CHESAPEAKE QUARTERLY

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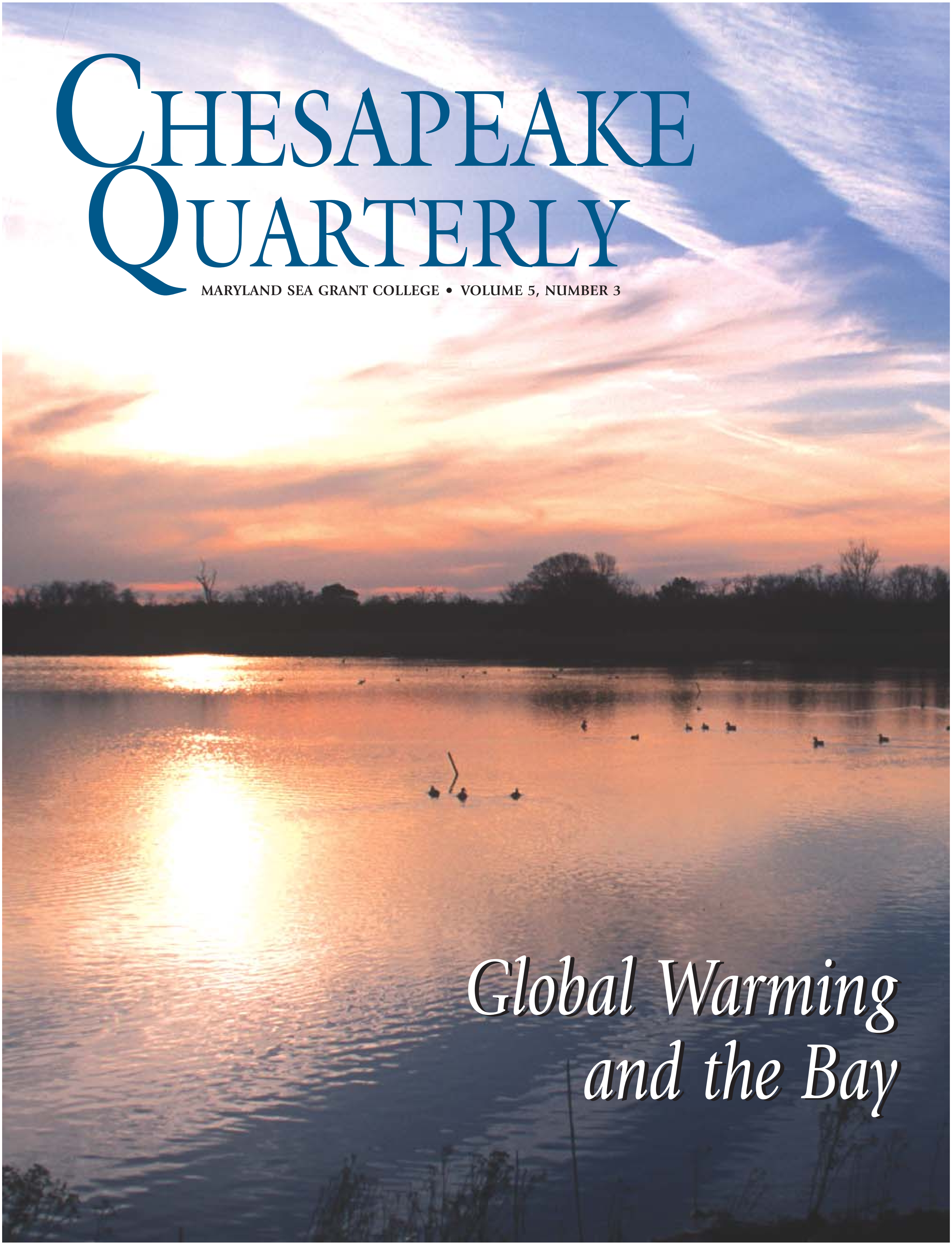

Global Warming and the Bay

contents

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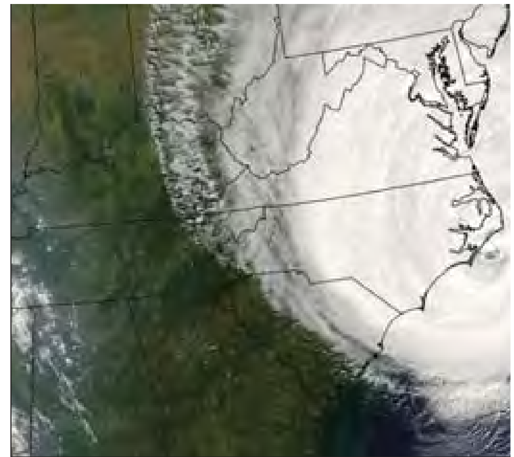
Cover photo: *As water temperatures rise and precipitation patterns change in a warming atmosphere,marshes like this one in the Chesapeake Bay will feel the effects.* PHOTOGRAPH BY SKIP BROWN.
Opposite page: *When Hurricane Isabel hit Maryland's coasts on September 18, 2003, the Chesapeake Bay Maritime Museum in St. Michaels, Maryland felt the full force of its flooding, waves, and storm surge.* PHOTOGRAPH BY CHESAPEAKE BAY MARITIME MUSEUM.



Facing the Bay's Inconvenient Truths

No doubt about it. The earth is warming. Projections for future climate change predict a global increase of 2 to 10°F by the end of the century. And there is no question that human activities — the burning of fossil fuels and the dismantling of the world's great forests — have woven a blanket of greenhouse gases, mainly carbon dioxide, which now insulates the Earth from above.

Globally, we have begun to see the effects of warming temperatures. We've all heard the statistics. Five of the hottest years in recorded history have occurred in the past decade. Glaciers and ice sheets are melting. Sea level is rising.

Global warming has also begun to seep into the public consciousness — even as it remains politically contentious. People are talking about it. Journalists are writing about it. Movies like *The Day After Tomorrow* and *An Inconvenient Truth* have brought strong messages to a broad public.

David Kimmel, a scientist at the University of Maryland Center for Environmental Science's Horn Point Laboratory, recently asked his hair stylist if she believes in global warming. She responded that only six months ago, she probably would have said, "I don't know," but now she answered, "You know, I think that something is going on."

Still, recognizing the immediate impact of global warming in our daily lives and in our local environment remains a challenge. And doing something about it could prove an even greater one.

This issue of *Chesapeake Quarterly* follows the imprint of climate warming on the Chesapeake watershed — on the Bay's plants and animals, on its coastlines, and on the storms that could threaten its coastal communities. We meet scientists like Kimmel, who studies the impact of climate on the Bay's food web, and others who discuss how the warming climate may already be changing the Bay — affecting resources like blue crabs and underwater grasses — as well as other ecosystems around the world. They also offer us some predictions for what we might expect to see in the future.

The Chesapeake watershed already faces more than its share of problems. The long-term effects of nitrogen and phosphorus pollution have wrought fundamental changes in the ecosystem. Algae now dominate waters that were once clear and lush with underwater grasses. The empire of the native oyster is a long distant memory. More than 25 years of effort directed towards restoring the Bay has failed to bring it back.

