United States
Environmental Protection
Agency

New Indicators of Coastal Ecosystem Condition

Introduction: Coastal ecosystems, from large estuarine systems to salt marshes, are recognized for their important ecological function and societal value. They provide habitat and nursery grounds for commercially- and recreationally-important finfish and shellfish. Marshes absorb energy from storms and protect the land from hurricanes. These important ecosystems are threatened by multiple human stressors as well as natural disturbances. The nation is losing much of its coastal marsh due to development, land subsidence, erosion, and sea level rise. In some areas, invasive species have displaced native species, threatening commercially important biological resources by altering habitat and productivity of the marsh. Reduction of water clarity, through increases in suspended sediments and algal blooms, adversely affects the growth of submerged aquatic vegetation, the nursery grounds for many fish and shellfish. In order to protect against continued degradation and loss of coastal ecosystem services and to plan for their remediation, new indicators are needed that will predict when and where ecosystem degradation and wetland losses will occur.

Three ecological indicators of coastal condition are being investigated by researchers with the Atlantic Coast Environmental Indicators Consortium (ACE INC, www. aceinc.org): 1) phytoplankton community composition; 2) salt marsh elevation and plant health; and 3) the size distribution of aquatic organisms (biomass spectra).

1) Phytoplankton Community Composition as an Indicator of Coastal Ecosystem Condition

Phytoplankton community composition is a gauge of ecological condition and change. Phytoplankton are suspended microscopic algae. They are the major primary producers in estuarine ecosystems, have fast growth rates, and are sensitive to environmental disturbances. Phytoplankton communities, such as diatoms, dinoflagellates, chlorophytes, cyanobacteria, and cryptomonads each have their own unique diagnostic photopigment signature that can be used to identify the composition of the phytoplankton community. (Photopigments, such as chlorophylls and carotenoids, are molecules that capture and convert light into chemical energy for powering photosynthesis).

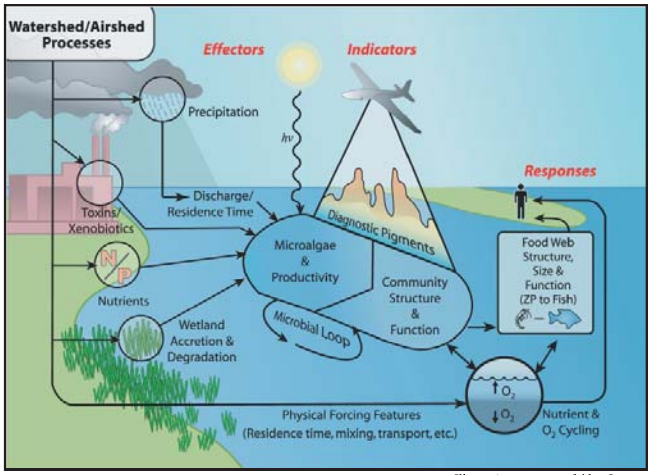

Illustration courtesy of Alan Joyner

Figure 1. Roles of diagnostic photopigments as indicators of ecosystem productivity and plant community composition in response to physical-chemical stressors in estuarine and coastal waters.

Ecological Indicator: The structure of phytoplankton communities is a broadly applicable, integrative indicator of ecological condition of aquatic ecosystems.

Ecological Effect/Impact: Changes in phytoplankton community composition are important indicators of estuarine and coastal ecological condition and health because phytoplankton plays a major role in primary production, eutrophication (including harmful algal blooms), nutrient cycling, water quality, and food web dynamics.

Environmental Application: Phytoplankton community composition can serve as an early warning signal of toxic or hypoxia-generating algal blooms. It has proven useful and applicable for evaluating ecosystem and regional responses to environmental stressors, including increased nutrient loads, changes in hydrologic characteristics, and climatic disturbances such as hurricanes and droughts. Together with the North Carolina Department of Environment and Natural Resources, researchers at the University of North Carolina at Chapel Hill's Institute of Marine Sciences are using diagnostic pigment (e.g., chlorophyll *a*) concentration as the criteria for meeting allowable total maximum daily (nutrient) loads (TMDLs). In addition, diagnostic photopigments are used to determine phytoplankton community changes in response to hydrological variability, including hurricanes and droughts. Results from North Carolina's Neuse River Estuary/Pamlico Sound system show that when conditions "freshen" in response to hurricanes and flooding, fast growing, low salinity-adapted chlorophytes (green algae) become dominant (Fig. 2). Conversely, when drought conditions prevail, slower-growing dinoflagellates prevail in wintertime and cyanobacteria (blue-green algae) prevail in summertime (Fig. 2). Cyanobacteria can be especially dominant when a moderate to wet spring is followed by summer drought conditions. This sequence of events introduces high nutrient loads, followed by a reduction in flow and flushing, and subsequent retention of the nutrients; an ideal scenario for cyanobacterial blooms. Aside form impacting water quality, such hydrologic and nutrient-driven changes have

