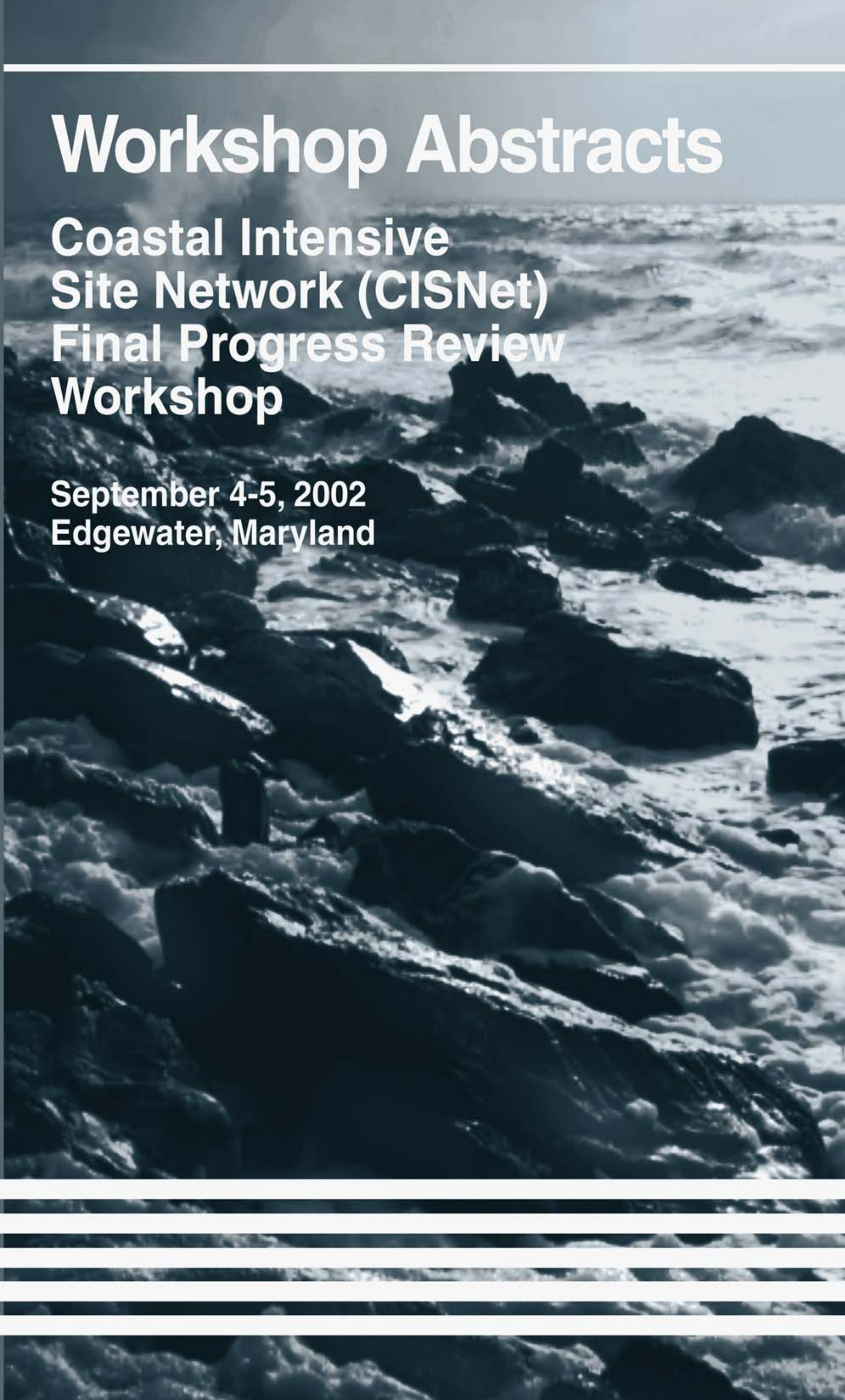
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY



Workshop Abstracts

Coastal Intensive Site Network (CISNet) Final Progress Review Workshop

September 4-5, 2002
Edgewater, Maryland

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Introduction

In Fiscal Year (FY) 1998, the U.S. Environmental Protection Agency (EPA), in partnership with the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA), funded a set of research grants through a competitive solicitation. The goal of the solicitation was to establish a network of pilot sites along the U.S. Marine and Great Lakes coasts known as the Coastal Intensive Site Network (CISNet). CISNet research topics focused on using ecological indicators and investigating the ecological effects of environmental stressors.

CISNet had three main objectives, which included:

- Developing a scientific basis for understanding ecological responses to anthropogenic stresses in coastal environments, including the interactions of exposure, environment/climate, and ecological factors, as well as the spatial and temporal nature of these interactions.

- Demonstrating the usefulness of intensively monitored sites for examining short-term variability and long-term trends in the relationships between natural and anthropogenic stressors and ecological responses.

- Evaluating indicators of change in coastal systems at particular intensively monitored sites.

In 2000, as a follow-on and expansion of the 1998 CISNet Research Program, EPA and NASA funded an additional set of larger, longer term grants, collectively referred to as the Estuarine and Great Lakes (EaGLe) Program. There currently are five EaGLe Programs focusing on ecological indicators, with two in the Atlantic, one in the Pacific, one in the Great Lakes region, and one in the Gulf of Mexico. Additional information about these programs and an open solicitation for a sixth EaGLe research program can be found at: http://www.epa.gov/ncer/centers/eagles/.

The *Coastal Intensive Site Network (CISNet) Workshop Abstracts* publication was developed in support of the Final CISNet Progress Review Workshop in Edgewater, MD, on September 4–5, 2002. This document contains abstracts outlining results and accomplishments for the eight CISNet grants funded by EPA in FY 1998 through the National Center for Environmental Research's (NCER) Science to Achieve Results (STAR) Program. EPA's STAR Program funds research grants in numerous environmental science and engineering disciplines through a competitive process and independent peer review.

This Final Progress Review Workshop provides a forum for EPA's STAR CISNet award recipients to discuss their results and lessons learned. EPA representatives and other interested parties also have been invited to attend to stimulate a discussion of research needs between government and private-sector researchers.

Any opinions, findings, conclusions, or recommendations expressed in this report are those of the investigators who participated in the research. For questions on the EPA CISNet grants, please contact the EPA CISNet Program Manager, Gina Perovich, by telephone at 202-564-2248 or by e-mail at perovich.gina@epa.gov. For further information about the EaGLe Program, please contact Barbara Levinson by telephone at 202-564-6911 or by e-mail at levinson.barbara@epa.gov.

