Annual Report for Period: 12/2007 - 11/2008
Submitted on: 10/10/2008
Principal Investigator: McGlathery, Karen .
Award ID: 0621014
Organization: University of Virginia
Submitted By:
Porter, John - Co-Principal Investigator
Title:
Long-Term Drivers, State Change and Disturbance on the Virginia Coast Reserve: LTER V

Project Participants

Senior Personnel

Name: McGlathery, Karen
Worked for more than 160 Hours: Yes
Contribution to Project:
Lead PI; research focuses on lagoon biogeochemistry and metabolism, seagrass restoration, and changes in marsh coverage in response to climate change (sea-level rise, storms)

Name: Wiberg, Patricia
Worked for more than 160 Hours: Yes
Contribution to Project:
Signatory PI; research focuses on lagoon hydrodynamics, sediment suspension and transport, and changes in marsh coverage in response to climate change (sea-level rise, storms)

Name: Porter, John
Worked for more than 160 Hours: Yes
Contribution to Project:
Signatory PI and Information Manager, research focuses on mammal population dynamics on barrier islands and GIS analysis.

Name: Anderson, Iris
Worked for more than 160 Hours: Yes
Contribution to Project:
Co-PI, Subcontract to Virginia Institute of Marine Sciences; research focuses on lagoon biogeochemistry and metabolism

Name: Bachmann, Charles
Worked for more than 160 Hours: No
Contribution to Project:
Co-PI, Naval Research Laboratory; research focuses on hyperspectral remote sensing of mainland, barrier island, marsh and lagoon systems

Name: Berg, Peter
Worked for more than 160 Hours: No
Contribution to Project:
Co-PI, University of Virginia; research focuses on application of novel eddy correlation technique to subtidal systems to investigate benthic metabolism and groundwater fluxes

Name: Blum, Linda
Worked for more than 160 Hours: No
Contribution to Project:
Co-PI, University of Virginia; research focuses on the effects of sea-level rise on marsh accretion, and bacterial community structure and intertidal and subtidal systems

Name: Brinson, Mark
Worked for more than 160 Hours: Yes
Contribution to Project:
Co-PI - Subcontract to East Carolina University; research focuses on state change in marsh ecosystems in response to sea-level rise

and disturbance

Name: Christian, Robert

Worked for more than 160 Hours: Yes

Contribution to Project:

Co-PI - Subcontract to East Carolina University; research focuses on state change in marsh ecosystems in response to sea-level rise and disturbance

Name: D'Odorico, Paolo

Worked for more than 160 Hours: No

Contribution to Project:

Co-PI, University of Virginia; research focuses on modeling of alternate stable states in coastal lagoons

Name: Day, Frank

Worked for more than 160 Hours: Yes

Contribution to Project:

Co-PI, Subcontract to Old Dominion University; research focuses on plant community dynamics on barrier islands

Name: Dueser, Raymond

Worked for more than 160 Hours: Yes

Contribution to Project:

Co-PI, Subcontract to Utah State University; research focuses on small mammal genetics, population dynamics and predator-prey interactions on barrier islands

Name: Erwin, Russell

Worked for more than 160 Hours: No

Contribution to Project:

Co-PI, University of Virginia and U.S. Geological Survey, Biological Resources Division; research focuses on population dynamics of waterbirds

Name: Fagherazzi, Sergio

Worked for more than 160 Hours: Yes

Contribution to Project:

Co-PI, Subcontract to Boston University; research focuses on model lagoon hydrodynamics, coastal geomorphology, and marsh accretion/erosion in response to climate change (sea-level rise, storms)

Name: Fuentes, Jose

Worked for more than 160 Hours: No

Contribution to Project:

Co-PI, University of Virginia; research focuses on land-atmosphere carbon dioxide fluxes in marshes using tower-based eddy covariance technique

Name: Galloway, James

Worked for more than 160 Hours: No

Contribution to Project:

Co-PI, University of Virginia; research focuses on atmospheric nitrogen deposition, and nitrogen cycling between land, water, and atmosphere

Name: Macko, Stephen

Worked for more than 160 Hours: No

Contribution to Project:

Co-PI, University of Virginia; research focuses on using isotope geochemistry to understand trophic dynamics in subtidal systems, specifically in relation to state change to seagrass system. On leave working at NSF 2008-2009.

Name: Mills, Aaron

Worked for more than 160 Hours: No

Contribution to Project:

Co-PI, University of Virginia; research focuses on groundwater hydrology and nutrient fluxes via tidal streams into lagoons, in particular on importance of denitrification in the riparian zone and stream sediments

Name: Moncrief, Nancy

Worked for more than 160 Hours: No

Contribution to Project:

Co-PI, Virginia Museum of Natural History, collaborates with Co-PI Dueser; research focuses on small mammal genetics, population dynamics and predator-prey interactions on barrier islands

Name: Oertel, George

Worked for more than 160 Hours: Yes

Contribution to Project:

Co-PI, Subcontract to Old Dominion University; coastal oceanographer whose research focuses on reconstructing antecedent landscape of the VCR, hypsometry, and water residence times of lagoons

Name: Reyes, Enrique

Worked for more than 160 Hours: Yes

Contribution to Project:

Co-PI, Subcontract to East Carolina University; research involves creating a landscape model of state change for the VCR marsh-lagoon-barrier island system in response to climate and land-use change

