

Coastal Wetland Indicators (Morris, Torres and Hopkinson)

Personnel:

Senior Personnel:

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Post-docs:

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Graduate students:

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Organizational (Institutional Partners):

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NOAA/NOS, Beaufort, NC
University of South Carolina, Columbia SC
Marine Biological Laboratory, Woods Hole, MA
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Other Collaborators or Contacts:

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Objective:

Develop a suite of indicators of the condition of coastal wetlands that are based on physical and biological criteria. Emphasis is on higher plant-based pigment indicators. Link these indicators to remote sensing capabilities.

Progress Summary:

The ACE INC, Coastal Wetland Indicators component has been active since August 2001. In the initial months of the project most of the activity was organizational. Two postdoctoral fellows have been hired, Helen Marshall, an expert on plant pigments and biooptical modeling with a PhD from the University of Wales, and Vinton Valentine with a PhD from the University of Delaware. Dr. Marshall is working on a major goal of our

project, which is to develop a suite of indicators of the condition of coastal wetlands that are based on biophysical 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. Dr. Valentine brings to the project expertise in image analysis and geographic information systems. With the addition of Vinton, our efforts in classification of marsh drainage networks will commence. 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 is diagrammed below (Figure 1).

Coastal Wetland Indicators ACE INC

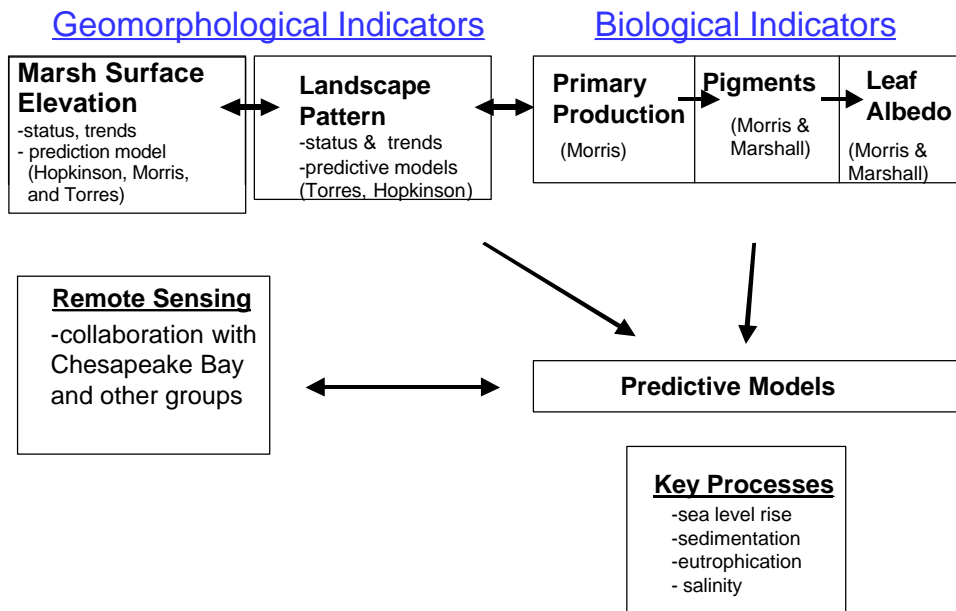


Figure 1. Schematic of the structure, elements, and principal scientists of Coastal Wetland Indicators.

Pigment Indicators

We have taken advantage of a long-term, N-P factorial fertilization experiment in our South Carolina salt marsh study site to test for the sensitivity of plant pigments and the spectrum of reflected light from plant leaves to nutrient condition. These are variables that make attractive indicators as they clearly have application to remote sensing. Our data show that *Spartina* biomass and productivity respond to N, but not to singular additions of P. However, results of scanning with a spectroradiometer (Fig. 2) showed that P-treated plants had significantly higher reflectance in the NIR, irrespective of N

treatment, in a spectral region that is largely determined by cell structure. Microscopic analysis showed that the bundle cells of P-treated plants were more lignified and also differed in the dimensions of their bundle sheaths. The observed differences in spectral reflectance should be great enough to be detectable by remote sensors and could provide a means of monitoring nutritional status.

