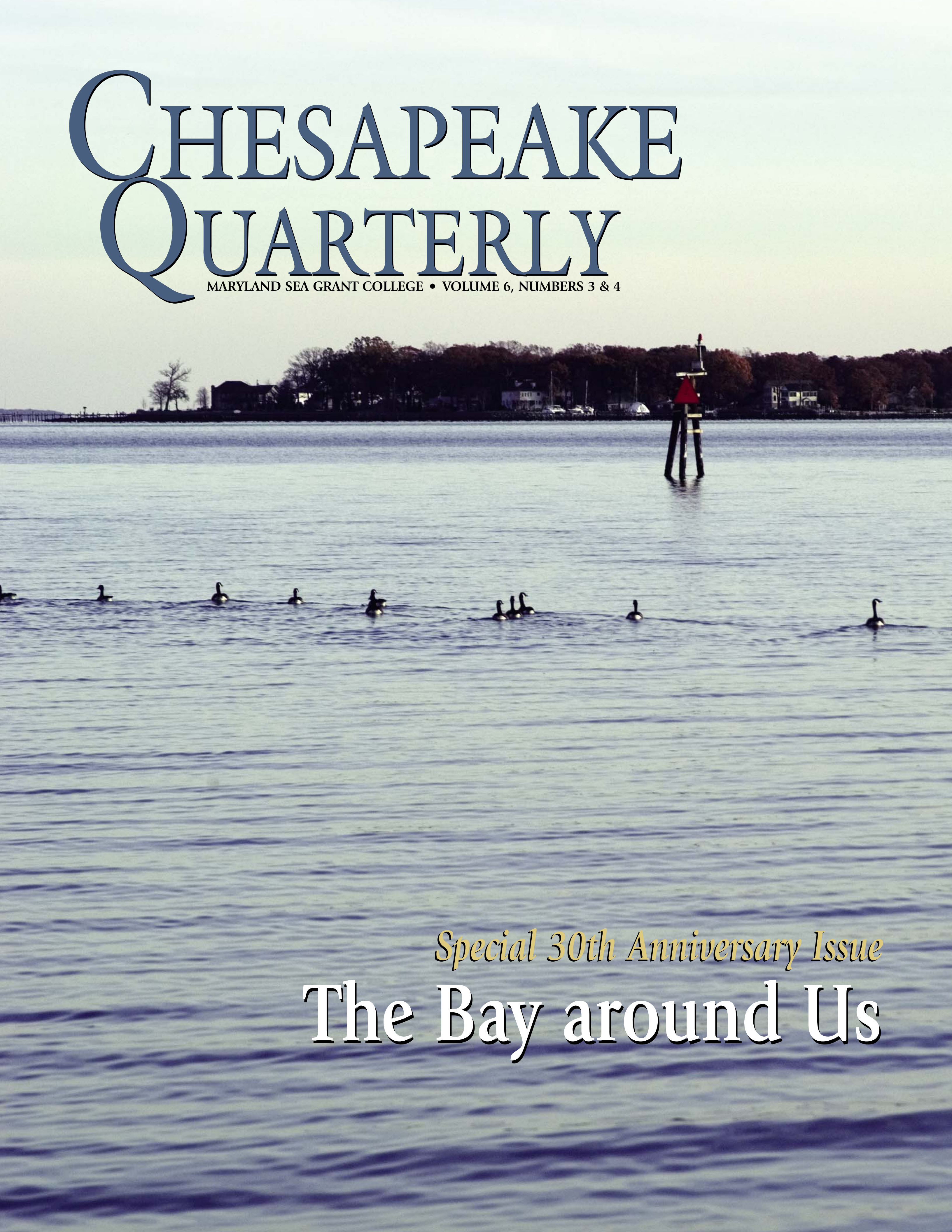

Chesapeake Quarterly

MARYLAND SEA GRANT COLLEGE • VOLUME 6, NUMBERS 3 & 4

Special 30th Anniversary Issue

The Bay around Us

30 Years

Maryland Sea Grant
1977-2007

contents

Special 30th Anniversary Issue — Volume 6, Numbers 3 & 4

CHESAPEAKE QUARTERLY

December 2007

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

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Maryland Sea Grant College
4321 Hartwick Road, Suite 300
University System of Maryland
College Park, Maryland 20740
301.405.7500, fax 301.314.5780
e-mail: mdsg@mdsg.umd.edu
www.mdsg.umd.edu

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Cover photo: *Canada geese arrive for winter near Galesville on the West River, where summer brought unwanted algae blooms.* PHOTOGRAPH BY SANDY RODGERS. ***Opposite page:*** *Golden marsh grass rises from the Chester River along the Eastern Neck Wildlife Refuge.* PHOTOGRAPH BY MICHAEL W. FINCHAM.

The Past Is Prologue

Thirty years in the lifespan of an estuary is a blink of an eye. Thirty years of scientific progress in understanding that estuary is a lifetime. Science moves rapidly, powered by the engine of individuals who have the rare ability to make connections in ways that others cannot — connections between disciplines, between colleagues, and to new technologies — all in pursuit of solutions to important problems. In places like the Chesapeake Bay, these problems are inherently complex and extend across large geographic and biological scales. This issue of *Chesapeake Quarterly* recounts two stories of how the research community has confronted this complexity.

In many respects, the Bay's scientific community is a crucible from which big ideas and big thinkers have emerged: individuals who have gone on to steer research on a much broader stage, often with an impact on national and international initiatives. Whether the scale of their research extends hundreds of kilometers or a few microns, these creative scientific thinkers have redefined how we look at and manage this Bay and its watershed.

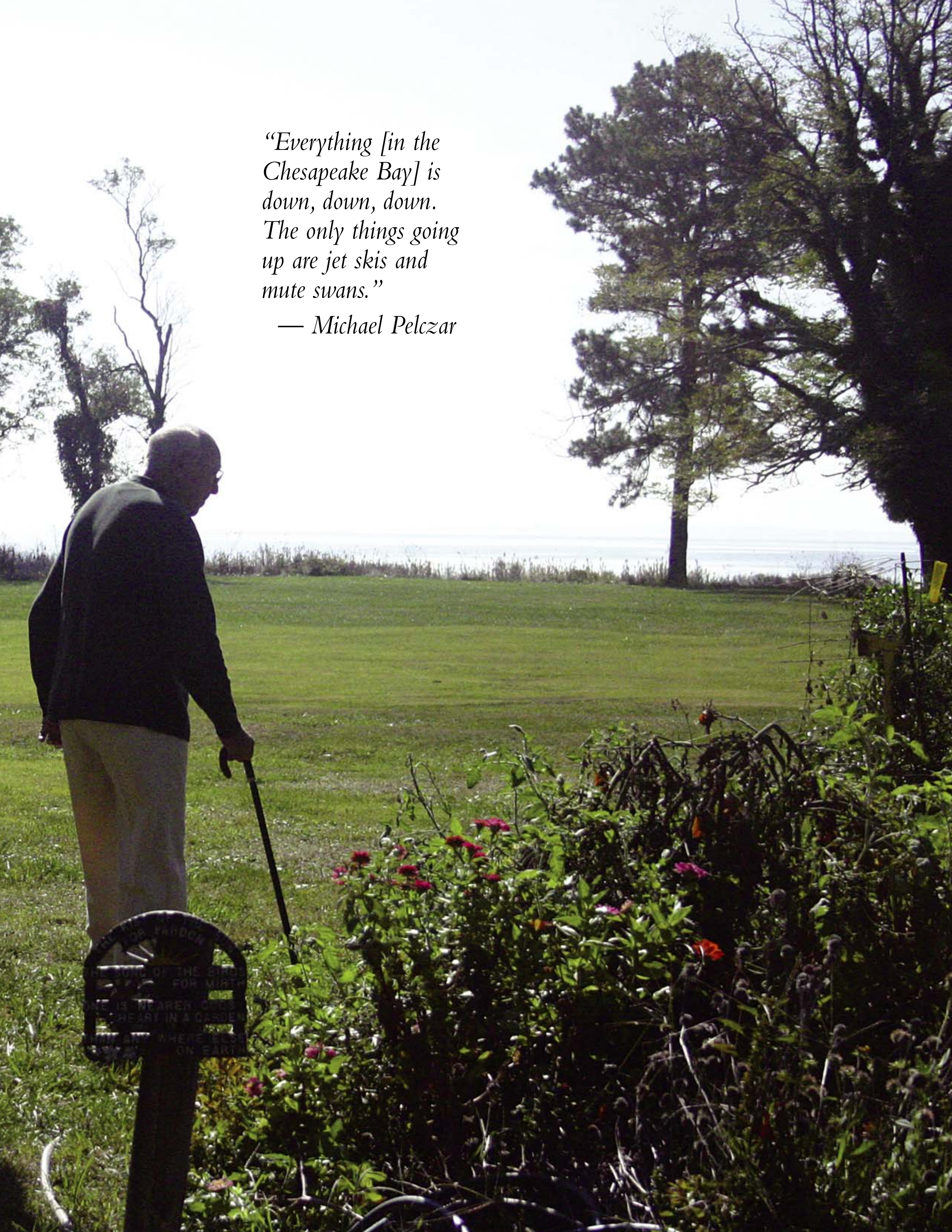
Deciphering the mystery of how coastal ecosystems work demands a lens that captures the flow of rivers, the push of tides, and the force of winds that move water masses across the shallows — all converging to initiate the plankton blooms that drive the Chesapeake's ecosystem. Capturing this complexity demands broad approaches and observations from buoys, ships, and satellites, and methods that can integrate all these streams of data into a coherent picture.

The mysteries of the microscopic world play out on a much smaller scale. Understanding microbial ecosystems and the staggering diversity of microorganisms that transform nutrients, metabolize oxygen, and perhaps cause disease requires a different lens. The tools to capture this complexity have evolved from petri dishes, to mass DNA sequencing, to the newest molecular probes and sensors that the biotechnology revolution can offer. The data that stream from these tools are equally complex and abundant, demanding new approaches for organization and analysis.

There is a need to unify science at these apparent extremes of ecological organization. Looking forward to advances in the science of ocean and coastal observation and progress in applying molecular tools to illuminate the microbial world, it's clear that we are on the verge of understanding the Chesapeake Bay in ways that we could not imagine in the 1970s. That understanding will come, when it does, because of the creativity, drive, and foresight of scientists like those featured here.

