Chesapeake Quarterly

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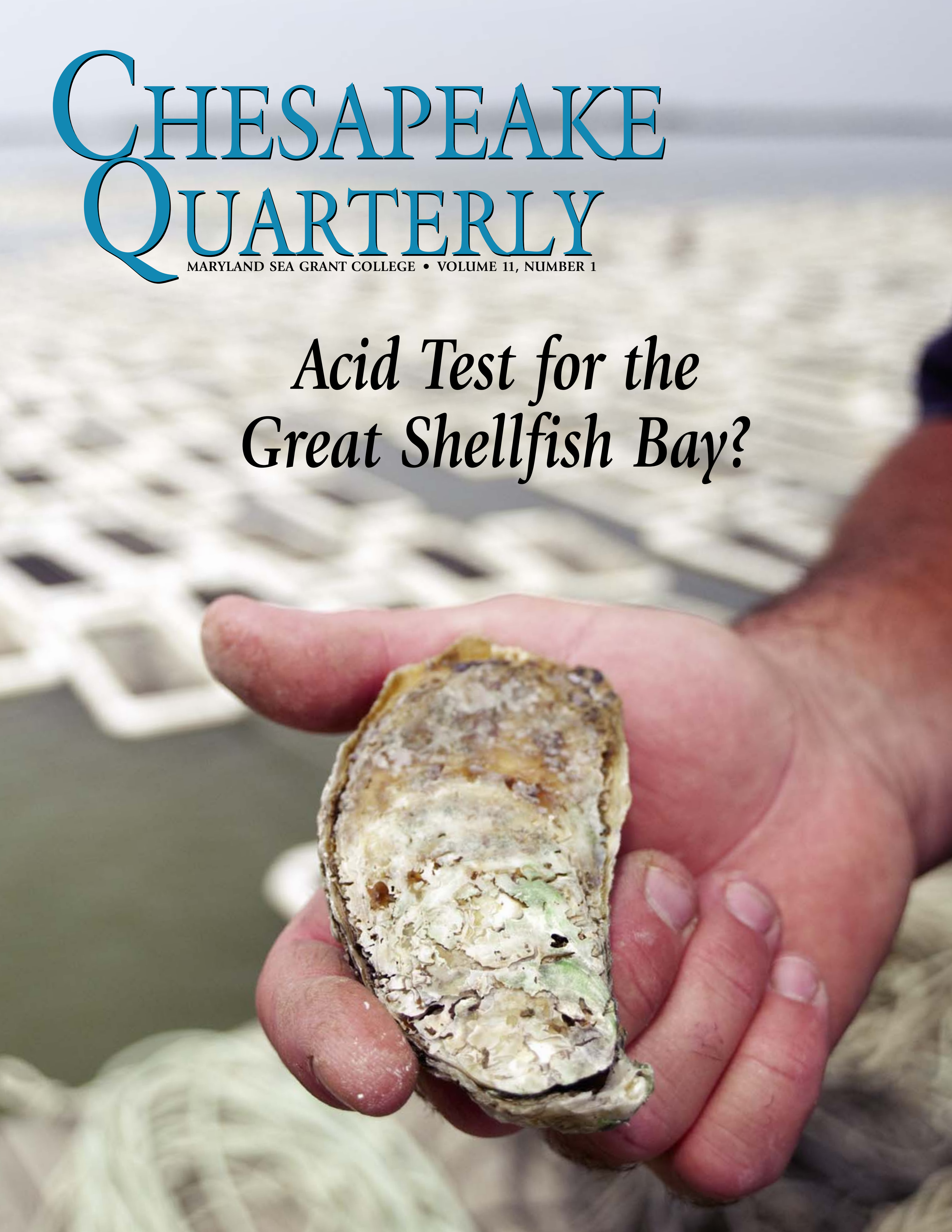
Acid Test for the Great Shellfish Bay?



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Chesapeake Quarterly explores scientific, environmental, and cultural issues relevant to the Chesapeake Bay and its watershed.

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Cover photo: *Did Algonquin tribes call the Chesapeake a "great shellfish bay?" Scholars disagree on the origins of the Bay's name, but scientists agree that the waters of the Chesapeake were once the greatest oyster grounds in the world. A new generation of oyster farmers could face a new challenge if acid levels rise in the estuary.* ***Pages 2 and 3:*** *Whitman Miller found that oysters did not grow well near Kirkpatrick Marsh on the Rhode River, a study site used by scientists from the Smithsonian Environmental Research Center.*
PHOTOGRAPHS BY MICHAEL W. FINCHAM.

AN ACIDIFYING
The "Other CO_2

Stephen P. Nash

The scene is more than a little askew here in a picnic park along the suburban shore of Maryland's Severn River not far from the Chesapeake Bay. On a drowsy, late-June morning, a high-school kid mows grass in the park, zodiacs and kayaks line the parking lot, and some pleasure craft are bobbing at anchor.

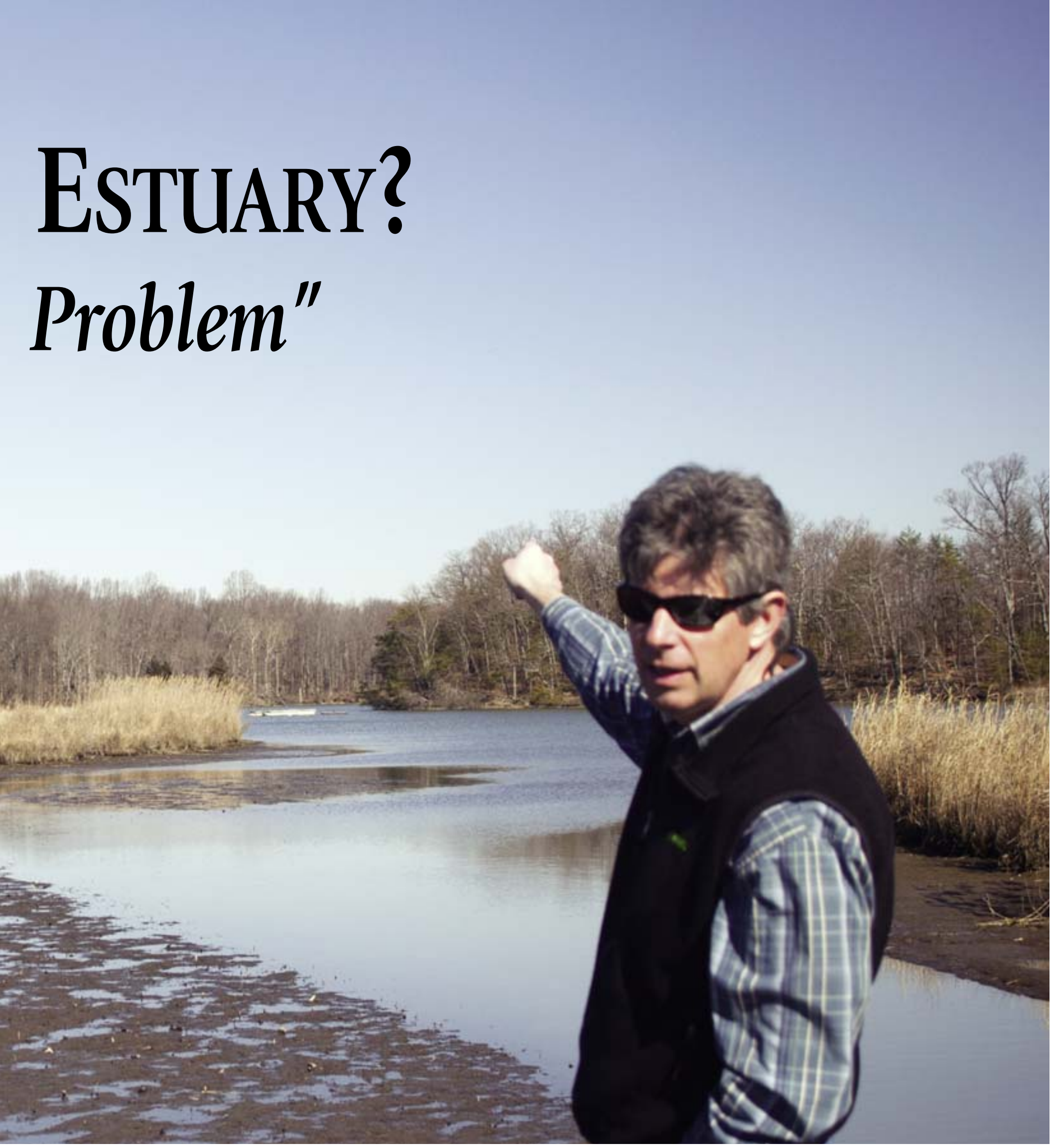
But the picnic tables are laden with an assortment of notebooks and odd tools. And some purposeful folks have unloaded tall green pressure tanks topped with gauges that could be mistaken for a welding kit, now installed in a big plastic chest under the trees. Tubes from their tanks run down into the river and out to a ten-meter square of water. It's marked off by colorful floating foam noodles and attended by two students in snorkel gear.

