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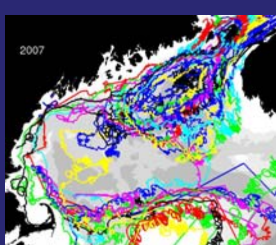
Gulf of Maine MONITOR

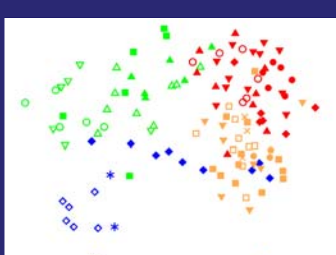
Quarterly review of observation and analysis in the Western Gulf of Maine

Center of Excellence in Coastal Ocean Observation & Analysis
COASTAL OCEAN Observing Center

www.cooa.unh.edu

The Coastal Ocean Observing Center was established at the University of New Hampshire in 2002 as part of NOAA's Coastal Observation Technology System. The Center is working to develop an observing system to monitor the Western Gulf of Maine ecosystem. We seek to understand how the ecosystem is changing seasonally and from year to year, what causes it to change, and ultimately to forecast changes.





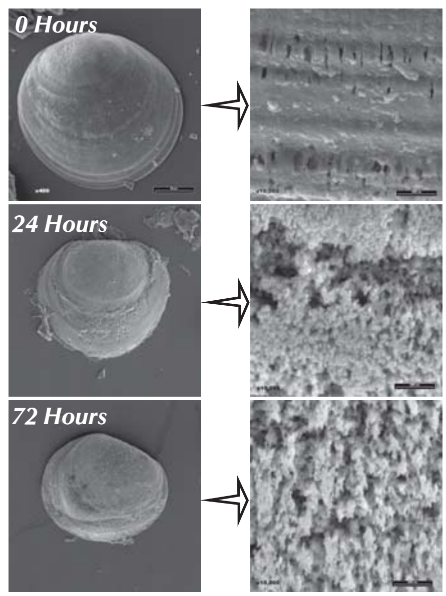
University *of* New Hampshire

Got Aragonite?

High calcium levels are also important for your mussels

Take a moment to consider how much work goes into building a five story brick building. Each brick needs to be laid by hand, in a precise pattern and orientation. Now imagine that cranes and hoists disappear, making it harder to get all those bricks up to the top of the structure. To make matters worse, individual bricks start spontaneously crumbling out of the wall, weakening the completed portion of the structure. Were this the case, brick buildings would disappear from our cities within years.

This situation may be occurring now, not to brick buildings, but to the shells of bivalves and other calcifying organisms in the Gulf of Maine. A building method that has worked for millions of years could become an increased energetic liability at best, and a biological hazard at worst. Unfortunately, bivalves are unable to choose to build their shells out of metal and glass instead of calcium carbonate.



*Scanning electron microscopy of larval clams (*Mya mercenaria*) growing in water with undersaturated levels of calcium carbonate show severe dissolution of the outer shell within 72 hours. Courtesy of Mark Green, Saint Joseph's College of Maine.*

Calcium carbonate is found naturally in oceans around the world. It commonly exists in two forms: aragonite and calcite. Aragonite is harder but more soluble and is used by many corals and bivalves. Calcite is used by many echinoderms, coccolithophores, lobsters, crabs, and oysters. Still other organisms use a combination of both, or are able to switch between the two forms. Like all calcifying organisms, bivalves must concentrate the calcium carbonate in the cells that create their shell, like having a pile of bricks next to the bricklayer. Concentrations within the cell are much higher than natural levels in the ocean, so this process requires energy. The lower the concentration of calcium carbonate in seawater, the more energy required to create that stockpile of calcium carbonate within the cell.

In general, seawater is supersaturated with calcium carbonate. The amount is measured by the saturation state, a ratio of the concentration of calcium carbonate to its solubility. Values higher than one indicate supersaturation; values lower than one indicate undersaturation. Near the equator, the saturation state can be higher than 4.0, while toward the poles it is less than 2.0. This natural variation is due to warmer water in tropical regions; temperature plays a major role in determining the saturation state, along with a notorious greenhouse gas.

The amount of calcium carbonate available is limited by the amount of carbonate, not the amount of calcium. Carbonate levels are in turn dependent on the amount of car-

(continued on page 2)

(continued from page 1)

bon dioxide. As carbon dioxide increases, carbonate tends to be converted into bicarbonate ions. Water with higher carbon dioxide levels will thus have a lower calcium carbonate saturation state. An increase in carbon dioxide increases the energetic costs of shell building. And as you may have heard, carbon dioxide levels have not been declining recently.

