Harmful Algal Blooms, Hypoxia and Multiple Stressors in the Chesapeake Bay Region

Introduction

The Chesapeake Bay, the Nation's largest estuary and a national treasure, has a watershed that stretches across six states - New York, Pennsylvania, Maryland, Delaware, Virginia and West Virginia - and the District of Columbia. The Chesapeake Bay proper is approximately 200 miles long, stretching from Havre de Grace, Maryland, to Norfolk, Virginia. It varies in width from about 3.4 miles near Aberdeen, Maryland, to 35 miles at its widest point, near the mouth of the Potomac River. Including its tidal tributaries, the Bay has approximately 11,684 miles of shoreline. The Chesapeake Bay region is a complex temperate zone ecosystem subject to extreme seasonal variability, large river runoff, strong winter storms and occasional fall hurricanes. The ecosystem depends on the interplay of estuaries and shelf systems through which numerous economically and recreationally important species routinely move to complete their life cycles. The Chesapeake Bay Region is one of the most populated coastal regions in the U.S with approximately 16 million people living in the watershed. Projected population growth will continue to increase impacts on the already heavily developed coastal areas. Resources in the Chesapeake Bay include fishery, recreational, shipping and commercial assets as well as large areas of coastal wetlands. The region's estuaries are vulnerable to land-based sources of pollution exacerbated in many cases by the large area of watersheds relative to water surface and poor flushing.

The Problem

In the Chesapeake Bay Region, human impacts have been and continue to be significant (e.g., multiple sources of pollution, commercial and recreational fishing, land-use changes, modification of shorelines) with resulting murky waters, algae blooms and shrinking beds of underwater grasses. Erosion and runoff from agricultural and urban lands have loaded large amounts of fine-grained silts and clays into the upper bays and tributaries reducing light penetration critical to submerged aquatic vegetation and smothering benthic habitats. Nutrients enter estuarine and coastal waters from point and nonpoint sources including the atmosphere, triggering algal blooms and causing hypoxic conditions which can be seasonally persistent in deeper stratified waters or ephemeral in shallower waters but still devastating to living resources. Toxic contaminants enter the Bay via atmospheric deposition, dissolved and particulate runoff from the watershed or direct discharge from point sources. Sediments and biota can accumulate these toxic contaminants which are typically concentrated in "hot spots" across the region in contrast to the more widespread nutrient pollution. Overfishing and habitat destruction have severely impacted once abundant populations of finfish, blue crabs, oysters and horseshoe crabs. Extensive shoreline modification has occurred via hardening to protect land and houses from erosion, placement of docks and other construction activities. These modifications, along with perturbations from invasive species, disease and climate change (e.g., warming temperatures, rising sea levels, post-glacial land subsidence) have cumulatively destroyed fringing marshes and seagrass beds that serve as critical habitats.

Program Description

NOAA is conducting a multidisciplinary and integrated program to study hypoxia, harmful algal blooms and the impacts of multiple stressors in the Chesapeake Bay region. Efforts include coupled modeling of physical circulation and biogeochemistry to analyze and improve understanding of mechanisms underlying hypoxia and develop predictive tools to simulate ecological responses to climate and nutrient input management. Predictive models are being developed to understand causes and consequences of nutrient pollution on estuaries and to forecast estuarine nutrient susceptibility and impacts on upper trophic levels. Ecological forecasting is being tested to predict the location, distribution and extent of favorable habitat, productivity of fish assemblages, seagrass beds and the impact of multiple stressors. Harmful algal bloom studies are focusing on recently-isolated dinoflagellate parasite from the genus *Amoebophrya* and its interaction with its host, *Alexandrium tamarense*, a bloom-forming, toxic dinoflagellate and development of an operational statistical nowcast/forecast system for three HAB organisms in the Chesapeake Bay ecosystem (i.e., dinoflagellates *Karlodinium micrum*, *Prorocentrum minimus*, and cyanobacteria *Microcystis aeruginosa)* to predict the probability of blooms.

