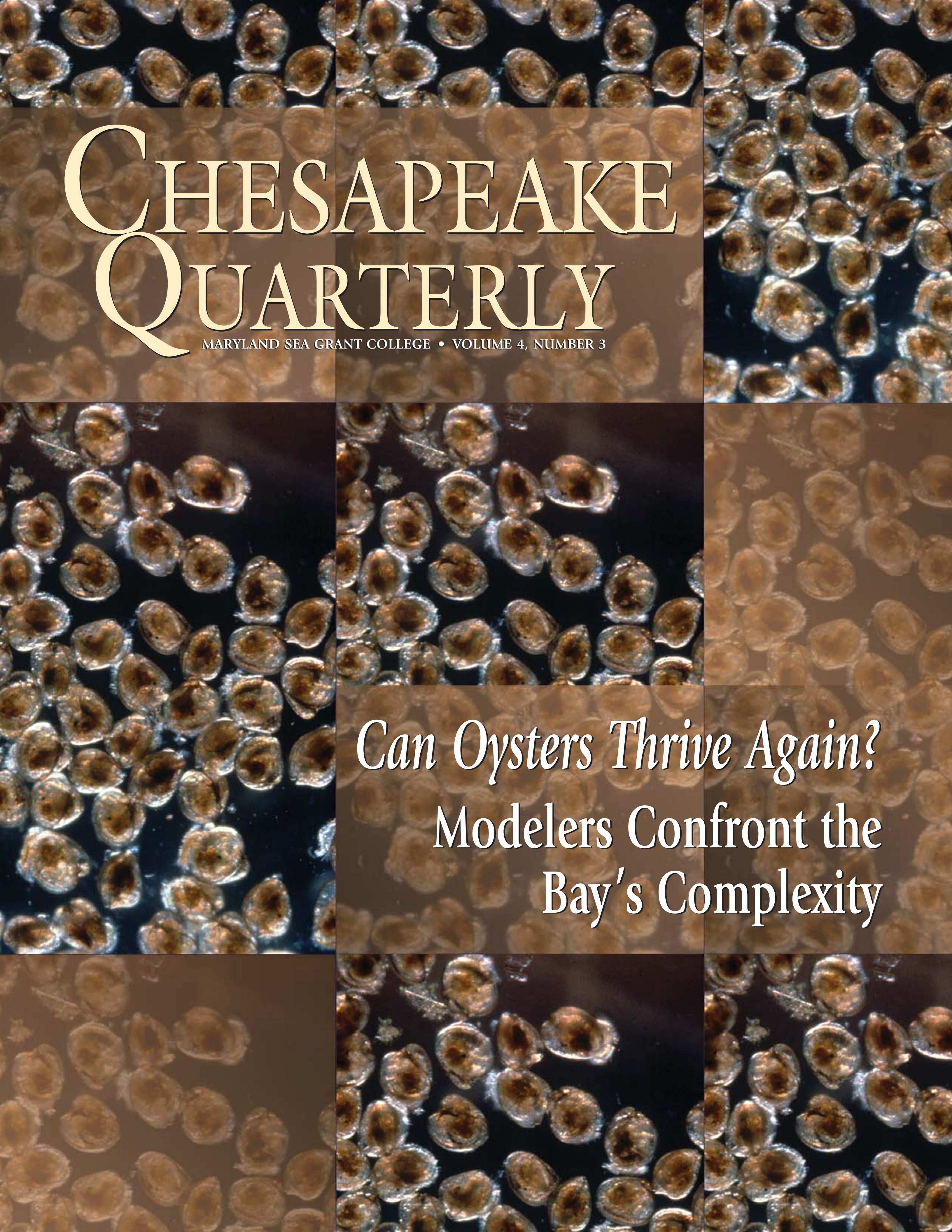


CHESAPEAKE QUARTERLY

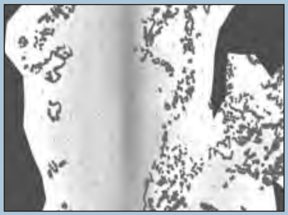
MARYLAND SEA GRANT COLLEGE • VOLUME 4, NUMBER 3

Can Oysters Thrive Again?

Modelers Confront the Bay's Complexity

contents

Volume 4, Number 3



CHESAPEAKE QUARTERLY

December 2005

Chesapeake Quarterly is published four times a year by the Maryland Sea Grant College for and about the marine research, education and outreach community around the state.

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Cover photo: *Like glittering gems, oyster larvae recall a time when watermen dubbed abundant Chesapeake Bay oysters "white gold." Invisible to the naked eye, these larvae of the native oyster,* Crassostrea virginica, *use tiny hairlike cilia to swim in search of a place to settle.* PHOTOGRAPH BY MARYLAND SEA GRANT EXTENSION. **Photos on opposite page:** *Two modelers, one Bay. Elizabeth North (top left) uses models to help decision makers tackle the tough issue of whether to introduce a non-native oyster to the Bay. Bob Ulanowicz (below left) has pioneered the field of ecological network analysis to help explain the complex food web that drives the Chesapeake.* PHOTO OF NORTH BY SKIP BROWN; PHOTO OF ULANOWICZ BY ERICA GOLDMAN. *Restoring oysters to the Bay could boost the oyster fishery and also improve the overall health of the estuary.* PHOTO BY SANDY RODGERS.

Holding a Mirror Up to Nature

Can you remember the first time you glimpsed the night sky, without the haze of streetlights, and realized that the number of stars so vastly surpassed your expectations? Or the first time you peered through the lens of a microscope to discover that a simple sheath of onion skin actually contains dozens and dozens of translucent cells, all lined up like dominoes?

Maybe it was something else for you. An abrupt feeling of smallness while hiking among tall trees, or a sudden sense of humility out on a small boat in building waves. Each of us has undoubtedly experienced moments of quiet wonder at nature's intricacy and power, in ways highly personal.

Much of the pursuit of science through human history emerges from our desire to augment this sense of awe with an understanding of nature's complexity. And lately, we've become better and better at tackling the large-scale questions.

As our capabilities for computation have improved, we've developed more sophisticated tools for predicting snowstorms and hurricanes. We've gained great insight into complex ecosystems like the Chesapeake Bay, amassing clues to what makes such systems function and what makes them falter.

Mathematical models serve as one powerful tool in our pursuit to make sense of the world's infinite complexity. Models enable us to hold a "mirror up to nature," to borrow from Shakespeare's *Hamlet*. They reflect reality, but simplify it to a form that computers can digest and the human mind can comprehend.

Models can help us understand how systems are put together. On an intellectual level, they can help clarify complex processes, from climate to cancer. On a practical level, they can inform immediate, real-life choices — anything from a city's decision to marshal its fleet of snowplows in advance of a storm to public health officials' ability to monitor a feared flu pandemic.

To match the right tool with the right problem, modelers rely on all flavors of mathematics. In the Chesapeake Bay community alone, their efforts run the gamut in scope. Models address questions that range from process-specific, such as how bacteria cycle nitrogen, to big-picture, such as how the whole Chesapeake watershed might respond to changes in land use, pollution, or nutrient reduction efforts.

In this issue of *Chesapeake Quarterly*, you will read about two very different modeling efforts and meet two very different modelers. First, you will learn about the efforts of Elizabeth North, a young scientist at the Horn Point Laboratory of the University of Maryland Center for Environmental Science (UMCES). She is conducting research to help policy makers in Maryland and Virginia as they decide whether to introduce the non-native oyster, *Crassostrea ariakensis,* to the estuary. The larval transport model developed by North and her colleagues falls into the practical category. It will assist resource managers directly, predicting the patterns of larval settlement on reefs throughout the Chesapeake to help them evaluate different scenarios for restoring oysters to the Bay.

Next, you will meet modeler (and philosopher) Bob Ulanowicz — a scientist nearing the end of his long and distinguished academic career at the UMCES Chesapeake Biological Laboratory. Ulanowicz's models fall into the more theoretical category, providing a unified framework for understanding how the Chesapeake Bay functions as a whole and how it has evolved over time. Using a technique called network analysis to model the Bay's food web, Ulanowicz's models provide a first principle approach that can be tailored to any complex ecosystem. Today, many practical models for resource management, such as multi-species fisheries models, employ Ulanowicz's theoretical basis at their core.