These are researchers, not welders, and the low-tech look of their apparatus belies the high-stakes questions behind their work. Designed as a kind of time machine, their river setup is meant to simulate Severn River waters as they will be in the future, circa 2050 and 2100. The green tanks are filled with carbon dioxide (CO_2), the same gas that now concentrates in the atmosphere as we burn coal, oil, and forests across the planet.

The Severn River project is part of a suite of new and recent research on the effects of rising CO_2 levels on the Bay. It is a collaboration between Whitman Miller, a marine ecologist with the Smithsonian Environmental Research Center (SERC), and Tom Arnold, a chemical ecologist with Dickinson College.

The two researchers plan to pump CO_2 out of their green tanks and down into that marked-off square of river

ESTUARY?
Problem"



As CO_2 levels are rising in the atmosphere, acidity levels are rising in the ocean, slowing growth rates for coral reefs, oysters, and other shell-building species. What's happening in the Chesapeake Bay?

water. They are doing on a small scale what industrial nations are doing on a global scale by pumping CO_2 into the atmosphere in ever-higher amounts. Nearly a third of that airborne CO_2 ends up absorbed in the world's oceans, unleashing chemical reactions that raise acidity levels and alter life for many marine species, especially shellfish.

What would happen to oysters in an acidifying Chesapeake? Miller plans to answer that question by placing baskets of young oysters out in that marked-off square of river and then raising CO_2 levels. He already knows that oysters don't grow well — at least in a lab — under higher CO_2 levels, but lab studies have their limits. "A lab study by its nature is a controlled environment," Miller notes. "The more controlled it becomes, the less realistic."

It turns out real-world experiments also have their limits, as Miller is discovering. Heavy, early summer rains have filled the Severn River with fresh, low-salinity water. Since oysters need moderate salinities to survive, he may have to delay deploying his samples.

The fate of oysters is a high-stakes question because oyster farming is on the rise in Maryland and Virginia, and both states have ambitious plans to rebuild some of the Bay's historic oyster reefs. Those ancient reefs played a key role in the ecology of an ecosystem once known as the "great shellfish bay."

A second question to be answered: what would happen to seagrasses in an estuary with higher CO_2 levels? Tom Arnold is planning on taking samples from the meadow of widgeon grass that seems to be flourishing in this part of the river. Heavy rains haven't hurt the widgeon grass, so Arnold can simply walk over and turn the handle on the tank regulator to start pumping CO_2 into the Severn River.

Miller and Arnold set up these experiments in the Bay because higher levels of CO_2 in the atmosphere are already changing both the climate of the Earth and the chemistry of the open oceans. We think of sky and water as distinctly separate in their vast reaches, but in fact where they meet, they mingle. As CO_2 gas increases in the atmosphere, it seeks equilibrium, pressing on the surface of open water and steadily diffusing into it, mixed in by wind and waves. As additional CO_2 dissolves into the ocean, it lowers pH and raises acidity. Scientists call this process ocean acidification.

The oceans, as a result, are changing at a faster rate than at any time in the last 300 million years, according to a report published this March in the journal *Science*. And that's worrisome. An earlier episode of rapid ocean acidification not only brought extinction to many one-celled organisms along the ocean bottom, it also caused the collapse of coral reefs and dissolved all the carbonate plankton shells that once littered ancient seafloors.

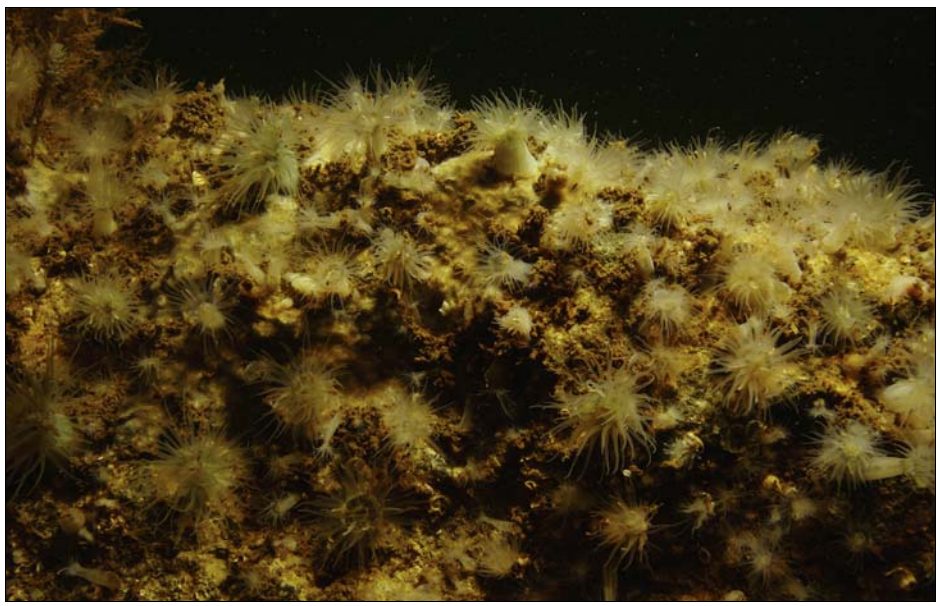
If the ocean continues to acidify, seawater could once again become corrosive to calcium carbonate structures, dissolving coral reefs and the shells of many marine organisms. The oceans are already 30 percent more acidic than they were 250 years ago, in the pre-industrial era. According to the *Science* paper, the current rate of acidification raises the possibility "that we are entering an unknown territory of marine ecosystem change."

What's happening in the ocean could affect the Chesapeake, according to scientists who launched several of the early studies on acidity in the estuary. It's difficult to draw sweeping conclusions, however, since only a handful of studies have been completed so far. If ocean acidification research is in its infancy, as the National Research Council suggests, then the research on estuaries like the Chesapeake is embryonic.

Basic questions, such as what are acidification levels and trends in the Chesapeake, are difficult to answer. To determine acidity, scientists test for pH, the classic scale used to measure the balance between acidity and alkalinity. In an estuary with changing salinities, most pH readings come with an inevitable — and large — margin of error. Checking on acidification, it turns out, is not as easy as dunking some litmus paper in the water.

As a result, "we don't really know how the Bay is going to respond," says ecologist George Waldbusser, whose expertise is in bottom-dwelling organisms. While at the University of Maryland Center for Environmental Science, he was lead author of a recent study that reviewed historical water quality data and tried to reconstruct how acidity has changed in the Bay over the past two decades. The records, he found, were imprecise and tricky to evaluate.

One trend, nevertheless, seems clear: acidity has increased sharply in the Bay's saltier waters — more than can be explained by CO_2 in the atmosphere. In the Bay, acidity levels are also driven by other factors, especially by the runoff of nitrogen and phosphorus pollution from farms and sewage. These nutrients generated by human activity lead to explosive growth of phytoplankton in the Bay's waters as photosynthesis converts nutrients and sunlight and CO_2 into plant material and oxygen. When all those excess plankton die, however, the decay process sucks oxygen out of the water, creating the Bay's famous dead zones every summer. It also releases a lot of little-noticed CO_2. The net effect can be a rise in the Bay's acidity.

