Harmful Algal Blooms, Hypoxia & Climate Change: West Coast Region

Introduction

Harmful algal blooms (HABs), hypoxia (severe oxygen depletion) and climate change are often interrelated issues affecting an increasing number of Great Lakes and coastal ecosystems. Virtually every coastal state has reported recurring blooms, and a recent national assessment revealed that over half of our Nation's estuaries experience hypoxic conditions. Impacts have included the devastation of critical coastal habitats, loss of economically and culturally vital shellfish resources, illness and death in populations of protected marine species, and serious threats to human health posed by algal toxins. Just one harmful algal bloom event can cost tens of millions of dollars to local coastal economies and the total costs associated with HABs over the past few decades have been conservatively estimated at over $1 billion.

Climate change brings an added dimension to the cold water ecosystems of the region influencing ocean temperatures, currents and biological production in yet poorly understood ways. The possibility of increasing coastal hypoxia and harmful algal blooms is a possibility under some West Coast climate change forecasts.

Sign posted on Washington beach indicating shellfish closure.

The Problem

There are several causes of HABs and hypoxia. Some are natural, but others are human-induced, and on-going research of the National Oceanic and Atmospheric Administration (NOAA) Center for Sponsored Coastal Ocean Research (CSCOR) continues to identify and distinguish these causes. Some of these blooms produce toxins which cause illness in humans and marine organisms, like blooms of two HAB species along the Pacific coast where toxins may accumulate in shellfish and cause illness in humans who consume neurotoxin-contaminated shellfish. Other types of harmful algal blooms, while non-toxic, reach such large size that the death and subsequent decay of the algae lead to hypoxia in the bottom waters of estuaries and coastal environments. A warming ocean climate threatens the cold-water California Current ecosystem with changes in plankton species and populations with cascading effects upon larger animal populations as salmon, smelt, and rockfish.

Program Description

In the Pacific Coast Region, CSCOR has supported multi-year, interdisciplinary research studies to address the issues of HABs, hypoxia, and climate change impacts in an ecosystem context. Working closely with our Federal, State, and academic partners, CSCOR has investigated the factors that regulate the dynamics of HABs and how they cause harm; developed linked bio-physical models that form a critical base for building ecological forecasts; and applied remote sensing (satellites and ocean observing systems), molecular methods from medical science, and bio-chemical analysis to the detection and tracking of algal species and their toxins. Through these efforts CSCOR has made considerable progress in the ability to detect, monitor, assess, and in some cases, predict HAB and hypoxia events. To predict future impacts of climate change in the region CSCOR supported the multidisciplinary California Current System long-term study, a component of the U.S. Global Ecosystem Dynamics (GLOBEC) Northeast Pacific Program in partnership with the National Science Foundation.

CSCOR Programs in the Pacific Coast Region

- ECOHAB
- MERHAB
- PCMHAB
- CHRP
- Climate Change
- Event Response
- Marine Biotoxins
- CoastWatch

Accomplishments

These interdisciplinary research studies are helping to advance the state of the science and also lead to results with direct application to needs of state coastal resource and public health managers. Recent successes in detecting and forecasting HABs and hypoxia events demonstrate the value of these research investments in helping coastal managers undertake short- and long-term efforts to reduce, and ultimately, prevent the detrimental effects caused by these phenomena:

HAB Detection: In 2004, on Washington's Olympic Coast beaches, levels of cells and toxins in coastal waters collected by MERHAB supported studies, allowed State and Tribal official to determine the safety of razor clams at four Olympic beaches. This allowed managers for to selectively open three of the beaches and to keep a fourth highly popular beach closed due to high levels of toxin. In the past all of the beaches might have been closed. By having the scientific data needed to selectively open and close the beaches, Washington State officials were able to ensure the safety of this highly popular recreational dig which generated nearly one million dollars in three days for Olympic coastal communities.

More than 30,000 clam diggers may descend on the Washington coast in a single weekend, filling beaches, restaurants, and motels.

