EPA STAR Grant Progress Report, Year 1

Program: Environmental Indicators in the Estuarine Environment
Title: Atlantic Coast Environmental Indicators Consortium (ACE INC)

Principal Investigator: **Hans W. Paerl, UNC-Chapel Hill, Institute of Marine Sciences, Morehead City, NC 28557** ***Co-P.I.'s:*** **Richard A. Luettich, UNC-Chapel Hill, IMS, Morehead City, NC 28557 ♦ James L. Pinckney, Texas A & M Univ, Dept. of Oceanography, College Station, TX 77843 ♦ Lawrence W. Harding Jr., Edward D. Houde, William C. Boicourt, Michael R. Roman, Univ. of MD, Ctr. for Env. Science, Cambridge, MD 21613 ♦ James T.Morris, Raymond Torres, Univ. of South Carolina, Depts. of Biology and Geology, Columbia, SC 29208 ♦ Charles Hopkinson, Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA 02453 ♦ Mark Fonseca, Judson Kenworthy, Donald Field, NOAA/NOS Beaufort Laboratory, Beaufort, NC 28516**

Reporting Period: **1 April, 2001- 31 March, 2002**

Project Overview and Objectives

We are developing and testing broadly-applicable, integrative indicators of ecological condition, integrity, and sustainability across four distinct and representative estuarine systems on the Atlantic Coast of the United States (Fig, 1). These include the Nation's two largest estuarine complexes, Chesapeake Bay, MD/VA and Albemarle-Pamlico Sound, NC, a small estuary, the Parker River, situated in the Plum Island NSF Long-Term Ecosystem Research (LTER) site in Massachusetts, and a river-dominated system in the southeast Atlantic Bight, the North River Inlet, SC. These sites are representative of three primary producer bases (intertidal marsh–Plum Island and North Inlet; plankton dominated–Chesapeake Bay and Pamlico Sound; seagrass dominated–portions of Chesapeake Bay and Pamlico Sound) (Table 1). They also have ongoing, long-term water quality/habitat monitoring programs in place, serving as the data bases for indicator development and testing. These systems contain both pristine and anthropogenically-impacted waters. Our primary objectives include:

- **Enhance the archive of existing data for these systems with remotely sensed and time-series information on key variables**
- **Exploit detailed knowledge of ecosystem structure and function to synthesize this archive and develop candidate indicators**
- **Test the ability of these indicators to gauge ecosystem health and unambiguously detect trends resulting from both natural variability and anthropogenic stresses in multiple estuaries.**

Our research plan includes the development of:

- **Indicators of microalgal and macrophyte functional groups controlling much of estuarine and coastal primary production**
- **Indicators capable of determining plankton and fish community structure (organization) and function, specifically indices that relate to trophic transfer and sustainable higher trophic levels**
- **Coupling these biological indicators to physical-chemical and remote sensing assessments of ecosystem function, trophic state and change**
- **Developing and applying indicators and assessments within a national coastal indicator framework (EPA-EaGLe Program)**

These indicators form the backbone of ecosystem, regional and national water quality, habitat assessment and living resources monitoring and modeling efforts (Table 2). From ecosystem structure and process perspectives, these indicators will serve to calibrate and ground truth aircraft and satellite remote sensing of estuarine and coastal resources. Specifically, plant photopigment-based bioindicators will be coupled to high resolution remote sensing spectral analysis of plant community structure, function, physiological and ecological health. These phytoplankton, marsh and seagrass proxies will be linked with metrics of trophic structure to provide indicators of living resources status.

Keywords
Media: air, water, watersheds, estuary, marine
Risk Assessment: ecological effects, bioavailability, metabolism, vulnerability, sensitive populations, stressor, susceptibility
Chemicals, toxic substances: nutrients, toxics, metals, effluent/discharge,
Ecosystem Protection: ecosystem, indicators, restoration, regionalization, scaling, aquatic, integrated assessment
Risk Management: innovative technology (bioindicators), restoration, water quality and habitat management
Public Policy: public policy, decision making, community-based, public good, socio-economic, conservation, environmental assets
Scientific Discipline: marine science, biology, physics, ecology, hydrology, geology, phycology, microbiology, wetland ecology, remote sensing
Methods Techniques: HPLC, modeling, monitoring, macrophyte indices, spatial analysis, geomorphic indices, circulation, SEAWiFS, LIDAR, aircraft remote sensing
Geographic Areas: Northeast, Chesapeake Bay, Pamlico Sound, Mid-Atlantic, Southeast, MA, MD-VA, NC, SC, EPA Regions 3 and 4
Sectors: Agriculture, fisheries, tourism, forestry

Quality Assurance: In accordance with EPA regulations and institutional laboratory/field protocols, the Quality Assurance (QA) component of this project is strictly and continuously adhered to. Day-to day QA issues and updates are discussed among P.I.s via telephone conferencing, E mail or interactive website. Annual “all hands” meetings among P.I.’s and collaborators include a discussion and updating session on QA issues.

