Exploring hypoxia

Professor Candace Oviatt’s research focuses on whole system responses to perturbations like nitrogen inputs, climate change and over-harvesting. Her latest efforts are challenging thinking about oxygen deficiency in marine environments.

As a starting point, can you briefly outline your current study and what you hope to achieve?

We are attempting to assess the relative roles of physical drivers, like stratification, compared to nitrogen inputs from sewage treatment plants, in causing low summer oxygen levels in Narragansett Bay. We are working closely with the Rhode Island Department of Environmental Management as they impose regulations to dial down nitrogen inputs from sewage treatment plants.

As the first 30 per cent of nitrogen reductions were imposed on sewage treatment plants in 2005, we found that, as expected, the standing stocks of nitrogen decreased by 30 per cent. However, that reduction has not so far reduced low oxygen events because of the high inter-annual variability in rainfall and thus stratification.

With a second round of reductions planned for the near future, we will be looking for changes in primary and secondary productivity as well as decreased low oxygen events. Our goal is to let managers know how Narragansett Bay is responding to their management actions so that appropriate set points for nutrient inputs can be achieved.

Why is Narragansett Bay of particular interest in this investigation?

Narragansett Bay is ahead of the curve in terms of attempting to decrease nitrogen inputs and it is a system that has been studied and modelled intensively, thus the low oxygen problem was viewed as one that could be understood, if not solved. The funding agency, Coastal Hypoxia Research Program in the National Oceanic and Atmospheric Administration, intended that the results of scientific studies would be made available to managers so that an interactive adaptive management could be developed.

What are the main sources of pollution in Narragansett Bay?

While the Industrial Revolution started in Rhode Island, the current levels of industry are low and not a major source of pollutants to the Bay. Current infrastructure includes transportation, hospitals, schools, scrap metals and light industries, among others. In recent years sewage treatment facilities have been the main source of pollution to Narragansett Bay. The fact that this one source of pollutants can now be, and is being, controlled also makes this bay attractive for our study.

How are benthic interactions negatively impacted by hypoxia?

On an organism level, the impact of hypoxia on the benthos has been simple. Sensitive organisms die, or if they are mobile they leave the area. Predators tend to move in to take advantage of dead or dying organisms. While biomass and numbers might not change much, the animal communities in these disturbed areas tend to be dominated by juveniles that have not yet experienced hypoxia, species not sensitive to low oxygen and mobile predators. The biogeochemical benthic story is complex because nitrogen decreases to the Bay are intertwined with climate changes that have led to declines in the winter spring diatom bloom and decreased organic inputs to the benthos. With reduced organic inputs benthic re-mineralisation and flux rates of oxygen and nutrients between the water column and the sediment have declined compared to historical measurements. Instead of the high denitrification rates of the past, nitrogen fixation has occurred.

It seems possible that in years with no winter spring diatom bloom the benthos could become a source of fixed nitrogen and mask any reductions from sewage treatment plants. This story is still evolving and it may be that hypoxia plays a role in the relative rates of denitrification and nitrogen fixation.

Does hypoxia result in long-term damage?

Changes to the pelagic community may be short-term with respect to hypoxic events. Transformation of the long-lived benthic members will last at least a generation. If hypoxia is alleviated by dialling down nitrogen inputs, primary and secondary productivity and biogeochemical cycling in the benthos may result in long-term changes that need to be understood better.

How has field data been incorporated into existing models on hydrodynamics?

An extensive series of field measurements have been made to identify patterns in currents in the Providence River area, in Greenwich Bay, and near the mouth of Narragansett Bay where exchanges with the coastal ocean occur. This field data has been used to improve the Regional Ocean Modeling System (ROMS) circulation model of the Bay and exchange rates between different areas within it.
THE DEPLETION OF oxygen in the water column, known as hypoxia, can ultimately result in the death of an entire aquatic system. This phenomenon arises from a number of natural processes, but is often caused by increased levels of nutrients from fertilisers and sewage effluent entering the water. These factors end up leading to blooms of phytoplankton which use up the available oxygen in the water and consequently reduce levels for the aquatic species. Researchers at the University of Rhode Island’s (URI) Graduate School of Oceanography have been using a number of modelling tools to help understand more about this manifestation in Narragansett Bay. Funded by a grant from the National Oceanic and Atmospheric Administration (NOAA) Coastal Hypoxia Research Program (CHRP), Alan Lewitus, Project Officer and a team of researchers have prepared and are using a hybrid model based on the simplified ecosystem model previously developed by Kremer-Brush. They have linked this model to a 3D hydrodynamic Regional Ocean Modelling System (ROMS) with high resolution across the entire Narragansett Bay.

