RINEHART COASTAL RESEARCH CENTER
WOODS HOLE OCEANOGRAPHIC INSTITUTION

COASTAL RESEARCH

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ECOHAB-GOM Investigators Plumb Red Tide Depths

Harmful algal blooms, commonly called "red tides," are a serious economic and public health problem throughout the world. Though most species of marine algae are benign, there are occasions when these microscopic organisms wreack havoc on coastal ecosystems. They do this by proliferating to concentrations that literally smother the rest of the marine life or by producing toxins that poison the carnivores (including humans) at the top of the food chain. The term "red tide" comes from the phenomenon where certain pigmented plankton attain such high concentrations that the water takes on a blood-red hue. Most "red tides" do not turn the water red, nor are they associated with the tides. Nevertheless, the name has stuck, although scientists now prefer the term harmful algal bloom (HAB).

In New England waters, "red tide" usually refers to outbreaks of a genus of dinoflagellate called *Alexandrium*, which contains dangerous neurotoxins. When shellfish feed on plankton containing toxic algae, the toxin accumulates in their tissues. When vertebrates (such as humans) eat the shellfish, it causes a condition known as paralytic shellfish poisoning, or PSP, which can cause temporary paralysis or even death. Since 1972 when a major outbreak occurred, PSP has become an annually recurring event along the New England coastline.

Diver Photo: Kristin Gribble. Alexandrium inset: Lawrence M. Fritz

Wayne Spencer retrieves bag of mussels for monitoring harmful algae. Inset: Electron micrograph image of Alexandrium tamarense.

PSP is not unique to the Gulf of Maine––various species of *Alexandrium* and other algae with similar neurotoxins occur along the west coast of the US and in both tropical and temperate regions of the world. Other kinds of HABs, such as "brown tides" in Long Island bays, or *Pfisteria*, the so-called "flesh-eating dinoflagellate" that affects the estuarine waters of the mid-Atlantic and Florida, or *Gymnodinium breve*, commonly referred to as the "Florida red tide organism," acutely impact the ecology of coastal waters and may provoke a wide range of human health effects. The frequency and severity of HABs appear to be increasing worldwide, in part because of increased eutrophication, and possibly because of more careful monitoring.

Recognizing the serious and growing HAB problem in the US, a partnership of federal agencies agreed to provide funding for the ECOHAB program (the ECology and Oceanography of Harmful Algal Blooms). Participants include NOAA, NSF, EPA, NASA, and ONR. The NOAA Coastal Ocean Program administers the program. Two regional research programs were funded during the first phase of the program, one in the Gulf of Mexico and the other in the Gulf of Maine. The Gulf of Maine study (ECOHAB-GOM) is led by Don Anderson and involves 17 researchers from ten institutions, seeking to understand the dynamics of *Alexandrium* and ultimately to predict the occurrence of PSP outbreaks in the Gulf of Maine.

Earlier studies of *Alexandrium* in the Gulf of Maine suggested that there might be two populations, one originating in the Bay of Fundy and the other originating near the mouth of the Kennebec River in the western

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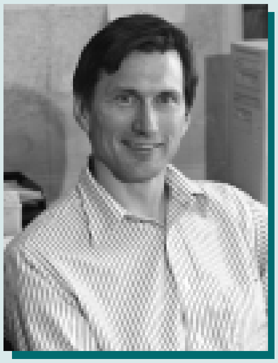
A Message from the Director of the RCRC:

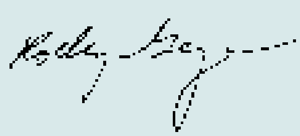


Ocean "observatories" are becoming a major priority for the ocean science community. There are several prototype coastal observatories in place, including the Rutgers LEO-15 observatory, the US Army Corps of Engineers' facility at Duck, NC, and the rapidly progressing Martha's Vineyard observatory being developed by WHOI scientists and engineers. I confess that I was initially confused by this flurry of interest in observatories, wondering why these facilities were of such interest to scientists and, perhaps more importantly, why they should warrant a significant share of public funding for ocean measurements.

Reflecting on some of the issues in New England waters, I am beginning to grasp the importance of the observatory concept. Consider the "red tide" problem in the Gulf of Maine. It takes about a week for toxic dinoflagellates to grow from the level of detection to the level at which they can render a clam lethal to humans. The State of Maine monitors the condition of shellfish weekly to determine the presence of toxicity, and has been doing so for more than 20 years. This is not only a critical service for public health but also a valuable research tool. This shellfish monitoring program provides key information for WHOI researchers on the physical transport of dinoflagellates in the Gulf of Maine.

Another example farther down the coast is the monitoring program for Boston's sewage outfall. The Massachusetts Water Resources Authority (MWRA) has been monitoring the receiving waters for seven years, eight by the time the outfall begins operation this fall. During this period, there have been large interannual variations in phytoplankton species and abundance, and one episode of low oxygen conditions near the future outfall. This baseline will be invaluable for properly interpreting changes that occur after the discharge commences. The MWRA's interest is obvious. So too is the interest of the scientific community.

Observatories come in all shapes and sizes, and they have a diverse constituency. As the scientific community shapes its agenda for enhanced coastal observatories, let's build on the strengths of these existing observatories, both with respect to their immediate societal relevance and their functionality. We might be able to make observatories better, but we cannot make them any more important.