To learn more about EPA's STAR Program, visit NCER's Web Site at: http://www.epa.gov/ncer.

Indicators of UV Exposure in Coral: Relevance to Global Climate Change and Coral Bleaching

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The overarching goal of this project has been to evaluate the potential contribution of interactions between climate change and ultraviolet (UV) radiation in coral bleaching. To provide additional tools for evaluating the role of UV radiation, UV-specific stresses on corals have been examined and factors that alter the penetration of UV radiation over coral reefs have been characterized at sites located in the Florida Keys.

The first objective of this project was to develop immunofluorescence techniques to examine UV-specific lesions in DNA (thymine dimers) of coral and zooxanthellae. A 96-well enzyme-linked immunosorbent-type assay for evaluating thymine dimers in coral and zooxanthellae has been developed. Methods for immunolocalization of thymine dimer and coral tissue also have been finalized.

The second objective was to determine whether UV-induced DNA damage and indices of coral bleaching are correlated, including laboratory and field assessments of photoprotective pigment concentrations. To date, this research group has complete laboratory and field exposures to address this relationship. Both laboratories (Bodega Marine Laboratory and EPA's Gulf Ecology Division, Gulf Breeze, FL) are completing analysis of the tissues from these experiments.

The third objective was to further examine the relationships between temperature, UV, and coral bleaching in controlled experiments. During the 2001 field season, an outdoor exposure test was conducted at the Mote Marine Laboratory for UV and temperature. Early in the course of this 8-day exposure, coral polyps demonstrated altered behavior based on level of exposure. Those in high UV/high temperature treatments spent more time retracted and were showing early stages of bleaching.

The fourth objective was to measure underwater solar UV irradiance and attenuation coefficients as well as to develop continuous observations of chromophoric dissolved organic matter (CDOM) concentrations and algorithms that relate CDOM concentrations to UV exposure of coral assemblages. Research has focused on factors that affect UV exposure of coral assemblages in the Florida Keys. The location of the sites used for these studies ranged from Sand Key near Key West, FL, to Sombrero Tower near Marathon, FL.

Activities included the following:

- Measurements of underwater solar UV radiation and optical properties of water samples at various sites located in the Lower Keys
- Development of algorithms that describe the penetration of UV radiation into the Florida Keys water
- Use of fluorometers for the measurement of UV-protective CDOM at SEAKEYS CMAN towers located at Sombrero Tower (near Marathon, FL) sites
- Comparisons of fluorescence and UV attenuation along transects from land out to the coral reefs
- Research on thermal stratification effects on UV penetration and initial studies in the field and under controlled conditions on UV attenuation by CDOM derived from Florida Bay sea grasses and mangroves
- Experiments on the rates of UV absorbance loss (photobleaching) to CDOM in water samples collected near the coral reefs when they were exposed to simulated solar radiation.

In Situ and Remote Monitoring of Productivity and Nutrient Cycles in Puget Sound

Steven Emerson, Allan Devol, and Wendi Ruef
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The Ocean Remote Chemical Analyzer (ORCA) is an autonomous, moored profiler developed to sense a variety of chemical and optical properties in the upper ocean. Since deployment in May 2000, ORCA has been used to monitor water quality parameters in South Puget Sound, a largely undeveloped area subject to extensive future urbanization that also is potentially sensitive to impacts from eutrophication. The goal of the ORCA Project was to use the long-term, high-resolution dataset collected with the profiler to monitor tidal, diel, seasonal, and interannual cycles and trends in stratification, dissolved oxygen (DO) concentrations, nutrients, and phytoplankton abundance.

ORCA has three main components: (1) a three-point moored autonomous temperature line acquisition system toroidal float; (2) a housed platform equipped with a computer, winch, cellular system, meteorological sensors (wind, temperature, humidity, irradiance), solar panels, and batteries; and (3) an underwater sensor package consisting of a Seabird conductivity, temperature, and depth (CTD) profiler, DO electrode, Wetlabs transmissometer, Wetlabs chlorophyll fluorometer, and a recently added WS Ocean EcoLab nutrient sensor. ORCA profiles the water column at regular sampling intervals, using the pressure information from the CTD to run the winch. The data are recorded on the computer and transmitted back to the laboratory automatically via cellular communications.

The dataset that ORCA has collected in the last 2 years reveals a covariation in temperature, salinity, oxygen, and chlorophyll, indicating a tight coupling between physical and biological processes. As seen in the 2002 data (see Figure 1), the water column was well mixed during the winter and early spring, with low DO and chlorophyll concentrations both at the surface and at depth. Variability in wind, rainfall, and sunlight forced changes in surface temperature and salinity, producing intermittent periods of either strong stratification or deep mixing throughout the summer.

At depth, temperature and salinity steadily increased during the summer. Chlorophyll and oxygen covaried, with a maximum chlorophyll concentration of 12.113 mg m^{-3}, observed at the surface during a spring bloom in April, resulting in an oxygen concentration of 440.45 $\mu mol\ kg^{-1}$ (154.15% saturation).

Following the bloom, the chlorophyll maximum moved subsurface, varying between 5 and 10 meters. At depth, chlorophyll concentrations remained low throughout the year, while oxygen, undersaturated in the winter, increased steadily during the spring to near saturation in mid-summer.

A box model calculation of the 2000 data suggests that oxygen variation primarily is a result of gas exchange and net biological oxygen production, and that oxygen production is largely dominated by photosynthesis. Net biological oxygen production in the summer of 2000 had a mean value of 0.2 mol $m^{-2}d^{-1}$. This value is nearly equal to ^{14}C uptake productivity measured over the same time period, indicating that there is very little respiration occurring in the euphotic zone during the summer months.

ORCA will continue to gather data through 2002, which will be combined with the existing data to further refine the box model terms and calculations as well as provide a better understanding of oxygen variability and other processes in the South Sound.