* * *

Models do not predict the future. They are not crystal balls. As human constructs they merely confer a greater ability to penetrate new scales of observation, to make sense of an intricate universe.

Let yourself think like a modeler for a moment. When you next confront nature's complexity — whether the countless stars overhead or the baffling "who-eats-whom" makeup of the Bay's food web — pause for a second and ask what it would take to understand how these things work. Where would you begin?

— The Editors

A Model Scientist

Following Oysters from Spawning to Settlement

By Erica Goldman

On a warm June day beneath the waters of the Choptank River on Maryland's Eastern Shore, oysters on one of the river's last remaining reefs begin to spawn. The male's shell parts slightly and a white thread of sperm issues forth from the gap in a steady stream. Nearby, a female oyster raises her shell and brings it down with a sudden clap, a pulse of whitish eggs puffing out. She claps again. Pretty soon, neighboring oysters join in, clapping their shells in unison, turning the water milky white with maybe billions of eggs and sperm. A single female may release as many as 25 million eggs during a single spawn.


Mike Reber

When the clapping subsides, the clouds disperse. The now-fertilized eggs divide again and again. Soon they sprout hairlike cilia and begin a microscopic journey. If the larvae survive tides, currents, let alone a score of predators, they will change shape and begin to make active decisions about where to swim. After two weeks, these tiny animals will begin to scout out an oyster reef on which to attach permanently and transform into adults.

How far will the larvae travel? How many will find an oyster bar on which to settle and begin adult life? How many will die before reaching one? With millions of larvae no larger than a pencil dot, answers to these questions lie beyond the reach of the human eye.

So how can one follow larvae on this unseen journey, a task critical to predict whether oyster populations can once again thrive in the Chesapeake Bay? Mathematical models may be able to take over where the eye leaves off, translating years of laboratory and field observations into equations that account for the major forces at work — currents, tides, and larval behavior.

With a few deft keystrokes, scientist Elizabeth North calls up a schematic map of the Choptank River on her computer screen — now she fills it with clouds of blue dots, simulated oyster larvae spread throughout the river. Small irregular shapes on the map represent oyster reefs, settlement targets where larvae will begin life as adults.

North's fingers play over the keyboard and the virtual larvae lurch into motion. Blue dots slosh back and forth on the screen, subject as they are to forces that numerically mimic the tides. The clock at the top of the screen ticks forward rapidly — six hour tidal cycles advance in a matter of seconds…Day 1…Day 2… Still the blue dots slosh back and forth in this computerized Choptank…Day 9… Day 10. On Day 14, some dots suddenly turn green and stop moving. The larvae are now mature enough to settle if they encounter suitable habitat. The pressure is on. The larvae's genetic code dictates that after they become competent to settle — a life stage called pediveliger — they must find substrate within another 7 days. If they fail to find a place, they cannot metamorphose. They will die.

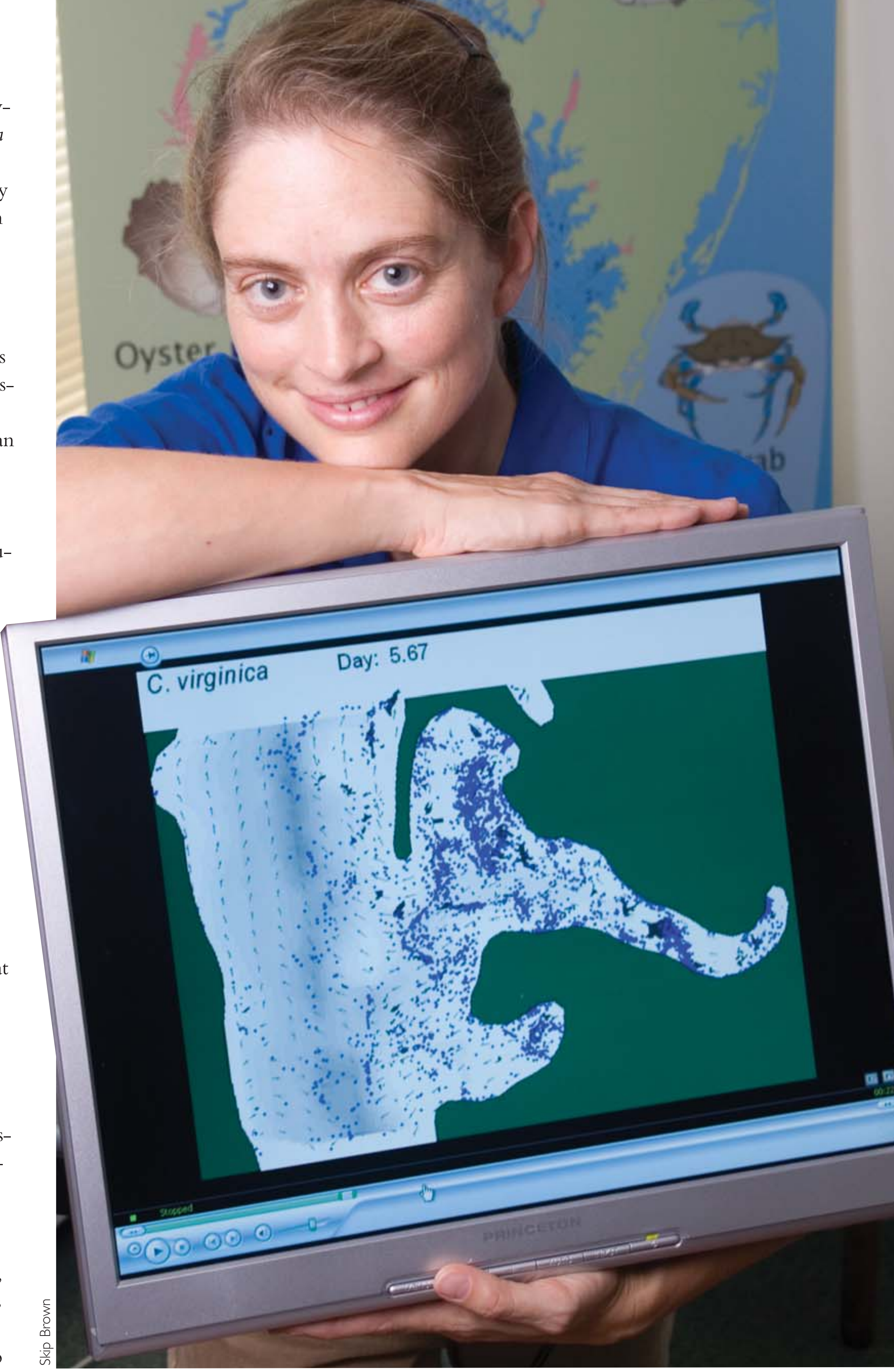
By Day 21, the sloshing stops. The larvae have met their fate. On North's screen, larvae that have successfully settled stay green, while the dead oyster larvae turn orange, rendering the virtual Choptank a patchwork of color.

This "settle or die" oyster drama will play out over and over again on her computer as North, a biologist and mathematical modeler, runs model simulation after simulation. From her quiet, uncluttered office on the shores of the real Choptank River, at the University of Maryland Center for Environmental Science (UMCES) Horn Point Laboratory (HPL), North first gives the blue dots the behavioral traits of the native oyster, *Crassostrea virginica*, derived from published data accumulated over years of scientific study and recent laboratory experiments. Then she will run the same scenarios again with the behaviors of the non-native Asian oyster, *Crassostrea ariakensis*.

As though comparing the performance of two cars, North's model serves as a tool to test drive the two species of oyster, projecting whether one species can reach the finish line (i.e., settlement on an oyster reef) more successfully than the other. Her work will help show which species might better repopulate the Chesapeake with sustainable oyster populations. During the half century from 1920-1970, oyster populations held steady while supporting a profitable — and sustainable — fishery for watermen and oyster farmers. A return to such levels is currently held as a restoration target for an ongoing Environmental Impact Statement (see Assessing a Potential Introduction, pages 6-7).

