Ghost Forests of the Mid-Atlantic: how sea-level rise is killing our coastlines

By

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ABSTRACT

Up and down the eastern seaboard of the United States, ocean levels are rising at rates faster than just about anywhere in the world. Coastal forests are dying off as a result—an early warning, if people will pay attention, of the disruptive changes in store for both natural ecosystems and human habitation. Dying coastal forests herald other coastal landscape changes: after the forests start to die, so do the marshes that live in zones between ocean and forest. As sea-level rise and human development combine to narrow the range of coastal ecosystems, problems arise for local flora and fauna, natural nutrient cycles, and coastal communities.

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Ghost Forests of the Mid-Atlantic: how sea-level rise is killing our coastlines

It's a beautiful day in the Palmetto-Peartree Preserve in North Carolina. The sun-soaked beach of the Albemarle Sound is warm, but the breeze rolling in across the water is cool with a hint of salt. Gentle ripples lap at the shore, making indents in the sand. A few feet back from the water, bright green marsh grasses rustle in the breeze, and further inland the fernlike foliage of cypress trees casts its shade. But there's something out of place.

A pair of dead cypress trees stand in the sound, several feet out from the shore. The thick, pyramidal bases of the trees emerge from brackish water, and a ring of damp, dark bark above the waterline reveals that the tide is receding. The narrow trunks curve up into broken, leafless branches. Nearby the water breaks around jagged stumps – more trees grew here once.

The drowning cypresses are captivating in their incongruity, and visitors to the sound like taking photos of them. They are "very picturesque," says Marcelo Ardón, an assistant professor in the department of forestry and environmental resources at North Carolina State University, who studies the drowning trees. To broaden his view of what's happening in the region, Ardón has created Sentinels of the Sounds, a citizen-science program that encourages visitors to upload their photos to a larger database online, where a thick layer of pins on a Google map shows a growing collection of stressed, dying, and dead trees.

These trees are not dying off one by one. There are places in the preserve, and elsewhere in North Carolina, where entire groves have died. In fact, coastal forests are dying up and down the

mid-Atlantic, creating what are often called "ghost forests." The name is easy to understand. Rows of barren trunks and leafless branches seem to haunt the places where a healthy forest once thrived.

Sentinels of the Sound gives Ardón's lab useful data points and lets curious visitors learn more about the problem of ghost forests. Ardón hopes that the program will encourage visitors to stop and think about what the drowning trees mean as they take their photos. Cypress trees cannot germinate except on dry land, so when those trees were seedlings, the places where they are standing must have been dry. Now they are covered by estuarine water. This raises a question that Ardón wants visitors to ask themselves: Why?

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Surprisingly few people seem to be asking this question. The scientists researching coastal forest decline are few in number, and the general public seems unaware of the problem or its cause: sea-level rise.

Sea levels have risen and fallen for millennia, of course. But in the modern era we have set in motion a cycle of climate change that is causing sea levels to rise at worryingly high rates. The global sea level is currently rising at a rate of around 3 millimeters per year, and by the end of the century, climate researchers suggest, it may have risen by as much as four feet (1.2 meters). That's the fastest rise in the past 2,000 years. Waters rising at this rate will overrun many current coastlines. But it's not just current coastlines that are under threat. Rising seas don't just rise,

after all—as they rise they move inland, altering ecosystems as they go. Most visibly, coastal forests.

Most people don't make the connection between sea-level rise and changes to coastal ecosystems. That's because it's hard to spot changes in sea level from year to year. Sea-level rise on the New Jersey shore, for example, amounts to about 4 millimeters per year, according to Ben Horton, the director of the Rutgers Sea Level Research Lab, in New Jersey, which studies both past and present sea levels around the world. Since the difference between high and low tide can be more than a meter, this yearly trend is masked by the day-to-day variance, much like overall climate trends are hard to notice when the weather changes drastically from day to day or season to season. Unlike the sea level rising, however, you can see trees receding and dying. Ghost forests, in other words, are a useful measure for observing—and pointing out to the public—the effects of sea-level rise. They are, as Horton puts it, a "canary in the coal mine for climate change."