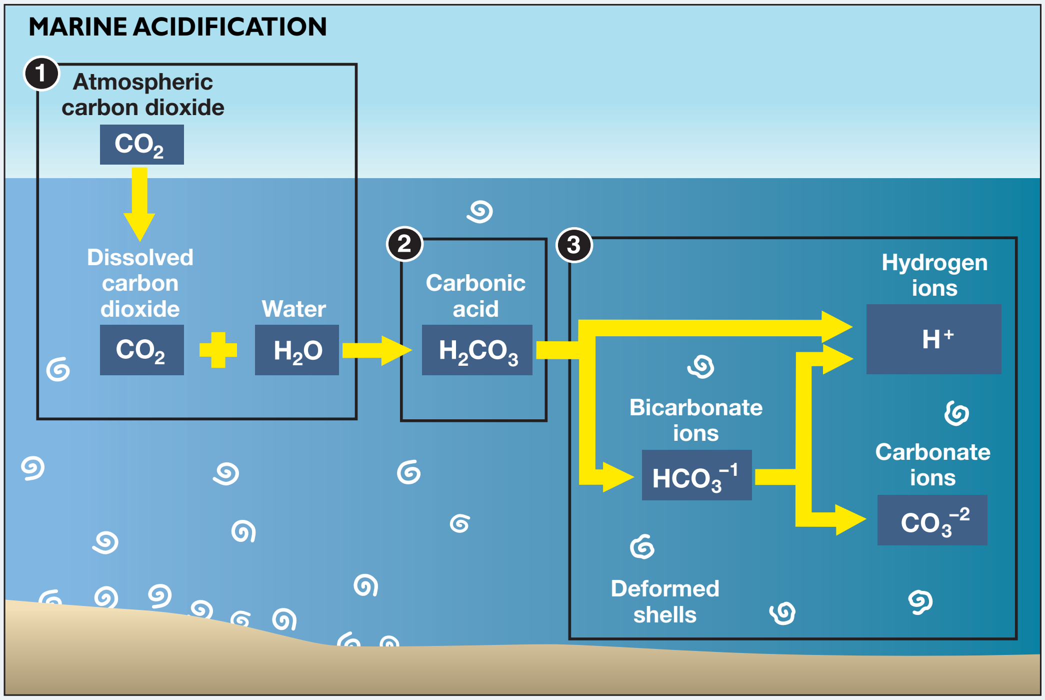


***Coral reefs are falling victim to** disease, warming waters, and acidifying oceans. The growth of coral reefs, especially in colder waters, is slowing in the open ocean as levels of CO_2 are rising in the global atmosphere. The oceans absorb nearly a third of the airborne CO_2, creating chemical changes that raise acidity and even threaten warm-water coral reefs, like this one (top) in St. Croix, U.S. Virgin Islands. Oyster reefs in the Chesapeake Bay (bottom) and other coastal waters could also suffer from growing acidification. Laboratory research indicates that higher levels of CO_2 would slow shell growth of young oysters.* PHOTOGRAPHS: NOAA (TOP) AND MICHAEL EVERSMIER (BOTTOM).

"If you say there is no CO_2 problem in the Bay, then you have to say there is no oxygen problem in the Bay," says Waldbusser, now a researcher at Oregon State University. "Hypoxia is a byproduct of that oxygen uptake and CO_2 release. Those things are linked through biology." For now, that biology and those land-borne nutrients create more acidity in the water than airborne CO_2 does.

CHEMISTRY 101

How Rising Carbon Dioxide Threatens Shell-Builders



Higher CO_2 reduces a key ingredient in shells.

1. CO_2 absorbed by seawater (H_2O).

2. CO_2 reacts to form carbonic acid; makes water more acidic (more hydrogen atoms).

3. Carbonic acid breaks down into bicarbonate and hydrogen ions (H^+). Bicarbonate breaks down into more H^+ and carbonate, key to organisms like oysters, clams, corals, and other marine organisms that make shells and skeletons. But as acidity increases, less bicarbonate changes into carbonate.

Higher CO_2 causes shells to dissolve.

Calcium carbonate is the main building block in the shells of marine animals. As seawater becomes more acidic, calcium carbonate — and the shells — can dissolve.

ACIDIFICATION AND OYSTER SHELLS IN THE CHESAPEAKE BAY

In an estuary like the Chesapeake Bay, sources other than the atmosphere — like runoff of excess nutrients — may add additional CO_2 to the water, contributing to acidification. Evidence suggests that higher acidity in the Bay could slow the rate of growth in the shells of young oysters, making them thinner and more vulnerable to predators.

David Liitschwager, National Geographic Images

The pteropod, *or "sea butterfly," is a tiny sea snail about the size of a small pea. The photos above show what happens to a pteropod's shell when placed in seawater with pH and carbonate levels projected for the year 2100. The shell slowly dissolved over 45 days.*

Other trends he found: some historical records show decreases in acidity in the less salty mid-Chesapeake, but surprisingly they also show sharp increases in acidity in the southern Bay where saltier waters have greater buffering power. Waldbusser's explanation: while more plankton dieoffs occur in the mid-Bay, much of the resulting CO_2 is transported downstream to the southern Bay.

When Waldbusser applied his findings to laboratory research, he was able to measure some of the impacts of acidification on young oysters and on shell reefs that are critical for the establishment and survival of oyster colonies. His three conclusions: At current average pH levels in some parts of the Bay, the rates of shell growth in young oysters are slowed, creating shells that are likely to be abnormally thin and more vulnerable to predators. In addition, the saltier waters in the southern Bay are likely to become even more acidic and increasingly corrosive to oyster shell. And, finally, some Chesapeake waters, he claims, may already be unsuitable for shell preservation in areas that once supported oyster populations. His analysis, says Waldbusser in his recent paper,

CHEMISTRY 102

The pH Scale: Yardstick for Acidity

The pH scale — that staple of introductory chemistry courses — is the measuring stick that scientists use to gauge acidity in the Chesapeake Bay.

The scale normally runs from 0 to 14; the lower the number, the greater the acidity. A pH of 7, the middle point, is regarded as neutral pH. That is the reading for distilled water, or pure H_2O with nothing dissolved in it.

The pH scale indicates the concentration of hydrogen ions in a solution. Strong acids like sulfuric acid contain lots of unattached hydrogen ions floating in them; strong alkalines, like bleach, contain few.

The scale is logarithmic, which means it measures a very big range. A difference of one pH unit is equivalent to a 10-fold difference in hydrogen ions. A reading of "4" is 10 times as acidic as a 5 and 100 times as acidic as a 6.

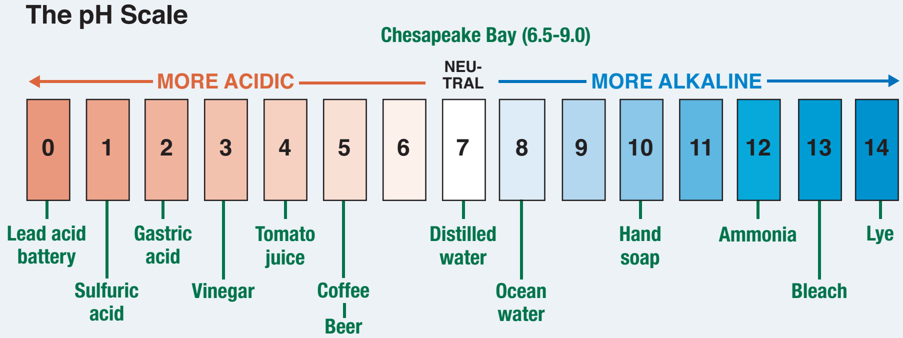
The "H" in pH refers to hydrogen, but the "p" has several meanings (for example, "power"), depending on which science historian you ask.

The pH in the Bay varies widely over time and along its length, influenced by salinity and temperature. The open ocean's different chemistry makes its pH range tighter and, on average, less acidic than the Bay's.

Neither the Bay's waters nor surface waters of the ocean typically register an average pH in the acidic range, below 7. Their waters are not acidic. Scientists, however, speak of ocean water as "acidifying" or "acidified" because its pH has dropped over time, making it more acidic than a few decades ago. On average, the ocean's pH has dropped from 8.2 to 8.1 since the industrial age began. That seemingly small change translates to a 30-percent increase in relative acidity. Scientists forecast a further drop of about 0.3 pH units by the year 2100, lowering pH to 7.8. That level would translate to a further increase of 150 percent in relative acidity.