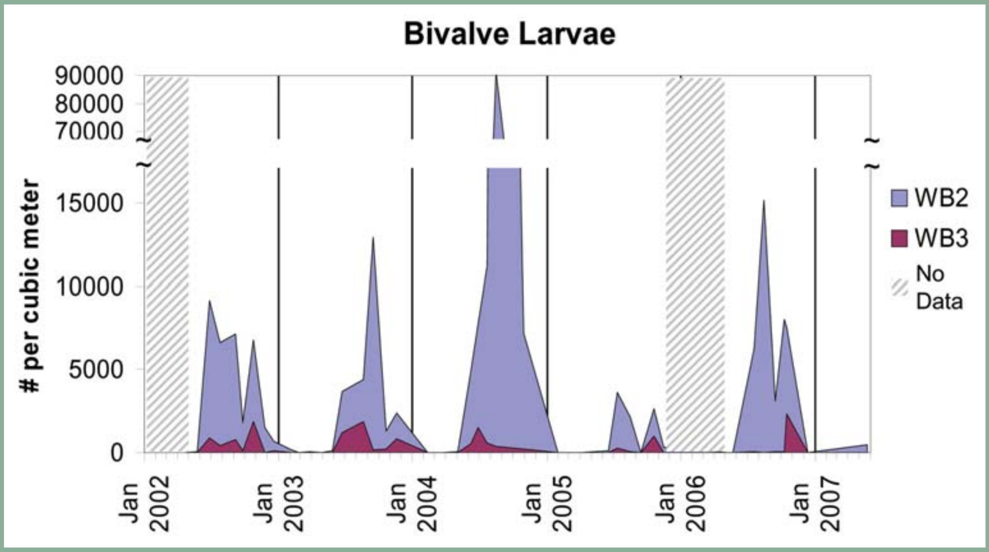
To make it worse, low levels of calcium carbonate not only make it harder for calcifying organisms to build shells, but also increase the rate at which their shells dissolve. Like bricks crumbling out of the building, low saturation states mean calcium carbonate molecules are more likely to break away from the shell and return to their dissolved state, a process known as dissolution. This weakens the structure, leaving the organism more vulnerable to predators and physical stress.

Recent work by Mark Green at Saint Joseph's College of Maine found that larval stages of bivalves are particularly susceptible to the stress of low calcium carbonate saturation. Bivalve larvae, known as veligers, spend several weeks as free swimming planktonic animals. During this time their shell is relatively thin and energy demand is high. Green reared larvae in water containing various levels of calcium carbonate. He found that nearly all larvae 0.2 mm in size died within 12 days when exposed to saturation states of 0.6 or lower. Roughly 60% died in the same time period with the saturation state at 1.6.

What is the calcium carbonate saturation state in the western Gulf of Maine? Flow-through data collected on Coastal Observing Center cruises show that it ranges from zero to almost four, with values increasing in a direct relationship with salinity (see figures on page 3). This is due to the fact that low salinity water entering our region has a very low acid buffering capacity, combined with high CO2 concentrations. In general, it appears that the western Gulf of Maine has lower levels of aragonite than what is optimal for the growth of bivalves, though it is unclear whether this is a recent trend or not.

We are beginning to analyze interannual variability in saturation states in relation to abundance of bivalve larvae. We have completed a model analysis of calcium carbonate levels for 2004 and 2005, showing a lower saturation state in 2005. Interestingly, the lower saturation state seen in 2005 corresponds with a drop in the numbers of bivalve larvae.