Name: Scanlon, Todd

Worked for more than 160 Hours: No

Contribution to Project:

Co-PI, University of Virginia; uses eddy covariance and laser techniques to study nitrous oxide and carbon dioxide fluxes from at the marsh-upland interface

Name: Shugart, Herman

Worked for more than 160 Hours: No

Contribution to Project:

Co-PI, University of Virginia; terrestrial ecosystem modeling of the barrier islands

Name: Smith, David

Worked for more than 160 Hours: No

Contribution to Project:

Co-PI, University of Virginia; leads SLTER program with Arthur Schwarzschild, research focuses on invertebrate and fish communities in the coastal lagoons

Name: Young, Donald

Worked for more than 160 Hours: Yes

Contribution to Project:

Co-PI, Subcontract to Virginia Commonwealth University; research focuses on plan community dynamics on barrier islands, specifically on shrub expansion, invasive species and birds as agents of seed dispersal among islands

Name: Zieman, Joseph

Worked for more than 160 Hours: No

Contribution to Project:

Co-PI, University of Virginia; research focuses on salt marsh chronosequence on barrier island and on nitrogen dynamics in salt marshes

Name: Schwarzschild, Arthur

Worked for more than 160 Hours: Yes

Contribution to Project:

Research Site Manager, Co-PI, University of Virginia; leads SLTER program with David Smith

Name: Long, Bridget

Worked for more than 160 Hours: Yes

Contribution to Project:
2007-2008 worked with PI's Blum, Christian and Brinson on marsh productivity database.

Post-doc

Graduate Student

Name: Battistelli, Joseph

Worked for more than 160 Hours: Yes

Contribution to Project:
Ph.D student (2004-2009). Advisor: Mills; working on the effects of physical arrangement of nitrifiers in spaces at the scale of the organism on nitrificaiton rates.

Name: Bissett, Spencer

Worked for more than 160 Hours: Yes

Contribution to Project:
MS & Ph.D Student (2005-2009). MS thesis (2005-2009): Avian dispersal of Frankia for successful nodulation of Myrica seedlings. Ph.D student (2009-2014); Working with PI Young, focusing on the physiological ecology of Myrica shrub expansion in coastal environments.

Name: Blecha, Staci

Worked for more than 160 Hours: Yes

Contribution to Project:
M.S. Student. (2006-2009) Advisor: Day; working on inter-island variability of interior-island marsh vegetation biomass (above and belowground) .

Name: Brantley, Steven

Worked for more than 160 Hours: Yes

Contribution to Project:
Ph.D student (2005-2009). Advisor: Young. working on spatial variation in carbon and nitrogen sequestration in Myrica thickets across the barrier island landscape.

Name: Cole, Luke

Worked for more than 160 Hours: Yes

Contribution to Project:
Ph.D. Student (2005-2010), Advisor: McGlathery; working on the effects of seagrass restoration on nitrogen cycling and retention in coastal lagoons

Name: Conroy, Patrick

Worked for more than 160 Hours: Yes

Contribution to Project:
M.S. Student (2005-2007), Advisor: D. Smith; worked on the effects of macrophytes on invetebrate density and diversity in coastal lagoons

Name: Fennell, Jeremy

Worked for more than 160 Hours: Yes

Contribution to Project:
M.S. Student (2005-2007). Advisor: Young; Thesis: Phragmites australis patch characteristics in relation to watershed landcover patterns on the Eastern Shore of Virginia

Name: Flewelling, Samuel

Worked for more than 160 Hours: Yes

Contribution to Project:
Ph.D student (2003-2008), Advisor: Mills; Dissertation: The hydrological control of nitrate fluxes from groundwater to streams on the Eastern Shore of Virginia.

Name: Harbeson, Stephanie

Worked for more than 160 Hours: Yes

Contribution to Project:

Ph.D Student (2003-2008). Advisor: Macko; working on source differentiation of individual dietary components to consumers in South Bay, VA restored Seagrass Habitats using stable isotopes.

Name: Hardison, Amber

Worked for more than 160 Hours: Yes

Contribution to Project:

Ph.D. Student (2004-2009). Advisor: Anderson; working on the influence of macroalgal blooms on biogeochemical processes in coastal lagoons using a dual isotope tracer and biomarker approach

Name: Haywood, John

Worked for more than 160 Hours: Yes

Contribution to Project:

MS Student; (2007-2009) working with Mark Brinson on effects of disturbance and stressors on ecological state change in tidal marshes at the VCR.

Name: Hume, Andrew

Worked for more than 160 Hours: Yes

Contribution to Project:

M.S. student (2004-2007). Advisors: Berg & McGlathery; Thesis: Dissolved oxygen fluxes and ecosystem metabolism in an eelgrass (Zostera marina) meadow measured with the novel eddy correlation technique

Name: Kathilankal, James

Worked for more than 160 Hours: Yes

Contribution to Project:

Ph.D student (2004-2008). Advisor: Fuentes. Dissertation: Carbon and Energy Flow Dynamics in a Coastal Salt Marsh.

Name: Koopmans, Dirk

Worked for more than 160 Hours: Yes

Contribution to Project:

Ph.D student (2006-2011). Advisor: Berg; working on using the eddy correlation technique to measure groundwater fluxes into coastal waters

Name: Kunz, David

Worked for more than 160 Hours: Yes

Contribution to Project:

M.S. student (2006-2008). Advisor:Brinson. Examining shorezone concept with respect to rising sea level. Includes comparisons of NC and Virginia.