ACE INC RESEARCH SITES

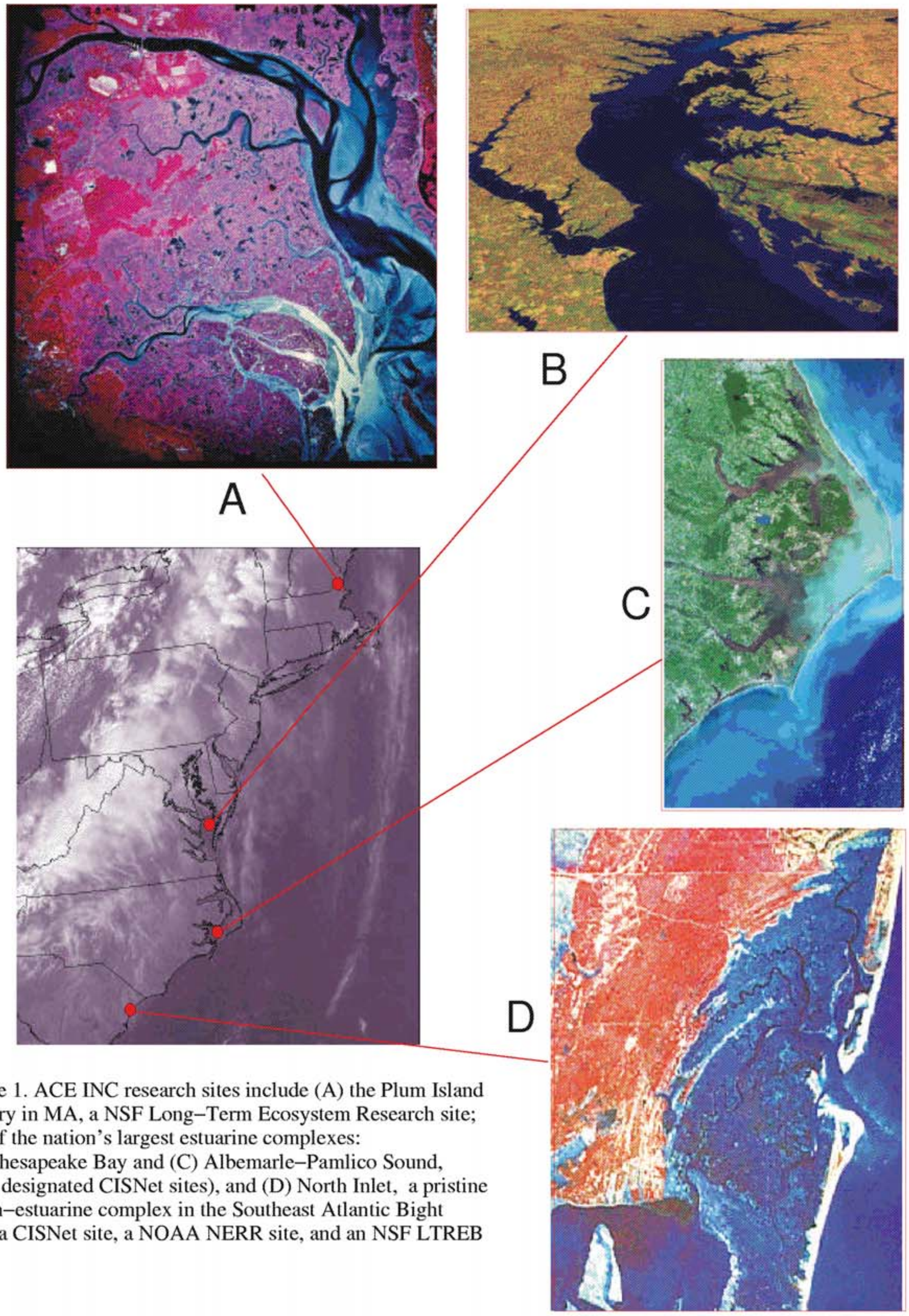

Figure 1. ACE INC research sites include (A) the Plum Island Estuary in MA, a NSF Long–Term Ecosystem Research site; two of the nation's largest estuarine complexes: (B) Chesapeake Bay and (C) Albemarle–Pamlico Sound, (both designated CISNet sites), and (D) North Inlet, a pristine marsh–estuarine complex in the Southeast Atlantic Bight (also a CISNet site, a NOAA NERR site, and an NSF LTREB site).

Table 1. Summary of the characteristics of the four estuarine sites comprising ACE INC.

Site Characteristic	Plum Island	Chesapeake	Neuse-Pamlico	North Inlet
Biogeographic Province	Acadian	Virginian	Virginian/Caro-linean-	Carolinean
Primary producer base	Tidal marsh, planktonic and benthic algal subsystems	Plankton dominates marsh and seagrass subsystems	Plankton dominates marsh and seagrass subsystems	Tidal marsh, planktonic and benthic algal subsystems
Geomorphic type	Bar-built lagoon	Drowned river valley	Bar-built lagoon	Bar-built lagoon
Water source	River	River	River and groundwater	Groundwater
Salinity range	0-32	0-30	0-25	25-32
N load	3.4 gN m^2 yr^{-1}	4 to 29 gN m^2 yr^{-1}	6 to >15 gN m^2 yr^{-1}	1.1 gN m^2 yr^{-1}
Circulation type*	Partially to well-mixed	Partially-mixed	Partially to well-mixed	Well-mixed
Residence time	0.5 – 40 days	7 months	days - 1 yr	2-10 days
Tidal range	>3 m	1 m	<0.1 m	2 m
Level of Impact	Low	High	Moderate	Low
Trophic State	Mesotrophic	Eutrophic	Eutrophic	Mesotrophic
Trophic trend	Steady – upward pressure	Rising but actively being managed	Rising	Steady – upward pressure
Monitoring programs	LMER – LTER	LMER, NEP, CISNet	CISNet, ModMon, FerryMon,	NERR, LTREB, CISNet

Table 2. ACE INC Environmental Indicators for Estuarine Habitat Components

Planktonic Component	Wetland Component	Seagrass Component
Temperature	Landscape-scale pattern (geometry)	Seagrass primary production
Photosynt. active radiation	Sediment elevation/relation to MSL	FV/FM ratio (photosynthetic efficiency)
Dissolved oxygen	Sediment organic matter	Plant morphology
Inorganic nutrients (nitrate, ammonium, phosphate, silicate)	Sediment N/P content	Physico-chemical indicators of macrophyte stress
Organic nutrients (DOC & DON, particulate C, H, N)	Above ground net primary production	Algal distribution (chlorophyll a and species composition)
Dissolved Inorg. C (ΣCO_2)	Plant pigments	Water clarity
Phytoplankton composition via diagnostic pigments (HPLC)	Remote sensing/SeaWiFS & LIDAR	Water surface temperature
Phytoplankton cell counts and biomass (microscopic)		Water column biomass and primary productivity
Primary productivity (^{14}C & O_2)		Spectral impacts of suspended materials
Remotely sensed Chl data/linked to models of primary productivity		Water color
In-water bio-optical properties		
Zooplankton and fish community biomass size spectra		

Project Organization

ACE INC consists of complementary research programs from three EPA CISNet sites (Chesapeake-Choptank, Neuse-Pamlico, North Inlet) and an NSF LTER site (Plum Island-Parker River) that are organized within the following network (Figure 2).