NOAA Programs in the Chesapeake Bay Region

- CHRP
- ECOFORE
- ECOHAB
- MERHAB
- PCMHAB
- REPP
- CoastWatch

Accomplishments

Since the 1990's NOAA has made investments in the Chesapeake Bay Region to develop observational and forecast systems to predict individual regional stressors such as harmful algae blooms, hypoxia and nuisance species and the cumulative impacts of multiple stressors. For example, NOAA has developed an operational model to nowcast and forecast the abundance and distribution of the nuisance jellyfish *Chrysaora quinquecirrha*. NOAA has developed molecular probes that have the potential to detect the presence of toxic dinoflagellate *Pfiesteria piscicida* and related *Pfiesteria*-complex dinoflagellates and provide a rapid response testing for their presence. In test mode is an operational statistical nowcast/forecast system for three HAB organisms; ecological forecasts to predict the location, distribution and extent of favorable habitat, and productivity of fish assemblages; and studies of the toxic compounds from the dinoflagellate *Karlodinum micrum* used in prey capture. Addressing multiple stressors, NOAA has developed a watershed modeling approach for understanding and predicting the effects of multiple stressors (e.g., nutrients, contaminants, low dissolved oxygen) on the natural system, living resources, and associated economies in the Patuxent River watershed.

Looking to the Future

The Chesapeake Bay region faces enormous challenges in the coming decades to maintain the quantity and quality of its living resources and recreational resources, resources which have contributed greatly to the economical well-being of the region. A critical need recognized by the scientific and management community is to understand the impacts and management of multiple stressors, especially nutrients entering and impacting the Bay and watershed and shoreline hardening to protect land and houses. NOAA is committed to and engaged in developing regional management tools to predict and effective manage these stressors.

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***From 1990 to 2010 NCCOS' Center for Sponsored Coastal Ocean Research (CSCOR) provided approximately $32.3M for activities in the Chesapeake Bay. The following is a list of planned, current and past funded research projects*.**

Regional Ecosystem Prediction Program (REPP)

Cumulative Impacts of Stressors at the Land-Water Interface in the Mid-Atlantic (FY 2009-planned 2014). Investigating the cumulative impacts of multiple stressors (including climate change) at the land-water interface of estuaries and bays on recreationally, economically or ecologically important living resource populations and communities in the Mid-Atlantic Region supporting a regional ecosystem approach to management of critical stressors (FY 09-14: ≈ $4M planned).

Coastal Hypoxia Research Program (CHRP)

Shallow Water Hypoxia - Tipping the Balance for Individuals, Populations and Ecosystems FY 2010- planned FY 2015). Smithsonian Institution Environmental Research Center, University of Delaware/Lewes, Environmental Protection Agency, Louisiana State University, Maryland Dept. of Natural Resources, University of Delaware/Newark, NOAA/National Marine Fisheries Service. Investigating effects of diel-cycling hypoxia, and associated day-night swings in pH, on shallow waters where they occur, and as factors that may tip the relationship between nutrient loads and system-wide secondary production positive to negative (FY 10-15: ≈$1,743K planned).

Modeling Hypoxia and Ecological Responses to Climate and Nutrients (FY 2007-planned FY 2011). University of Maryland, University of Delaware, Dalhousie University. With initial focus on Chesapeake and Delaware Bays this project is producing science-based predictive tools readily implemented for any coastal system to simulate ecological responses to climate and nutrient input management. A coupled model of physical circulation and biogeochemistry will be used to analyze and improve quantitative understanding of mechanisms underlying hypoxia responses at fine scales (FY 07-11: ≈$1,858K planned).

Watershed-Estuary-Species Nutrient Susceptibility (FY 2005-2009). University of Michigan, U.S. Geological Survey, Smithsonian Institution, Cornell University. Developing predictive understanding of causes and consequences of nutrient pollution on estuarine ecosystems through integration of existing data and models to forecast estuarine susceptibility and impacts on upper trophic levels. Involves USGS' SPAtially Referenced Regressions on Watershed (SPARROW) watershed models to assess the effects of climate change and land use on nutrient delivery to selected estuaries, including Chesapeake Bay (FY 05-09: $2,407K).

Ecological Forecasting (ECOFORE)

Development and Implementation of an Operational Model for Predicting Near Real Time Distribution-Abundance of the Scyphomedusa, *Chrysaora quinquecirrha*, in Chesapeake (FY 2004-2006). University of Maryland, Yale University, Western Washington University, NOAA Coast Survey Development Lab. Development of an operational model to nowcast and forecast the abundance and distribution of the nuisance jellyfish *Chrysaora quinquecirrha* in Chesapeake Bay (FY 04-06: $620K).