Parts of the Bay are already at least as acidic as pH 7.8. As for the trend of pH in the Chesapeake, that is less extensively studied.

The pH Scale



SOURCE: FIGURE ADAPTED FROM *CURRENT: THE JOURNAL OF MARINE EDUCATION*, VOLUME 25, NUMBER 1, 2009.

should be viewed "cautiously" and followed up with additional research.

If acidification is affecting oysters in the laboratory, could it also be stressing animals and plants out in the waters of the Chesapeake Bay? That's the question that brought scientists Whitman Miller and Tom Arnold to the Severn River last summer. According to Miller, "Nobody's really been looking."

That may be changing. Arnold designed a project to examine the impact of rising CO_2 levels on the Bay's underwater grasses by pumping CO_2 gas into an underwater research plot that held widgeon grass. His focus was photosynthesis and the protective compounds that grasses use to ward off predators and disease.

Perhaps more CO_2 in the water could improve prospects for the Bay's underwater seagrasses. Under ideal conditions, CO_2, sunlight, and water all combine to drive photosynthesis for these submerged grasses, a key support system for the health of the Bay. Since the 1970s, unfortunately, conditions have been less than ideal, and nearly all seagrass species have declined dramatically. The Bay's waters remain so clouded with silt pollution that the grasses no longer get much light.

Arnold's findings from last summer's fieldwork were less than hopeful. Starved for light, seagrasses, he found, are unlikely to take advantage of added CO_2. There may not be enough light to help CO_2 stimulate photosynthesis, but there is enough acidification, unfortunately, to erode the grasses' protective compounds. By the end of the season, his research established that a rise in CO_2 levels was followed by a sharp reduction of those protective compounds.

"I've been doing this for about 20 years now, and it's the largest change I've ever seen," Arnold said recently, summing up last year's experiment. "Everything we see so far tells us that it's not going to be so great for the seagrasses after all."

There were no findings at all, however, about oysters in the Severn River. Miller had planned to chart the physical development of juvenile native oysters as they matured over the summer, sitting in a basket amid plumes of elevated CO_2 and rising acidification. When heavy rains kept salinities too low for oyster survival, Miller decided he would have to postpone his river experiment.

Based on his earlier lab findings, Miller suspects that rising acidification will make it more difficult for the Bay's oysters to form calcium carbonate structures — shells and skeletons. When he charted shell growth under a variety of CO_2 regimes, he found that higher CO_2 brought slower shell growth. At levels predicted for the year 2100, he found that the shell area of maturing native oysters decreased by 16 percent, and their calcium content by 42 percent.

Similar failures have already shown up among ocean calcifiers such as sea butterflies, some planktons, and corals. In oyster hatcheries along the northwest Pacific Coast, large dieoffs of oyster larvae have been linked to upwellings of acidic ocean water (see "Shell Game," p. 8). In the Chesapeake, acidification could also affect plankton as well as some or all of the many mollusk species that grow shells (see "Crab vs. Oyster," p. 13).

Not all scientists agree, however, that

How would small oysters *like these (above) grow in more acidic waters? Researchers Whitman Miller (far right) and Tom Arnold (right) wanted to pump* CO_2 *from tanks into a patch of the Severn River to see whether small oysters and widgeon grass would grow well in an acidifying river.* PHOTOGRAPHS BY STEPHEN P. NASH.

rising acidity levels will be a threat to the Bay's ecology. This brand of optimism, for example, is sometimes heard: because plants and animals in the Chesapeake ecosystem are adapted to variability, they will not be sensitive to added increments of acidification. Native species may in a sense be pre-adapted, from an evolutionary standpoint, to at least some degree of future change in acidity.

But shellfish calcification in particular is a long-term process of integration, says Richard Feely, a senior scientist who studies ocean acidification with the National Oceanic and Atmospheric Administration. "When they calcify, they calcify all day long, so what matters is that average value, over the course of time," he says. "That's what affects their rates. So yeah, you see a lot of variability, but you want to know what the overall trend is."

The overall trend is clear, at least according to scientists like Waldbusser, Miller, and Feely. The change in atmospheric CO_2 is permanent — it will be with us for hundreds or thousands of years — and it is all in one direction.

And it's that long-term, one-way direction that may pose a future threat to the Chesapeake Bay. "What we're most concerned about is a baseline shift of the whole system," Miller says. "You can imagine if we increase the CO_2 just a bit more, what happens is you will still have variability, but you'll shift that variability to a different place on the pH scale. And it may not take a tremendous amount before many parts of the cycle of variation are outside the tolerance level of the organisms. If we have a shift in the baseline, that could mean bad news for lots and lots of organisms, no matter how adaptable they are."

The idea is worth dwelling on. You can think of the Chesapeake's normal cycles as rising and falling within certain limits, as if they were inside a picture frame. Aquatic life has adapted to live within those boundaries, but survival rates fall off near the edges. If you move the whole picture frame incrementally — as atmospheric CO_2 rises, for example — survival chances diminish. The Miller-Arnold experiments are moving that frame, simulating acidification that is an evolving threat to the already sorely challenged, unstable health of the Bay.

Because their projects simulated CO_2 in the years 2050 and 2100, they may give the illusion that we have plenty of time to figure things out and ease the threat. The changes, though, are incremental — they won't arrive all at once, a few decades out. "Fifty to 100 years is not a very relaxed schedule, actually, given the magnitude of the problem," Miller says. "We're fighting against a time clock here."

The fight, however, has to focus first on the immediate, and crucial, job of throttling back on land-based pollution threats, especially farm runoff and sewage flows (see "Should We Regulate Acidity in the Bay?" p. 15). For now, these nutrients generate more CO_2 in estuaries like the Chesapeake than atmospheric CO_2 does. According to Waldbusser and Miller and other scientists who study acidification in the Chesapeake, these nutrients are the strongest factors that may move the baseline, tipping acidification levels beyond the tolerances of life in the Bay.

"We've altered coastal ecosystems in ways that have affected that carbonate chemistry and already pushed the system to levels that are predicted for [the open ocean] a hundred years from now, or even further into the future," adds Waldbusser. "I think we're worse off than the open ocean."

Stephen P. Nash teaches journalism at the University of Richmond and has written for Bioscience*,* The New York Times*,* The New Republic*,* The Scientist *and* The Washington Post. *His most recent book is* Millipedes and Moon Tigers: Science and Policy in an Age of Extinction.


LEARN
PLAY
OBSERVE
EXPLORE
CONNECT

SHELL GAME

Finding Answers for Acid Waters

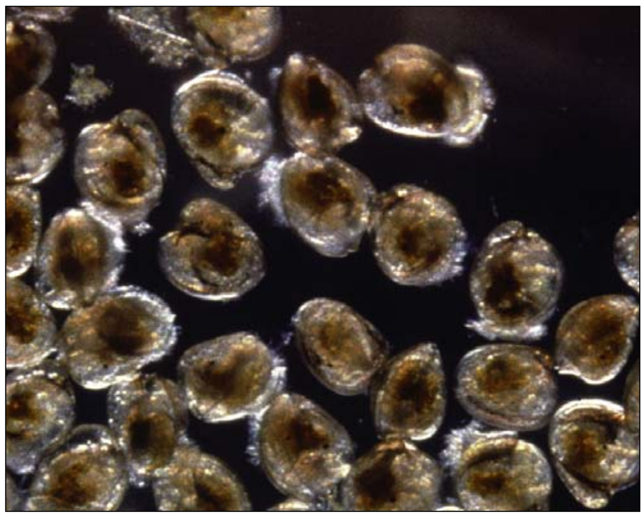
Michael W. Fincham

Mike Congrove was cruising through a pretty good season for spawning oysters when the water in the Piankatank River began to change. He runs a commercial hatchery down on Gwynn Island where this Virginia river meets the Chesapeake Bay. There he takes in water from the river and the Bay, coaxes males and females to spawn, and sells their offspring to a growing number of oyster farmers and gardeners in Virginia.

About the middle of June 2011, his good season hit a big slowdown. At his hatchery, Oyster Seed Holdings LLC, new oyster larvae began dying in large numbers. Larval production dropped from 100 million larvae a week down to 10 million. "We were spawning the same amount of oysters, fertilizing the same number of eggs," he said, "but we were getting extremely low survival rates."