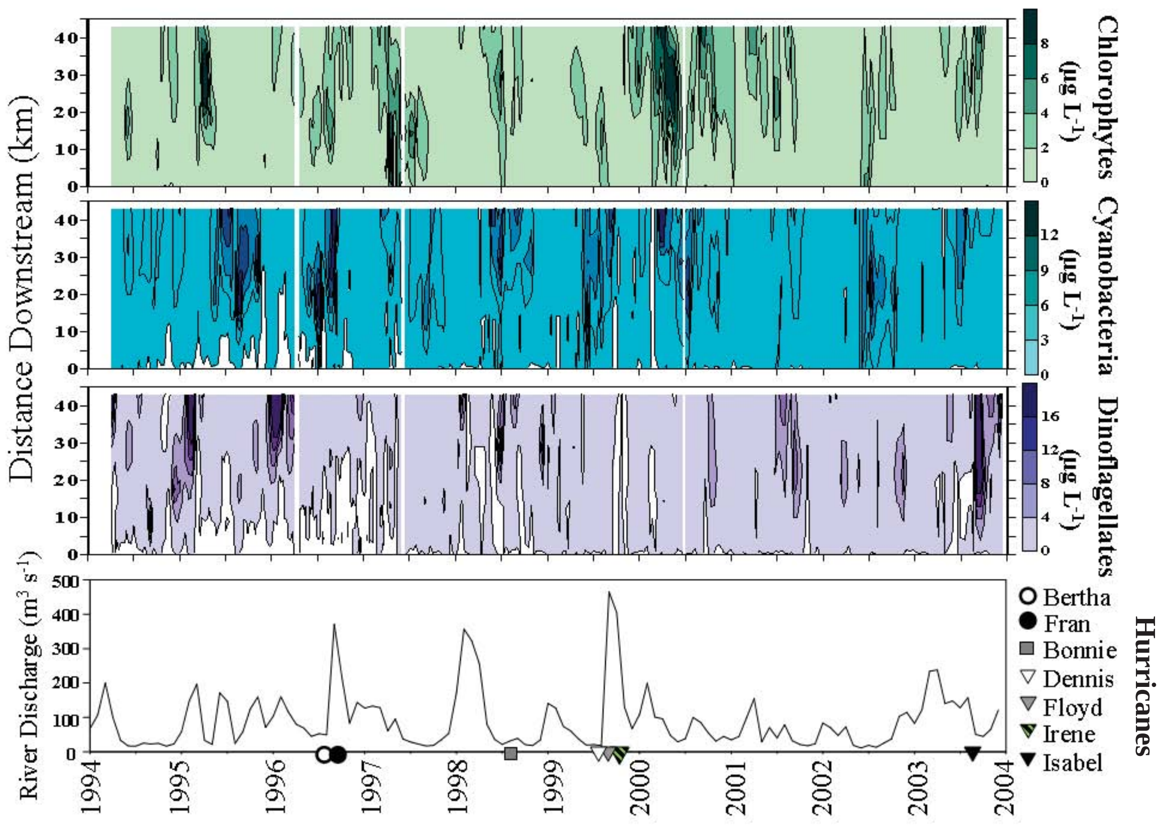

Figure 2. Contribution of some key phytoplankton taxonomic groups (chlorophytes, cyanobacteria and dinoflagellates) to total chlorophyll a concentrations in the Neuse River Estuary, NC. The dates of landfall of the seven major hurricanes that have significantly affected flow and nutrient enrichment since mid-1996 are shown.

significant food web ramifications, affecting finfish and shellfish productivity and habitability in estuaries.