Trees and forests are obviously not the only victims of sea-level rise. It will also kill off marshes, which sequester carbon, increasing greenhouse-gas emissions and creating a dangerous feedback loop—more emissions mean more warming, which means more sea-level rise. It will cause more erosion and flooding. It will endanger coastal agriculture, fishing, lumber, and recreation. And ultimately—if it keeps happening at the rates scientists now suggest it will—it will decimate coastal towns and cities.

Though sea-level rise is a global phenomenon, regional rates vary. The East Coast, it turns out, is experiencing faster rates than the global average, because not only is the sea level there rising, but the land is sinking. This is largely because the region is still adjusting geologically to the end of the last ice age. Ice that weighed down the Midwest during the ice age pushed the mid-Atlantic coast up, and now that the ice is gone, the land is readjusting, gradually rising back up in the middle and settling down on the coast. People are also causing the land to sink, with such practices as groundwater removal, which causes the land around emptied aquifers to compact. Exacerbating the effects of sea-level rise on the East Coast is the region's low elevation, which means that a small vertical rise in sea level covers a lot of land.

Because the East Coast is experiencing such significant rises in sea level, and because ghost forests represent an easy way of tracking the effects of sea-level rise, Horton and his colleagues at the Rutgers Sea Level Research Lab, much like Marcelo Ardón at North Carolina State, are now working hard to document what is happening. They began simply in 2016, by driving and kayaking along the Bass River, in New Jersey, looking for stands of dead trees. But last October two researchers—Jennifer Walker, a Ph.D. student, and Ken Able, the director of the Rutgers Marine Station—took to the sky in a helicopter to get a better view.

They flew over central New Jersey, tracing the creeks and tributaries at the freshwater-brackish boundary where Atlantic cedars grow. Walker's intent was to find a ghost forest that would be easily accessible by foot, to use as a research site. Initially, as they observed the shore from the helicopter, they saw stretches of densely packed Atlantic white cedars, some as tall as seventy feet, lining the creek in a mottled assortment of green. But Walker did not have to wait long to

spot a potential site. As they followed one thin blue ribbon of water, dots of grey interrupted the forest's sea of color. Then the palette of healthy greens disappeared, and they were flying over a band of trees that was all bare, all grey. A ghost forest.

In one hour spent searching a small part of New Jersey, Walker and Able spotted at least six ghost forests or places with drowned stumps. Walker was stunned by the prevalence of dying trees. "It definitely put it in perspective a lot better for me, seeing it from above," Walker says. She ultimately chose a site at Port Republic, with a stand of cedars in a section of forest by a creek. The cedars are not far from a recently made recreational trail; locals could easily stumble upon them if they wandered off the path. Walker chose Port Republic because the site contains all of the transitional zones of ghost forests. Look upstream and you'll see living cedar trees, downstream and you'll see stumps in open water. At the site itself, standing dead trees linger in an area that is not quite forest, but increasingly dominated by marsh.

Walker's site is almost ten miles from the actual coast, and yet there's salt in the water. Tidal rivers ebb and flow with the ocean, and the effects of sea-level rise are far reaching. During high tide, the ocean encroaches on the river, sending salt upstream. At low tide, the water level lowers with the sea. At Port Republic, the tree stumps in the water can only be seen at low tide.

Along with the tree stumps, entire dead trees emerge in the creek bed during low tide. "You have all these fallen, laying-down dead cedars actually in the water, that are covered by the sediment," Walker says. Atlantic white cedars are unusual trees because they do not rot in water, so they can remain intact in the river for centuries. In the 1800s, New Jersey had an entire timber industry

built around mining cedars from riverbeds, which allowed them to bypass the hard work of cutting tress down. These submerged intact cedars are useful for Walker today: by sampling wood from them, she can develop a picture of the state of coastal forests over time. The felled trunks also mark the ever-changing boundary of the coastal forest as it has retreated from the natural, gradual rise of the sea for thousands of years.

Now that sea-level rise is increasing rapidly, the trees cannot keep up, and forests are dying off. How quickly is a question that Walker is working on. She also hopes to map where the ghost forests are, perhaps by once again taking an aerial view. The research is still in its early stages, so the Rutgers lab cannot yet say what the extent of the damage is, but they already know two things for sure: salt water is killing these forests, and it's going to get worse.