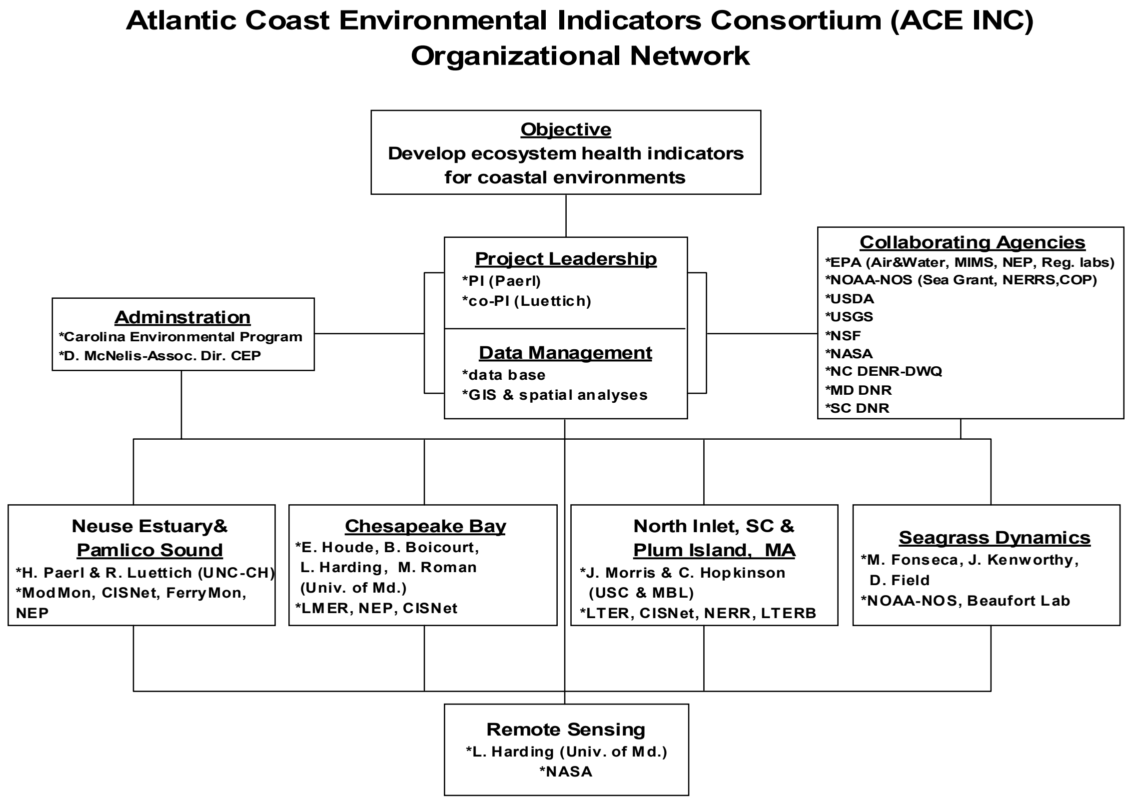

Figure 2 ACE INC Organizational Structure

The administration and management of ACE INC is under the overall Directorship of Dr. Hans Paerl and Co-Directorship of Dr. Rick Luettich of UNC IMS. Each functional unit is responsible for developing, testing/evaluating and applying relevant bioindicators at their home research site and for integrating their results with those from complementary sites in the ACE INC. The ACE INC project is administered through the University of North Carolina, Carolina Environmental Program (CEP). Our overarching research priority is the development of indicators of environmental health based on the research conducted in each functional unit. Research priorities within each functional unit (as outlined in each unit's proposal) have been set by the individual PIs in consultation with the group as a whole. Any adjustments to these priorities during the course of the project will be discussed at the annual project workshop/progress meeting, although the final decision on adjustments within any functional unit will reside with the PIs of that unit. In addition, each project has a specific set of Quality Assurance protocols for executing research and analyzing results. These are adhered to on a regular basis within each project and reviewed annually at an "all hands" project meeting. Our initial all hands meeting was to take place on Sept. 17, 2001, but due to the circumstances surrounding the tragic events of 11 Sept, was deferred to an abbreviated meeting during the Estuarine Research Federation meeting in St Petersburg, FL, November, 2001 which most of us attended. A year 2 meeting is scheduled for 16-17 May, 2002 at the Horn Point Environmental Laboratory, Cambridge, MD.

Component Project Progress Reports:

1. Phytoplankton Community Structure as an Indicator of Coastal Ecosystem Health

1. Personnel

Senior Personnel:

Hans W. Paerl & Richard A. Luettich Jr, Institute of Marine Sciences, University of North Carolina at Chapel Hill

James L. Pinckney, Dept. of Oceanography, Texas A&M Univ.

Post-docs:

Luke Twomey & Lexia Valdes, IMS, UNC-CH

Graduate students:

Janelle Fleming, PhD Student (advised by R. Luettich)
Nathan Hall, MSc Student (advised by H. Paerl)
Benjamin Peierls, PhD Student (advised by H. Paerl)

2. Organizational (Institutional Partners)

Carolina Environmental Program, UNC-CH, NC
Duke Univ. Marine Laboratory, Beaufort, NC
Marine Biological Laboratory, Woods Hole, MA
NC Dept of Environment and Natural Resources, Raleigh, NC
NOAA/NOS, Beaufort, NC
Texas A&M University, College Station, TX
Univ. of Maryland, Center for Environ. Science, Horn Point & Solomons, MD
Univ. of South Carolina, Depts. of Biology and Geology, Columbia, SC
US EPA Modeling and Environ. Assessment Labs, Research Triangle Park, NC

3. Other collaborators or contacts

D. Millie, FL Instit. Marine Research, St. Pete, FL
J. Bales, USGS, Raleigh, NC
J. Burns, CyanoLab, Palatka, FL
G. Cherr and S. Anderson, Bodega Marine Lab, Univ. of Calif., Davis, CA
R. Christian, East Carolina Univ., Greenville, NC
C. Gallegos, Smithsonian Environmental Research Center, Edgewater, MD
R. Lunetta, A. Gilliland and R. Dennis, US EPA, RTP, NC
J. Ramus, Duke Univ. Marine Lab, Beaufort, NC
P. Tester, NOAA/NOS Fisheries Laboratory, Beaufort, NC

4. Research and education activities

The ACE INC, "Phytoplankton Community Structure as an Indicator of Coastal Ecosystem Health" has been operational since April, 2001. All aspects of the proposed work plan have been in place since then thanks to the existence of ongoing collaborative water quality and habitat monitoring programs on the Neuse River Estuary (NRE), (CISNet & ModMon: www.marine.unc.edu/Neuse/ModMon) and Pamlico Sound (www.marine.unc.edu/Paerllab). These programs have served as the backbone for the collection of nutrient, photopigment (chlorophylls and carotenoid), productivity, water optical property turbidity and physical data needed to characterize the structure, function and environmental controls of indicator phytoplankton communities comprising the base of the estuarine food web. In particular, we have been collecting comprehensive diagnostic (of phytoplankton community composition) photopigment samples that will serve to establish a baseline of phytoplankton community composition against which we will be able to gauge trophic state and ecological change in response to a wide variety of environmental forcing features, including; nutrient inputs, salinity (reflecting freshwater inputs and residence time), water clarity and other optical properties, zooplankton grazing and toxic substances. We have also been collecting in situ hydrographic, dissolved oxygen and water velocity data to allow calculation of the residence time in the system.

Photopigment indicators have already proven to be highly-sensitive, diagnostic indicators of seasonal and interannual changes in hydrologic and nutrient inputs to these systems (Pinckney et al., 2001, 2002; Paerl et al., 2001; Paerl et al., in preparation). Our long-term vision of the regional deployment and interpretive use of photopigment indicators is shown in Figure 3. Note the strategic location of these indicators in the context of estuarine and coastal ecosystem function, resourcefulness and service.

Diagnostic photopigments as indicators of WQ and habitat condition

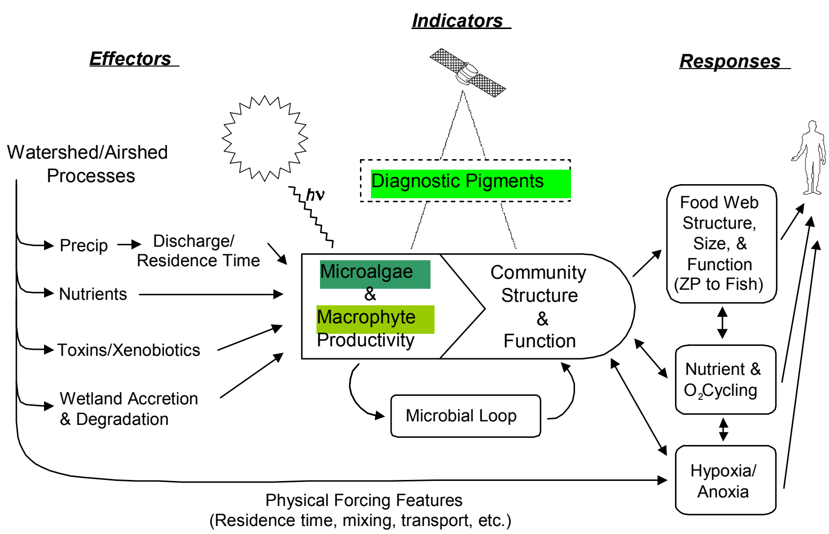

Figure 3. Ecosystem and regional roles of diagnostic photopigments as indicators of ecosystem productivity, plant community composition in response to physical-chemical stressors in estuarine and coastal waters

Dr. Luke Twomey (Post-Doc.) has been involved in the establishment and refinement of the diagnostic photopigment component of this project. His work has helped establish a long-term sampling and analytical design that will serve as the framework for evaluating these indicators. We are working closely with L. Harding (Univ. of MD-CEES), P. Tester (NOAA/NOS) and R. Lunetta (EPA) to utilize field-based photopigment indicator data for calibrating and verifying remotely-sensed assessments of phytoplankton production and community structure for the Neuse-Pamlico Sound. To this end, aircraft-based flyovers (SeaWiFS and Lidar) have been initiated for the Sound and adjacent sub-estuaries. These flyovers closely parallel and complement similar efforts on place in Chesapeake Bay (see CB-ACE INC/NASA Component, L. Harding), with the objectives being a data set enabling us to examine comparative ecosystem responses to physical-chemical forcing features. These efforts will be extended to smaller estuarine systems (North Inlet, Galveston Bay, Plum Island Sound) in years 2-4 of this project. We are also interacting with several of the companion EaGLe projects (PEER, CEER, GLEI) to set the stage and framework for incorporating photopigment-based indicators as a routine measures of productive and trophic state of the planktonic components of coastal ecosystems.