Photopigments also provide a key data source for verification and calibration of remote-sensing measurements of phytoplankton production and community composition for estuarine and coastal water bodies nationally. The use of remote sensing allows researchers and managers to “scale-up” to whole ecosystem assessments of productivity and ecological condition. For example, in the Chesapeake Bay, aircraft-based remote sensing data are being coupled to diagnostic pigment analysis to “scale-up” assessments of nutrient and freshwater discharge controls on phytoplankton and bloom formation for the entire estuary at monthly and seasonal intervals (Figure 3). These indicators are also now part of unattended water quality monitoring of estuarine and coastal sounds. Data from regular ferry crossings were used as indicators of large-scale assessment of the impacts of Hurricane Isabel (Sept. 2003) on North Carolina’s Pamlico Sound (www.ferrymon.org).

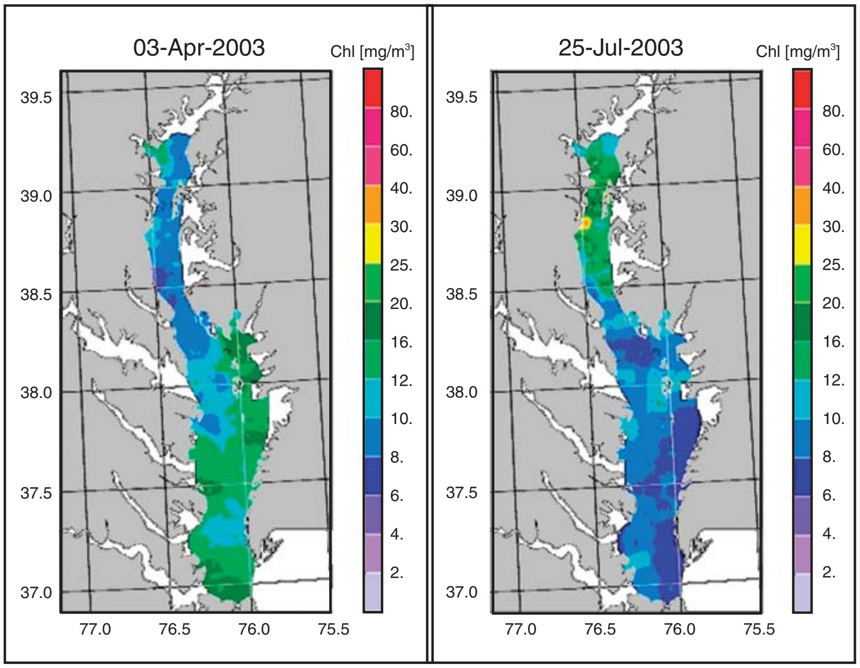

Figure 3. Chlorophyll (chl-*a*, mg m^{-3}) distributions in Chesapeake Bay from aircraft remote sensing of ocean color using SAS III for spring and summer flights in 2003.

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* 53(10) 953-964.

Paerl, H. W., J. Dyble, J.L. Pinckney, L.M. Valdes, D.F. Millie, P.H. Moisander, J.T. Morris, B. Bendis, B., and M.F. Piehler. 2005. Using microalgal indicators to assess human and climactically-induced ecological change in estuaries. Pp. 145-174, In S. Bartone (Ed.) *Proceedings of the Estuarine Indicators Workshop*. Boca Raton, Florida: CRC Press, Orlando

2) Relative Elevation and Plant Health as Indicators of Coastal Marsh Stability and Productivity

The health and productivity of coastal wetlands are dependent upon the success of the plant life, which in turn is dependent upon the plant’s relationship to sediment, sea level, and the tide. Many coastal marshes depend on sediments supplied by rivers to counteract the effects of land subsidence, sea-level rise, and sediment compaction. In some areas, changes on the land have led to reduced riverine sediment supply to marshes, leading to a decrease in height relative to mean sea level. Where dams or levees have been constructed to prevent flooding, marshes have been cut off from their source of sediment, and the net effect is conversion of marsh habitat to open water.

Vertical elevation is a critical variable that determines the productivity and stability of salt marshes. The long-term existence of the salt marsh depends on the success of the dominant plants, such as *Spartina* and *Juncus*, and their close relationship to sediment supply, sea level change, and tidal range.