Recently, massive blooms of the single-celled alga, *Heterosigma akashiwo*, can secrete toxins that destroy fish gills, causing suffocation of both wild and farmed fish such as the economically important salmon. CSCOR is leading an investigation to understand what causes spikes in the population and toxicity of *Heterosigma.*

Ecological Forecasts: A long term ECOHAB project goal in the Pacific Northwest is to develop a mechanistic basis for forecasting blooms of the toxic diatom, *Pseudo-nitzschia*. Researchers in this region are testing the hypothesis that these bloom events affecting Olympic coastal communities are largely caused by toxic algal species growing in the vicinity of the Juan de Fuca eddy and being subsequently transported to nearshore waters by storms. Investigators are looking at the variability of this eddy (size, location, intensity) and at the timing and frequency of storms with respect to presence of the HAB species. Results will benefit coastal managers by providing insights into possible predictors of toxic blooms and by helping identify oceanic/atmospheric conditions favorable for the transport of toxic *Pseudo-nitzschia* onshore where it frequently is transferred up the food chain impacting higher order marine mammals and humans. A Coastal Hypoxia Research Program (CHRP) has looked at paleo- and recent historical trends of hypoxia to support forecasting tools for hypoxia in Puget Sound.

Event Response: Based partially on the dramatic mass mortality events of marine mammals that took place on the California coast during 2000, NOAA has established a suite of programs which provide immediate assistance to state and federal coastal managers and public health officials to reduce the impact of HAB events through rapid, coordinated assistance during toxic algal blooms, related health incidents, and marine animal mortality events. Event Response supported an assessment of toxicity related to a bloom of the cyanobacteria *Microcystis aeruginosa* in upper San Francisco Bay in 2003. Results were used to inform the public, stakeholders, and government resource managers and guide future management action. In 2005, Event Response funding sponsored a workshop where 12 environmental and human-health officials from Oregon learned new techniques, such as phytoplankton cell counts and rapid toxin tests, which can provide early warnings for potential toxin-related shellfish bed and beach closures. In 2010-11, CSCOR supported scientists in Alaska have been monitoring a massive and unusual outbreak of the toxic alga *Alexandrium* and its related potent toxin that can accumulate in shellfish.

Climate Change: From 1997 to 2008 CSCOR supported the Global Ecosystem Dynamics (GLOBEC) program in partnership with the National Science Foundation to model and forecast current and future impacts of climate change on the California Current System (CCS). Studies so far have included the growth and condition of juvenile salmon; long-term changes in hydrology and zooplankton; moored long-term observations of currents; temperature and salinity; fine-scale distribution of juvenile salmon; top-down and bottom-up controls on juvenile salmon; variations in upwelling, nutrient supply, and freshwater effects; and euphausiid population dynamics. Recently, CSCOR has examined the effects of long-term temperature changes on the population biology of dominant species in intertidal areas as an indicator of the effects of climate variability and climate change on marine species. Five West Coast National Estuarine Research Reserves from Alaska to California serve as monitoring sites.

Looking to the Future

CSCOR is poised to make accelerating advances in the capacity for resource managers to anticipate and respond to climate, HAB and hypoxic events along the Pacific Coast. Regional efforts, such as Ecology and Oceanography of Harmful Algal Blooms- Pacific Northwest (ECOHAB-PNW), Olympic Region Harmful Algal Bloom (ORHAB), and Monitoring Oregon Coastal Harmful Algae (MOCHA) fund scientific research that focuses on climate change, HAB events in the Pacific Coast Region and continue to address community concerns. Efforts are underway to implement long-term climate change observations and HAB monitoring and toxin detection programs that incorporate innovative technologies, increasing the precision and lead time of warnings. For example in April 2008 a NOAA-cosponsored Regional Workshop for HABs in California Coastal Waters was convened where California harmful algal bloom researchers and marine animal, public health and water quality managers agreed to work together to initiate the development and implementation of a statewide HAB alert system for California. This alert system will improve the response of managers and scientists to HAB events, such as allowing for more rapid and targeted closures of shellfish beds and better management of impacted marine mammals and seabirds. In California, the CSCOR Ecological Effects of Sea Level Rise program (EESLR) is planning a new initiative regarding future sea level rise impacts to coastal wetlands.