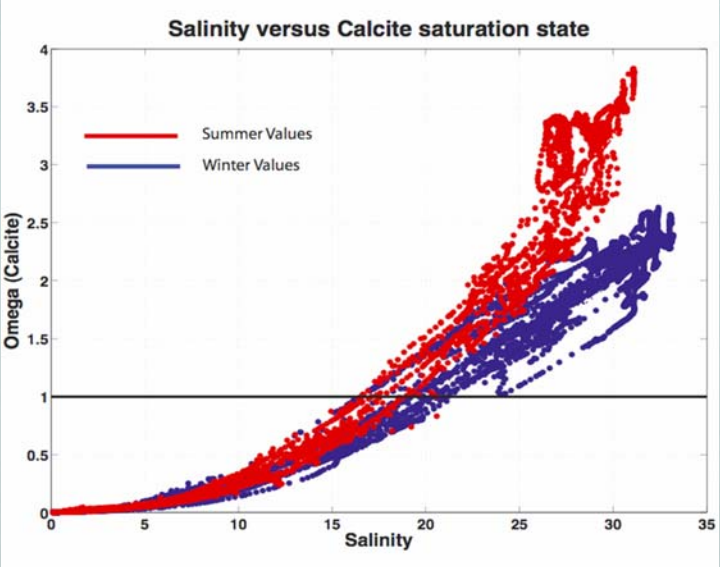
Surging levels of carbon dioxide in the atmosphere may prove to be a double whammy for the oceans, not only increasing temperatures via contact with a warmer atmosphere, but by impeding the growth of ecologically important calcifying organisms such as corals, bivalves, and gastropods. Each species' sensitivity to changes in aragonite or calcite levels varies, and scientists have differing opinions on how far calcium carbonate saturation state would need to drop before significantly affecting population levels. Without doubt, though, it is one more reason to make you think about your carbon footprint. Sea levels are rising but ocean pH and calcium carbonate levels are falling - like offsetting penalties in a football game, can't we just do the play over?

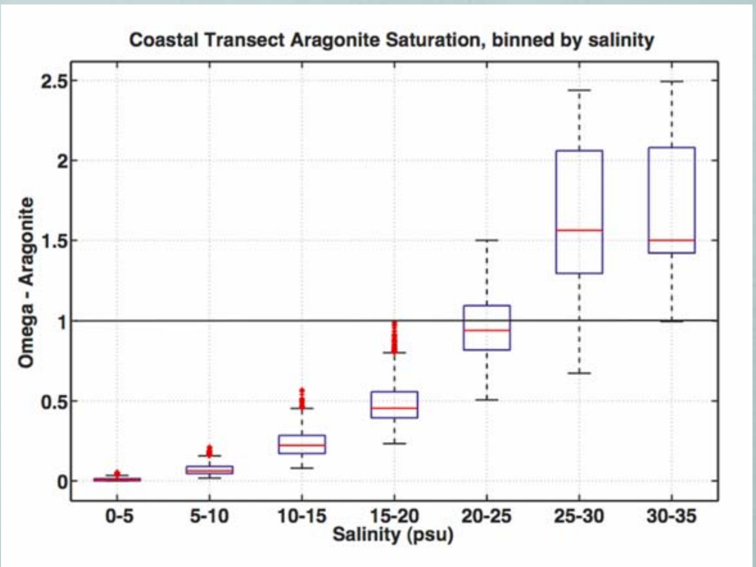


Density of bivalve larvae captured at two stations during the monthly Coastal Ocean Observing Center cruises. Bivalve larvae are present in the water column from late spring through early winter. Numbers peak in summer, a time when saturation levels of aragonite tend to be at their highest due to the warmer water temperatures. The drop in abundance during 2005 corresponds to a drop in calcium carbonate levels.

We would like to thank all those who completed the Gulf of Maine Monitor survey online. We appreciate the feedback!

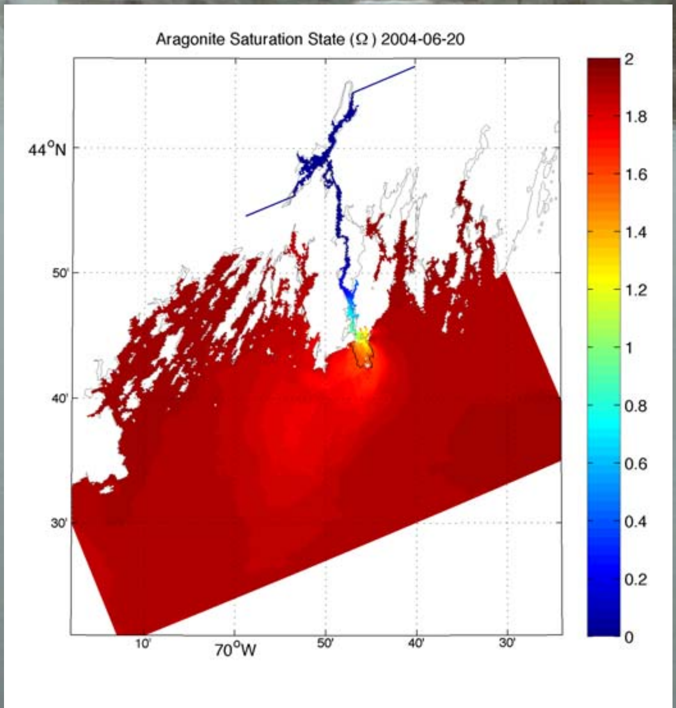
Special thanks to the technical staff at the Coastal Ocean Observing Center, without whom the research cruises and sample processing would not be possible: Tom Gregory, Chris Hunt, Tim Moore, Mike Novak, and Shawn Shellito.

