BREAKING THE WAVES

As a defense against rising seas, shorelines made of marsh grasses and oyster reefs may work better than concrete armor

By **Gabriel Popkin** *Photography by* **Dylan Ray**

When Hurricane Irene hit North Carolina's coast in 2011, waves 2 meters high began pounding the shore. Two properties on Pine Knoll Shores, a community on one of the state's many barrier islands, provided a study in contrasts. One homeowner had installed a concrete bulkhead to protect his yard from the sea. But the churning waves overtopped and ultimately toppled the wall, washing away tons of sediment and leaving a denuded mud flat.

Less than 200 meters away, another owner had installed a "living shoreline"—a planted carpet of marsh grass that gently sloped into the water, held in place by a rock sill placed a few meters offshore. The onrushing water bent the marsh grasses almost flat, but their flexing stalks dampened the waves and their deep roots held the soil. After the hurricane passed, the grasses sprang back; the property weathered the storm largely intact.

The contrast highlights how defenses in-

A marsh constructed on Pivers Island in North Carolina is helping researchers understand the costs and benefits of so-called living shorelines.

spired by nature, rather than concrete armor, can protect coastlines from battering storms, says ecologist Rachel Gittman of Northeastern University's Marine Science Center in Nahant, Massachusetts. In a study of Irene's effects, Gittman found that in hard-hit areas along the North Carolina coast, the storm destroyed or damaged three-quarters of the seawalls and bulkheads and washed away valuable soil. Yet, shores fringed by marsh grasses experienced almost no erosion, and damaged vegetation bounced back within a year. "Plants are really good at handling big storms," Gittman says. "Bulkheads are really not."

Such findings are getting more attention as researchers and coastal planners confront rising seas—and possibly more powerful storms—caused by global warming. That double punch, they say, threatens hundreds of millions of coastal residents around the world and infrastructure worth trillions of dollars.

To be better prepared, many researchers are calling on coastal nations to rethink traditional approaches to shoreline defense, which rely largely on massive earthen dikes, rock barriers, and concrete walls. Such "gray" infrastructure damages coastal ecosystems, researchers argue, and can be difficult and expensive to adapt to changing environmental circumstances. Gittman and others argue that softer, "greener" approaches inspired by marshes, oyster reefs, and other natural features (see graphic, p. 758) can do better. With clever engineering, they say, such features can provide not only cost-effective storm protection, but also healthier ecosystems able to adapt to rising seas. "When you put in a marsh," says environmental scientist Bhaskar Subramanian of the Maryland Department of Natural Resources (DNR) in Annapolis, "you're doing good by nature."

Not everyone is enthusiastic. Many people feel safer behind concrete, and—given the potentially high stakes—policymakers and regulators have been reluctant to shelve time-honored engineering techniques in favor of less familiar approaches. Some researchers also worry that even supposedly green designs could harm marine ecosystems by introducing exotic species and foreign materials into underwater habitats.

Despite the skeptics, the push to green traditionally gray coastal defenses is gaining traction. Prompted by the devastation caused by Hurricanes Katrina and Sandy, the U.S. government is bolstering research into nature-inspired coastal engineering. And a growing number of researchers around the world are evaluating which green techniques might work best—and how gray and green engineering might be combined to create layered defenses.

"There is so much happening on this right now," says ecologist Ariana Sutton-Grier of the University of Maryland (UMD), College Park, and the National Oceanic and Atmospheric Administration (NOAA). "We probably are at a sea change in the way we approach coastal protection."

FOR MILLENNIA, humans have tried to hold back the sea. In China and along the Mediterranean, archaeologists have found evidence of seawalls and other shoreline structures some 2000 years old. And as human populations have grown, so have coastal defenses. In the United States, nearly 23,000 kilometers of shoreline—some 14% of the total—is armored, Gittman and colleagues estimated in August in *Frontiers in Ecology and the Environment*. That proportion could grow to one-third by the end of the century, they add, if coastal development continues at its current pace.

Armoring can have devastating ecological consequences. Rock and concrete barriers reflect rather than dissipate wave energy, causing fast-moving waters to scour the sea floor, destroying marsh and underwater grasses that nurture fish, crabs, and other sea life. Hard structures can also cut off critical flows of sediments from uplands to the coast, starving and obliterating beaches and marshes. And as global sea levels have risen by an estimated 20 cm over the past century, many marshes and beaches have become squeezed between the higher water and unmoving concrete.