Resources: Contact Quay Dortch, ECOHAB Program Manager, 301-713-3338 x157, quay.dortch@noaa.gov , Marc Suddleson, MERHAB Program Manager, 301-713-3338 x162, marc.suddleson@noaa.gov, Alan Lewitus Hypoxia Research Program Manager, 301-713-3338 x178, alan.lewitus@noaa.gov , or Elizabeth Turner, Climate Change Program Manager, 603-862-4680, elizabeth.turner@noaa.gov; For more information visit the CSCOR website: http://www.cop.noaa.gov/

CSCOR Harmful Algal Bloom, Hypoxia & Climate Change Activities: West Coast

From FY 1997 to FY 2011 the Center for Sponsored Coastal Ocean Research (CSCOR) provided about $52.5M for activities in the U.S. West Coast Region. The following is a list of all current projects and most past projects.

Current Projects

Ecology and Oceanography of Harmful Algal Blooms (ECOHAB)

A Regional Comparison of Upwelling and Coastal Land Use Patterns on the Development of HAB Hotspots Along the California Coast (FY 2011-continuing). University of California, Santa Cruz & Los Angeles, San Jose State University, Monterey Bay Aquarium Research Institute, University of Southern California, Southern California Coastal Water Research Project, NOAA Center for Coastal Ecosystem Health and Biomolecular Research. Developing a better understanding of the ecophysiological conditions leading to bloom and toxin initiation for *Pseudo-nitzschia*, by simultaneously comparing two "hot spots", Monterey Bay and San Pedro, California (FY 11: $865K).

Ecophysiology and Toxicity of Heterosigma akashiwo in Puget Sound: A Living Laboratory Ecosystem Approach (FY 2010-continuing). San Francisco State University, University of Maine, University of Western Ontario, NOAA National Marine Fisheries Service. Identifying the primary toxic element and the specific environmental factors that stimulate fish-killing *Heterosigma akashiwo* blooms and thereby provide managers with the fundamental tools needed to help reduce the frequency and toxic magnitude of these harmful algal events (FY 10-FY 11: $485K).

Modeling Favorable Habitat Areas for *Alexandrium catenella* in Puget Sound and Evaluating the Effects of Climate Change (FY 2010-continuing). University of Washington, Woods Hole Oceanographic Institution, NOAA National Marine Fisheries Service. Providing advanced warning of *Alexandrium catenella* blooms to managers to know how much, where and when "seed" is available to initiate blooms and how favorable habitat areas for cyst germination and vegetative growth will be altered by climate change (FY 10-FY 11: $685K).

PNWTOX - The Columbia River Plume and HABs in the Pacific Northwest: Bioreactor, Barrier or Conduit? (FY 2010-continuing). University of Washington, University of California Santa Cruz, Fisheries and Oceans Canada. Improving predictability of HAB events on Pacific Northwest coastal beaches by advancing understanding of HAB development/dissipation and transport and mixing processes using existing data and models that include, for the first time, both the Columbia River plume and potential HAB source regions off both Oregon and Washington (FY 10-FY 11: $1,742K).

Effects of Chronic Domoic Acid Exposure on Gene Expression in the Vertebrate Central Nervous System (FY 2008-continuing). NOAA National Marine Fisheries Service Northwest Fisheries Science Center, University of Washington. Developing a general model for the characterization of gene expression effects in the vertebrate central nervous system and morphological damage in major organs associated with long-term, low-level toxin exposure as applies to fish, seabirds, marine mammals, and humans (FY 08-FY 11: $349K).