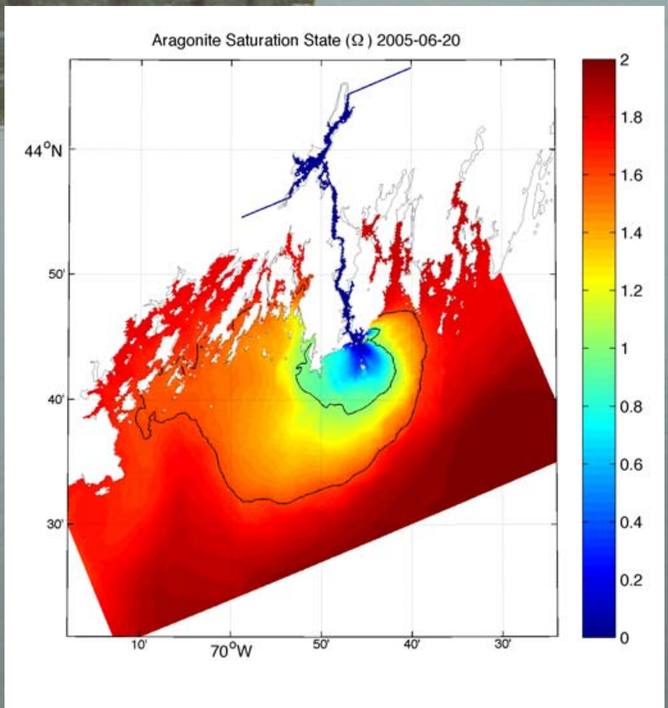




Saturation states (omega) for both calcite and aragonite as derived from flow through data taken during Coastal Ocean Observing Center cruises from Portsmouth, NH to Bath, ME. Both calcite and aragonite exhibit direct relationships with salinity, since fresh water contains less calcium carbonate in general. But temperature also has an impact, with higher temperatures (summer) lowering the amount of carbon dioxide in the water. Aragonite values are extremely low, and may limit bivalve larvae survival in some years.

Snow blows past Fort Popham on a chilly Coastal Transect cruise. The structre pictured was built to defend the Bath shipyards during the Civil War, but was not completed. (Photo by Erin Hobbs)





Snapshots of modeled aragonite levels in Casco Bay, ME, for 2004 (left) and 2005 (right). The lower values seen in 2005 are largely due to the extensive plume from the Kennebec River. Clams in Casco Bay have been noted to have years of weak shell development and recruitment, which could be explained by aragonite levels this low. If additional input of carbon dioxide lowers aragonite and calcite levels farther, it may make it more difficult for small clams and other calcifying organisms to survive the natural fluctuations in calcium carbonate.

By Air and by Sea

Coordinated Sampling Effort Takes Aim at Estuary Waters

By Dave Kellam and David Sims

On a clear day in August, a small airplane flew over the Piscataqua River, Little Bay, and Great Bay in New Hampshire to take pictures of the large, beautiful estuary system. But it was not a sightseeing tour. The project is part of a $70,000, multi-agency effort to understand the effect of increasing nutrients on the complex seacoast system.

The overall goal of the effort, which is being led by the New Hampshire Estuaries Project, is to create a conceptual model to help determine the sustainable amount of nutrients that can be released into the state's largest estuary. Based on this work, the NHEP will make recommendations to the NH Department of Environmental Services (NHDES), which is ultimately responsible for developing nutrient criteria to protect water quality and ecosystems of the Great Bay Estuary.

This intense effort is being driven by concerns over rising levels of nitrogen entering Great Bay. According the NHEP State of the Estuaries Report, the amount of nitrogen in Great Bay has increased 59% in the past 25 years. This trend is troubling because too much nitrogen in an estuary will cause algal blooms that cloud the water and disrupt the ecology of the bay.

One species especially affected by high nitrogen levels and the resulting cloudy water is eelgrass. Eelgrass is a vital habitat for aquatic creatures and waterfowl, however, data indicate that eelgrass beds have diminished by 17 % from 1996 to 2004 in Great Bay. A major factor that limits eelgrass growth is the amount of sunlight penetrating the water. Water clarity is reduced when nutrients feed phytoplankton and when suspended inorganic particulates or dissolved organic matter in the water increases.

A Maryland company took hyperspectral aerial images, recording 64 wavelengths across the visible and near-infrared spectrum.