Now global climate change could further slow restoration, hard news to swallow for a region where the political will to save the Bay has already been put to the test. Will we have what it takes to face up to this next challenge?

Scientists and managers in the region realize that we can't afford not to. They recognize that if we don't think about climate warming as we plan future restoration efforts for the Bay, we could end up spinning our wheels and squandering our dollars. But understanding the effect of climate change in this estuary is no small feat. Dramatic year-to-year variation in rainfall and temperature mask many telltale signatures. We have to start by learning to separate the signal from the noise.

As individuals, it is easy to feel paralyzed by the sheer magnitude of global warming. Over a pizza lunch one day in early October, just days after California governor Arnold Schwarzenegger signed that state's landmark Global Warming Solutions Act of 2006, the staff at Maryland Sea Grant sat down in the conference room to discuss how our office might reduce the size of our emissions footprint. We talked about our commutes, car gas mileage, office lighting, and computer energy savings — offering ideas about how to trim our consumption.

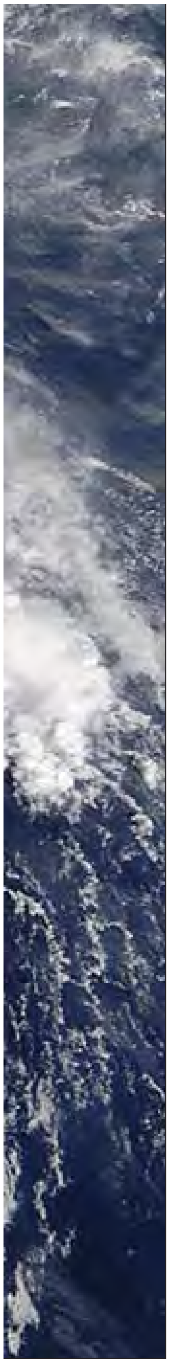
Lunchtime rhetoric over shared pizza seems a very small drop in a very large bucket, but the effort we dubbed "fighting carbon dioxide with carbs" felt like a step in the right direction. We all have to start somewhere, don't we?

— *Erica Goldman*

Footprints of Global Warming

Tracking Climate Change in the Chesapeake

By Erica Goldman



MODIS Rapid Response Project at NASA/GSFC

Sandy Rodgers

The behavior of small creatures in the food web, — oyster and crab larvae, shrimp, copepods, and amphipods — may provide clues to the effects of climate change on the Chesapeake.

The boat's engine coughs once but does not turn over. David Kimmel tries the key in the ignition again. Still nothing. He checks the horn and the boat's winch device. What's the problem?

Everything else seems to be working fine. The boat has a brand new motor and, if he can get it started, Kimmel will be the first to take it for a test-drive.

Kimmel turns the key once more, and this time the engine roars to life. He shrugs his shoulders quizzically, red windbreaker almost reaching up to blue Yankees cap, and starts casting off lines. His first challenge: to maneuver out of the narrow boat harbor, here at the Horn Point Laboratory in Cambridge, Maryland, part of the University of Maryland Center for Environmental Science (UMCES) located on the Choptank River.

On this cool, clear day, Kimmel is heading out to the deepest spot in the river in search of zooplankton, tiny floating animals that form a key but often under-appreciated link down at the base of the Bay's food web. Subtle shifts in the who-eats-whom cycles down among these tiny, microscopic animals could be a sign of a huge, planet-wide change — a change called global warming.

His boat is carrying gear that will let Kimmel "look" for zooplankton by listening for them. The key piece is an acoustic sensor that drops in the river and beeps out sound waves through the water column. When the sound bounces off the hard exoskeletons (carapaces) of tiny animals, Kimmel can look at the volume of the bounce-back responses and then estimate roughly which creatures inhabit the depths — oyster larvae, shrimp, copepods, and amphipods to name a few.

***Storms like** Hurricane Isabel (shown on opposite page), which slammed into the Chesapeake in 2003, may increase in frequency and severity as global warming continues. Biologist David Kimmel (above) uses a laptop and sensitive instruments to gather data about zooplankton populations which may give clues to how a warming climate could alter the Chesapeake's food web.*

Kimmel spins the wheel several rounds to the right, and then quickly cuts back left. It takes a lot of effort just to keep the boat moving straight through the narrow channel. Once the boat clears the jetty, Kimmel slowly takes the engine up to 4500 rpm, then alternates between high and low speeds, carefully breaking in the new motor. The boat heads toward the Choptank's deep hole, where the river bottom lies more than 90 feet down.

The concept behind Kimmel's sampling scheme is simple. Find out where in the Bay different zooplankton live and pinpoint hot spots of abundance. Then try to understand how these hot spots behave, how they move around, how they appear and disappear. By comparing his current findings with findings from the past, he hopes to spot the early warning signs that show how global warming could change the Chesapeake.

Signals and Noise

Clues to global warming are hard to come by in an estuary like the Chesapeake. Wet years or dry years, cold winters or warm winters, active hurricane seasons or quiet spells — all alter the Chesapeake with some frequency. They raise or lower the volume of riverwater flowing into the estuary, shaping the boom and bust cycles of algae and other species in the Bay each year. All that year-to-year variability makes it hard to pick out the larger, long-term changes triggered by global warming. How do you separate the signal from the noise? How do you find evidence of climate warming among all that annual variability?

When Kimmel first came to Horn Point Laboratory in 2001 as a postdoctoral fellow, scientists did not yet have a firm understanding of how variation in temperature and rainfall affect the Bay's animal life on an annual basis. With his expertise in zooplankton, Kimmel decided to explore the effect of climate variability on this middle level of the food web. In the eat-or-be-eaten hierarchy, zooplankton appear on the menu between fish and algae — with algae forming the base of the food chain as primary producers that convert the sun's energy into food.

To sort out swings between wet years and dry years, Kimmel turned to a new tool called "synoptic climatology." He teamed up with David Miller, then a Ph.D. student at Horn Point working in the lab of oceanographer Larry Harding. Synoptic climatology helps to assess how climate varies on a regional scale, explains Miller. The approach uses data on daily sea level pressure to classify common atmospheric circulation patterns that influence the Chesapeake Bay region. By looking back through a time series of weather data, Miller can statistically sort weather patterns into categories and calculate the mean conditions that occur in a given time period. Examining as many as ten dominant patterns, he compares weather shifts to changes in flow in the Susquehanna River, and then to downstream changes in the Bay.

Kimmel is linking this climatological approach to the Bay's eat-or-be-eaten hierarchy by working with a zooplankton monitoring record maintained by the EPA Chesapeake Bay Program from 1984 to 2002. He and his colleagues are making connections between year-to-year changes in the Bay's climate patterns and its populations of zooplankton and fish. In a paper published in *Estuaries and Coasts* in July 2006, the team found that wet winters followed by high river flows in the spring produce conditions favorable to the zooplankton species *Eurytemora affinis*, a major food source for striped bass larvae. Closing the statistical loop, the group found that wetter winters could be positively linked to robust, healthy striped bass populations.

That's evidence this tool has some predictive power, but the response of the Chesapeake Bay food web to the influence of longer-term climate warming, not just year-to-year variability, remains largely unknown.