Monitoring and Event Response for Harmful Algal Blooms (MERHAB)

Environmental Sample Processor (ESP) Development: Targeting Cost Reductions, Robustness and an Improved User Interface (FY 11- continuing). McLane Research Laboratories, Inc., Monterey Bay Aquarium Research Institute, Woods Hole Oceanographic Institution, Spyglass Biosecurity, Inc. Modify the existing Environmental Sample Processor (ESP), a fully automated, highly compact, miniature underwater genomic research laboratory that targets microorganisms and gene products, to make it a more affordable, reliable, versatile, and useable instrument for both the West Coast and East Coast (FY 11: $1,060K).

Monitoring Oregon Coastal Harmful Algae (MOCHA) (FY 2007-continuing). Oregon State University, University of Oregon, Oregon Departments of Fish and Wildlife and Agriculture, and NOAA National Marine Fisheries Service. Integrated HAB (e.g., *Pseudo-nitzchia spp.)* monitoring, event response and forecast development for coastal Oregon (FY 07- FY 11: $2.300K).

Past Projects

Ecology and Oceanography of Harmful Algal Blooms (ECOHAB)

Ecology and Oceanography of Toxic *Pseudo-nitzschia* in the Pacific Northwest Coastal Ocean (FY 2002-2009). University of Washington, San Francisco State University, University of Maine, University of Western Ontario, Fisheries and Oceans Canada, NOAA Fisheries. Developing a forecasting capability to predict toxic *Pseudo-nitzschia* species bloom development off Washington and in other similar coastal regions in Eastern Boundary upwelling systems off the Pacific Northwest Coast (FY 02-09: $3.440K)

Dynamics and Mechanisms of HAB Dinoflagellate Mortality by Algicidal Bacteria (FY 2003-2006). University of California, San Diego/Scripps Institution of Oceanography. Identifying compounds in economically important shellfish species implicated in shellfish toxicity, evaluating the performance of the ELISA antibody-antibody methodology for shellfish monitoring, and preparing standardized material to perform independent multi-laboratory assay evaluations (FY 03-06: $212K)

Effects of Algal Toxin Exposure in the Early Life History Stages of Fish (FY 2002-2005). NOAA Northwest Fisheries Science Center. Investigated chronic effects of HABs on the viability, fecundity, and recruitment of key fish species in the marine environment to provide insight into the relationships between HABs and the productivity of marine fish populations (FY 02-05: $277K)

Harmful Ulvoid Macroalgal Blooms in Washington State: Distribution, Environmental Effects, and Toxin Production (FY 2005-2007). Western Washington, University, Seattle Pacific University. Ulvoid green macroalgae in Washington coastal waters (e.g., *Enteromorpha spp., Ulva fenestrata*, and *Ulvaria obscura*) produce toxins detrimental to macroalgae, microalgae, and invertebrates. Determining when/where ulvoid blooms occur, physical, chemical, and biological factors associated with blooms, and examining toxin production and impacts (FY 05-07: $455K)

Identifying Regulatory Mechanisms for *Heterosigma akashiwo* Bloom Formation: Predation Interactions With Algal Behavior and Resource Use (FY 2006-2007). Western Washington University. Identifying protozoan predators of the HAB species *Heterosigma akashiwo* to regulate blooms causing yearly fish kills in coastal waters of the Pacific (FY 06-07: $271K)

Relationship Between Paralytic Shellfish Toxins and *Alexandrium* Cysts in Puget Sound, WA (FY 2004-2007). University of Washington. Addresses relationship between paralytic shellfish toxins in shellfish based on historical records from the Washington Dept. of Health and the distribution of cysts and vegetative cells of the dinoflagellates *Alexandrium spp*. in Puget Sound (FY 04-07: $478K)

Understanding Shellfish Resistance Strategies as a Means to Predict and Manage PSP Toxicity (FY 2006-2007). University of Washington, NOAA Northwest Fisheries Science Center. Characterizing mechanisms underlying bivalve susceptibility to paralytic shellfish toxins and species-specific toxin accumulation to understand factors contributing to shellfish toxicity in the presence of HABs and reduce impacts by providing tools to predict toxin retention by shellfish (FY 06-07: $404K)