Above: *A false color image of the Great Bay estuary compiled from several overflights of the area. Using the amount of light reflected from the water at over 60 different wavelengths, scientists can determine the turbidity (cloudiness) of the water, and whether the turbidity is caused by phytoplankton, suspended sediments, or dissolved organic matter.*

Right: *Down at sea level on the same day, Tom Gregory collects water in order to groundtruth the imagery gathered during the overflight.*

The resulting imagery shows colorful swirls of a variety of suspended and dissolved materials in the water over the 17-square-mile region. To check the reliability of the image data, teams of researchers from the University of New Hampshire and NHDES took water samples in a variety of locations during the flight.

Additionally, a state-of-the-art buoy deployed in Great Bay by the UNH Coastal Observing Center made continuous measurements of the hyperspectral water clarity as well as other physicochemical parameters, including turbidity, chlorophyll-a, colored dissolved organic mater, and nitrate. The buoy is a prototype deployed as part of the national Integrated Ocean Observing System (IOOS) with funds from NOAA Coastal Services Center and was designed to answer management issues like wa-

Sampling equipment aboard the R/V Galen J, *motoring from station to station on Great Bay during the overflight.*

ter clarity. Information from the buoy, together with flow-through surveys coinciding with the flight, will be invaluable in piecing all the information together.

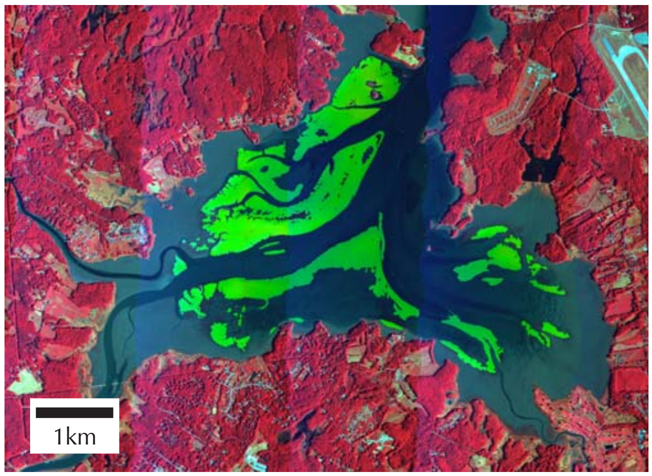
Phil Trowbridge, NHEP Coastal Scientist, believes this project is the best way to enhance understanding of how the Great Bay Estuary system responds to nutrient loading. "The Great Bay Estuary is unique because of its geography and the degree of development throughout its watershed. Existing models for nutrient loading don't quite make sense for this system. We need real data and observations from several sources to determine what is happening."

Ru Morrison, a bio-optical oceanographer of the UNH Coastal Observing Center within the UNH Institute for the Study of Earth, Oceans, and Space (EOS), concurs and explains the value of multiple data collection approaches. "To fully understand water clarity in the Great Bay Estuary we need information from multiple sources. The buoy in Great Bay is great at collecting long-term information at one spot but how does that compare to the rest of the estuary? We need the aerial information corroborated or 'ground truthed' with the spatial surveys to expand results from the buoy. Synthesis of data from all these sources will provide valuable insight into light penetration in the waters of the Great Bay Estuary."

Trowbridge notes that there is need for further research and monitoring. "This project captures the conditions at one point in time. To understand how the estuary reacts to changing environmental conditions, including climate change and increased upland development, we must monitor these parameters over the next 10 to 15 years so we have reliable data on which to base decisions."

The New Hampshire Estuaries Project, in cooperation with the UNH Coastal Observing Center, secured the funding for this project from the US EPA Regional Dedicated Water Quality Program.

Dave Kellam is Project Coordinator for the NH Estuaries Project.
David Sims writes for the Institute for the Study of Earth, Oceans, and Space at UNH.



Reflected light from Great Bay not only gives information about water clarity, but reveals the location of river channels and eelgrass beds (highlighted in green at left).

Above: *Sunrise over Great Bay on a beautiful day for field research.*

Left: *Onshore, water samples collected from Great Bay were filtered for particulates and nutrients. Here, Mike Novak prepares a flask for filtering dissolved inorganic carbon.*

Adrift in the Gulf of Maine

Wouldn't it be nice if the ocean were a pond? Sure, it would be less majestic, but so much easier to study. Alas, the ocean is huge, and fluid. Water is constantly flowing from one place to another; nothing holds still for replicate samples. The enormous volume of seawater prohibits comprehensive sampling, even in a corner pocket of the ocean like the Gulf of Maine. Oceanographic research boils down to sampling some of the water all of the time, and all of the water none of the time.