Three decades in the lifespan of a Sea Grant program is considerably longer than the blink of an eye. Moving in parallel with the growing wealth of scientific understanding about the Bay, Maryland Sea Grant has worked to keep pace with the changing needs of our stakeholders. Looking back from the vantage of our 30th anniversary, our focus on translational research — research that builds from discovery to application, joined with a commitment to engagement and education — remains as relevant today as it was at the program's inception. In the coming decades, when population growth along the coast and throughout the watershed collides with the impacts of climate change, we'll need strong science, innovative outreach, and active engagement if we are to navigate toward a more sustainable future. As we look toward the next thirty years, all of us at Maryland Sea Grant look forward to playing our part.

— Jonathan Kramer
Director, Maryland Sea Grant



"Everything [in the Chesapeake Bay] is down, down, down. The only things going up are jet skis and mute swans."

— Michael Pelczar

From Microbes to Mute Swans
Evolving Portrait of a Changing Bay

By Erica Goldman

At the end of a long driveway, flanked by fields of wheat-colored grass, Michael Pelczar walks towards the house and ushers two energetic Chesapeake Bay retrievers into a fenced yard. He moves slowly, using his cane to hold open the door as he carefully makes his way up the steps and enters a brightly lit farm kitchen that smells of freshly roasted coffee. When he first started coming to this family farm more than half a century ago, the kitchen still had a dirt floor.

Today a modern picture window in Pelczar's living room frames a garden ripe with peppers and tomatoes. An intricate array of duck decoys lines the windowsill. The window also frames the Bay, which sparkles an almost healthy shade of blue in the forgiving light of early autumn. Pelczar has lived on Avalon Farm on Kent Island full-time now since 1984, moving down soon after he retired from 31 years as a scientist and administrative leader at the University of Maryland. Now in his mid-90s, he's watched and contemplated the Bay from this spot for more than 60 years.

A lot has changed in the waters off Avalon Farm since the 1940s. Underwater grasses grew so thick then that they tangled the seine the Pelczars cast to catch fish. On any given day in the winter, upwards of 30 oyster boats would work the patch of the Chesapeake known as Crab Alley Bay, as rich then in oysters as it was in crabs.

Witness to change, *microbiologist Michael Pelczar has watched the Bay's decline for 60 years from his vantage at Avalon Farm on the Eastern Shore. As a university administrator he worked hard to bring the tools of science to bear on the Bay's problems.* PHOTOGRAPH BY ERICA GOLDMAN.

The oystermen are gone. He hasn't seen a single boat in years. Only a few crab boats cruise Crab Alley. The invasive plant *Phragmites* has usurped the place of native cord grass. Once abundant diving ducks have all but disappeared. Just past the turnoff to Avalon Farm's long dirt driveway, cars pour down Route 50 in a steady stream and clusters of condos push up through the ground like mushrooms after a rain. Mute swans cruise the water under the Kent Narrows Bridge, indignant in their graceful, destructive beauty.

"Everything is down, down, down," says Pelczar. "The only things going up are jet skis and mute swans."

To Pelczar, the mute swan is a visible symptom of a sick Bay, of an ecosystem gone awry. This invasive species eats 10.5 million pounds of underwater grass each year, destroying habitat for waterfowl, fish, and shellfish. And underwater grass has a tough time bouncing back, with all the other problems in the Bay standing in the way — too much nitrogen, not enough oxygen, too much algae, not enough light. Burgeoning development, traffic, more sewage, more impervious surfaces, even more nitrogen. These are the harsh refrains of the Chesapeake's swan song.

Pelczar hears subtler sounds too, bringing the ear of his own scientific discipline of microbiology to his perspective on the Bay. He knows that many processes in the environment start with microbes — the tiniest of algae species, bacteria, single-celled protists, and even viruses. He knows that the Bay functions as an interconnected web spanning many orders of magnitude — from the tiniest microbe to the 27-pound mute swan and beyond. But he also knows that connecting the dots across scale and scientific discipline is no small matter.

If We Build It…

When Michael Pelczar joined the faculty of the microbiology department at the University of Maryland in 1946, the Chesapeake Bay Bridge connecting the Western and Eastern shores of the Bay would not be built for another six years. Although the population was on the rise after World War II, suburban development would not hit full force for another decade. Modern roads were just starting to shrink distances around the region, but much of the Bay still relied on slow ferry service.

Pelczar's own field of microbiology would soon see a major revolution. That year, 1946, saw the invention of the first large-scale electronic computer. Computing power that now fits in a wristwatch then filled a room. That same year, scientists first discovered that bacteria could exchange genetic information with each other in a form of sexual reproduction known as conjugation — a discovery that would lay the groundwork for genetic engineering. Scientists would also realize that it is DNA that acts as a transforming

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UM Center for Environmental Science

***Teacher and researcher** in the microbiology department (top), Michael Pelczar shaped plans to rebuild the microbiology building in February 1963 (middle). His vision for Horn Point Environmental Laboratory (now HPL) came to fruition in 1973 at the groundbreaking ceremony for the oyster hatchery (bottom, Pelczar in white suit, far right).*

agent in cells, but it would be another seven years before James Watson and Francis Crick would unravel its famed double helix.

The degree of technological advance and the extent of change in the Chesapeake watershed fated for the next half century were perhaps inconceivable when Pelczar first began his career at the University of Maryland. But he soon recognized that the organization of the scientific enterprise would have to keep pace as the scale of information grew.

To study a place like the Chesapeake Bay, he realized, would take capacity, expertise from multiple disciplines and across varying scales of organization — from microbiologists to oceanographers. Pelczar's administrative vision soon gained recognition within the University of Maryland. In 1966, he became the Vice President of Graduate Research. From this position, Pelczar helped to shepherd several key administrative changes in the scientific landscape of the Chesapeake region.

Most research grants from University of Maryland researchers began to make their way across Pelczar's desk. He soon realized that Bay science was diffuse and fractionated. The Smithsonian Environmental Research Center, Johns Hopkins University, the University of Maryland, and Virginia Institute of Marine Sciences were all major players in the region, but no central body existed to coordinate these efforts.

One day Pelczar fielded a call from the director of the National Science Foundation (NSF). "No more funding for separate institutions to study the Chesapeake Bay. Put together a single program to identify regional priorities." This was the mandate handed down from NSF. The directive resulted in the creation of the Chesapeake Research Consortium (CRC), Inc., a nonprofit corporation chartered by the State of Maryland. The consortium, which now comprises an association of six institutions, provided an umbrella for Chesapeake science, one under which collaborations between institutions could begin to grow in a more integrated manner.

With the CRC in place as a foundation, Pelczar continued to work to build capacity at the University of Maryland for studying the Chesapeake Bay through an interdisciplinary lens. When the city of Cambridge approached the University in 1970 with a proposal to build an Eastern Shore campus on the old Horn Point estate of Francis du Pont, Pelczar chaired a university-wide committee to decide what that new campus should look like. The committee developed a proposal to create the Horn Point Environmental Laboratory (HPEL), now Horn Point Laboratory (HPL).

Pelczar's vision for Horn Point grew from the need to bring scientists from different disciplines to a central place to study the Bay, from oceanographers to biologists to chemists. According to the proposal Pelczar helped author, Horn Point would serve as the administrative home for a new Center for Environmental and Estuarine Studies, which would bring together university-based efforts to study the Bay.

There is "a unique opportunity to create something new and different at Horn Point," Pelczar wrote in the proposal. "The physical and the intellectual resources are clearly available. What remains to be seen is if we have the institutional will to redirect these resources to meet real problems of real people."

Together Horn Point and the Chesapeake Research Consortium boosted the capacity for environmental science in Maryland, creating a platform to go still further. For Pelczar, the next step would be to resume planning efforts to bring a Sea Grant program to the University of Maryland, a process that had begun in 1970 but was displaced by efforts to start up the Chesapeake Research Consortium and the Center for Environmental Studies.

Pelczar helped shape a proposal to the National Sea Grant office based on the need to solve the problem of the declining oyster population in the Bay. Recognizing the growing capacity in Maryland to apply marine science to real world problems, the National Oceanic and Atmospheric Administration awarded the University of Maryland Sea Grant Program status in 1977. Pelczar tapped fellow microbiologist Rita Colwell, a colleague at the University of Maryland who shared his vision for interdisciplinary research, to become Maryland Sea Grant's founding director.

In 1977 the Chesapeake Bay was already a changing place. The floodwaters of Tropical Storm Agnes in 1972 had tipped the balance, transforming the Bay from a state with clear waters and abundant underwater grasses to one overrun by algae. Oyster populations were down, while human populations soared. Environmental consciousness was also on the rise, the result of a growing understanding that humans were having an impact on the environment.

That same year, the Environmental Protection Agency commissioned a Bay-wide study to uncover reasons for the Bay's decline, a study that would take six years to complete. With the added capacity and coordination brought to the region by the Chesapeake Research Consortium, Horn Point Environmental Laboratory, and Maryland Sea Grant, the scientific community was better poised than ever before to confront the Bay's problems — problems that seemed to increase in complexity every day.

Embracing Complexity

At the end of a long hallway that smells of fresh paint, Rita Colwell's office in the new center for Bioinformatics and Computational Biology at the University of Maryland is one of the only occupied offices on the floor. Most of her boxes are unpacked, save a few stacks of journal reprints. A bowl of fruit and miniature Oreos on the table in the middle of her office invite visitors to make themselves at home. Pictures of Colwell's children and grandchildren sit on a bookshelf under the window, next to a picture of herself with former president Bill Clinton. Diplomas and honorary degrees hang next to simple canvas artwork that looks like it was collected overseas. Three hard hats sit high on a shelf, souvenirs of various ground-breaking ceremonies — one from the University of Maryland Biotechnology Institute, where she served as founding director and president, one from the Christopher Columbus Center, which she helped create, and one from the American Association for the Advancement of Science, where she served a term as president.

Colwell is at home in the new center, one dedicated to multidisciplinary research on questions arising from the genome revolution, a revolution in scientific thought that's been 30 years in the making. It seems a logical fit for the road she's traveled. The center aims to bring together scientists and

University of Maryland College Park

Michael W. Fincham

Pioneer in marine microbiology, *Rita Colwell became the founding director of Maryland Sea Grant in 1977. She would go on to build infrastructure for science in Maryland and beyond, as founding director and president of the University of Maryland Biotechnology Institute and later as the director of the National Science Foundation. Her groundbreaking research showed that microbes like* Vibrio cholerae, *which can cause cholera, thrive as part of the natural ecology of estuarine waters.*

engineers from many fields, including computer science, molecular biology, genomics, mathematics, statistics, physics, and biochemistry to answer questions about the complexity of the biological world. This crosscutting approach resonates at her intellectual core.