Name: Lawson, Sarah

Worked for more than 160 Hours: Yes

Contribution to Project:

Ph.D student (2002-2008), Advisor: McGlathery & Wiberg; Dissertation: Physical and biological controls on sediment and nutrient fluxes in a temperate lagoon

Name: Marsh, Amanda

Worked for more than 160 Hours: Yes

Contribution to Project:

M. S. Student (2005 û 2007), Advisor: Christian. Thesis: Effects on a salt marsh ecosystem following a brown marsh event

Name: McMillan, Brett

Worked for more than 160 Hours: Yes

Contribution to Project:

Ph.D student (2003-2008), Advisor: Day. Dissertation: Plant assemblage structure on 'pimple' dunes at the Virginia Coast Reserve

Long-Term Ecological Research site.

Name: Michaels, Rachel

Worked for more than 160 Hours: Yes

Contribution to Project:

Ph.D student (2003-2009). Advisor: Zieman; working on the effects of Uca pugnax on pore water biogeochemistry and salt marsh productivity and stability in the context of sea-level rise

Name: Mozdzer, Thomas

Worked for more than 160 Hours: Yes

Contribution to Project:

Ph.D student (2004-2009), Advisors: Zieman & McGlathery; working on dissolved organic nitrogen uptake in native and invasive intertidal marsh plants

Name: Naumann, Julie

Worked for more than 160 Hours: Yes

Contribution to Project:

Ph.D student (2002-2007). Advisor: Young. Dissertation: Linking physiological responses, chlorophyll fluorescence and hyperspectral imagery to detect environmental stress in coastal plants.

Name: O'Connell, Michael

Worked for more than 160 Hours: Yes

Contribution to Project:

Ph.D. student (2003-2008), Advisor: Shugart; working on using remote sensing to determine vulnerability to change in barrier island upland ecosystems

Name: Poleto, Juliette

Worked for more than 160 Hours: Yes

Contribution to Project:

M.S. student (2007-2009). Advisor: Anderson; working on net ecosystem metabolism in coastal lagoons that differ with respect to nutrient loading

Name: Reynolds, Laura

Worked for more than 160 Hours: Yes

Contribution to Project:

Ph.D. student (2006-2011). Advisors: McGlathery & Zieman; working on genetic basis of seagrass restoration success in coastal lagoons

Name: Robertson, Travis

Worked for more than 160 Hours: Yes

Contribution to Project:

M.S. Student (2006-2008). Advisors: Blum, McGlathery & Wiberg; working on effects of seagrass restoration on bacterial community structure

Name: Sahu, Parameswar

Worked for more than 160 Hours: Yes

Contribution to Project:

Ph.D student (2005-2007). Advisor: Scanlon; worked on nitrous oxide fluxes from marsh-upland ecosystems

Name: Vick, Jackie

Worked for more than 160 Hours: Yes

Contribution to Project:

M.S. student (2005-2007). Advisor: Young. Thesis: Corticular photosynthetic dynamics for a coastal evergreen shrub: Myrica cerifera.

Name: Voss, Christine

Worked for more than 160 Hours: No

Contribution to Project:
M.S. student (2005-2007). Advisor: Christian; worked on network analysis of nitrogen cycling in coastal lagoons

Name: Weinmann, Richard

Worked for more than 160 Hours: Yes

Contribution to Project:
Ph.D student (2003-2008). Advisor: Shugart; worked on water budgets of coastal watersheds.

Name: Shafer, Justin

Worked for more than 160 Hours: Yes

Contribution to Project:
M.S. student (2006-2009). Advisor: Day; working on on interisland variability of dune vegetation biomass (above and belowground) on the barrier islands

Name: Shiflett, Sheri

Worked for more than 160 Hours: Yes

Contribution to Project:
M.S. student (2006-2008). Advisor: Young. Thesis: Avian seed dispersal on Virginia barrier islands: potential influence on vegetation community structure and patch dynamics.

Name: Mcleod, George

Worked for more than 160 Hours: No

Contribution to Project:
M.S. student (2006-2009) Advisor: Oertel; working on data interpolation for DEM's and comparing lagoon hypsometry and repletion in Hog Island Bay, Chincoteague Bay and Magothy Bay

Name: Gomez, Loreto

Worked for more than 160 Hours: No

Contribution to Project:
M. S. student (2006-2008) Advisor: Oertel; working on repletion and hydrohypsography of the Gargathy lagoons system.

Name: Clarkson, Charles

Worked for more than 160 Hours: Yes

Contribution to Project:
Ph.D Student (2007-2012). Advisor: Erwin; working on waterbird population dynamics

Name: Priestas, Anthony

Worked for more than 160 Hours: Yes

Contribution to Project:
Ph.D. student (2007-2011), Advisor: Fagherazzi; working on marsh erosion and modeling feedbacks with vegetation

Name: Harrington, Christine

Worked for more than 160 Hours: No

Contribution to Project:
M.S. student (2007-2009), Advisor: Fagherazzi; working on field measurements of marsh erosion

Name: Mariotti, Giulio

Worked for more than 160 Hours: No

Contribution to Project:
Ph.D. student (2008-2012), Advisor: Fagherazzi; modeling tide and wave dynamics in the coastal lagoons