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Salt is toxic to freshwater ecosystems, even at very low levels. According to Gregory Noe, a research ecologist with the U.S. Geological Survey in Virginia, who studies the biochemical changes that take place when saltwater gets into freshwater coastal ecosystems, deciduous trees and most plants will die when exposed to saltwater that is only a little more than one-twentieth the saltiness of seawater. And even if they don't die, salt-stressed trees have trouble transferring the nutrients in their leaves to their trunks and roots, where they store them during the winter. As a result, the trees lose these nutrients when their leaves fall. In a healthy forest, if some trees die in this way, at least their hardship benefits the rest of the ecosystem: a nutrient-rich feast of leaf litter on the ground can lead to an explosion of plant and microbial growth. But if the salinity of

the soil is high, most forest plants will have already died out. So from the forest's perspective, the nutrients go to waste.

Bald cypresses, which are hardy coastal trees, can tolerate water that is one-tenth the saltiness of seawater. Ghost forests are often made up of bald cypress because they were the last trees standing as salt levels rose. Atlantic white cedar, another common ghost-forest species, is similarly hardy. Below these levels of saltwater intrusion, a cypress grove can still survive, albeit with little biodiversity, and its trees still provide useful ecosystem services. They sequester carbon. They store inorganic nitrogen and phosphorus, critical nutrients for most living things. Moreover, cypress trees, like most coastal plants, can "hold their breath" and ride out a short period of increased salinity—a useful evolutionary adaptation for coastal plants, where saltwater intrusion isn't a constant but tends to happen in pulses. Cypress trees can survive several years of frequent saltwater intrusion near their salinity tolerance threshold, but eventually even they succumb.

By the time hardy adult cypress trees finally die, the forest is most likely past saving. If a forest's canopy is healthy, most people will assume the forest is healthy, but that's not necessarily the case. In order for a forest to survive, it needs lots of healthy seedlings underneath the adult canopy, so when older trees die, young ones are in position to grow and take their place. But in this context, says Matt Kirwan, an assistant professor at the Virginia Institute of Marine Science, seedlings are just like human babies—"much more sensitive to their environments than adults." Adult trees are good at clinging to life even in rough circumstances, such as droughts and storm surges, but seedlings are not so hardy. A small influx of salt water kills them off and may make

the soil too salty for any new seedlings to grow there in the future. Sand carried along with seawater or shifted during a storm can also bury seedlings, and severe flooding drowns them. No matter how tenaciously the adult trees cling to life, if no seedlings survive, then the adults' effort is futile. "The forest," Kirwan says, "is essentially dead before it dies."

As the forests die, the creatures that call them home suffer too. Birds, mammals, insects—all must find new habitats as the forest disappears, a challenge when surrounded by human development. Some species cannot survive outside of coastal forests at all. These dependent animals include the red-cockaded woodpecker, an endangered species, and the Delmarva fox squirrel, only recently taken off the endangered species list. Migrating neo-tropical birds from across the Americas also rely on the mid-Atlantic coastal forests, which they roost in as they fly north and south. When the trees die off, entire ecosystems are thrown out of order.

Those whose livelihoods depend on coastal ecosystems are well aware of the changes. "People that are involved in forestry understand that some of the [salt-stressed] forests, when they cut them, they will not get another crop," says Matt Whitbeck, the supervisory wildlife biologist at the Chesapeake Marshlands National Wildlife Refuge Complex, in Maryland and Virginia. Whitbeck has seen pine plantations abandoned because the salt-soaked ground has become uninhabitable for trees. And in North Carolina, Marcelo Ardón and his colleagues frequently hear from farmers who want to know if their research can help them identify where saltwater intrusion is poisoning their fields. The general public may not yet understand what's happening, but among farmers and foresters, Whitbeck says, "everybody's seeing the writing on the wall." Once-vibrant coastal forests are turning into muddy, salty marsh.

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Once a coastal forest is dead, the land doesn't become barren. The ecosystem simply changes – either to open water or to salt marsh. The species that live in coastal forests disappear, and new species move in. Just as we've had cycles of sea-level rise and fall for eons, so too we've had cycles of coastal ecosystem change for eons. The process, which involves transitions from forest to marsh to ocean, is natural. At Port Republic in New Jersey, the mud of the salt marshes hides old cypress trunks underneath, remains of the ecosystem that stood there in a previous era. Farmers and foresters (not to mention cypress trees and migrating birds) might not like the transition to marshland, but it isn't inherently a bad thing. That's because marshes are, as Matt Kirwan puts it, "one of the most valuable ecosystems in the world."