Data Synthesis, Model Comparisons, and a Risk-Based Decision Support System for Managing Coastal Systems Exposed to Multiple Stressors (FY 2003-2004). Academy of Natural Sciences, Smithsonian Institution, University of Maryland, University of Virginia. Synthesis and modeling component of the Complexity and Stressors in Estuarine Systems (COASTES) project for cumulative effects of multiple stressors in the Patuxent River (see MULTISTRESS, next page) (FY 02-03: $1,307K).

Ecosystem Variability and Estuarine Fisheries: A Synthesis (FY 2002-2003). University of Maryland, NOAA Great Lakes Environmental Research Laboratory. Developed a suite of tools that synthesize physical and biological data (e.g.,

hypoxia) to provide ecological forecasts to predict the location, distribution and extent of favorable habitat, and productivity of Chesapeake Bay fish assemblages (FY 02-03: $1,277K).

Synthesizing Seagrass Models: Application to Ecological Forecasts (FY 2002-2003). University of Maryland, Mote Marine Laboratory, University of Rhode Island. Synthesized information on seagrass models for use as forecasting or predictive tools through comparative analysis and publication of two critiques for evaluating the models on how closely they addressed local management issues in three target watersheds (Chesapeake Bay, Tampa Bay and Southern Pamlico Sound) (FY 02-03: $152K).

Ecology and Oceanography of Harmful Algal Blooms (ECOHAB)

Role of Parasitism on HAB Dynamics: *Amoebophrya sp. ex Alexandrium tamarense* (FY 2005-2009). Smithsonian Institution. Focused on the recently-isolated dinoflagellate parasite from the genus *Amoebophrya* and its interaction with its host. *Alexandrium tamarense*, a bloom-forming, toxic dinoflagellate that impacts coastal waters. Characterized the parasite, developed a series of molecular probes, studied host-parasite interactions, examined host range and determined role of parasitism on host populations (FY 05-09: $487K).

Molecular Approaches to *Pfiesteria*-Complex Dinoflagellates in Chesapeake Bay (FY 1998-2002). University of Maryland. Developed molecular probes that have the potential to detect the presence of toxic dinoflagellate *Pfiesteria piscicida* and related *Pfiesteria*-complex dinoflagellates (PCDs), distinguish between species, and determine if PCD toxins are present both in the wild and in the laboratory (FY 98-02: $2,488K).

Toxic Dinoflagellates and Nutrients: Toward a Mechanistic Understanding of Outbreaks of *Pfiesteria* and Related Dinoflagellates: A Regional, Comparative Study (FY 1998-2002). University of Maryland, North Carolina State University, University of South Carolina, University of Delaware. Investigated relationships between nutrients and, at the time, the newly identified toxic dinoflagellate *Pfiesteria* in Chesapeake Bay and other East Coast estuaries (FY 98-02: $4,505K).

Consequences and Causes of Variable Toxicity in *Karlodinum micrum* - a Cosmopolitan Ichthyotoxic Dinoflagellate (FY 2004-2006). University of Maryland. Studies of the hemolytic, ichthyotoxic, and cytotoxic toxic compounds from *K. micrum* which help explain some of the variability of toxin production used primarily in prey capture at high densities in Chesapeake Bay and other East Coast areas (FY 04-06: $451K).

Monitoring and Event Response for Harmful Algal Blooms (MERHAB)

Development and Implementation of an Operational Harmful Algal Bloom Prediction System for Chesapeake Bay (FY 2005-planned 2010). University of Maryland, Maryland Department of Natural Resources, University of North Carolina, NOAA Coast Survey Development Laboratory. Development of an operational statistical nowcast/forecast system for three HAB organisms in the Chesapeake Bay ecosystem, specifically the dinoflagellates *Karlodinium micrum*, *Prorocentrum minimus*, and cyanobacteria *Microcystis aeruginosa* to predict the probability of blooms in specific regions (FY 05-10: $1,665K).

In Situ Nutrient Monitoring and Eutrophication-Related Blooms (FY 2004-2006). University of Maryland. Development of methodologies and approaches leading to efficient/cost-effective monitoring of nutrients and eutrophication-related blooms of harmful algal species in Chesapeake Bay and coastal bays (FY04-06: $324K).