By aligning the climate record both with the historical zooplankton data and with data from his current acoustic sampling effort, Kimmel hopes to begin answering the question of how the system is responding to current environmental pressures. The next step, according to Kimmel, would be to try to anticipate what might happen in the future, as the climate changes.

Adam Frederick

Kimmel has linked robust, healthy striped bass populations to wetter winters that bring an abundance of their major food source, the zooplankton Eurytemora affinis.

Signs of Change

The first thing to happen under global warming will be rising temperatures. Worldwide projections now forecast an increase of 2.5°F to 10.4°F by the end of the century. According to oceanographer Ray Najjar from Penn State University, who studies climate effects on the Chesapeake region, the Bay has never experienced years as warm as those predicted since we started keeping records. This means we don't have a clear sense of how the estuary will respond.

Najjar even questions whether temperature increases will bring more or less precipitation to the area. The response to temperature increases may vary depending on the month of the year, he explains. This frustrates scientists, because they have a better grasp on how the Bay responds to precipitation extremes than to temperature changes. "We know that it's going to get warm, but we don't know what the effects of that warmth will be. We don't really know whether it's going to get wetter or drier, but if we did know, then we'd really be able to say how the Bay would respond," Najjar says. "So we know half the story."

The second change global warming will bring is a rise in sea levels around the world, up to 50 cm by the year 2100. What will that mean for the Bay?

In the Chesapeake region, sea level rise could go twice as high (up to 1 meter by the end of the century). While the sea is rising worldwide, land in Bay country is subsiding (sinking), making the relative impact of sea level rise much greater, explains Thomas Cronin, a paleoclimatologist with the U.S. Geological Survey in Reston, Virginia. During the last ice age — when the great ice sheets pushed down to New York, New Jersey, and Pennsylvania — the ice was so heavy that it depressed the area underneath.

"It's like squeezing a rubber ball," says Cronin. "The area you squeeze goes down, but the area around it would go out." But when the ice began to melt, the area previously buried begins to bounce back (rebound), while the land outside the ice sheet, like the Bay, begins to sink. Low-lying regions like Smith Island and the Blackwater National Wildlife Refuge could eventually be underwater.

Sea level rise could also raise salinity in the Bay. Salt water will move in from the ocean and flow from the southern reaches of the Bay northward, similar to what happens in a drought year now, but on a sustained basis, explains Michael Kearney, a geographer at the University of Maryland College Park.

Evidence for the sea level-salinity hypothesis comes from recent modeling efforts. Using a historical data record for salinity over the past 50 years, mathematical modeler Ming Li from the UMCES Horn Point Lab is able to predict future salinity patterns. If the 1-meter rise in the level of the Bay comes to pass, Li's model predicts that the salinity in the southern part of the Bay could see an increase of up to 5 psu (practical salinity units) by the end of the century.

To further complicate matters, rainfall could also increase with global warming, and river flow from the tributaries may extend the reach of freshwater farther south. "This could cause a biological squeeze," says Victor Kennedy, a biologist at the UMCES Horn Point Laboratory and the first author of a 2002 report for the Pew Center on Global Climate Change on coastal and marine ecosystems. "You've got sea level increasing from one end and rainfall at the other end," he says. "If the estuary becomes constricted in this manner, it would have an effect on the organisms that cannot tolerate either higher or lower salinities."

Shifting Ranges

Some species in the Chesapeake may already be feeling the heat. Eelgrass, blue crabs, and the oyster parasite Dermo have shown signs that they may be vulnerable to a climate-related shift in the places they call home (their geographic distribution, or range).

Eelgrass, an underwater grass that provides critical nursery habitat for juvenile blue crabs, experienced a major die-off in 2005. A one-year decline could be a blip on the radar, but seagrass ecologist Bob Orth, of the Virginia Institute of Marine Science, doesn't think so. Orth notes that five of the warmest years in the last century have occurred within the past decade. "Global warming has entered our conversation," he says. "In the last ten years we've seen changes in eelgrass populations that cannot be explained just by poor water quality."

Eelgrass grows best in cool, temperate areas with high salinity. It's already near the southernmost part of its range in the Chesapeake Bay, he explains. Within the estuary itself, eelgrass cannot shift its distribution northward because it cannot tolerate freshwater. If it fails in the southern reaches of the Bay, eelgrass will likely disappear from the Chesapeake.

Loss of eelgrass could have profound consequences for the ecosystem. Best known for its role as nursery habitat for juvenile crabs, eelgrass dominates in shallow water habitats, and its so-called "ecosystem services" may not be readily replaced by another grass species. The cascade of effects through the food web is "a tough one to predict," warns Orth.

As tough as the loss of eelgrass might be, blue crabs may face other profound effects, according to Tom Miller, a researcher at the UMCES Chesapeake Biological Laboratory who has just begun studying prospects for the Bay's largest and most valuable fishery in a warmer world. Miller suspects that blue crabs may be highly sensitive to an increase in global temperature because of their unique life history. In fact, says Miller, a long-term climate shift might lead to a population boom south of the Chesapeake Bay.

Here's how.

The blue crab's life cycle changes dramatically according to latitude, Miller explains. From South Carolina down to the Gulf of Mexico, crabs grow continuously and complete their life cycle within the year. From South Carolina northward, crabs must bury themselves in sediment to survive cold winter temperatures — which means that they won't reach maturity until the following year.

Whether or not crabs overwinter depends entirely on temperature. "There is a magical 11°C threshold," explains Miller. When water temperatures get below 11°C [52°F], crabs can no longer grow and molt. If a warming climate causes winter temperatures to rise in the Mid-Atlantic, the North Carolina blue crab fishery could quickly become more like the fishery in South Carolina — and more productive than the fishery in the Chesapeake Bay, creating an economic squeeze on the Bay's crab fishery. The southern states could replace the Bay as the blue crab capital of the country.

Oysters, of course, were once the Bay's most profitable fishery, and perhaps the best-documented example of a disastrous range shift is the spread of the Chesapeake's number one oyster-killer — Dermo disease. Beginning in 1990, scientists noticed a big explosion of *Perkinsus marinus*, the parasite that causes Dermo, in oysters in Delaware Bay. Susan Ford, a parasitologist at Rutgers University's Haskin Shellfish Research Lab, started searching up the coast in New Jersey and her team began finding it everywhere they looked. Then they started to get reports from growers in Long Island Sound. By the end of 1991, scientists found the parasite as far north as Cape Cod — a range extension of over 500 kilometers in just a couple of years. Formerly limited to Chesapeake and Delaware bays at its northern extreme, by 1996 Dermo was identified as far north as Maine.

When Ford looked at temperature records for this period, she realized that the range extension of the Dermo parasite corresponded with a clear warming trend, particularly one associated with warmer winter temperatures. A close look at historical patterns of disease incidence revealed that, following a period of high abundance after its initial introduction to Chesapeake Bay in the 1950s, the parasite virtually disappeared during the next decade, years dominated by cooler temperatures — in particular, cold winters. Publishing her findings in the September 15, 2006 online issue of *Marine Biology*, Ford hypothesizes that the parasite never really disappeared, but waited in some latent state for temperatures to warm.

Climate warming projections for the northern hemisphere point towards even warmer winters in the coming years, says Ford. Oysters further north could soon become susceptible to Dermo, still further changing the dynamics of the troubled East Coast oyster fishery.

