ENVIRONMENT

Arc

DELAWARE BAY: After engineers improved freshwater creeks flowing into a tattered salt marsh so more fish could thrive, nature rebuilt dying plant life into thick, healthy vegetation.

hitects of the Swamp

Many wetland recovery programs have failed by trying to re-create the original ecosystems. Recent successes have focused on one or two limited goals and have let nature take it from there

By John Carey

IN BRIEF

Wetlands across the U.S. and the world continue to disappear at a rapid rate.

Projects to revive wetlands have largely failed and wasted millions of dollars, primarily because they have attempted to fully engineer all aspects of an ecosystem to their original conditions.

Instead scientists should attempt to achieve one or two benefits, such as boosting fish populations or improving water quality, leaving the rest alone.

A growing number of restorations built on that principle are succeeding in Delaware Bay, in coastal Louisiana and around the globe.

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JOY ZEDLER CAREFULLY PLANNED THE THREE EXPERIMENTAL WETLANDS AT THE University of Wisconsin–Madison's Arboretum to be identical: parallel marshes 295 feet long and 15 feet wide, carved by engineers into the green landscape. Zedler's contractors planted all three tracts with similar species to see how the vegetation would absorb and clean water runoff during storms.

Zedler's team also allowed the same amount of water to flow into the test beds from a pond at the front ends of the tracts. They planned to measure the nutrients in the water entering each plot and draining into a basin at the far end, as well as soil stability, water absorption, and the productivity and diversity of the grasses and other plants. The scientists expected that each of the three wetlands would behave similarly.

The stakes were higher than for the typical university project. The city of Madison was keenly interested because it wanted to learn how to use wetlands to slow and cleanse storm water pouring out of town into neighboring Lake Wingra, which is suffering from high levels of nutrients such as nitrogen and phosphorus in the runoff. And the question of how to maximize the many valuable so-called ecosystem services that wetlands can provide, from reducing runoff and flood damage to boosting biodiversity, has been growing more urgent by the year as wetlands worldwide vanish at an alarming rate. Zedler, a professor of botany and restoration ecology at the university, had hoped the experiment would provide some insight.

Three years later, however, it was clear that the experiment had raised new questions the researchers had not anticipated. "Nothing about the system behaved as we supposed," Zedler says. The first surprise: even though the tracts were just three feet apart and had been planted and expected to develop similarly, one plot became dominated by cattails, whereas the other two blossomed with up to 29 plant species. Second, although the cattail plot produced more plant material overall, it was lousy at everything Zedler expected from lush growth. It did not slow floodwater or control soil erosion. It did not absorb much of the nutrients in the water. The other two tracts provided more of the expected benefits—except for high productivity.

Why the surprising differences? Zedler's team discovered that a layer of clay under the cattail marsh was slightly thicker and thus less permeable than the layer under the two adjacent plots—so water ponded instead of percolating into the ground. That allowed storm water and nutrients to race down the channel. Meanwhile the cattails shaded out soil-stabilizing moss—which grew well in the neighboring swales—so soil erosion was higher.

Zedler's unforeseen results are helping her and other experts explain why the track record of past restoration efforts is poor, and they are pointing the way to improving the success rate. The big lesson from multiple investigations is to forget about trying to re-create a fully functioning wetland that is identical to the one being lost. "We don't know how to do it," says Doug Wilcox, professor of wetland science at the College at Brockport, S.U.N.Y. There are too many variables.

Instead scientists should focus on one or two key objectives, such as rebuilding land, improving water quality or boosting fish populations, and engineer the system to optimize those objectives. Then, once the basic engineering is done, let nature fill in the details as it pleases.

Another lesson is to monitor wetland projects for years, as Zedler continues to do with her experiment. That time is needed to uncover the often surprising details of what works and why and to take corrective action when necessary. Unlike cars, "wetlands do not come with repair manuals," Wilcox says.

Accepting the notion that we usually cannot restore wetlands to their original state is a sobering reminder of the limits of science. But achieving one or two goals can be a major step forward. Inspiration is coming from a growing list of successful projects, from Delaware Bay and the Mississippi River Delta to Iraq and the Guyana coast. "Restoring is a heck of a lot better now than it used to be," says William J. Mitsch, director of the Everglades Wetland Research Park in Florida.

NATURE'S KIDNEYS

RECENT SUCCESSES ARE WELCOME NEWS because wetlands are so valuable. Mitsch calls them "nature's kidneys" and "ecological supermarkets, where all the critters go to eat or be eaten." Michael Weinstein, a senior scientist at the New Jersey Institute of Technology, has a bumper sticker that says "No wetlands, no seafood," and he has proved that the food chain born in marshes extends vital links far out into offshore waters. "They really are our support systems," he says.

