

Phytoplankton Community Structure as an Indicator of Coastal Ecosystem Health (Paerl, Luetlich and Pinckney)

Personnel:

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Organizational (Institutional Partners):

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Other Collaborators or Contacts:

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Objective:

Develop broadly-applicable, phytoplankton-based indicators of estuarine and coastal ecological condition. Link these to nutrient and physical-chemical forcing features and remote sensing analyses of water column optical properties.

Progress Summary:

The ACE INC, “Phytoplankton Community Structure as an Indicator of Coastal Ecosystem Condition” component has been operational since April, 2001. All aspects of the proposed work plan are in place and coordinated with ongoing water quality and habitat monitoring programs on the Neuse River Estuary (NRE), (CISNet & ModMon: www.marine.unc.edu/Neuse/ModMon) and a ferry-based water quality monitoring program for the NRE and Pamlico Sound (www.ferrymon.org). 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. 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 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., 2002, Paerl et al., submitted). Our long-term vision of the regional deployment and interpretive use of photopigment indicators is shown in Figure 2. 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

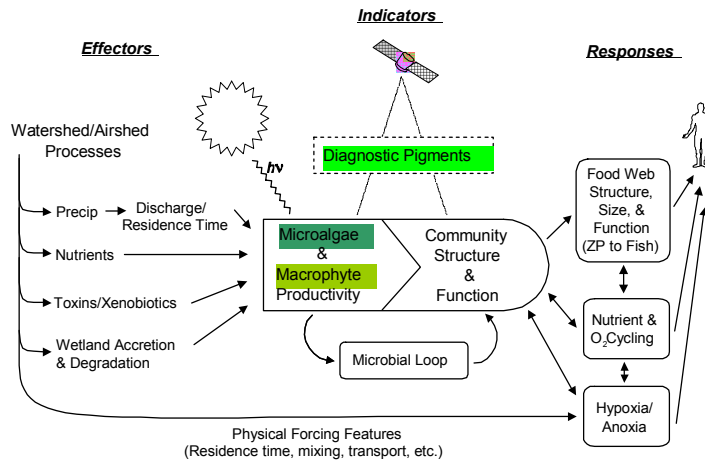


Figure 2. Roles of diagnostic photopigments as indicators of ecosystem productivity, plant community composition in response to physical-chemical stressors in estuarine and coastal waters