5. Findings

Figure 4 presents an example of the long-term data set on phytoplankton biomass and community composition for the NRE in response to various hydrologic/nutrient loading events, including hurricanes (Floyd, 1999) (Paerl et al., 2001; Luettich et al., in preparation, Pinckney et al. in preparation).

Figure 5 presents a sample of data from one of the two autonomous profiling platforms that we have deployed in the NRE. Graduate student Nathan Hall is using this data to examine the role of vertical

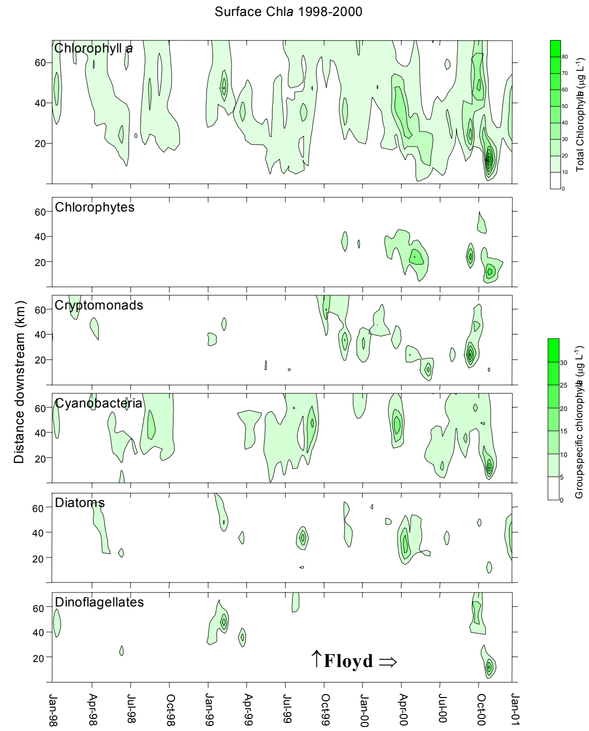

Figure 4. Application of diagnostic photopigments for examining NRE phytoplankton community production and composition response to hydrologic/nutrient loading events. Left: long-term chlorophyll a data set obtained from ModMon and CISNet transect from 1994-2001. Right; application of diagnostic photopigments (via HPLC analyses), showing the impacts of Hurricane Floyd's floodwaters on phytoplankton community composition.

migration of phytoplankton during routine surface assessments (i.e., what is detected via remote sensing) of production and community structure. As shown in Figure 5, vertical migration has an important (and confounding) role in the quantification of phytoplankton biomass simply based on surface readings. We will be incorporating his findings in modeling efforts aimed at improving predictive phytoplankton responses to physical-chemical forcing features in this and other estuarine systems. Graduate student Benjamin Peierls is examining the spatiotemporal relationships between phytoplankton community structure and function and bacterial (heterotrophic) production dynamics in the estuary. In particular, he is examining potential linkages between changes on phytoplankton community composition (i.e., blooms) and potential microbial shifts playing kay roles in nutrient and oxygen cycling (i.e., hypoxia/anoxia) in these waters. Graduate Janelle Reynolds- Fleming is working with the 3-dimensional, finite difference Environmental Fluid Dynamics Code (EFDC) model to simulate hydrodynamic conditions in the NRE. The model was calibrated with MODMON/CISNet data from 1998 by US EPA region 4 to provide assistance to the State of North Carolina in its efforts to develop a nutrient Total Maximum Daily Load (TMDL) for the NRE. We have completed an independent validation study with the model and found that it compares well with salinity and velocity data from two bottom mounted CTDs and ADCPs moored on opposite

Figure 5 Time series of physical and Chl-a data near the bend in the Neuse River Estuary shores of the upper NRE during 1999-2000. Regressions between model data and field data suggest that the model explains 78% of the variability seen in the field data. The model is presently being used to study transit time and flushing rates over a variety of discharge scenarios in the system.

6. Training and Development

No training or development activities beyond graduate student training were conducted in CY2001.

7. Outreach Activities

Both Drs. Paerl and Luettich are involved in a variety of statewide and national scientific advisory and educational activivities. These include serving on NC-DENR's Technical Advisory Committee (Luettich), NC-DWQ's TMDL modeling group (Luettich), the NC Water Resources Research Institute's Technical Committee (Paerl), the Albemarle-Pamlico Sound NEP Technical Advisory Committee (Paerl), the NC Environmental Management Commission (Paerl), providing technical and evaluative advice for a variety of stakeholder groups (Luettich and Paerl), including the Neuse River Foundation, the Pamlico River Advisory Board, the Wilson Bay Advisory Committee and the Neuse Basin Council of Municipalities. Nationally, Paerl has been involved in an advisory role in the EPA-Chesapeake Bay Program, the Tampa Bay NEP, the Narragansett Bay Program (URI). Paerl currently serves on the Florida Bay Technical Advisory Committee. We are sharing technological developments and evaluative approaches/tools with scientific, agency (state-, federal and international-level) colleagues as well as public educational institutions, informational media and resource (i.e., fisheries, tourism) managers. Examples of the utility, informational value and application (scientifically, management and public education) of data thus far obtained can be found on the ModMon and FerryMon websites which are routinely and frequently accessed by our colleagues and the public.

8. Web/Internet Sites

Specific web pages for ACE INC and the Phytoplankton Indicator component can be found at www.marine.unc.edu/Paerllab. We are currently constructing an interactive website for all components of ACE INC, which will be operated and coordinated by a website manager located at the UNC-CH Institute of Marine Sciences. This website will be constructed in consultation with the other EaGLe projects and EaGLe coordinator Dr. Valerie Brady (vbrady@nrri.umn.edu).

9. Contributions to State of Knowledge

The pigment-based and associated physical-chemical indicators that are being developed and applied in this component project have already proven useful and applicable for evaluating ecosystem and regional responses to a variety of environmental stressors, including nutrient loads, changes in hydrologic characteristics (salinity, circulation), large-scale frontal passages (i.e., "noreasters") and major storms, including hurricanes (Paerl et al., 2001, Paerl et al, in preparation). In addition, they offer great promise as a data source for development, verification and modification of remote-sensing of plankton production and community structure of a range of estuarine and coastal water bodies regionally and nationally.

10. Publications supported by this project

Pinckney, J.L., T.L. Richardson, D.F. Millie, H.W. Paerl. 2001. Application of photopigment biomarkers for quantifying microalgal community composition and in situ growth rates. Organic Geochemistry 32:585-595.

Paerl, H.W., C.P. Buzzelli, M. Go, B.L. Peierls, R.A. Luettich, T.L. Richardson, J.S. Ramus, L.E. Eby, L.B. Crowder, L.W. Ausley, J. Overton and J.D. Bales. 2001. Water quality and fisheries habitat changes in the Pamlico Sound after three hurricanes: A short-term and long-term perspective. Pp. 255-263, In, J.R. Maiolo, J.C. Whitehead, M. McGee, L. King, J. Johnson and H. Stone (Eds.), Facing Our Future: Hurricane Floyd and Recovery in the Coastal Plain. Coastal Carolina Press, Wilmington, NC.

Paerl, H.W. J. Dyble, L. Twomey, J. L. Pinckney, J. Nelson and L. Kerkhof. 2001. Environmental control of microbial biodiversity and activity in coastal ecosystems: Distinguishing human from natural factors. Antonie van Leeuwenhoek (in press).

Buzzelli, C.P., S. P. Powers, R. A. Luettich Jr., J. E McNinch, H.W. Paerl, C.H. Petereson and J.L. Pinckney. 2001. Estimating the spatial extent of bottom water hypoxia and benthic fishery habitat degradation in the Neuse River Estuary, NC. Marine Ecology Progress Series (in press).