INTEGRATING PHYSICAL AND BIOLOGICAL PROCESSES

Through this work, the researchers, led by Professor Candace Oviatt, hope to forecast low oxygen events and predict how the Bay will respond to a reduction in nitrogen inputs. They have developed a novel simplified ecological model designed to forecast low oxygen levels. The ROMS hydrodynamic model will be used to drive circulation in the ecological model. To calibrate and verify this the researchers will gather a range of new data. “We are hoping to collect new information about primary production, water column and benthic respiration, vertical mixing rates, vertical current structure and spatial extent of hypoxia, as well as synthesise data on oxygen dynamics,” explains Oviatt. At the same time, Brown University researchers will examine historical oxygen level signatures in sediment cores.

All of these efforts will help decision makers better predict ecosystem responses related to hypoxia generation for present nutrient conditions and future nutrient controls.

This project is being implemented in close collaboration with the Rhode Island Narragansett Bay Estuary Program. The Program has already built on a number of historical monitoring efforts and models on the forces that drive hypoxia in Narragansett Bay. This includes the NOAA National Marine Fisheries Service Bay Window grant which measured the biologically-driven responses of the system and associated physical characteristics at a high resolution over time at continuous monitoring buoys. The technology advanced through this latest project is integrating physical driving forces that control stratification, including tidal and wind currents, river flows and local hydrodynamics, as Dr Chris Deacutis from the Program elucidates: “These are all factors which influence flushing with biological processes that increase oxygen at the surface and respiration in bottom water, all of which removes oxygen.” Information on these physical and biological processes will support the group’s attempts to predict hypoxia in Narragansett Bay, and ultimately inform nutrient management decisions.

SUPPORTING MANAGEMENT OUTCOMES

The work plan for the project includes the application of the hybrid model to a number of different physical and nutrient-load scenarios in order to calculate the dynamics of oxygen within the water column. Each spatial element will be carefully checked and confirmed using the latest data. A new mass balance for nitrogen in the Bay will then be put together. Finally, the group will develop a number of management
INTELLIGENCE

MODELING TOOLS TO UNDERSTAND AND MANAGE HYPOXIA: APPLICATION TO NARRAGANSETT BAY

OBJECTIVES

• Develop a new simplified ecological model to predict low oxygen
• Collect new data to calibrate and verify the ecological model
• Adapt the Regional Ocean Modeling System (ROMS) hydrodynamic model to Narragansett Bay collect new data on currents for calibration and verification and link to the ecological model
• Collect new data on vertical mixing rates and vertical current structure
• Collect new data on the spatial extent of hypoxia and synthesise data on oxygen dynamics
• Provide regulators with the tools to assess decisions to reduce nutrients

KEY COLLABORATORS

Daniel Codiga, Physical Oceanography, Graduate School of Oceanography, URI • Christopher Deacutis, Biological Oceanographer, Rhode Island Department of Environmental Management • Mark Brush, Ecological Modeler, Virginia Institute of Marine Science • James Kremer and Jamie Vaudrey, Ecological Modelers, University of Connecticut • Sue Kiernan, Deputy Chief Water Resources, Rhode Island Department of Environmental Management • Chris Kincaid, Physical Modeler, Graduate School of Oceanography, URI • Scott Nixon, Systems Ecologist, Graduate School of Oceanography, URI • Warren Prell, Chemical Oceanographer, Brown University • David Ullman, Physical Oceanographer, Graduate School of Oceanography, URI

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CANDACE OVIATT has several years of experience in coastal ecology and is currently Professor of Oceanography at the Graduate School of Oceanography at the University of Rhode Island. She has taught the graduate core course in Biological Oceanography and currently teaches an Oceans and Climate Course and a Course on Narragansett Bay.

TOS

NUTRIENT LOADING

For these researchers, the ultimate vision is to measure and assess nutrient loading to Narragansett Bay. Historically, one of the main targets for reduction has been large point sources, such as sewage treatment plants. The state of Rhode Island currently places strict limits on nitrogen being released to the Bay, which aims to manage these point source discharges.

The harder issue to deal with, notes Deacutis, is the loading that results from stormwater runoff, which is on the rise due to increased precipitation levels in New England. “The most difficult situation will be how to manage stormwater from fully urbanised areas with little room for treatment,” he underlines. Low impact development techniques will be needed for much of the urban areas; however, the level of opportunity to capture stormwater is limited. Controlling air sources of nitrogen is another option, which will help to decrease the concentration of nitrogen compounds in stormwater. It is hoped that the outcomes from this unique hybrid model will play a key role in assessing and improving management of nutrient loading entering the Bay.