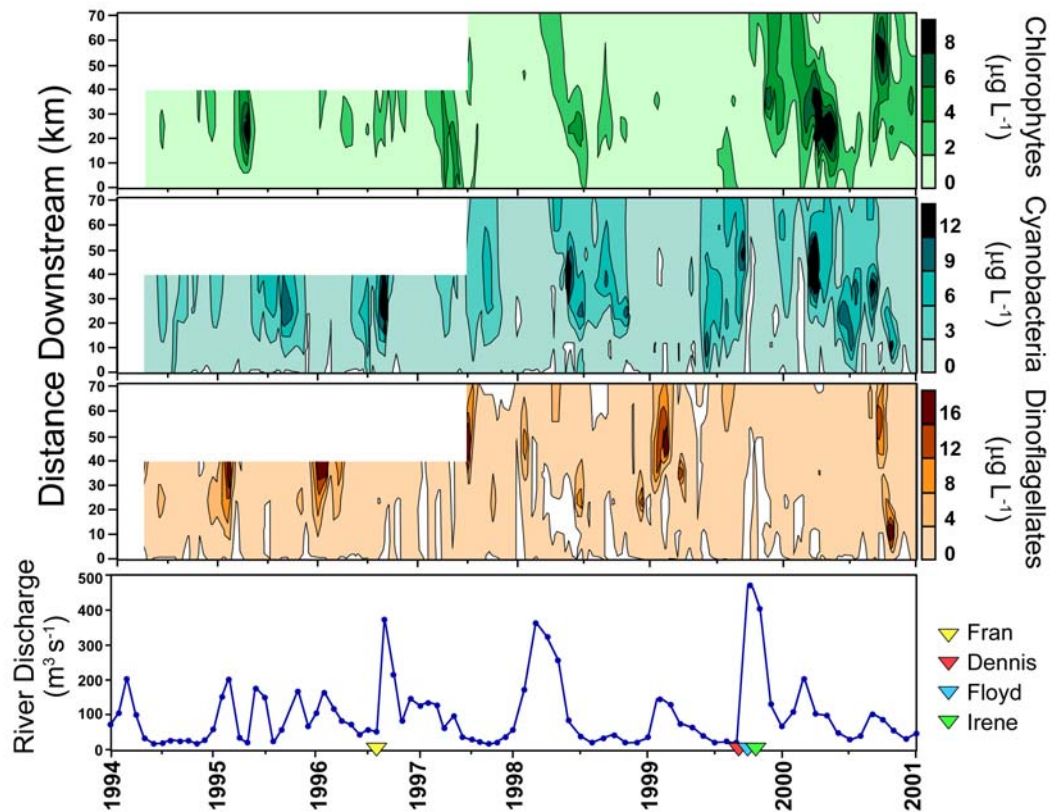


Figure 3. Concentrations of chlorophyll *a* ($\mu\text{g Chl } a \text{ L}^{-1}$) contributed by chlorophytes, cyanobacteria and dinoflagellates. Values were derived using CHEMTAX for surface water at a mesohaline location (Station 120, see Figure 2) of the Neuse R. Estuary during 1994-2000. Data were collected bi-weekly and were temporally extrapolated. White areas indicate instances where data were not collected. CHEMTAX data were plotted along with freshwater discharge at the head of the estuary. The dates of landfall of the four major hurricanes that have significantly affected flow since mid-1996 are shown.

Chlorophylls and carotenoid photopigments are diagnostic for certain phytoplankton functional groups (*i.e.*, diatoms, dinoflagellates, chlorophytes, cyanobacteria, cryptomonads). They are being used to identify and distinguish nutrient from hydrologically-driven changes in phytoplankton community composition and activity in the Neuse River Estuary (NRE), Pamlico Sound (PS) and Chesapeake Bay. We have been able to utilize ongoing intensive data for this purpose in the NRE (1994-present), PS (1999-present) and Chesapeake Bay (1993-present). During this period, these estuarine systems have experienced the combined stresses of anthropogenic nutrient enrichment, droughts (reduced flushing combined with minimal nutrient inputs), and in the NRE/PS since 1996, elevated hurricane activity (high flushing accompanied by elevated nutrient inputs). These distinct perturbations have allowed us to examine impacts of both anthropogenic and natural stressors on phytoplankton community structure. Seasonal

and/or hurricane induced variations in river discharge, and the resulting changes in flushing rates and hence, estuarine residence times, have differentially affected phytoplankton taxonomic groups as a function of their contrasting growth characteristics. For instance, the relative contribution of chlorophytes, cryptophytes, and diatoms to the total chl-*a* pool coincided, and was therefore enhanced by periods of elevated river flow in the NRE. It is hypothesized that these effects are due to the efficient growth rates and enhanced nutrient uptake rates of these groups. Cyanobacteria, however, demonstrated greater relative biomass when flushing was minimal and residence times were longer, specifically during the summer (Fig. 3).

Further evidence that changes in hydrologic conditions have significantly altered phytoplankton community structure is provided by the observed historical trends in dinoflagellate and chlorophyte abundance in the NRE. Both decreases in the occurrence of winter-spring dinoflagellate blooms and increases in the abundance of chlorophytes coincided with the increased frequency and