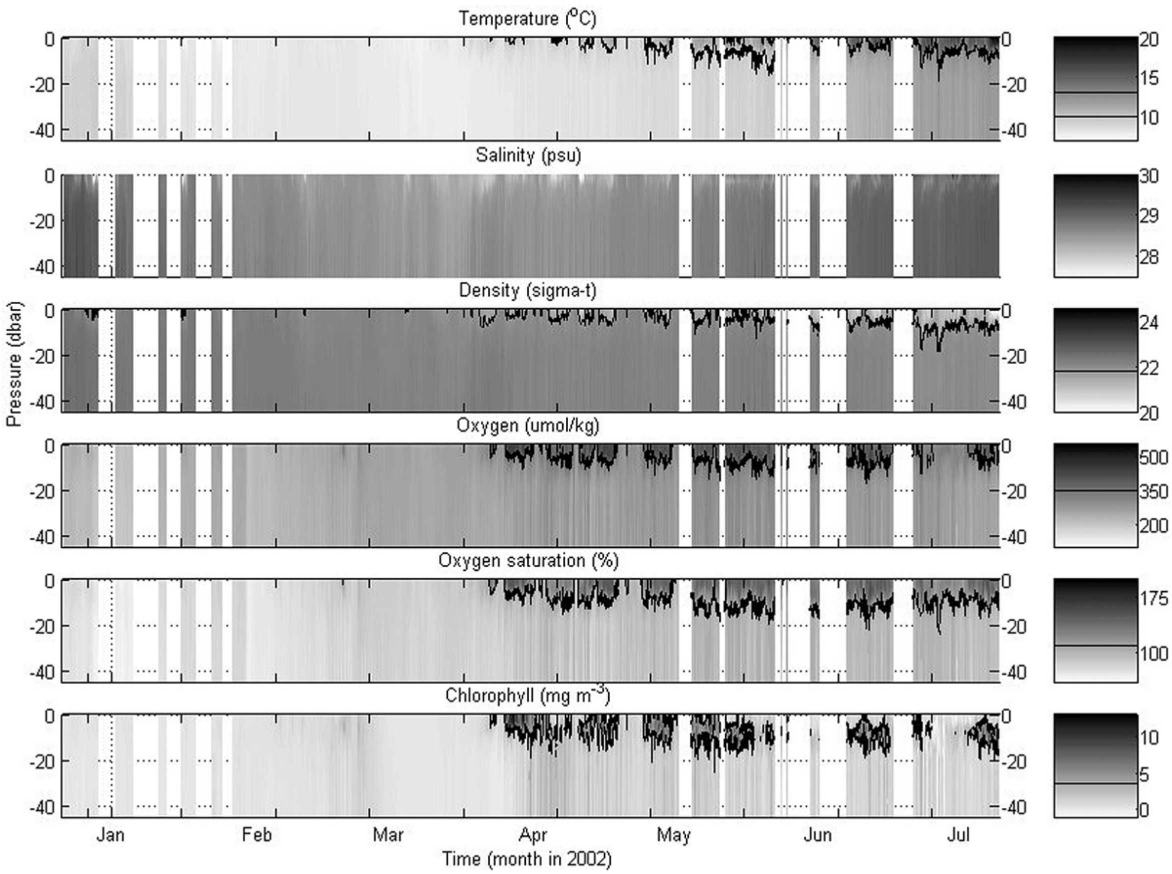

Figure 1. Maps of temperature (ºC), salinity, density (σ_t), oxygen (µM kg^{-1}), oxygen saturation (%), and chlorophyll fluorometry (mg m^{-3}) versus pressure (decibars) and time (yearday) from Carr Inlet, Puget Sound (January 1, 2002–July 22, 2002).

Rhode River CISNet: Estuarine Optical Properties as an Integrative Response to Natural and Anthropogenic Stressors

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The primary objective of the Rhode River CISNet was to develop monitoring of estuarine spectral optical properties as an integrated measure of estuarine response to perturbations. Research to interpret continuously monitored optical properties focused on: (1) determination of the concentrations of suspended particulate matter (SPM), phytoplankton chlorophyll, and colored dissolved organic matter (CDOM); (2) quantification of nutrient inputs and their effects on concentrations of chlorophyll, SPM, and CDOM; and (3) research to examine the effects of solar ultraviolet (UV) radiation on near-shore plankton communities, as influenced by potential changes in estuarine optical properties.

The approach combined automated monitoring to measure salinity as a surrogate for nutrient inputs and inherent optical properties to gauge system responses, *in situ* measurements of nutrient concentrations and benthic nutrient fluxes, and experimental measurements of biological weighting function (BWF) of phytoplankton response to UV radiation. Optical data and BWF were used to model phytoplankton photosynthetic response to UV radiation.

Almost 2 full years of data on continuously monitored inherent optical properties were obtained. The seasonal pattern in absorption coefficient appeared remarkably similar in the 2 years (see Figure 1), although differences in magnitudes of spring and fall blooms between the 2 years were apparent. Salinity monitors documented that the onset of the spring blooms was initiated by the spring freshet of the Susquehanna River. Together, the 2 years of hourly data on inherent optical properties gave an unprecedented picture of the optical variability in a shallow coastal system.

Measurements of sediment nutrient release rates revealed a high degree of spatial and temporal variability. Rates of ammonium release appeared to largely follow the temperature cycle, with peak rates occurring in June to July. Phosphate release rates peaked later than ammonium release. The nitrogen:phosphorous (N:P) ratio for benthic nutrient release rates appeared to average approximately 4, which is similar to the average N:P ratio of sediment discharged from the local watershed.

Variations in irradiance-dependent BWFs showed considerable variation in BWFs within each season. The average, absolute spectral weightings for inhibition of photosynthesis in phytoplankton assemblages from the Rhode River was similar to an average BWF for Antarctic assemblages.

The monitored inherent optical properties and estimates of diffuse attenuation coefficients derived from them documented the effect of eutrophication on degradation of the underwater light climate for supporting submerged aquatic vegetation in this system. Both remote (i.e., Susquehanna River) and local (i.e., benthic release) sources of nutrients were shown to be important in fueling eutrophication. The models of phytoplankton photosynthetic response showed that UV radiation contributed to wide daily swings in inhibition, ranging between a maximum of 35 percent and a minimum of 5 percent of daily water column production.

Ongoing work will extend the geographical extent of the inventory of inherent optical properties. This will be used in radiative transfer modeling to develop indicators of habitat suitability for submerged aquatic vegetation using data available from government-sponsored water quality monitoring networks throughout the Mid-Atlantic States.