Recently scientists have begun to unearth evidence for ecological and evolutionary changes linked to climate warming practically everywhere they look. Statistical analyses show that 41 percent of 1598 species studied — ranging from grasses to mollusks, butterflies to mammals — have responded to the global average warming of 0.6°C that has occurred in the last century, either by shifting their range or the timing of reproduction or development (called phenology). When Camille Parmesan, an ecologist at the University of Texas in Austin, published her first study on the effect of climate on the distribution of Edith's checkerspot butterfly in 1996, it was "a field of one or two," she says. Now journals have published a total of

Lessons from a Lake

In some ecosystems, food webs have already shown obvious signs of rising global temperatures. In Seattle's Lake Washington, for example, scientists identified an "uncoupling" of the link between algae (phytoplankton) and the tiny animals that graze on them (zooplankton) that can be traced directly to climate warming. Limnologists Monika Winder and Daniel Schindler at the University of Washington used a historical data set to identify a mismatch between the timing of the spring phytoplankton bloom and a key zooplankton grazer, publishing their results in a 2004 paper in the journal *Ecology*.

Since 1962, increasingly warmer springs in the region advanced the timing of the seasonal phytoplankton bloom by 20 days, explains Winder, who is now a research scientist at the Tahoe Environmental Research Center in Davis, California. As a result, the water flea *Daphnia*, a keystone grazer in the system, experienced a long-term decline that may have severe consequences for upper levels in the food chain — like fish.

Other zooplankton species in Lake Washington, however, seem to have adapted better to the early onset of spring warming, says Winder. One grazer (the rotifer *Keratella*) shifted its peak densities 21 days earlier to correspond with new peak timing of the phytoplankton population. Another zooplankton species in the lake, a copepod, cut its generation time in half, so that it fits a whole additional reproductive cycle into the longer growing period.

For predator and prey, who eats what when is very important, says Winder. But the mechanisms that allow some species to adapt to such shifts in climate better than others are still poorly understood, she says. Moreover, the effects higher up on the food chain are still very hard to quantify.

If the food web impacts of climate warming are difficult to account for in an ecosystem like Lake Washington, they are that much harder in a place like the Chesapeake Bay. Unlike the Bay, Lake Washington is relatively unpolluted and has been stable and free from nutrient overloading (eutrophication) since the 1970s. In the Bay, the impacts of nutrient pollution and hypoxia on species distribution interactions can be dramatic, potentially masking the effects of climate, says Kimmel.

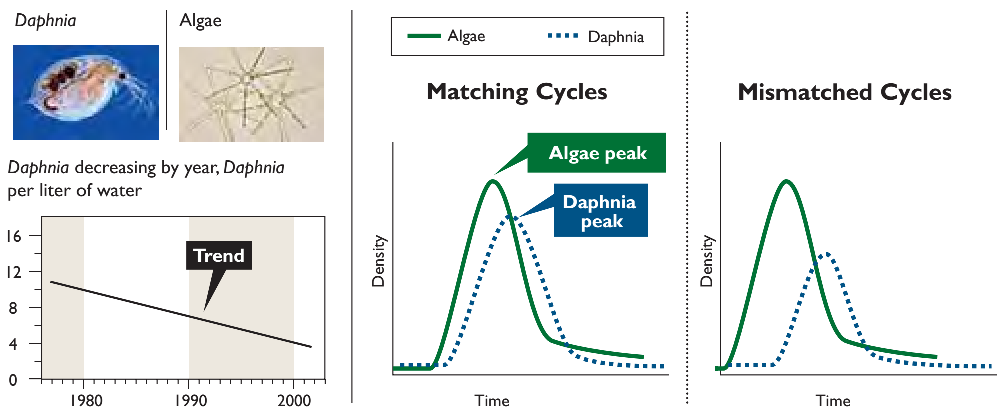
Additionally, since estuaries experience far more seasonal climate variability as a result of freshwater flow than lakes do, many species in the Bay are adapted to the "ephemeral nature" of an estuary and a wide range of temperatures, explains Tom Miller, a fisheries biologist at the UMCES Chesapeake Biological Laboratory in Solomons Island, Maryland. "Species that make their living in estuaries need to be able to respond to that variability," he says. "But global climate change will certainly be a factor, because the one thing that species do respond to are changes in minimum and maximum temperatures."

— *Erica Goldman*

Washington Sea Grant

Declining Food Source in Lake Washington, Seattle

In Seattle's Lake Washington (left), climate warming led to a mismatch in timing between blooms of algae and a tiny water flea called Daphnia, *that eats algae. Now algae bloom early in the season and die off, leaving* Daphnia *hungry when their population booms in late spring.*



Graphic reprinted, with permission, from the Seattle Post-Intelligencer. *Data Sources: University of Washington scientists Monika Winder, Michael Brett, Dave Beauchamp, Tommy Edmondson, Arni Litt, Daniel Schindler; Sally Abella, King County; Dave Seiler, Washington Department of Fish and Wildlife; Intergovernmental Panel on Climate Change.*

Seattle-Post Intelligencer

866 peer-reviewed papers on the subject — 40 percent of them hitting the scientific literature between 2003-2006, Parmesan reports in a synthesis in the *Annual Review of Ecology and Evolutionary Systematics* published in December 2006.

Why the sudden surge of studies on species and climate change? It's a combination of factors, says Parmesan.

"Scientists are getting more interested in looking at their data sets with respect to climate change," she says. "But in almost every case I've looked at, the last five years have shown an enormously stronger response than I've seen over the last 30 years. People who might not have noticed anything in their system are suddenly saying, 'Gee…the last five years have been really weird.' That is prompting them to go ahead and publish."

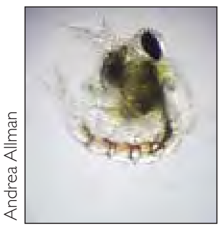
Searching for Signals

Fifteen minutes out from the Horn Point harbor, Kimmel checks the depth sounder and slows the boat. The depth sounder reads 70 feet, then 80. Over the Choptank's deep hole, he cuts the motor and drops anchor just shy of 90 feet.

"I hope the anchor's tied on," he says only half-jokingly and begins setting up the odd equipment that will help him

Sandy Rodgers

Adam Frederick



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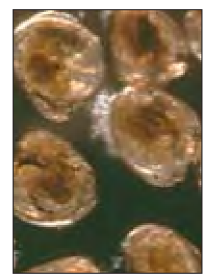


***Reaching out to stabilize** the instruments' bulky frames, post-doctoral fellow Jamie Pierson helps to position the sensors to begin their descent into the Choptank River's deep hole. The instrument on top sends out sound waves to count tiny zooplankton in the water column. The instrument below delivers a continuous profile of salinity, temperature, and depth back to researcher David Kimmel's laptop aboard the boat. Among the zooplankton counted are copepods, amphipods, and crab and oyster larvae (shown at right, from top).*

locate and identify zooplankton species in the Choptank. On the flat surface above the steering wheel, he plants his computer data logger while Jamie Pierson, his post-doc fellow, and Horn Point microbiologist Byron Crump untangle the mess of wires at the winch. Then they clip the hook onto the metal cage that holds two instruments about to make their way to the Bay's bottom. Something they call TAPS is actually a Tracor Acoustic Profiling System and their CTD is a traditional meter for recording Conductivity, Temperature, and Depth.