Monitoring and Event Response for Harmful Algal Blooms (MERHAB)

Domoic Acid Dip Stick Test Kit: A Rapid, Inexpensive, Sensitive Field Assay for Managers, Health Officials, Shellfish Harvesters, Monitoring Groups (FY 2007-2010). NOAA National Ocean Service Center for Coastal Habitat and Fisheries Research, NOAA National Marine Fisheries Service Northwest Regional Science Center. Developed a rapid, affordable and easy-to-use portable test kit for domoic acid (Amnesic Shellfish Poisoning) (FY 07-10: $185K).

California Program for Regional Enhanced Monitoring of Phyco-Toxins (Cal-PReEMPT) (FY 2004-2010). University of California. Expanded capabilities of the California Department of Health Services by incorporating new in-field monitoring technology, implementing a tiered decision-making process, coupling of remote sensing

and relying on a volunteer network to enhance detecting and tracking capabilities of *Alexandrium* and *Pseudo-nitzschia* HAB events (FY 04-10: $1,998K)

RAPDALERT - Rapid Analysis of Pseudo-nitzschia and Domoic Acid, Locating Events in Near Real Time (FY 2005-2010). University of Southern California, University of California, University of Maryland. Pilot project for shifting much of the burden of HAB monitoring to an automated system to ensure early warning of impending blooms while minimizing unnecessary and expensive field-based sampling and lab-based testing. Results will advance understanding and ability to predict HAB events (FY 05-10: $2,480K)

Monitoring Toxic Alexandrium in Puget Sound Using qPCR (FY 2005-2010). Woods Hole Oceanographic Institution. Incorporated a proven, high-sensitivity detection method for *Alexandrium catenella,* widespread in the NW part of North America and Puget Sound and responsible for seasonal harmful algal blooms and paralytic shellfish poisoning (PSP), into existing PSP monitoring efforts and examines efficacy in predicting or early warning of shellfish PSP toxicity (FY 05-10: $304K)

Quinault Indian National Shellfish HAB Sampling and Monitoring Project (FY 2005-2007). Quinault Indian Nation (QIN). As domoic acid continues to threaten QIN shellfish resources and health of tribal and surrounding communities, the project expanded and improved the current monitoring program established in 2000 for *Pseudo-nitzshia* and domoic acid in water and shellfish beds along the Quinault Indian Nation coastline in Washington State (FY 05-07: $221K)

Quileute Indian Tribe Monitoring Domoic Acid in Marine Food Webs and Water (FY 2001-2003). Quileute Indian Tribe, NOAA Northwest Fisheries Science Center, NOAA NCCOS. Improved the current monitoring program for *Pseudo-nitzshia* and domoic acid in water and shellfish beds along the Quileute Indian Tribe coastline in Washington State (FY 01-03: $186K)

Coastal Hypoxia Research Program (CHRP)

Historical Trends of Hypoxia in Three Basins of Puget Sound (FY 2005-2007). Battelle Memorial Institute, Bryn Athyn College, University of Washington, U.S. Geological Survey. Reconstructed history of hypoxia in three basins of Puget Sound from chemical and biological records of past hypoxic events recorded in sediments. Tools in the form of biomarkers or chemical parameters allow predictive capability for current conditions and potential natural/anthropogenic scenarios, including management alternatives like nutrient removal and river flow control (FY 05-07: $545K)

Ecological Forecasting and Climate Change

Climate Change and Intertidal Biogeography: Forecasting the Effects of Climate Change on the Biogeography of Foundation Species in Estuarine and Rocky Intertidal Ecosystems (FY 2004-2010). University of South Carolina. Developed forecasts of impacts of climate change on populations of intertidal and estuarine species to predict impacts on commercially and recreationally important species. West Coast sites at NOAA National Estuarine Research Reserves at Kachemak Bay, AK, Padilla Bay, WA, South Slough, OR; Elkhorn Slough, CA and Tijuana River, CA (FY 04-10: $2,478K)