We also have made progress in relating the density of chlorophyll in the plant canopy to the reflectance data in remote imagery, and we have successfully trained a neural network to classify remote imagery. With stunning success, the neural network was able to map chlorophyll density as well as plant community distributions and major landscape features. This is an important step, because chlorophyll concentration provides information about a plant's condition. The concentration of chlorophyll 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 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

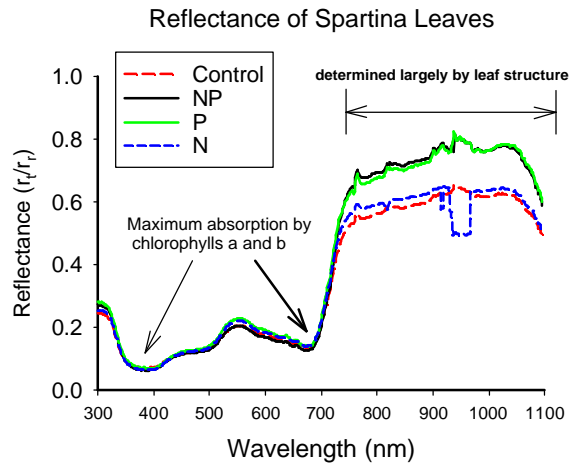


Figure 2. The spectrum of light reflected from the leaves of *Spartina alterniflora*. Plants treated with phosphorus had higher reflectance in the near infra-red .

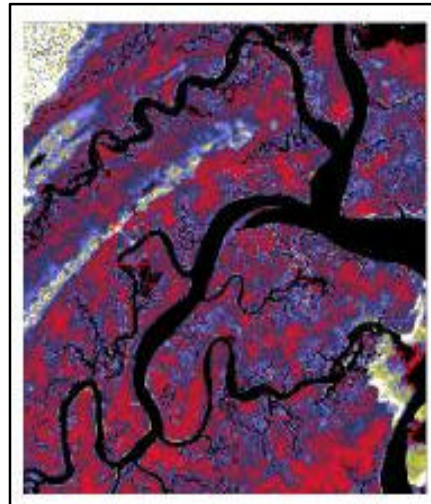


Figure 3. An ADAR image, classified to show chlorophyll density in a salt marsh at North Inlet.

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 (Fig. 2) and the density of pigments in the plant canopy (Fig. 3 and 4).

At North Inlet previous attempts to remotely sense pigments have met with some success (Fig. 2 and 3) 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.

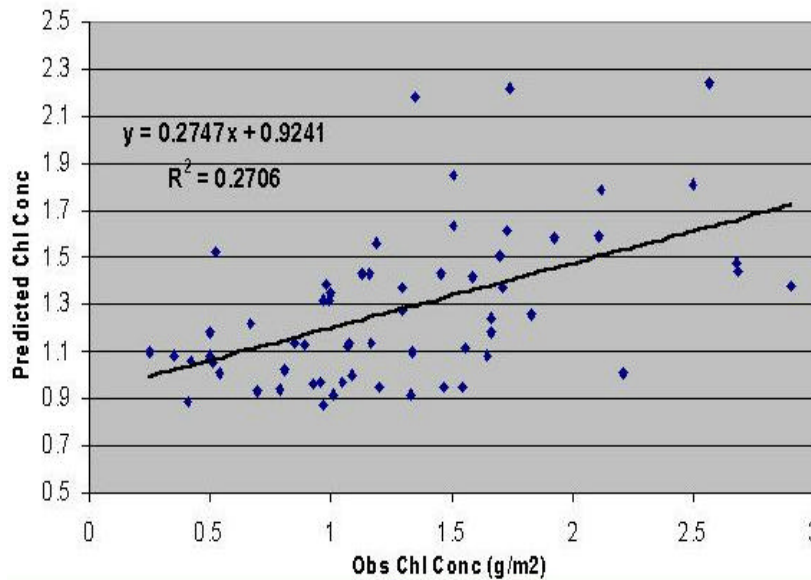


Figure 4. A neural network was trained to interpret the 4 ADAR bands (blue, green, red and NIR). The output of the neural net is the chlorophyll density in the plant canopy. The fit using the NN is significantly better than can be obtained using regression analysis and traditional models.