When Colwell became director of Maryland Sea Grant in 1977, the idea of mounting research efforts across departments was just beginning to gain traction. So was the intellectual challenge of understanding the world at varying scales. Both ran counter to traditional reductionist science, which distilled systems down to their smallest parts. Within a few years, ideas such as the Gaia hypothesis would popularize the notion that living and nonliving parts of the earth operate as a complex interacting system.

Scientific discovery had also begun to penetrate new levels of observation, especially the molecular realm. 1977 ushered in a new era of understanding the microbial world and how it functions. That same year, scientists discovered life at deep-sea hydrothermal vents, thousands of meters beneath the ocean's surface, revealing a strange new world fueled by sulfur-breathing bacteria. The first method to sequence DNA also came online that year. And for the first time, a human protein was produced inside bacteria, which proved the start of the field of genetic engineering. New companies focused on molecular approaches began to sprout like weeds. Many cite 1977 as the "Dawn of Biotechnology."

But for Colwell, a sense for the complexity of biological interaction and the need for integrative approaches to study them predate this new era by many years. She remembers spending unstructured summer days as a child near Beverly, Massachusetts. These were the kind of days that kids rarely experience anymore, where she "would pack a lunch, go out on the beach, and come back by dinnertime." She recalls storms that roared through and left her wondering how the beach, with all of its life and structure, could rebound from such an insult.

The marine environment would come to exemplify to Colwell "the origin or protection of life on earth, or both." She developed her research program in marine microbiology at a time when the very field was in its infancy. Gravitating towards interdisciplinary questions, she sought to apply tools of yeast genetics to microbes from the marine environment. She was immediately impressed by the complexity of the coastal and estuarine habitat. And microbes, she thought, might hold clues to what makes the marine environment either resilient or vulnerable to change, an idea ahead of its time.

Microbes, she thought, might hold clues to what makes the marine environment either resilient or vulnerable to change.

"Microbes allow us to look at populations and derive fundamental principles that we couldn't before," she says. When she completed her graduate work at the University of Washington in Seattle in 1960, Colwell was one of just a handful of scientists working in the field.

Colwell's own research program merges her interest in microbes with her passion for understanding the complexity of the biological world, taking her all the way from the Chesapeake Bay to Bangladesh, from microbial ecology to human health. She studies the marine bacterium *Vibrio cholerae*, which can cause the disease cholera. What started in 1970 with the discovery in the Chesapeake that the bacteria that causes cholera is a natural inhabitant of brackish water environments — one which associates with shrimp-like copepods — evolved into a paradigm for studying the environmental conditions that can lead to cholera outbreaks worldwide. The integrated framework that ultimately emerged from her work provided the tools to predict and control pandemics of cholera in regions like Bangladesh, where the disease is endemic. It can also help predict how environmental changes like global warming might impact epidemics of the disease.

That a microbe with a reputation for causing virulent disease could occur naturally in a marine ecosystem proved a major sea change in thinking. Some had argued that airplanes that dumped their lavatory waste while in flight were spreading cholera. The fact that *Vibrio cholerae* functions as a natural part of many estuarine systems issued a challenge to scientists to look at the microbial world through a new lens, one that until recently belonged more comfortably to ecologists that study the world on macro scales. And as the tools of molecular genetics started to become available, the ability to explore these kinds of ecological questions on the microbial scale became like "opening a Venetian blind," Colwell says.

Colwell's vision of the inherent complexity of the marine environment also provided a frame through which she approached the problems faced by the Chesapeake Bay. Sea Grant in particular, according to Colwell, provided a unique opportunity to apply basic science to address real world problems. "Sea Grant will provide us the best of both worlds: we can enlarge the scope of our scientific inquiry to include those events governing the estuarine ecosystem while simultaneously seeking solutions for the Chesapeake Bay," she wrote in 1977.

To understand why oysters and crabs are diminishing in numbers, she articulated, "we must learn more about the species we are harvesting, about the chemicals, wastes and materials discharged into the Bay. . . ." Questions about basic biology, physiology, and ecology were of utmost importance to Colwell. For example, in order to understand how waste discharges might affect oyster populations, she believed that it would first be necessary to understand the basics of oyster reproduction and larval settlement.

The earliest projects funded by Maryland Sea Grant reflected Colwell's vision for understanding how a system functions in order to drive the discovery

■ *New Research*

Biocomplexity and the Bay

Nitrogen. In the Chesapeake, it has become the element we love to hate. But this leading cause of the Chesapeake's problems also serves as an essential nutrient for the growth of the plants and algae that form the base of Bay's food web.

In a delicate balancing act, different chemical processes enable nitrogen in the Bay to change form as it moves through the ecosystem. Understanding the nature of these transformations can help clarify how and why too much nitrogen can become a problem. Measuring different forms of nitrogen in the environment has provided key information about when, where, and how fast these different processes occur.

Without microbes, key chemical transformations of nitrogen would not be possible. Different communities of bacteria shepherd different stages of biochemical processes, using nitrogen to meet their metabolic needs. Of these bugs, of their ecological habits and their genetic makeup, scientists still know very little.

Making connections across scales of observation — between genetic function, microbial ecology, nutrient transformation — clearly requires expertise from multiple disciplines.

The time for such an effort seemed right in 1998, when molecular biologists Bess Ward from Princeton University, Mary Voytek from the U.S. Geological Survey in Reston, Virginia, and Jon Zehr at the University of California Santa Cruz, approached sediment biogeochemist Jeff Cornwell and physiological ecologists Pat Glibert and Todd Kana at Horn Point Laboratory, part of the University of Maryland Center for Environmental Science. The ambitious "Biocomplexity of aquatic microbial systems" project was born.

The goal: to use molecular tools to assess the diversity of microbes associated with the Bay's nitrogen cycle. The team would target the genetic makeup of these bugs across a broad geographic gradient, from the Bay's Choptank River all the way to the Sargasso Sea in the open Atlantic. That gradient moves from waters with too much nitrogen to waters with very little. Along the way researchers would ask questions about the relationship between complexity in microbial communities and the physical and chemical factors in the environment around them.

Funding for this effort came from the National Science Foundation's Biocomplexity in the Environment program in 2000. This funding initiative, launched by Rita Colwell at the beginning of her tenure as NSF director in 1998, was designed specifically to bring together scientists from different disciplines to address complex environmental problems. Armed with new molecular tools and a new framework, the team set out to make cross-scale connections about the role that microbes play in the Chesapeake's nitrogen cycle. It was not always smooth sailing. The molecular biologists and the estuarine ecologists had to learn each other's languages — at times a real communication challenge. And the original molecular approach proposed to evaluate microbial diversity, using gene chips (also called DNA microarrays), turned out to be less of a "wonder technique" than expected for this application, says Voytek.

But some tantalizing results have begun to emerge from the project, which is just wrapping up this year. For example, the team found across the board that the genetic diversity of the microbes involved in the nitrogen cycle was much higher than expected. "We were really stunned at the microdiversity," says Voytek.

That high genetic diversity showed up in the gene responsible for nitrogen fixation, she says. Nitrogen fixation, which takes nitrogen gas from the environment, is a metabolically expensive way for bacteria to get nitrogen, she explains. Nitrification, which uses nitrogen in the form of ammonia, and denitrification, which uses it in the form of nitrate, are less costly. If these other forms of nitrogen are readily available, which they almost always are in the Bay, any process besides nitrogen fixation would be cheaper from an energetic standpoint. "We hypothesized that we would only find the ability to fix nitrogen in environments that were poor in nitrogen, not in places like the nitrogen-rich Choptank River," says Voytek. The idea that microbes were "efficient and frugal" with their genetic material — that if they didn't need to perform a process, they would lose the ability to do it — proved wrong in this case.

Another surprise came from the nitrifying bacteria, says Voytek. The only thing these bugs do is oxidize ammonia to make nitrate, she says. One would expect to find high diversity in the Choptank River, which did prove to be the case, because ammonia levels fluctuate dramatically due to fertilizer input. But genetic diversity also measured quite high in the Sargasso Sea, where the environment is stable with respect to ammonia concentration.

From the other side of the equation, some interesting patterns are also beginning to materialize, says researcher Jeff Cornwell. When we measure high rates of denitrification in the sediment, we almost always find a rich and diverse community of microbes, he says. These are the early stages of trying to connect "who is out there to what is going on."

This synthesis of molecular and biogeochemical techniques applied to study microbes in their environment is still in its infancy, agrees Voytek. "I can't tell you yet how to make the Bay healthier from what we've done." Right now, she says, more traditional approaches such as measuring rates of sediment erosion will tell managers more about the potential success of restoration efforts than evaluating the structure of microbial communities. But understanding how microbes function in the ecosystem to modulate the Bay's water quality could prove important in the future, she says, especially as we anticipate changes in the Bay's water cycle in response to climate change. This approach to biological complexity, Voytek says, linking microbial genetic diversity to ecosystem function, is definitely where research needs to go.

— *E.G.*

What Is Biocomplexity?

Design by Sara Raimo, National Science Foundation

What does biocomplexity as a concept really mean? According to researcher Todd Kana, a scientist at Horn Point Laboratory, it means that there's something about a biological system, like the ecology of the Bay, which cannot be explained by a simple sum of its parts. "It's what happens when you add biology with its unpredictable nature to a physical system," he says.

And the complexity part comes in, adds researcher Pat Glibert, in the range from molecules, to elemental cycling, to the shape of an ecosystem's structure. "It is a scaling issue — from molecular to community-level scaling," she says. Shown at left is a part of the image developed to provide a graphic identity for the biocomplexity initiative at NSF launched by Rita Colwell.

Is biocomplexity something new? "In a sense, we have always studied biological interactions and questions of scale," says Kana. "But understanding how biology drives the complexity of a system is something new."