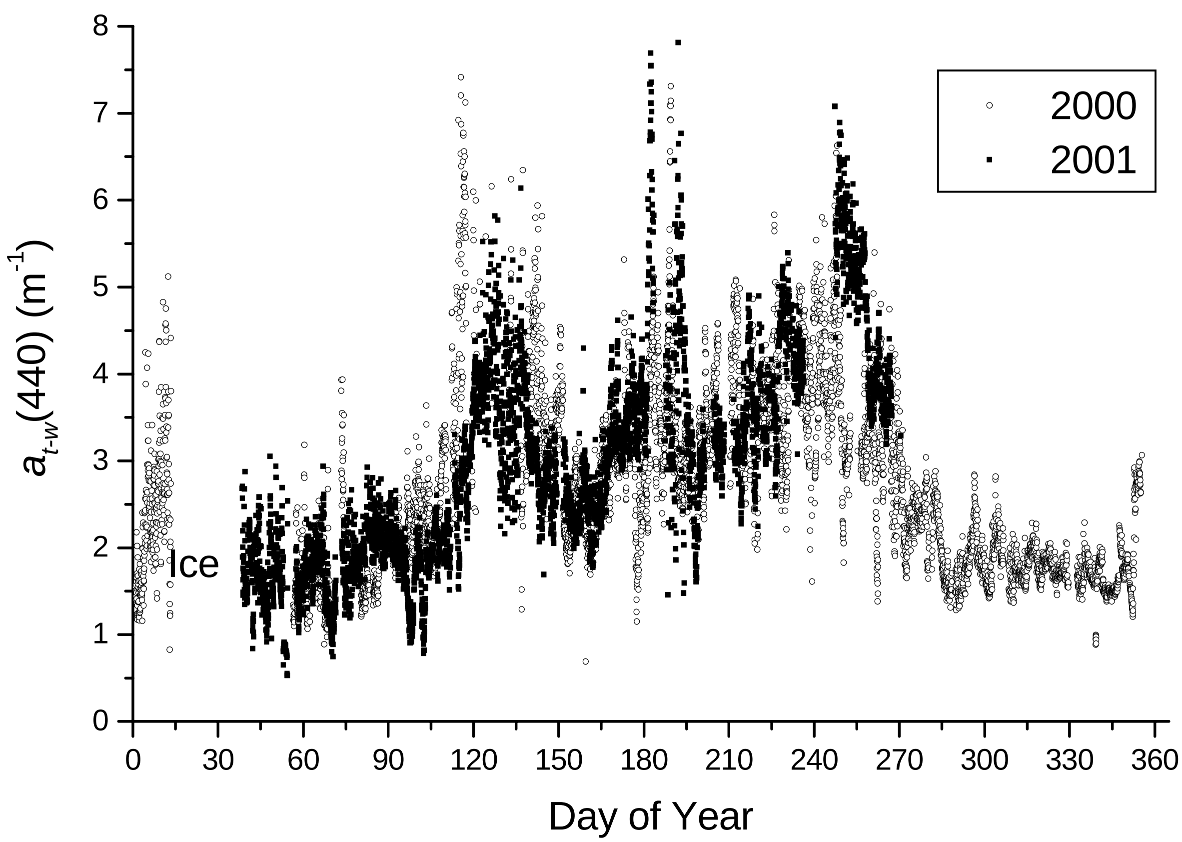

Figure 1. Time-series of hourly monitored absorption coefficient at 440 nm [total less that due to water, $a_{t\text{-}w}(440)$] in the Rhode River, MD. The seasonal pattern is driven by the spring phytoplankton bloom (approximately day 100–145), and a gradual increase in absorption by nonalgal particulates during the summer.

CISNet for the Neuse River Estuary, NC: A Program for Evaluating Nitrogen-Driven Eutrophication Associated With Changing Land Use in a Coastal Watershed

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During the past 2 decades, the Neuse River Estuary (NRE) has been plagued with nuisance algal blooms, hypoxia, toxicity, and fish kills associated with declining water quality. Increased nitrogen (N) loading has been implicated.

In 1997, the State of North Carolina legislated a 30 percent reduction in external N loading to the NRE by 2003. In 1999, Hurricane Fran caused 100–500 year flooding in the Neuse River Basin and generated an extreme loading event to the NRE. Both the longer term load reduction and the extreme, episodic loading represent large-scale manipulations to the NRE and provide the opportunity to examine the effects of nutrients on the ecosystem.

In 1998, a suit brought by the Neuse River Foundation against the U.S. Environmental Protection Agency (EPA) was settled, resulting in an agreement by the State of North Carolina to set a formal total maximum daily load (TMDL) for total N for the NRE. This CISNet project has contributed substantially to the development of this TMDL.

The approach has included field-based studies of: (1) hydrography, nutrients, dissolved oxygen (DO), and light and phytoplankton dynamics; (2) atmospheric N inputs; and (3) circulation in the NRE-Pamlico Sound system. The project has focused on DO and the planktonic microalgal community as easy-to-measure indicators of biotic response of this ecosystem to external stressors. DO depletion restricts benthic habitat and plays a causal role in fish kills. Phytoplankton dominate primary production and nutrient fluxes. A natural attribute of the phytoplankton—photopigments (determined by high-performance liquid chromatography coupled to spectrophotometry)—have been utilized to rapidly and effectively distinguish major phytoplankton functional groups.

This research has provided quantitative data on: (1) the role of atmospheric loading in the delivery of N to the NRE; (2) circulation patterns in the NRE, including wind-driven upwelling of low-oxygen bottom water in the near-shore regions (a causal mechanism for fish kills); and (3) the response of microalgal communities to several years of N loading. The most dramatic response occurred following Hurricane Floyd, when the organic and inorganic nutrient load caused extensive bottom-water hypoxia and the development of an algal bloom (chlorophyll-α levels above 20 µg/L compared to typical values of approximately 3–6 µg/L) at the mouth of the NRE. Diagnostic pigment analysis indicated a shift toward mainly freshwater species with low diversity. Physical, microalgal, and DO conditions in the NRE appeared to return to near normal during the summer of 2000.

The NRE may be expected to respond very differently to long-term chronic stress and short-term episodic stress. This grant has allowed the research group to build toward time-series that are capable of separating long-term trends from interannual variability in the NRE. It also has provided the unprecedented opportunity to observe the ecological consequences of an extreme event in the NRE. Understanding the relative roles of chronic and event-based stressors is critical for determining the effectiveness of nutrient reduction in the NRE, given the forecast of enhanced hurricane activity for the next 20 years.

To meet the State of North Carolina's responsibility to establish a TMDL for total N, three water quality models were developed for the NRE from 1999–2001. Data collected in the NRE as part of this grant were crucial for calibrating and verifying these water quality models (see Figure 1). The State of North Carolina submitted the N TMDL to the U.S. Environmental Protection Agency (EPA) for review in December 2001.

The CISNet research efforts have been expanded to include the response of Pamlico Sound (which lies downstream of the NRE), aircraft remote sensing of algal pigments, and comparative studies in other East Coast estuaries. Funding for this work is being provided in part by an EPA grant from the Estuarine and Great Lake Ecosystems Program.