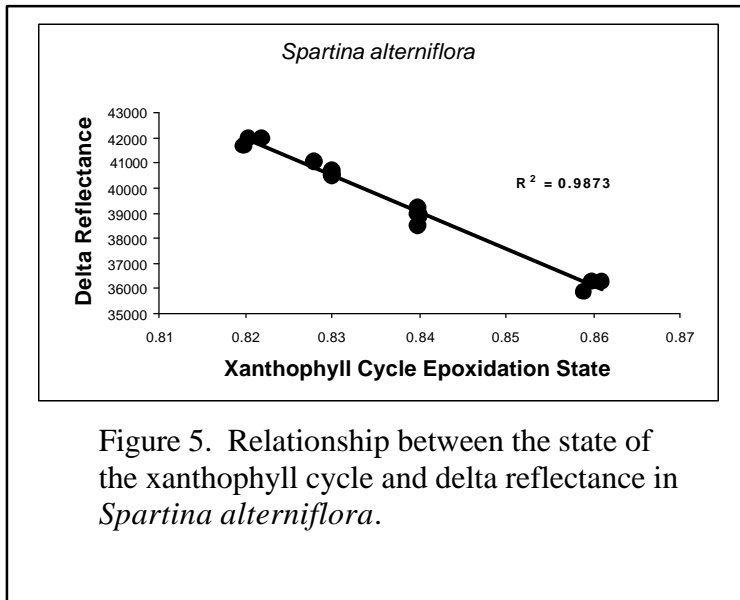
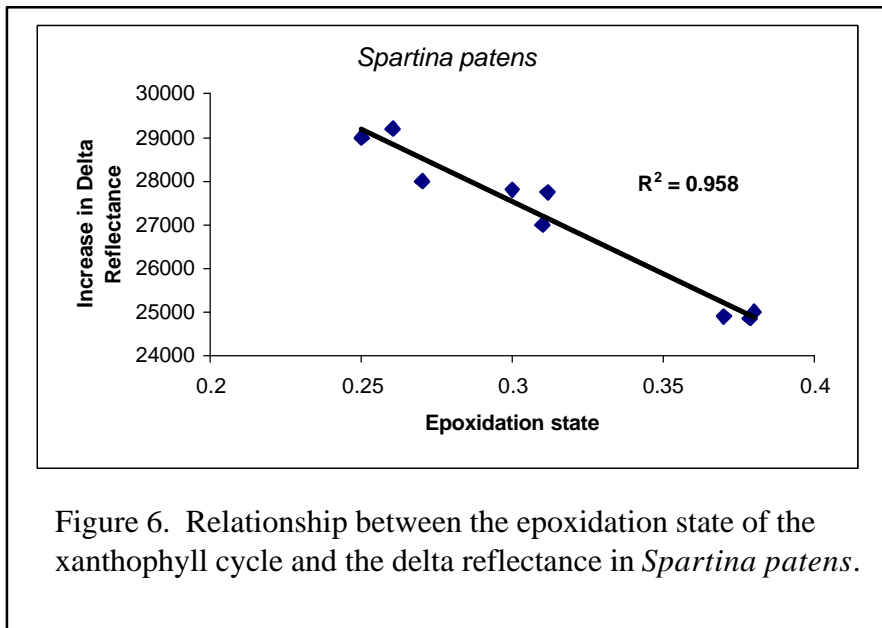


Figure 5. Relationship between the state of the xanthophyll cycle and delta reflectance in *Spartina alterniflora*.

