel was already well established in Lake St. Clair and was spreading fast. It was swept downstream, via the Detroit River, into Lake Erie, where the population exploded.

It took about a year for the zebra mussel to make its way across Lake Erie and down through Niagara Falls and into Lake Ontario and the St. Lawrence Seaway, where it is poised to spread to the lakes and rivers of New York. This summer zebra mussels have been sighted in all the Great Lakes. And it is just a matter of time until the zebra mussel makes its way into the Mississippi River basin and the lakes and reservoirs of the Southeast.

What makes the zebra mussel such a pest is that it latches onto any hard surface it can find—rocks, bridge abutments, water intake pipes, even the shells of other mussels and clams—clamping on with up to 200 filaments, known as byssal threads. As they pile up, one atop the other, the mussels form a dense mat of shells. The zebra mussel is also remarkably fecund—a single female spews 40,000 eggs into the water column—so once it finds a place to its liking, it quickly takes over. In 1988, biologists at the Detroit Edison plant on western Lake Erie counted 200 zebra mussels per square meter on the intake screen. The following year, the number had jumped to 700,000.

During the summer of 1988, water flow in the intake pipe at the Monroe water plant was reduced about 25%. Then in mid-Decem-

ber water flow was shut off completely for 2 days from a combination of zebra mussels and frazzle ice, closing down businesses and schools and necessitating emergency conservation measures. The city spent a quarter of a million dollars to restore the water intake and expects to spend $6 million more on a new intake system designed to keep the zebra mussel out.

Jon Stanley, director of the FWS's National Fisheries Research Center–Great Lakes, puts the cost of cleaning and retrofitting pipes in Great Lakes cities at $2 billion over the next decade. The ecological impact is far trickier to ascertain, though Stanley puts it at a very rough $2 billion.

SOME GREAT LAKES INVADERS

Species	Year detected	Origin	How introduced	Damage
Sea Lamprey	1830s	Atlantic	Via canals	Decimated population of coregonids and lake trout; tens of millions spent on control and restocking.
Alewife	1870s	Atlantic	Via canals	Died in massive quantities in the 1960s, littering beaches.
Spiny Water Flea	1984	Europe	Ballast water	Potential disruption of lower food web and thus fisheries.
Ruffe	1987	Europe	Ballast water	Competes with perch; eats eggs of other species.
Zebra Mussel	1988	Europe	Ballast water	May edge out native mussels and clams and disrupt fisheries.
Tube-Nose Goby	1990	Caspian Sea & Black Sea	Ballast water	Unknown, probably minor.

Because the zebra mussel filters huge quantities of water, sucking out most of the phytoplankton, the biggest concern is that it will disrupt the lower food web, with effects reverberating up the food chain. Walleye are directly endangered, as zebra mussels have encrusted their prime spawning beds. There's good reason for alarm: walleye fishing in Lake Erie alone is a $900-million-a-year business. But so far, at least, the worst fears have not materialized, says Joe Leach of the Ontario Ministry of Natural Resources. "After this summer's work we came out feeling kind of good," says Leach. "The walleye spawned, eggs hatched OK, and we have a good year–class of walleyes."

Native clams are also in jeopardy, says Tom Nalepa, a biologist at NOAA's Great Lakes Environmental Research Laboratory in Ann Arbor. Nalepa fears that many of these species, some of which are already endangered, may be wiped out. Divers find the native species literally covered with the intruder, which means the zebra mussels get first access to any food in the water column. "Once there was a nice diversity," says Nalepa, who found 18 different species of clams in Lake St. Clair in 1986. "And the more species there are, the more stable the ecosystem. We could end up with the zebra mussel as the only filter-feeding mollusk."

To biologists like Nalepa and Gannon, the $64,000 question is how far the zebra mussel will spread—and, more important, whether the population will explode as it has in Lake Erie, or remain relatively low as it has so far in Lake Ontario. They are finding that experience in Europe, where the mussel invaded from the Black and Caspian seas in the early 1800s, offers little guidance because the Great Lakes ecosystem is different.

