technologies to industry—something SERI was doing long before technology transfer became the policy fashion, says Dallas Martin, NREL's technology transfer manager. Since 1991, the pace has picked up with the signing of a dozen Cooperative Research and Development Agreements (CRADAs), which are cost-shared collaborations between government labs and industrial partners.

The first of them may be the closest to commercial viability. Under the agreement, with the New Energy Company (NEC) of Indiana Inc., the second-largest U.S. ethanol producer, NEC expects this year to flick on the switch of a pilot plant that will convert corn into ethanol using NREL-developed improvements on a process called simultaneous saccharification and fermentation (SSF). SSF relies on fungi-derived enzymes called cellulases, which break the corn's cellulose into sugars. The sugars in turn are fermented into ethanol by the biochemical machinery of yeast cells.

Because the improved process can convert previously inaccessible cellulosic fiber in the kernels, it could increase NEC's ethanol yield from its current 2.55 gallons per bushel of corn to about 3.30 gallons per bushel. That should bring the price of ethanol down to $1.27 a gallon, says Charles Wyman, director of NREL's alternative fuels division, another step closer to the 67 cents a gallon that would make it competitive with gasoline. "In 1980, we would have had to sell ethanol for $3.60 per gallon," Wyman says. "We're not far away."

In spite of that kind of progress, the laboratory still hasn't spawned a stand-alone, economically viable industrial infrastructure based on alternative energy, 16 years after its founding. That failure results not from a lack of viable technologies, Sunderman argues, but from the lack of enough funding to build pilot plants that would achieve economies of scale and demonstrate the competitiveness of renewable energy. Adam Heller, a chemist at the University of Texas, Austin, who has visited the lab many times since its founding, agrees. Given NREL's achievements in wind energy and photovoltaics, Heller thinks the appeal of its technologies would be clear if they could be displayed on a larger scale.

Sunderman is eager to have a larger canvas. In April, he made a pitch to the Senate Subcommittee on Renewable Energy, Energy Efficiency and Competitiveness to recommend up to $275 million over the next 5 years for NREL-led industry-building initiatives in wind energy, biofuels, and photovoltaics. That's chutzpah in a time of national belt-tightening. But this time around, he hopes the government will see the wisdom of steady support. Says Sunderman: "People at NREL are out to solve the world's energy problem for all times."

–Ivan Amato

CONSERVATION

Wetlands Trading Is a Loser's Game, Say Ecologists

In the early 1980s a growing number of conservationists and regulatory officials thought they saw a way to reconcile developers' hunger for land with the need for environmental protection: Use the fledgling science of ecological restoration and creation to replace the lands being devoured by development. Compensatory mitigation, as this approach became known, promised a way to have your K-mart and your wetland, too. You want to build a new mall here, on top of this salt marsh? No problem, the new reasoning went; just create a new marsh on another stretch of coast. Your highway will disrupt the habitat of an endangered bird? No sweat, just move the bird to a new ecosystem built conveniently out of the way.

JULIETTE MURQUIA

Hard to please. A wetlands denizen, the light-footed clapper rail.

Sounds great, but 10 years later, after thousands of mitigation projects, that supposedly scientific fix seems more like smoke and mirrors than a panacea. Many mitigation projects, the vast majority of which have been attempted in wetlands, don't work, or at least don't work well. "Most mitigation stories read like horror stories," says Ken Berg, chief botanist for the California State Office of Land Management. Some restored or created wetlands literally disappear—2 or 3 years after completion, a marsh may be little more than a dry pit used by off-road vehicles. Others persist but bear little resemblance to natural wetlands. Still others are close mimics, with look-alike vegetation, but fail to support the birds or endangered plants they were intended to preserve. All told, says Michael Bean, a lawyer with the Environmental Defense Fund (EDF), wetlands mitigation has been "well short of a smashing success."

Part of the problem, ecologists say, is that developers often don't keep up their end of the bargain: Many of these mitigation projects aren't completed according to the plans filed with government agencies—and many aren't even started, according to a recent study by the Environmental Protection Agency (EPA) scientists. And when the projects do get under way, the practitioners often find themselves humbled by the difficulty of mimicking natural systems. No one knows a sure way to assemble a functioning ecosystem from its components, at least with any reliability, admits Peter White, director of the North Carolina Botanical Garden. In mitigation, he and others agree, a priceless original is all too often bargained away for a cheap counterfeit. "It is not a fair trade," says White.