Our group is also looking specifically at xanthophyll pigments. These pigments react rapidly to a variety of environmental stressors in both micro algae and higher plants. The xanthophyll pigments perform a cyclic inter-conversion (epoxidation and de-epoxidation) during light and nutrient stress, which directly affects the rate of carbon fixation and therefore of primary production, by competing with the photosystem 2 light



harvesting antenna. This cycle causes changes in the proportion of different wavelengths of light reflected by the photosynthetic apparatus and as such can be used as a remote sensing indicator to assess nutrient availability and the rate of primary production in a

variety of ecosystems. Experiments have been performed at the Plum Island Estuary in Massachusetts and North Inlet in South Carolina. These experiments used a series of fertilized plots to assess how changes in nutrient stress affect xanthophyll cycling and concurrent changes in leaf reflectance both at single leaf and community levels. Reflectance was analyzed around 530nm wavelength and the change from a 'no feature' was calculated and named delta reflectance. Delta reflectance correlated linearly with the epoxidation state of the xanthophyll cycle at both single leaf (Fig.5) and plant canopy levels (Fig. 6). Changes in the overall size of the xanthophyll pool affected the magnitude of values of delta reflectance, and can be used to predict actual concentrations of each of the xanthophyll pigments. In this way the environmental stress that salt marsh plants are under can be remotely sensed using the reflectance as an indicator. The work is currently being developed to take into account larger scale community work such that the reflectance data may be collected by airborne sensors. Common coastal pollutants and their affects on xanthophyll cycling are also being examined. Xanthophyll cycling occurs rapidly (10 minutes) and so can provide an environmental indicator with high spatial and temporal resolution.

Primary Production Indicators

Long-term research at North Inlet has documented a trend of increasing primary production in the salt marsh (Morris et al. 2002). Interannual variation that exists around a trend of increasing production is related to anomalies in mean sea level. Several lines of information lead 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 interpretations are 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.

Geomorphological Indicators

Research on marsh stability in northern marshes continues on several fronts – 1) establishment of sites for monitoring sedimentation and erosion, 2) marsh elevation surveys, 3) geomorphic descriptions of marsh condition. Vinton Valentine joined the effort in January 2003. Vinton is a postdoctoral scientist at MBL having graduated from the University of Delaware in December 2002. He brings to the project his expertise in image analysis and geographic information systems. With the addition of Vinton, our efforts in classification of marsh drainage networks will commence.

Monitoring sedimentation and erosion – SET (sedimentation-erosion tables) platforms have now been established at 6 primary locations (Fig 7 and 8) that stretch across multiple gradients: a) land-sea or riverine vs oceanic sediment source, b) vegetation communities (*S. alterniflora*, *S. patens* and *T. augustifolia*), and c) distance from creek waters (creekside vs inland marshes). SET platforms and marker horizons have been established along 300-m long transects extending away from creekbanks. Five transects have been established along the Rowley River, which is one of the rivers discharging into Plum Island Sound. Three additional SET sites have been established at experimental sites where marshes are fertilized with N and P. Initial elevation was measured at each SET platform in the fall of 2002. Sites will be monitored with a 6-month frequency.

Additional SET platforms will be established once we have mapped and classified the estuarine drainage creek network. Our hypothesis is that drainage network configuration will give an indication of whether a marsh is keeping up with sea level rise or not. We will establish SET platforms in each major network type to test this hypothesis.



Figure 7. Installation of SET platforms in Plum Island marshes during winter so as to minimize disturbance to vegetation.