Enclosed in their metal frames and tethered together with white line, the two instruments make a bulky package. Pierson and Crump position the instruments and Kimmel engages the winch. The rope sways precariously for a moment, but soon stabilizes as the winch lowers the instruments into the water. Kimmel turns on both devices just beneath the water's surface to get the air out and let them stabilize in their new surroundings.

Soon the TAPS system and the CTD meter are headed for the river's bottom. As they descend, the CTD meter sends Kimmel's computer a continuous stream of information. Water temperatures are actually warmer several meters down this time of year, typical of an early fall profile when the night air begins to cool. The water is well mixed and there are no signs of low oxygen (hypoxia).

The TAPS instrument uses six transducers to send out sound signals at six different frequencies. Each frequency measures a different size class of zooplankton, from 200 microns to 18 mm. That range spans the size of tiny copepod juveniles called nauplii, up to the size of a large shrimp, about as big as a seedless grape, at the top end of the range. The lower the frequency of the sound emitted, the bigger the animal the transducer can detect. As it descends, the CTD meter measures a continuous profile of salinity, temperature, and depth.

Kimmel stops the instruments at different depths and records continuously for several minutes at a series of heights off the river's bottom. Data come in fast and furious but the acoustic pinging of the TAPS device registers no signal on Kimmel's laptop. All those data are logged into the instrument itself, to be downloaded and analyzed at a later date. To figure out which organisms inhabit these depths will require a lengthy analysis process back in the lab.

Whether or not Kimmel has hit upon a hotspot of zooplankton with this measurement remains to be seen. This day will register as only one in a long series, this sampling station one of many that line the length and width of the entire Bay — one data point in a vast array. It's the giant zooplankton record as a whole that will offer clues about the impact of global warming on the Chesapeake's food web.

Model Forecasts for a Warming Watershed

When it comes to using models to predict the impact of future climate change on the Chesapeake, scientists face a two-pronged challenge. First, they must try to predict how climate warming will affect temperature and precipitation on this regional, rather than global scale. Second, they must take these predictions and apply them to ask specific questions about the Bay itself — questions such as: How much coastal land will become submerged by the end of the century? Will the estuary become more hypoxic? Will existing nutrient loads increase or decrease?

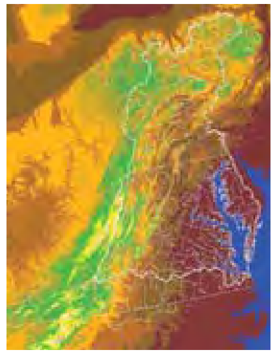
To forecast scenarios for changes in temperature and precipitation on a regional basis, scientists must refine models that were designed to make global predictions. Roughly 20 so-called "coupled general circulation models" currently operate out of 14 supercomputing centers around the world, part of the fourth major assessment by the Intergovernmental Panel on Climate Change (IPCC). These models link atmosphere, ocean, and land interactions to reconstruct climate history of the past and to project scenarios for the future. Current model runs will recreate "controls" such as the climate of pre-industrial times and the present day. They will also forecast climate scenarios under different amounts of CO_2 emission in the future — such as 100-year predictions under conditions of low, middle, and high CO_2 emissions.

In a report soon to be published by the Pew Center on Global Climate Change, researchers at the University of Maryland Center for Environmental Science (UMCES) compare two of these general circulation models to predict the impact of climate change for Chesapeake Bay hypoxia — a depletion of dissolved oxygen in the bottom waters that occurs each summer and can be devastating for fish, crustaceans, and mollusks.

Precipitation, river runoff, sea level, and temperature interact with each other to affect seasonal hypoxia. All of these variables will respond to climate warming. "When you think about all the things that can change with climate and how they interact with things that we are trying to manage in the Bay, there are a lot of moving parts that we have to understand," says Donald Boesch, first author of the upcoming Pew report and president of UMCES.

At the high and middle levels of the CO_2 emissions scenarios used by the IPCC, the two models predict precipitation increases in the Bay region of up to 30% in some months and decreases greater than 10% in the fall by the end of the century — including more events with extreme rainfall. Both models predict temperature increases ranging from 3.5 to 6.5°C, clustered in the summer months. But the global models do a better job of predicting temperature than precipitation at the regional scale, cautions mathematical modeler and study co-author Victoria Coles.

Chesapeake Bay Models



Air Quality Model
Depicts air deposition of nitrate and ammonia

Watershed Model
Depicts land use and changing best management practices (BMPs)

Estuary Model
Depicts sediment, algal blooms, and the effects of filter feeders

Chesapeake Bay Program

Models use mathematical representations of the real world to estimate the effects of complex and varying environmental events and conditions. The Watershed Model (above center), for example, estimates the delivery of nutrients and sediment to the Bay by simulating hydrologic and nutrient cycles, using inputs such as atmospheric nutrient deposition, precipitation, fertilizer application, and land cover or land use. As the Chesapeake Bay Program prepares to re-evaluate its current set of benchmarks for 2010 and to set new goals for 2030, new model scenarios will incorporate predictions for warming temperatures and changing precipitation patterns.

"We know that climate change is going to happen. Step one is to quantify the effects we might see in this region."

But even with some uncertainty surrounding the precipitation changes under climate warming scenarios, researchers can make some overall predictions related to the Bay's hypoxia. The team anticipates that increasing streamflow, increasing summertime temperatures, plus an increased depth of the Bay due to sea level rise, would reduce the exchange between warmer surface waters and cooler deeper waters (enhancing stratification). This change would spread hypoxia into shallower areas of the Bay.

Although this study is preliminary and the researchers are currently looking for funding to do a more in-depth analysis, their findings carry a clear warning message for restoration efforts. "Given the long lag times, both in terms of implementation of nutrient control strategies and in the responses of the ecosystem," they write, "it is not too early to begin assessing the implications of climate change on management objectives for hypoxia and for Chesapeake Bay restoration."

The Environmental Protection Agency's Chesapeake Bay Program has already begun to factor climate warming predictions into their modeling scenarios for the next two-year period of decision-making. The Bay Program's models are used for management purposes — primarily to track nutrient loads and to evaluate progress towards reaching water quality goals.

As part of their 2008-2010 assessment, modelers will for the first time be able to include predictions for future changes in temperature and precipitation into a set of scenarios run through the year 2030, explains Lewis Linker, coordinator of the Bay Program's modeling subcommittee. Although the model runs will not yet be able to factor in projected sea level rise or changes in the Bay's depth (bathymetry), this new climate assessment tool will allow managers to assess how climate change may interact with progress towards restoration goals.

"We know that climate change is going to happen," Linker says, "but we don't know what it will do with respect to the flow of the rivers, or with respect to [nutrient] loads. Step one is to quantify the effects we might see in this region."

When it comes to policy decisions, these model scenarios provide a base of information. "We'll be able to make all these runs," says Linker. "How they will get used will be up to the decision makers in the Bay Program."