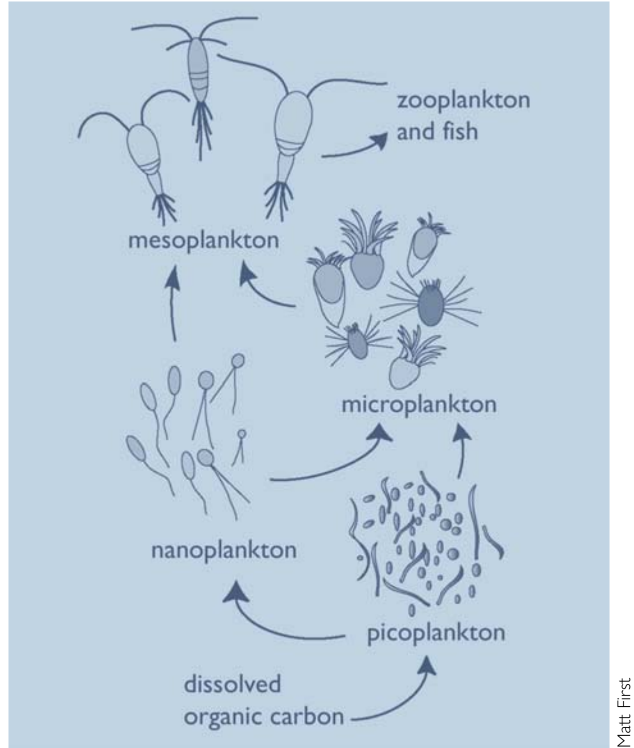
of applied solutions to environmental problems. Projects funded ran the gamut from a study investigating the microbial indicators of water quality to recruitment dynamics of blue crabs to the development of collection devices for oyster spat. Colwell also set a tone for rigorous peer review that carries through to the present day. "I got accused of setting up a mini-NSF," she says, with no irony despite the fact that she did go on to serve as the director of the National Science Foundation (NSF) from 1998 to 2004.

Strong basic science, bolstered by the emerging tools of biotechnology, could help uncover the mechanisms behind the Chesapeake's decline, according to Colwell. And scientific efforts that could transcend disciplinary boundaries would be key. Where would the major breakthroughs about the Bay's health originate? What scales of observation would prove most informative? As it had with Colwell's cholera discovery, would unraveling the complexity of the Chesapeake's microbial realm aid in the Bay's recovery?

Microbes Rule

Michael Pelczar leaves the kitchen table and heads for his home office in the next room. His desk is piled high with papers and, like Colwell's office, the walls are covered with photographs and diplomas. Pictures of each of his six children, grandchildren, and great-grandchildren hold places of honor. He returns to the table carrying a copy of the textbook *Microbiology*. Pelczar first authored and published the book in 1958. He's updated it over the years as the field has changed, publishing the most recent edition in 1986. The book has become a classic in undergraduate courses. Now colleagues in India want to carry the torch. Pelczar's book sold over 29,000 copies there in 2006 and publishers have recently contacted him for advice on updating it again. "Let me take this opportunity to convey my heartfelt appreciation for the wonder that your text on microbiology is," begins the note from publisher McGraw-Hill, Inc.

One of the major breakthroughs in the field of marine microbiology that Pelczar had not been able to capture in the first edition of his book was the discovery of the so-called microbial loop in marine food webs, a paradigm-shifting change that began to gather momentum in the mid-1970s. Selected by NSF as one of the landmark discoveries in ocean sciences in the past half century, the emerging concept of the role of microbes in the open water (pelagic) food web upset the commonly held belief that phytoplankton, zooplankton, and fish were the major players.



The discovery of the microbial loop *revealed the key role that bacteria, picoplankton, micrograzers, and viruses play in directing nutrients through marine systems. This paradigm shift was selected by the National Science Foundation as one of the major breakthroughs in 50 years of ocean sciences.*

Questions about whether the marine food web is actually microbe-centric began in the early 1970s with work by Tom Malone, now at the University of Maryland Center for Environmental Science, who introduced the notion that very small plankton (picoplankton) and micrograzers might be playing an important role in the food web (see "Thinking Deeply about the Shallows," p. 12). A prescient paper published in 1974 by ecologist Lawrence Pomeroy at the University of Georgia receives credit for propelling the microbial loop into the limelight. In his paper, "The ocean's food web: A changing paradigm," Pomeroy posed a series of questions about the marine food web. He asked whether single-celled grazers (protozoa) played an important role as consumers of other microorganisms in the food web and as recyclers of dead matter. He questioned whether microbes, more than any other group of organisms, might carry out the bulk of the cellular respiration in the food web, using oxygen to make energy to live.

But the answers to Pomeroy's questions would not be possible until two technological breakthroughs took place. The first came in 1977, with the invention of a fluorescent staining technique that permitted rapid counting and discrimination of bacteria, protozoa, and phytoplankton. The second, flow cytometry, a technique which uses laser light to count, examine, and sort microscopic particles suspended in a stream of fluid, came in the mid-1980s. Flow cytometry enabled the discovery of a novel microbe (a picoplankter, so-called for its size range of 0.2 to 2 microns) that would prove to be the most abundant photosynthesizer (autotroph) in the world.

Understanding the complex role that microbes play in marine food webs like the Chesapeake's was a major advance in basic science. This discovery would help map the flow of energy through the Chesapeake Bay's food web and show how microbes could shunt energy away from larger organisms like fish, crabs, and birds to feed their own metabolism. By inserting the concept of the microbial loop into the Bay's food web, scientists

Erica Goldman

Outspoken in his beliefs, *Michael Pelczar has spent a lifetime devoted to the discipline of microbiology and to his home waters of the Chesapeake Bay. Author of the widely used textbook* Microbiology, *he has watched microbes like the parasite MSX destroy oysters. But he also knows that other microbes can fix nitrogen, degrade organic matter, and help maintain the health of the Bay.*

For More Information

50 Years of Ocean Discovery: National Science Foundation 1950-2000
books.nap.edu/openbook.php?record_id=9702&page=9

Bay Journal article on the microbial loop
www.bayjournal.com/article.cfm?article=1341

National Research Council report on metagenomics
books.nap.edu/catalog/11902.html

Sorcerer II Expedition
www.sorcerer2expedition.org/version1/HTML/main.htm

Marine Biotechnology in Maryland (video interviews)
www.marinebiotech.org/md.html

would learn how to connect the dots between excess nutrients like nitrogen, algal blooms, and low oxygen conditions (hypoxia) — filling out a picture for how microbial demands for oxygen would pull it away from fish and the tiny animals that they eat (zooplankton).

The current hypothesis: Excess nitrogen fuels more algal growth than can be eaten by zooplankton, fish, oysters, and others. When the algae dies and sinks to the bottom, it becomes food for microbes — populations of single-celled protozoans and bacteria that comprise the microbial loop. The microbial population grows in response. Since small organisms have faster metabolisms than large organisms — a pound of bacteria consumes more oxygen than a pound of fish — microbes can suck oxygen away from larger organisms.

Today, the identity of most of the microbes in the microbial loop remains a mystery. In fact, some 90 percent of the microbial world is still believed to be unknown to science. And approaches that can go the next step to connect specific microbes to their function in the food web are still in their infancy (see "Biocomplexity and the Bay," p. 9). But not for long. The *Sorcerer II*'s journey of microbial exploration, led by the J. Craig Venter Institute, recently started publishing the findings of a trans-oceanic voyage of discovery meant to recreate the expedition of Charles Darwin's *HMS Beagle*. Researchers sampled the ocean in 41 locations, isolating and subsequently freezing bacterium-sized cells. They also recorded the temperature, salinity, pH, oxygen concentration, and depth. So far their efforts have turned up over 400 novel species of microbes able to make millions of proteins that were previously unknown to science.

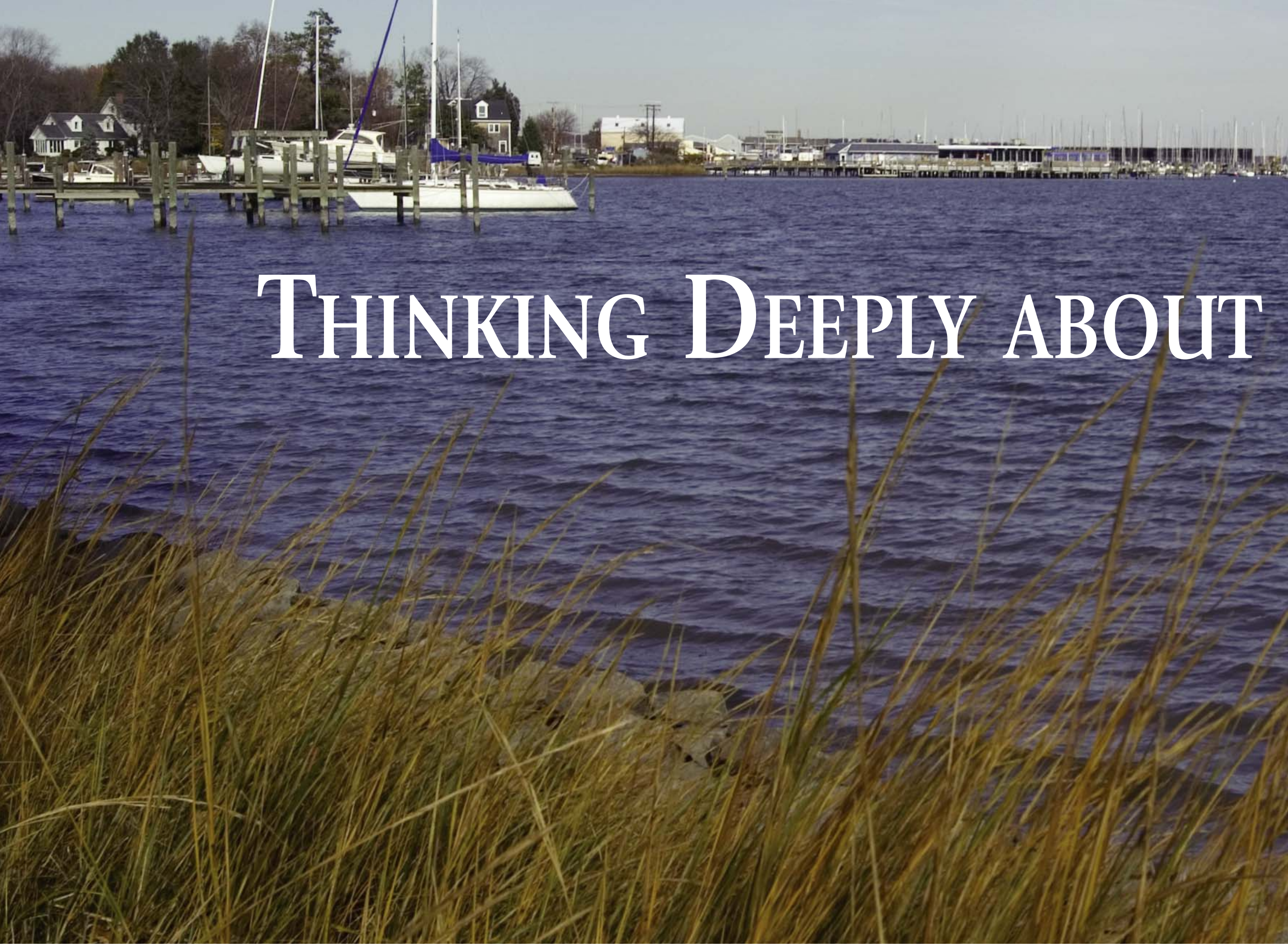
As in the 1970s, microbiology once again may be poised on the cusp of revolution. In March 2007, a new report from the National Research Council stated that the emerging field of environmental genomics (metagenomics), where the DNA of entire communities of microbes can be studied simultaneously, presents the greatest opportunity — "perhaps since the invention of the microscope" — to revolutionize understanding of the microbial world.