Marsh Elevation Surveys – High precision GPS surveys of marsh elevation have been conducted throughout the Plum Island Sound marshes, from the salt water marshes surrounding Plum Island Sound to the tidal freshwater marshes along the upper Parker River. Kinematic surveys were conducted following the establishment of a series of high precision benchmarks throughout the Plum Island Sound region. This benchmark network was tied into the geoid by surveying up to the primary elevation benchmark at Salisbury Beach in New Hampshire. The precision and accuracy of our benchmark network is 2-3 mm and that of the kinematic elevations is better than 1 cm. Our next goals are to attempt to extrapolate spot



Figure 8. Locations of SET platforms (triangles) and elevation measurements (red circles) in the Plum Island estuary.

measurements across the marsh platform. We will determine if we can do this by coupling aerial imagery and elevation measures with a neural net analysis. Ultimately we need much better elevation data for our study marshes, and the coast as a whole. High precision lidar imagery is our first choice of elevation data. This is expensive data to obtain and we seek assistance from the EPA national office in getting it.

Geomorphic Characterization - Our efforts in this area began in earnest with the addition of Vinton Valentine to the project. Thomas Millette from Mt. Holyoke College is also teaming up with us in our effort to classify marsh drainage networks. Our first priority is to catalog the available maps and imagery of our study region. We are contacting numerous state, federal and local research groups for information on these items. Our catalog will indicate product type, scale, area of coverage, date, quality, and price. Once we have cataloged the sources of information, we will attempt to obtain those that should

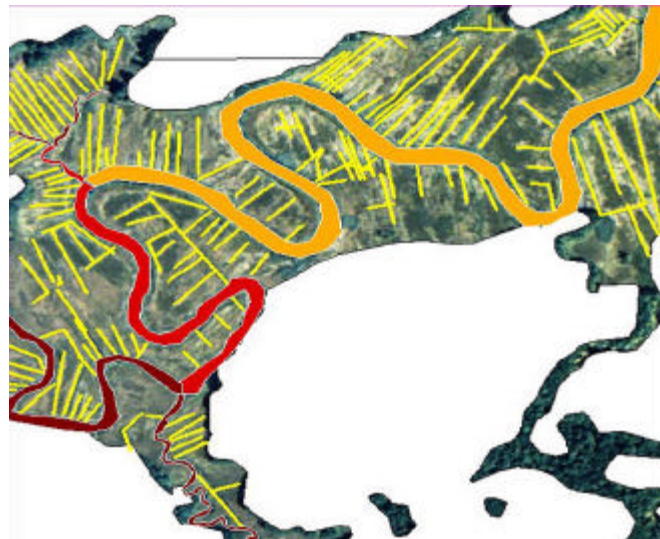


Figure 9. An example of one of the 1 sq km grids analyzed for geomorphic characteristics along the Plum Island Sound marshes.

be most useful in 1) mapping drainage networks, 2) mapping plant community composition and distribution and 3) illustrating change over time.

An undergraduate student in the MBL Semester in Environmental Science, Jennifer Franklin, conducted her semester research project on geomorphic characteristics of the Plum Island marshes (Franklin 2002). She analyzed the distribution of creeks and ponds in marshes along the entire salinity gradient of the estuary. In each of three regions (fresh, brackish and marine), she documented the length and drainage density of 1st, 2nd, 3rd, and 4th order streams as well as mosquito ditches (Fig 9). She also quantified total edge and the

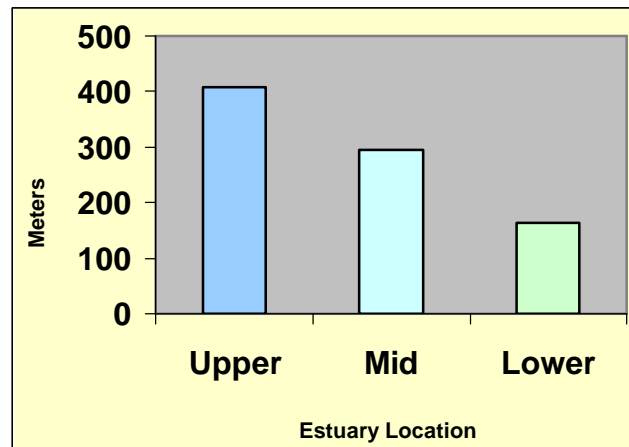


Figure 10. Drainage density (m per hectare) along the Plum Island Sound marshes.