Rinehart Coastal Research Center announces 1999 Funding Awards

The Rinehart Coastal Research Center is pleased to announce funding of the following projects:

John Stegeman—New Approaches to Detecting Developmental Toxicity in Estuarine Fishes;

Kenneth Halanych—Assessing Genetic Subdivision in the Ocean Quahog (*Arctica islandica*);

Wade Powell and Mark Hahn —Physiological Consequences of Multiple Environmental Stresses to Estuarine Fish: Dioxin-like Compounds and Hypoxia;

Roger François —An Investigation of the Seasonal Variability in Trace Metal Cycling in Pristine and Contaminated Buzzards Bay Sediments;

Timothy Eglinton, Christopher Reddy, and Carl Wirsen —Microbial Degradation of Polychlorinated Biphenyls in Marine Coastal Sediments: An Isotopic Investigation;

Anne Cohen and Graham Layne —A History of Paleo-Hurricane Activity Recorded in the Stable Isotope Composition of Coral Skeleton;

Daniel McCorkle and Dempsey Lott —Tritium/Helium Studies of Groundwater Discharge in Coastal Environments;

Peter Tyack and Patrick Miller —Demonstrating a New Tool to Study Coastal Marine Mammals: Source Levels, Directionality, and Signature Information in Killer Whale Calls.

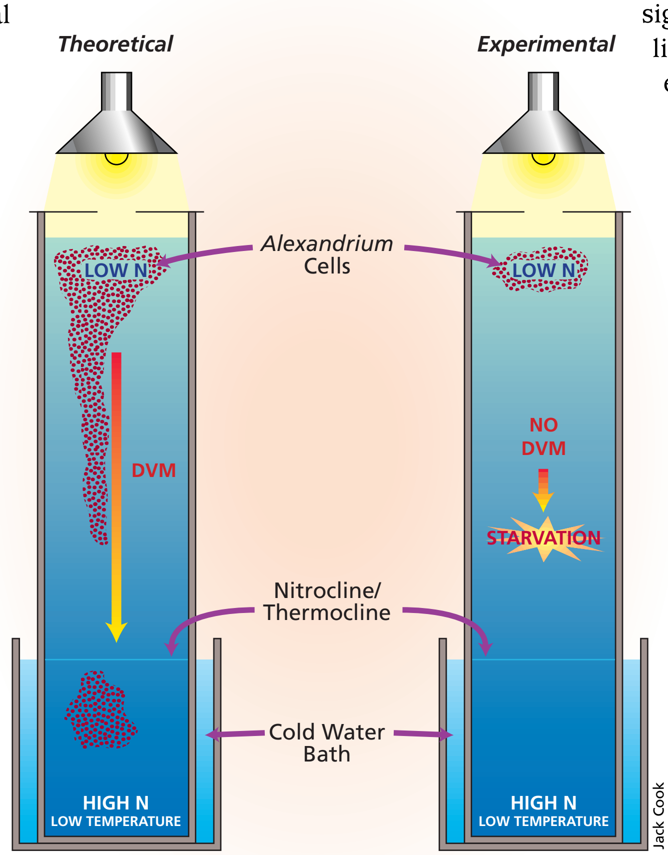
ECOHAB-GOM Experiments Study Toxic Dinoflagellate *Alexandrium*

One ECOHAB-GOM project is designed to determine the physiological and behavioral features of the toxic dinoflagellate *Alexandrium* that define its ecological niche in the coastal environment.

Since dinoflagellates are motile, they can exploit nutrients at depths below the nutrient-limited surface layer. This is primarily achieved through diel vertical migration, but it also requires an ability to acquire nutrients in low light or in the dark. Since surface nutrient concentrations are usually very low during an active spring bloom, vertical migration behavior has long been considered the adaptation that allows some dinoflagellate species to persist and survive longer than nonmotile phytoplankton that are incapable of accessing nutrient-rich deep water.

The primary objective of this experiment is to determine the nutritional, physiological, and behavioral responses of *Alexandrium* cells isolated from Casco Bay, Maine, during nutrient (specifically nitrate) depletion and starvation.

For our studies, we conducted an experiment using a 2-meter tall, thermally stratified water column (mesocosm–see figure). The temperature of the mesocosm ranged from 17° C at the surface to 7° C near the bottom, representing a range of coastal temperatures typically observed during *Alexandrium* blooms. Initially, the nitrate concentration was constant throughout the tank (50 micromoles per liter) when *Alexandrium* cells were added. Cold temperatures at the base of the mesocosm stratified the system. The mesocosm was sampled four times a day by removing water from discrete depths to monitor changes in the nitrate concentration, cell distribution, and cell physiology/composition. During the light period, a dense surface layer of cells formed and rapidly depleted the nitrate from the surface by Day 3. By Day 12 nitrate had only been depleted in the top 20 centimeters and no nocturnal migration had occurred. During a previous experiment, conducted by colleagues using an *Alexandrium* isolate from the Gulf of St. Lawrence (Canada), vertical migration behavior was observed, and all nitrate in the mesocosm (including that below the thermocline) was taken up by Day 12.



Cross-Section of Theoretical and Experimental mesocosms.

The Casco Bay *Alexandrium* in our mesocosm maintained a dense surface layer and showed signs of progressive nitrogen limitation during the 35-day experiment.