In the early 1980s, however, mitigation looked like a promising way to resolve a stubborn impasse. Environmental groups and, increasingly, the public were coming to view wetlands not as marginal land to be "improved" but as crucial habitat for plant and animal species (many endangered), a buffer for storm tides, and a natural water purification system. At the same time, developers were finding that many of the most tempting sites for new housing or shopping centers were wetlands that had been overlooked in earlier tides of development.

Restraining the developers was Section 404 of the Clean Water Act, which since the late 1970s has forbidden the filling of wetlands without a permit. The act requires applicants to avoid damaging wetlands if possible, and to minimize or mitigate any unavoidable loss. At first, "mitigation" usually meant minimizing the impacts by modifying the project's design or time of construction.

No net loss. Before long, however, that approach was losing favor. As EDF's Bean recalls, environmentalists realized that even though some wetlands were being protected as others were developed, the overall result was a net loss—and by the early 1980s more than half the wetland area in the contiguous United States was already gone. Developers, meanwhile, chafed at the slow permit process, and the Reagan Administration was eager to help them. In 1981 President Reagan's Task Force on Regulatory Relief targeted Section 404 with the goal of getting the Army Corps of Engineers to issue more permits faster.

The answer seemed to lie in a little-used style of mitigation, according to William Kruczynski, who was at EPA at the time: the restoration or creation of an equivalent wetland either on or off site. Ecologists and conservationists were reporting some success in restoring vanished ecosystems (see box). As developers destroyed some wetlands, it seemed, others could be resurrected by removing dikes or drainage tiles from reclaimed land and letting nature take its course. Or a

Bringing Vanished Ecosystems to Life

Most ecologists cringe at attempts to restore or create ecosystems so that natural ones can be ceded to development—a widespread practice known as compensatory mitigation (see main text). But they feel differently about the underlying science of ecological restoration, when it's not part of such trades. In fact, they are enamored of it. As an effort to bring back long-lost ecosystems, restoration is "the art of the possible," says Donald Falk, director of the Center for Plant Conservation at the Missouri Botanical Garden.

Not that this more "correct" form of such restoration, being tried at hundreds of sites around the country, is easy to pull off. Notes one practitioner, Steve Packard, scientific director of The Nature Conservancy in Illinois, it's not "orderly science. There is lots of guesswork or art." But there is also far less at stake in such restoration than in mitigation, which, as Falk says, "is a game you can lose." If a restorationist fails to return a chewed up cornfield to flourishing prairie, nothing irreplaceable is lost. And even if a project fails as a conservation tool, say various practitioners, it may yield the scientific insights and practical expertise to put mitigation on the right track.

The idea of ecological restoration isn't new. Some of the first attempts took place near the University of Wisconsin, Madison. In 1945, for example, Wisconsin botanist Henry Greene began painstakingly tilling a pasture and planting native species—an effort that took 15 years and yielded a 40-acre prairie that is still considered one of the best examples of a restored ecosystem. Yet this style of restoration was so labor-intensive that it never really caught on, says William Jordan III of the University of Wisconsin Arboretum, and in the 1960s it fell out of favor as the environmental movement made preservation its priority and frowned upon intervention.

In the past decade, however, restoration has regained some of its respectability. Working at several sites, including the 160-acre Northbrook site outside of Chicago, Packard has been one of the pioneers of a new style of restoration. Gone is the meticulous tilling, planting, and gardening of earlier efforts, replaced by an approach called "successional restoration" that lets nature do the bulk of the work.

Having concluded from earlier studies that part of the "prairie" at the Northbrook site was actually a community of species that Packard calls the oak savanna ecosystem—grasslands dotted with oak trees—he set out to restore it, first looking for the obscure plants of the long-vanished savanna. Searching along railroads and horse trails, he found some of these "refugees," collected their seeds, and returned to the restoration site. Instead of plowing, Packard and colleagues simply toss out the seeds and rake them in. Often, they prepare the land for planting by burning it, on the theory that fire was once a regular part of the ecosystem before the prairies and savannas were settled.

Packard won't claim that he and other restorationists are rapidly resurrecting high-quality ecosystems, indistinguishable from natural ones. "No one remotely knows how to restore a 10,000-year-old ecosystem," he admits. Still, he says, "our sampling data tell us we're headed in the right direction." Not only have savanna plants thrived at his site, but they in turn attract animals not seen for years, including rare butterflies and various birds.