11. Presentations

H. Paerl. "Atlantic Coastal Environmental Indicator Consortium (ACE INC)". Invited presentation, EMAP Symposium, St. Pete, FL, April, 2001.

H. Paerl. "New Issues and sources of nitrogen in estuarine and coastal waters: What's manageable and what's not?". Invited Lecture, 7th International Wetlands Conference, Duke University, Durham, NC, June, 2001.

H. Paerl et al. "Long-term Impacts of Hurricanes Dennis, Floyd and Irene on Water Quality and Fisheries Habitat in Pamlico Sound, North Carolina". Invited Lecture Hurrane Floyd: A year later. Symposium, East Carolina University, Greenville, NC, May 2001.

H. Paerl. "Environmental control of microbial biodiversity and activity in coastal ecosystems: Distinguishing human from natural factors". Keynote lecture. 9th International Microbial Ecology Sympium, Amsterdam, Netherlands, August, 2001.

H. Paerl. "Using Bioindicators to Assess Man-made vs. Climatic Impacts on Estuarine and Coastal Water Quality in North Carolina - Implications for Research and Management". Invited Lecture, Narragansett Bay Indicator Symposium, URI-Narragansett Bay Campus, October, 2001.

H. Paerl, D. Whitall and R. Dennis. "Integrating Atmospheric N Deposition in Estuarine and Coastal N Cycling and Eutrophication Dynamics". Invited Lecture, N2001 Symposium, Potomac. MD., October, 2001.

H. Paerl. "Neuse River Estuary Water Quality". Invited Lecture, special symposium on the Neuse River Basin, Annual Meeting of the American Society for Agronomy & Soil Science, Charlotte, NC October, 2001.

H. Paerl et al. "Atlantic Coastal Environmental Indicator Consortium: An Overview". 1st Annual EaGLe Conference, Morehead City, NC, Dec., 2001.

H. Paerl. "The Problem with Atmospheric Nitrogen Deposition". Keynote Lecture, Workshop on the Importance of Atmospheric Nitrogen Deposition in Coastal Environments, Univ. of MD Appalachian Laboratory, Frostburg, MD, December, 2001.

H. Paerl. "Harmful Cyanobacterial Blooms". Invited Lecture, Univ. of MD, Horn Point Environmental Lab., Jan. 2002.

H. Paerl, J. Dyble and P. Moisander. "Indicators of ecological change in coastal waters". Invited Lecture, Univ. of MD, Horn Point Environmental Lab., Jan. 2002.

H. Paerl, J. Dyble, P. Moisander and J. Pinckney, "Developing and assessing microbial indicators of ecological change in the coastal zone". Invited Lecture, Univ. of CA, Bodega Bay Laboratory, Feb. 2002.

H. Paerl, "Using Microbial indicators to Assess Human vs. Climatic Impacts on Estuarine Water Quality: The North Carolina Experience". Invited Lecture, US Geological Survey, Reston, VA, March, 2002.

12. **Products**

None to date.

2. Trophic Indicators of Ecosystem Health in Chesapeake Bay

1. Personnel

Senior Personnel:

William C. Boicourt, UMCES, Horn Point Laboratory (HPL)
Lawrence W. Harding, Jr., UMCES, HPL
Edward D. Houde, UMCES, Chesapeake Biological Laboratory (CBL)
Michael R. Roman, UMCES, HPL

Post-docs:

David G. Kimmel & Andrea Magnuson, UMCES, HPL

Graduate students:

Jason Adolf, Christy Jordan & W. David Miller, UMCES, HPL (L.Harding, Advisor)

2. Organizational (Institutional Partners)

University of North Carolina, Institute of Marine Sciences, Morehead City, NC
NOAA/NOS, Beaufort, NC
University of South Carolina, Columbia SC
Marine Biological Laboratory, Woods Hole, MA
Texas A&M University, College Station, TX

3. Other collaborators or contacts

C. Gallegos, Smithsonian Environmental Research Center, Edgewater, MD

4. Research and education activities

Project Status

The ACE INC, Chesapeake Bay component has been active since August 2001. Much of the activity in initial months has been organizational. Our goal is to develop a suite of indicators of estuarine health that are based on physical and biological criteria. Our indicators are broad and integrative, and emphasize the role of physical forcing on tropho-dynamic relationships. They are being developed primarily from existing data and information in Chesapeake Bay Program databases and from programs supported previously by EPA, NSF, NOAA, and state agencies. New, but limited in scope, field programs will be instituted to collect integrative data on dissolved oxygen, primary production, zooplankton dynamics and fish communities. Proposed field work in CY2001 was deferred until CY2002 because of late arrival of funds to initiate the project.

The structure of the program, its elements, and principal scientists are diagrammed in Figure 6.

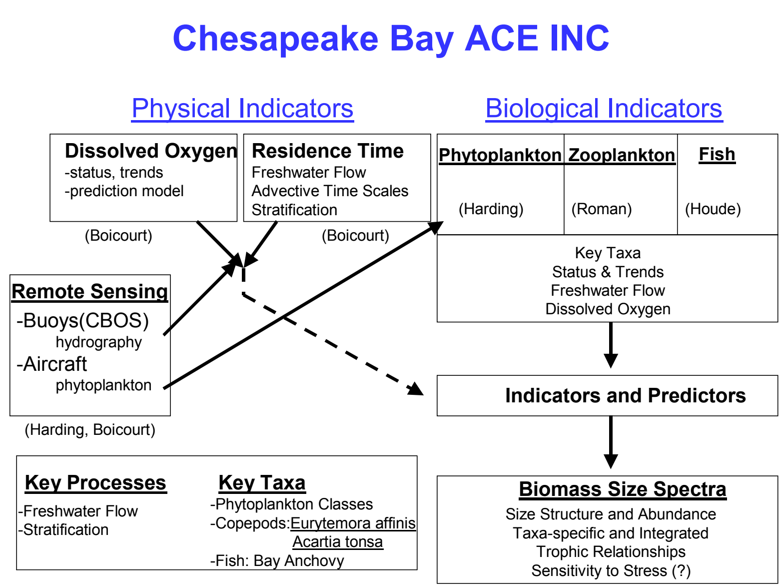

Figure 6. Schematic of the structure, elements, and principal scientists of Chesapeake ACE INC.

Dissolved Oxygen and Stratification Indicators
The utility of dissolved oxygen as an indicator of estuarine health is being explored, first in Chesapeake Bay and the NRE individually, then over a broad range of estuarine types. In Chesapeake Bay, this effort involves a retrospective analysis, the development of a predictor model, and a field program examining high-frequency variability and adapting new sensor technology to the hostile environment of biofouling and anoxia. In addition to oxygen, residence time formulations are being explored as component variables in estuarine indicators.

In the Chesapeake Bay ACE INC effort, both analytical and field efforts are focused on developing relationships between short-term wind mixing and high-frequency oxygen variability. The analytical efforts are directed toward constructing an indicator of wind mixing. We are using known background stratification as an input. We intend to develop a reliable predictor of wind mixing with this observed stratification, then to predict stratification from wind and freshwater input for use as an indicator. Autonomous sensors are being prepared for deployment on Chesapeake Bay Observing System (CBOS) moorings to monitor these variations during the seasonal oxygen decline. In addition to employing YSI Model 600 electrodes, we are evaluating new sensor technology that promises to reduce the degrading effects of biofouling and anoxia on measurements. We have deployed the Stephens-Greenspan diffusion-rod sensor at two locations in the Bay and plan to acquire a test model of the new Aanderaa Oxygen Optode optical detection system. We are also entering a partnership of manufacturers, scientists, engineers, and managers called the Alliance for Coastal Technologies (ACT) seeking to develop and adapt sensors for coastal waters. We are developing autonomous profiling capability for examining details of the vertical structure of oxygen and stratification in the mainstem Chesapeake Bay. Full profiles will help improve the wind-mixing model, and will also aid comparison of the wind mixing processes being measured in the Neuse River Estuary during the ACE INC studies.