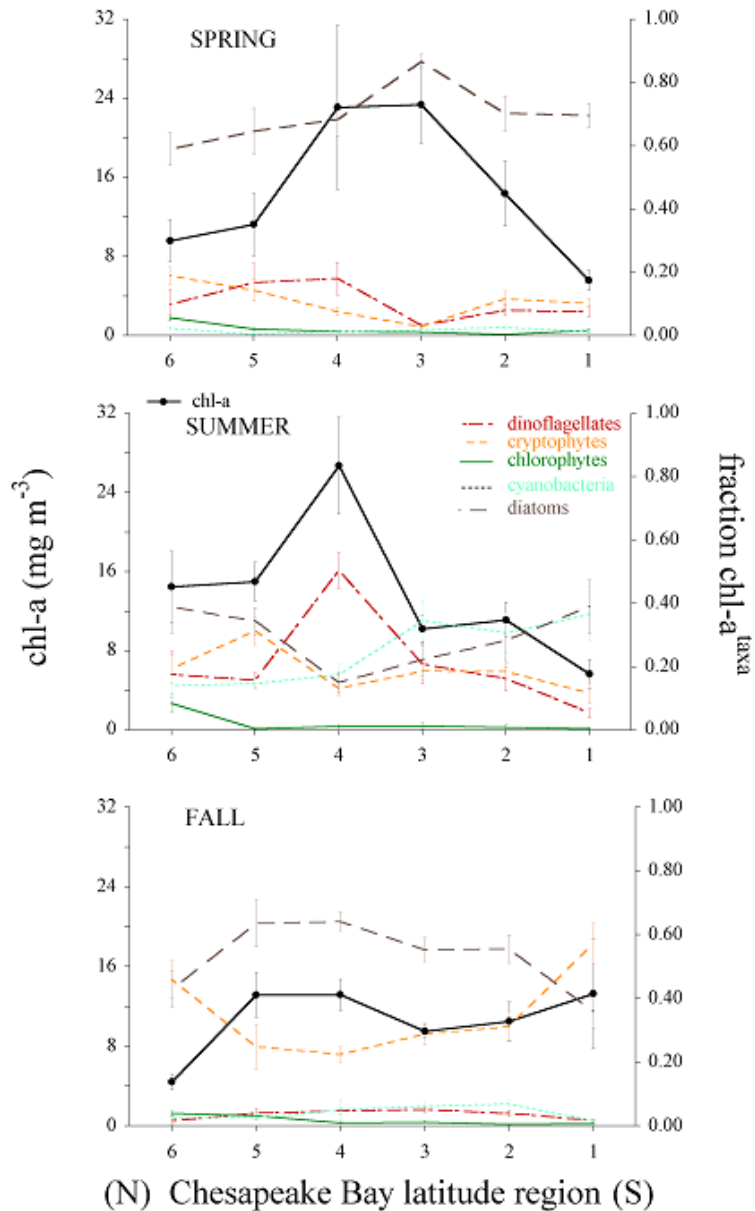


Figure 4. Regional means \pm s.e. (1995 – 2000) for chl-*a* (mg m^{-3}) and the relative abundance (fraction chl-*a*^{taxa}) of phytoplankton groups determined by CHEMTAX. One approach to developing indicators from measurements of phytoplankton biomass and composition is to define the ‘average’ conditions, as shown above, and then conduct analyses of deviations (seasonal, regionally, inter-annually) in relation to differences in environmental forcing functions and patterns of primary production.

magnitude of tropical storms and hurricanes since 1996. The relatively slow growth rates of dinoflagellates may have led to their reduced abundance during these high river discharge events. These results indicate that phytoplankton composition has been altered since 1994 in conjunction with major hydrologic changes, specifically hurricanes accompanied by floods. These phytoplankton community changes could have potentially altered trophodynamics and nutrient cycling in the NRE during these years (Fig. 3).

The reconstructed taxonomic composition for Chesapeake Bay (Fig. 4)(see Chesapeake Bay Component Study as well) also shows strong contrasting responses between dominant phytoplankton groups during the spring and summer due to the variability of freshwater flow and nutrient loading. This pattern is strongest in the spring-early summer wherein high flow alleviates N limitation of the mid to lower estuary and supports diatom blooms in the spring, and sometimes in the summer. Low flow produces improved photic conditions but causes an expanded zone of N limitation in the main stem of the bay during the summer, thereby changing phytoplankton dominance to those groups that can grow efficiently under these conditions.