North's steady presence in front of the flat computer screen reveals no hint of the contentious nature of the debate that swirls at the heart of her work. The outcomes of North's model — maps that predict where larvae of the two oyster species will settle — will likely play an important role in the decision about whether to introduce the fast-growing, non-native Asian oyster to Chesapeake Bay. On one hand, the Bay's oyster industry hangs by a thread — Maryland's harvests alone have declined by more than 90 percent from 1970s levels. Each year more watermen abandon their heritage for more economically sustainable work, while only a handful of shucking houses remain. Equally important, the filtering prowess of oyster populations could help reverse seasonal oxygen depletion and turbid waters, helping to renovate the Bay's damaged ecology. Many have argued that the Asian oyster might have the capability to do just that.

But a decision to introduce the Asian oyster may be a risky one. This species



Skip Brown

Master of a virtual Choptank River, *Elizabeth North turns hours into seconds and days into minutes, tracking the ebb and flow of oyster larvae as they search for a place to settle. North's models form part of an elaborate process aimed at predicting the survival of both native and non-native oysters in the Chesapeake. Opposite page: Oyster reproduction begins with a spawning oyster, like this native one, releasing a cloud containing millions of eggs.*

could not only invade areas outside of the Chesapeake Bay, it could also bring new shellfish diseases to the region. In addition, the Asian oyster could outcompete the native oyster for already-diminished reef habitat, which might deal a final deathblow to its restoration. Furthermore, there are no guarantees that such an introduction will even work to bring oysters back to the Bay or clear up its murky waters. Much of its promise is based on preliminary research and extrapolation from studies of its biology in other regions. North's computer simulations, which compare the settlement patterns of the native and non-native species, will help provide some of the first predictions of the potential for sustainable oyster populations in the Chesapeake Bay.

North works in the midst of this controversial spotlight. She recognizes that her research will provide tools to environmental managers directly, a rare and exciting opportunity to serve as a bridge between science and policy. But the glare can be intense. With policy makers in Maryland and Virginia awaiting the results of research from her and other oyster scientists in the region, she works rigorously and as quickly as possible. Her project is one of 12 funded by the Maryland Department of Natural Resources to address urgent scientific questions about the non-native oyster to help assess potential risks posed by an introduction. And whatever the final decision by the states about whether to introduce the Asian oyster to the Chesapeake Bay, North knows that the outcome of her modeling efforts could someday land at the center of a controversial debate.

As a young researcher, North is grateful for collaborations with colleagues Raleigh Hood, Ming Li, and Liejun Zhong of HPL, and Tom Gross of the National Oceanic and Atmospheric Administration/Chesapeake Research Consortium, and she welcomes the tough scrutiny of academic peer review every step along the way. Peer review will help ensure that her work is of the highest caliber and it will insulate her science against potential political jostling down the road. For now, North stays focused on providing decision makers with the best information possible.

Denizen of the Chesapeake

The path North followed to her current place in the scientific high beams derives from a lifelong connection to the Bay. She grew up on the shores of the Severn River, "catching yellow perch and then not catching yellow perch" when major fish kills occurred in the Bay during her elementary school years. She attended ecology camps in the summer run by the Chesapeake Bay Foundation and interned at the National Aquarium in Baltimore. Her father, a physician, taught her to fish. Her mother, an artist, taught her to identify marsh plants.

As a college student at Swarthmore, North studied comparative religion, with some biology classes along the way. She wanted to learn about differences and commonality in the human experience. As it turned out, studying religion prepared her well for studying science. Both, she says, offer a framework, a structure for understanding the world.

A Non-Native Oyster: Assessing a Potential Introduction


Jim Wesson

Elizabeth North's oyster model will serve as one of many tools to inform the Environmental Impact Statement (EIS) currently being conducted by the states of Maryland and Virginia, along with federal partners. The ultimate goal of the EIS is to "identify a strategy and subsequent actions that will successfully re-establish an oyster population in Chesapeake Bay to a level of abundance that would support sustainable harvests comparable to harvest levels during the period 1920-1970."

The EIS is considering one so-called proposed action, to introduce reproducing populations of the Asian oyster (*Crassostrea ariakensis*) to the Bay and continue restoration efforts for the native oyster, and seven alternatives to that action. These alternatives include recommendations such as a harvest moratorium, improved aquaculture, and the introduction of sterile (triploid) populations of the non-native oyster.

Likely in late 2006, the states will decide whether to introduce the non-native oyster to the Chesapeake. At each level, decision makers will evaluate the available information and weigh the risks and benefits. They will also look closely at the uncertainty associated with these predictions — carefully considering that predicting the future of an ecosystem is inherently an uncertain enterprise.

Decision makers will weigh multiple levels of scientific, economic, and cultural analysis in their final assessment. Models, combined with experimental research on oyster disease and human health, will help predict how the introduced species would fare, as well as evaluate potential risks to the ecosystem. Other research will help quantify potential benefits to the ecosystem of a restored oyster population, such as reduced levels of nitrogen and phosphorus, and will evaluate effects further up the food chain, such as oyster interactions with blue crabs, fish, and birds that eat oysters. An economic analysis quantifies the benefits to the industry of a restored oyster fishery and estimates the economic value of environmental improvements to the Bay that could result from a healthy oyster population. Finally, a cultural analysis evaluates stakeholder attitudes to a restored fishery, to potential environmental improvements, and to the risks of introducing a non-native species.

While the ultimate decision on the out-

Decision Timeline for *C. ariakensis*

Severe disease impacts native oyster; 1987-88 Maryland harvest drops to 363,259 bushels	Oyster industry requests introduction of non-native oysters	Chesapeake Bay Program adopts policy on non-native oysters, VIMS conducts tests on *C. gigas*	National Academy of Sciences agrees to study the implications of introducing *C. ariakensis*	Maryland's oyster harvest for 2003-04 ends at record low of 53,000 bushels	National Academy of Sciences report released	Army Corps launches EIS; notice in Federal Register
1985-88 ▸▸▸	**1991** ▸▸▸	**1993** ▸▸▸	**March 2002** ▸▸▸	**March 2003** ▸▸▸	**August 2003** ▸▸▸	**January 2004** ▸▸▸

After college, North started down a path of long-time interest. She took a job in Annapolis with the Chesapeake Bay Office of the National Oceanic and Atmospheric Administration. She went on to work for the Environmental Protection Agency Chesapeake Bay Program in Solomons and to pursue a master's degree in environmental policy at Johns Hopkins, becoming deeply aware of the need for good science to support sound resource management.

Her interest in applied research next led her to pursue a Ph.D. with UMCES fisheries biologist Ed Houde. At the Chesapeake Biological Laboratory, she focused on physical oceanography, studying how the Bay's complex water circulation affects the distribution of fish larvae in the Bay. She spent long hours on research vessels and peering through a microscope, honing her knowledge of the Bay's intricate biology. As she went on with her research, North realized that mathematical modeling would provide a valuable tool to help link her observations in the physical and biological domains, to "visualize the world" in a way that would be useful to fisheries managers and other decision makers.

North became fluent in the language of modeling through a post-doctoral fellowship with UMCES researcher Raleigh Hood, a biological oceanographer at Horn Point Laboratory who uses mathematical modeling to study algae and primary production in ecosystems around the world. She later accepted a faculty position at the Horn Point Laboratory — a rare occasion to remain at the institution that trained her. For North, this job was the ideal chance to still further strengthen her link to the Bay, an opportunity to continue crabbing and fishing on the Choptank with her husband Tim, a research vessel engineer who used to tong for oysters in the fishery's more prosperous days.

Through her research program, North tries to link the Bay's physical environment to its biological resources, combining modeling, field, and lab-based approaches to studies of blue crabs, underwater grasses, and oysters. Models, she knows, provide just one tool of many, an attempt to visualize the complex network of relationships in the Bay, making the real world easier to understand. But the right tool must match a specific problem, North is careful to point out. "If we had only one tool for every project," she says, "there wouldn't be Home Depot."

Meeting the Model Challenge

A few more keystrokes from North's slender fingers and a new screen pops up: a blank graph stares back, waiting for her to execute a subsection of code that accounts for the different larval behavior of the two species. As native larvae mature, they tend to cluster above the salt barrier (halocline) that cleaves the Bay in two layers: a buoyant, less salty layer of river water flowing seaward and a layer of dense, saltier ocean water flowing upriver. But non-native *C. ariakensis* larvae stay low and hover within one meter of the bottom, according to new experiments by oyster researchers Joan Manuel, Roger Newell and Vic Kennedy, also at Horn Point Laboratory.

come of the EIS rests with the states, the agencies involved — the Maryland Department of Natural Resources (DNR), along with the Virginia Marine Resources Commission, the Army Corp of Engineers, National Oceanica and Atmospheric Administration, Environmental Protection Agency and the U.S. Fish and Wildlife Service — have engaged scientists and several high-level scientific advisory panels at many stages of the EIS process.

