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LIVING WORLD

The hidden strengths of freshwater mussels

The humble bivalves can clean polluted water and bump up diversity — but in dammed rivers and fouled watersheds, many species face extinction. With help, maybe they can save themselves.

By Sharon Levy 06.21.2019

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the river bottom where the creatures' siphons pierce the sediment.

Yet even though they're hunkered out of sight, freshwater mussels shape ecosystems.

They funnel food downward, fueling life in the riverbed and clarifying water for other species. They help to mitigate nutrient pollution, a widespread problem that leads to dead zones in some waters.

And today they are in trouble, with one of the highest extinction and imperilment rates on the planet. In North America alone, 30 freshwater mussel species have gone extinct over the last century, and 65 percent of those surviving are considered endangered, threatened or vulnerable — primarily due to the

large-scale damming of rivers.

A blitz of dam construction from the 1920s to the 1980s destroyed thousands of miles of habitat and fragmented far more. Adapted to shallow, free-flowing waters, mussels can't survive in the deep, cold and oxygen-poor conditions that major dams create for scores of miles downstream, says Wendell Haag, a fisheries research biologist at the Kentucky Department of Fish and Wildlife Resources' Center for Mollusk Conservation.

brink. They are working on building the mussels' PR by spreading word about the water-cleansing services they provide. And they aim to put the creatures to work reclaiming waters, by rearing them in large numbers then releasing them to the wild.

In so doing, the scientists are turning traditional conservation on its head: Instead of protecting habitat to rescue a threatened creature, the goal is to use mussels to rescue their habitats themselves. "Mussels are biofilters," says Caryn Vaughn, an ecologist at the University of Oklahoma who coauthored an article about the ecological roles of the creatures in the 2018 *Annual Review of Ecology, Evolution, and Systematics*. "And if we can convince people that's important, then I think that's a tool to save them."

A complex life, out of sight

In healthy streams, mussels live in large beds that may hold thousands of individuals of several species, each adult as big as a baseball or larger. They're

long-lived — some species have lifespans of more than 100 years. They lead flamboyant reproductive lives that likely got their start more than 100 million years ago, when an ancestor of today's mussels evolved a strategy of having its larvae hitchhike on fish.

Each female produces millions of these larvae, called glochidia, and many mussel species make elaborate lures that resemble the prey of their specific fish hosts. Once on board a fish, glochidia form cysts on the creature's gills or fins until they transform into juveniles, drop off and settle to the stream bottom. Perhaps two in a million will live to reproductive age.

The Ouachita kidneyshell mussel packages its larvae, called glochidia, in a membrane that resembles a small fish. When a real fish snaps it up, the membrane bursts, releasing the glochidia, which will live in the fish's gills for a period.

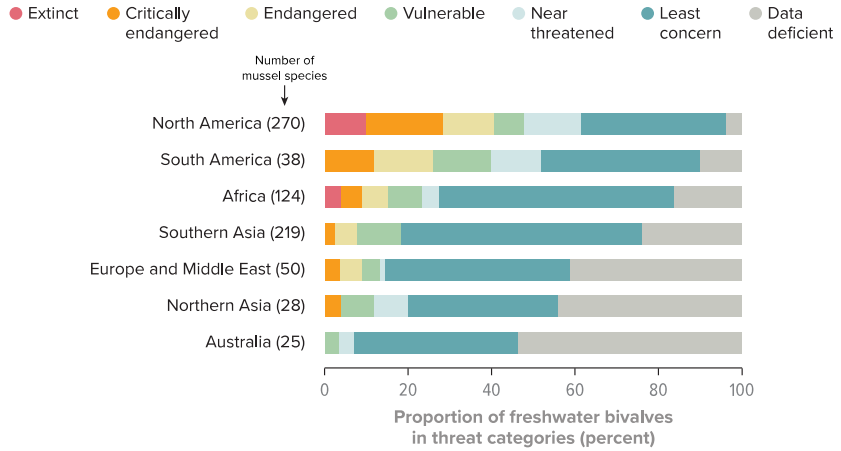
CREDIT: CHRIS BARNHART / MISSOURI STATE UNIVERSITY

This complex interaction with fish hosts helped mussels thrive and spread. "Fish can swim upstream, while mussels cannot," notes Chris Barnhart, a biologist at Missouri State University who works on propagating mussels for research and restoration. By riding on fish, mussels can colonize upstream habitats — an innovation so powerful that all living members of the freshwater mussel family, the Unionidae, are descended from the long-gone ancestor that adopted the tactic.