Two autonomous profiling platforms have been deployed in the NRE. These platforms are designed to add to the archive of data by automatically taking complete profiles of the water column several times per day at key locations in the estuary. Figure 5 presents a sample of data from one of these platforms. Graduate student Nathan Hall is using this data to examine the vertical distribution of phytoplankton in the mesohaline region of the Neuse River Estuary. As shown in Figure 5, the vertical distribution of chlorophyll is often complex which could confound accurate assessments of water column chlorophyll by surface measurements such as remote sensing techniques. Additionally, data from the automated vertical profilers has revealed that diurnal vertical migration is a prominent feature of the vertical distribution of phytoplankton in the mesohaline region of the Neuse River Estuary. Fig. 6 shows chlorophyll depth distributions from a week in June of 2002 when diurnal vertical migration was apparent. Time series analysis techniques revealed that diurnal vertical migration was a prominent feature of the depth distribution of chlorophyll during the late spring through late fall but not during the winter or early spring. A temporal correlation between the occurrence of diurnally vertically migrating phytoplankton and time periods when bottom water inorganic nitrogen exceeded surface water inorganic nitrogen

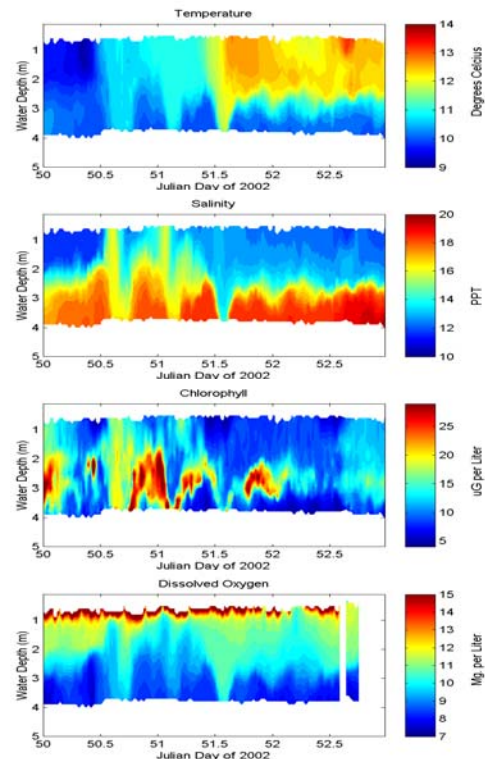


Figure 5. Time series of physical and Chl-a data near the bend in the Neuse River Estuary

concentrations suggests a relationship between diurnal vertical migration and nitrogen deficiency in the photic surface waters. Thus, the presence of diurnal vertical migrating phytoplankton could possibly be used as an indicator of surface water nitrogen deficiency. We will be incorporating Nathan Hall's 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 key roles in nutrient and oxygen cycling (i.e., hypoxia/anoxia) in these waters. Graduate student 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 1998-2000 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 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.

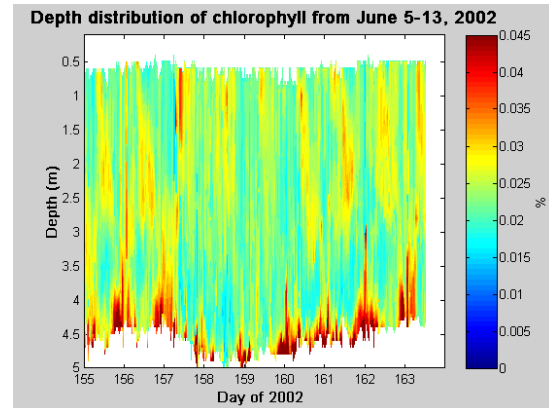


Figure 6. Depth distribution of chlorophyll from an automated vertical profiler. Values are percent of total water column chlorophyll in each 10 cm depth bin.