Primary Production Indicators
We have made significant progress in the past year developing phytoplankton primary productivity as an indicator of ecosystem function in Chesapeake Bay. Our efforts have focused on the analysis of a multi-year data set derived from cruises (1982-98, n = 455) to develop a set of predictive models. Mean net ^{14}C-PP is 1,055 mg C m^{-2} d^{-1} in the main stem Bay for all seasons and regions, and phytoplankton dynamics are dominated by a spring biomass maximum, expressed as euphotic-layer chlorophyll (chl-a), and a summer maximum of net ^{14}C-PP displaced by approximately four months from the biomass maximum (Figure 7). An integrative indicator of Bay function on annual to inter-annual time scales is the annual integral of production (AIP). We used the large empirical data set on primary productivity to estimate AIP of 282 to 538 g C m^{-2} yr^{-1} (net) and 347 to 662 g C m^{-2} yr^{-1} (gross).

We are using several recently developed PP models based on the vertically-generalized productivity model (VGPM) of Behrenfeld & Falkowski (1997). These models estimate net and gross PP for Chesapeake Bay with high accuracy, calibrated and validated with independent data sets (Harding *et al.,* 2002). We have applied the models to input data from remote sensing to generate time-series of PP for over 320 airborne surveys of ocean color in the Bay, spanning 1989-2002 (Figure 8). The time-series of PP supports computations of AIP for years that encompass a wide range of freshwater forcing.

Figure 7. Monthly averaged euphotic layer chlorophyll-a and annual net primary production in Chesapeake Bay, 1982-1998.

Figure 8. Images of modeled output of primary production in Chesapeake Bay on two dates, based on remotely-sensed, aircraft ocean color.

One of our main efforts in 2001-2 is to take advantage of the improved spatial and temporal resolution of phytoplankton biomass and PP in Chesapeake Bay that is possible by combining shipboard, remote sensing and modeling to support new predictive capabilities. We are now basing AIP computations on calibrated and validated models applied to biomass data from 20-30 aircraft over-flights per year, vs three seasonal cruises per year in shipboard programs (e.g., LMER, PROTEUS and TIES). The combination of shipboard, remote sensing, and modeling also allows us to approach regional, seasonal, and inter-annual variability in the phytoplankton composition, with obvious trophic implications. Taxonomic composition of phytoplankton estimated by reconstructing pigment concentrations from high performance liquid chromatography (HPLC) reveals strong contrasts accompany distinct flow regimes. Concurrently collected data on bulk biomass as chl-a from remote sensing thereby provide a Bay-wide context in which detailed shipboard data can be placed. Similarly, application of the recently developed PP models to these input data extends the usefulness of both sources of data.

Zooplankton Indicators

The zooplankton portion of the Chesapeake Bay ACE-INC group has focused on synthesis of Chesapeake Bay Program data. Long-term time series of zooplankton abundance and water quality parameters have been analyzed in order to establish predictive relationships. Established relationships are used to develop statistical models in order to predict zooplankton abundance for various regions of the northern Chesapeake Bay. Once developed, these models will be used to assess the potential effects of human impacts. Strong correlations between zooplankton species and water quality parameters were noted in order to identify potential indicator species. Long-term trends and changes in species composition were evaluated in the context of inter-annual variation in freshwater flow. The trends in abundance and species composition may shift in a predictable manner in response to long-term or short-term climate change (i.e., N. Atlantic Oscillation, droughts, etc.).

Research cruises in 2002 will focus on the development of zooplankton indicators using recently developed technologies. Hydroacoustic and optical measurements of zooplankton will be taken in order to aid in the construction of a biomass size spectra indicator for ecosystem "health." The refinement of these methods will lead to a more rapid and sensitive measure of zooplankton status throughout the bay.

Biomass Size-Spectra Indicators
Biomass size spectra, including phytoplankton, zooplankton, and fish are being developed as integrative indicators of estuarine status. The slopes, elevations, and modes within the spectral domain are hypothesized to be indicative of the status of biological communities and an indicator of anthropogenic or natural stress. Physical forcing, including freshwater input, dissolved oxygen and stratification, as well as anthropogenic nutrient and contaminant inputs, or fishing will be evaluated with respect to spectra.

5. Findings

Preliminary findings from CY2001 activities are representative of the status of indicator development in Chesapeake Bay ACE INC.

Dissolved Oxygen/Stratification Indicators
Initial efforts toward relating dissolved oxygen in Chesapeake Bay to freshwater flow in the post-1985 era have shown that stratification in the Deep Trough region (where summer oxygen depletion occurs) of the Bay is controlled by freshwater inflow over long time scales and wind mixing over scales of days to weeks. But we have identified a third, intermediate scale of weeks to a month, related to the inflow of salt water from the adjacent ocean. There is strong evidence that stratification in mid-Bay is ultimately controlled by the freshwater inflow, but the discovery of hydraulic regulatory processes helps explain why the relationship is highly nonlinear. Tests of the Stephens-Greenspan oxygen sensor were delayed due to due to instrument malfunction. The instrument has been replaced. An intercomparison deployment of 3 sensors (YSI 600, Aanderaa Optode, Stephens-Greeenspan) is planned during the spring oxygen decline.

Phytoplankton Indicators
The main phytoplankton indicators we are developing rely on remote and in-situ determinations of chlorophyll (chl-a) concentrations, and high performance liquid chromatography (HPLC) to determine taxonomically-specific pigments in combination with cell counts for verification. Observational data collected over two decades have allowed us to develop a conceptual view of how freshwater flow regulates the position and magnitude of the spring bloom. This view is illustrated by the cartoon showing peak phytoplankton biomass for years of low, moderate and high flow (Figure 9).

Figure 9 Cartoon of peak phytoplankton biomass for different flows

Zooplankton Indicators
A significant relationship between zooplankton abundance and inter-annual variation in freshwater flow has been found in the northern Chesapeake Bay. Freshwater flow causes variation in zooplankton abundance and species composition. This relationship varies both temporally, spatially and with the magnitude of freshwater input. Freshwater flow correlates with many water quality parameters, thus it was possible to use principal component (PC) analysis to graphically explain these relationships and reduce the number of predictor variables for model development.

Overall, findings to date suggest that certain species of zooplankton may be reliable indicators of changes in freshwater flow. The results also reveal significant relationship between zooplankton and water quality parameters in particular regions of the northern bay. The interaction of zooplankton with other trophic levels needs to be studied further. The evaluation of these interactions in biomass size spectra will be useful to identify how zooplankton trends and shifts in species composition relate to the spectra and to shifts in biomass and productivity of phytoplankton, zooplankton, and fish.

Biomass Size Spectra
In CY2001, spectra for fish, but not other trophic levels, were constructed and analyzed for Chesapeake Bay. Spectra for fish in Chesapeake Bay are not 'flat,' but are typically bimodal or multimodal. The spectra, based on data consolidated from six years (1995-2000) of midwater trawl collections by the NSF-sponsored TIES Program, are regionally similar throughout the Bay, although not composed of the same species, especially for taxa in the larger mode. The spectra do indicate similar trophic structure among the upper, middle and lower regions of Chesapeake Bay, although the mechanism that generates the clear bimodal character is conjectural at this point in time. The biomass of larger fish (second mode) in the middle Bay is considerably reduced relative to the upper and lower bay regions, possibly a reflection of stress from hypoxic conditions that are common in the middle Bay but not in the other regions. The first mode of the spectra is dominated by the small, pelagic bay anchovy (*Anchoa mitchilli*), the most abundant fish in Chesapeake Bay.