Name: McLoughlin, Sean

Worked for more than 160 Hours: Yes

Contribution to Project:
M.S. Student (2008-2010). Advisors:Wiberg/McGlathery; working on measuring plant feedbacks controlling marsh erosion

Name: Gulbransen, Dana

Worked for more than 160 Hours: Yes

Contribution to Project:

PhD student (2008-2013). Advisor: McGlathery; working on effects of invasive macroalga, Gracilaria vermiculophylla, in subtidal seagrass and intertidal marsh ecosystems

Name: Romanowich, Jennifer

Worked for more than 160 Hours: Yes

Contribution to Project:

PhD Student (2007-2012). Advisor: Reidenbach; working on hydrodynamics in seagrass beds and effects on sediment suspension

Name: Funk, Clara

Worked for more than 160 Hours: Yes

Contribution to Project:

M.S. Student (2008-2010). Advisor: Scanlon; working on nitrous oxide fluxes from marsh-upland interface to atmosphere

Name: Webster, Kirby

Worked for more than 160 Hours: Yes

Contribution to Project:

PhD student (2007-2012). Advisors: Berg & McGlathery; working on measuring benthic metabolism in lagoons using eddy correlation system, with specific focus on state change from benthic algal to seagrass dominance

Name: Robertson, Wendy

Worked for more than 160 Hours: Yes

Contribution to Project:

M.S. student (2006-2008). Advisors: Mills & UVA colleague Janet Herman; working on groundwater fluxes through tidal streams to coastal lagoons

Name: Probasco, Paul

Worked for more than 160 Hours: Yes

Contribution to Project:

PhD student (2006-2012). Advisors: Herman & Mills; working on dentrification in riparian zones and stream beds in coastal watersheds

Name: Serebryakova, Alexandra

Worked for more than 160 Hours: Yes

Contribution to Project:

Ph.D student (2007-2008). Advisor: R. Christian; working in Coastal Resource Management at ECU on a long-term data set of vegetation cover in a salt marshes to use in GIS analysis.

Name: Rafferty, Emmett

Worked for more than 160 Hours: Yes

Contribution to Project:

M.S. student (2007-2009); working with G. Oertel on modeling field-generated depth data to create a DEM of Magothy Bay.

Undergraduate Student

Name: Curtis, Ben

Worked for more than 160 Hours: No

Contribution to Project:

2007 worked with PI Zieman and graduate student Thomas Mozdzer on nitrogen cycling in salt marsh communities.

Name: Hippert, Rachel

Worked for more than 160 Hours: Yes

Contribution to Project:

2007 worked with PI McGlathery on seagrass restoration.

Technician, Programmer

Name: Overman, Kathleen
Worked for more than 160 Hours: Yes
Contribution to Project:
Technician, Laboratory Manager, assists with long-term monitoring

Name: Boyd, David
Worked for more than 160 Hours: Yes
Contribution to Project:
Technician, responsible for boat logistics and assists with long-term monitoring

Name: Buck, Christopher
Worked for more than 160 Hours: Yes
Contribution to Project:
Technician, assists with long-term monitoring

Name: Fauber, Donna
Worked for more than 160 Hours: Yes
Contribution to Project:
Fiscal Technician

Other Participant

Research Experience for Undergraduates

Name: Richards, Joshua
Worked for more than 160 Hours: Yes
Contribution to Project:
Worked with graduate student Andrew Hume and PIs Berg and McGlathery on benthic metabolism in lagoons during 2007.

Years of schooling completed: Sophomore
Home Institution: Same as Research Site
Home Institution if Other:
Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree
Fiscal year(s) REU Participant supported: 2007
REU Funding: REU supplement

Name: Smith, Chris
Worked for more than 160 Hours: Yes
Contribution to Project:
2007 Worked with Iris Anderson on lagoon nitrogen studies.

Years of schooling completed: Junior
Home Institution: Same as Research Site
Home Institution if Other: Virginia Institute of Marine Sciences/ William & Mary
Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree
Fiscal year(s) REU Participant supported: 2007
REU Funding: REU supplement

Name: Hondula, Kelly
Worked for more than 160 Hours: Yes
Contribution to Project:

2008 worked with PI McGlathery and graduate student Laura Reynolds on seagrass demographics

Years of schooling completed: Junior
Home Institution: Same as Research Site
Home Institution if Other:
Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree
Fiscal year(s) REU Participant supported: 2008
REU Funding: REU supplement

Name: Barry, Savannah
Worked for more than 160 Hours: Yes
Contribution to Project:
2008 REU worked with PI Reidenbach and graduate student Jenny Romanowich on clam filtration and seagrass studies

Years of schooling completed: Sophomore
Home Institution: Same as Research Site
Home Institution if Other:
Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree
Fiscal year(s) REU Participant supported: 2008
REU Funding: REU supplement

Name: Pendergrass, Jessica
Worked for more than 160 Hours: Yes
Contribution to Project:
2008 REU, worked with PIs Christian & Blum on genetics of salt marsh cordgrass, Spartina alerniflora

Years of schooling completed: Junior
Home Institution: Other than Research Site
Home Institution if Other: East Carolina University
Home Institution Highest Degree Granted(in fields supported by NSF): Master's Degree
Fiscal year(s) REU Participant supported: 2008
REU Funding: REU supplement

Organizational Partners

USGS Biological Resources Division
Co-PI R. Michael Erwin is supported by USGS/BRD.

Department of Navy Naval Research Laboratory
Co-PI Charles Bachmann is supported by, and works at, NRL.