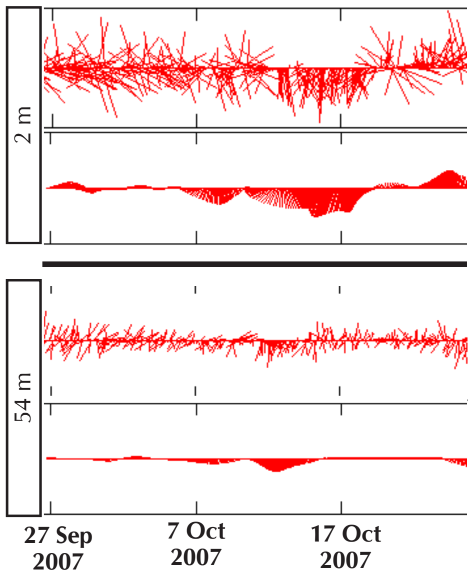
A transect line or buoy in the Gulf of Maine will only sample a few drops from the bucket. Conclusions derived from the data gathered can only be assumed to apply to nearby areas of ocean. These assumptions can be strengthened with two important pieces of information: where the water came from, and where it went. Unfortunately, this picture is not always clear. Water currents in the Gulf of Maine are like rivers, but the boundaries of flow are not as well delineated, direction and speed vary considerably with depth, and "downhill" might be as impermanent as the direction of the prevailing wind. Add tidal forces and complex bathymetry, and the picture starts to resemble a Jackson Pollock painting.

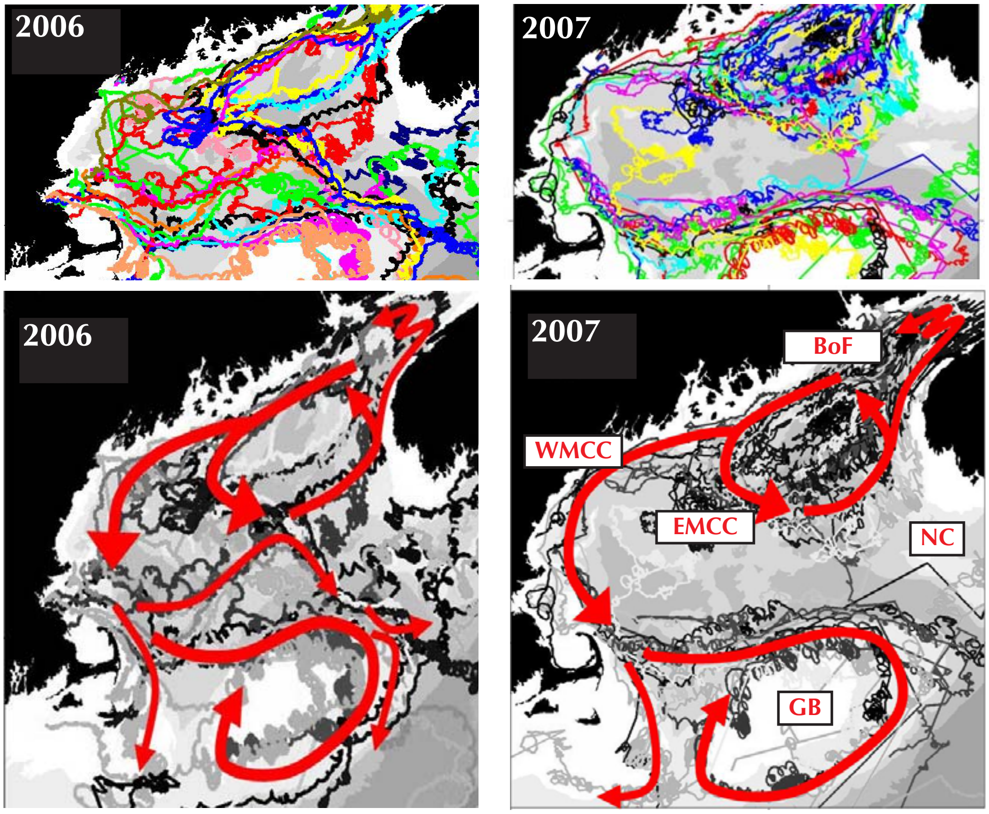
Fortunately, technology enables oceanographers to collect detailed information on currents in the Gulf of Maine. Several Gulf of Maine Ocean Observing System (GoMOOS) buoys are equipped with acoustic doppler current profiler sensors that measure the speed and direction of water flowing past the buoy at multiple depths. Jim Manning at the NOAA Northeast Fisheries Science Center and Dennis McGillicuddy at the Woods Hole Oceanographic Institute have attached GPS transmitters to free floating drifters to track the flow of surface currents. This high temporal and spatial resolution data not only helps us understand where water was going at a specific time and place, but can be used to improve mathematical models of current dynamics in the Gulf of Maine.