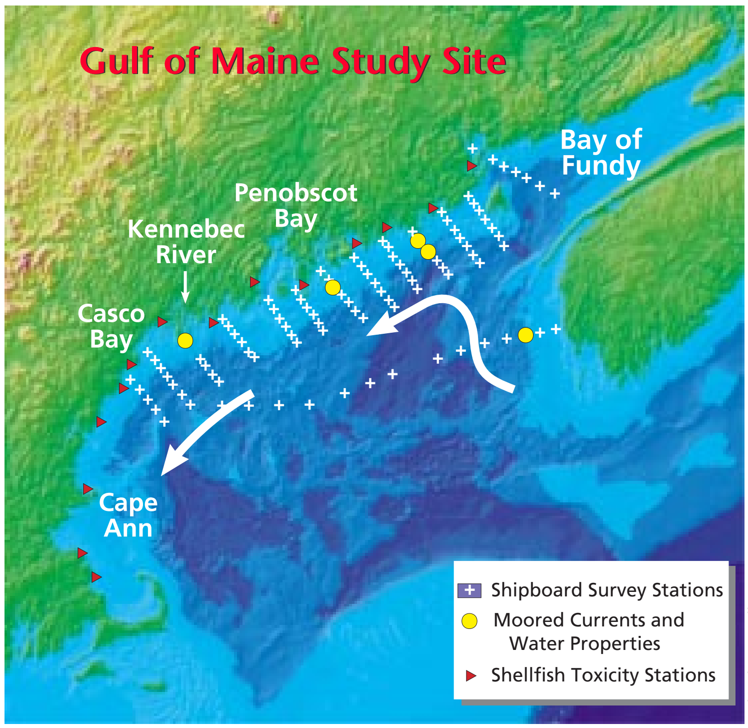
These results are significant with respect to *Alexandrium* population dynamics in the Casco Bay region. *Alexandrium* blooms in the Western Gulf of Maine have much lower cell densities than blooms observed in the Eastern Gulf of Maine, especially in the Bay of Fundy, and this difference may relate to the strict reliance of the former populations on new or recycled nutrients. With further experiments using additional isolates from the Casco Bay region, we hope to examine this physiology and behavior in more detail. The next step will be to incorporate these physiological and behavioral adaptations of *Alexandrium* into numerical models (see article on page 6) that will ultimately be used to simulate and perhaps even predict the occurrence of these toxic phytoplankton in the Gulf of Maine.

This article was contributed by Nicole J. Poulton, an MIT/WHOI Joint Program student with the Biology Department.

ECOHAB – from page 1

Gulf. Outbreaks in the western Gulf are initiated a month or two earlier than the Eastern Maine blooms, yet the motion of the water is typically from east to west (see map). This suggests that the two populations are distinct; indeed there is a section of the coast of Maine near Penobscot Bay that rarely experiences shellfish toxicity, yet there are frequent closures of the shellfish beds due to red tides to the east and west. This "PSP-sandwich" is evidence of the separation of the two populations. It has also been suggested that the offshore veering of the Eastern Maine Coastal Current near Penobscot Bay may keep the toxic cells from making landfall in this part of the coast. Objectives of the current study are to understand the similarities and differences between the dynamics of these two regional populations and to determine whether there are connections between them.

Identifying the origin of the annual blooms of *Alexandrium* is still a major, unsolved problem in both the Western Maine and Eastern Maine regions. Extensive studies by Anderson and colleagues in the western Gulf suggested a "seed" population near the mouth of the Kennebec that would initiate western Gulf blooms, which are then carried by the western Maine Coastal Current toward New Hampshire and Massachusetts coastal waters. A likely source of cells is cysts of *Alexandrium* found in sediments throughout the western Gulf (see figure on page 5). Major questions to be addressed concern whether the blooms can be traced back to the germination of cysts and locations of the cyst beds that initiate the blooms. Do the cysts germinate in the shallow waters of Casco Bay that warm more rapidly during the spring, or do they arise from the deeper, colder offshore waters?



Richard P. Signell

Outbreaks are observed both in the nearshore waters and offshore, and it is not yet clear where the bloom starts.

In the effort to track down the source, a cruise was conducted in late 1997 to map the distribution of *Alexandrium* cysts in the sediments of the western and eastern Gulf. No cysts were found in the Kennebec River, and surprisingly few cells were found in Casco Bay, heretofore the prime suspect for the bloom origination. The highest concentrations of cysts were in the muddy sediments offshore, in water depths greater than 100 meters. The environmental physiology of cyst germination was examined in a series of laboratory experiments to determine how temperature and light affect the rate of germination. These data are being incorporated into a cyst germination model that provides the source condition for the *Alexandrium* transport model (see article on page 6).

Documenting the onset of blooms is one of the more challenging aspects of the ECOHAB research program. Cells first appear in the surface waters in early April, which is still gale season in the western Gulf. A seaworthy team of researchers lead by Bruce Keafer from Anderson's lab went out weekly, regardless of weather or sea conditions, on the University of New Hampshire's 50-foot R/V *Gulf Challenger* to document the cell distributions. In addition to direct sampling of the water for cells, bags of mussels were deployed on mooring buoys to provide biological integrators of the previous week's *Alexandrium* concentrations. Toxin analysis was provided by the Maine Department of Marine Resources.