As 1977 was dubbed the dawn of biotechnology, will 2007 begin an era of microbial rule?

Back at the kitchen table, Pelczar opens *Microbiology* and prepares to autograph it. He adjusts his thick glasses and flips past the Table of Contents, pointing to the beginning of the book's Preface. It opens with his favorite quote by Louis Pasteur, one of the founding fathers of microbiology. "Messieurs, c'est les microbes qui auront le dernier mot." Or "The microbes will have the last word."

Most still don't look at the problems of the Chesapeake and think about microbes orders of magnitude smaller than the eye can see. But what if Pasteur proves right? What if microbes do have the last word to say about the Chesapeake Bay? Will we be ready to hear what they are saying?

— *email the author, goldman@mdsg.umd.edu*



Thinking Deeply about

The setting sun shoots light straight down the West River. Autumn's last leaves ignite all along the shore. Summer is ending on this quiet western shore river just south of Annapolis.

It should have been a better summer.

With drought conditions sending little runoff into the river all summer long, the waters should have looked cleaner, clearer. Instead, warm weather brought an unwanted crop of algae blooms.

"I've never seen so many mahogany tides," says Bob Gallagher. Gallagher is the riverkeeper for the West River and Rhode River. He oversees a team of citizen monitors to watch water quality and to look out for the rivers' health. One thing he doesn't want to see is a mahogany tide — a reddish-brown algal bloom that can cause fish kills.

For the past couple of years Gallagher and his team have measured the vital signs of these two rivers — oxygen levels, bacteria, suspended sediment. They also consult data collected by the Maryland Department of Natural Resources and others, including the Smithsonian Environmental Research Center and the National Oceanic and Atmospheric Administration.

For Gallagher, this summer raised questions that the data don't seem to answer. "This was a strange summer," he says. In particular, they expected to see clearer water because of the drought. "That's not the way it turned out," he says. Even though dissolved oxygen levels were slightly better than the year before, the water was cloudy, and there were those worrisome mahogany tides.

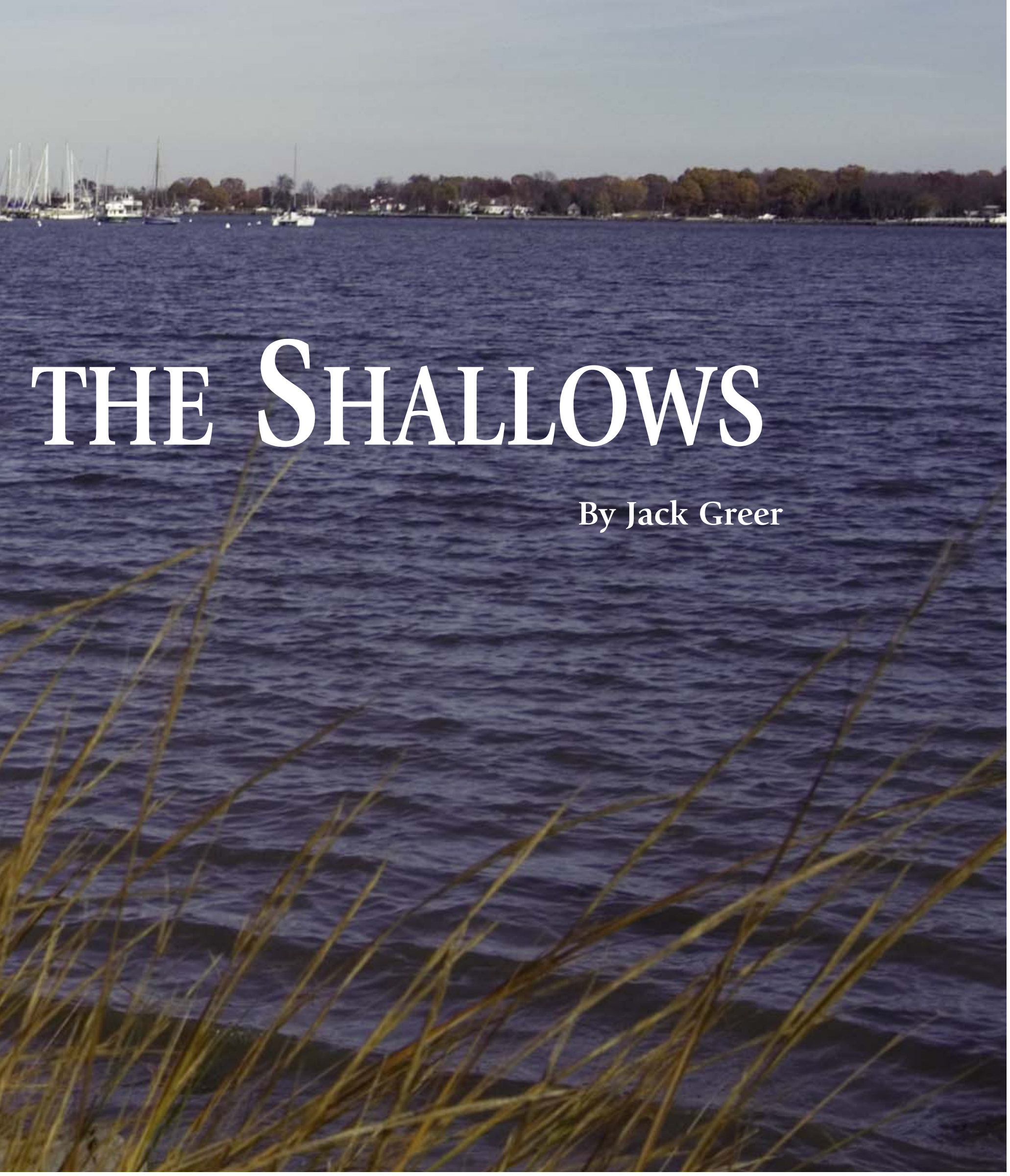
With so little runoff, why didn't the rivers run a little clearer in the summer of 2007? Where did all those algae come from — not only in the main Bay, but in the shallower water of the tributaries? Why wasn't it a better summer?

Thirty years ago we could not have answered these questions. Can we answer them now?

The Productivity Puzzle

Tom Malone looks out the window of his 12th story office in Silver Spring, Maryland. Behind him loom other steel-and-glass office towers wrapped with dark windows, as if the buildings themselves were wearing sunglasses.

He swivels back to his desk and pokes at his computer's keyboard. He's trying to get on the network, and it's not working. He knows there's a sharp irony in this, given why he's here.



Sandy Rodgers

Malone, whose longish hair and beard are going gray, is a key figure in the fight for global advanced observing systems. He has taken time from his position as a university researcher to serve as the Deputy Director of Research for the National Office for Integrated and Sustained Ocean Observations. He's leading a charge to expand the nation's capacity to observe changes in the world's oceans and coastal waters, using buoys, satellites, ships, and underwater vehicles. He testifies before Congressional committees. He wrangles with policy makers and officials at every level. In about an hour he has a conference call with two admirals. And his computer's not working.

Last light of an autumn afternoon *settles on the West River. Gone are hot summer days that brought unlooked-for algae blooms and turbidity. Scientists are tracking water quality in the Bay's tributaries as never before to find out where all those algae come from.*

Malone's leg jiggles as he speaks. He seems in a hurry even when sitting still. There must be times when he wishes he were back on the water, doing the research that's been his life for more than thirty years.

Malone's career in oceanography began back in the 1960s working in the blue waters of the Pacific. There he studied the effects of nutrients on tiny floating plants called phytoplankton, from the equator to the California coast. He found that when currents brought up nutrients from deeper waters — known as upwelling — larger forms of plankton thrived. It is these larger forms that support food chains leading directly to fish. He was also among the first to discover the importance of very small phytoplankton (or picoplankton) in the ocean's overall productivity, something previously overlooked.

During this period, Malone saw that to understand how marine food webs work as part of the earth's carbon cycle meant understanding how ocean physics and biology interact. And to do that required close observations — at least once a month, he says, or more often if possible. That posed a challenge in the open ocean.

Malone had a chance to get closer to his subject when he accepted his first academic appointment back East, at the City College of New York. There he started a research program on the Hudson River estuary and the coastal waters of the New York Bight. In these shallower waters he could study how phytoplankton respond to nutrients from human sources — mostly from sewage discharge. He could observe up close how they move through the estuary and onto the continental shelf.

Here in the shallows Malone discovered the delicate dance of nutrients, phytoplankton, and estuarine currents that leads to the summertime loss of oxygen. With this new understanding he was able to show, for example, that a harmful algal bloom that developed over several months and spread over the entire New York Bight was not caused by nutrients from sewage discharges, as many assumed. Instead, it was fed by an unusual circulation pattern that brought nutrients into the Bight from deep waters of the North Atlantic.

He had turned his training as a blue water oceanographer toward the shallows.

Malone first came to the Chesapeake in 1983 after persuasive conversations with a gregarious Welshman named Ian Morris, then President of the University of Maryland Center for Environmental and Estuarine Studies (now the UM Center for Environmental Science, UMCES). Part of the attraction, he says, was that Morris was also wooing a physical oceanographer named Bill Boicourt.