Wetlands are our protectors, too. Events such as superstorm Sandy woke many people to the fact that "doing away with

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WILD SANDHILL CRANES exit a pond that collected rainwater early in the design of an experimental wetland at the University of Wisconsin–Madison; urban runoff allowed into the pond led to an unexpected invasion of cattails (*dark green*).

COURTESY OF JOY ZEDLER *University of Wisconsin–Madison*

marshes and dunes was a stupid idea," says John M. Teal, salt marsh expert and scientist emeritus at the Woods Hole Oceanographic Institution. The mere remnants of salt marshes in Long Island's Jamaica Bay helped to dissipate the storm's fury there, for instance, whereas the complete lack of wetlands around Manhattan left it exposed to the raging sea. Wetlands also soak up the nutrients that run off farmlands and down rivers and that fuel harmful algal blooms and oxygen-free dead zones in the nation's coastal waters. They tame floods. Moreover, Mitsch says, "they are probably the best system on the planet for sequestering carbon" in the forms of thick vegetation and rich organic soil.

Yet wetlands have been disappearing fast. The soggy ecosystems have been drained to grow corn in Iowa and salt hay in Delaware, flooded to create fish and shrimp ponds in Thailand, filled to build airports and cities across the globe, and starved of their needed river sediments by levees everywhere. Mitsch estimates that wetlands once covered 4 to 6 percent of the earth's land surface—and fully half of them have already been lost.

Concerted efforts are being made to stem the tide. Jessica Bennett Wilkinson, senior policy adviser for mitigation at the Nature Conservancy, calculates that $3.9 billion a year is laid out in the U.S. on wetlands under section 404 of the Clean Water Act alone. The act requires developers or others who destroy wetlands to restore them or to create compensatory ones.

Much more money is spent around the world on projects such as planting mangrove trees. Unfortunately, the evidence suggests that the money is not being well spent; for example, 90 percent of efforts to rebuild mangrove swamps fail, estimates Robin Lewis, president of consultation firm Lewis Environmental Services. "We're talking millions and millions of wasted dollars every year doing bad projects—and we have very similar failures with all wetland types," he says. A recent analysis of 621 restored wetlands, led by wetland ecologist David Moreno-Mateos, then at Stanford University, shows that restorations fall far short in providing the full functions of equivalent natural wetlands—even after 50 to 100 years.

One reason for the poor success rate is a chasm between biology and engineering. "The guy in the biology department is doing one thing, and the guy in engineering is doing another, and they're both part right and half wrong," Mitsch says. A related criticism of work conducted by the U.S. Army Corps of Engineers, which oversees the vast majority of federally funded restorations, is that engineering often neglects biological realities.

Most fundamentally, efforts founder on the lack of detailed knowledge that Zedler, Wilcox and others are painstakingly gaining. "My irritation is that people have been funded to do wetland restoration without ever developing the methods, first, to do it the right way," Wilcox says.

GET THE WATER RIGHT

SO HOW CAN WE DO IT BETTER? In every project, the starting point is to focus work on one or two benefits. Then select one primary technique to achieve that objective. One of the most fundamental techniques might seem obvious but is often not taken seriously enough: get the water conditions right. "It's not rocket science," Lewis says. "It's hydrology, hydrology, hydrology."

In some rare cases, simply bringing water back works magic. Because of wars, dams and Saddam Hussein's effort to rob opponents of their livelihoods, 90 percent of the 7,700 square miles of marshes in southern Iraq were destroyed by 2000. After Hussein was deposed in 2003, a pioneering project, Eden Again, began to return the water from the Tigris and Euphrates rivers. The marsh bloomed. Thousands of former residents returned to raise water buffalo, harvest fish and weave mats from the reeds. The marsh's survival, though, is tenuous; a dam being built on the Tigris in Turkey could cause new water shortages.

Getting the water conditions right is crucial for rebuilding mangrove swamps, now being lost at a rate of more than 250,000 acres a year worldwide, Lewis says. Here the limited goal is to help trees thrive so they can cut down storm surges and high tides. Any other benefits that might accrue are bonuses.

In the old, standard approach, a project team builds a nursery, grows thousands of seedlings and plants them on coastal mudflats. "These projects are called successful, but in three to five years the [trees] are all gone," Lewis says.