Researchers at the University of South Carolina, Columbia, SC and the Marine Biological Laboratory, Woods Hole, MA have developed two coastal indicators that can be applied to assess the condition of coastal marshes. One is vertical elevation relative to mean sea level (geomorphic) and the other is level of stress of marsh vegetation (physiologic).

Geomorphic Indicator: The vertical elevation relative to mean sea level is an important geomorphic indicator of marsh productivity and stability and is determined by using Light Detection and Ranging (LIDAR) remote sensing. This LIDAR elevation data is combined with a high resolution Airborne Data Acquisition and Registration (ADAR) digital camera image of the marsh landscape to construct a frequency distribution of marsh landcover with elevations relative to the elevation of mean sea level. The frequency distribution is then compared to optimal distributions across the range of tolerance for the specific vegetation.

Ecological Effect/Impact: The height of coastal marshes relative to sea level will move upwards or downwards toward equilibrium with the sea depending on factors such as the rate of sea level rise and amount of sedimentation. When this equilibrium drops below an optimum level either by a rapidly changing sea level or changes in the supply of mineral sediment and organic matter, the salt marsh vitality will decline. A decline in relative elevation of the marsh surface below an optimum suggests that coastal marshes are on a course leading to degradation.

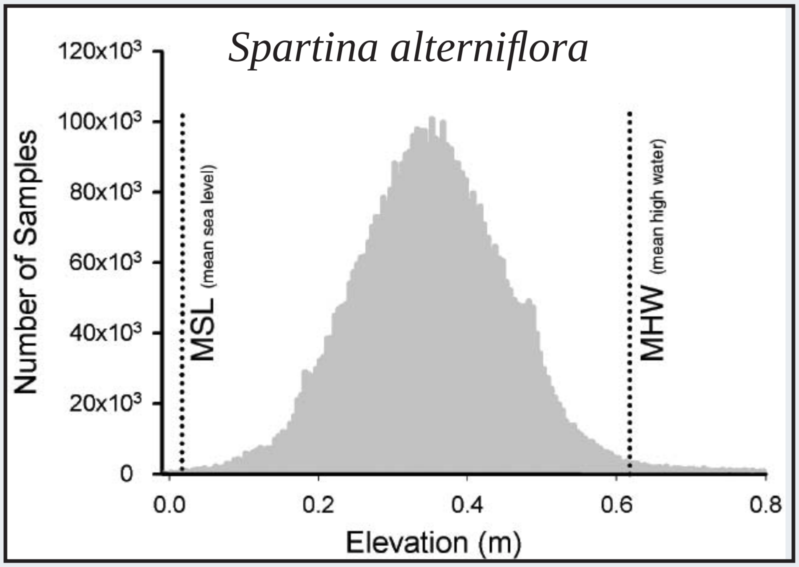

Figure 4. The distribution of Spartina habitat elevations at North Inlet, SC (Tide Range - 1.39 m). Distribution is a function of the rates of sea level rise and land subsidence.

Physiological Indicator: The level of stress of marsh vegetation is an important indicator of marsh productivity and stability. Two complementary measurements, one ground-based and the other remotely-sensed, are applied to measure stress. The ground-based technique is based on the fluorescence emitted by a leaf as measured by a Pulse Amplitude Modulated (PAM) fluorescence meter and gives an estimate of the efficiency of energy utilization by the leaf. A healthy leaf will have a higher energy efficiency than a leaf that is stressed. The remotely-sensed measurements detect different forms of xanthophyll pigments. Xanthophyll pigments change form in order to protect the plant's photosytems so can they be used as an indicator of stress.

Ecological Effect/Impact: The stress of marsh vegetation, as measured by the spectral reflectance of plant pigments, is governed by nutrient and water availability, phytotoxins, salinity, and relative sea level. Combining marsh elevation data with measurements of the level of stress of vegetation is an integrative indicator of marsh productivity, health, and stability.

Environmental Application: These indicators offer a cost-effective alternative for assessing risk for wetland loss, as well as monitoring the condition of coastal wetlands and the success of restoration efforts. Resource managers can use this information, for example, to apply mitigation techniques for adjusting sediment supply for wetlands at high risk of inundation.

Morris, J.T., P.V. Sundareshwar, C.T. Nietch, B. Kjerfve, D.R. Cahoon. 2002. Responses of coastal wetlands to rising sea level. *Ecology* 83:2869-2877.