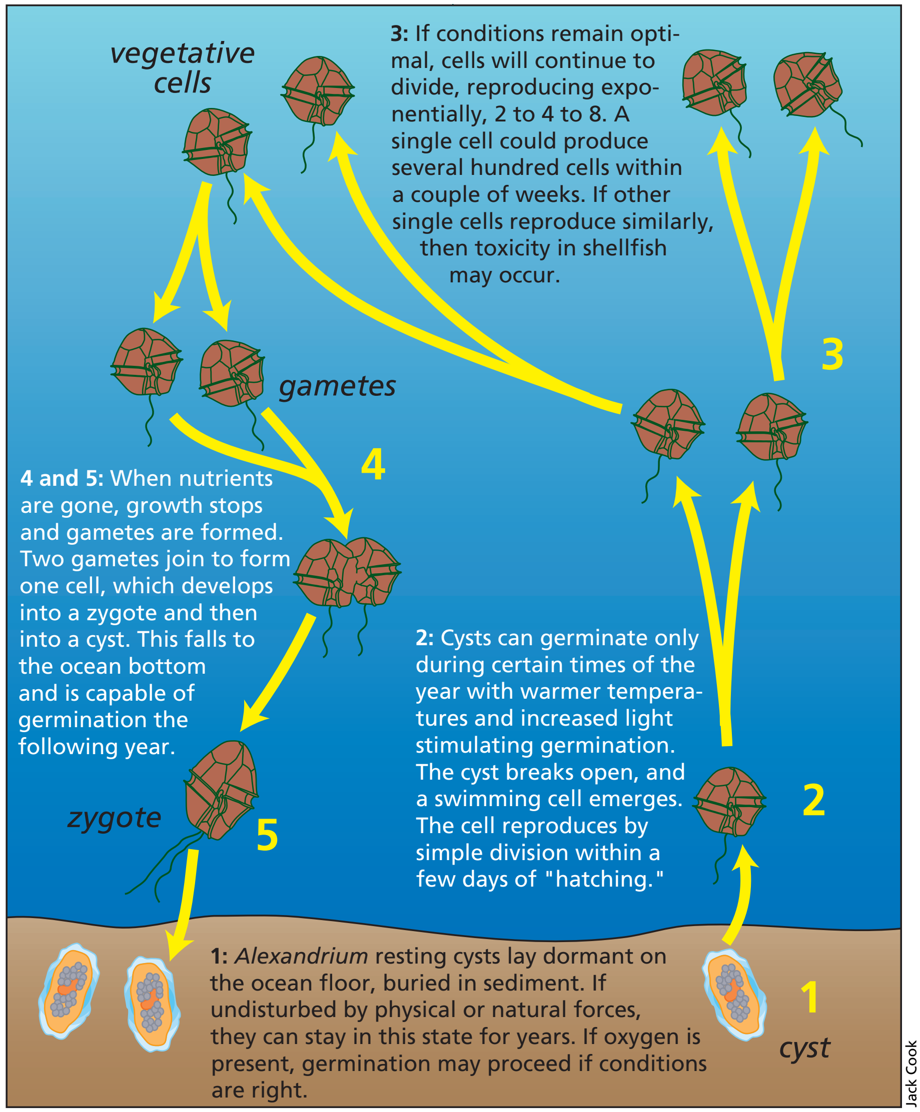
The mussels provided the first indication that the blooms may be initiated offshore. Mussels on the farthest offshore mooring became toxic first, and then toxicity spread shoreward in subsequent weeks. This pattern was generally confirmed by *Alexandrium* cell counts obtained by the shipboard surveys, although there were also low densities of cells present inshore.

A more far-reaching question involves the connection of the western Gulf population to large blooms of *Alexandrium* that occur later in the summer in the eastern Gulf. Three cruises were conducted under the supervision of Dave Townsend of the University of Maine during the summer of 1998 to determine the distribution of the Eastern Maine population, its response to the oceanographic regime, and its possible connection to the western Gulf region. Resulting data showed maximum cell densities in the offshore waters of the Gulf, and not immediately adjacent to the shoreline as might be expected based on previous patterns of shellfish toxicity. When the distributions were compared with the satellite images of sea surface temperatures, it became clear that the highest cell densities were well correlated spatially with the cold surface waters that characterize the Eastern Maine Coastal Current.

In order to explain the patterns of abundance of dinoflagellates in the eastern Gulf, Townsend is testing the hypothesis that these distributions are controlled by the joint influence of light and nutrient availability, as some initial comparisons of the patterns of nutrient-plus-light availability and *Alexandrium* suggest.

There remain a large number of unresolved questions, but the study has three years to go. It is still not clear whether the large eastern Maine population is related to the western Maine outbreaks. The bloom initiation question is still unsolved. Progress is being made on how light and nutrients affect *Alexandrium*, but little is known about how grazing might impact their distribution. There is considerable uncertainty about whether the motility of these dinoflagellates may augment their ability to obtain nutrients from deeper waters (see article on page 3). As these questions are resolved, the information will be incorporated into a physical-biological model, moving toward the ultimate goal of predicting the occurrence of HAB outbreaks and the protection of coastal resources and human life.

Donald M. Anderson is a Senior Scientist and Bruce Keafer is a Research Associate in the Biology Department at Woods Hole Oceanographic Institution. David Townsend is a Professor of Oceanography at the University of Maine.

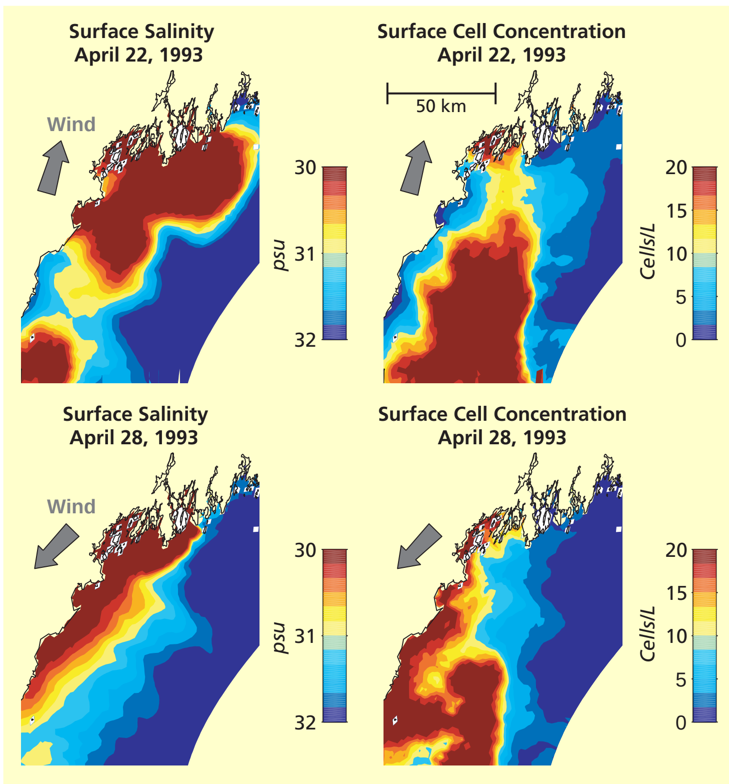


The Life Cycle of an algal cell.