A slim, bearded, and blonde-haired young man, Congrove has worked in the seafood business long enough to know this kind of sudden slowdown could have multiple causes. In this dieoff, however, one major change drew his attention: he was seeing river water with lower levels of pH, a traditional measure of the balance between acidity and alkalinity. The Piankatank and the Chesapeake — at least for a while — had become more acidic.

The Piankatank incident raised a red flag with Congrove — and with operators at half a dozen other Virginia hatcheries who also were seeing a lot of dying and deformed larvae. Their problems here in the Chesapeake sounded a lot like the dieoffs of oyster larvae that struck two Pacific Coast hatcheries back in 2008 and 2009. Researchers and hatchery experts eventually concluded that upwellings from deep in the Pacific had brought acidic water up into the intake pipes for these hatcheries. One result of the acidic influx was a series of oyster dieoffs at Taylor Shellfish Farms in Washington state and at Whiskey Creek Hatchery in Oregon. A second result was a crisis for the entire West Coast oyster industry.



Mike Congrove checks oysters *(opposite page) spawned and raised by Oyster Seed Holdings, LLC at its Gwynn Island hatchery down on Virginia's Piankatank River. Hatcheries like this are supplying larvae (above) and disease-resistant oyster seed to a growing number of oyster farmers in Virginia. After episodes of acidic water led to dieoffs of early-stage larvae, hatchery owners began adapting new monitoring techniques and workarounds to keep turning out new oysters for a growing industry.* PHOTOGRAPHS: TOM CHILLEMI (OPPOSITE PAGE) AND DONALD MERITT (ABOVE).

Those two large hatcheries produced much of the oyster seed used by growers from Canada down to Mexico. Oysters seemed to be dying because acidity levels in the ocean were rising.

The West Coast crisis, according to a number of scientists, was another dramatic sign of a disturbing global change. The world's oceans are becoming more acidic as levels of carbon dioxide (CO_2) are rising in the earth's atmosphere. The oceans are a great carbon sink absorbing much of the CO_2 that industries and automobiles send into the atmosphere when they burn fossil fuels like coal and oil. All that extra CO_2 alters the chemistry of seawater, eventually lowering the levels of calcium carbonate, a key ingredient for many ocean dwellers that use calcium to build skeletons or shells. Around the globe, the poster child for ocean acidification is the coral reef. In the Chesapeake Bay and other coastal waters, it may be the oyster.

For hatchery operators in the Chesapeake, the West Coast crisis comes at a time when oyster farming in the Bay seems to be entering a growth phase after decades of decline. In Virginia, the sale of farmed oysters has increased nearly tenfold since 2004, and growers in 2010 planted three times more seed oysters than ever before. And in Maryland, the state is hoping to imitate the Virginia boom by opening up more areas of Bay bottom for leasing by would-be oyster farmers.

Is rising acidity also a risk for oyster hatcheries and farms here in the Chesapeake? It's a question with no easy answer. An estuary, of course, is not an ocean. The Chesapeake is shallower and less salty than coastal waters along the Pacific, so hatchery operators and farmers here are not exposed to upwellings of acidic waters from the bottom of the ocean. That combination of shallows and lower salinities, however, actually makes the Bay more vulnerable, at least in theory, to rising acidity and declining pH. "At low salinity, the water is less buffered," says Whitman Miller, a researcher at the Smithsonian Environmental Research Center. "So that means any molecule of CO_2 has a much bigger effect on a lower-buffered system."

Miller is one of several researchers who've run laboratory studies looking at how rising acidity could affect oysters in the Chesapeake. When he spawned groups of oysters under differing acidities, he did, in fact, find that larvae fared poorly under high acidities. "The larvae grew slower, and they calcified less at high CO_2," he says. It was not, he cautions, a real-world test. In the lab he subjected larvae to CO_2 levels well above those currently found in the Bay, reaching heights projected for 50 and 100 years from now. And his oyster larvae, he points out, were living under steady-state exposures while larvae in Bay waters would experience fluctuating CO_2 levels. Despite these caveats, Miller thinks the risk from rising acidity is real. "The answer is yes," he says. "There is a potential effect."

Acidic water, he found, seems to have its greatest effect on early-stage larvae, a finding that matches the experience of hatchery operators on both the East and West Coasts. After males and females spawn, fertilization of new oysters occurs in the water, creating larvae that begin to float and feed. At his hatchery down on the Piankatank River, Mike Congrove has seen new larvae begin to struggle almost immediately as they try to form their first shell and digestive tracts. "It's probably in the first 48 hours or so that these animals are being compromised," he says, "so they don't make it past the first week or so of life."

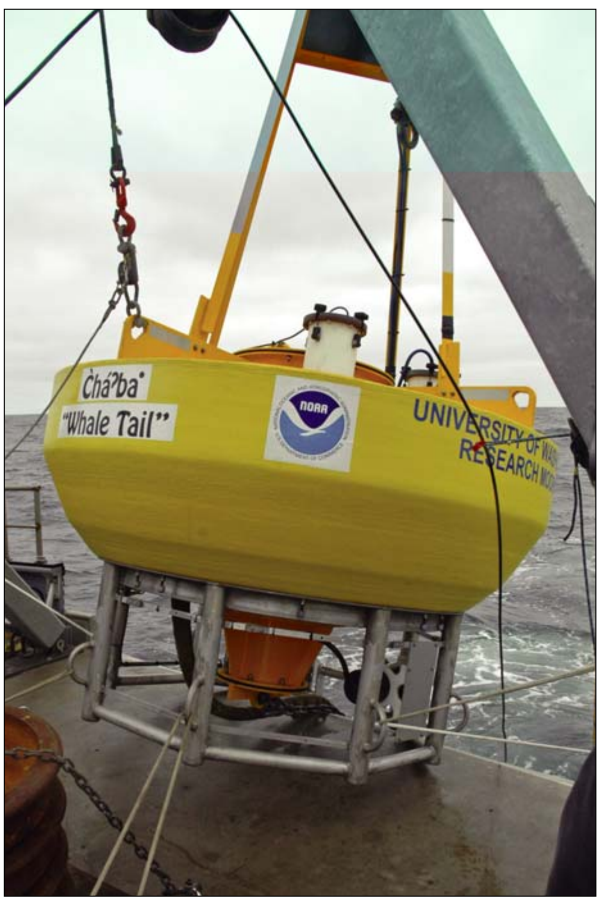
Those early larval failures in Chesapeake hatcheries are similar to what had happened on the West Coast, according to Alan Barton, the man who was hired to find out what was killing oysters at the Whiskey Creek hatchery in Oregon. "The larvae are dead on day one," he says, "but they don't die until 10 days later."

What Barton discovered has led hatchery operators to change their thinking about the water they let into their tanks. When he went to work at Whiskey Creek, he instinctively focused first on bacteria, specifically a bacterium called *Vibrio tubiashi* that was known to kill larvae. After engineering a system to filter the bacterium out of the water, he discovered that the larvae kept dying. "We always looked at diseases and bacteria as the culprits killing larvae, and they are," says Barton. "But it turns out those problems get a leg up because of carbon chemistry problems."

The key to the mystery, he decided, was the correlation between dieoffs of larvae and surges of acidic water. When winds blowing from the north push surface waters out to sea, cold water wells up from the deep carrying little or no oxygen, a lot of nutrients, and a lot of dissolved CO_2 gases. Not only does this acidic water kill off larvae, it helps support bacteria that also kill larvae. Before these episodes, says Barton, most hatchery operators had not been paying much attention to carbonate chemistry.

Not only are they paying attention now, they are busily looking for workarounds that could keep hatcheries profitable. The first step — monitoring the water coming into the hatchery — seems obvious, but it proved neither easy nor inexpensive. West Coast hatcheries joined together to seek federal grants to install instruments and establish protocols for measuring pH, temperature, salinity, and dissolved oxygen.