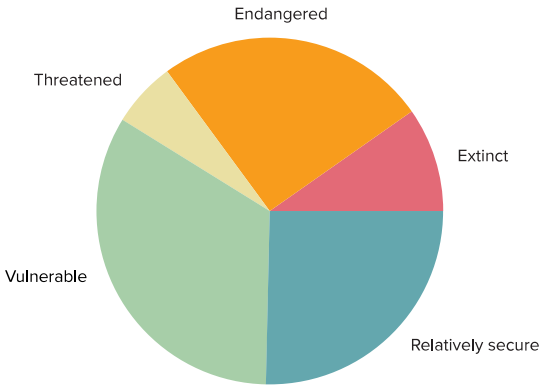
But the proliferation of dams has blocked fish movements, cutting off many mussel populations from their hosts and ending their ability to reproduce. Other populations dried out when water diversions lowered flows in their home streams, or they fell victim to water pollution from sewage plant discharges, industrial spills and nutrient-heavy runoff from farms and cities. Invasive species threaten still others (nonnative zebra and quagga mussels outcompete native mussels, for example, and zebra mussels stick to native mussels in great

numbers). Even as conservationists focus on rescuing species listed as threatened or endangered, the overall decline in mussel numbers continues — contributing, in turn, to the degradation of freshwater habitats throughout the US and the world.

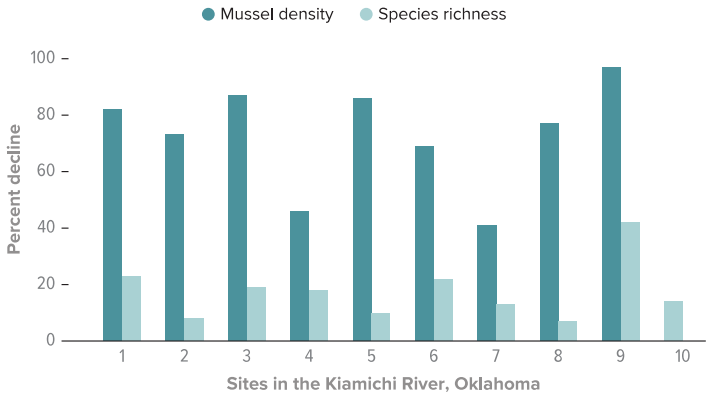
Threat level for freshwater bivalves by region



Proportion of imperiled US freshwater mussel species



Declines in species density and richness between early 1990s and early 2000s



SOURCE: C.C. VAUGHN *ET AL* / *AR ECOLOGY, EVOLUTION, AND SYSTEMATICS* 2018 KNOWABLE MAGAZINE

Human activity hits mussels hard: Of the 270 North American freshwater mussel species (top graph), 30 have gone extinct in the last 100 years, 95 have been listed as endangered or threatened, and a large proportion of the remaining species are considered vulnerable (middle pie chart). A case in point is the Kiamichi River (bottom graph), where several years of drought combined with damming the river raised the water temperature, killing many mussels. (A bar for decline in mussel density is not shown for Site 10 because the change was too slight for the scale of the chart.)

Trying to make the most of water

When Vaughn began studying one US river — the Kiamichi — in the early 1990s, she witnessed firsthand a precipitous decline. The river, which originates in uplands in southeast Oklahoma, was home to an abundance of freshwater mussels belonging to 31 different species. Her long-term study documented a drastic drop-off: 60 percent of the mussel population has vanished over the last 20 years.

Significant loss began during a severe drought that started in 1998 and didn't subside until 2005. "Drought is common in this region, it's cyclical, and has been going on for as long as people have been keeping records," Vaughn says. But the mussels had to contend with something new: water management at a dam, built in 1982, that holds back flow of a major Kiamichi tributary. The drier conditions became, the more water was held back for human use, elevating the temperature of the remaining water and killing many mussels.

Mussel fieldwork at the Kiamichi river in Oklahoma. Mussels play an important role in nutrient cycling, removing organic matter from the water, excreting dissolved nutrients back into it, and depositing these nutrients in the sediment. In the Kiamichi, mussels can process the entire volume of overlying water during the summer.