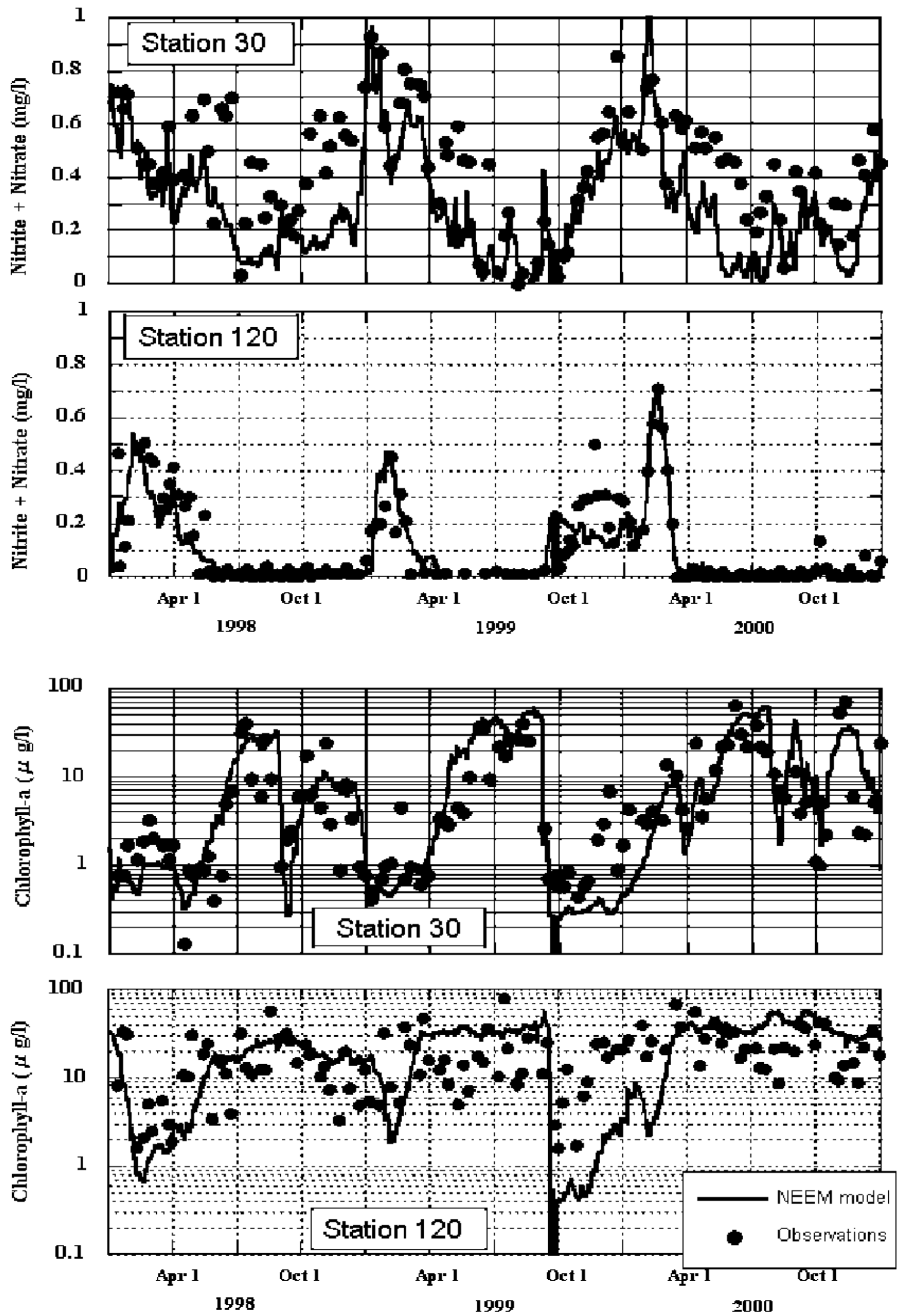

Figure 1. Comparison between 3 years of observed data and model output from the Neuse Estuary Eutrophication Model at upstream (Station 30) and downstream (Station 120) stations in the NRE. Results from this and two other water quality models were used to determine a TMDL on total N for the NRE.

The Choptank River: A Mid-Chesapeake Bay Index Site for Evaluating Ecosystems Responses to Nutrient Management

Thomas C. Malone, Jeffrey C. Cornwell, William C. Boicourt, Lawrence W. Harding, Jr., and J. Court Stevenson
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The primary goal of this research project was to develop and examine methods for detecting responses to anthropogenic stresses in the Choptank River Index Site and to establish the Site as a sentinel of change for a broader domain of coastal plain ecosystems. Of particular interest are the impacts of meteorological fluctuations and nutrient management in the Choptank drainage basin on water quality and living resources in the estuary. The intent is to: (1) resolve responses caused by human activities from the variability imposed by nature, (2) develop key indices of ecosystem change, and (3) predict trends and their consequences. The strategy has been to use modern, high-intensity, high-resolution sampling and analytical tools in conjunction with the historical record to understand these changes.

The use of high temporal resolution nutrient and physical measurements at few sites was contrasted to similar measurements taken at the monthly time scale over large spatial scales. The use of buoys, airborne remote sensing equipment, and research vessels provided different views of estuarine processes. Nutrient retention within the tidal wetlands in the Choptank River Estuary was assessed using ^{210}Pb-dated cores at a large number of sites. Small-scale (tens of meters) variability in sediment and nitrogen (N) and phosphorus (P) burial have been compared to that observed over a larger (tens of kilometers) scale, with a goal of optimizing the extrapolation of nutrient burial rates to the whole system.

Highlights from within the Choptank CISNet Site Program were the construction of nutrient burial estimates from core analyses, the successful measurement of high-resolution time-series observations, and the production of an interactive geographic information system-based data structure for delivery to a wide variety of users. The expansion of the time-series observations occurred not only through internal CISNet efforts, but also through linking and collaboration with related programs.

Core analysis from the Choptank River CISNet Site indicated that sedimentation rates varied from less than 1 kg m^{-2} y^{-1} to more than 5 kg m^{-2} y^{-1}. Estimates of N and P burial were 8–43 g m^{-2} y^{-1} and 0.5–3.7 g m^{-2} y^{-1} (n = 23), respectively, clearly indicating that these tidal marsh sediments are important sinks for N and P in this system. Trends in water column N and P over the 3-year CISNet Program were dishearteningly upward throughout the upper Choptank River (see Figures 1 and 2).