Salt marshes grow in the intertidal zone of the ocean, between the low and high tide lines, or just beyond it. They often fill the space between coastal trees and tidal waters, a transitional ecosystem bridging the aquatic and terrestrial. They have a higher tolerance for salt than the forests, but when sea-level rise floods the marshes too frequently, the land becomes inhospitable for them. With the ocean in front of them and forests behind, the marshes have nowhere to go, at least until coastal trees start to die. Then the marshes can retreat into the ghost forests, where the salty soil has become increasingly favorable for marsh plants. There are both environmental and economic benefits to this expansion of marsh territory.

Coastal forests and marshes combine to provide many important ecosystem services for the coastal landscape and its species. The system works best when forest and marsh coexist. However, if sea-level rise leads to competition for space between the ecosystems, then it may be a good thing if marsh comes out on top, Kirwan argues, because marshes provide many irreplaceable services, and the U.S. has fewer marshes than forests, which exist abundantly inland.

Marshes provide homes for land and sea animals of all kinds. Many birds rely on them for food and nesting habitat, and some, among them the saltmarsh sparrow, can't survive anywhere else. Salt marshes are breeding grounds for many of the fish species, shellfish, and crabs that people harvest commercially. Seventy-five percent of fisheries species, including blue crab, finfish, and shrimp, have nurseries in marshes, or use them for food and shelter. (If you like crab cakes, Whitbeck says, you should care about marshes dying.)

Salt marshes are home to many plants, including salt grass, cord grass, rushes, marsh mallow, and sea lavender. These plants often have very specific habitat requirements, and they are an integral part of the regional ecosystem, providing food for insects and birds, and shelter for a variety of animals. Marsh vegetation is also one of the best barriers to prevent inland flooding. The plants break and disperse storm waves as the water drags against them. As the frequency and severity of storms increase with climate change, coastal towns and inland ecosystems will need this natural barrier, along with the buffer of the trees, to protect them.

Marshes are also widely acknowledged as one of the best ecosystems for carbon sequestration. They represent a natural water-purification system: their vegetation slows down water movement, giving sediment and pollutants time to settle out and deposit. They are home to plants that metabolize potentially harmful nutrients, which prevents the nutrients from escaping into the atmosphere or impacting water quality. By slowing down water flow and trapping sediment, marshes build elevation—a natural means of gradually adjusting to sea-level rise. Marsh plants also build elevation by producing extensive roots. The roots prevent erosion, trapping the soil in place so waves and storm tides cannot sweep it away. When these roots die, most of them decompose, but some ten to twenty percent accumulate as organic matter underground, which leads to rich, thick soil.

Because of the many services they provide, marshes are a key element of the coastal ecosystem. And they may need ghost forests to survive. As sea-level rise outpaces marshes' ability to build elevation, the marshes must migrate inland. Conveniently, by the time the marshes are struggling, sea-level rise has killed off coastal trees, offering the marshes a new habitat to colonize—which, in turn, may create a new buffer that protects the development of coastal forest farther inland. "One of the things that scientists don't really acknowledge enough," Matt Kirwan says, "is that the death of the coastal forests is what allows salt marshes to survive." Left to its own devices, the system works—as long as there's room for both ecosystems to move.

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Before anthropogenic climate change caused sea-level rise to accelerate, the sea level along the East Coast had been rising gradually for thousands of years. At the slower historic rates, marshes and forests had plenty of time to migrate inland, and the farther the sea chased them, the farther they moved. But then people showed up.

Since Europeans colonized the mid-Atlantic, forests and other habitats have been disappearing. During the 18th and 19th centuries, the majority of forest cover in the Eastern United States was cleared to make way for agriculture and buildings. Humans have entirely reordered the coastal landscape for our own convenience, to the detriment of the ecosystems around us. Towns, cities, timber plantations and agricultural fields take up room that used to belong to coastal ecosystems. Coastal forests have been logged for centuries, both for their lumber and to make way for farmland.