6. Training and Development

No training or development activities beyond graduate student training were conducted in CY2001.

7. Outreach Activities

No formal outreach activities, beyond making agencies and institutions aware of our research, were conducted in CY2001. We have discussed our ACE INC project with agency staff in the Chesapeake Bay Program and will develop outreach and collaborative with the CBP in CY2002 and succeeding years.

8. Web/Internet Sites

<http://www.cbrsp.org> Additional web pages and sites will be developed.

9. Contributions to State of Knowledge

The indicators that we are developing will provide a new ability to evaluate health of Chesapeake Bay and other large estuarine ecosystems. Each of the indicators can stand alone (DO, Primary Production, Zooplankton, Fish Biomass Spectra). For example, development of estuarine productivity models and the application to remotely sensed estimates of phytoplankton biomass will enable improved spatial and temporal resolution of primary productivity on seasonal to inter-annual time scales. The combined Biomass Spectra approach offers an opportunity to develop an integrated indicator of abundance and productivity that includes taxa from phytoplankton to fish and which can be evaluated with respect to environmental conditions, including freshwater inflow, stratification, and DO.

10. Publications

Harding, L.W., Jr., M.E. Mallonee and E.S. Perry. In press. Toward a predictive understanding of primary productivity in a temperate, partially stratified estuary. Estuar. Coast. Shelf Sci. (in press).

Harding, L.W., W.D. Miller, R.N. Swift, and C.W. Wright: 2001. Aircraft remote sensing, In: Steele, J., S. Thorpe, and K. Turekian, (eds.), *Encyclopedia of Ocean Sciences*, Academic Press, London, UK, p. 113-122.

11. Presentations

EaGLe 1st Annual Meeting, 3-5 December 2001, Morehead City, NC

E. D. Houde, “Trophic indicators of ecosystem health in Chesapeake Bay”

W. C. Boicourt, “Incorporation of physical processes in estuarine indicators ”

L. W. Harding, Jr. “Remote sensing in Chesapeake Bay and Albemarle-Pamlico Sound to estimate chlorophyll and primary productivity”

L.W. Harding, Jr. “Aircraft remote sensing of ocean color in Chesapeake Bay to estimate chlorophyll and primary productivity,” Invited talk, EPA EMAP Symposium, Pensacola Beach, Florida, April, 2001.

12. Products

None to date.

3. Coastal Wetland Indicators

1. Personnel

Senior Personnel:
James T. Morris, Biological Sciences, University of South Carolina
Ray Torres, Geological Sciences,
Chuck Hopkinson, Ecosystems Center, Marine Biological Laboratory

Post-docs:
Helen Marshall, Biological Sciences, University of South Carolina

Graduate students:
Gabe Herrick, Biological Sciences, University of South Carolina (advised by J. Morris)
Juana M. Montane & Karyn Novakowski, Geological Sciences, University of South Carolina (advised by R. Torres)

2. Organizational (Institutional Partners)

University of North Carolina, Institute of Marine Sciences, Morehead City, NC
NOAA/NOS, Beaufort, NC
University of South Carolina, Columbia SC
Marine Biological Laboratory, Woods Hole, MA
Texas A&M University, College Station, TX

3. Other collaborators or contacts

C. Gallegos, Smithsonian Environmental Research Center, Edgewater, MD

4. Research and education activities

Project Status
The ACE INC, Coastal Wetland Indicators component has been active since August 2001. In the initial months of the project most of the activity has been organizational. One postdoctoral fellow has been hired, Helen Marshall, an expert on plant pigments and biooptical modeling with a PhD from the University of Wales. She will help enormously with a major goal of our project, which is to develop a suite of indicators of the condition of coastal wetlands that are based on physical and biological criteria. One set of indicators that we are developing are based on measurements of plant pigments. These will be correlated with the optical properties of single leaves and with whole canopies in order to develop algorithms that be used to interpret remotely sensed data and to derive indices of wetland plant productivity, stress, and change at the landscape-scale. Hypotheses that address the responses of leaf pigments and their optical properties to nutrients and salt stress will be tested using samples collected from experimentally manipulated test plots in the field. A second indicator of coastal wetlands that can be derived from remotely-sensed data relies on interpreting the geomorphic pattern and fractal signature of coastal wetland drainage networks. The pattern of existing channel networks is a consequence of the existing geomorphic equilibrium and conveys information about the stability of coastal wetlands. Proposed field work in CY2001 was deferred until CY2002 because of late arrival of funds to initiate the project.

The structure of the program, its elements, and principal scientists are diagrammed in Figure 10.

5. Results

Pigment Indicators
Chlorophyll concentration provides information about condition, because its concentration in plant tissues varies with phenology and with nutrition. Moreover, since photosynthetic rate and Chl-a concentration are directly related (Bokari 1983), Chl-a is actually a more sensitive indicator of the condition of higher

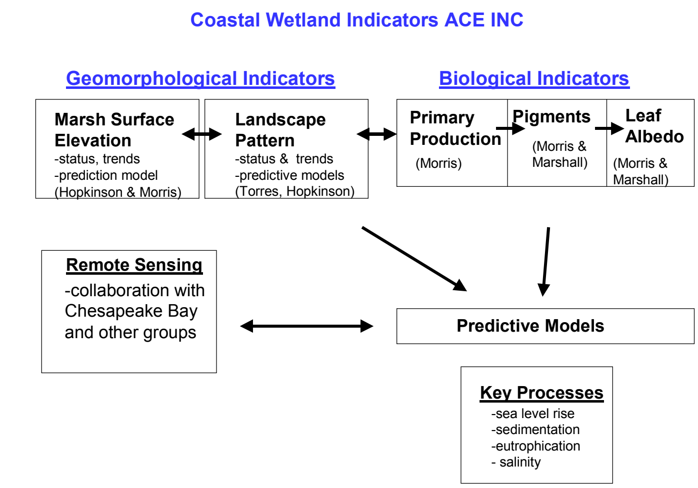

Figure 10. Schematic of the structure, elements, and principal scientists of Coastal Wetland Indicators.

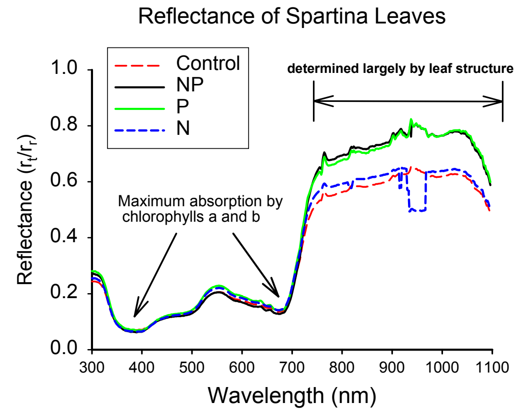

Figure 11. The spectrum of light reflected from he leaves of *Spartina alterniflora*. Plants reated with phosphorus had higher reflectance

plants than biomass and should be investigated as an index of stress. Accessory pigments, measured by HPLC, provide even more information about the condition of plants. Further, since chlorophyll-a is highly absorbent of radiation in the range of Landsat Thematic Mapper spectral band 3 (630-690 nm) and reflective in spectral band 4 (760-900 nm), it should be feasible to use remote sensing techniques to monitor the condition of vegetation (Figure 11) and the density of pigments in the plant canopy (Figure 12 and 13).