It is a complex project, says Tom O'Connell, DNR Project Manager for the oyster EIS. "The Administration is wholeheartedly behind oyster restoration, but we are committed to having a scientifically defensible EIS," he says.

With the goal of "scientific defensibility," DNR aims to conduct the EIS in a rigorous and transparent manner. On the research side, the agency has funded 12 projects to address eight specific ecological risk factors identified in a report released in 2003 by the National Academy of Sciences. North's larval transport model, one of the projects funded, will help address four of the eight risk factors — re-establishment of a self-sustainable oyster (either species) population, re-establishment of oyster reefs (either species), distribution of oysters in the Bay (either species), and dispersal of the Asian oyster beyond the Chesapeake Bay.

To help advise researchers and evaluate the quality of their work, DNR also appointed a high level Independent Advisory Panel in the fall of 2004. This body is comprised of top university scientists, including two members of the earlier panel that produced the National Academies report. The Advisory Panel is charged to:

1. Review the adequacy of data and assessments used to identify the ecological, economic, and cultural risks and benefits and associated uncertainties for each EIS alternative.
2. Advise states of any incomplete information relevant to reasonably foreseeable significant adverse impacts on the human environment that the Panel considers essential to a reasoned choice among alternatives.
3. Advise states on the degree of risk that would be involved for each EIS alternative if a decision were made based on the available data and assessments.

After the Panel has reviewed the final reports from each of the projects underway, it will issue a report to DNR recommending either the proposed action, one of the alternatives, or some combination of alternatives. Although the states are not legally obligated to act on the Panel's findings, they will "in all probability" follow their recommendations, according to panel member Michael Roman, a biological oceanographer and director of the University of Maryland Center for Environmental Science Horn Point Laboratory.

"Decision makers will take what we have to say very, very seriously," says Brian Rothschild, chair of the Oyster Advisory Panel and dean of the University of Massachusetts at Dartmouth's intercampus Graduate School of Marine Sciences and Technology. "But decision makers live in a political climate," he says. "They also need to take into account how people feel about the issues."

—E.G.

Draft EIS originally due; delayed to gather additional information	Decision Point: publish draft of EIS or determine if more information is needed	Approximate timeframe for final decision on determination to release *C. ariakensis*
Spring 2005	▸▸▸ **June 2006**	**★ late 2006**

North believes that these differences in behavior could strongly affect which parts of the Bay these two species will populate. For example, if non-native oyster larvae hang close to the bottom, they may ride bottom ocean currents up the estuary. If larvae hover in the surface water as do the native oyster, they might go down estuary, she explains. For her model to accurately simulate a virtual larval journey, she must capture these differences in behavior.

When North starts the model clock running, the two virtual oyster species behave as she expects. The simulated native oyster larvae float up above the salt barrier, five meters off the Bay's bottom. The non-native oyster larvae stay low. Day 1…Day 2. The model seems to be working well. Day 14…. The larvae are now biologically competent to settle.

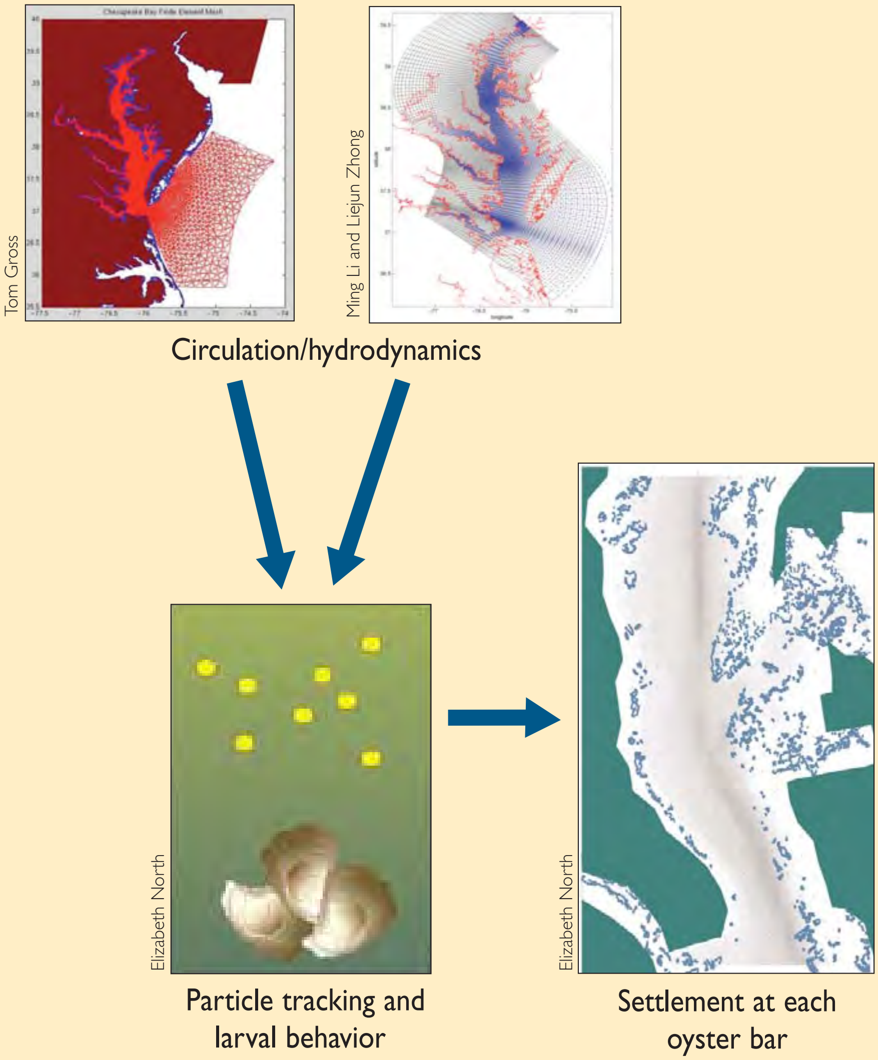
On Day 15, however, North encounters a problem. All of the larvae of both species freeze in place. She recognizes this as an error, perhaps a bug in her computer code, perhaps a problem with the boundary conditions that keep particles from jumping out of the virtual water onto land. At this stage, the simulated larvae should have had at least another seven days to swim around looking for suitable habitat. She knows that she'll diagnose the problem, but needs to find it fast. She wants to present this portion of her model results at an upcoming scientific meeting.

With another series of rapid keystrokes, North calls up the screen that masterminds her model, filled with code that to the untrained eye might as well be hieroglyphics. Leaning forward, she scans the language intently, proofreading and editing in an attempt to pinpoint the source of the problem.

In many ways, North's work as a modeler is much like that of a writer. She writes in the language of mathematics, but the actual syntax is the computer code Fortran. She weaves together themes with a complicated architecture of concepts to recount a classic epic journey, a coming-of-age tale of sorts. Her model uses mathematics to reflect the story of an oyster's search for a place to start life. Not

A Tale of Two Oysters

Volume I…Where Will Larvae Settle?



Tom Gross

Ming Li and Liejun Zhong

Elizabeth North

Elizabeth North

The larval transport model follows the oyster's journey from spawning to settlement. Two circulation models recreate water-driven (hydrodynamic) forces on the larvae, such as currents and tides. These models (top) divide the Bay with a finely meshed grid, each using different geometric rules. To compute fluid motion, the computer solves a system of equations in each of the compartments generated by the grid, in ten-minute intervals of real time. One hydrodynamic model may do a better job predicting currents in the upper estuary and the other a better job in the lower estuary. Using the two together helps quantify potential sources of error in the predictions, according to researcher Elizabeth North.

The particle tracking model (bottom left) uses information from the hydrodynamic models to predict where larvae will go, as though they were passive particles. North will run this model using the hydrodynamic conditions during five different years, 1995-1999, allowing the model to capture the range of flow conditions in the Chesapeake Bay from wet to dry years.