Dr. Lexia Valdes has been involved in establishing and analyzing a long term data base of diagnostic phytoplankton photopigments for the Neuse R. Estuary-Pamlico Sound. She is also collaborating with L. Harding and Jason Adolph, UMD-HPEL to develop and analyze parallel data bases for Chesapeake Bay and the Neuse-Pamlico system in order to examine and evaluate the interactive affects of anthropogenic nutrient enrichment and natural forcing features, including large storm events, flooding, and droughts on the structure and function of estuarine phytoplankton communities. We are planning several publications that will comparatively examine large-scale ecosystem responses to these forcing features in both systems. 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, AVIRIS 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.

Coupled physical-biological studies: Neuse/Pamlico component

ACE INC field sites were chosen to provide a range of residence times from long (the Neuse/Pamlico Sound) to short (Plum Island Sound). In the Neuse River Estuary (NRE), relatively little quantitative analysis has been performed to establish residence time as a function of discharge or position in the estuary. We have recently completed lagged correlation analyses of observed discharge at Streets Ferry and observed salinity at several locations along the axis of the NRE. These indicate mean travel times of 18.4 days at New Bern, 29.5 days at US Coast Guard Marker 11 and 31.4 – 33 days at station 95. We are in the process of setting up the 3D circulation model EFDC for the system to allow more detailed analysis of residence time as a function of river discharge.

The use of aircraft for the remote sensing of biological pigments requires assumptions or knowledge concerning the vertical structure of biological populations/pigments in the water column. We have collected nearly one year of continuous vertical profiles of water column hydrography (salinity, temperature, turbidity) and in situ chl-a fluorescence. These profiles reveal strong diurnal vertical migration of the chl-a source as well as close correspondence between chl-a levels and mixing events. We have begun analysis of this data to provide insight into its implication for remotely sensed pigments.

Future Activities:

Analyses and interpretation of the long term data are being performed to develop qualitative and quantitative relationships between the abundance of specific phytoplankton functional groups and various estuarine chemical and physical variables. These analyses will yield information that will link the abundance of each phytoplankton functional group with a particular set of environmental conditions. This way, specific phytoplankton functional groups can be used as bio-indicators of estuarine condition. Recent correlative statistical analyses revealed that phytoplankton functional groups in the NRE differed in their relationship to these variables. In addition, the extent of these associations varied with season. Due to the non-linear and complex associations between these biological, chemical and physical variables, we will be using more robust data analysis procedures, including neural network analysis, to establish quantitative associations between these variables.

Training and Development:

This project has largely focused on Graduate and Undergraduate student training during 2002-2003. In addition, project results have been used (via the websites; www.aceinc.org and www.marine.unc.edu/neuse/modmon) to train middle school and high school teachers and students. Websites have also been used to instruct Technicians and data managers.

Outreach Activities:

Both Drs. Paerl and Luetlich are involved in a variety of statewide and national scientific advisory and educational activities. These include serving on NC-DENR's Technical Advisory Committee (Luetlich), NC-DWQ's TMDL modeling group (Luetlich), 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 (Luetlich 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), and 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, 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.

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, 2002, 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.

Presentations at National and International Meetings:

Reynolds-Fleming, JV and RA Luetlich. "Wind-driven across channel circulation in the Neuse River Estuary." IAPSO/IABO conference, October 22, 2001. Mar del Plata, Argentina.

Reynolds-Fleming, JV and RA Luetlich. "Lateral variability in a shallow, lagoonal estuary and its relationship to fish kills." ERF conference, November 4, 2001. St. Pete Beach, FL.