Ironically, the mussels' most alarming characteristic—their voracious appetite—could limit their numbers in some areas, says Gannon. They are filtering algae out of the water column at a higher rate than anyone expected. Indeed, the water clarity in Lake Erie has doubled in just the past year—most likely because of the zebra mussel's grazing. What's more, notes Gannon, this year the normal diatom bloom just didn't happen. Already, "they are eating themselves out of

Why Do Some Invasions Succeed?

Predicting just what the zebra mussel will do is no mean feat, biologists are learning—especially since no one can explain why the population exploded now, when the mollusk probably had access to the Great Lakes throughout the 1960s and 1970s as European ships dumped their ballast water. The improved water quality in the lakes is undoubtedly a major factor, but why did the zebra mussel take off now and not, say, 3 years ago?

Numerous factors figure in any successful invasion, including the size of the initial invasion force, the diversity of its gene pool, the status of its competitors, and so on. But theory aside, what it basically comes down to is chance, says Harold Mooney, a Stanford ecologist who recently headed a project on biological invasions for the United Nation's Scientific Committee on Problems of the Environment.

There are countless examples in which people have tried repeatedly to introduce a new species—say, a new game bird—with no success, even though the species and the habitat were closely matched, says Mooney. Then on the 50th try it works. On the flip side, a bird fancier introduced 50 pairs of starlings into Central Park 100 years ago; the starling is now the most populous bird in the United States.

Biologists tracking the zebra mussel have a few clues, however. They suspect that a ship must have picked up a passel of the critters when they were in just the right stage, their free-floating larval, or veliger, stage, during which they are easily dispersed. And there is some evidence that were several ships, not just one. Soon after they detected the intruders in 1988, Paul Hebert of the University of Windsor and his Canadian colleagues examined their DNA and found a remarkable degree of genetic diversity, which suggests either that huge numbers made the trip or, more likely, that there were multiple introductions occurring at more or less the same time. This genetic diversity probably got the zebra mussel through the first hurdle that usually fells an invader—a genetic bottleneck.

Peter Moyle of the University of California, Davis, finds a common thread to many biological invasions. "In California at least, the places you find invaders are in disturbed ecosystems. It is easier for them to become established when the system is off balance." He cites the Asian clam, which has colonized the San Francisco Bay at an astounding rate. "The reason it probably took over so quickly is because the estuary is very disturbed," says Moyle, noting that the area has suffered a 4-year drought. "Water has been diverted, fish populations have crashed."

Mooney agrees: "With the movement of organisms and the breaking down of barriers, we have restructured the whole biotic framework in a way. We are in for all sorts of surprises." ■ L.R.

house and home," he says. And that, in turn, means that the zebra mussel will probably reach huge numbers only in the very productive parts of the Great Lakes, where there is enough food to sustain them, such as Lake St. Clair, Lake Erie, and probably Green Bay and Saginaw Bay.

Food shortages, disease, and a host of other factors may also cause the population of mussels to fluctuate wildly in heavily infested areas over the next few years. Biological invaders typically build up a huge population and then crash, often repeating the cycle several times before settling into an equilibrium. Gannon, for one, expects a population crash in Lake Erie sooner rather than later. "The big unknown for Lake Erie," he says, "is at what level they reestablish themselves after the crash."

Again, Europe is little guide. Despite extensive study, European biologists are still at a loss to explain why the zebra mussel crashed and then came back in force in Sweden but never quite recovered in mainland Europe. And in Great Britain, the zebra mussel never reached the high population densities of mainland Europe.

Prospects for the Mississippi River are mixed. On the bright side, while still a nuisance, the zebra mussel stayed at relatively low levels in European rivers. But it could still wreak tremendous ecological havoc in the Mississippi, which has the highest diversity of clams in the world, many of them already endangered. And what gives everyone pause, with the recent sightings in Tennessee, is that the zebra mussel reached its highest levels in European reservoirs.

For all the uncertainties about the zebra mussel invasion, two things are abundantly clear: Great Lakes biologists should have seen it coming, and more intruders are on the way. Indeed, scientists actually did sound the alarm about ballast water almost 10 years ago. In a 1981 study for Environment Canada, researchers examined the ballast water of 55 cargo ships entering the Great Lakes. About 17 species arrived alive in each ship, and the number of individuals per species ranged from 10,000 to a whopping 8 billion. Although no zebra mussels turned up, the authors warned that they, too, were likely stowaways.