Then North builds behavior into the model, making it more realistic. As the larvae grow larger, they swim faster. The model increases their swimming speed from 0 to 3 millimeters per second (based on the scientific literature). As they age, larvae also make behavioral "choices" about their position in the water column. The model provides virtual larvae with behavioral decisions every 30 seconds.

The final output of the larval transport model are maps (bottom right) that show settlement at each oyster bar in the Chesapeake Bay, for both *C. virginica* and *C. ariakensis*. These maps will feed directly into the juvenile/adult demographic model (see page 9).

just one oyster protagonist but a cast of hundreds of thousands of each of the two species.

As complicated as the plot of a complex computer model can become, the larval transport model developed by North and her colleagues dramatically simplifies ecological reality. For example, the model cannot track more than 100,000 oyster larvae in one run, while in the real world, a single oyster in the Bay can release millions of eggs, explains North. The challenge of modeling is to represent reality as accurately as possible while dealing with necessary limitations of available data and computer power, she says. The model must be strategically simplified to maintain realism yet complete simulations within a reasonable time frame, she continues. "If we don't simplify, it will be 2050 before we have an answer."

A Model Epic in Two Volumes

If the craft of a modeler can be compared to that of a writer, then the model itself could be considered an elaborate work of literary nonfiction. In the case of the oyster model, this work would read like an epic in two parts. North's larval transport model would be Volume I, the story of oysters coming-of-age. Volume II would follow the oyster and its progeny and its progeny's progeny ten years into the future. Other scientists will write this tale, technically known as the juvenile-adult demographic model.

In the opening chapter of Volume I, hydrodynamics — the Chesapeake's currents and tides — drive the plot. These forces determine the large-scale movement of oyster larvae of two species (native and non-native) over a three-week period, from spawning to settlement.

After hydrodynamics set the stage in Chapter 1, the oyster larva emerges as the central character of Chapter 2. Here a particle-tracking model takes information from the hydrodynamic chapter on currents and salinity and projects where in the Bay larvae will move during their journey. Though larvae in the wild begin to swim vertically, the computer's particle-tracking routine at this stage treats them as passive particles, entirely at the mercy of water, wind and waves.

By Chapter 3, however, the model begins to account for oyster biology and the larvae develop depth and complexity. Mimicking real life, they are no longer passive particles, but acquire attributes of age, swimming speed and behavior. That is, virtual larvae are now able — like real larvae — to direct their movements.

Chapter 4, the denouement of the larval oyster's "settle or die" drama, brings all of the plot lines together to make predictions about the potential distribution of larvae, both the native and non-native species. The pieces (hydrodynamics, particle-tracking and behavior) link together mathematically to generate maps of the Bay that forecast the distribution of each species (see graphic on page 8).

Later, North's maps will feed into another model developed by her collaborators, statistician Mary Christman of the University of Florida in Gainesville and quantitative ecologist Jon Vølstad from Versar, a science and technology consulting company. Volume II is a sequel of sorts. This so-called juvenile/adult demographic model will make predictions about what will happen as the oysters grow, reproduce, and die over the next ten years — projecting populations of the two species into the year 2015.

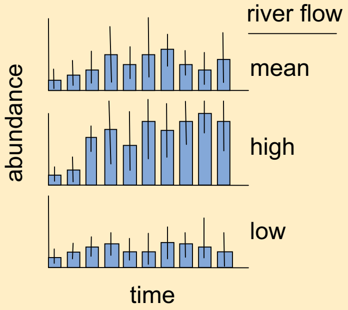
The outputs of Volumes I and II of the epic — the larval transport and the juvenile/adult demographic model — will generate maps that predict the potential distribution and abundance of the native and non-native oyster in the year 2015. These results will feed directly into policy makers' evaluations of the different restoration scenarios, providing one tool of many to assist them in making a final decision (see When Science Meets Policy, page 11).

. . . and Volume II, Where Will They Thrive?


Jim Wesson

Juvenile/adult demographic model

Predictions



The juvenile/adult demographic model builds directly on the larval transport model to predict oyster (native and non-native) populations in the Bay over time, up to the year 2015. This model incorporates estimates of natural oyster mortality, along with mortality from disease and harvesting, and uses equations to describe the growth rate, derived from over 60 data sets from different oyster bars.

"In its simplest form, the demographic model grows them, harvests them, reproduces them, and kills them," says model statistician Mary Christman.

Although it spans many generations, the demographic model is simpler than the larval transport model. The demographic model makes calculations based on whole oyster bars, some more than a kilometer in size, while the larval transport model parcels the Bay into small, one-meter square packages. Whereas the former also runs on a yearly time step, incorporating annual data on growth and mortality, the larval transport model builds in new hydrodynamic data every 10 minutes and updates the behavior of individual larvae every 30 seconds.

So there is a huge difference in computational time between the two models, explains Elizabeth North. The juvenile/adult demographic model can look at a whole year of oyster growth, mortality, and reproduction in the Bay in 10 minutes of computation. The larval transport model takes 24 hours to simulate four days of larval dispersal in the Bay.

Shorter computation time also means that researchers can run the demographic model many times to explore the effects of different environmental scenarios, such as extended periods of either high or low river flow (graph above). (For more on the demographic model, see When Science Meets Policy, page 11.) *GRAPH FROM ELIZABETH NORTH.*

In the Public Eye

It's 5 p.m. on Monday. The day doesn't usually end so early for North, who puts her computer to sleep, picks up her gym bag, and leaves her office. This is the one day each week that she leaves work behind at a reasonable hour. She drives over to the Aquaculture and Restoration Ecology Laboratory, a new building on the Horn Point campus, to teach a class. She moves the tables out of the spacious lobby so that her students will have space to spread out across the floor.

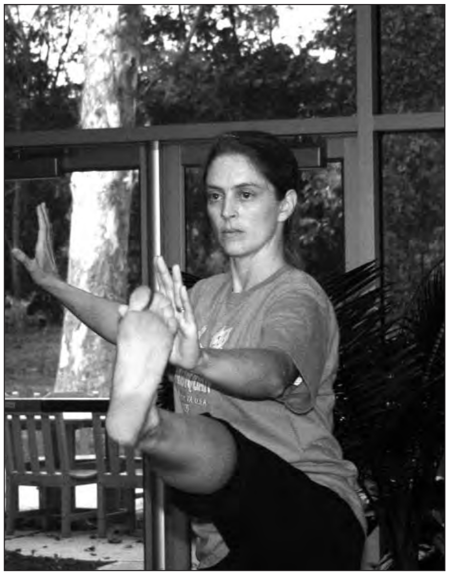
Soon a small group of regulars arrive in the lobby and take off their shoes and socks. Several older women join a couple of graduate students at the lab for North's weekly Tai-chi instruction, their camaraderie evident as they fill each other in on the week gone by. Sitting in a circle on the floor, North begins to lead the group in a series of warm-up stretches, limbering up for the challenging poses to follow.

Class begins and North guides her students through a sequence of moves that they learned in the last session. She concentrates intently on her own form and balance, while providing tips to the class on how to improve technique. To become fluent in the full practice of Tai-chi can take years of study and practice and most of her students have only recently begun.

North's own practice of this ancient Chinese art form has evolved over the past 19 years, drawing from her skills in dance and her interest in Eastern philosophies, born of her studies of comparative religion. She takes Tai-chi, a powerful tool for mind-body relaxation, very seriously, participating in retreats and classes taught by masters of the art whenever possible.

When the class finishes the steps that they know, North goes through the complete sequence of 108 exercises on her own, while her students watch her form carefully. For this moment at least, North's mind and body are far away from models, oysters, and the pressures facing a young scientist in a political spotlight.

She anticipates the day when the spotlight may sharpen its glare in her direction, when the states of Maryland and Virginia issue the final decision on the oyster Environmental Impact Statement. She braces for the maelstrom of clashing worldviews that could hit, whatever the outcome. But for the most part, North works to make the larval transport model as iron clad as possible. She also reaches out to colleagues for advice and builds support in the academic community for her modeling efforts through seminars and presentations at national meetings.