ECOHAB-GOM Investigators:
Don Anderson, WHOI
David Townsend, University of Maine
Jim Churchill, WHOI
John Cullen, Dalhousie University
Greg Doucette, NMFS, Charleston, SC
Rocky Geyer, WHOI
Bruce Keafer, WHOI
Maureen Keller, Bigelow Lab
Ted Loder, University of New Hampshire
Dan Lynch, Dartmouth College
Jennifer Martin, Canadian Fisheries and Oceans
Dennis McGillicuddy, WHOI
Neal Pettigrew, University of Maine
Nicole Poulton, WHOI
Rich Signell, USGS, Woods Hole, MA
Andrew Thomas, University of Maine
Jeff Turner, UMASS–Dartmouth

Scientists Model Harmful Algal Blooms for ECOHAB-GOM

Numerical modeling plays a key role in ECOHAB-GOM due to the number and complexity of processes that affect *Alexandrium* through its life cycle (see figure on page 5). A numerical model is an important tool that can help fill gaps in data sets, isolate key dynamical processes and weak links in our understanding, and act as a numerical laboratory in which specific hypotheses can be tested. The models currently used in ECOHAB-GOM range from sophisticated three-dimensional biological/physical models to simpler models that include excystment, swimming and cell growth. The models are being applied in several different domains and scales, from a high-resolution Casco Bay model to a lower resolution model of the entire Gulf of Maine.



Richard P. Signell

Previous to this study, it was known that harmful algal blooms in western Maine, New Hampshire, and Massachusetts are usually associated with fresh water plumes from Gulf of Maine rivers that transport organisms along the coast (see map on page 4). Early modeling work has demonstrated the importance of these plumes in the transport and fate of the cells. However, there remain major questions about the origin of blooms. The river plumes originate at the coast and are typically coastally trapped, while peak cyst concentrations are generally found 30–50 kilometers offshore, seaward of the 100 meter isobath.

How do the offshore cells get into the plumes? It was thought that small pockets of cysts in coastal embayments might be responsible for inshore initiation of the blooms. The modeling does not refute the mechanism of inshore initiation, but it has identified a mechanism for offshore initiation as well. When the wind blows from the southwest, the plume moves rapidly offshore in a thin layer only a few meters thick. In a couple of days, the plume can extend 30–50 kilometers offshore (see upper panel). Cells from the offshore cyst beds can swim directly up into the plume, where the buoyancy of the plume helps them to maintain high light conditions and perhaps find beneficial nutrients or trace elements that stimulate growth. A subsequent wind event from the northeast induces downwelling which returns the plume water shoreward and delivers the cells to the coast (see lower panel of figure). This was consistent with spring 1998 field data, which had strong evidence of offshore initiation. Realizing this, Maine officials modified their monitoring program for spring 1999, adding shellfish toxicity testing sites at offshore islands that could provide an "early warning system" for the Maine coast.

Ongoing modeling work by Dennis McGillicuddy and Rich Signell (USGS) focuses on defining cell transport pathways during the 1998 field season by conducting sensitivity studies to initial cyst distributions, excystment rates, and growth processes in an attempt to isolate the key factors that currently limit our ability to simulate observed cell distributions. In the future, the understanding that stems from projects like ECOHAB-GOM will enable us to construct realistic simulation models driven by real time data collected at strategic locations to predict the landfall of red tide blooms in the Gulf of Maine.

This article was contributed by Richard P. Signell, an Oceanographer with the US Geological Survey. Dennis McGillicuddy is an Assistant Scientist in the Applied Ocean Physics and Engineering Department at Woods Hole Oceanographic Institution.

Balancing the Sediment Budget of the Hudson Estuary

Jon Woodruff

April 1999 research team Craig Marquette, Peter Traykovski, Rocky Geyer, and Jay Sisson on M/V Samantha Miller.

The Corps of Engineers estimates that 2 million tons of sediment enter New York Harbor annually—they know because they have to dredge it out. Geochemical evidence suggests that the sediment is coming from the Hudson watershed, based on minerology and radioactive tracers. However there is one problem with this story: No one has ever observed significant seaward transport of sediment in the Hudson River estuary. Thus there remains a major question—how and when does all of this sediment get through the estuary?

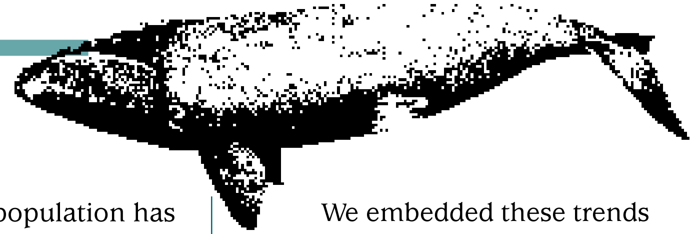
Geyer and colleagues have been looking at sediment transport in the Hudson for a number of years, focusing in the past on how the currents in the estuary move the sediment around and affect the distribution of suspended sediment. These studies did not indicate any simple pattern of transport—picture swirling leaves during an autumn storm. It is hard to miss two million tons passing through your study area, but after five field studies, there was still no clear indication of a net seaward transport of sediment.