Morris, J.T., D. Porter, M., Neet, P. A. Noble, L. Schmidt, L. A. Lapine, and J. Jensen. 2005. Integrating LIDAR, multispectral imagery and neural network modeling techniques for marsh classification. *Int. J. Remote Sensing*. (In press).

3) Biomass Size Spectra as an Indicator of Ecosystem State

A biomass size spectrum (BSS) depicts the abundance and distribution of organisms by size classes in an ecosystem. In aquatic ecosystems, the biomass (i.e., aggregate weight) of organisms at each level in the food chain from microscopic phytoplankton to the largest vertebrate animals is nearly equal. Because biomass is near equal, numbers of small organisms greatly exceed numbers of large organisms. Size-specific predation (big organisms eat smaller ones) in aquatic communities maintains the observed biomass size structure and has led to methods for evaluation of biomass-size relationships to characterize the structure and state of ecosystems. To derive BSS, data from monitoring programs on organism abundances must be aggregated into size categories. BSS models can serve as ecological indicators because properties of BSS respond to natural or human-induced stressors. ACE INC scientists at the University of Maryland are evaluating BSS as an indicator of ecosystem state in Chesapeake Bay.

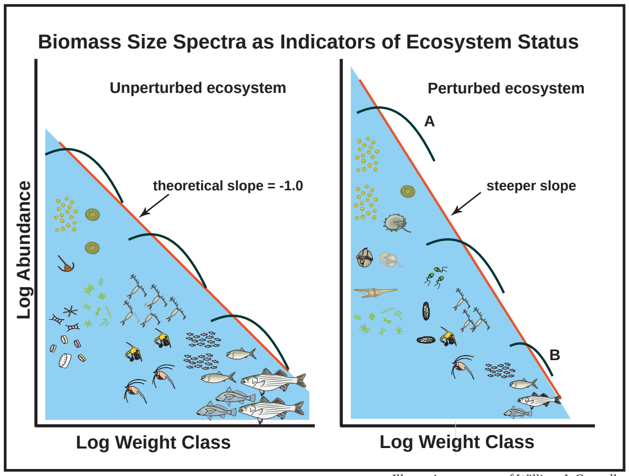

Illustration courtesy of William J. Connelly
University of Maryland Center for Environmental Science

Figure 5. Conceptual illustration of a normalized biomass size spectrum (numbers of organisms plotted against weight classes) in an unperturbed (left panel) and perturbed (right panel) ecosystem. In a perturbed ecosystem, abundance of small, undesirable phytoplankton (A) may increase while abundance and size of large organisms (fish) may decline (B). As a result, the slope of the disturbed biomass size spectrum becomes steeper and other statistical properties (e.g., levels of abundance) may shift.

Ecological Indicator: Changes in the slope or other statistical properties of the normalized BSS relative to reference standards or historical benchmarks is an indicator of changes in the abundance and biomass of the suite of organisms in an aquatic ecosystem.

Ecological Effect/Impact: Changes in the slope of the normalized BSS can be indicative of changes in the biological community structure, productivity, food-chain efficiency, predator-prey relationships, and effects of environmental variability, fishing, nutrient loading, and habitat change. BSS of stressed ecosystems often have steep negative slopes. For example, in heavily fished ecosystems larger fish may be reduced in number and biomass. Or, in highly eutrophic ecosystems with excess nutrient loading, blooms of microscopic phytoplankton can greatly increase the abundance and biomass of small organisms, leading to stressful conditions such as hypoxia and mortality of larger organisms (e.g., crabs, fish).

Environmental Application: BSS can be used by managers to describe long-term effects of stress or the success of restoration efforts in estuaries impacted by human activities. BSS can be applied to a broad suite of aquatic biological communities, not only to selected organisms, and thus can indicate how whole ecosystems are responding to either deteriorating conditions or remediation efforts in resource management (e.g., better fisheries management, habitat restoration, improved water quality). Periodic monitoring of sizes and abundances of organisms is required to apply BSS as an indicator.

Jung, S. and E.D.Houde. 2005. Fish Biomass Size Spectra in Chesapeake Bay. *Estuaries* 28(2): 226-240.