Computer models are becoming more accurate as processing speed and data sources increase. While models are still calculated assumptions, the input of real data "groundtruths" one or more points in space and time. By measuring the characteristics of water along a transect, or the flow of an entrained drifter, we establish starting points, checkpoints, and endpoints for the models.

As our knowledge of these oceanic rivers increases, so does our knowledge of the ecosystem as a whole. Currents are essentially conveyor belts transporting nutrients, food, predators, prey, larvae and adults from place to place. Many sedentary species take advantage of the free ride by having planktonic stages in their life cycle. For commercially important species, knowing how currents may deliver larvae from source populations is critical information for effective management plans.

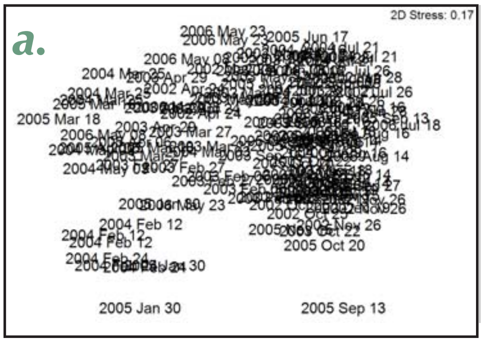
Stickplots of water currents measured at 2 m and 54 m by GoMOOS buoy B are shown in raw form (spiky) and with the tidal signal removed (smooth). The direction of the stick indicates direction of water flow; length indicates velocity. Higher velocity is common at the surface, as is the difference in direction between surface and deep waters. (Courtesy of GoMOOS, www.gomoos.org.)

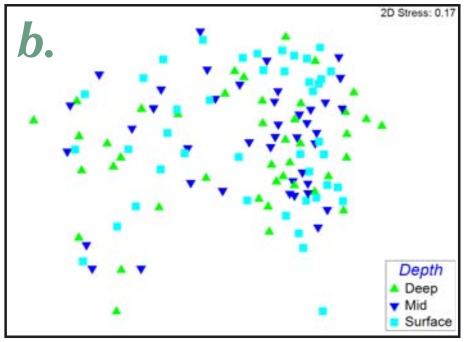


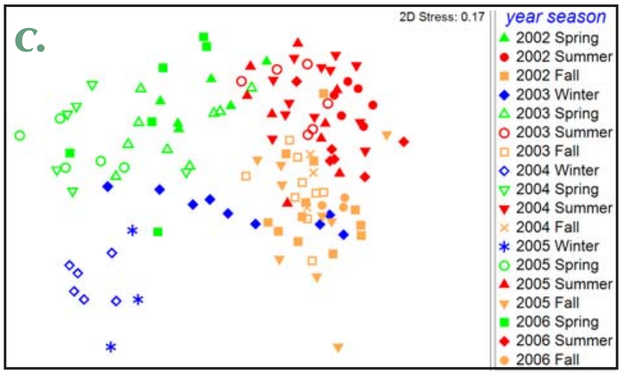


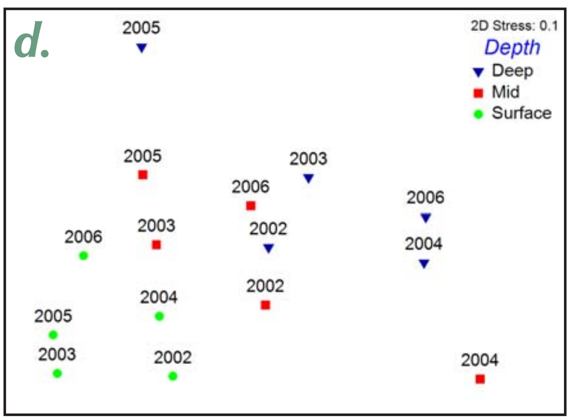
Actual GPS tracks (top) and simplified vectors (bottom) for drifters deployed in the western Gulf of Maine in 2006 and 2007. Drifter tracks highlight the major surface currents in the Gulf of Maine: the gyre in the Bay of Fundy (BoF), the Eastern Maine Coastal Current (EMCC) turning away from the coast creating its own gyre, and the Western Maine Coastal Current eventually supplying the gyre on Georges Bank (GB). Drifters released were both surface and 10 m drogue types. Not shown here are deep water currents, most importantly the influx of water through the Northeast Channel (NC). Original drifter track maps courtesy of Jim Manning (NOAA). For more information, visit http://www.nefsc.noaa.gov/drifter/.