With support from the Hudson River Foundation, Geyer's team set out to measure the sediment transport and accumulation through an entire spring season, when the high flows are likely to deliver most of the sediment to the estuary. One set of instruments measures the sediment coming in from the north, another measures the export to the south, and a third array measures the accumulation (or erosion) of sediment in the estuary. In addition to these instruments, a comprehensive sediment-coring program is tracking the accumulation of new sediment in the estuary.

The coring studies started in June 1998 to determine whether new sediment deposition could be identified. Previous research indicated that high accumulation rates occur in certain parts of the estuary, but it still came as a shock when cores came up with layers of newly deposited sediment ranging in thickness from 10 to 45 centimeters (see photo on page 11). The results of the 1998 survey indicate that half a million tons of sediment were trapped in the estuary during the spring. However it still isn't clear how much sediment passes through the estuary, what conditions lead to sediment trapping, and where the trapped sediment comes from.

The combination of sediment transport measurements and coring during the spring of 1999 should provide the answers. Early 1999 coring surveys suggest that the trapping first occurs farther to the south, and then moves northward into the estuary during the spring. Preliminary results of our sediment transport measurements suggest that the

SEDIMENT– page 11



Will the North Atlantic Right Whale Survive?

The North Atlantic population of the Northern Right Whale (*Eubalanea glacialis*) is one of the most endangered whale populations in the world. It was nearly decimated by commercial whaling, and has recovered only slowly after becoming protected in 1935. It currently numbers about 300 individuals.

Right whales are subject to anthropogenic mortality from entanglement in fishing gear and collisions with ships. For any endangered species, but especially one at risk from human-caused mortality, it is critical to obtain accurate estimates of the vital rates (a collective term for rates of survival, growth, maturation, and reproduction) and to design a population model in which those rates appear as parameters.

With funding provided by the Rinehart Coastal Research Center Masami Fujiwara, Solange Brault, and I have been pursuing population analysis of the right whale. The key to our efforts is the fact that a trained observer can identify individual right whales from photographs on the basis of unique markings and scars. Since 1980, a photographic database of the North Atlantic population has been maintained at the New England Aquarium. This database provides an invaluable record of the histories of individual whales (when first sighted, whether sighted or not in each successive year, and when observed with a calf) over nearly two decades.

The probability of the sighting history of an individual whale can be written in terms of a sighting probability (s_t) and a survival probability (p_t). These probabilities may vary over time, or as a function of sampling effort or environmental variables. The parameters p_t and s_t can be estimated by maximum likelihood methods, and different models for survival and sighting can be compared statistically.

Our results were dramatic. We documented a hitherto unexpected decline in annual survival probability, from about 0.99 (that is, about a one percent chance of death each year) in 1980 to about 0.94 in 1995. The trend is highly statistically significant. At the same time, workers at the New England Aquarium reported a declining trend in the birth rate of the population.

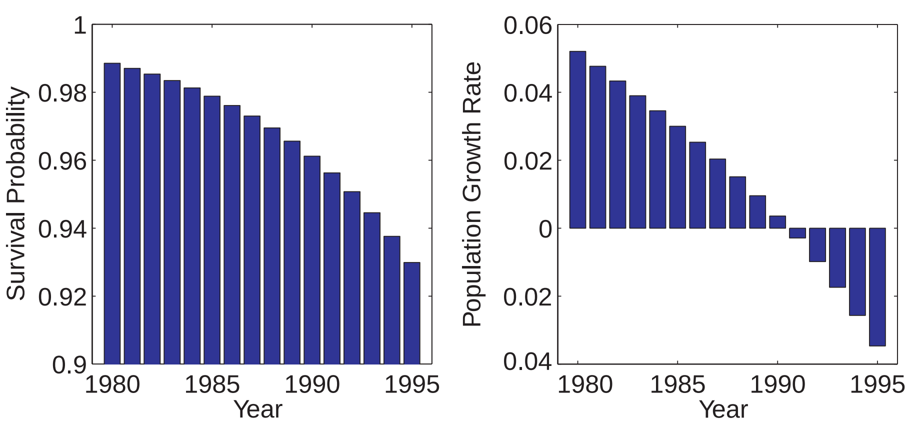
We embedded these trends in a stochastic population model and computed the population growth rate. As the figure shows, the decline in survival and birth rate together have been sufficient to reduce population growth rate from an increase of 5 percent per year in 1980 to a decline of about 2.5 percent per year in 1995. In other words, by the late 1990s, conditions for the right whale had deteriorated to the point that the population is unable to persist.

Our model lets us calculate the time to extinction, assuming (and this is a completely hypothetical assumption) that current conditions are maintained. The expected time is just under 200 years, with a distribution from about 100 to about 400 years. If survival and reproduction continue to deteriorate, if the environment fluctuates, or if declining population size begins to interfere with social structure, extinction will be hastened.

Our results, while discouraging, are not hopeless. Conditions in the early 1980s appear to have supported positive population growth; thus, mortality need be reduced only to levels appropriate to 20 years ago, not to pre-Columbian levels, in order to give the population a chance of persistence.

We are currently working to extend these results. To get a more detailed picture of the population, we are developing models that divide the population into males and females, and yearlings, juveniles, and mature individuals. To get an idea of the causes of the trends, we are exploring relations between survival and fishing, shipping, and

RIGHT WHALE – page 11



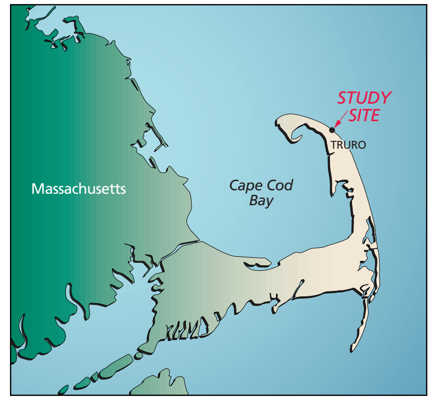
(Left) Annual survival probability of the North Atlantic right whale, as estimated by mark-recapture analysis. (Right) Population growth rate, per year, calculated from survival probability and birth rate.