- Fleming, JG, JV Reynolds-Fleming, T Whipple and RA Luetlich. "A Portable, Autonomous, vertical profiler for estuarine applications." ERF conference, November 8, 2001. St. Pete Beach, FL.
- Paerl, H., B. Peierls, L. J. Fear, Twomey, and J. Bales. 2002. Ecological response of Pamlico Sound, NC to hurricanes Dennis, Floyd and Irene: A glimpse into potential impacts of climate change on large estuaries. Invited talk, Americ. Soc. Limnol. Oceanogr. meetings, Victoria, Canada, June, 2002.
- Reynolds-Fleming, JV and RA Luetlich. "Lateral variability in the upper NRE, NC and its relationship to low DO fish kills." Mitsubishi Heavy Industries, July 8, 2002, Nagasaki, Japan. Invited lecture.
- Reynolds-Fleming, JV and RA Luetlich. "Lateral variability in the upper NRE, NC and its relationship to low DO fish kills." Nagasaki University, July 9, 2002, Nagasaki, Japan. Invited lecture.
- Reynolds-Fleming, JV and RA Luetlich. "The simulation of hydrodynamics in the upper NRE." Alpha Hydraulic Engineering Consultants, Co. Ltd., July 31, 2002, Sapporo, Japan. Invited lecture.
- Reynolds-Fleming, JV and RA Luetlich. "Simulation of the lateral variability in the upper NRE, NC.", Kawasaki Heavy Industries, August 6, 2002, Nishi-Akashi, Japan. Invited lecture.
- Reynolds-Fleming, JV and RA Luetlich. "Lateral variability in a shallow, wind-driven estuary." PECS conference, September 18, 2002, Hamburg, Germany.
- Paerl, H., Microbial Ecology at the Forefront of Regional and Global Environmental Change. Plenary Presentation, 8th Society of Aquatic Microbial Ecology meetings, Taormina, Italy, October, 2002.
- Paerl, H. 2002. Ecological nutrient thresholds in estuaries: Moving targets influenced by human and climate change. Invited presentation, EPA-Workshop on Ecological Thresholds, Washington, DC, November, 2002.
- Reynolds-Fleming, JV. "Lateral variability in the upper NRE, NC and its relationship to low DO fish kills." PhD defense, November 15, 2002, Institute of Marine Sciences.
- Paerl, H.W., J. Dyble, M.F. Piehler and P.H. Moisaner. 2002. Developing indicators for assessing coastal eutrophication. Invited Seminar, Scripps Institution of Oceanography, UC San Diego, La Jolla, CA, Dec. 2002.

Dyble, J. and H.W. Paerl. 2003. Studies of cyanobacteria in estuarine environments. Invited talk, Environmental Sampler/Processor Workshop. Monterey Bay Aquarium Research Institute, Monterey, CA, Jan. 2003.

Valdes, L.M., M.F. Piehler, J.L. Pinckney, L. Twomey, and H.W. Paerl. 2003. Historical relationships between phytoplankton taxonomic groups and estuarine dynamics: Developing bio-indicators of ecosystem condition and change. Aquatic Sciences Meeting, American Society of Limnology and Oceanography, Salt Lake City, UT, February 2003.

Paerl, H.W. M.F. Piehler, L.M. Valdes and M.E. Lebo. 2003. Nutrient dynamics and water quality in North Carolina Estuaries: Past, present and future. Aquatic Sciences Meeting, American Society of Limnology and Oceanography, Salt Lake City, UT, February 2003.

Paerl, H.W. 2003. The ecological conditions contributing to blue-green algal blooms in North Carolina. Invited Presentation, NC-DENR Workshop: Blue-Green Algae and Public Water Supplies, UNC-Chapel Hill, NC, Feb. 2003

Paerl, H.W. 2003. Assessing Estuarine Ecological Change: A Moving Target Influenced by Human and Climatic Perturbations. 4th Ecological Integration Symposium. Texas A&M Univ., College Station, TX, Feb. 2003.

Publications:

Luettich, RA, SD Carr, JV Reynolds-Fleming, CW Fulcher, and JE McNinch. "Semi-diurnal seiching in a shallow, micro-tidal lagoonal estuary." *Continental Shelf Research*, 22(2002):1669-1681.

Paerl, H.W. 2002. Connecting atmospheric deposition to coastal eutrophication. *Environmental Science and Technology* 36, No.15:323A-326A.