CREDIT: CARYN VAUGHN

But Vaughn also witnessed something hopeful. As she and colleagues reported in the journal *Ambio*, while the Kiamichi lost significant numbers of species during the drought and overall abundance dropped too, populations in the nearby Little River held steady. The key was a difference in management. At the dam on the Little River, the largest releases of water were in late summer and fall, the driest time of year, which protected mussels from high temperatures in shallow water during the drought. In other words, enlightened water management can help sustain mussels even as climate change increases human demand for freshwater.

Conservationists are now suing to demand flows high enough to protect endangered mussels in the Kiamichi.

Mussel power

Endangered mussels can provide legal leverage, but they lack the gut appeal of a wolf or a falcon. “A freshwater mussel is the opposite of a charismatic species,” says Vaughn. “People don’t see it and don’t know what it’s doing.”

But in fact, an adult mussel is a powerful, durable and efficient water filter inside a hard shell. It can filter up to 10 gallons of water daily, removing algae and organic matter and transforming water from cloudy to clear so that bottom-dwelling plants get more light.

It builds its own tissues from the material it filters, locking up nitrogen, phosphorus and carbon for decades. And it deposits its waste on the streambed, providing nutrients for bottom-dwelling algae, insects and other invertebrates, which, in turn, feed fish.

A riffleshell mussel patiently awaits a visit from a fish, which becomes temporarily trapped while the mussel releases its larvae. The tiny mussel offspring will live and develop in the gills of the fish until the small, juvenile mussels are ready to take up life in the stream bed.

CREDIT: CHRIS BARNHART / MISSOURI STATE UNIVERSITY

A study of the Upper Mississippi River published in the journal *PeerJ* found that the relatively healthy mussel population there filters more than 14 billion gallons of water daily, removing tons of biomass and depositing tons of carbon and nitrogen at the sediment surface. Bacteria that transform nitrogen compounds into harmless nitrogen gas thrive beneath mussel beds.

Other studies, published in *Environmental Science & Technology,* showed that the California floater, a threatened mussel native to California and the Pacific

Northwest, dramatically lowers the amount of fecal bacteria in river water and lakes.

If freshwater mussels can be restored to their former abundance, write ecologist Danielle Kreeger and her colleagues in the *Journal of Shellfish Research*, there's reason to think that the creatures can mitigate nutrient pollution and reduce the costs of drinking-water filtration. "If your system had a mussel population historically, and no longer does, I'm not convinced it's healthy until you have your natural mussel community back," Kreeger says.

Nutrient pollution is a widespread threat to aquatic ecosystems. Sewage discharges and synthetic fertilizers used in intensive agriculture release heavy loads of nitrogen and phosphorus to rivers, triggering harmful blooms of algae and cyanobacteria. As dead cells sink to the bottom, bacteria digest them, depleting oxygen in the water. During intense blooms, fish and other aquatic creatures may suffocate.

The tiny larvae of the endangered oyster mussel (*Epioblasma capsaeformis*) spend part of their lives nestled in the gills or fins of a host fish. Glochidia are visible here as translucent blobs on the fin of a darter fish.

CREDIT: CHRIS BARNHART / MISSOURI STATE UNIVERSITY

The Chesapeake, North America's largest estuary, is a prime case, says Kreeger, who works at the nonprofit Partnership for the Delaware Estuary. Early settlers there recorded clear waters thick with fish. The bottom sediments held a bounty of green plants, mussels and oysters. But starting in the 1600s and accelerating in the twentieth century, forest clearing and farming increased runoff of nutrient-laden sediments into the waters. Shellfish populations diminished, and the Chesapeake became cloudy with sediment and algal blooms, and native, bottom-

dwelling plants and animals faded away.

To limit nutrient runoff, farmers must use best management practices, or BMPs — strategies such as minimizing fertilizer use and planting wetland vegetation along drainage ditches. Restoration of native bivalves — specifically, oysters — was recently approved as a BMP. Efforts so far have focused on the eastern oyster, a saltwater species that clears the water and is also a valuable delicacy that Chesapeake watermen harvest. Freshwater mussels may not be as tasty, but they could help to improve water quality just like oysters and in a wider range of habitats, Kreeger says.