Here Today — Gone Tomorrow?

Eastern Cape Cod is one of the most rapidly changing coastal zones in the entire US. Frequent severe storms ("Nor'easters") cause episodes of sea cliff slope failure and beach erosion, causing retreat of the cliff line at a rate of one to two meters per year. Such rapid loss of shoreline material poses severe hazards to the "built" environment, including historic structures like Highland Light at Truro. The rapid pace of change, however, provides an excellent opportunity to understand more thoroughly the links between erosion of sea cliffs and the oceanographic processes of the nearshore zone.

Neal Driscoll is linking his research on sea-cliff erosion (which was initiated with a grant from the Rinehart Coastal Research Center) to investigations by Jeff List (USGS) of episodic erosion of the beaches on the outer Cape. Driscoll believes that beach width and the mechanisms of sea cliff erosion are related. The beach width systematically varies in this area by about 500 meters. Similar morphologic features observed on other beaches are referred to as megacusps, rhythmic topography, or giant cusps, and are commonly attributed to edge waves (low-frequency waves along the coast that result from interactions between the incoming surf and the shoreline topography), although the linkage is far from conclusive. List has documented large variations in storm-induced erosion along the outer Cape, with some places showing shoreline retreat exceeding 20 meters and other places not retreating at all. How does this variability in beach erosion relate to cliff erosion, and how does it relate to the dynamics of waves in the nearshore zone?

Recent work on coastal cliffs in California suggests that geological properties and freshwater processes can in some cases play the dominant role in cliff retreat and erosion, and that wave erosion is subordinate. However, the evidence on the outer Cape suggests that wave erosion plays a more dominant role, at least over long time scales. If material properties and freshwater processes were



Jayne Doucette

the dominant control on cliff erosion, embayments and promontories would likely have formed as the sea cliffs retreated approximately 10 kilometers over the last 10,000 years.

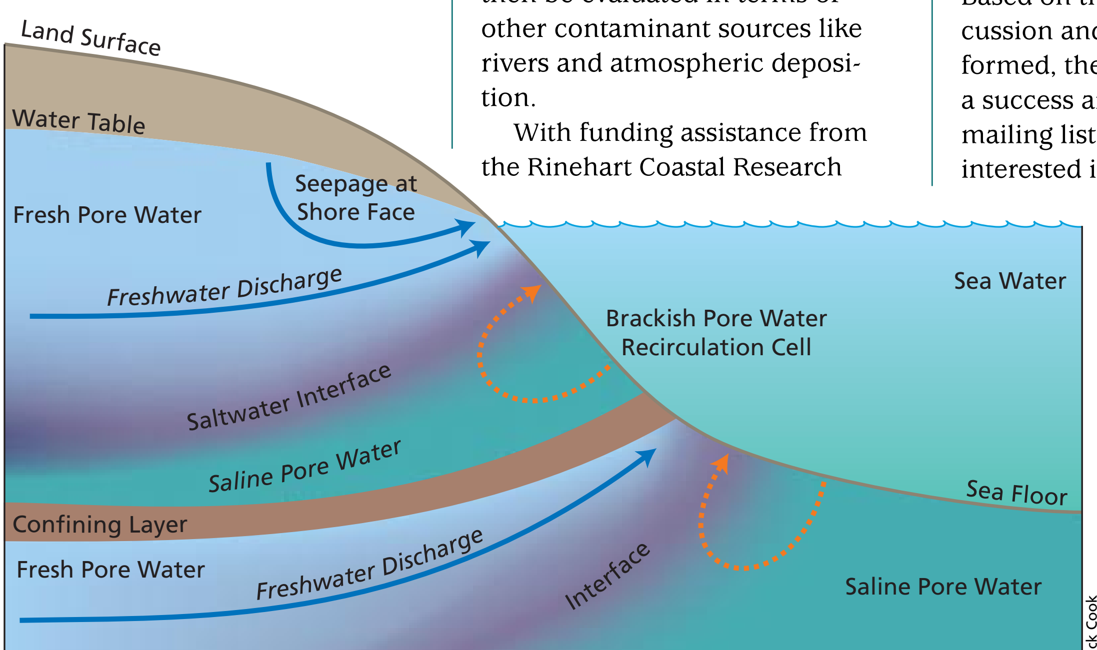
We need to understand the complex interplay and feedbacks among the sea cliffs, beaches, and shallow water regions in order to determine why Cape Cod's long-term cliff retreat appears uniform and linear despite the short-term localized erosion ("hot spots"). Driscoll and List's research will try to determine what controls the locations of erosional hot spots and, more importantly, what causes these regions of focused erosion to migrate through time? By answering these questions, we will be in a better position to understand why long-term sea cliff retreat on the Lower Cape appears smooth and linear. The knowledge gained from this study should allow us to develop greater insight into mechanisms of slope failure and landsliding that can be used to prepare for landslides and lessen their impacts both along Cape Cod and in other high risk coastal areas.

This article was contributed by Neal Driscoll, an Assistant Scientist in the Geology and Geophysics Department at Woods Hole Oceanographic Institution, and Jeff List, an Oceanographer at the US Geological Survey.