relative extent of marsh, water and ponds along this gradient. Franklin observed some very striking gradients along the length of the estuary, which may correlate with marsh success in keeping up with sea level rise. The low salinity, upper estuary marshes had the greatest extent of marsh (85%), the greatest drainage density (Fig 10), the greatest length of mosquito ditches (347 m ha⁻¹) and the least areal extent of ponding (0.02%). In contrast, the saline marshes, closest to the ocean, had the least extent of marsh (11%), the lowest drainage density, the least length of mosquito ditches (105 m ha⁻¹) and the greatest extent of ponding (6%). Whereas drainage creek divides were marked by high marsh in the low salinity marshes, they were frequently marked with broad expanses of marsh depressions and ponds in the saline marshes. We would conclude from this preliminary survey of geomorphic characteristics that the upper estuary marshes, which are close to their sediment supply (the Parker River) are maintaining their elevation relative to sealevel while the high salinity marshes, which are the most removed from sediment supply are not keeping up with sealevel rise.

Geomorphic indicator research at the North Inlet, SC estuarine marsh is focused on assessment and trend analyses of 1-D, 2-D, and 3-D topographic data from the intertidal zone, and intertidal channel network pattern. Karyn Novakowski (graduate student with R. Torres) digitized ~7000 intertidal channel networks and quantified their main channel length (L) and contributing area (A). Her analyses show that L and A are related by a power function, and that most intertidal channel L-A data plot within the range of terrestrial channel network values (Figure X). Hence, tidal channel networks with bi directional flow and cohesive sediment are similar to terrestrial channel networks with unidirectional flow and noncohesive sediment. These observations indicate that channel evolution and channel optimization theories developed for terrestrial systems may apply to intertidal systems. We are currently exploring this inference.

Although intertidal marsh landscapes seem flat and featureless they have very subtle topographic variations that dictate the spatial variability of hydroperiod, and direction and magnitude of sheetflow during tidal inundation. The status and stability of this subtle topography may be used as an indicator of estuarine health and stability.

Juana Montane (graduate student with R. Torres) is creating the first ever, high density, high resolution, high accuracy digital

elevation model (DEM) for an entire, pristine intertidal marsh island using RTK GPS. The South Carolina Geodetic Survey is a collaborative partner in this effort. Together we installed 2 class A (National Geodetic Survey standards) bench marks on Merry Island. Their lateral positions are known to within 5 mm, and their vertical positions are known to within 10 mm of the geoid. To date we have 9000 of an estimated 13000 xyz coordinates needed to fully characterize the island surface; density of points is $\sim 5\text{m}^2$ on the marsh island platform and $\sim 1\text{m}$ in and around the channels (Figure Y). These data will serve as ground truth for a LiDAR mission planned through the newly formed, NSF sponsored National Center for Airborne LiDAR Mapping (NCALM). Our DEM shows that marsh platform has ~ 80 cm of vertical relief and channels have 200 cm (Figure Y). When the DEM is completed we will perform spatial analyses of hydroperiod, and hypsometric integrals. We hypothesize that these topographic indices, combined with tidal prism estimates, can be used as indicators of estuarine stability.