Like so many government reports, this one was promptly shelved and was dusted off only after the zebra mussel and other ballast water stowaways, like the ruffe and spiny water flea, had announced their presence in the Great Lakes. Says Gannon: "We're kicking ourselves." The report's ominous findings have been buttressed by a recent survey by Leach and Ed Mills of Cornell University, who found that of the more than 120 exotic species in the Great Lakes, about one-third came in via ballast water. And this year, Carlton of Mystic College and his colleagues at the University of Oregon counted 300 species of living animals and plants in the first 100 ships they sampled from the Western Pacific.

Prompted by the zebra mussel invasion, Congress is now considering a bill that would require ships entering the Great Lakes to exchange their ballast water on the open seas, as the Canadian Coast Guard already does in its voluntary program. (Any organisms picked up in mid-ocean would be unlikely to survive in freshwater or brackish ports.) Citing California's intruders as well, the American Fisheries Society is lobbying Congress to broaden the bill to all U.S. ports. Prospects for passage of the bill, which would also provide about $15 million for research and control, are said to be good.

Meanwhile, the door is still wide open. Just this summer, biologists spotted the tube-nose goby, a small bottom-dwelling fish, in the St. Clair River, just arrived in ballast water from the Caspian and Black seas. ■ LESLIE ROBERTS

Massey Named to Head NSF

It's official: Walter E. Massey is President Bush's choice to be the next director of the National Science Foundation. The White House announced his nomination last Friday, 14 September. As first reported in *Science* (17 August, p. 737), Massey had been strongly supported by Bush's science adviser, D. Allan Bromley.

Massey is likely to be a popular choice among researchers to head the science foundation. He is from an academic background, having been on the physics faculty of both Brown University and the University of Illinois at Urbana. In 1979 he left Brown to become director of Argonne National Laboratory, a post he held until 1984 when he moved to his present position as University of Chicago vice president for research and for the Argonne laboratory. Massey was president of the American Association for the Advancement of Science in 1989.

W. Massey

Robert M. Rosenzweig, president of the Association of American Universities, says, "It would be hard to find a better person for the job." "Massey has great respect in the scientific community and the university community in general," says Rosenzweig. "I think it's terrific for NSF," adds Alan Schreisheim, current director of Argonne who served as Massey's deputy at the laboratory.

In recent years, most of Massey's published work has been on science policy—primarily science education and opportunities for minorities in science. In the 1970s he coauthored numerous articles on condensed matter physics.

Reached in his office in Chicago, Massey said he was pleased by his selection but would offer no specifics about his plans for the agency. Massey is presently on sabbatical leave from the University of Chicago, studying how European countries are transferring technology from universities to industry. Massey says he intends to complete his sabbatical project, which is based in Paris and is scheduled to end in January, "unless it proves impossible." In any event, Massey's nomination must be confirmed by the Senate, and hearings are unlikely to be held in this year's session of Congress. ■ JOSEPH PALCA

Gene Therapy Begins

The NIH researchers who have been working for years to be the first human gene therapists were ready and waiting when the last of a series of approvals was handed down last week. At 8:52 a.m. on Friday, 14 September, the Food and Drug Administration signed off on the last of the paperwork for a test in which the gene for adenosine deaminase (ADA) would be given to an ADA-deficient child with a compromised immune system (*Science*, 31 August, p. 975).

Four hours later, at exactly 12:52 p.m. the test began. The patient, a 4-year-old girl whose identity has not been disclosed, took the therapy sitting up in bed while her own white blood cells, carrying a foreign ADA gene, dripped into her arm.

R. Michael Blaese and Kenneth W. Culver of the National Cancer Institute, with W. French Anderson of the National Heart, Lung, and Blood Institute, are principal investigators for the test. Said Culver, "Everything about the study has gone well—from obtaining the patient's cells to growing the gene-corrected cells in culture."

The patient has already gone home from the hospital. Solid results about whether the new ADA gene will restore her immune system may be as long as a year away.

■ BARBARA J. CULLITON