The results of this program have shown how: (1) different scales of observation provide similar ideas of estuarine processes; (2) the inclusion of marsh processes, particularly in a system with relatively high rates of sea level of rise, is important for understanding estuarine nutrient balances; and (3) cooperative data cataloging efforts involving citizen monitoring can provide important information needed for local decisionmaking.

The award of the STAR Grant to the ACE INC EaGLe Program provides a mechanism to continue a portion of the CISNet Program, and thereby allow a longer term assessment of the effects of land use on ecosystem health. Sea Grant-funded efforts on understanding oyster restoration have benefited from this improved understanding of the estuary.

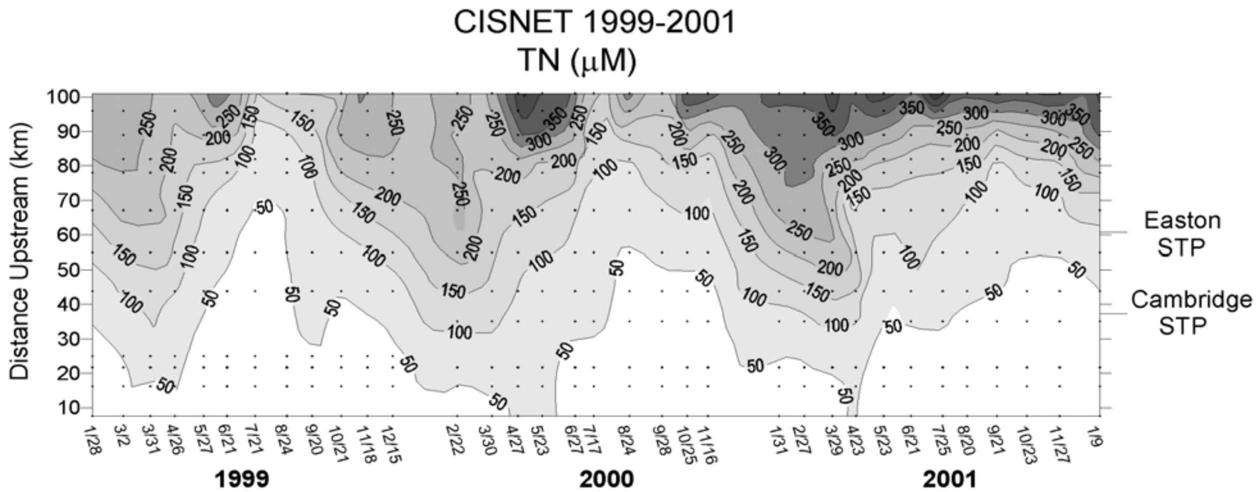

Figure 1. Contour plot of CISNet total nitrogen (TN) data. The vertical axis is distance from the mouth of the river. The horizontal axis is time, with all sampling dates indicated. The contours are of total nitrogen, with the spatial trends driven mainly by changes in nitrate concentration. The high TN concentrations at the freshwater end of the estuary have increased in the last decade. Nitrogen inputs are largely from diffuse sources.

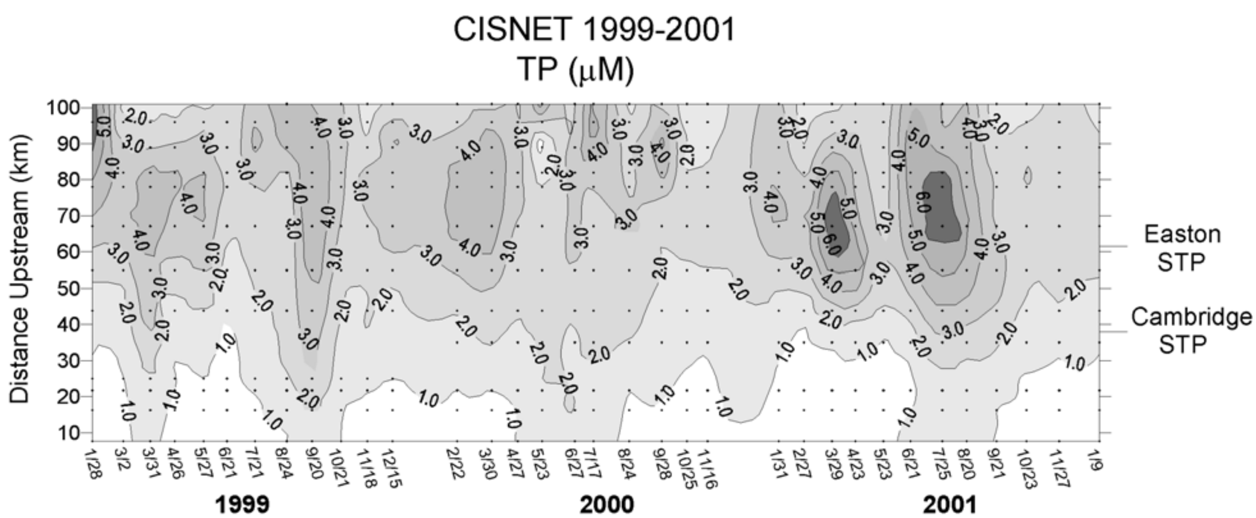

Figure 2. Contour plot of total phosphorus data. The highest concentrations are located in the part of the upper river receiving inputs from a sewage treatment plant.

CISNet: Molecular to Landscape-Scale Monitoring of Estuarine Eutrophication

James T. Morris, Madilyn Fletcher, John Jensen, Alan Lewitus, Peter Noble, and Dwayne Porter
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University of South Carolina, Columbia, SC

This research group investigated: (1) molecular approaches (polymerase chain reaction/denaturing gradient gel electrophoresis, pigments) for quantifying changes in the composition and abundance of bacterial and phytoplankton communities among South Carolina estuaries; (2) the dependence of plankton community composition on water quality; (3) spatial and temporal variation in canopy chlorophyll density in salt marshes; (4) technologies for remotely sensing canopy chlorophyll density; and (5) neural net technologies for classifying remote images and microbial communities.

High-performance liquid chromatography (HPLC) pigments have been analyzed from taxonomically diverse algal species acclimated to growth at saturating or limiting light, and harvested from exponential or stationary growth phase. The CHEMTAX algorithm has been calibrated to predict community composition. Neural networks successfully have been trained to HPLC pigment profiles and environmental data, and correlative relationships between pigments and physicochemical properties have been found. Seasonal differences in community composition and differences among estuaries will be discussed.