Too much water is the usual culprit. "A mangrove actually spends most of its time out of the water," Lewis explains. "That's something people didn't understand for decades." When restoration expert Jamie Machin arrived in Guyana in July 2012, then as team leader for development consultation company Landell Mills, he measured the tide levels at the sites of a number of failed past projects. The shore bottoms were, on average, 20 inches too low; tree bottoms and roots spent too much time in saltwater, which slowly killed them.

Machin worked with a government team to build structures called groins and to plant *Spartina* grass, which together will trap sediment and raise the mudflats, reducing the time in which the trees are inundated. That single step should also eliminate expensive replanting of seedlings; as nearby trees grow, they will produce propagules—tiny, pod-enclosed living trees—that drop into the water and float around, colonizing new shores. "Once the sediments are built up, there are enough propagules in the system so the mangroves will come back," Machin says. There is no need to engineer a fully functioning ecosystem.

Similarly, Lewis is rescuing 1,000 acres of mangrove swamp in the Rookery Bay National Estuarine Research Reserve in southwestern Florida. A shore road built in the 1930s cut off much of the natural tidal flow to the area. Heavy rains also now fill the swamp like a bathtub, choking the trees. To fix the hydrology, Lewis is planning to install big culverts under the road and clean out cluttered tidal creeks so that heavy rains can quickly drain and Gulf waters can swirl in and ebb out. The main goal, again, is simply to keep the trees from dying. Yet ancillary benefits have already arisen; measurements show that the first six-acre phase of the project has not only improved the health of the mangroves but also brought substantial increases in the number of fiddler crabs and snook. When the entire project is done, "we'll get extremely valuable fish populations restored to areas where they don't exist today," Lewis says.

As the Guyana and Florida cases show, nature can do a great deal of restoration once the water conditions are fixed. In other cases, nature needs more help. The main reason for the loss of tens of thousands of acres of sedge-grass wetlands once dotting the shores of Lake Ontario has been a policy of holding water back behind dams to keep lake levels high for shipping and hydropower. Without periods of low water, encroaching cattails wipe out the highly diverse sedge-grass ecosystem. Regulators are now considering a new policy of allowing lake levels to drop more during times of naturally low water.

The goal of bringing back the sedge grass determined the second vital step: knocking back the cattails. Wilcox and his students are cutting down the cattails in the spring—just after the plants have used stored energy to grow tall but before new photosynthesis can replenish the reserves. They then use herbicide to kill any new shoots that appear.

TORN SALT MARSH in Delaware Bay (*top, 1998*) was restored by cutting a few gaps in adjacent dikes so freshwater could flow in and naturally create tidal creeks, which allowed plants to reseed and flourish (*bottom, 2013*).

COURTESY OF PSEG

A SUCCESS STORY

FOCUSING ON ONE MAIN OBJECTIVE has paid off handsomely in Delaware Bay. The estuary was once lined with salt marshes, an ecosystem teeming with crabs, fish and other aquatic life. Dutch settlers, however, built dikes and drained thousands of acres to grow salt hay for animal feed. Today salt-hay farms still produce weed-free mulch and material for coffin mattresses.

Looming on the New Jersey shore of the bay is the Salem nuclear power plant, owned by utility giant PSEG. The plant sucks in billions of gallons of water a day for cooling and kills millions of tiny fish and other creatures as they get drawn through the intake valves. In the early 1990s state regulators asked PSEG to build cooling towers to end the carnage. Reluctant to spend $1 billion to $2 billion, the utility proposed an alternative: restore enough salt marsh to compensate for the loss of fish—more than 10,000 acres.

PSEG's environmental project manager at the time, John Balletto, brought in a dream team of restoration experts. They determined that the best way to boost the fish populations was to cut gaps in the dikes that would let just the right amount of water into the marsh to create a maze of primary and secondary tidal creeks, which had vanished. It was important not to do too much. "If you engineer a drainage system in great detail, the system is forced to go the way you think it ought to be," explains Teal, one of the consultants. "But if you allow it to develop itself, it's more likely to be stable."

The team dug the main channels and a few side branches and left the rest of the creeks to develop on their own. The scientists' faith that nature would quickly reseed the entire marsh was proved correct. Today the increase in fish populations more

Disappearing Act

50% Wetlands lost in North America, Europe and China since 1900	**8.9 million** Acres of mangroves lost worldwide since 1980
252,000 Acres of mangroves lost globally every year	**74%** Vegetation in restored ecosystems versus naturally healthy sites

SOURCES: "STRUCTURAL AND FUNCTIONAL LOSS IN RESTORED WETLAND ECOSYSTEMS," BY D. MORENO-MATEOS ET AL., IN *PLOS BIOLOGY*, VOL. 10, NO. 1, ARTICLE NO. E1001247; JANUARY 24, 2012 (*top left* and *bottom right*); "THE WORLD'S MANGROVES 1980–2005," BY FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2007 (*top right* and *bottom left*)

than makes up for the losses from the power plant's water intakes. And the restoration looks indistinguishable from adjacent natural marshes, Teal says, even though the main purpose was to create a better environment for fish.