The squeeze will worsen if global greenhouse gas emissions continue unabated. Under some scenarios, modelers warn, sea level rise could accelerate to as much as 9 mm per year, driven by melting ice sheets and the expansion of warming seawater. At the same time, warming could catalyze more powerful storms, heightening the threat of wave damage and coastal flooding. Many point to the flooding that occurred in New Orleans, Louisiana, and along the Gulf of Mexico after Hurricane Katrina in 2005, and the devastation wrought by Hurricane Sandy in 2012, as examples of what the future may hold.

The shores of the Chesapeake Bay in Maryland are among the most vulnerable in the United States: Land subsidence there is causing local sea level rise to greatly exceed the global average, making coastal areas more vulnerable to storms. In 2003, a powerful hurricane, Isabel, swept up the coast and across the Chesapeake Bay area, killing 16 people and causing $7 billion worth of damage. It also amplified one of the nation's most prominent efforts to promote living shorelines.

Not long after the storm passed, calls began coming in from distraught landowners, recalls Subramanian of the Maryland DNR, which provides coastal protection assistance to landowners. "All the calls were: 'My bulkhead is floating in the neighbor's property,'" he says.

In contrast, the agency received no complaints from landowners who had installed living shorelines with the agency's help. The constructed marshes had dampened the storm waves and reduced damage, he says, just as they would in North Carolina nearly a decade later. Soon, landowners once wedded to concrete were lining up to get help building their own protective marshes.

Today, Maryland is considered a pioneer in green coastal infrastructure. In 2008, it adopted the nation's first law requiring landowners who want to protect their waterfront to use a living shoreline unless

they can prove that only a hard structure will do the trick. The state has issued permits for more than 1000 living shorelines, almost all around the Chesapeake Bay and its tributaries. Many have not only survived but thrived through storms likely to have overwhelmed traditional gray structures.

Other states, however, have been slow to follow suit, in part because of lingering questions about the environmental impact, effectiveness, and life span of living shorelines and other nature-inspired features.

ONE RESEARCHER trying to answer those questions is ecologist Carolyn Currin of NOAA's Beaufort, North Carolina, laboratory. The lab sits on Pivers Island, a spit of land near Pine Knolls Shore. In 2000, when lab officials had to replace a failed seawall on the island, Currin persuaded them to install a living shoreline, turning an otherwise humdrum construction job into an experiment. NOAA worked with local partners and volunteers to install bags of oyster shells off the island's shore and plant marsh grasses on a graded sand slope.

The new marsh—along with a second one built on the other side of Pivers Island using a rock sill—has allowed researchers to gain new insights into the capabilities and behavior of living shorelines. One finding is that they appear to keep pace with local sea level rise, building up soil that keeps the marsh's surface above the low tide line.

They also have potentially valuable "co-benefits." The artificial marshes pack away relatively large quantities of carbon, Currin and colleagues reported (this month) in *PLOS ONE*. And, as suspected, the rock and oyster-shell sills used to anchor such marshes support more abundant and diverse communities of fish and crustaceans—including economically important species—than do traditional concrete structures, a team led by Gittman concludes in a paper in press at *Ecological Applications*.

Currin, Gittman, and colleagues also are assessing whether shorelines colonized by living oysters can provide an additional layer of defense in shellfish habitat such as North Carolina and the Gulf of Mexico. In one experiment, they have used thousands of bushels of shells to build three artificial oyster reefs off a rapidly eroding beach on Carrot Island in the Rachel Carson Reserve, not far from Pivers Island.