In situ radiometric and biophysical (chlorophyll, biomass) data were obtained seasonally at approximately 50 locations within each of the *Spartina alterniflora*-dominated study areas in the North Inlet Estuary and the Ashepoo-Combabee-Edisto (ACE) Basin. The biophysical data were correlated to leaf radiance data collected using the field spectrometer and with remotely sensed data.

Spectrophotometer scans of plant leaves from experimentally fertilized plots have demonstrated that significant differences exist between treatments in reflected light. Significant differences in canopy chlorophyll density were found between the North Inlet and ACE Basin Estuaries, and it was shown that the chlorophyll:biomass ratio varies seasonally.

Existing regression models (e.g., Normalized Difference Vegetation Index) were used to fit chlorophyll density to brightness values from Airborne Data Acquisition and Registration (ADAR) imagery. In addition, a neural net was trained to classify ADAR imagery (see Figure 1) and predict canopy chlorophyll density. The neural net model was significantly better at predicting chlorophyll than traditional regression approaches. A neural network is proving to be an excellent tool for classifying coastal landscapes. Excellent resolution of wetland areas, open water, and uplands has been found using this approach (see Figures 1 and 2).

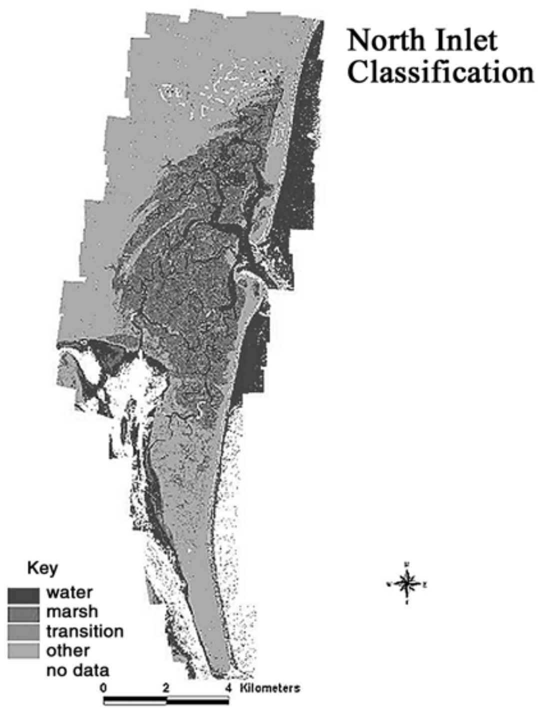

Figure 1. Neural network classification of North Inlet intertidal marshland and open water based on an ADAR image with a 60 cm spatial resolution.

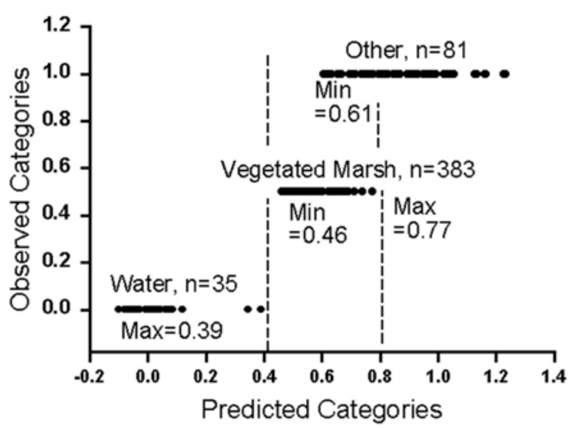

Figure 2. Observed and neural net predicted classification categories from North Inlet Estuary. Results show perfect separation between water and other classes. The overlap between marsh and other categories was 8 percent of the total number of samples, 466, in those two classes. The overlap represents transition area.

CISNet San Pablo Bay Network of Environmental Stress Indicators

S. Geoffrey Schladow[1], Thomas M. Young[1], Inge Werner[2], Bruce Thompson[3], Jay Davis[3], Nadav Nur[4], and David Schoellhamer[5]
[1]Department of Civil and Environmental Engineering, University of California, Davis, CA; [2]Department of Anatomy, Physiology, and Cell Biology, School of Veterinary Medicine, University of California, Davis, CA; [3]San Francisco Estuary Institute, Richmond, CA; [4]Point Reyes Bird Observatory, Stinson Beach, CA; [5]U.S. Geological Survey, Sacramento, CA

San Pablo Bay and its surrounding rivers, sloughs, and marshlands, is a highly complex and energetic estuarine system that is subject to the influence of several major environmental stressors. These include sediment loads; heavy metal and pesticide residues from California's Central Valley, the Sierra Nevada, and the coastal range; the impact of a population of more than 7,000,000 people; and industrial waste from the San Francisco Bay Area (including several oil refineries). The objective of this project was to assess the adequacy of conventional monitoring protocols, test potential indicators, and design a monitoring network that is temporally and spatially compatible with the system's inherent complexity.

The approach was based on investigating linkages between waterborne and sediment-borne contaminant fluxes and toxicity. A network of intensive and intermediate measurement stations was established. Measurements included the continuous acquisition of current, temperature, salinity, and suspended sediment concentration data, as well as monthly water and sediment sampling.

Biochemical, cellular, and histological indicators of ecological stress in resident clams (*Macoma spec.*, *Potamocorbula amurensis*) and amphipods (*Ampelisca abdita*) were analyzed to foretell subtler and possibly longer term consequences of exposure to chemicals in the environment. Ecological stress indicators considered included number and diversity of species within benthic assemblages, contaminant bioaccumulation in fish tissue, and reproductive success for two bird species, double-crested cormorants (*Phalacrocorax auritus*) and song sparrows (*Melospiza melodia*).

From the standpoint of hydrodynamic and sediment transport processes, the system presents tremendous complexity, in both a spatial and temporal sense. Of the areas studied in greatest detail, the Napa River and the Petaluma River, both have a unique and somewhat singular set of controlling factors. In the Napa River, there is baroclinic flow convergence arising due to a phase mismatch at the junction of two tidal channels. By contrast, in the Petaluma River there is the formation of a transitional sediment storage zone, driven by the interaction of the semidiurnal tides with the river-estuary interface.

Both mechanisms lead to the concentration of suspended sediment in a relatively small geographic zone. For sediment-borne contaminants—both organic and inorganic—this has led to local "hot spots" in both areas. Benthic assemblage sampling at the Petaluma River Site showed unusually high species diversity and high abundances coupled with the presence of many opportunistic and contamination-tolerant species, suggesting that this station may be impacted. In addition, seasonal "first flush" phenomena have been responsible for observations of organic contaminants several orders of magnitude above observations from regional monitoring efforts.