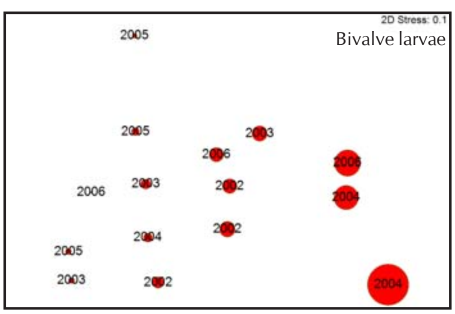
Viewing Multivariate Zooplankton Data

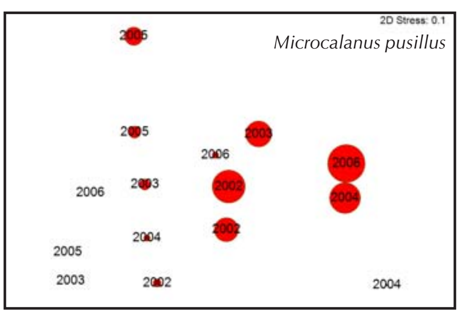


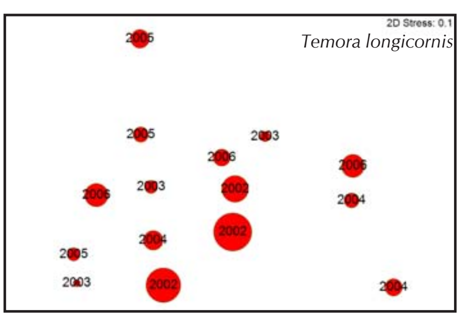


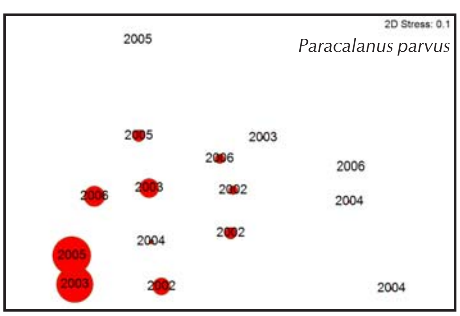












Having large amounts of data is great, but when you have data recorded for multiple species at multiple depths within multiple stations within multiple months within multiple years, teasing out patterns and trends can become difficult. Fortunately, modern computers can do in seconds what would have taken a month on a hand-held calculator. Visualizing the data is not a statistical test but a way to more thoroughly understand it.

One method for viewing complex data is multi-dimensional scaling, or MDS. An MDS plot is based on the similarity between samples; the closer two points are on the plot, the more similar the samples. The samples could be of any type of data - in this case we'll look at the Coastal Observing Center zooplankton data collected monthly at one station in the Gulf of Maine, from three depths, over a five year period. The closer two points are, the more similar the abundance of each individual species of zooplankton within those two samples.

Simply plotting the data and labelling it by date is not immediately helpful (Fig. a.). By coloring the samples, patterns are more easily visible. Coloring the samples by collection depth shows an apparently random pattern (Fig. b.); coloring them by season shows a visible clustering of the data (Fig. c.). Year after year, zooplankton in the spring samples tends to be similar to other spring samples, so they are plotted in a rough cluster.

Depth did not initially seem to play a factor, given the scattering of points in Fig. b. This is simply due to the strength of the seasonal signal. This can be hidden by averaging the samples taken at each depth over an entire year. The resulting MDS shows more pronounced clustering of depths. (Fig. d.).

Another way to interpret the figures is that the zooplankton assemblage changes most significantly from season to season, then by vertical location in the water column, then year to year.

Finally, replacing the symbols in Fig. d. with bubbles scaled to the abundance of a specific species allows us to see how they change individually. Bivalve larvae and the copepod *Temora longicornis* show strong interannual variability. The copepods *Microcalanus pusillus* and *Paracalanus parvus* show strong depth discrimination, being found primarily in deep and shallow samples respectively.

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Mike Novak takes a break from sampling to enjoy the sunrise on Great Bay. The trip was part of a coordinated sampling effort aimed at improving our knowledge of estuarine water quality. (Photo by Ru Morrison)

Gulf of Maine MONITOR

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