Their early monitoring efforts led to their first workaround. CO_2 levels, they



***The oyster crash that hit Pacific Coast hatcheries** in 2008 drove home the need for close monitoring of coastal and estuarine waters. Federal agencies began adding carbon and pH sensors to open ocean and coastal moorings already in place. International Ocean Observing System (IOOS) partners in the Northwest Association of Networked Ocean Observing Systems (NANOOS) deployed this buoy in 2010 as part of a three-piece observing array to assess issues in the Pacific Northwest, including ocean acidification, hypoxia, harmful algal blooms, and climate change. The coastal buoy aids computer models that predict ocean and atmospheric conditions. Known as "Chá bă," the buoy is named for the Native American word (pronounced "chay buh") for "whale tail." Data from these buoys can now alert hatchery operators to oncoming acidic upwellings in time to adjust their water intake schedules. Workarounds like this have helped hatcheries increase their production again.* PHOTOGRAPH COURTESY OF JOHN PAYNE, PACIFIC OCEAN SHELF TRACKING PROJECT.

found, were lowest late in the afternoon, after photosynthesis had spent the day turning CO_2 and sunlight and water into plant material and oxygen. Photosynthesis, of course, shuts down during nighttime, but phytoplankton and seagrasses don't turn off their natural respiration. The metabolism that keeps them alive continues around the clock, creating CO_2 as waste and releasing it into the water column during all the dark hours. As a result, levels of CO_2 are always highest at the start of the day. Hatchery operators now time their water intakes for later in the day.

A second workaround came from weather buoys moored in coastal waters by the U.S. Integrated Ocean Observing System (IOOS), a program led by the National Oceanic and Atmospheric Administration (NOAA). By tracking wind shifts that unleash upwellings, the buoys give early warning alerts to shut down intake pipes. At Taylor's Shellfish Farms, located along inlets off Puget Sound, operators found relief by raising their intake pipes out of deep waters and positioning them near the surface. In 2009, NOAA also began adding carbon and pH sensors to many of its monitoring buoys in coastal waters.

Another solution that helped: adding sodium carbonate and bicarbonate when hatchery waters got too acidic or too alkaline. It's the same ploy the rest of us try when we get an acid stomach: we pop Alka Seltzer to lower the acidity, but its greatest effect is to raise the alkalinity. The chemistry in hatcheries may get a little more complicated than in our stomachs, but the principle seems to be working. "We're probably still in business because of that," says Barton.

Thanks to a combination of research and practical workarounds, West Coast hatcheries have been able to increase their annual production of oyster larvae in recent years.

Those solutions may not be as helpful along the East Coast, where hatcheries in the Chesapeake face a different kind of acid test. The Chesapeake is not the Pacific. Upwellings from the ocean and deposition from the atmosphere are not the major sources of CO_2 in the Bay. According to Whitman Miller, "The issue is really how much stuff is coming off the land."

Researcher Whitman Miller on how biology drives CO_2 cycles: *"In the open ocean, if something dies, it sinks down to the abyss, and that carbon is lost from the surface waters for hundreds of thousands of years. If something dies in the water column in the Chesapeake, it falls a few meters to the bottom, rots, CO_2 comes off, and it's back in the water column."* PHOTOGRAPH BY MICHAEL W. FINCHAM.

The ongoing overenrichment of the Chesapeake is a well-publicized problem — but it has a little-noted effect. Nutrients running off the land include decaying detritus, animal waste, fertilizer, and sewage, all of which help create blooms of phytoplankton and zooplankton. When these floating plants and animals die, the process of their decomposition lowers oxygen levels, creating well-documented dead zones in the Bay every summer. The surprise kicker: all that decay also recycles CO_2 back into the water. And, in the shallows of rivers and creeks, all that CO_2 could slow shell growth for young oysters.

Estuarine acidification, it turns out, is quite different from ocean acidification, according to Miller. With acidification in the ocean, the chemistry is driving the biology, but it's the exact opposite with acidification in estuaries. "If you come into the coastal systems," he says, "it is the biology that is driving the chemistry."

Miller saw dramatic evidence of how biology drives CO_2 chemistry when he grew test oysters in the Rhode River. He placed one batch next to a dock and another batch next to a nearby salt marsh. Most salt marshes are traps that become biological decay zones for plant material washing off the land, and Miller discovered that CO_2 levels coming out of the salt marsh biology were often 10 times higher than levels at the dock. His test oysters grew well near the dock — but not near the marsh. "The ones near the marsh are sort of devastated," says Miller. "Lots of them die. They barely grow at all, even after months and months and months."

There's obviously a lesson there for Chesapeake oyster farming and restoration. "If I were going to site an oyster restoration," says Miller, "it would not be right at a [marsh] location." Oyster growers are already advised not to plan in river areas with high fecal counts. Now they need to avoid low pH levels before planting seed oysters, paying close attention to fringe habitats like sewage outfalls and tidal marshes. Some places in the Bay are better to grow oysters than others.

Some lessons from the West Coast crisis are helpful, some are not. On the Piankatank River, Congrove is already shutting down his intakes when CO_2 levels are high and adding sodium carbonate to his hatchery water when pH levels are low. A West Coast solution like early warning buoys is less relevant in the enclosed waters of the Bay. What's needed here, according to Miller, are close readings of water chemistry on smaller, regional scales like the rivers, creeks, and coves where hatcheries or farms might be located.

The search for that kind of Bay-area solution is already underway. This year a coalition of six hatcheries in Virginia is beginning an ambitious effort to monitor a suite of water quality conditions that could be at play in their larvae dieoffs. With funding from the Virginia Secretary for Natural Resources and the Coastal Zone Management Program, hatchery operators will be able to work with more sophisticated gear, train their staff, send samples out for laboratory analysis, and follow a consistent testing protocol at each hatchery.

A skeptic at work. *Like most hatchery operators, Kevin McClarren has seen mysterious dieoffs of newly spawned oyster larvae, but he's unconvinced acidity is at fault. As manager of the Choptank Oyster Company, he runs one of the most successful oyster farms in Maryland and the only privately funded oyster hatchery in the state. "I don't know that anybody who's had a bad season could say it's because of acidity," he says. "I don't know." He's also skeptical about predictions of rising acidity. "People are guessing what the pH is going to be in 30 years."* PHOTOGRAPH BY MICHAEL W. FINCHAM.

Costs could run up to $30,000 per hatchery, according to Congrove. That's a hefty outlay, he says, for hatcheries that are "capital limited," but the payoff could be survival and expansion of the growing oyster industry in the state.

The chemistry of acidic water will not be the only focus for the monitoring. "We're looking at a number of things we've never looked at in the past," says Dave Kuhn, a researcher at Virginia Tech who will be analyzing data collected from all the hatcheries. In addition to carbonate chemistry like pH and alkalinity, the tests will cover parameters that include algae toxins, pesticides, minerals such as silicates, and nutrients such as ammonia, nitrates, nitrites, phosphorus, and total organic carbon. They will also look for vibrio and other disease-causing microorganisms.

Not every operator, at the moment, is convinced that acidic water is the killer at fault in the Chesapeake. "It's something that's on people's radar," says Kevin McClarren, who manages the Choptank Oyster Company in Cambridge, Maryland. "But pH is not something we really look at in oyster culture." His skepticism is rooted in a familiar experience: oyster spawning can be notoriously variable and the causes for larval dieoffs can be maddeningly mysterious. "There are so many things that are going to do in your larvae. But whether it's one problem or another, we can never figure out," says McClarren. "Once the larvae are dead, the larvae are dead. It's a guessing game after that."

A game changer may yet come out of the new monitoring, a finding that could cut down most of the guessing about dieoffs of oyster larvae. Perhaps some clear correlations will leap out of all that data. Which factors correlate with growth? Which with dieoffs? Mike Congrove has also noticed high ammonia levels in his hatchery water during larvae dieoffs at his Piankatank River hatchery. If larvae are dying at different hatcheries with similar readings — whether it's high levels of acidity or ammonia or some other parameter — then scientists and hatchery operators can start to zero in on the oyster killers.

And they can try more precise solutions, whether it's better filtration to keep out disease vibrios or some new kind of oyster Alka Seltzer to rebalance the acidity of their hatchery waters. "The real purpose of all this monitoring is the practical application," says Congrove. "How can we change the parameters that seem to be problematic?"

Perhaps that's the silver lining in the West Coast crisis. Now that hatchery operators on both coasts have started paying close attention to acidification, carbonate chemistry, and dozens of other factors, they may start finding answers to some old mysteries about what was killing off their baby oysters. And they may find some workarounds to keep their oysters alive and their industry growing.