Ecologists aren't unanimous in approving of such efforts, however. A recent article in *Restoration and Management Notes* blasts Packard, contending that savanna restoration does not restore "nature" but a degraded "artifact," with artificial plant assemblages and architecture. Critics scoff at the long-term management these restored sites require, preferring instead to preserve land and let nature take its course.

But pragmatists like Packard and tropical ecologist and noted restorationist Daniel Janzen, who works in Costa Rica, are undeterred. Their critics define nature simply as an absence of people, which is simply not realistic, says Packard. "If you take a piece of Illinois prairie or oak woodland and leave it alone, you gradually lose the species that lived here with the buffalo and Indians," who put their own stamp on the ecosystem. "Without a certain amount of stewardship and restoration, many species don't survive."

–L.R.


STEPHEN PACKARD


LAUREL ROSS


STEPHEN PACKARD

Restoring the oak savanna. An overgrown thicket *(far left)* is burned and seeded with bygone species *(middle)* to resurrect the savanna.

new wetland could be created by bulldozing uplands to wetland elevations, altering the hydrology—water flow and drainage—to mimic that of a natural system, and transplanting wetland species. If an existing ecosystem could be replaced or relocated, then why drag out the permit process with worries about minimizing the impact of a development? In 1988, at the National Wetlands Policy Forum, scientists and environmentalists as well as representatives from government and business embraced the strategy, and it was enshrined as the "no net loss" policy of then-presidential candidate George Bush.

If this "win-win" scheme has failed to live up to expectations, it's not for want of trying. As restoration became a shortcut to getting a permit for wetlands development, the number of mitigation projects has soared. But unlike the "pure" experiments in ecological restoration now under way, which are driven both by scientific curiosity and a desire to conserve natural lands, these mitigation projects are economically and politically driven. As Berg says, "The political objectives don't always mesh with the biological needs of the ecosystem, and the time frame doesn't often allow…thorough, biology-based design, monitoring, and remediation."

Developers contract the job of designing and constructing wetlands restoration to a growing industry of consultants, most of whom have never "designed" a wetland before and don't know how, says Edgar Garbisch, president of Environmental Concern Inc. in St. Michaels, Maryland. "A lot of inexperienced people are doing design and construction work," says Garbisch, one of a small number of highly respected consultants in the field. Plans often give little attention to the hydrology of the created site—the most crucial factor in successful wetlands restoration, he says. Vegetation plans, too, are often slipshod. Agency officials, meanwhile, often lack the expertise to catch obvious mistakes,

says Garbisch. Executed by construction crews who often go unsupervised, says Mary E. Kentula, head of EPA's Wetlands Research Program in Corvallis, Oregon, these flawed designs can lead to projects that look more like swimming pools than the gently sloping marshes found in nature. Post-construction monitoring is also rare, says Kentula.

In one of the first comprehensive analyses of mitigation—a 5-year study to see how restored and created wetlands stack up against natural ones—Kentula and her colleagues uncovered another failing: Not only were the designs themselves inadequate, with poor specifications for hydrology or vegetation, but often they simply weren't followed. In Oregon, in fact, none of the projects she surveyed was built as specified on the permit. All in all, Kentula and her colleagues concluded, wetland projects are "fundamentally different" from the wetlands they are intended to replace, and indeed, from other natural wetlands in the same region. The most common type of created wetland they found—indeed, the only wetland type that is increasing in acreage in the country—is an open water pond with a fringe of wetland vegetation. In Oregon, for instance, though no natural ponds were affected by development, 23% of created wetlands were ponds, says Kentula—because they are easy to build.

But even if mitigation were done properly, with the best ecologists designing the projects and the construction meticulously supervised, would it work? The answer depends on the definition of success—and that varies with the scientific and political bent of the definer. To some, says Kentula, "Success means, 'Did you do whatever is in the contract?' To others it is, 'Give me back exactly what I think I lost.'" Garbisch defines success as hydrology and vegetation that persists over time; Kentula and other ecologists view it as restoring an ecosystem to natural or near-natural functions.

If the goals are relatively modest, most practitioners would agree that they can often be met. For instance, it's a cinch to design habitat for certain waterfowl, since there is now lots of experience in doing so and mallards aren't particular. And it's straightforward to design a wetland that helps buffer floods, says Kentula, because the right topography is easy to create.