— Erica Goldman

Critical Mass

Despite studies like those by Kimmel, David Miller, Tom Miller, Harding, and Orth, the Bay region has lagged behind other ecosystems in the U.S. and around the world in evaluating the current and future impacts of climate on its flora and fauna. "The Bay community is becoming interested in climate issues, but we are not yet at the tipping point where there is a significant amount of funding available," says Kimmel. "It's kind of a shame because this is one of the best studied estuaries, especially from a historical perspective."

Elsewhere the impact of global warming on plants and animals has definitely reached a threshold that has caused the scientific community to sit up and take notice. Will changes like these — the northward drift of a butterfly or even the loss of eelgrass in the Chesapeake — be sufficient to rally broad public and political will?

Kimmel has his doubts. The political will in the Chesapeake Bay region may be close to maxed out, he suggests. "Unless we demonstrate that there is going to be a large-scale fisheries change, people might not care. Even *then*, they might not care," he says. "This is going to be the hardest sell of all, because it's a prediction. We've been making these predictions for fisheries, like blue crab, for some time. But climate is even a tougher sell because many people don't believe in global warming."

Part of the problem, he says, is that climate change does not have an immediate impact on people's lives. The only way that we get a taste of what it might be like is with events like the heavy rains in June 2006, he says. But even that was temporary. "How do you get people to understand what it could be like in the future, and what if we are wrong?"

Rallying people around the issue of climate change in the Chesapeake Bay may indeed prove difficult. The long-term effects of nutrient pollution in the region have taken a toll on public and political will and consumed the lion's share of

"How do you get people to understand what it could be like in the future, and what if we are wrong?"

resources directed at the watershed. People have only just started to consider the possibility that global warming may offset the positive impacts of the tremendous nutrient reduction effort in this region.

"Climate predictions may tell us that if we stay on this trajectory with greenhouse emissions, even if we spend $15 billion in nutrient reduction, climate change could just increase nutrient levels in the Bay and that money would be wasted," says Kimmel.

Does this mean that climate warming will doom restoration efforts to failure? While we can't know the answer with certainty, the outlook is likely not as bleak as all that. Managers have already begun to incorporate scenarios for climate warming into their next round of model predictions for 2030, which will amend the nutrient reduction strategy for the period after 2010 — the court-ordered deadline for getting the Bay off the federal list of impaired waters (see "Model Forecasts for a Warming Watershed," page 10). Researchers have already begun to work more closely with city planners to incorporate predictions for sea level rise with community growth objectives (see "Bad Storms on the Rise," p. 12). While not a guarantee, proactive efforts to anticipate the impact of climate change on the region should help safeguard against unexpected surprises.

Anticipating changes in the estuary itself, shifts in the composition of plants and animals, and the who-eats-whom interactions of the food web, may mean revising our assumptions that a Bay in the warming world of the future will closely resemble the Bay of the past. Restoration of eelgrass in the southern Bay, for example, may prove difficult or impossible if the region gets warmer, promising little return on our financial investment. But this does not necessarily mean that ecological services provided by other species of underwater grasses, if healthy and abundant once again, would not perform most, if not all the necessary functions — providing sufficient food and habitat for waterfowl, fish, and shellfish, filtering and trapping sediment, absorbing excess nutrients, and inhibiting shoreline-eroding wave action.

Meanwhile, the alarming current trajectory for global warming might yet be temporary. While rising temperatures are a fact of the near-term future, because current levels of greenhouse gases in the atmosphere cannot be immediately reversed, future policy decisions on local, national, and global scales may buy us time — time for a further course correction for the Chesapeake watershed.

Kimmel flips the switch on the winch and the acoustic zooplankton counter and CTD instrument slowly make their way to the surface, wending up from a depth of 87 feet. He keeps an eye on the screen of his laptop to keep track of the depth so that the instruments do not break the surface too fast.

He looks at his laptop and then back out toward the water. The screen reads 1.5 meters (5 feet) and still the two large instruments, encased in their bulky metal frames, are nowhere to be seen. The waters of the Choptank River, murky and turbid, completely conceal them from view, even at that shallow depth.

Kimmel glances at Jamie Pierson, his post-doc who is a recent transplant from Seattle and the clearer waters of Puget Sound. Pierson is eyeing the water incredulously, astounded that he still can't see the instruments. "Welcome to the Chesapeake Bay," Kimmel says ironically. Once he has the high-tech package back aboard, he turns the boat around and starts heading for shore.

— *e-mail the author, goldman@mdsg.umd.edu*

Annapolis Capitol

BAD STORMS ON THE RISE

Global Warming May Worsen the Blow

When Jeff Holland closed the doors to head home for the night, he thought that he'd done all he could to secure the Annapolis Maritime Museum against the approach of Hurricane Isabel. The museum director and his staff had moved all of the museum's artifacts and records upstairs, securing them on the second floor under a tarp. They placed furnishings and big items, like a large-scale model of the Thomas Point lighthouse, up on sawhorses, expecting high water to come and go. On the museum dock, Holland flipped all the picnic tables face down, diligently drilling and bolting them into the wood surface. If the tide topped the dock, floating picnic tables might hurt someone.

But the picnic tables did not float away. When Holland located them the next day, the tables were still well secured, still bolted. What he had a hard time finding was the dock itself. He never suspected that Isabel's nearly 8-foot storm surge, piled on top of the normal high tide, would lift the entire dock, smash it into the building, and drop it at the end of the street.

When Hurricane Isabel slammed the Mid-Atlantic region as a Category-2 storm on September 18, 2003, the impact of the storm caught everyone — even many experts — by surprise. With its eye located just south of the Chesapeake Bay, the storm took 23 lives and brought widespread flooding that damaged buildings and washed away homes. What made Isabel so destructive? Should we expect to see more such storms in the future? If so, could a warming climate be to blame?

Surge of Rising Seas

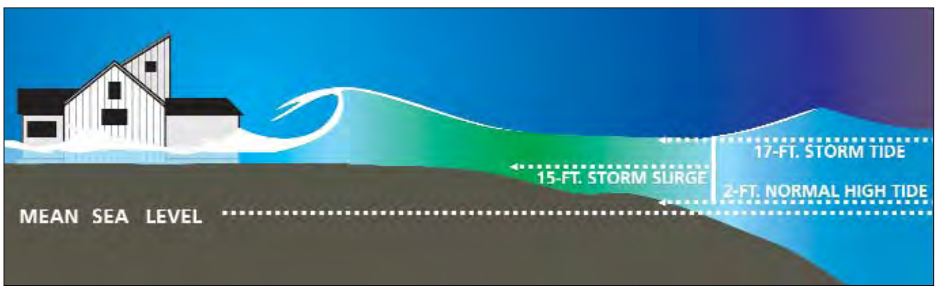
Wind and waves gave Isabel its hefty punch. During a hurricane, low pressure and high winds create a large dome of water — a storm surge. Topped by wind-whipped waves, this giant dome, often 50 to 100 miles wide, combines with the normal tide, producing what is known as a storm tide. If the surge reaches the coastline at high tide, as it did in Annapolis during Isabel, the water can top an average high tide by many feet. "And it only takes a 1-meter wave to knock down an average house

Annapolis Maritime Museum

Annapolis Maritime Museum

"I looked down the gutter there and saw my desk drawer floating by, and I thought, that's probably not a good sign. This is the desk that I put up on the sawhorses inside the building. And there was all my stuff in the drawer, just floating down the gutter."