Lessons from the button trade

But before one deploys mussels, one has to learn to grow them. Over the past 20 years, several labs in the US have worked on honing mussel propagation techniques in the lab to raise animals for restoration efforts. In doing so, they've turned to research from almost a century earlier, when freshwater mussel shells were used to manufacture buttons, forming the basis of a major US industry.

The center of the button business was in the Midwest, where a single mussel bed near New Boston, Illinois, produced more than 9,000 metric tons of shells from 1894 to 1897 — but was exhausted by 1899. It was just one of many cases in which natural mussel beds were wiped out by overharvesting. By the 1910s, researchers in Iowa and Missouri were working to increase the growth and reproduction of mussels to keep the button industry going.

In the late 1800s, "pearl" buttons made from mussel shells were a hot commodity; by 1899 there were some 60 factories in the midwestern US producing millions of buttons each year. The industry severely depleted local mussel populations, but records from that time have informed today's mussel researchers who are propagating mussels in the lab for release into the wild.

CREDIT: STEVE SIMMONS

They left information on how and when to find females carrying glochidia, and which fish are hosts for local mussels. “We learned a lot from reading those old papers,” says Barnhart. His own lab found that the next step, attaching larval mussels to host fish, was relatively simple: Get glochidia from the female, keep the water in the tank stirred up, and add the right fish.

Barnhart’s team next focused on getting large numbers of glochidia through their parasitic phase on host fish to produce as many juvenile mussels as possible. But most microscopic juveniles don’t survive, they found. The lab had to figure out how to get them to grow to an inch or so, at which point “they’re bulletproof and have a high probability of survival,” Barnhart says.

Still, rebuilding lost mussel populations in the wild is a complex task even after successful lab-rearing. The Upper Clinch River in Virginia, where pollution wiped out native populations, is one of a handful of locations where restoration efforts have been demonstrably successful.

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In 2005, after a cleanup, researchers tried releasing tiny juvenile mussels, and host fish carrying glochidia, both with no luck. Only when they released larger juveniles, cultured in a lab for a year or more, did the mussels dig in and, in time, show behavioral signs of natural reproduction, says Jess Jones, a restoration biologist with the US Fish and Wildlife Service who worked on the effort. Female mussels holding larvae in their gills were spotted rising to the sediment surface to display their lures for host fish.

A new perspective on restoration

As efforts to restore endangered mussel species continue, and as scientists learn more about water management practices that can help them, Kreeger and colleagues are moving ahead with a plan to apply the techniques on a grander scale, using common, not endangered, mussel species. The goal is to deploy the mussels to improve and protect water quality and thus help restore whole ecosystems.

The project follows years of work propagating and culturing local mussels and will focus on reviving their populations in the Delaware and Chesapeake watersheds. Kreeger and colleagues conclude that five species — the eastern elliptio, alewife floater, tidewater mucket, eastern pondmussel and yellow lampmussel — would be prime restoration candidates. All have high filtration

capacities, were historically widespread and abundant and remain relatively common in the region.

Raising mussels in the lab is tricky; among other steps, scientists must induce the parent mussels to release their tiny larvae, called glochidia. For some species, such as this member of the genus *Epioblasma*, this task is best accomplished by presenting the mussel with a fish head on the end of a small pipette, mimicking a promising host in which the glochidia can develop. Once released, the glochidia are drawn into the pipette and can be reared in tanks.

CREDIT: CHRIS BARNHART / MISSOURI STATE UNIVERSITY

To that end, the Partnership for the Delaware Estuary recently signed an agreement with the state of Pennsylvania to build a mussel production hatchery in Philadelphia. “When the hatchery is built and we switch on the lights and pumps, our goal is to produce half a million mussels per year that would persist in our streams and rivers, and provide a return on that investment in the form of clean water,” Kreeger says.

The water must be somewhat clean to start with: Larval and juvenile mussels can be poisoned by relatively low levels of ammonia, a form of nitrogen common in waters polluted with sewage or agricultural runoff. Decades of dam-building and pollution caused the drastic decline of mussel populations in the Chesapeake watershed. Work by Kreeger and others shows that some habitats can now support mussels again.

“There hasn’t been a facility before that’s been able to focus on producing large numbers of common species,” Kreeger says. “Therefore, we haven’t really had the opportunity to test a lot of these concepts in a very significant way — where you put the numbers up in a river, then see if you get the needle to move on water quality.

“We’re looking forward to being able to finally test that.”

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