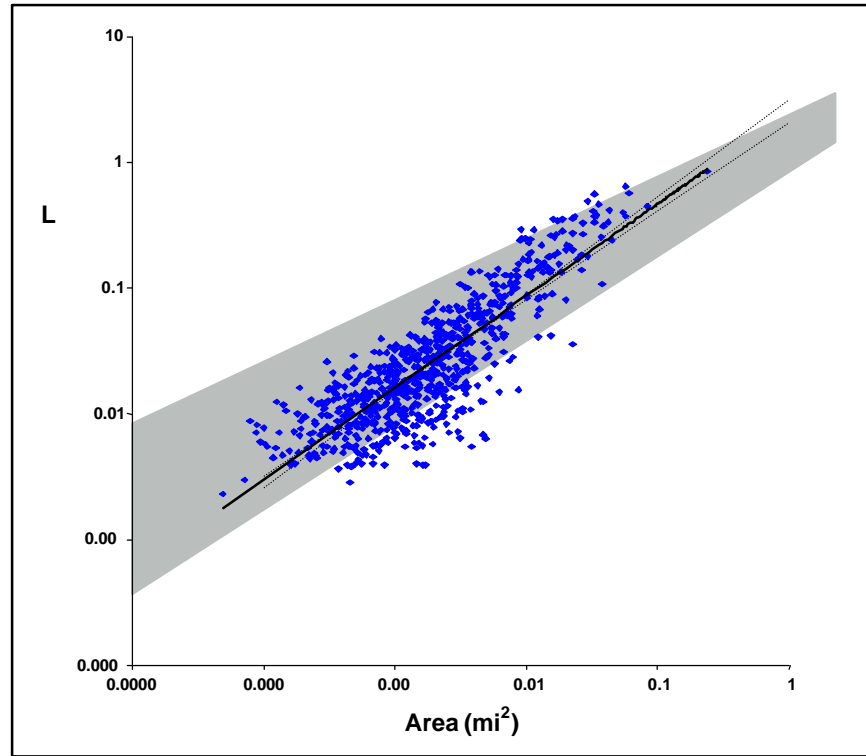
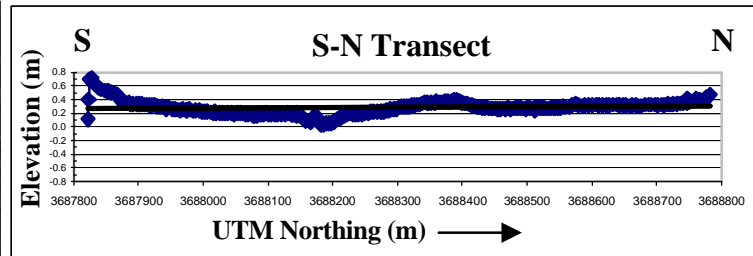


Figure X. Log-log plot of main channel length and watershed area for creek networks in North Inlet, SC. The trendline through the marsh data gives a value of $L=2.53 \pm 1.11A^{0.733 \pm 0.02}$ with an R^2 value of 0.75. The 95% confidence intervals are shown as dashed black lines.



Figure Y. Post map showing position and track of RTK GPS topographic survey. Each dot represents a single x,y,z coordinate for the marsh surface. S-N elevation transect location indicated on post map.



Training and Development:

An undergraduate student in the MBL Semester in Environmental Science, Jennifer Franklin, conducted her semester research project on geomorphic characteristics of the Plum Island marshes (Franklin 2002). The project currently supports two graduate students. The North Inlet project supports two female PhD candidates, one Hispanic and one Caucasian. A workshop is planned for the spring 2003 ACE Inc meeting to be held in Charleston, SC.

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. Karyn Novakowski (R. Torres grad student) presented her findings to the "Friends of the Baruch Institute" in Feb., 2003.

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. There is a

paucity of detailed topographic information from intertidal marshes. This results from a lack of studies designed to investigate interactions between process and form in intertidal environment. Our efforts will help fill the gap in our understanding of the evolution and stability of intertidal landscapes.

Future Activities:

Continue to explore the use of pigment and geomorphic indicators to a broader suite of conditions and systems. Collaborations are underway with EaGLE GOM-CEER and ASC scientists to compare and expand indicators being evaluated in this project. Future activities will emphasize these collaborations in the context of the EaGLE and other (e.g. NSF-LTER) research efforts aimed at long-term, cross-ecosystem indices of coastal wetland condition and change. Our future activities are focused on investigating the development of optimal channel patterns and form that facilitate water and nutrient exchange between subtidal and intertidal environments.