— Jeff Holland



NOAA

***Hurricane Isabel, September 18, 2003** left downtown Annapolis underwater (opposite page) transforming a street usually packed with tourists into a flooded mess. When the storm surge, created by the hurricane's high winds (above, bottom left), arrived, waves crashed over the top of the Annapolis Maritime Museum, located in the former McNasby Oyster Company packing plant (above, top left). According to museum director Jeff Holland (above right), debris in the waves acted as battering rams, making big holes in the side of the building.*

wall," says Rick Murnane, a program manager for the Risk Prediction Initiative (RPI) — a science-business partnership based at the Bermuda Biological Station for Research.

The risk posed by storm surges is further exacerbated by rising sea levels, a global problem that is tied to the warming of Earth's climate. Higher sea levels encourage the formation of larger waves that break close to shore. Because the Bay is so shallow, just 1 foot of sea level rise causes a big increase in waves, explains geographer Michael Kearney at the University of Maryland College Park. In addition, sea level is rising at a rate nearly twice the global average in the Bay region, 3.5 millimeters per year. This extra inundation results from the fact that land in this region is simultaneously sinking (see "Footprints of Global Warming, p. 4).

A warming atmosphere, due in part to greenhouse gas emissions, will continue to raise ocean temperatures, causing the surface of the ocean to expand, explains paleoclimatologist Thomas Cronin, at the U.S. Geological Survey in Reston, Virginia. This expansion serves as a major contributor to global sea level rise, he says. But the melting of the great ice sheets in Greenland and Antarctica, along with the world's glaciers, may also play a huge role, a factor that has become "scarily apparent" in the past three to four years, says Cronin.

Picture an ice cube sitting on the edge of your bathtub, Cronin says. When that ice melts and flows into the bathtub, it will raise its level. This is what will happen as the ice sheets melt because they sit on land, not water. If the Greenland ice sheet were to melt, for example, it could cause an additional 6 to 7 meters of sea level rise globally, says Cronin.

Even in the absence of storms, global sea level rise, sped locally by the Bay's sinking shores, has already affected the Chesapeake. The Bay has lost many islands and marshlands to this combination of sea level rise and subsidence and stands to lose more still. Court Stevenson, an ecologist at the UMCES Horn Point Laboratory who works to preserve marshland, advocates physically rebuilding areas by relocating sediment to counteract the forces that threaten to destroy this critical habitat for crabs and juvenile fish.

Unfortunately, says Stevenson, we are "applying band-aids to stop hemorrhaging." The real changes need to be made in reducing carbon dioxide emissions, he says, but if "we do nothing at all we stand to lose a tremendous resource."

Another part of the problem stems from the high growth rate in the Chesapeake region. A 2005 report from the National Oceanic and Atmospheric Administration ranked the Chesapeake Bay watershed as the second most populated coastal watershed in the country and Maryland and Virginia as "hot spots" of growth. Growth puts pressure on sensitive coastal areas and, as Kearney points out, there is no real plan to account for sea level rise in planning for development.

According to Brent Yarnal, "In every place we've looked, infrastructure tends to be clustered in very vulnerable areas." A geographer at Penn State University, Yarnal worked with the Bayside community of Hampton Roads, Virginia on this overlooked intersection of storm surges, sea level rise, and coastal development. He used a model called SLOSH (Sea, Lake, and Overland Surges from Hurricanes) to evaluate how rising sea levels could increase the reach of storm surges into 16 counties in Hampton Roads and the surrounding area. The model allowed him to explore different scenarios — like the impact of a hurricane if sea level were to rise by 1 foot versus 3 feet and the effect of population growth in the region.

Yarnal then used census data, such as age and poverty, and information about the placement of critical infrastructure, such as water and sewer, to construct a "social vulnerability index" for the community. He's now working with local planners to incorporate projections for worsening storm surges into plans for future development. "When it comes time to replace that infrastructure," he says, "all planners really have to do is think about moving out of the risk zone and building it in fairly secure places. Higher ground."

Stronger Storms in Store?

The climate connection between rising sea levels and worsening storm surge may just be the tip of the (melting) iceberg. Over the past two years, a flurry of scientific papers has also established a link between warming global climates and the intensity of tropical storms.

Since 1970, the number of Category 4 and 5 hurricanes has increased by 80 percent, with the most dramatic increase occurring in the past ten years. According to a paper published in *Science* in September 2005 by meteorologist Peter Webster from the Georgia Institute of Technology in Atlanta, this increase in hurricane intensity correlates with rising sea surface temperatures worldwide.

In a complementary study, meteorologist Kerry Emanuel from the Massachusetts Institute of Technology evaluated the intensity of a storm relative to its duration, calculating a measure known as the "power dissipation index." Publishing these results in an August 2005 issue of *Nature*, he found that this index — and therefore storm intensity — has increased dramatically since the 1970s. He also found that this increase correlates with global warming trends. Emanuel's results suggest that continued warming would further increase the destructive potential of storms that, especially given growing coastal populations, could make hurricane-related losses even worse.

Is it possible that warming ocean temperatures and intensifying storms are part of a natural cycle of increased activity rather than the result of human influence? Not likely according to a collaborative study published earlier this year (September 2006) by Benjamin Santer and others in a *Proceedings of the National Academy of Sciences*. This study found that human-caused greenhouse gases are the main driver of the 20th century changes in sea surface temperatures now linked to intensifying storms.

Scientific evidence points convincingly to the possibility of stronger storms as the 21st century unfolds. For the Chesapeake region, rapidly rising sea levels make the specter of such storms, and the storm surges they may bring, even more threatening to coastal communities.

Confronting the future with eyes wide open, by incorporating predictions for climate warming and sea level rise into model projections and community planning, seems the best defense against a potentially tempestuous future.

— *Erica Goldman,*
with reporting by Alison Kahn

For More Information

Footprints of Climate Change

Pew Center on Global Climate Change
www.pewclimate.org/global-warming-basics/index.cfm

Chesapeake Futures
www.chesapeake.org/stac/futreport.html

Bay Journal issue on climate and underwater grasses
bayjournal.com/index.cfm?issue=276

Model Forecasts for a Warming Watershed

EPA Chesapeake Bay Program modeling efforts
www.chesapeakebay.net/model.htm

Intergovernmental Panel on Climate Change (IPCC) – Climate Change 2001: The Scientific Basis
pame.arctic-council.org/climate/ipcc_tar/

Bad Storms on the Rise

Maryland Marine Notes article on sea level rise in the Bay
www.mdsg.umd.edu/MarineNotes/Apr90/

Consortium for the Atlantic Regional Assessment (CARA)
www.cara.psu.edu/

SLOSH (Sea, Lake and Overland Surges from Hurricanes) Model
hurricanes.noaa.gov/prepare/slosh.htm

Maryland Sea Grant's educational panels on Hurricane Isabel – Teaching the public about the hazards of coastal storms. Panels located in Solomons, St. Michaels, Annapolis, and Baltimore.
www.mdsg.umd.edu/Policy/coastalhazards/

Summer Students Test Scientific Waters

The summer of 2006 marked the 18th year that college students from around the country had an opportunity to work alongside marine scientists in labs at the University of Maryland Center for Environmental Science (UMCES). Research Experience for Undergraduates (REU), a Maryland Sea Grant program funded by a grant from the National Science Foundation (NSF), pairs students with faculty mentors at Horn Point Laboratory (HPL) in Cambridge and Chesapeake Biological Laboratory (CBL) in Solomons to conduct academic research projects for 12 weeks.