Fish Health, Habitat Quality and *Pfiesteria* Surveillance in Support of Maryland's Response to Toxic Outbreaks of Pfiesteria and Similar Dinoflagellates (FY 2001). Maryland Department of Natural Resources. Supported MD DNR to provide a rapid response testing of and reporting on habitat quality and presence of *Pfiesteria* or *Pfiesteria*-like organisms (FY 01: $350K).

Intensive Monitoring for *Pfiesteria* and HAB Related Events in Maryland (FY 1999-2001). Maryland Department of Natural Resources, University of Maryland. Supported MD DNR and the Univ. of Maryland to provide a rapid response testing of the presence of *Pfiesteria* or *Pfiesteria*-like organisms (FY 99-01: $1,212K).

Prevention, Control, and Mitigation of Harmful Algal Blooms (PCMHAB)

Mitigating Microcystis in the Chesapeake (FY 10-planned FY 13). University of Maryland/Baltimore, Maryland Dept. of Natural Resources, Chesapeake Research Consortium, University of Maryland/College Park. Determining

concentrations of local sediments and commercial clays combined with a flocculating compound effective for removal of *Microcystis aeruginosa* populations both in the field and laboratory FY 10-13: ≈$1,684K planned).

Multiple Stressors of Coastal Systems (MULTISTRESS)

Complexity and Stressors in Estuarine Coastal Ecosystems (COASTES): The Importance of Understanding Ecological Complexity to Predicting Effects of Multiple Stressors on Coastal Systems (FY 1995-2002). Academy of Natural Sciences, Smithsonian Institution, SENES, Inc., SUNY/Buffalo, University of Maryland, University of Virginia, Maryland Dept. of Natural Resources. Six-year study of the cumulative effects of multiple stressors in the Patuxent River. Developed a unique watershed modeling approach for understanding and predicting the effects of multiple stressors (nutrients, contaminants, low dissolved oxygen) on the natural system, living resources, and associated economies (FY 95-02: $6,230K).

Environmental Valuation

Chesapeake Bay Environmental Evaluation Training (FY 1993-1995). University of Maryland Sea Grant, NOAA Economics Group. Environmental valuation training to provide comprehensive information on the methods and applications of natural resource economic valuation and ecological economics to state/local planners, coastal zone/marine sanctuary managers, and natural resource trustees (FY 93-95: $82K).

Satellite Remote Sensing Science

Ocean Color Measurements from the Chesapeake Bay Observing System (CBOS) in Support of Sea WiFS Data Validation for Estuaries (FY 1996-1998). University of Maryland. Early development of algorithms for validation of satellite remote sensing of ocean color in coastal regions (FY 96-98: $316K).

Atmospheric Nutrient Input to Coastal Areas (ANICA)

Atmospheric Nutrient Input to Coastal Areas (ANICA) (FY 1991-1995). NOAA Air Resources Laboratory, University of Maryland, Skidaway Institute of Oceanography. Developed methods for assessing the importance of atmospheric nutrient input, using Chesapeake Bay as a target region as set forth in the Clean Air Act Amendments of 1990. Determined the wet and dry deposition of nitrogen (i.e., nitrogen oxides, , ammonia, ammonium and organic nitrogen); developed models to predict present and future atmospheric deposition scenarios, and linked the findings to the Clean Air Act Great Waters Program (FY 91-95: $715K).

Coastal Change Analysis Program (C-CAP)

Coastal Change Analysis for the Chesapeake Bay Region (FY 1990-1992). DOE Oak Ridge National Laboratory. Development of a prototype habitat change analysis including landcover classification, accuracy assessment, and field validation of Landsat data for Chesapeake Bay (FY 90-92: $527K).

CoastWatch

CoastWatch Technical Development for the Mid-Atlantic Region (FY 1990-1995). CSCOR led the development of the NOAA CoastWatch program through a cooperative effort from all NOAA line offices. CoastWatch was the first application of satellite data to oceanography to be used on an operational basis to report winds, sea surface temperature and ocean color. Initially implemented for the East Coast Mid-Atlantic it now covers all U.S. coastal waters and was operationally transferred to NOAA's NESDIS in 1995. CoastWatch established its East Coast Node at the NOAA Chesapeake Bay Office (FY 90-94: $2,809K).

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