But if the goal is to mimic closely the functions of the original ecosystem, as many ecologists believe it should be, then the job is much tougher. Says Berg: "We are learning that restoration is not as simple as people might want it to be. Often an engineer can assure you he can build anything—but that is not true for an ecosystem the way it is for a bridge." And when one of those functions is providing habitat for an endangered species, the prospects are dimmer still. "Our ability to create or restore [endangered-species habitat] is very low," says Joy Zedler, director of the Pacific Estuarine Research Laboratory at San Diego State University.

No going back. Zedler should know, for she has been butting her head against that problem for the past 4 years on a restored wetland in San Diego Bay, within the Sweetwater Marsh National Wildlife Refuge. The restored wetland was conceived as part of a compensation deal after the California Department of Transportation got the go-ahead to widen Interstate 5—a project that damaged a cordgrass marsh and jeopardized two endangered birds, the light-footed clapper rail and the least tern. In 1984, following a suit by the Sierra Club and the League for Coastal Protection under the Endangered Species Act, a federal court imposed some of the toughest criteria yet on a mitigation project: restore a marsh to provide habitat for the two endangered birds and an endangered plant, the salt marsh bird's beak.

But by 1989 there was still no sign that the clapper rail was nesting in the new marsh, says Zedler, who was called in to see what was wrong and figure out how to fix it. The cordgrass marsh looked fine, and judging by the usual structural criteria—for instance, water level and plant composition—the project could be considered a success. So why wouldn't the clapper rail nest there? Zedler and her colleagues identified at least one key missing factor: By comparing this site to a natural one nearby, they realized that the cordgrass had not achieved its full height, and the clapper rail needs tall grass so its nests can float when the tide rises.

JOY B. ZEDLER

The best intentions. Restoring a wetland in San Diego Bay.

Through extensive research she traced that problem to inadequate nitrogen supplies, which she laid in turn to sandy soils. Zedler and her students increased the frequency of nitrogen fertilization, but 3 years later the cordgrass was decimated by an insect outbreak. To Zedler, that meant a predator was likely missing. More research identified the predator, a beetle, but Zedler doesn't expect that to be the last of her problems.

Indeed, she's admitting defeat. "We learned a lot we never knew about marshes, but in terms of providing the functions of an ecosystem, it is not working 9 years after it was built. And it is not on a trajectory to natural improvement. It seems to be stuck," says Zedler. She thinks her experience points to questions that need to be answered before any restored wetland will be able to duplicate the functions of a natural one.

Perhaps the biggest gap is in the understanding of the interaction of soil, surface water, and groundwater on which the ecosystem depends. Getting it right, says Zedler, is "a crap shoot." And while it's easy to figure out which plants to bring in, where to put them—specifically, at what elevation—is not so clear. Planting them a few inches too high or too low, in relation to the tidal regime, can spell death to a newly introduced plant population.

In spite of the challenges, Zedler and other critics are not ready to abandon compensatory mitigation, even if that were a realistic option, for they still see somewhere within it the outlines of a valuable conservation tool. Says Berg: "I am a strong supporter of mitigation—not in terms of what it is but what it might become." Getting the practice to the point where it is actually a fair trade will require both more science and stricter standards, they say. As a first step, concluded a National Research Council committee on wetland restoration on which Zedler served, "Wetland restoration should not be used to mitigate avoidable destruction of other wetlands until it can be scientifically demonstrated that the replacement ecosystems are of equal or better functioning."

A better course, says Berg, is comprehensive land-use planning, in which local, state, and federal governments work together to steer developers away from sensitive lands and direct them to better sites. Perhaps most important, say Kentula and others, is that "the decision of whether to permit the destruction of a wetland...be based on whether we can afford to lose that system, not whether we can replace it." Compensatory mitigation should be the last resort, and must be based on the best available science. Kentula, Berg, and others also advocate strict, agreed-upon standards to judge success, long-term monitoring, perhaps by a government agency or private group, and a commitment by developers to make mid-course corrections when needed—what Zedler calls "adaptive management" of the ecosystem.

When compensatory mitigation does end up as part of the deal, says EDF's Bean, the regulatory agencies should require, whenever feasible, that the replacement wetland be completed up front, before the natural one is destroyed. For now, says Bean, "we should accept the sober reality that losses are likely to be uncompensated for and that what we call mitigation has a high chance of failure."

–Leslie Roberts