Indicator species, such as *P. amurensis,* showed markedly reduced survival when exposed to sediments from the Napa and Petaluma Rivers (see Figure 1). Tidal marsh song sparrow nest success is low both in San Pablo Bay and the adjoining Suisun Bay, although further analysis is required to ascertain whether the population viability is at risk, and the role (if any) that aquatic contaminants play.

The results suggest that spatial and temporal variations in the study system are discontinuous, and that characterizing such a system requires *a priori* knowledge of where and when to conduct sampling. Whereas many of the sampling locations yielded information similar to a parallel regional monitoring program, the greater intensity of observations allowed for a vastly different picture of contaminant transport and flux to emerge.

Future research is centered on better characterization of the hydrodynamic flows to identify those areas most likely to harbor conditions of contaminant accrual. Sensor development, to provide more continuous chemical data in remote and hostile conditions, is a further key area of research. This approach is being carried forward in several parallel research efforts.

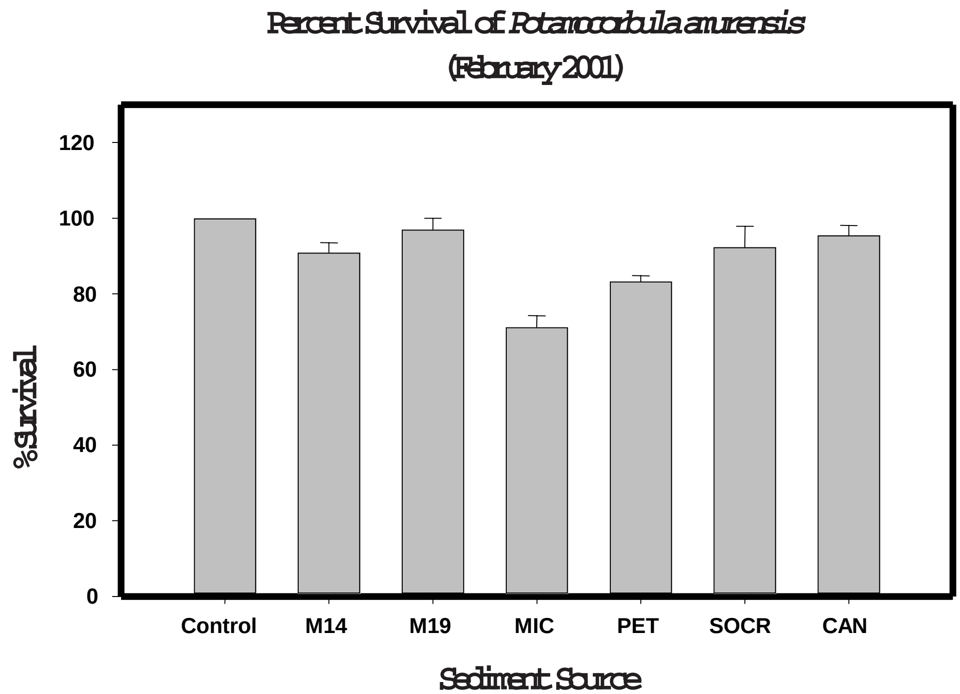

Figure 1. Survival (%) of *Potamocorbula amurensis* exposed for 10 days to sediments from sampling sites in San Pablo Bay and adjacent marshes (mean and standard error). Sediments were collected in February 2001. Sites MIC and PET were from the Napa and Petaluma Rivers, respectively.

CISNet: Nutrient Inputs as a Stressor and Net Nutrient Flux as an Indicator of Stress Response in Delaware's Inland Bays Ecosystem

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This project focused on the input and cycling of nutrient elements (nitrogen [N], phosphorus [P], carbon, and silicon) in the Delaware Inland Bays, a member of a common but understudied class of shallow coastal plain estuaries. Subprojects encompassing surface and groundwater discharge, atmospheric deposition, water-salt-nutrient exchanges with the ocean, and internal cycling within the Bays have been pursued during the last 4 years.

Surface water discharges and nutrient loads were measured at sites representing the range of land uses and land cover common in this system. For the agricultural subwatersheds, the total dissolved nitrogen (TDN) loading ranged from 21 to 23 kg/ha/yr. TDN loading for a forested subwatershed was substantially lower (4 kg/ha/yr). TDN loading for the most urbanized subwatershed was only 2 kg/ha/yr. Total phosphorus loading ranged from 0.008 to 0.35 kg/ha/yr, with both agricultural and urbanized watersheds significantly contributing. The CISNet Water Quality Database (http://www.udel.edu/dgs/ftp/cisnet/CHEMDATA/) currently is being used by the State of Delaware to establish total maximum daily load targets for the watershed.

The areal distribution of groundwater discharges to the Bays was determined by thermal infrared imagery of the Bay margins. In addition, seismic, resistivity, hydrogeological, and stratigraphic surveys were conducted along the margins and across the Bays to determine the extent to which groundwater transport and discharge were focused by the underlying geology. At some sites, discharge was measured directly; at other sites, techniques to determine discharge are still under investigation.

Atmospheric deposition to the watershed was estimated from preexisting and new data. Atmospheric ammonia ($NH_{3,g}$) concentrations varied from 0.1 to 14 $\mu g/m^3$, with the highest values measured in poultry production areas. Highest $NH_{3,g}$ concentrations were found in the spring and summer when fertilizer application is greatest and poultry production facilities are most intensively ventilated. A study of $NH_{3,g}$ concentrations around poultry production facilities is being used to estimate the extent to which local versus distant sources of atmospheric N contribute to loadings to the watershed.

The distribution of nutrients in the Bays, at tributary discharges, and at ocean discharges has been monitored. Patterns of nutrient distribution reflect both seasonal patterns of biogeochemical cycling within the Bays and hydrological forcing. Generally, dissolved N concentrations reflect inputs from the watershed, and dissolved P concentrations reflect patterns of internal cycling of particles and inputs from wastewater discharges and the ocean. N/P ratios of waters and of plankton vary seasonally and spatially, and reflect changing patterns of nutrient limitation.

Temperature, salinity, and current surveys were conducted at the principal hydrographic boundaries in the Bays. These data have been used to determine the tidal and nontidal contributions to discharge, and the intra- and interannual variability in these contributions. Both local and remote wind effects contribute to subtidal exchange within the Bays. These results currently are being used together with nutrient data to estimate the role of tidal and nontidal flows on the exchange of nutrients between the Inland Bays and the coastal ocean. In addition, these data were used to develop a new hydrodynamic/water quality model for the Inland Bays that already is being used by State of Delaware managers.

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