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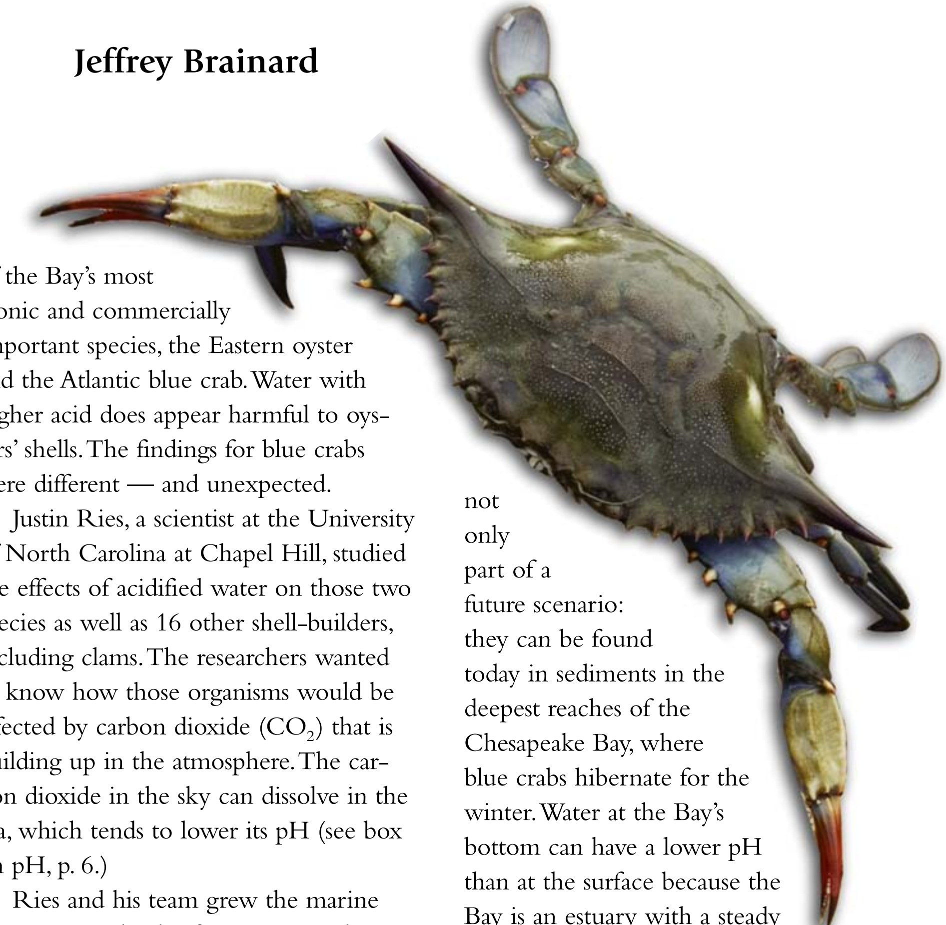
Crab vs. Oyster

As Acidity Increases, Some Species May Win and Others Lose

Jeffrey Brainard

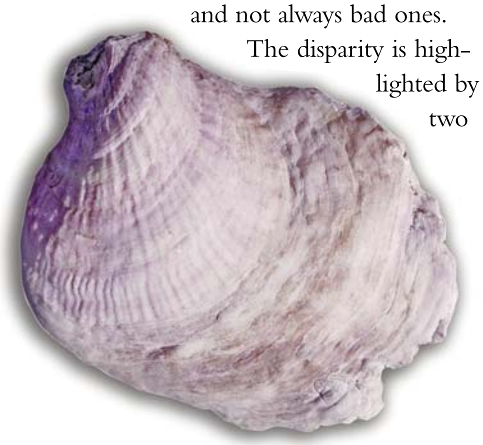


In the Chesapeake Bay and the open ocean, waters with rising acidity are poison for some species and tonic for others.

Those discoveries came from recent laboratory studies about how Bay species are affected by water with different levels of pH, the laboratory scale that describes acidity. (Lower pH readings correspond to higher acidity.) That's important because of predictions that the Bay and the open ocean will slowly become more acidic in coming decades. Water in parts of the Bay is already naturally more acidic than in the open ocean.

This water threatens to degrade the shells and skeletons of marine organisms. As pH in seawater falls, so does the level of a form of carbon (called carbonate) that the creatures need for building those structures. Their shells could grow smaller or even dissolve, making them more vulnerable to predators and threatening their survival.

The laboratory findings suggest, however, that decreases in pH may have quite different effects on different species — and not always bad ones. The disparity is highlighted by two of the Bay's most iconic and commercially important species, the Eastern oyster and the Atlantic blue crab. Water with higher acid does appear harmful to oysters' shells. The findings for blue crabs were different — and unexpected.



Justin Ries, a scientist at the University of North Carolina at Chapel Hill, studied the effects of acidified water on those two species as well as 16 other shell-builders, including clams. The researchers wanted to know how those organisms would be affected by carbon dioxide (CO_2) that is building up in the atmosphere. The carbon dioxide in the sky can dissolve in the sea, which tends to lower its pH (see box on pH, p. 6.)

Ries and his team grew the marine creatures in a bank of aquarium tanks similar to those in pet stores but outfitted to bubble carbon dioxide into the water. The pH in some tanks corresponded to today's level of carbon dioxide. The pH in other tanks reflected levels of CO_2 two and three times higher than amounts before the Industrial Revolution; those levels are projected to occur by the year 2100 if carbon dioxide in the atmosphere continues to increase at the rate seen in recent decades. Another set of tanks held a still bigger dose of CO_2, representing 10 times the pre-industrial level, predicted to occur within the next millennium.

Acidity at the Bay's Bottom

Ries says it was relevant to study water with CO_2 levels that high because they're not only part of a future scenario: they can be found today in sediments in the deepest reaches of the Chesapeake Bay, where blue crabs hibernate for the winter. Water at the Bay's bottom can have a lower pH than at the surface because the Bay is an estuary with a steady inflow of nutrients from streams and rivers. The nutrients feed algae that bloom in the summer and eventually sink to the Bay's bottom, where they decompose. The process of decomposition creates more carbon dioxide, a waste product of metabolism, and raises acidity.

Ries's interest in what is going on in the Chesapeake sediments is more than purely academic. He grew up in Baltimore and spent summers at his grandfather's marina on Gunpowder Cove and at a summer home on Harris Creek in Maryland. In fact, he obtained the blue crabs he used in the study from the breeders at the Institute of Marine and Environmental Technology (part of the University of Maryland Center for Environmental Science) in Baltimore Harbor.

His laboratory experiments included a seemingly surprising result: the lower the pH in the tanks, the heavier and larger were the crabs' shells. Higher acidity seemed to help blue crabs grow bigger. "Honestly I did not expect it," he says.

Ries chalks this up to the blue crab's body type. Its outer shell or exoskeleton is covered by a substance, called chitin, that protects it from the corrosive effects of surrounding water. What's more, crabs appear able to regulate the pH of fluid inside that covering, keeping the level higher (or less acidic) than the surrounding water. That's important because organisms like crabs build their shells from calcium and a form of carbon called carbonate. The pH level affects the amount of carbonate available for the crab to incorporate into its shell: a higher pH leads to more carbonate, and a lower pH results in less. So when crabs control their internal pH, they can generate more raw material for shell building.

Elevated levels of carbon dioxide and acidity *affected the shells of marine animals in a study by Justin Ries of the University of North Carolina (above, with tanks used in his study). High levels of acidity hurt growth in Eastern oysters but helped it in Atlantic blue crabs. Surprisingly, crabs grown experimentally (bottom) at the highest levels of carbon dioxide (10 times pre-industrial levels, right) developed larger shells than those grown at today's levels (left.) The scale is in centimeters after 60 days of growth.* PHOTOGRAPHS COURTESY OF JUSTIN RIES.

The blue crab probably evolved that capacity because it molts, Ries explains. Its survival depends on building and solidifying a new shell within days after it sheds its old one. So blue crabs needed a physiology that could maximize the amount of carbonate available to build their shells. That same mechanism can probably help blue crabs grow larger shells when carbon dioxide levels are higher than today's, Ries says. The effect is similar to what we see in modern humans, who grow taller on average than people who lived during the Middle Ages because today we enjoy diets richer in protein and calcium.