Human development has also had a powerful impact on marshes. Dams built in major rivers and reservoirs that redirect natural water flow block sediment from reaching the coast, so there is less material available for the marshes to trap. Historically, these marshes would have been able to build enough elevation to keep pace with sea-level rise, but without their usual sediment deposition, they cannot. And even marshes that are keeping pace with sea-level rise for now will not be able to do so in the near future. Most marshes can cope with up to ten millimeters per year of sea level rise, according to Horton, but the East Coast will likely be experiencing levels higher than that by the end of the century.

Humans have disrupted the natural succession of coastal ecosystems from native forest to native marsh by introducing invasive species, such as the marsh plant phragmites. Although this slender reed with its wispy wheat-like tuft may not look dangerous, it has been a disaster for coastal ecosystems. "If it wasn't for phragmites," Whitbeck says, "I would sleep a lot better at night."

Phragmites is an aggressive grower with a relatively strong tolerance for salt, and it grows rapidly in tightly packed reeds that crowd out native marsh plants and animals. Birds that will only nest in native salt marsh disappear. Other animals find the reeds uninhabitable. "That's my main concern," Whitbeck says. "It's not so much the extent of wetland here in the Chesapeake, but the quality of that wetland."

When coastal forests die, phragmites takes over before other plants get the chance to move in. If you visited Port Republic, or the Chesapeake ghost forests, you would see little of the native marshes that conservationists hope will colonize the ghost forests. Instead you would see phragmites sprouting up around the standing dead trees in thick, dense rows. Once phragmites establishes itself, it's incredibly hard to kill. Even controlled burns and herbicides are not guaranteed to work. Whitbeck says the best strategy is to monitor land that's transitioning from forest to marsh, and prevent phragmites from moving in in the first place—an important reason to identify and study ghost forests more carefully.

Even if land managers can keep phragmites under control and ensure that native marsh takes over the land made available by ghost forests, the solution only works up until a certain point: when the inland migration of ecosystems hits human development.

Human development isolates and traps coastal ecosystems between the sea and manmade barriers. The problem is known as coastal or urban squeeze. Roads and highways along the coast cut off marshes from inland migration. So do seawalls built to prevent inland flooding. Paradoxically, by building walls to keep rising seawater out of towns, people are killing off the best natural system of flood prevention. Stuck between rising seas on one side and concrete on the other, marshland shrinks until it disappears. Even when people aren't building intentional barriers, development obstructs coastal ecosystem growth. "In many areas," Whitbeck says, "there is no place for marsh to migrate to, because you butt up against somebody's yard."

Storm flooding is an increasingly large problem in coastal towns. As local governments try to decide how to defend themselves from dangerous weather, they must weigh short-term protection, like sea walls, against the long-term protection provided by coastal marshes and forests. And while many economists and scientists suggest that people move away from the coast before sea-level rise ruins their towns, for now many urban coastal populations are growing, meaning the cities are sprawling to take over more precious land from coastal ecosystems, even while the amount of land available is shrinking. "There's going to be more and more competition for space," Horton says. "Something's going to give."

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That sea level rise will flood coastal forests and marshes is inevitable. Even if greenhouse-gas emissions get drastically reduced in the near future, the effects of climate change are already underway. The scientists studying these ecosystems understand that many of the forests and marshes they are monitoring now won't exist by the end of the century.

In order to save coastal forest and marshes, land managers and conservation agencies have to change their strategy. They cannot only protect the land where the coastal ecosystems are. They have to find somewhere for the marshes and forests to go, allowing them to escape the squeeze between rising seas and human development. One solution is to purchase migration corridors, strips of land perpendicular to the sea that trees and marshes can use to move inland. With such corridors established, seeds will be able to float inland and germinate on safer ground, instead of drowning alongside the adults in ghost forests.

The scientists studying sea-level rise approve of the migration-corridor strategy. "If you can preserve the land where you think the marshes are going be in one hundred years," Kirwan says, "I think that makes you a smart manager." Horton agrees that migration corridors are forward-thinking, but he suspects the corridors will still not be enough. He believes that policies that fight climate change must be enacted as soon as possible, or the migration corridors will be irrelevant. If sea-level rise keeps accelerating, the trees and marshes will not have time to migrate. Instead, Horton says, "they will just drown in place."