Presentations:

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. 2001. Overview of Coastal Wetland Indicators. EaGLE 1st Annual Meeting, 3-5 December 2001, Morehead City, NC

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

Marshall, H.L. and J. Morris. 2003. Xanthophyll pigments and their application to remote sensing of environmental quality. Abstract of presentation to be given at the winter meeting of the American Society of Limnology and Oceanography, February, 2003, Salt Lake City.

Morris, J.T. 2003. Effects of rising sea level on coastal wetlands. Seminar given at the College of Charleston, Feb. 24.

Neet, M., D. Porter, J. Morris, P. Noble. 2003. Using multi-spectral imagery, LIDAR, and neural nets to predict chlorophyll and habitat changes in the estuarine habitat of North Inlet, South Carolina.. Coastal GeoTools Conference, Charleston, SC.

Publications:

Jensen, J.R., G. Olsen, S. R. Schill, D. E. Porter, J. Morris. 2002. Remote sensing of biomass, leaf-area-index and chlorophyll a and b content in the ACE Basin and National Estuarine Research Reserve using sub-meter digital camera imagery. *Geocarto International* 17:1-10.

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.

Mwamba, M.J., Torres, R. 2002. Rainfall Effects on Marsh Sediment Redistribution, North Inlet, SC, *Marine Geology* 189, 267.

Torres, R., M.J. Mwamba, M.A. Goni, Properties of Marsh Sediment Mobilized by Low Tide Rainfall, in press, *Limnology and Oceanography*

Abstracts of talks given at National Meetings:

Mwamba, M.J., R. Torres, Fluxes and Properties of Rainfall-mobilized Intertidal Sediment, *EOS Transactions AGU* 83(47) F789, 2002

Novakowski, K.I., R. Torres, Geomorphic Analysis of Marsh Creek Networks, *EOS Transactions AGU* 83(47) F788, 2002

Marshall, H.L. and J. Morris. 2003. Xanthophyll pigments and their application to remote sensing of environmental quality. Abstract of presentation to be made at the winter meeting of the American Society of Limnology and Oceanography, February, 2003, Salt Lake City..

Morris, J.T., G. Herrick, J. Herr, D., Porter, P. Noble, J. Jensen. 2003. Determinants of the spectral reflectance of the marsh grass *Spartina alterniflora* and a neural network classification of a coastal landscape. Abstract of invited talk given at a special EAGLES session at the AAG meeting, March, New Orleans, March 5.

Morris, J.T., G. Herrick, and J. Herr. 2002. Nutritional status and spectral reflectance of *Spartina alterniflora*. Abstract of talk given at the annual meeting of the American Society of Limnology and Oceanography, June 10-15, Victoria, B.C.

Morris, J.T. Indicators of coastal wetland responses to rising sea level. Abstract of invited talk given at the Society for Conservation Biology 17th Annual Meeting, Duluth, MN. 28 June-2 July 2003.

Seminars:

Morris, J.T. 2002. Responses of coastal wetlands to changes in sea level. Talk given Oct. 30, Florida State University, Tallahassee; Oct. 25, Duke University; Oct. 4, University of Florida, Gainesville.

Reports:

Franklin, J. 2002. Salt marshes and sealevel rise: sediment dispersal in the Plum Island Sound marsh ecosystem. Final Semester Research Project report, 41 p.

Products:

Databases:

All research results are posted on an annual basis on the Plum Island Ecosystems LTER database (<http://ecosystems.mbl.edu/PIE>). Each data file is fully documented in separate metadata files.

Related Website:

A specific website for the Coastal Indicators project is under development.

Supplemental Keywords:

coastal wetlands, marsh habitat, higher aquatic plants, photopigments, geomorphology, tidal ecosystems, regional indicators, LIDAR, nutrient status, physiology, sea level rise, neural network analysis, wetland management