The Nature Conservancy
The Virginia Coast Reserve of the Virginia Chapter of The Nature Conservancy provides access to study sites and field research facilities. They are frequent collaborators on research projects.

NOAA National Environmental Satellite Data Information Service
NOAA installed an operates a Climate Reference Network station at our laboratory in Oyster, VA. The resulting data provides a valuable adjunct to LTER meteorological data.

Coastal Zone Management - Virginia
In 2007 a monthly public seminar series on environmental issues and research activities at the VCR-LTER was established with support by the Coastal Zone Management and Seaside Heritage Program of the Commonwealth of Virginia.

Virginia Museum of Natural History
Collaboration on GIS databases of predator locations involving PI's Dueser (USU), Moncrief (VMNH) and Porter (UVA)

Other Collaborators or Contacts

Dr. Robert Orth of the Virginia Institute of Marine Sciences has collaborated with us extensively on the seeding of seagrass beds at our research sites.

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)
See attached PDF file

Findings: (See PDF version submitted by PI at the end of the report)
See attached PDF file

Training and Development:
We have engaged in training at all levels of education. At the graduate level we have a large number of students who participate in the research conducted at the VCR/LTER. A smaller number of undergraduate student REUs participate in research, while a larger number of undergraduates experience the LTER site through class field trips. In the K-12 area we are engaged in taking hands on science into the classroom in the area of field measurements using state-of-the-art equipment. This involves classroom teaching on the part of VCR scientists, field demonstrations and WWW-based communications.

Graduate Training

During 2006-2008, the VCR/LTER project helped support research activities by forty-three graduate students at six universities. Since Nov. 2006, seven masters and three Ph.D students have completed their graduate degrees.

Undergraduate Training

Two REU students were supported in 2007: Chris Smith worked with Iris Anderson on nitrogen processing in the lagoon system and Josh Richards worked with graduate student Andrew Hume and PI Peter Berg. Additional undergraduate research assistance (either volunteers or supported by VCR/LTER core funds) were: Ben Curtis worked with PI Zieman on a project related to the spread of Phragmites and Rachel Hippert worked with PI McGlathery on seagrass and lagoon studies. Bridget Long, a University of Virginia, Department of Environmental Sciences undergraduate student, was supported by the core VCR LTER grant to work with Blum and Christian on the project's marsh grass productivity monitoring database. Bridget completed processing of summer 2006 samples and was instrumental in facilitating sample collection during August 2007.

We supported 3 REU students during the 2008 field season:
-- Kelly Hondula (UVA) worked with Karen McGlathery and her Ph.D. student Laura Reynolds to study the expansion of restored seagrass meadows by clonal growth. Kelly also worked on all aspects of the synoptic survey of the seagrass restoration sites in July. She continues to work with Karen McGlathery and Laura Reynolds on a Distinguished Majors thesis in the Environmental Sciences Department at UVA. She will defend her thesis in April. Her plans are to attend graduate school in Fall 2009.
-- Savannah Berry (UVA) worked with Matt Reidenbach and his Ph.D. Jennifer Romanowich to understand how restored seagrass meadows are affecting boundary-layer flow dynamics and how this impacts the deposition and erosion of sediments within this barrier island lagoon. Savannah has now enrolled in the Department of Environmental Sciences Mentor Program to work with Ph.D. student Luke Cole and Karen McGlathery on nitrogen dynamics in the restored seagrass meadows.
-- Jessica Pendergrass (ECU) worked with Bob Christian and Linda Blum to determine if the genetic makeup of the tall and short forms of the salt marsh cordgrass, S. alterniflora, in the VCR are genetically distinct.

In addition, we supported an undergraduate from UVA (Rachel Baker) to help with the fieldwork and processing of samples for the synoptic

survey of the seagrass restoration sites. Rachel worked one month over the summer 2008, and continues to work on the samples in Karen McGlathery's lab during the 2008-2009 academic year.

Schoolyard LTER

During the 2007, the VCR-LTER program continued to support science education on the Virginia Eastern Shore through continued support of water quality monitoring projects and assistance in the development of a new Ecology class at Northampton High School. Science staff from field station presented guest lectures on a variety of environmental topics to Earth Science, Ecology, Environment Science and Marine Biology classes at Northampton High School.

In July 2007 a 10-day, teacher training and curriculum development workshop for the High School science faculty of both Northampton and Accomack Counties was conducted by VCR/LTER researchers at the new Anhueser Busch Coastal Research Center. VCR-LTER researchers presented lectures, led field trips, and moderated discussion groups. The participating high-school teachers developed new lectures and classroom activities based on the topics covered in the lectures and targeted towards specific 'Standards Of Learning' (SOL) objectives.

During 2007 a new Research Experience for High School Students (REHS) program modeled on the REU program was initiated, pairing 4 highly motivated and qualified high school students with graduate students conducting field research at the VCR/LTER. The students presented the results of their research projects to high school science classes, civic organizations and at the annual VCR-LTER All Scientist Meeting in January 2008.

During 2008, the VCR SLTER program has continued its commitment to enhancing scientific education and understanding in grade-school education in the local county. As in the past few years our efforts have been focused mainly at the high school level. We have maintained support of the Environmental Science II class at Northampton High School, originally developed through a partnership between the High School science teachers and staff of the VCR-LTER program. This class provides instruction in water quality analysis, with an emphasis on the impacts of land use changes on local watersheds.