Erica Goldman

Balance and form *are everything in the ancient art of Tai-chi. Here researcher Elizabeth North works through a series of 108 poses to sharpen her concentration and focus — attributes she finds equally valuable in her scientific work.*

Now that the Department of Natural Resources has provided updated maps of currently available oyster habitat, North can begin the final runs of her model. Her computer will run day and night to generate maps that show where the two species of oysters could distribute in the Bay to feed into the projections of the demographic model. Soon DNR will ask North to present her results at their headquarters in Annapolis in what will be the fourth in a series of public meetings, held to keep the EIS process transparent and open to all interested stakeholders.

North knows that communicating the idea of "model as tool" to the public could be challenging. "People get angry at weathermen when the 7-day forecast is wrong and this is a 10-year playing field. These are not predictions of what is going to happen," she says, only what could happen. She also realizes that her findings will likely face intense scientific, public, and possibly political scrutiny.

"It is scary and it is great. I like being involved. I like the idea that the tools I am developing are going to be useful," North says.

She has spoken with other scientists about how to insulate herself from the high profile nature of the EIS project. A respected colleague advised her first and foremost to publish her model expeditiously in the academic literature, to vet it through the peer review process. "If this ends up in court, which it very well could," North recounts, "published papers will be important for credibility."

North has already written the framework for the manuscript she wants to publish. An outline sits in a file folder on her desk. She needs to complete the final model runs before she can write the Results and Discussion sections. But on the same day that she delivers her final report to the Department of Natural Resources, North plans to drop the manuscript in the mail.

For Further Information

Elizabeth North's Web Page
northweb.hpl.umces.edu/

Maryland DNR's Oyster InFocus
www.dnr.state.md.us/dnrnews/infocus/oysters.asp

Maryland Sea Grant Oyster Node
www.mdsg.umd.edu/oysters/

National Academy of Sciences Report on *C. ariakensis*
www.nap.edu/books/0309090520/html/

Chesapeake Bay Program Scientific and Technical Advisory Committee information on *C. ariakensis*
www.chesapeake.org/stac/ariakensis.html
www.chesapeake.org/stac/stacpubs.html

When Science Meets Policy

By Erica Goldman

Uncertainty — the disparity between what is known and what actually is or will be — will inevitably color the high profile decision to introduce or not introduce a non-native oyster to the Bay. Scientists can predict the abundance and distribution of oyster populations under different environmental conditions. They can model the potential for oysters to improve water quality in the Bay and evaluate the risk that a new disease or habitat change might cause to the ecosystem. Economists can predict the potential benefit of a restored oyster population for the fishery. Anthropologists can assess the social dimension of an introduction. But in the end, the Chesapeake Bay cannot simply fast-forward to 2015 to reveal what will happen under each proposed restoration scenario.

We live in an uncertain world.

"The tools we have to attach certainty to our understanding of complex systems are still evolving," explains Ann Kinzig, a biologist at Arizona State University in Phoenix who has worked extensively in the national policy arena, including a recent fellowship in the Office of Science and Technology Policy in the Office of the President. Many experiments that we undertake with ecosystems, such as emitting gases into the atmosphere, are a one shot deal, she says. Many of the statistical tools used by repeatable manipulative experiments simply do not apply.

The introduction of a non-native oyster would be a clear case of Kinzig's "one-time experiment." Once reproducing populations of the non-native oyster enter the Bay, the decision becomes irreversible, with consequences that could extend far beyond the Chesapeake region. So when it comes to the great oyster controversy, how should policymakers approach scientific uncertainty and what tools do they have at their disposal?

Uncertainty often complicates policy decisions related to the environment, especially when the stakes are high.

Uncertainty and the Oyster

To make the final decision on the oyster Environmental Impact Statement (EIS), policy makers must weigh multiple sources of uncertainty. An "uncertainty analysis" of predictions from the oyster population model forms one key part of that total evaluation, explains Jon Vølstad, from the consulting company Versar.

Scientists turn to statistical methods to quantify uncertainty in model predictions. Vølstad and Mary Christman, with input from collaborators Jodi Dew at Versar and Danny Lewis at the University of Maryland, will run the juvenile/adult demographic model thousands and thousands of times. This repetition allows them to evaluate the effect of natural variation in the system — the fact that not every oyster grows at the same rate, for example, or the fact that oysters might experience higher or lower disease-related mortality as salinity changes in wet and dry years.

Modelers can also assess the effect of uncertainty in their choice of parameters. Since data for the non-native oyster rely predominantly on lab-based studies — the species does not live in the Bay — estimates for parameters like growth rate will carry a higher degree of uncertainty than for the native oyster. To ensure that they have the best possible information to plug into the model, the researchers work collaboratively with different advisory groups, including a special "growth rate advisory committee," explains Christman.

To address sources of uncertainty in the model, Christman, a statistician at the University of Florida, Gainesville will also conduct what is known as a "sensitivity analysis." This will help deal with environmental situations that may factor significantly in the model's predictions, but occur intermittently and remain hard to predict. For example, if she finds oysters in the model sensitive to short-term patches of freshwater, Christman will ask other scientists to determine the probability that a patch of freshwater (freshet) will occur in a given area. She can incorporate this probability into the model.

"From my perspective," says Christman, "If you tell me you are uncertain, I can run the model under different conditions. But understanding that uncertainty is one thing, interpreting what to do with it is another."

The interpretation of uncertainty will occur through a formal risk assessment process, explains Vølstad. The risk assessment will provide synthesis of the total body of knowledge available and will encompass the results of all of the different components of the Environmental Impact Statement (EIS) — including modeling efforts, a literature review, and results of the ecological, economic and cultural assessments (see Assessing a Potential Introduction, pages 6-7). Scientists and managers will evaluate the quality of that information and associated risks, and make recommendations for action.

To sort and evaluate various streams of information from different sources, the Maryland Department of Natural Resources has developed a matrix with the different parts of the Environmental Impact Assessment spelled out — a decision-making worksheet of sorts. This worksheet concisely distills years' worth of research and analysis by scientists, economists, and anthropologists into a set of "decision factors."

To make this worksheet useful to decision makers, an Ecological Risk Assessment Advisory Team developed a set of objective criteria to evaluate the risk and uncertainty associated with each entry. These criteria assign each entry in the matrix with an estimated level of risk: *high*, *medium*, or *low*, and an uncertainty code: *very certain* (as certain as we are going to get); *reasonably certain*; *moderately certain* (more certain than not), *reasonably uncertain*, and *very uncertain* (a guess).

The Team will apply risk and uncertainty codes to each decision factor in the matrix for each scenario in the Environmental Impact Statement. This approach to risk assessment emulates the U.S. Geological Survey's protocol, developed when Maryland faced the first unintentional introduction of the northern snakehead fish in 2002, explains Vølstad, who works closely with the Team.

The decision matrix provides a scheme to quantify scientists' confidence in the body of knowledge on the non-native oyster in a manner that policy makers can easily interpret. But when the time comes for the final decision on whether to introduce the non-native oyster to the Chesapeake, data and decision matrices will only go so far. Different stakeholders will have different perspectives on how much risk they can tolerate. Societal values will play a key part in the final decision.

Oyster Advisory Panel chair Brian Rothschild, from the University of Massachusetts, Dartmouth, sketches the following scene: Picture a hungry man standing on a street corner. On the opposite corner, a restaurant beckons but cars zoom through the intersection. If the man could be described as normal with respect to risk tolerance, he would look both ways, cross the street, and go to the restaurant. A risk-prone man would dash into the street without looking, while a risk-averse man would never cross the street and never make it to the restaurant. Part of the challenge with the oyster decision, says Rothschild, stems from the fact that we have each of these three types of street-crossers in the Bay.

Skip Brown

At Scientific and Political Crossroads

Finding common ground between the spheres of science and policy when it comes to interpreting risk and uncertainty presents no small challenge. Uncertainty often complicates policy decisions related to the environment, especially when the stakes are high, according to Daniel Sarewitz, Director of the Consortium for Science, Policy and Outcomes, a think tank at Arizona State University. Scientific research can help reduce uncertainty to an extent, he argues in a 2004 paper published in the journal *Environmental Science & Policy*, but it will never eliminate it. And at the end of the day, policy decisions related to ecological problems — such as whether to introduce the non-native oyster to the Chesapeake Bay — must be made despite scientific uncertainty.