At North Inlet previous attempts to remotely sense pigments have met with some success (Fig. 11 and 12) using spatially precise ADAR data, but our experience has shown that hyperspectral data will be needed to make significant advances in the remote sensing of plant pigments. However, we have great success in training neural networks to interpret remote data, and we expect that significant progress will be made using neural networks to interpret hyperspectral data

Figure 12. An ADAR image, classified to show chlorophyll density in a salt marsh at North Inlet

Figure 13. A neural network was trained to interpret the 4 ADAR bands (blue, green, red and NIR). The output of the neural net is the chlorophyll density in the plant canopy. The fit using the NN is significantly better than can be obtained using regression analysis and traditional models.

Primary Production Indicators
Long-term research at North Inlet has documented a trend of increasing primary production in the salt marsh (Fig. 14). The interannual variation that exists around the trend line is related to anomalies in mean sea level, and a variety of information leads us to believe that the long-term trend is an indication that the elevation of the salt marsh surface has not kept pace with sea-level rise during the last decade. If this trend continues, and if our interpretation is correct, then marsh productivity will begin to decline as marsh elevation falls to a level that is suboptimal. Then if the trend continued, the marsh would be replaced by intertidal mud flat and then open water.

Figure 14. Annual aboveground production of *Spartina alterniflora* at North Inlet.

Geomorphological Indicators
The accompanying Figure 15 shows the changes in the relative elevation of the marsh surface at North Inlet since 1996 in plots that have been experimentally fertilized, increasing the density of standing biomass, and in controls. This results document the interaction between sediment accretion rate and plant production. Where biomass density was increased, sediment accretion increased due to the filtering effect of the vegetation. This is an example of one of the geomorphological indicators that is being developed. We also are examining landscape-scale geomorphological patterns such as drainage density to determine if changes or differences in pattern can signal that a coastal wetland is in equilibrium with sea level or not. Patterns at the landscape scale can be detected by remote technologies.

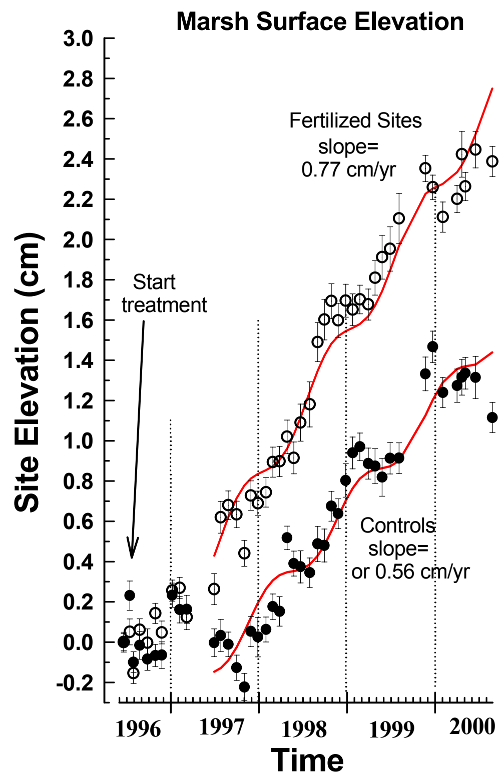

Figure 15. Changes in the relative elevation of the marsh surface at North Inlet in control and fertilized plots.

6. Training and Development

No training or development activities beyond graduate student training were conducted in CY2001.

7. Outreach Activities

We made a presentation before the Science & Technology Advisory Comm., Chesapeake Bay Program on the use of remote sensing technologies to assess the status and trends of coastal wetlands.

8. Web/Internet Sites

Specific web pages for the CWIproject have not been developed to date.

9. Contributions to State of Knowledge

The indicators that we are developing will provide new tools for evaluating the condition of coastal wetlands. The actual products will be indicators that are based on measurements made in the field. However, all the indicators being developed have a significant potential for being developed as applications that can be calibrated using remotely sensed data. To date, a) progress has been made using pigments and reflected light as indicators of the condition of vegetation, b) neural networks have proven to be effective tools for classifying remote sensor data, c) significant trends in the productivity of coastal wetlands have been observed, and d) we have documented that we are able to discern interannual changes in the relative elevation of the marsh surface.

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10. Publications

Morris, J.T., P.V. Sundareshwar, C.T. Nietch, B. Kjerfve, D.R. Cahoon. Homeostatic response of coastal wetlands to rising relative sea level. Ecology, in press.

11. Presentations

Morris, J.T. 2001. "Overview of Coastal Wetland Indicators. EaGLe 1st Annual Meeting, 3-5 December 2001", Morehead City, NC

Morris, J.T. 2001. "The stability of coastal wetlands depends on the tidal amplitude". Abstract of presentation made at the 86th annual meeting of the Ecological Society of America. Madison, Aug. 5-10.

Morris, J.T. 2002. "Present status and future trends in estuarine and watershed monitoring using remote sensing technology", Jan 7-8, 2002. Sci. & Tech. Admisory Comm., Chesapeake Bay Program, Annapolis, MD.

12. Products

None to date.

4. Seagrass Component, Atlantic Coast Environmental Indicators Consortium

Most of the effort in the seagrass portion of the study has focused on planning and experimental design for field studies to be initiated in May 2002. Staff from Beaufort participated in the ACE workshop held in December 2001 at UNC, IMS in Morehead City NC. Following the workshop Beaufort Laboratory personnel began working with Drew Pilant of the US EPA National Exposure Research Laboratory to coordinate the AVIRIS over flight. It was determined that the original flight lines for the mission would pass just to the west of Cape Lookout, excluding several areas of seagrass coverage which have been the focus of extensive investigation over the past two decades. Inclusion of these areas will add a great deal of baseline data that will be extremely valuable to this study and also provide one of the endpoints along an optical water quality gradient extending from the local river basins to the inlets connecting the lagoon system to the coastal ocean. Beaufort staff proposed re-positioning the flight lines so as to cover these areas.

Beaufort Lab personnel have also been helping to coordinate the ground truthing activities and acquisition of the equipment that will be needed for ground truthing the AVIRIS over flight. This coordination is on-going and critical to the study. The study site covers an expansive area from Beaufort to Oregon Inlet, providing a logistical challenge to collect adequate environmental data on the day of the over flight. The Beaufort Lab will be providing a 41 ft. research vessel as well as other smaller craft to assist personnel in reaching sampling locations. The biggest challenge to date has been locating adequate numbers of instruments such as spectral radiometers and YSI's, and trained personnel to operate them. To meet some of these needs we are presently developing the specifications and prices for the purchase of an Ocean Optics portable field fiber optic spectrometer. This system can be used as a spectral radiometer as well as a reflectance sensor and a portable spectrophotometer.

A third part of our effort has been directed at recruiting a qualified graduate student/post doctorate candidate to participate in the project. Prospective candidates were recruited and interviewed throughout the winter and a final selection was made in February 2002. Patrick Biber, a doctoral student at the University of Miami, was interviewed and selected for the project. Since then we have begun to formalize discussions regarding appropriate bioindicator parameters for seagrasses and the analytical and experimental design for the seagrass phase of the project. Included for consideration are; 1) developing an optical water quality gradient transect along a river basin to inlet axis which would include a steep gradient in photosynthetically active radiation (PAR), 2) correlating optical water quality with indicators of seagrass health to include plant fluorescence (photosynthetic efficiency), pigment composition and leaf morphology. Especially critical to the bioindicator question is determining whether the satellite sensors can detect water quality changes at a scale sensitive enough to correspond with a bioindicator in the plants. Additional design considerations also include manipulating growing conditions in field and mesocosm experiments and simultaneously examining indicator responses in order to calibrate the time and spatial scales needed for field observations.