"We think that the crabs have evolved a sophisticated mechanism, not necessarily to prevent the effects of acidification, but just to go about their normal molting process," Ries says. "The carryover effect is that it makes them more resilient to acidification."

Different Oysters, Different Effects

Other Bay species tested by Ries and his colleagues included hard- and soft-shell clams, and he found that their shells actually dissolved at the highest levels of carbon dioxide. That's an effect of acidification that doesn't offer good news for the blue crab, because clams are among its prey. It's an example of why scientists say that the effects of acidification have to be studied holistically within ecosystems, not just species by species.

When Ries tested Eastern oysters (*Crassostrea virginica*) from Cape Cod, he found effects that were less severe than in clams but still significant: the rate of growth in its shell steadily declined as the water's pH fell. Other researchers studying the Eastern oyster have found similar effects (see "Shell Game," p. 8.)

At least one species of oyster, it turns out, can survive in higher acidity waters. When Whitman Miller ran laboratory experiments at the Smithsonian Environmental Research Center, he found that the Asian oyster (*Crassostrea* *ariakensis*) showed no loss of shell when exposed to higher acidity levels. Scientists think that the Asian oyster, native to the rivers of China, is better adapted to low pH waters because it evolved under more acidic conditions.

Oysters' bodies and shells are different from crabs' in several important respects. Oysters have a protective covering (called the periostracum), but it doesn't completely cover their shells. And unlike crabs, they don't molt. An oyster builds its shell continuously.

Other researchers have looked beyond shellfish to study other species that dwell in coastal waters. A study of moon jellyfish by researchers at Western Washington University showed they reproduced just fine in highly acidified water. And although underwater grasses might be expected to fare well in water rich with carbon dioxide, which they photosynthesize, they instead appear to sustain damage under some circumstancess (see "An Acidifying Estuary?" p. 2.)

A big caveat to these laboratory studies, acknowledged by Ries and other researchers, is that they may not accurately predict what would happen to those same creatures in the natural environment of the Bay. Ries gave the oysters a constant dose of low pH for two months, something they would not experience in nature, where pH levels fluctuate. In the Bay, the creatures may be able to compensate and build their shells despite these unfavorable conditions — although at a cost in energy that could reduce their survival, scientists say.

Still, these studies are significant because some earlier reports about acidifying water have implied that lower pH puts all shell-building organisms at risk. Ries and other scientists have offered a more nuanced picture, one that highlights the importance of differences in adaptations among different species. The impact on marine life of higher atmospheric carbon dioxide, Ries wrote, "is more varied than previously thought."

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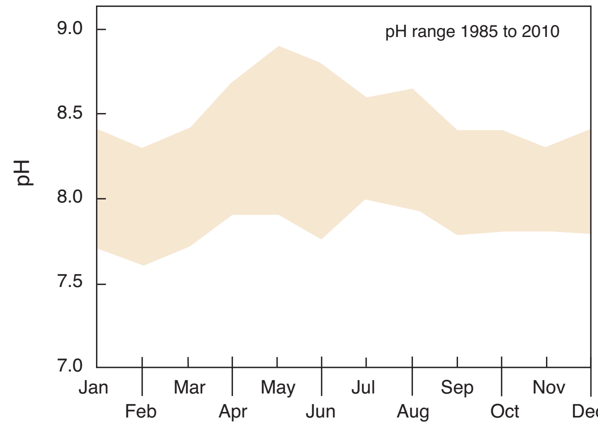
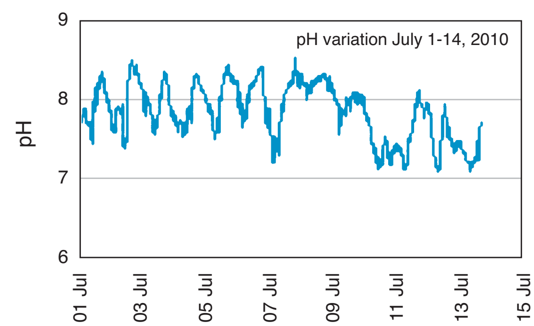
Should We Regulate Acidity in the Bay? If So, How?

Jeffrey Brainard

Levels of acidity may be rising in parts of the Chesapeake Bay, and as a result, oyster larvae may be dying and oyster shells may be thinning. According to state and federal regulators, there isn't yet enough proof to say the Bay is suffering from acid indigestion or to prescribe an antacid. One environmental advocacy group, however, has been working the regulatory umpires to persuade them otherwise.

A byproduct of carbon dioxide inputs from the land and the air, acid levels can fluctuate wildly in an estuary like the Bay, presenting a challenge for anyone seeking to measure or control them. Levels of pH, the numerical scale for acidity, can vary hugely over months and even hours, much more than in the open ocean. In the Bay, measurements in a single year at a single location can vary from 6.5 (more acidic) to 8.5 (less acidic) on the pH scale (see box on pH, p. 6.) That's a difference of more than one hundred times. Ebbs and flows of fresh water from rivers contribute to this unevenness; so do tides that stir the water.





Measuring pH in the Bay *is a challenge. Levels can vary widely over time and at different locations, and officials say that the available data don't indicate that acidity is rising in Maryland. The top graph shows the ranges of monthly pH at one station in the Bay, Cedar Point, from 1985 to 2010. The bottom graph shows variation of pH over 14 days in July 2010 at Fort Howard.* SOURCE: MARYLAND DEPARTMENT OF NATURAL RESOURCES, EYES ON THE BAY.

The federal government acknowledged the natural variability of pH in estuaries when it wrote an allowable range for acidity in salt water under the Clean Water Act back in the 1980s: the range is between 6.5 and 8.5 in pH. Maryland adopted the same range.

So far, the Maryland Department of the Environment, which has lead responsibility for enforcing the act in Maryland, has not seen evidence that the Bay's acidity has transgressed those boundaries, says the agency's Matt Stover. The data don't indicate that the water is growing more acidic. "At this point, it doesn't seem like the localized data are conclusive enough

Continued on p. 16

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Regulating Acid, from p. 15

to show that there's an immediate effect on shellfish" from acidity levels, he says.

That conclusion doesn't satisfy Miyoko Sakashita, ocean director at the Center for Biological Diversity, an environmental advocacy group. The organization, based in Tucson, Arizona, has been pushing Maryland, Virginia, and other states to declare their coastal waters to be in violation of the law, so far without success. Sakashita argues that Maryland has grounds to declare portions of the Bay as "impaired" because new research, based on laboratory tests, indicates that current pH levels threaten to damage oysters (see "Shell Game," p. 8.) The oysters are "the elephant in the corner," Sakashita says.

The U.S. Environmental Protection Agency, which oversees how the states enforce the Clean Water Act, weighed in on the issue in 2010, encouraging the states to pay attention to acidification in their coastal waters. (The EPA made the statement to settle a lawsuit filed against it by Sakashita's organization.) States should declare waters as impaired by acidity "where data and assessment methods are available," said the agency, while recognizing "that information is absent or limited for [acidification] parameters and impacts at this point in time in many states." The EPA encouraged states to focus on protecting vulnerable ecosystems, including those where shellfish live.

If acidified water indeed threatens the Bay's ecology, communities in the Chesapeake watershed are already planning measures that could ease the risk, by controlling the excess nutrients that contribute to acidified water. According to Sakashita, it's not clear that Maryland would need to do more to control acidity beyond the steps it has already promised to control nutrient threats to the Bay's water quality. Those steps include a reduction of about 25 percent each in nitrogen and phosphorus by 2025. Excess levels of these nutrients feed algal blooms that kill fish and contribute to rising acidity. The EPA has directed Maryland and other states in the Chesapeake watershed to improve stormwater systems and expand vegetative buffer areas that can filter out those nutrients before they reach the Bay.

While those efforts might help control acidity in the Bay, Sakashita and many scientists believe the controls on nutrients must be complemented by new national and global measures to curtail carbon dioxide emissions into the atmosphere. Those gases can dissolve in waters of both the Bay and the open ocean. The EPA won the legal authority to regulate CO_2 emissions under the federal Clean Air Act and began doing so in 2011. Legal challenges to that authority, however, are still underway.

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For Further Reading

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