PSEG continues to monitor the marshes and fix problems that pop up. "We're still doing follow-ups at 20 years," Teal says. "In most restorations, people go back one year and maybe the third year, and that's it." Doing it right is expensive; the total cost to date has been more than $100 million. But that is far less than the $1 billion or more for cooling towers.

THE HIMALAYAS OF ECOSYSTEM SERVICES

SUCCESSFULLY RESTORING THOUSANDS of acres of Delaware Bay salt marsh is one thing. But can scientists reverse what National Wetlands Research Center director Phil Turnipseed has called "the greatest environmental, economic and cultural tragedy on the North American continent"—Louisiana's coastal land loss? Experts say that more than 1,800 square miles of marsh have disappeared there in the past 80 years.

We may soon find out.

The state has created a 190-page Louisiana Comprehensive Master Plan for a Sustainable Coast to restore dying wetlands and to build new ones, mainly by diverting sediment-laden Mississippi River water into marshes and shores. And because the region expects to receive billions of dollars from oil giant BP as compensation for the Deepwater Horizon oil spill, "there is now both a plan and money, which has never happened before," says Steve Cochran, director of Mississippi River Delta restoration at the Environmental Defense Fund.

The plan obeys the lesson of focusing on one goal: rebuilding and sustaining hundreds of square miles of land. But the scale is orders of magnitude larger than anything previously attempted. Get it right, and there is a chance to protect an entire coast from storms while revitalizing a vast and richly productive region that John Day, professor emeritus of coastal ecology at Louisiana State University, calls "the Himalayas of ecosystem services." Get it wrong, and with sea-level rise, Gulf waters could turn New Orleans into a modern-day Atlantis and permanently flood out hundreds of thousands of people on the tattered coast. "We can't afford to get it wrong," Day says.

The poster child for successful restoration is the Wax Lake Delta, an expansive area of new marshland created southwest of Morgan City, La., after the army corps began to divert sediment-laden water from the Atchafalaya River in 1942. "It's a beautiful area, with wonderful patterns and variations and willows on the banks," says Denise Reed, chief scientist at the recently formed Water Institute of the Gulf in Baton Rouge, La. "The soil is really firm—you can jump up and down on it."

Reed and other scientists who devised the master plan estimate that similar diversions can build 300 square miles of new wetlands in 50 years. Skeptics, such as Gene Turner of Louisiana State University, say that figure is wildly optimistic, however. He maintains that even when conditions are perfect for land building, the historical record shows a gain that is only about one fiftieth of that calculated by the master plan's models. Some smaller test diversions that have been in place for a decade or more show no gains at all. "They may be wasting a lot of resources on projects that are proved to be wrong," he says.

Turner is in the minority. The data do, however, show that providing the correct type and amount of sediment is crucial. The Wax Lake Delta is built on a foundation of sandy mineral sediment 6.5 to 13 feet thick—which typically comes from deep cuts in a river levee. A shallower cut will divert only finer-grained organic sediment, which is more likely to wash away in the next hurricane. A further complication is that the Mississippi River is flush with nutrients from midwestern farms, which will allow plants to thrive in the newly created marsh without putting down deep, soil-stabilizing roots—making the fragile land vulnerable to storms. That is why Turner and others favor an alternative to diversions: filling in canals dug by oil companies with the dredged material along the canal banks to slow encroaching seawater, helping plants grow.

Whether massive sediment diversions will succeed or fall short "is a hot and heavy controversy, with some legitimacy on each side," Cochran says. Yet time is running out. Most scientists agree that the effort must start now, or else there will not be any natural wetlands left to reconstitute; the delay would also mean no chance to learn from, or adjust to, any stumbles.

Just as a slightly thicker layer of clay made all the difference in Zedler's tiny Wisconsin wetlands, details will determine the results in Louisiana and other restoration projects around the world. And although the challenges are still daunting, Zedler is encouraged that scientists have come a long way in understanding what they need to do. "We can't turn back the clock," she says, "but we also can't stop trying." SA

MORE TO EXPLORE

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SCIENTIFIC AMERICAN ONLINE
Read about the fight to save wetlands by filling in old oil industry canals at **ScientificAmerican.com/dec2013/carey**