Piehler, M.F., J. Dyble, P.H. Moisander, J.L. Pinckney and H.W. Paerl. 2002. Effects of modified nutrient concentrations and ratios on the structure and function of the native phytoplankton community in the Neuse River Estuary, North Carolina USA. *Aquatic Ecology* 36: 371-385.

Paerl, H.W, R. L. Dennis and D. R. Whitall. 2002. Atmospheric deposition of nitrogen: Implications for nutrient over-enrichment of coastal waters. *Estuaries* 25:677-693.

Paerl, H.W. J. Dyble, L. Twomey, J. L. Pinckney, J. Nelson and L. Kerkhof. 2002. Characterizing man-made and natural modifications of microbial diversity and activity in coastal ecosystems: *Antonie van Leeuwenhoek* 81:487-507.

Paerl, H., J. Dyble, P. Moisander, R. Noble, M. Piehler, J. Pinckney, T. Steppe, L. Twomey and L. Valdes. 2002. Microbial Indicators of Aquatic Ecosystem Change:

Current Applications to Eutrophication Studies. *In*: L. Giuliano & R. Conrad (Eds.), Proceedings of the 8th Society of Aquatic Microbial Ecology meetings, FEMS (in press).

Reynolds-Fleming, JV, JG Fleming, and RA Luetlich. "Portable, autonomous vertical profiler for estuarine applications." *Estuaries*, 2002, 25(1):142-147.

Buzzelli, C.P., Ramus, J.R. and Paerl, H.W. (2003) Ferry-based monitoring of surface water quality in North Carolina estuaries. *Estuaries* (in press).

Paerl, H.W., L.M. Valdes, J.L. Pinckney, M.F. Piehler, J. Dyble and P.H. Moisander. 2003. Phytoplankton photopigments as indicators of estuarine and coastal eutrophication. *Bioscience* (submitted).

Reynolds-Fleming, JV. "The hydrodynamics of the upper NRE and their influence on dissolved oxygen distribution." PhD dissertation. 2003.

Reynolds-Fleming, JV and RA Luetlich, Jr. "Wind-driven lateral variability in the upper Neuse River Estuary and its effect on fish kills." submitted to *Continental Shelf Research*.

Reynolds-Fleming, JV and RA Luetlich, Jr. "Lateral variability of dissolved oxygen and density in a shallow, partially mixed estuary.", in prep for *Estuaries*.

Reynolds-Fleming, JV and RA Luetlich, Jr. "Simulation of lateral salinity variability in a shallow, wind-driven estuary affected by fish kills." ,in prep for *Ocean Dynamics*.

Other notable accomplishments:

Hans W. Paerl was awarded the G. Evelyn Hutchinson Award of the American Society of Limnology and Oceanography (ASLO) at their annual meeting on February 8-14, 2003. The G. Evelyn Hutchinson Award has been presented annually by ASLO since 1982 to recognize excellence in any aspect of limnology or oceanography. The award is intended to symbolize the quality and innovations toward which the society strives and to remind its members of these goals. In lending his name to the award, Hutchinson asked that recipients be scientists who had made considerable contributions to knowledge, and whose future work promised a continuing legacy of scientific excellence. Emphasis in selection for this award is given to mid-career scientists for work accomplished during the preceding 5-10 years.

Relevant Websites:

Specific web pages for ACE INC and the Phytoplankton Indicator component can be found at www.aceinc.org. This is an interactive website for all ACE INC activities

(linked in with the EaGLE website) which is maintained by Alan Joyner, ACE INC website manager and communication/data coordinator ACE INC. Additional technical information on sample collection, analysis and applications to large-scale estuarine studies (Pamlico Sound) can be found at www.ferrymon.org.

Supplemental Keywords:

phytoplankton, estuarine & coastal indicators, photopigments, nutrients, hydrology, water quality, habitat, ecosystem and regional scale, management, physical factors, climatology, hurricanes, nutrient management, TMDLs, modeling, remote sensing, ferry-based monitoring