In spite of concerns like Horton's, land managers are doing what they can to purchase migration corridors, hoping to give coastal ecosystems at least a fighting chance. The Chesapeake

Marshlands National Wildlife Refuge Complex has adopted this strategy. A few years ago, Blackwater, the main Chesapeake refuge, collaborated with Salisbury University on a survey that compared images of the refuge from 1938 and 2006. They mapped open water, marshes, forests, and other habitats, and then compared the time periods. The survey found that 5,000 acres of marshes had converted to open water, and 3,000 acres of forested uplands had converted to marsh. The results, Whitbeck says, completely changed the way the refuge thought about land management.

The refuge used the sea-level rise maps to make models that could predict which marshlands were likely to convert to open water next, and which uplands might be good places for marsh to migrate to. Now, when landowners offer to sell their land to the refuge, Whitbeck's colleagues pull out their sea-level maps.

More so than in the past, the refuge today is less willing to buy marsh habitat that's high risk, and more willing to buy forested uplands. The Chesapeake refuges were originally built to protect the marshes, but the forests have become a higher priority of late. "We realize that they have a lot of benefits for forest birds now, and will eventually turn into tidal marsh in the future," Whitbeck says. "Purchasing uplands habitats within these marsh-migration corridors has been really just a huge shift in the way we think about land protection."

There is a lot riding on Blackwater's land acquisitions. While migration corridors may not be a perfect solution, they're the best strategy right now to protect coastal forests and marshes long term.

People have a lot at stake here too. Sea-level rise is already causing billions of dollars in damages to coastal towns and cities, destroying infrastructure and forcing families to abandon places where they have lived for generations. Financial analysts expect tens of billions of dollars worth of real estate to be underwater by 2050. The Federal Emergency Management Agency's National Flood Insurance Program (NFIP) now carries close to $25 billion in debt, after paying out for recent flood disasters. Congress and the Senate have both held hearings on how to update the NFIP's risk assessment to better match the realities of flood risk as sea level rises.

The effects of sea-level rise on coastal towns and cities are so numerous that the statistics are almost overwhelming. The number of flood days per decade in Wilmington, North Carolina, has increased over 2600 percent since the 1950s, from 14 to 376, according to an analysis by Climate Central. In the same timeframe, the analysis shows that flood days in Annapolis, Maryland have increased by over 1200 percent, from 32 to 394. A recent report on Virginia, funded by the National Oceanic and Atmospheric Administration, predicted that within a few decades dozens of communities will become less accessible during high tides and storms as miles of coastal roads flood. Seven communities, the report concluded, are at risk of becoming completely inaccessible during high tide. This will make the towns practically unlivable, as people are left stranded from the outside world on a daily basis, unable to access grocery stores, schools, or emergency services. Like the trees and marsh before them, people will have to migrate inland to survive.

In spite of the mounting economic and emotional costs to coastal communities of coping with sea-level rise, the Trump administration has espoused a policy dismissive of climate change and is less supportive of research and mitigation than ever. This frustrates the scientists studying coastal ecosystems. "Climate change *is* occurring," Jennifer Walker says, responding to the idea of climate change denial with an incredulous laugh.

Whitbeck focuses on doing what he can to mitigate the effects of climate change locally. His role at the Chesapeake refuge, he feels, is to prepare migration corridors for the coastal ecosystems—and, just as Marcelo Ardón does with his Sentinels of the Sound project in North Carolina, to use what's happening to coastal forests to educate visitors about climate change and sea-level rise. What's happening there, he argues, is much easier to see than the changes typically described in the press. "There's a lot of media coverage," he says, "on how many millimeters this is changing and that is changing—you know, the ice in Antarctica—and it seems very far away and very theoretical." Things are different at the Chesapeake refuges. "You come down to the refuge," he says, "and you see stumps in open water. There's only one thing that creates that."

Whitbeck, Ardón, and Walker are all hopeful that people confronted with the sight of ghost forests—those stands of dead trees rising eerily out of the marsh—will wake up to the reality of sea-level rise and grasp the growing scope of the problem. "That visual example," Walker says, "I think is more important than ever now."

The question, of course, is whether enough people will wake up to the problem quickly enough for us to save our coastal ecosystems. Maybe the sight of ghost forests will serve as a call to

action. In the meantime, however, the forests stand as a stark reminder of what has already been lost.

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