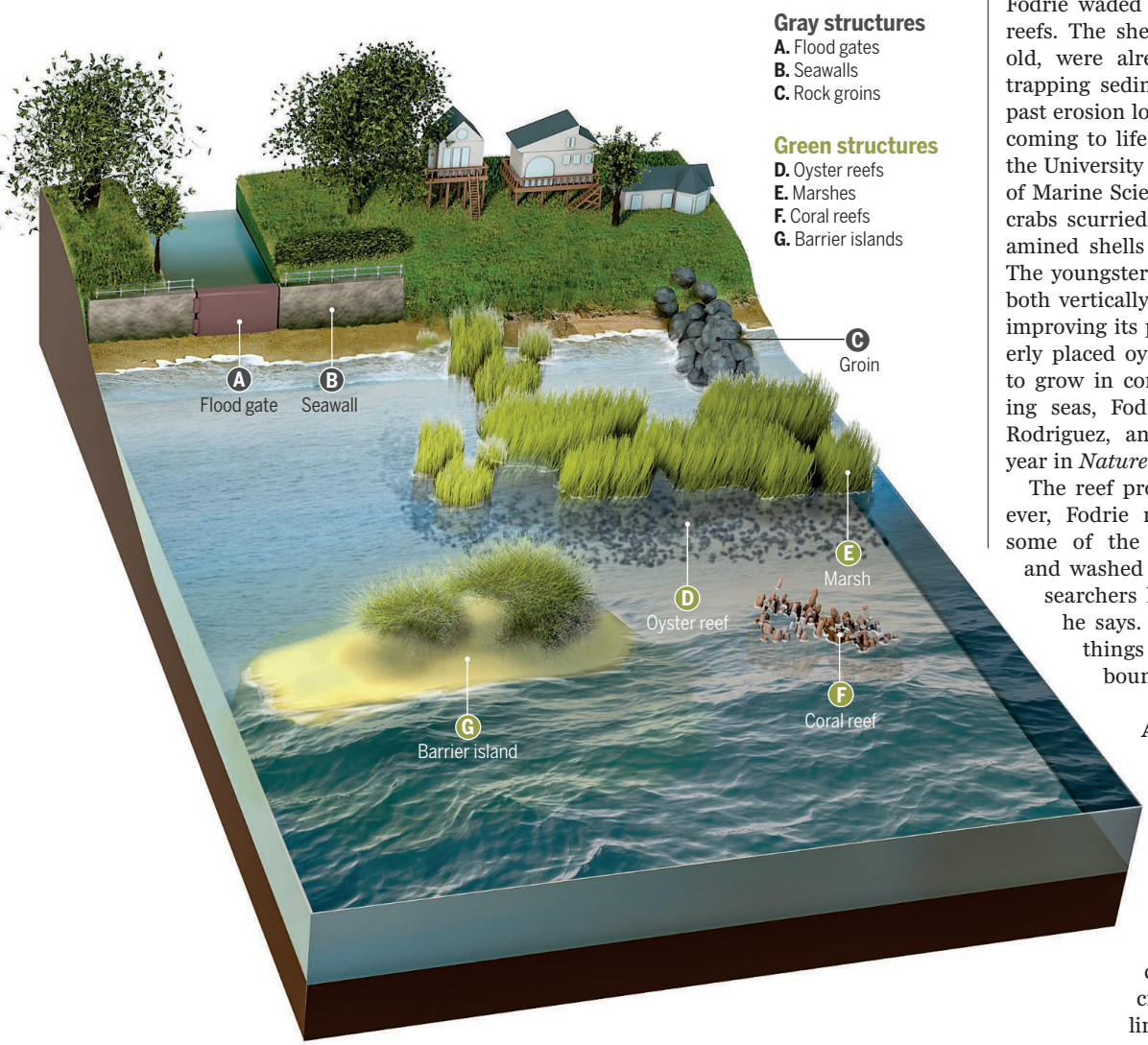
On a visit to the site, ecologist Joel Fodrie waded through quiet water to the reefs. The shell piles, now about 3 years old, were already protecting the beach, trapping sediment and helping it reverse past erosion losses. Better yet, the reef was coming to life, says Fodrie, who works at the University of North Carolina's Institute of Marine Sciences in Morehead City. Tiny crabs scurried across his hands as he examined shells covered with baby oysters. The youngsters should help the reef grow both vertically and horizontally, he noted, improving its protective effects. And properly placed oyster reefs have the capacity to grow in concert with even rapidly rising seas, Fodrie, the institute's Antonio Rodriguez, and colleagues reported last year in *Nature Climate Change*.

The reef project faces challenges, however, Fodrie noted. Waves have pushed some of the oyster sills toward shore and washed away some grasses that researchers had planted. But that's OK, he says. "We planned to have some things fail, so we can see where the boundaries are."