We have also partnered with the faculty to assist in the development of a new Ecology Class being added to the science curriculum at Northampton High School.

During the summer of 2008 we continued the successful REHS program initiated in 2007 by recruiting and hiring 2 highly qualified and motivated high school students to work with our ongoing seagrass restoration experiment. These high school interns participated in all aspects of field research this summer, from field sampling, sorting and processing plant and sediment samples in the lab, conducting chemical analysis, assisting in data entry, and generating preliminary data summaries.

We also expanded our education activities through participation in the Coastal Ocean Science Education Excellence (COSEE) program through a partnership with the University of Maryland's Horn Point Laboratory. Through this program, a high school science teacher and minority undergraduate student from Hampton University were recruited to spend the summer at the ABCRC where they participated in our seagrass restoration program. Along with assisting in all aspects of the summer field campaign, these COSEE participants, along with a graduate student (Laura Reynolds) from the UVA Department of Environmental Sciences and under the guidance of UVA Faculty (Karen McGlathery, Arthur Schwarzschild), developed new curriculum materials for teaching seagrass ecology.

Outreach Activities:

ABCRC Public Seminar Series: 2007-2008 season

A monthly public seminar series was initiated at the Anheuser-Busch Coastal Research Center (field laboratory for the VCR/LTER)in September of 2007. Working with the high school science teachers, we have encouraged local students to attend the seminars and then present summaries of the topics discussed to their classes. The schedule included:
September 20 - Art Schwarzschild, UVA ABCRC - Intro to the VCR-LTER program
October 18 - Art Schwarzschild, UVA ABCRC - Seagrass Ecology
November 15 - John Porter, UVA VCRLTER - Barrier Island History
December 20 - Laura McKay, DEQ/CZM/SHP - Intro to the Seaside Heritage Program
February 21 - Alex Wilke, TNC-VCR - Oyster Catcher Ecology
March 20 - Ruth Boettcher, DGIF - Sea Turtles
April 17 - Joe Scalf, TNCVCR - Habitat restoration migratory

songbirds
May 15th - Dot Field, DCR - Natural Heritage Program Eastern Shore
June 19 - Linda Blum, UVA - Salt marshes and sea level rise
July 17 - Jim Wesson, VMRC - Oyster restoration
August 21 - Bob Orth, VIMS - Seagrass restoration

Information Management

We continue to fully participate in LTER Network activities, such as Ecotrends. All metadata is available as high-quality Ecological Metadata that is available from the LTERNET Metacat server. Our web server has provided over 3.6 Terabytes of information and responded positively to formal 253 data requests (See the 'Contributions to Resources for Research and Education' section for detailed statistics on data access and use.).

In August 2007 we completed installation of a network of ten water-level monitoring stations on Hog Island, Virginia. The new stations use 900 MHz serial wireless communications to connect to the Wi-Fi network installed on the island in previous years. This upgrade replaces a mix of mechanical well monitors (using paper chart recorders) and electronic recorders (that required manual monthly dumps). The upgrade has dramatically cut data outages, because problems are identified at UVA, using graphs that are produced three times per day, and fixed before they become serious. Additionally, we have added an additional tide station and a flux tower to our wireless network.

We have begun a move towards Linux from the proprietary UNIX (SunOS) we use for servers. In this context, we worked on the implementation of virtual machines on a variety of low and high-end hardware. On the high end, in spring 2008 we purchased an eight processor Linux server that will, ultimately, replace the VCR/LTER web server (currently running on a Sun workstation). Although that transition is only starting, we have used the new server to develop new analysis and graphical tools for specific datasets. On the low-end, we have used PCs that were discarded due to low speed or lack of memory required to run new versions of Windows to install Linux variants which are much less consumptive of resources. These machines have been used to take over primary electronic data collection tasks using the wireless network at the ABCRC. By using VNC (Virtual Network Console) all the machines can be administered using graphical tools from anyplace in the world. Updated data from these systems is placed on the public web several times each day.

International Outreach

We have continued our work with Taiwan Ecological Research Network (TERN) and participated in an East-Asia Pacific ILTER Urban Forestry and Information Management Workshop in Seoul Korea in the fall of 2007.

Three presentations were given in Italy in 2008 by Sergio Fagherazzi and Enrique Reyes to researchers working in the Venice lagoon and in the Po River delta, the two areas are part of the Alto Adriatico Italian/European LTER:
- Long-Term Environmental Change at the Virginia Coast Reserve, Department of Environmental Sciences, Parma University, Italy June 2008
- Long-Term Environmental Change at the Virginia Coast Reserve, ISMAR-CNR, Venice, Italy, June 2008
- Long-Term Environmental Change at the Virginia Coast Reserve, Department IMAGE, University of Padua, Italy, June 2008

One Ph.D. student from Boston University (Anthony Priestas) spent a month at the University of Padua in the summer 2008 funded by the LTER International Supplement. The student participated in field measurements in the salt marshes of the Venice Lagoon. Another Ph.D. student from Padua (Alberto Canestrelli) is spending six months at Boston University working on modeling of intertidal hydrodynamics.

Mark Brinson represented the VCR LTER at the Man and the Biosphere in the winter 2008. He presented a poster entitled 'Research and Education at the Virginia Coast Reserve Long-Term Ecological Research Project.'