Class of 2006 REU fellows and their instructors.

In the summer of 2006, fourteen students from Maryland, Virginia, Colorado, Georgia, Michigan, New York, California, Wisconsin, Maine, Pennsylvania, New Jersey, South Dakota, and Puerto Rico participated in the REU program at UMCES. Students worked with advisors to complete projects in fields ranging from fisheries to physical oceanography. Among this year's project titles were: "The Effects of Differing Hurricane Tracks on Storm Surges on the Chesapeake Bay," "The Effects of Oyster Reefs and Breakwaters on Seagrass Beds," and "The Effects of Polychlorinated Biphenyls on Snapping Turtle Behavior and Metabolism." At the end of the summer, students presented their results at a special symposium and wrote papers that synthesized their findings. To see photos of the orientation cruise in the Chesapeake Bay and read abstracts of all their projects, visit the web at www.mdsg.umd.edu/Education/REU/students.

In addition to their research, students also participated in special programs focused on communication, careers, and ethics. Another highlight was sharing research experiences with students from the Multicultural Students at Sea Together (MAST) program, run by Hampton University in Virginia, whose sailboat anchored at HPL and CBL during a three-week voyage on the Chesapeake.

The REU program nationwide is a major contributor to NSF's goal of developing a diverse, internationally competitive, and globally engaged science and engineering workforce. Research experience is one of the most effective avenues for attracting talented undergraduates and retaining them in careers in science and engineering, including careers in teaching and education research. Maryland Sea Grant has successfully applied to NSF for funding for its REU program for nearly 20 years and is one of only two Sea Grant programs which is an REU site.

Maryland Sea Grant is currently seeking students for the summer 2007 REU program, which runs from May 20–August 12. To be eligible, students should be undergraduates who have completed at least two years of study towards a bachelor's degree and still be undergraduates in the fall of 2007. Preference is given to students who are rising seniors. Those from underrepresented groups and institutions with limited research opportunities are especially encouraged to apply. Applicants must be U.S. citizens or permanent residents of the U.S. and its possessions. The University of Maryland is an equal opportunity employer and educator.

Fellows receive a stipend of $3,700, housing costs, and round-trip travel expenses. Opportunities exist for students to publish or present their summer research findings at regional and national conferences. Applications are due February 13, 2007. To apply, visit the web at www.mdsg.umd.edu/Education/REU/. Contact Fredrika Moser (moser@mdsg.umd.edu) with questions.

2007 Fellowship Opportunities

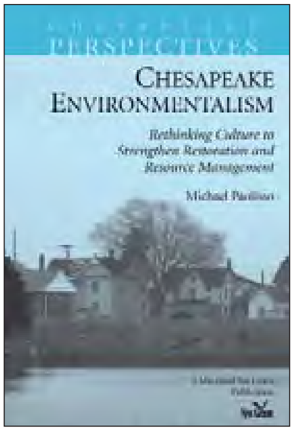
Coastal Management Fellowships, NOAA Coastal Services Center. These two-year fellowships, currently available for 2008-09, were established in 1996 to provide on-the-job education and training opportunities in coastal resource management and policy for postgraduate students and to provide project assistance to state coastal zone management programs. The program matches postgraduate students with state coastal zone programs to work on projects proposed by the state and selected by the fellowship sponsor, the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center. Fellowships offer a competitive salary, medical benefits, and travel and relocation expense reimbursement.

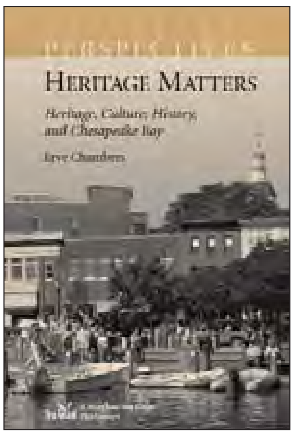
The application deadline for submitting fellowships to the Maryland Sea Grant office is January 29, 2007. For information about the projects and states where fellowships will be located and for application details, visit the web at www.csc.noaa.gov/cms/fellows.html.

Dean John A. Knauss Marine Policy Fellowships, National Sea Grant College Program. Maryland Sea Grant seeks applicants for these 2008 fellowships, funded by the National Sea Grant office and administered through individual state Sea Grant programs. Knauss Fellows spend a year in marine policy-related positions in the legislative and executive branches of the federal government. Past Fellows have worked in the offices of U.S. Senators and Representatives, on Congressional subcommittees, and at agencies such as the National Science Foundation and NOAA. Fellowships run from February 1, 2008 to January 31, 2009 and pay a stipend of $33,000 plus $7,000 for health insurance, moving, and travel.

Applications are due at the Maryland Sea Grant office March 1, 2007. For application details, visit the Maryland Sea Grant web site, www.mdsg.umd.edu/Policy/knauss. For information about the fellowship program nationally, visit the National Sea Grant Office, www.seagrant.noaa.gov/Knauss/ knauss.html.

New Perspectives on the Chesapeake





Home to a remarkable ecosystem and a treasured heritage, the Chesapeake Bay is now the subject of a new academic monograph series, *Chesapeake Perspectives*. The new series from Maryland Sea Grant is designed to provide a platform for scholars, researchers, and other experts to share their insights into the Bay's physical, biological, and cultural complexities, its mysteries and conflicts.

In the first two volumes, two cultural anthropologists hold a rigorous lens to our familiar images of the Bay. What exactly, they ask, do we mean by heritage? Which aspects of the Bay do we celebrate, and which do we ignore? And, most importantly, who gets to decide?

In an essay entitled, *Heritage Matters*, Erve Chambers questions the often expressed view that Bay cultures are "dying." According to Chambers, a characteristic that most defines the iconic Eastern Shore watermen is their resilience, their capacity to make do. Watermen and their families pass down a range of skills, the daily lessons of life. These skills and beliefs form part of what Chambers calls "cultural heritage," a genuine form of inheritance that he contrasts with the "public heritage" we so often see in museums and tourist shops.

Chambers expresses a deep faith in the ability of local communities to adapt and change, and worries that we may be conceptually forcing those communities into the rigid — even if celebratory — visions we have of them.

Michael Paolisso also describes the ways in which we may misunderstand each other's cultural maps. In his essay, *Chesapeake Environmentalism*, Paolisso considers the ways in which farmers, watermen, scientists, and activists all value the environment. Paolisso argues that each group has its own set of deep-seated beliefs that form the foundations of their "cultural models."

Because we discount the validity of different cultural models, says Paolisso, we often fail to include watermen, farmers, and others as "environmentalists," and therefore don't take full advantage of their own strong ethic for preserving both the soil and the Bay.

To order a copy of either monograph, call 301.405.6376 or visit the web at www.mdsg.umd.edu/store/CP/.

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

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