Reconciling scientific uncertainty with the political process requires balancing the fundamentally different goals of science and policy, based on significantly different standards of evidence, asserts Kinzig and her colleagues in a paper entitled "Coping with Uncertainty: A Call for a New Science-Policy Forum." Published in the journal *Ambio*, the article resulted from a meeting of ecologists and economists sponsored by the Royal Swedish Society in 2002. "Science doesn't tell you what you should do under a given scenario," Kinzig says.

Scientific studies must reach either a 95 percent or often a 99 percent statistical level of confidence to be considered conclusive, she explains. In contrast, the standard of evidence for many political decisions can vary, becoming more or less stringent depending on whether the perceived cost of being wrong is low or high. If a physician is certain that a patient is going to die shortly, for example, there is little hazard in prescribing a drug whose efficacy is largely unknown, but that could offer some hope of life extension, Kinzig's paper argues.

Kinzig and her colleagues identify four factors related to the difference in "evidentiary standards" between science and policy that can introduce difficulties to environmental decision making:

- A failure to communicate about the nature of the difference in standards between science and policy may cause fundamental misunderstandings.
- The need for a scientific conclusion to reach 95 percent confidence can slow the introduction of important information to policymakers, especially in studies that involve complex systems.
- The probabilities associated with future environmental scenarios can be too intractable for scientists to quantify.
- Scientific information cannot answer a value-based question about how to act, only help illuminate future outcomes and potential trade-offs.

So with all of these differences in how the scientific and political realms deal with uncertainty, do any unifying themes emerge to guide decision makers in their decision on non-native oysters in the Chesapeake Bay?

In a crowded room at the headquarters of Maryland Department of Natural Resources in Annapolis, resource economist Doug Lipton offered one answer. Lipton, an associate professor at the University of Maryland, College Park and program leader of the Maryland Sea Grant Extension Program, spoke at the third in the series of public outreach meetings for the oyster Environmental Impact Statement. He concluded his presentation on economic projections for oyster restoration with a slide that read: "Decision making under large uncertainty calls for a precautionary approach. But what is precautionary is in the eye of the beholder."

Risk may mean something different to different stakeholders, Lipton explains. Faced with near economic extinction, the oyster industry may perceive *not* introducing the non-native oyster as the riskier option. For other stakeholders, potential risks associated with introducing a new species to the Bay, such as the possibility of introducing a new disease, habitat destruction, or extinction of the native oyster, may far outweigh the risk of doing nothing.

Whether action or inaction would constitute a precautionary approach depends on the future outcome desired — again often a question of values and societal preferences. Uncertainty does not make a possible outcome less harmful, says Kinzig, nor is it an excuse for inaction. This is especially true in cases with clear global impact, such as climate change, she says. On the other hand, "when we first exploded the atom bomb, we didn't know that it would not ignite the atmosphere," Kinzig says. "In this case it might have been good to wait."

For more on this subject, visit these sites:

Publications of the Beijer Institute of Ecological Economics of the Royal Swedish Academy of Sciences
www.beijer.kva.se/publications/pdf-archive/pdf_archive.html
Archived Publications of the Consortium for Science, Policy & Outcomes
www.cspo.org/ourlibrary/themes/environment.htm

Profile

A Scientist for All Seasons

By Erica Goldman

Goggles in hand, Bob Ulanowicz descends the two narrow flights of stairs from his sloped-roof, attic office at the Chesapeake Biological Laboratory (CBL) and makes his way down toward a long, wooden pier that juts out several hundred feet into the Patuxent River. When he reaches the end, he stops and leans against a wooden piling to stretch his calf muscles and swings his arms like a windmill to work out the kinks. Removing his t-shirt and denim shorts, he takes off his eyeglasses and pulls on his black, almost opaque goggles. Then he jumps feet first into the water. Ulanowicz never dives.


Erica Goldman

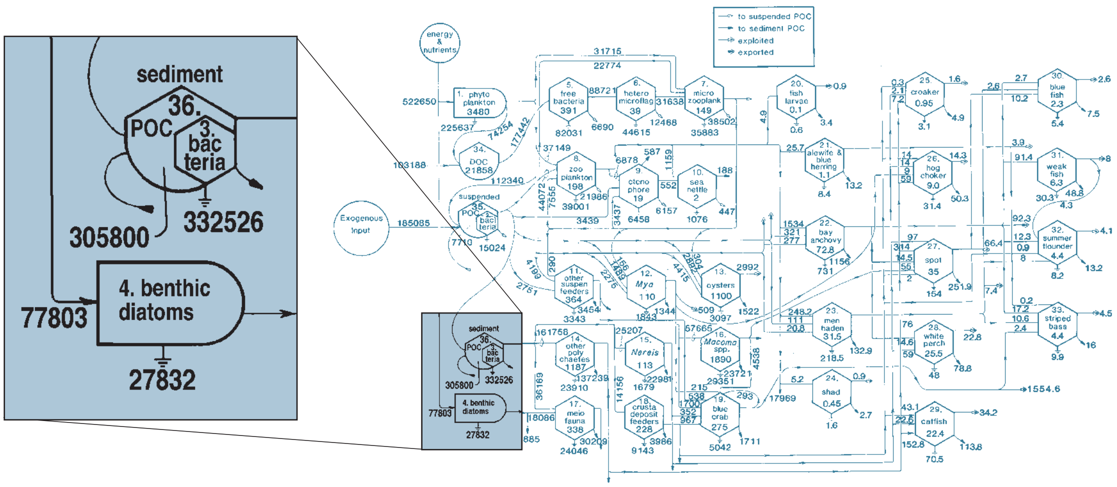
Warming up for his daily swim, *Bob Ulanowicz prepares to jump into the Bay at the same spot he experienced a career-shaping moment of clarity many years ago.*

Ever since Ulanowicz became a faculty member at the University of Maryland Center for Environmental Science, just over 35 years ago, he has jumped off the dock at lunchtime to swim for exercise. Every day, beginning May 8 — his father's birthday and the approximate date that Bay water temperatures reach 60°F — and continuing until November 1, Ulanowicz makes this daily pilgrimage to the edge of the CBL pier to swim 700 yards out to a navigation buoy. He enters the water at the exact spot where he experienced what he calls his "Faustian moment."

Standing at the edge of that same dock many years ago, shortly after starting at the lab as a young researcher, Ulanowicz peered into the water and experienced a sense of wonder and clarity. Like Faust in the classic legend, he suddenly realized that he had a near limitless thirst for knowledge about how the Chesapeake Bay food web functions. He decided then that he would go a great intellectual distance to understand this ecosystem. If only, he mused, we could measure the interactions of all of the organisms with each other — the copepods, the isopods, the fish — and put this together in one major model, then we would know how this system works. Or at least that was what he thought at the time.

When he first embarked on his quest to study the Bay, Ulanowicz had to strike a bargain, albeit a much kinder, gentler one than Faust's pact with the devil. In 1970

Network Map of the Chesapeake Bay Ecosystem



A wiring diagram for the Bay. In the "who eats whom" world beneath the Chesapeake, Bob Ulanowicz's network map of the Bay's food web builds links from the smallest algae all the way to the biggest fish. A framework for understanding the function of the ecosystem, his network map connects organisms (shapes) as they eat and are eaten, accounting for the amount of carbon (numbers outside shapes) that flows between them.

Ulanowicz, then an Assistant Professor of Chemical Engineering at Catholic University of America in Washington, D.C., approached CBL director Gene Cronin with the idea of developing an ecological model of the Chesapeake Bay food web. At the time, there was no job opening for the theoretical work that he proposed, but the lab did need help with a project for the Army Corp of Engineers to measure detailed hydrodynamic properties of the Bay. Ulanowicz would be a perfect person for the job. So Cronin offered him a deal: Do the hydrodynamic work for four years, then he would give him the green light to transition into the ecological modeling Ulanowicz really wanted to pursue.

Ulanowicz spent countless hours on the Bay measuring tidal height and salinity as part of a major field program. He observed the Chesapeake carefully, honing his ideas and waiting for the opportunity to make the jump into theoretical work.

When the time came, Ulanowicz was poised and ready to embrace the world of ecological modeling. His engineering background had equipped him to approach the problem at the level of the whole ecosystem, a "big model, big science" way of thinking. "It didn't dawn on me until a number of years after I started in biology that this approach was very much at odds with the way that most biologists were taught," he says.