Network Activities

Bob Christian has collaborated with the LTER Network Office on a social network analysis project to evaluate the way the LTER network is coalescing as a network. They are using inter-site joint publications as the variable.

Journal Publications

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Web/Internet Site

URL(s):

http://www.vcrlter.virginia.edu

Description:

This is the main web site for the VCR/LTER project and serves as the "file cabinet" for all aspects of the project. The web site provides access to data, interactive maps, images, bibliographic listings and full-text of student theses and dissertations.

Other Specific Products

Product Type:

Data or databases

Product Description:

The VCR/LTER publishes over 100 datasets using standard Ecological Metadata Language metadata.

Sharing Information:

Data is made available to all researchers online. Researchers fill out a data license indicating their agreement with LTER policies on proper acknowledgment and are immediately granted access to the requested data.

Contributions

Contributions within Discipline:

We have continued to contribute to the understanding of coastal systems through our efforts in studying the effects of sea level rise (which involves developing detailed understandings of the processes that effect accretion in marshes - both physical and biotic, and encroachment into uplands), coastal eutrophication, seagrass restoration, controls on plant production, determinants of faunal biogeography in an island system, and prediction of future state change.

WATERSHEDS AND LAGOONS

Coastal eutrophication has been recognized as an increasing global problem. Symptoms of eutrophication include blooms of phytoplankton, which when they decompose may reduce available oxygen in the water; blooms of harmful algae that are toxic to fish, shellfish, and occasionally humans; blooms of macroalgae that cause die-backs of seagrasses which are vital to maintaining populations of many fish and crabs; and increasing anoxia. Eutrophication generally results from export of excess nutrients from land, in particular nitrogen. Sources of nitrogen include agriculture, septic tanks, waste-water treatment plants, industry, and atmospheric deposition of nitrogen derived from automobiles, power plants, and other industrial sources. Nitrogen from these sources is most often transported to coastal waters in shallow groundwater and in surface water runoff.

Coastal lagoons are common features of the land margin, especially along the East and Gulf coasts. We have hypothesized that these lagoons play an important role in retarding and transforming nitrogen during transport from land to the sea. Our study of the Virginia Coast Reserve lagoonal system has been designed to: (1) measure groundwater sources of nutrients to the lagoon; (2) measure rates of biological processes that remove or transform nitrogen in the waters and sediments of the lagoon; (3) compare rates of nitrogen cycling processes to physical transport across and out of the lagoon in order to determine whether the nitrogen remains in the lagoon for a sufficient length of time to allow biological processing to occur.

Our modeling and process studies have indicated that the VCR lagoons receive relatively low inputs of nitrogen from the coastal watersheds compared to more eutrophic lagoons in the mid-Atlantic. This is true in part because population densities are relatively low in the VCR

watersheds and there is little point-source agriculture (e.g., chicken farms). Much of then fertilizer nutrients that enter the groundwater is removed by an intact riparian zone and by stream sediments, both of which are active sites of denitrificaiton. Nitrogen that enters the lagoon is rapidly removed by both benthic macro- and microalgae. As a result, there is little flux of nutrients from the sediment to the water column and phytoplankton concentrations are typically low. Blooms of macroalgae that occur in early summer typically crash during mid-summer, releasing much of the nitrogen as dissolved inorganic and organic nitrogen. The sediments act to rapidly remove the nitrogen released to the water column by a combination of mechanisms including immobilization by benthic microalgae and coupled nitrification - denitrification. We are currently attempting to determine how the nitrogen released during decomposition of the macroalgal bloom is partitioned between the various potential consumptive mechanisms.

Our conclusions regarding the importance of macroalgae in influencing the dynamics of nutrient movements within the lagoon helps to explain the role of the lagoon as an active mediator between mainland nutrient sources (e.g., agricultural fields) and the coastal ocean. The recent discovery that the dominant macroalga in the lagoon is an exotic (rather than its native congener), will be important to understanding long-term changes in the lagoon's characteristics.

Shallow bays in the VCR and elsewhere along the US Atlantic coast experienced a dramatic state change in the 1930's when a single storm decimated seagrass populations already decimated by disease. Until recently, VCR lagoons persisted in an alternate, algal-dominated state. Recent field work and modeling showed that high turbidity events in the VCR were episodic and wind driven and we estimated that average light availability over 65-87% of the lagoon bottom is suitable for seagrass recolonization (Lawson et al., 2007). Beginning last fall, in collaboration with Robert Orth from the Virginia Institute of Marine Science, we began to restore seagrass in a 509 acre 'set aside' we have obtained from the Virginia Marine Resources Commission in our primary lagoon study site, Hog Island Bay. This restoration builds on our 10-year database on patterns and process in Hog Island Bay in the absence of seagrass, and gives us the opportunity to determine experimentally the ecosystem-level effects of a rapid state change back to the original seagrass-vegetated state.

The seagrass restoration project contributes to important theoretical and applied problems related to coastal ecosystems. On a more theoretical level, it directly addresses questions related to ways in which biotic feedbacks modify the response to of the systems to external drivers by maintaining a stable state or facilitating a change to another state. In the lagoons, the biotic feedbacks that influence the success of seagrass establishment and growth include the vegetation effects on reducing sediment resuspension and the potential facilitation of seedling establishment by benthic fauna. In addition, a state change from algae to seagrass will have system-wide impacts because these benthic primary producers play key roles in determining rates and patterns of primary production and nutrient cycling and in trophic interactions. Variations in the rates and dominance of these processes as primary producer communities change, will ultimately determine the fate and retention of watershed nutrients as they pass through the lagoon 'filter' to the open ocean. As the community shifts to seagrass dominance, we expect the retention time of watershed N in the lagoon to increase.