ALTHOUGH SOME SEE living shorelines as a return to nature, others see them as coastal hardening by another name. Retired earth scientist Orrin Pilkey of Duke University in Durham, North Carolina, who has called for limiting coastal development, has criticized many living shoreline projects along the Atlan-

Defending against rising seas, in gray and green

Some researchers are urging a move away from so-called gray coastal defense structures, such as seawalls, flood gates, and rock groins. They say greener structures—including natural or built marshes, oyster and coral reefs, and sandy barrier islands—can provide protection with less ecological damage, and a greater ability to adapt to rising seas. Combining green and gray structures could create hybrid, layered defenses that offer both ecological and economic benefits.



GRAPHIC: V. ALTOUNIAN/*SCIENCE*

Biologist Joel Fodrie inspects an oyster reef that researchers built to protect an eroding beach on North Carolina's Carrot Island. Within 3 years, it was colonized by oyster larvae, creating a living defense that might be able to keep pace with sea level rise.

tic coast because they make heavy use of offshore rock sills to shelter the planted grasses from wave action. The sills, he says, can bury native sea grasses and make it more difficult for fish and crabs to reach intertidal marshes.

Pilkey also complains that a lack of regulatory oversight and scientific monitoring makes it hard to figure out what works and what doesn't. "To me the living shoreline thing is the Wild West," he wrote in an email. "No standards, no enforcement, no real studies especially long term and an aura of environmental holiness."

Even living shoreline promoters acknowledge that projects can come with ecological tradeoffs. Newly constructed marshes in the Chesapeake Bay, for example, can bury sandy, near-shore habitats. "Everyone devalues flat, nonstructural bottoms," says ecologist Donna Bilkovic of the Virginia Institute of Marine Science in Gloucester Point. "But there are lots of animals that live in those sediments."

Green defenses also face substantial regulatory and political hurdles. In the United States, it can often take just a few days to obtain the needed federal and state permits to build a new bulkhead, for instance, but the paperwork for nature-inspired projects can take much longer, in part because they may involve underwater components that bury shallow-water habitats and stretch into shipping lanes. Large projects can also trigger complicated mandatory cost-benefit analyses. For gray projects, economists and engineers have long known how to calculate life span and financial return, but the task can be trickier for green projects, for which the calculus includes cobenefits such as carbon storage or improved fish habitat.

SOME COASTAL EXPERTS have concluded that combining green and gray approaches promises the best payoff, because of their complementary strengths and weaknesses: Green infrastructure is dynamic and adaptable, but can take several years to become fully established, whereas concrete works on day one. Such hybrid defenses might involve building an oyster reef or marsh in front of a concrete seawall or dike, to provide both ecological benefits and multiple layers of storm protection.

> ***"To me, the living shoreline thing is the Wild West. No standards, no enforcement, no real studies ..."***
>
> **Orrin Pilkey**, Duke University

The U.S. Army Corps of Engineers has embraced such "gray-green" thinking, and is promoting it in concert with NOAA and other institutions through an initiative called the Systems Approach to Geomorphic Engineering. The hope, says UMD's Sutton-Grier, is to "capitalize on the strengths of both approaches—you can use gray to protect green as it establishes, or green to protect gray so that [its] lifetime is longer."

The idea is also catching on internationally, with Korea, China, and Australia recently considering or installing combinations of marshes and hard structures. In the Netherlands, where coastal defenses are a matter of national existence, planners are introducing salt marshes and shellfish beds to help lessen storm impacts on seawalls and dikes. (Japan also considered greening its shoreline protection arsenal after the devastating 2011 tsunami, but has so far opted for even larger seawalls.)

The success of green infrastructure, however, may ultimately depend less on governments than on the willingness of millions of individual landowners to try something new, because so much coastline is in private hands. Persuading risk-averse homeowners can be a frustrating process, Gittman says. After Hurricane Irene, she showed the landowner with the toppled bulkhead how much better his neighbor's living shoreline had performed.

But the landowner opted to build a new concrete bulkhead instead, and then put his house up for sale. "People are stubborn," Gittman says. ■

Gabriel Popkin is a freelance writer in Mount Rainier, Maryland. *Reporting support provided by a fellowship from the Institute for Journalism and Natural Resources.*

Breaking the waves

Gabriel Popkin

Science **350** (6262), 756-759.
DOI: 10.1126/science.350.6262.756