Ulanowicz's thinking about how to model the Bay ecosystem matured and solidified in the late 1970s and early 1980s. As an invited member on the Scientific Committee for Oceanic Research (SCOR) Working Group, he became keenly aware that the popular approach to modeling complex ecosystems like the Chesapeake Bay had not performed well. While serving the group's charge to assemble a volume on mathematical models in oceanography and recommend future directions for research, Ulanowicz began to scour the literature to evaluate alternatives to these "multiple process ecological models."

If you want to model one process, such as one animal's respiration rate as a function of temperature, you can do a reasonably good job with the process models, explains Ulanowicz. But when you try to model multiple processes (respiration and feeding, for example), the problem becomes more complicated. There are two routes to take but each has a major tradeoff, he says. If you try to be as realistic as possible, the system quickly acquires multiple dimensions, which can cause the model to become unstable or chaotic. But if you simplify the model to try to correct the instability, you sacrifice fidelity to nature, Ulanowicz says.

The inadequacy of these multiple process models to capture the dynamics of complex ecosystems led Ulanowicz to expand upon his earlier thinking. He realized that if he could create a map of just the "who-eats-whom" interactions between all of the organisms in the Bay, he could represent the interactions between organisms as flows — exchanges of energy, carbon, nitrogen, phosphorus, or anything for which you can do the ecological "bookkeeping." Such an approach would help simplify and visualize complex ecological systems.

With this shift in his thinking, Ulanowicz began to borrow ideas from the field of information theory, a statistical approach that deals with the processing of information. He developed a scheme to describe the Chesapeake Bay ecosystem mathematically as a network of players, each connected by flows of carbon between them. This approach, called network analysis, maps the connections between players and the rate at which the interactions take place.

Network analysis takes a snapshot of the anatomy of an ecosystem, akin to an X-ray in which all of the bones show plainly. "There is a lot that you can tell about the body and how it is operating from a snapshot of the bones," says Ulanowicz. For example, a network map can show an ecosystem's organizational framework, identifying niches and smaller networks within the larger network. With the mathematical tools of network analysis, the map can help unravel the functional importance of one niche, such as the oyster, to the ecosystem as a whole.

Visualizing an ecosystem as a network can also provide clues about how an estuary like the Chesapeake Bay evolves over time, Ulanowicz explains. If you take a picture of a network at one time and a picture of it at another point in time, you can say whether the network has grown

Erica Goldman

Back in his office, *Bob Ulanowicz prepares to review a grant proposal — in Spanish — one of five languages in which he is proficient.*

and developed or retrogressed. As an ecosystem matures, a certain measure of its organization tends to increase. Ulanowicz calls this measure the *ascendancy index*. A mature ecosystem, which has a higher ascendancy index, may be organized in a way that performs better in some respects than a less mature system. But maintaining structure carries an energetic cost that becomes greater with increasing complexity, says Ulanowicz.

"I like windows in my car that you can roll up by hand, because they can't go bad. When you have something that is more complicated, more highly organized, more specific, it always costs more to maintain," Ulanowicz says.

What causes the organization of an ecosystem to change or mature over time? The answer to this question, Ulanowicz now realizes, contradicts the thesis of his "Faustian moment" to some extent. Network theory helped him understand that creating a giant model that captured all of the processes in the ecosystem would not reveal exactly how the Chesapeake Bay worked. It could not, because such a model would not allow for "singular events" or explain how the system could develop and grow.

Singular events are things that have happened "once and for all time in the history of the universe and will never happen again." Ulanowicz paints the following picture: If you were to go to Grand Central Station in New York and take a photograph of a certain area, where there are 96 people milling about, the chances of your ever coming back and taking an identical photograph of those exact 96 people is "zip, zilch, nada." It is meaningless to calculate the probability that the same people will be in the same place at another time because it transcends physical reality — it will never happen. That configuration of people is a singular event.

Although every singular event itself is unique, individual rare events happen all around us, all of the time, Ulanowicz explains. Most events happen and go away, leaving no impression on the system or causing a short-lived reaction. Very rarely, but every so often, a singular event can cause a major functional change to a system's performance — like the Chesapeake Bay's response to Tropical Storm Agnes in 1972. That event will then become part of the system's history and fundamentally alter its structure, he says.

On a theoretical level, Ulanowicz's work stretches your mind, tending toward the philosophical, even the epistemological. He's just begun writing his third book now and he hopes that this one will bring all of the intellectual pieces of his life's labor together in a unified framework.

Beyond theory, however, Ulanowicz's work laid the foundation for Ecopath, a very practical modeling tool with applications for ecosystem management. Developed by scientists at the University of British Columbia in Vancouver, Ecopath is a freely available ecological/ecosystem modeling software package that can address complex problems, such as the multi-species management of fisheries. Ecopath's software counterpart, called Ecosim, can explore policy scenarios, "what if" cases of what would happen as an ecosystem undergoes changes. Ecopath/Ecosim software currently underlies more than 100 published ecological models, including an adaptation for the Bay developed by the National Oceanic Atmospheric Administration's Chesapeake Bay Office. At Ecopath's core lie Ulanowicz's ideas on ecosystems as networks connected by flows of matter or energy.

* * *

When Ulanowicz returns to his office and sits down at the computer, his silver blond hair is still wet from his post-swim shower. He settles into an orange desk chair and prepares to spend the afternoon reading and evaluating a grant proposal written in Spanish, a language that he began studying 6 years ago — to supplement his linguistic facilities in German, Ukrainian, Polish, and French. The office grows quiet, the only sound coming from Ulanowicz's fingers clacking on the keyboard.

Ulanowicz, now 62, plans to retire in a few years, after he has helped his two remaining graduate students complete their degrees. Ulanowicz's contributions to the field of ecological network modeling assure a lasting legacy and, without doubt, a new generation of scientists will build upon his work. But Ulanowicz's unique hybrid of ecologist, engineer, and philosopher may be what theoreticians like himself would characterize as one of those rare singular events that makes a difference.

For more about Ulanowicz and related research, visit the web:

Bob Ulanowicz's Home Page
http://cbl.umces.edu/~ulan/
Ecopath
http://www.ecopath.org/

Maryland Sea Grant RFP

Maryland Sea Grant's Request for Proposals (RFP) is now available for February 1, 2007–January 31, 2009. The program offers support on an open, competitive basis. This funding cycle will focus on coastal conservation and restoration. Principal Investigators (PIs) must be affiliated with an academic institution or research laboratory in Maryland. Co-PIs can be from institutions outside Maryland.

The RFP and application materials are on the web at www.mdsg.umd.edu/Research/RFP/. To request a paper copy or for more information, call 301.405.7500.

Fellowship Opportunities

Dean John A. Knauss Marine Policy Fellowships. These fellowships are 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. Fellowships will run from February 1, 2007 to January 31, 2008 and pay a stipend of $33,000 plus $7,000 for expenses such as health insurance and travel.

To qualify for a fellowship, students must be enrolled in a graduate or professional degree program in a marine-related field at an accredited institution in the United States on April 1st of the year of application.

The application deadline is March 1, 2006; however, applicants are urged to check with the Maryland Sea Grant office by mid-January for guidance and application details. For general information, please check the web at www.seagrant.noaa.gov/knauss. html.

Coastal Management Fellowships. These fellowships offer on-the-job education and training opportunities in coastal resource management and policy for postgraduate students and provide project assistance to state coastal zone management programs. Established by the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center in 1996, this two-year opportunity offers a competitive salary, medical benefits, and travel and relocation expense reimbursement.

Students completing a master's, doctoral, or professional degree program in natural resource management or environmental-related studies at an accredited U.S. university between January 1, 2005 and July 31, 2006 are eligible. Those studying a broad range of environmental programs are encouraged to apply.

The application deadline for the fellowship program is January 30, 2006. Those interested in applying should check with the Maryland Sea Grant office as soon as possible for guidance in the application process. For general information, please check the web at www.csc.noaa.gov/cms/fellows.html.

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For application details concerning either the Knauss Marine Policy fellowships or the Coastal Management fellowships, contact Susan Leet, Maryland Sea Grant College Program; phone, 301.405.6375; e-mail, leet@mdsg.umd.edu.

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

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