Here was another researcher interested in how physics and biology interact to shape shallow-water ecosystems.

That Morris recruited a biological and a physical oceanographer at the same time was no accident. In addition to their individual accomplishments, Morris saw in them the future of estuarine science. He saw the importance of understanding how circulation patterns and mixing affect the Bay's biological productivity — especially of phytoplankton — and how this in turn determines how too many nutrients affect the health of the Chesapeake.

Understanding these interactions could help explain why algal blooms occur in some places and not in others, why they would occur in some years more than others. Even in a dry summer.

The Chesapeake's Algae Factory

Malone stares at his computer screen as if he could see the past recaptured. When he first arrived in Bay country, he could not have foreseen that he would become interim President of UMCES after Morris' tragic death in 1988 at the age of forty-nine. That he would become the Director of the Horn Point Laboratory in 1990 — a position he held for 12 years. That he would step down from that post to work on an integrated observing and prediction system for the oceans, here on the 12th floor of this high-rise office outside Washington, D.C.

When he first came to the Bay, Malone spent time on the water. He and his colleagues — like Michael Kemp from UMCES and Tom Jones from Salisbury State University — motored back and forth across the Bay every week on the 25-foot research vessel *Osprey*. They ran a zig-zag course from the Eastern Shore to the Western Shore as they worked their way from the Bay bridge at Kent Island down to the mouth of the Patuxent River. Their zig-zags were deliberate. The measurements they took were meant to provide a new dimension for understanding how the Bay works.

In contrast to prior research on the Bay that focused on changes occurring along the axis of the main stem, this effort focused on shifts that occur laterally from shore to shore. Their work showed that water sloshes back and forth between the Eastern and Western shores as water flows up and down the main axis. This led to the discovery that nutrients and oxygen-depleted bottom water from the main channel can slop into shallow waters, stimulating phytoplankton production and causing fish kills during the summer.

Their work got a major boost in

Skip Brown

Filling the gaps in ocean observing systems, *researcher Tom Malone takes time from his post at the University of Maryland Center for Environmental Science to build a national program. Widely known for detailing links between nutrients, algae, and oxygen, he now works with the Intergovernmental Oceanographic Commission to integrate observing and prediction systems.*

1985, when federal funds came through for a five-year research initiative to determine why bottom waters in the Bay lose oxygen (become anoxic) during the summer. Managers and others wanted to know what determines the timing and extent of that anoxic zone. The program, administered by the National Oceanic and Atmospheric Administration and the Sea Grant programs of Maryland and Virginia, directed researchers to study the very processes that intrigued Malone and his colleagues. Precisely what mechanisms drive the disappearance of oxygen during the summer months? How much of this is natural and how much is manmade? Is it getting worse and, if so, why?

The results of this work were captured in a landmark book, *Oxygen Dynamics in the Chesapeake Bay* (see "A Classic Text," below right). Among other findings, the study determined that most of the Bay's nutrient load comes during the winter and spring when river flows and runoff from the land are high — and long before the seasonal onset of oxygen depletion in bottom waters of the Bay. Come spring, as water temperatures and sunlight increase, algae production kicks into high gear. As the waters warm, algae soak up light, drink in nutrients, and bloom.

This spring bloom is nothing new — it's been going on for thousands of years. But because so many nutrients now wash into the Bay from human sources — some six to eight times the amount of nitrogen of pre-Colonial times — the amount of biomass that accumulates during the spring is enormous. It exceeds the capacity of the Bay's herbivores — everything from oysters to menhaden to copepods — to eat it. Most of this algal biomass sinks to the bottom. There bacteria populations explode as they metabolize this organic matter, a process that sucks oxygen from the water.

Malone and his colleagues were able to show that summer anoxia is related to the accumulation of phytoplankton in the Bay during winter and spring (when grazing rates by herbivores are low). They showed that the amount of biomass that accumulates depends on the size of the nutrient load. The bigger the nutrient load, the bigger the spring bloom. Says Malone, "That makes estuaries like Chesapeake Bay particularly sensitive to human activities in their watersheds."

Meanwhile, all through the warmer months, more nutrients enter the Bay and those that came in during winter and spring recycle. All summer algae bloom, fall to the bottom, and decay. As they break down, they release more nutrients to feed more algae blooms.

Malone and his fellow scientists found that the Bay and its rivers had become a remarkably efficient algae factory.

Turning to the Shallows

Long shallow shoulders run along the edges of the Bay's main channels, the hidden history of sea level rise over the past fifteen centuries. The shallows reach into countless tributaries, where depths may drop to only a few feet or disappear altogether as tidal flats go dry twice a day. Writers have called it skinny water. The Bay is nothing if not skinny.

It is in the shallows where underwater grasses once grew in abundance, where oyster bars flourished.

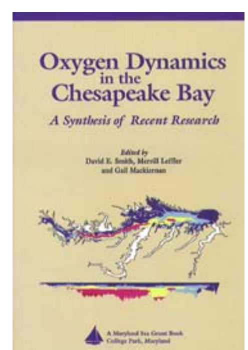
And yet most of the monitoring that informs our picture of the Bay has tested deeper waters. Tom Malone realized this when he first set his zig-zag course back and forth across the Bay. So did Walter Boynton. Boynton, an ecologist, always had a special interest in the Bay's small coves and backwaters. Working out of the UMCES Chesapeake Biological Laboratory in Solomons Island, he studies nutrient dynamics and the health of sediments. He's found that he can learn a lot about the quality of the water by studying the health of the sediments lying beneath them.

In waters as shallow as those of the Chesapeake, the link between bottom and top is strong. In the shallows, nutrients in the sediment lie close to the surface. This puts nutrients nearer algae as they float beneath the surface, using light for photosynthesis. In shallow water, dying algae don't have far to sink before gathering on the bottom, where they decompose, releasing more nutrients. And with less volume than deeper waters, the shallows tend to concentrate algal blooms. On the other hand, oxygen can reach the shallows more quickly than in deeper water, and, when waters are clear enough, rooted plants can grow in the shallows and still see the sun.

Things can change fast in the shallows.

With all this and more in mind, during the mid-1990s, ten years after the federal-state Chesapeake Bay Program launched its main monitoring effort, Boynton began a rigorous focus on shallow water monitoring. He used emerging technologies that allowed real-time or

A Classic Text



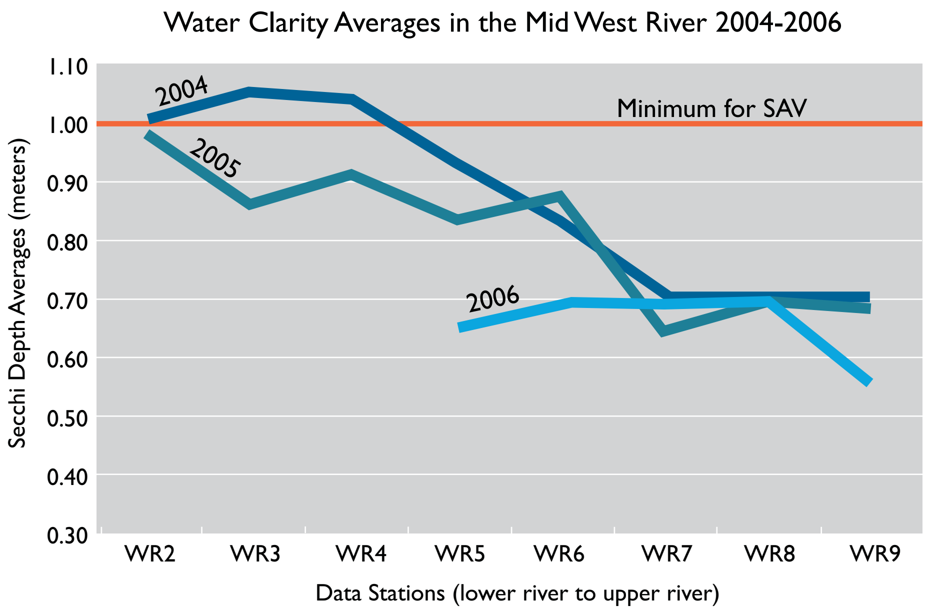
Understanding why the Bay gasps for air in the summer months has proved one of the major breakthroughs in Chesapeake science.

In 1985, the Sea Grant Programs of Maryland and Virginia teamed up with the National Oceanic and Atmospheric Administration to launch a five-year research effort focused on oxygen processes in the Chesapeake. The results of this work were captured in the 1992 book, *Oxygen Dynamics in the Chesapeake Bay*.

"This book is a classic," says Daniel Conley of Sweden's Lund University. Conley is now using the book to inform a similar effort underway in the Baltic Sea, which also suffers from too many nutrients.

"That book changed the way we look at the Bay," says longtime Bay researcher Larry Harding at the University of Maryland Center for Environmental Science. Before then, he says, we tended to look at the problem in pieces, and for scientists, in experimental terms, project by project. The 1992 book took the wide view, he says, the long view.

Many of the processes detailed in this book are now part of the public's broad understanding of how nutrients, algal blooms, and dissolved oxygen interact in the Bay.



***Little light makes it through** the turbid waters of the West River, according to these data from a team of volunteer monitors. Much of the river sees too little light for submerged aquatic vegetation (SAV) to grow, and the outlook for 2007 looks no better. Increased monitoring by volunteers, state and federal agencies, and research laboratories is painting a stronger picture of conditions in the shallows.* SOURCE: RICHARD CRENSHAW AND THE WEST RIVER WATER QUALITY TEAM.

near real-time testing from small boats. As the boat traveled along, an intake drew water through a hose and ran it into a monitoring machine. They called it a Data Flow device.

"Walter Boynton deserves a lot of credit for starting the shallow water monitoring effort," says fellow UMCES researcher Michael Kemp. "He and Chris Madden."

Christopher Madden, now at the South Florida Water Management District, developed the package of technologies and techniques for shallow water monitoring. Boynton's group then refined the process.

Boynton started making the case for an ongoing, continuous effort to monitor the Bay's shallows. Given the importance of the shallows to the Bay ecosystem, he argued, the lack of data there represented a huge knowledge gap. His proposal presented a daunting challenge to government agencies, given the extent of shallow habitats in the Chesapeake, but the Maryland Department of Natural Resources (DNR) understood the need.