A New Approach for Studying Coastal Groundwater Discharge

Nearly 97 percent of Earth's freshwater reservoir exists as groundwater, yet this source is often ignored when constructing geochemical budgets for elements in nearshore environments. The problem lies in the fact that the flow of groundwater through coastal marine sediments (see figure), called submarine groundwater discharge (SGWD), is difficult to quantify using traditional hydrologic methods such as seepage meters. (A seepage meter consists of a bottomless cylinder, usually the top of a 55-gallon drum, which is placed over the sediment and connected to a deflated plastic bag that collects the SGWD.)

Groundwater discharge is often patchy and may vary with time, due to natural and anthropogenic changes in the forcing functions (such as changes in sea level, tides, rain, permeability, dredging activities, etc.). Therefore, a large number of seepage meters must be deployed to obtain accurate estimates of SGWD in a given location.



Recently, radium has been shown to be a useful chemical indicator of SGWD and, having four isotopes with half-lives ranging from four days to 1600 years, can be used to estimate rates of SGWD on a wide range of time scales. Radium is useful because it is naturally enriched in groundwaters, relatively chemically inert, and continually regenerated through the radioactive decay of the parent thorium isotopes.

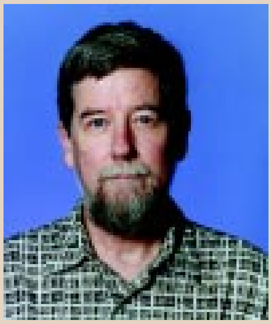
By constructing a simple mass balance for radium in the coastal zone, the flux of groundwater and any contaminants dissolved within it can be estimated. Even if SGWD flows are modest, pollutant concentrations in groundwater may be sufficiently high for SGWD to have an important impact on the fate of pollutants in coastal harbors and estuaries.

The objective of our study is to quantify SGWD-driven fluxes of contaminants from local coastal embayments using the radium quartet. The contaminant fluxes from groundwater sources can then be evaluated in terms of other contaminant sources like rivers and atmospheric deposition.

With funding assistance from the Rinehart Coastal Research Center, we have purchased new radium detection technology from Willard Moore (University of South Carolina), a pioneer in radium isotope measurement (see page 11). Beginning in late May 1999 and continuing through the summer, we will sample West Falmouth Harbor and Waquoit Bay in order to construct SGWD budgets for these watersheds. We will conduct this work in collaboration with the lab of Charlie Harvey, Assistant Professor of Civil and Environmental Engineering at MIT, who will both deploy seepage meters and construct hydrological models of SGWD cycling. These budgets and mathematical models can then be used to estimate the transport of such contaminants as nitrogen from septic tanks or organic pollutants from the Massachusetts Military Reservation plumes, through this underground pathway.

In January of this year, over 20 researchers from the Woods Hole scientific community including MBL, MIT, USGS, and WHOI met to discuss groundwater research. Based on the turnout, spirited discussion and collaborations formed, the meeting was deemed a success and a groundwater e-mailing list was formed. If you are interested in this kind of research and would like to be added to the list, please contact Matt Charette at: (mcharette@whoi.edu).

This article was contributed by Matt Charette, a Postdoctoral Fellow, and Ken Buesseler, an Associate Scientist, both in the Marine Chemistry and Geochemistry Department.



Billy Moore

Billy Moore Receives Bostwick H. Ketchum Award June 30

Willard (Billy) Moore is the 1999 recipient of the "Buck" Ketchum Award at Woods Hole Oceanographic Institution. Moore's outstanding contributions to our understanding of the coastal ocean through the study of radionuclides and his use of radium isotopes to study the fate of terrestrial run-off in the ocean have had broad impact across all of the oceanographic disciplines. His recent results suggesting a major or even dominant role of groundwater in the freshwater input to the coastal ocean is one of the most exciting new developments in coastal research. He is honored both for the legacy of his radium isotope work over his career and the exciting new ideas he has put forth on groundwater transport. Moore's Ketchum lecture is scheduled for June 30.

RIGHT WHALE – from page 8

environmental variables. Finally, we hope to compare our results with data on the South Atlantic population of right whales, which is believed to be recovering nicely. Such a comparison might give us a hint on why the North Atlantic right whale is in such difficulty.

This article was contributed by Hal Caswell, a Senior Scientist in the Biology Department at Woods Hole Oceanographic Institution. Masami Fujiwara is a graduate student in the MIT/WHOI Joint Program and Solange Brault is in the Biology Department of the University of Massachusetts, Boston.

SEDIMENT – From page 7

sediment is usually transported northward, but that there are brief periods during high flow lasting for less than a week when there is a large, net outflow of sediment. It remains to be determined whether we can account for the 2 million tons that the Corps estimates, or even if we can confirm a southward net transport of sediment. It does appear that these large outflow events result in the formation of strong salinity fronts, which cause intense focusing of the outflowing sediment. The trapping of sediment at these fronts probably explains the massive accumulation of sediment observed in the cores.

Rocky Geyer

Courtney Harris of USGS measures the new deposition (light brown layer) in a sediment core collected in the Hudson Estuary in April 1999.

Although there remain some major, unsolved questions, some of the implications of the study can be anticipated. The exposure of organisms to contaminants depends sensitively on sediment transport processes, because most contaminants are associated with the sediment. The deep burial of sediment during spring floods provides a possible "sink" of sediment; however, there remains the possibility of remobilization during other flow conditions. This would imply that there is a much larger pool of contaminated sediment that is potentially exposed to the biota than would occur without these large seasonal fluctuations. The good news is that most of this exposure might be limited to brief periods of extreme flow conditions. Another important outcome of the study will be a better understanding of the processes causing the rapid shoaling of New York Harbor, with application not just to the Port of New York but to the numerous ports throughout the world that are found at the mouths of major estuaries.

This article was contributed by Rocky Geyer, an Associate Scientist in the Applied Ocean Physics and Engineering Department.

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Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543 USA

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