Fisheries and Climate Change
California Current System (CCS) Northeast Pacific Global Ocean Ecosystem Dynamics (GLOBEC) **(FY 1997-FY 2008, ≈ $25,164K)**

Effects of Climate Variability on *Calanus* Dormancy Patterns and Population Dynamics Within the California Current. NOAA Southwest Fisheries Science Center. Calanoid copepods are key organisms throughout the world's oceans serving as prey for invertebrates, larval and small pelagic fish, seabirds, and marine mammals and growth and reproduction is directly and indirectly affected by climate variability. Project identifies factors that control onset of and emergence from dormancy in *Calanus* in the Northeast Pacific.

Effects of Meso- and Basin-Scale Variability on Zooplankton Populations in the CCS using Data-Assimilative, Physical/Ecosystem Models. Oregon State University, NOAA Pacific Marine Environmental

Research Laboratory. Using physical-ecosystem models to determine extent of mesoscale variability in controlling ecosystem dynamics, especially zooplankton dynamics, in the CCS and demonstrate how interannual and interdecadal variability impacts regional ecosystem structure.

Juvenile Salmon Habitat Utilization in the Northern California Current - Synthesis and Prediction. Oregon State University, NOAA Northwest Fisheries Science Center. First attempt to define in detail habitats of juvenile salmonids in coastal ocean waters of the Pacific Northwest. Producing better understanding of how environmental variability (e.g., coastal upwelling, El Niño events, regime shifts) and/or biological interactions (predator-prey relationships, diseases, parasites) affect quality of salmon habitats and their growth and survival.

Large-Scale Influences on Mesoscale Structure in the CCS - A Synthesis of Climate-Forced Variability in Coastal Ecosystems. Oregon State University, NOAA Southwest Fisheries Science Center. A variety of extreme climate events occurred during the period of monitoring and process studies in the California Current System (1997-2003) and provide unprecedented opportunity to examine climate variability experienced by the CCS. Project provides indicators of response of marine populations to climate change, a useful tool for resource assessment/management.

Latitudinal Variation of Upwelling, Retention, Nutrient Supply and Freshwater Effects in the California Current System. Oregon State University, Naval Post Graduate School, University of Washington. Project synthesized moored current meter, shore-based HF radar, ship-based hydrographic, and remotely sensed data from the GLOBEC Northeast Pacific Long-Term Observation Program and related programs into a coherent, best description of the mesoscale variability along the Pacific Northwest coast. Provided best possible comparison point for the initialization and verification of both physical and ecosystem models being developed and tested by other GLOBEC investigators.

Synthesis of Euphausiid Population Dynamics, Production, Retention and Loss Under Variable Climatic Condition. Oregon State University, NOAA Northwest Fisheries Science Center. A long-term study comparing life history, population dynamics, vital rates, and production of co-occurring euphausiid species, *Euphausia pacifica* and *Thysanoessa spinifera* in the CCS and includes synthesis of this large data set using a coupled bio-physical model of population dynamics.

Oceans and Human Health
(FY 2005- FY 2007, ≈$5,940K)

Exploiting Marine Actinomycete Genomes for Natural Product Discovery. University of California, San Diego. The newly discovered fungal genus *Salinispora* provides an excellent model that can be used to test new approaches for natural product discovery. Research includes preparation of a genomic DNA library, culture, cloning and sequencing of biosynthetic gene clusters for production of therapeutic bioactive compounds.

PBDE Accumulation in Pacific Salmon and Effects *in utero*. NOAA Northwest Fisheries Science Center, University of Washington, Washington Department of Fish and Wildlife. Levels of brominated flame retardants such as the polybrominated diphenyl ethers (PBDEs) congeners have increased in fish, wildlife and human tissues during the last decade. Study uses Chinook salmon, human adult liver tissue, and human fetal cell models to establish the linkages among PBDE in Pacific salmon and toxicity to human fetal cell targets of maternally-transferred PBDEs.

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