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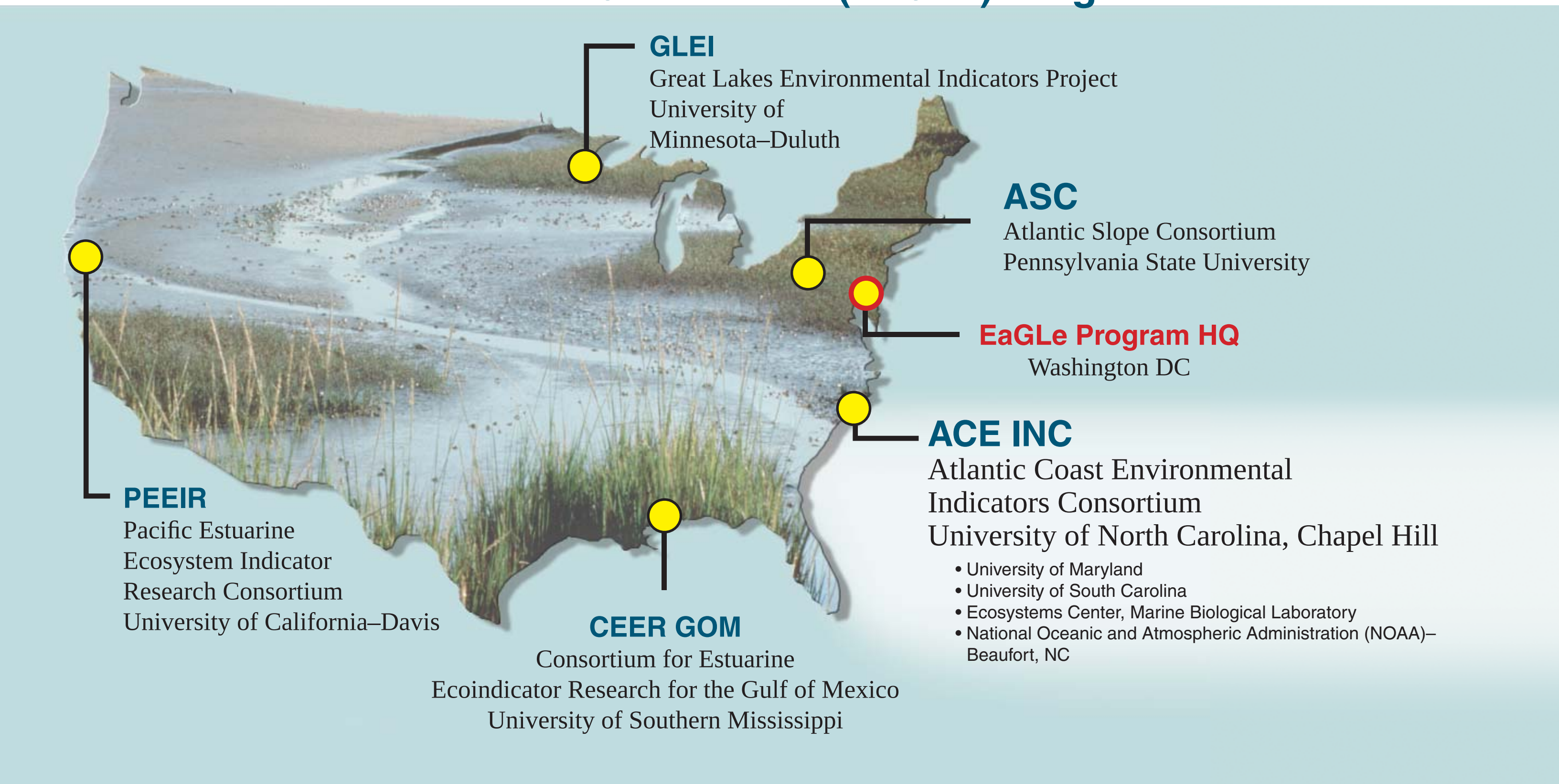

Direct and indirect effects of human activities have taken a toll on the nation's estuaries, yet few direct linkages have been identified between human activities on land and responses in estuarine ecosystems. The Atlantic Coast Environmental Indicators Consortium (www.aceinc.org) is one of five national projects funded by EPA's EaGLe program. The goal of the EaGLe program is to develop the next generation of ecological indicators that can be used in a comprehensive coastal monitoring program.

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