Since 2002, the Maryland DNR has supported a shallow water monitoring system comprised of fixed monthly monitoring sites and continuous monitoring sites. They call it Eyes on the Bay, and it's impressive (see Eyes on the Bay, p. 17).

Donald Boesch, the president of UMCES, agrees that it's a remarkable resource. While preparing for a recent radio talk show in Washington, D.C., Boesch wanted a quick update on conditions during the summer of 2007. It struck him immediately how much information we now have, thanks to efforts like Eyes on the Bay. A quick click tracked conditions in the Patuxent, the Choptank, all around the state. "It's a tremendous tool," he says. "And its potential is probably under-used."

Since 2003 the Virginia Institute of Marine Science (VIMS) and the Chesapeake Bay National Estuarine Research Reserve in Virginia have mounted a similar continuous monitoring program, also available on the web (see "For Further Information," p. 17).

Those early zig-zag cruises by Malone and others provided wonderful "snapshots," Kemp says. They told us a lot about the sloshing of salty bottom waters up on the edges, including waters devoid of oxygen (or, anoxic) that could harm life on the Bay's shallow shoulders. Now we have running tallies of salinity, oxygen, and other details thanks to dozens of shallow monitoring sites around the Bay.

Over the past thirty years, we have come a very long way.

Confusion in the Rivers

All this tracking provides unprecedented information about nutrient levels, water clarity, salinity, oxygen levels, and other factors. It does not necessarily provide a coherent picture

Consider, for a moment, the riverkeepers.

All around the Bay, riverkeepers are keeping score. Much like the annual report card the Chesapeake Bay Foundation (CBF) uses to grade the whole Bay, riverkeepers are tracking large amounts of data to come up with scores for oxygen, clarity, and other criteria.

In Bob Gallagher's view, data gathering is "haphazard." "The agencies aren't always looking for what we want," he says. "Their data collection is usually project-driven. Once the project is over, they move to something else."

But even the data gathered by the riverkeepers themselves can confuse. One look at the scorecards for different rivers illustrates the problem. Someone living on the Western Shore, for example, may want to see scorecards for the Magothy, the Severn, the South, the West, and the Rhode. But while information exists for all these rivers, comparisons are tough. One scorecard will use a bar graph, the other a line graph. One will show data relative to the habitat needs of fish or oysters, the other will show the same data as a percentage of a stated goal.

Comparing the health of rivers using these scorecards is a brain tease at best. Biologist Peter Bergstrom understands the problem. Working out of the Annapolis office of the National Oceanic and Atmospheric Administration (NOAA), Bergstrom is pushing a standardized format for all the river scorecards. He has floated suggestions for a common format, where tabulations for oxygen, salinity, bacteria, and other factors will look the same from river to river, from year to year. The University of Maryland Integration and Analysis Network (IAN), located at UMCES, is cooperating with Bergstom and others to develop standard ways of representing data across the board.

Whether or not riverkeepers and others will sign on to a standard tracking scheme remains to be seen.

And there is a more profound problem. Even when data are well organized and standardized, it does not alone provide the answers to some very complex scientific questions.

A rich data stream is very good at "tracking trends," says Michael Kemp. The data tell us, for example, what's up and what's down, he says. Whether it was a "good year" or a "bad year" for oxygen. But, he asks, "What does all that mean?"

In particular, what does it mean for an estuary like the Chesapeake Bay, where nutrient levels, despite some progress, have remained high since Baywide monitoring began in 1985?

To make his point, he refers to recent work in Europe by researchers who tracked nutrient loading in about half a dozen European rivers. While they started by tracking nutrient increases, he says, these researchers were fortunate enough to eventually track decreases in nutrient loading. In the Chesapeake, he says, declining nutrient trends are hard to find.

The European example shows that tracking nutrient increases and decreases proved relatively easy. Explaining what happened next is not.

According to two researchers, Daniel Conley from Sweden and Carlos M. Duarte from Spain, nutrient levels declined, but algae levels remained high.

Those rivers did not appear to respond to nutrient reductions. Why not?

New Technology

Eyes on the Bay

Keeping track of the Chesapeake is no mean feat. All too often now the estuary's mix of tides, currents, seawater, and rainwater make for a dreary dance of harmful algal blooms, sediment, and low oxygen levels. How can managers and citizens keep up with that constant change, to know where things are getting better, where they are getting worse?

To help us keep track, Maryland (in 2002) and Virginia (in 2003) launched continuous monitoring efforts. Now anyone with Internet access can keep tabs on oxygen, turbidity, and other vital signs.

Data specialist Mark Trice heads up the Maryland Department of Natural Resource's Intensive Monitoring Assessment and Development Program and has played a key role in developing Maryland's Eyes on the Bay. He says the effort built on continuous monitoring efforts that dated back to the *Pfiesteria* events of 1997 — when blooms of a tiny dinoflagellate incited concern over water quality and public health. Stations set up in the Pocomoke to closely monitor conditions at the time demonstrated the effectiveness of the method.

Continuous monitoring — real time or near-real time tracking of water quality — took its first flights on the wings of new technology back in the 1990s. The first technical tool, called DataFlow, allowed small boats to pull samples through an intake hose and analyze them, all while underway. The second used fixed monitoring stations that gather data at regular intervals — say, every fifteen minutes. These innovations feature devices like windshield wipers that regularly swipe sensors clean — important in the Bay's productive soup, where almost anything becomes fouled fast.

Even at that, Trice says, they have to pull the fixed monitors every week or two to clean them and recalibrate them, a time-consuming task.

As of 2007 there are some 50 fixed monitoring sites in Maryland's portion of the Bay, and about a third of them stream information for instant access. Virginia deploys more than 30 fixed stations, as well as areas monitored by small boats underway.

These intensive monitoring programs, developed in cooperation with the regionwide Chesapeake Bay Program, got going at about the same time that the U.S. Environmental Protection Agency (EPA) published new water quality standards for turbidity, chlorophyll, and dissolved oxygen. The drive to get the Bay off the EPA's list of impaired waters has made this kind of accurate water quality monitoring essential throughout the Chesapeake and its rivers. Plans are underway to link these systems with other regional observing systems, which are in turned linked to national and even global observation systems.

— J.G.

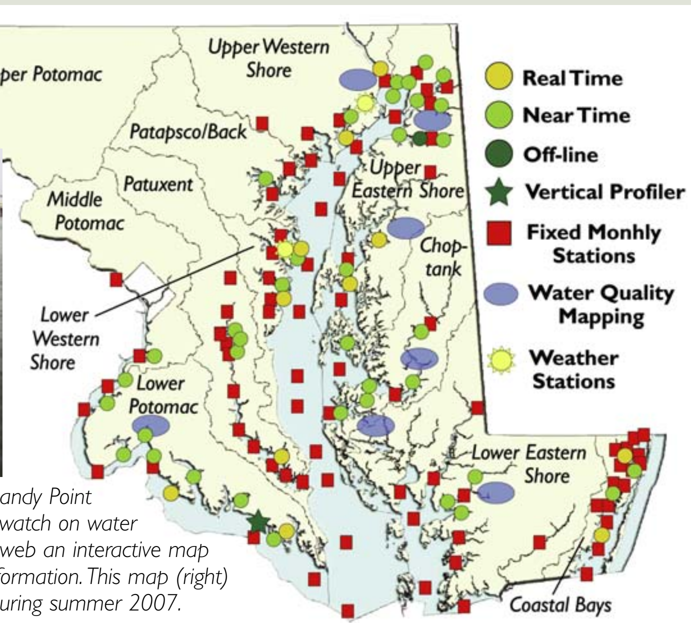
For Further Information

Eyes on the Bay
www.eyesonthebay.net
Virginia Estuarine and Coastal Observing System (VECOS)
www2.vims.edu/vecos/
The Chesapeake Bay Observing System (CBOS)
www.cbos.org/
Maryland's BayStat
www.baystat.maryland.gov/

Snapshots of the Summer of 2007

Chesapeake Bay Program's Monitoring and Analysis Subcommittee
www.eco-check.org/pdfs/2007_lookbackltr.pdf
Chesapeake Bay Foundation Bad Waters Report
cbf.org/badwaters

Maryland Department of Natural Resources



Fifty fixed stations, like the Sandy Point site above, keep a constant watch on water quality in Maryland. On the web an interactive map links users to a wealth of information. This map (right) shows stations on the Bay during summer 2007.

New Report

On the Threshold

Is the Chesapeake Bay stuck in an ecological rut? If we can reduce the input of nutrients, will the Bay and its rivers cross certain thresholds for recovery that will jumpstart self-healing? Can we find those thresholds and aim our efforts toward getting there?

According to researchers like Michael Kemp at the University of Maryland Center for Environmental Science, there is good reason to think that such thresholds exist, because we've almost certainly crossed them before. In particular, following centuries of deforestation, an increase in human wastes and farm fertilizers, and one very bad storm named Agnes in 1972, the Bay apparently slipped over a threshold into a new state where it remains today. Symptoms of that degraded state include catastrophic loss of underwater vegetation and an explosion of algae production that leads to oxygen loss in the Bay's bottom waters.

To help wrestle with these questions, Kemp organized a conference on thresholds, sponsored by the Chesapeake Bay Program's Scientific and Technical Advisory Committee (STAC) and the Maryland Sea Grant Program. Researchers came to Maryland in early 2007 from as far away as Denmark and Sweden to discuss what the public might call the Bay's tipping points.

Joining them were managers like the Executive Director of the Chesapeake Bay Commission, Ann Pesiri Swanson. Swanson spoke for elected officials and decision makers when she said that we have to be able to ask research questions in a way that makes clear which efforts are likely to trigger a recovery response. We have to ask questions, she said, that will help us target limited resources to make the most effective changes.

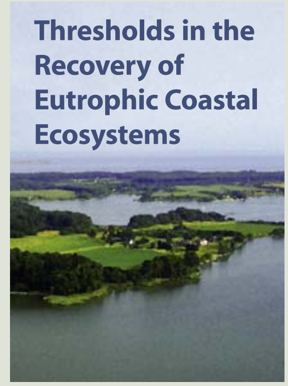
This conference on thresholds set out to frame those questions.

A number of case studies from the Chesapeake Bay, Pamlico Sound, Europe, and elsewhere demonstrated the complexity of the problem. Some rivers in these systems improved after nutrient reductions — and some did not. Or they responded in some areas but not in others. Take the Patuxent, for example. Reductions of nutrients upstream led to some improved conditions in the middle portions of the river, according to Kemp. Fewer algae blooms appeared. More native grasses came back. Downstream, though, near the river mouth, was a different story. Water quality did not improve.

In the lower Patuxent tides apparently bring in over-fertilized water from the Bay itself, say Kemp and other researchers. The influx of nutrients from the Bay seems to overwhelm reduction efforts of those living on the river. Instead of the river polluting the Bay, it seems that the Bay is polluting the river. At least that's what preliminary research suggests.

In other regions, researchers have learned other lessons. In the Neuse River, for example, work by Hans Paerl at the University of North Carolina suggests that focusing nutrient-reduction efforts on phosphorus alone can cause problems. In the Neuse, a tributary of Pamlico Sound, such efforts led to a decrease in algal growth upstream, but left nitrogen free to flow downstream, where it caused even more massive blooms and oxygen dead zones.

The lesson here: reduce both phosphorus and nitrogen.



Identifying when or where future thresholds might be crossed will require a close look at the past. That's where the clues to the future will be, researchers say. They called for taking "the long view" to better understand the dynamics of thresholds in the Bay. In particular they called for making better use of historical datasets — treasure troves of information that remain underappreciated and underutilized.

To gauge whether we're moving in the right direction, the group called for a close connection between monitoring and modeling and a close accounting for future impacts of climate change.

Further work should show how nutrient reduction efforts push natural systems like the Bay toward a particular threshold. When, for example, reductions in nitrogen input, on the one hand, and the increases of buffers like wetlands and underwater grasses, on the other, will tilt the Bay away from its downward spiral and toward ecosystem recovery.

A report from the thresholds conference is forthcoming from STAC and Maryland Sea Grant. For further details, contact Melissa Fagan faganm@si.edu at the Chesapeake Research Consortium or Erica Goldman goldman@mdsg.umd.edu at Maryland Sea Grant.

— J.G.

Conley and Duarte argued at a recent meeting of the Estuarine Research Federation that the rivers did not respond because something had changed. That something is the climate. Because of global warming, they say, baseline conditions are no longer the same. Trying to return to a prior state would be, in their words, like trying to return to "Neverland."

Their findings reinforce Kemp's point. We can track trends, but it will take our very best science to explain them.

Does Kemp agree that global warming has made returning to a prior state more difficult — if not impossible?

Maybe. But he offers another hypothesis. Kemp suspects that over-fertilized systems — like the Chesapeake — have become stuck in a rut. Some call this a "perverse resilience." In order to move out of this state, he says, we need to reduce nutrients and then provide the Bay with enough time for "self-healing," borrowing a phrase from the Chesapeake Bay Foundation.

To know when the Bay is responding, he says, we need to track the return of positive feedback loops. The return of bottom dwellers and filter feeders. The comeback of underwater grasses. We need to pay close attention to how the Bay is responding to such key factors as nutrient loading, sediment, and climate.

"The action," he says, "will be in the shallows."

It is in the shallows, Kemp argues, that we will see the quickest response and the earliest signs of change.

A New Synthesis?

The summer of 2007 offered a glimpse of what could happen in the shallows if the climate warms and nutrients continue unabated.

It also revealed why so many algal blooms can show up even in a drought year.

First, we know from Tom Malone and his colleagues that much of the nutrient loading to the Bay occurs in the cooler months. During most of the winter and spring of 2007 rainfall was, according to the U.S. Geologic Survey (USGS), average or above average. By the time the drought began in early summer, nutrients were already in the Bay.

Second, with very little rain and a lot of sunlight, the tributaries cooked. Since the rivers already had plenty of nutrients in them, they didn't need any more runoff to fuel the summer's blooms — blooms largely of dinoflagellates, some of them toxic.

"It was a banner year for harmful algal blooms," says Allen Place, researcher at the University of Maryland Biotechnology Institute (UMBI). Place, who studies toxic algae at UMBI's Center of Marine Biotechnology in Baltimore, points out that dinoflagellates thrive in still waters. Diatoms can swirl happily in spring runoff, but dinoflagellates don't like agitation. At least that's what he's observed with species he's studied, including the toxic dinoflagellate *Karlodinium*. He was not surprised to find *Karlodinium* showing up at fish kills during hot still weather in Baltimore Harbor, in Weems Creek near Annapolis, and down on the Potomac River.

It's widely understood that when algal blooms crash, low oxygen conditions usually follow. But while dinoflagellates can cause dense algae blooms they tend to show up in lower numbers than do springtime diatoms. For this reason, they may form mahogany tides, perhaps even toxic ones that cause fish kills, but not cause the huge drops in oxygen associated with thicker clouds of diatoms or other algae.

This is likely the answer to riverkeeper Bob Gallagher's question about the summer of 2007. Algae bloomed in a dry summer because nutrients were already there from the previous winter and spring. The blooms were largely comprised of dinoflagellates that thrive in hot still weather. These mahogany tides did not cause the kind of oxygen drops associated with the spring bloom because dinoflagellates probably bloomed at densities well below that of spring diatoms.

With no rain to flush them out during hot, dry conditions, tributaries may well become reactors pumping out harmful algal blooms.

In the end, this is disturbing news. As long as heavy loads of nutrients run off the land in winter and spring, algae will bloom and cause a loss of oxygen in the Bay's deeper waters. Even worse, despite a dry summer, harmful algae blooms, caused by dinoflagellates, will bloom in the shallows and tributaries. With no rain to flush them out during hot dry conditions, the tributaries may well become reactors pumping out harmful algal blooms.

Place and Kemp are quick to add that for now this still-water scenario is only conjecture. Though their years of research have led them to these explanations, connecting the dots between climatic conditions and the appearance of particular kinds of algae will require a lot of data and a lot of experimentation and analysis. It will, they say, require a lot of synthesis, a lot of thinking.

Kemp is now working at synthesis — trying to make sense of huge amounts of data. To do this, he's partnering with a team of experts he calls "super" computer geeks. Experts from Johns Hopkins University, the University of Delaware, Dalhousie University, and the San Diego Supercomputing Center. Kemp and UMCES colleague Ming Li will provide the link between all that computing power and the Bay-related questions they're trying to answer.

Their project, funded by the National Science Foundation (NSF), will serve as a "proof of concept." The idea is to manipulate the huge profusion of data now available from advanced observing systems to achieve a new level of scientific understanding.

With the advent of new technologies, observing systems have proliferated, Kemp says, for everything from climate change to tsunamis. Because of the years of sophisticated research directed at understanding the Bay's oxygen cycle by Malone and many others, the Chesapeake will serve as a national experiment. The Bay will help answer to what degree and in what way we can put new massive data streams to use in answering fundamental science questions.

Their plan is to draw from many different data sources and to organize that data in ways never before possible. Their goal is a new "cyber-infrastructure."

We are clustering (or "federating") different datasets, Kemp says. But this is not just a matter of hooking up piles of data. The key, Kemp says, will be to shape the data in various ways, to ask the right questions of it. While data are always used to create models, these researchers will reconstruct models in various ways to spit out specific information they want. They will target information geared to test particular hypotheses or concrete management choices.

Over the next thirty years, the vast array of observation sites that Malone and others are pushing for will track what happens as we reduce the flow of nutrients into the Bay. It will keep a sleepless watch on the shallows, to see when rivers reach their thresholds of recovery, when algal blooms abate, oxygen levels rise, and water clarity improves.

And more than this, if Kemp and his colleagues are successful, scientists will use a new cyber-infrastructure to explain why change is happening, why the ecosystem is responding, why algae is blooming — or not — even in a dry summer.

Or, if we do not have the political will to reduce the flow of nutrients into the Bay, this new approach will show us precisely where the toxic algal blooms are likely to occur, where the fish kills will be, where the oxygenless dead zones will spread.

That is a picture no one wants to see.

— email the author, greer@mdsg.umd.edu

Preparing for the Next 30 Years

Global warming. Urban sprawl. Dead zones. To address these challenges in the Chesapeake and beyond will require new thinking. It will require new experts, new leaders.

For thirty years Maryland Sea Grant has helped prepare for the future by supporting researchers and students as they move into undiscovered territory. With Sea Grant support, scientists have explored new ways of tackling pressing problems. They have experimented with promising techniques and tested big ideas, often with modest funding that laid the groundwork for more ambitious efforts.

Since 1977, Maryland Sea Grant has funded graduate students to work with marine scientists and scholars, supporting them at a key point in their careers. Since 1979, Sea Grant has also awarded Knauss Fellowships to students seeking advanced degrees, sending them to Capitol Hill or to the nation's ocean agencies to apply their education to real-world problem solving. Many of these students are now researchers themselves, and some are leaders in marine science and policy.

To expose undergraduates to the excitement and rigors of marine science, Maryland Sea Grant has, since 1989, run a Research Experiences for Undergraduates (REU) program supported by the National Science Foundation. The REU program brings college students from around the country to spend a summer working with researchers on Bay-related science projects.

Sandy Rodgers

In order to link K-12 education directly with the science and engineering enterprise, Maryland Sea Grant Extension connects middle and high school teachers with researchers through the Environmental Science Education Partnership (ESEP), a collaborative effort with the University of Maryland Center for Environmental Science (UMCES). Teacher fellows spend seven weeks of the summer working with scientists on projects at field laboratories at UMCES or at the University of Maryland Biotechnology Institute.

Another unique program, Aquaculture-in-Action, helps educators learn how to use recirculating aquaculture to enhance their science curriculum — providing a framework for integrating the teaching of biology, chemistry, engineering, and environmental science. Today 41 schools in Maryland, Pennsylvania, and West Virginia have aquaculture programs based on the Aquaculture-in-Action approach.

Increasingly, the Internet has created new frontiers for education. Students can share lessons and data in real time with students across the state or in other countries. Maryland Sea Grant's interactive web-based lessons have now been downloaded in all 50 states and in 58 countries.

To glimpse where Maryland Sea Grant has come in the past three decades, and to learn about our research and educational materials, visit www.mdsg.umd.edu/timeline. There you can comment on our past work and suggest new initiatives for the future. We look forward to helping to prepare the next generation to take on the challenges of the next thirty years.

Send us your comments — visit *Chesapeake Quarterly Online* at www.mdsg.umd.edu/CQ

Maryland Sea Grant College
4321 Hartwick Road, Suite 300
University System of Maryland
College Park, Maryland 20740

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