On a more applied level, the experimental approach we are taking to establishing and monitoring the seagrass plots in Hog Island Bay, a relatively pristine system, will provide important baseline information for restoration projects undertaken in more highly impacted systems. To put our results on the new seagrass beds in context, we have established a chronosequence by augmenting the Hog Island Bay meadows with those recently seeded (1-7 yr old) using the same technique in South and Spider Crab Bays, just south of Hog Island Bay, and a natural meadow in South Bay, which is at least 10 years old.

We have begun measurements of productivity, nutrient cycling, algal density/diversity, faunal densities/diversity, flow conditions and sediment resuspension in the new seagrass beds; a subset of these measurements are being made at sites along the seagrass chronosequence. In addition, we are quantifying macroalgae epiphytes, benthic microalgae, benthic invertebrates and fish through the seagrass recolonization period to assess changes in faunal abundance and diversity.

Surface Elevation Tables (SETs) are used at numerous VCR/LTER research sites to quantify subtle changes in sedimentation that ultimately will determine the fate of marshes in the face of sea level rise. These baseline measurements at different marshes are then used in association with process-based studies focusing on the processes such as transport of material through tidal flooding, burial of organic matter and its decomposition, marsh plant production (both above and below ground), bioturbation by crabs and even herbivory by insects to develop models aimed at predicting changes in marshes over the coming decades. Our results indicate that the rate of acretion are position dependent, with the upper marsh receiving less input. Results in the lagoon marshes suggest that sea-level rise may be exceeding the ability of the marshes to keep up, but that some unvegetated pool/tidal flat areas are vegetating, a somewhat unexpected result.

Recent work on microbial communities in the marshes and tidal creeks at the VCR (as well as 9 other coastal systems as part of a cross-site comparison study) contribute to our understanding of what abiotic and biotic factors determine microbial community structure and the scales over which microbial communities vary. Linking information about variation in microbial community structure and microbially controlled processes (e.g., nitrogen-fixation), will allow prediction of how critical ecosystem processes will be affected by disturbance. (Blum)

BARRIER ISLANDS

The results of this work to date have increased our understanding of dynamic vegetation changes and their causes in coastal barrier island ecosystems. New cross site and cross species analyses are linking meteorological and climatological drivers to plant production. This analysis is revealing complex patterns showing that all species and sites do not respond similarly to meteorological drivers.

To date, one of our most significant contributions has been to demonstrate that biotic interactions are very important in the coastal environment of the VCR, which we often define as being dominated by physical parameters. We have demonstrated the importance of the presence for a soil actinomycete, Frankia, for the successful establishment of Myrica cerifera. Myrica usually is usually the first woody species to establish in these environments. Once established, Myrica rapidly forms extensive thickets in coastal environments. These thickets are excellent indicators of island stability and may be precursors to the establishment of maritime forest.

Twenty years of research in shrub thicket ecology has provided excellent background and experience for studying the potential for invasive species in coastal environments. This is especially true for the weedy grass, Phragmites australis. Populations of Phragmites are establishing and rapidly expanding throughout the VCR as well as in coastal environments of the mid-Atlantic region. Phragmites often establishes in habitats similar to those of shrub thickets. The detailed understanding of the ecology of P. australis with respect to nutrient uptake and competitive relationships provide a basis for predictions regarding its ultimate distribution.

Studies of island-dwelling organisms, such as those underway at VCR, have long played an important role in testing ecological and evolutionary theory about patterns and processes related to distribution and abundance of species and genetic variation within and among natural populations. The Virginia coast is a highly dynamic, frequently disturbed landscape, and the Virginia barrier islands are the only undeveloped barrier system on the Eastern seaboard. As such, this system affords a unique opportunity to study phenomena associated with island systems, including fragmentation of habitats and populations, local extinction, dispersal, and colonization, which are also important issues in conservation biology. The relative isolation of the islands also provides an excellent opportunity for assessing the roles of parasitism and disease in overall vertebrate population dynamics.

The role of mammals and predation on the large waterbird community has been chronicled, and continues to show annual changes. Managing foxes and raccoons at selected barrier islands has dramatically enhanced the reproductive success of a number of species of ground-nesting waterbirds, including the federally threatened piping plover. Nonetheless, fewer colonies (but larger) of nesting terns (4 species) and black skimmers have consolidated onto fewer islands over the past decade compared to the distribution pattern in the 1970-80s.

SYSTEM-WIDE INTEGRATION

One of the questions we have begun to address is what the composition and structure of the VCR landscape patterns will be in the future and what processes will drive ecological states changes in those landscapes. We are using two types of models to synthesize our long-term monitoring and experiments and shorter-term process studies to address the causes and consequences of state change on the VCR landscape. The goal of this modeling effort is to be able to predict the non-linear and threshold responses of the VCR ecosystems to long-term environmental change and short-term disturbance events.

Landscape modeling: Previous VCR efforts focused on developing various conceptual and mathematical models of limited parts of the landscape and demonstrated a need to integrate the diverse spatial and temporal information into a regional model for the VCR ecosystem. In response, we have begun developing a mechanistic, process-based ecological basin model to understand the coupling between hydrologic and geomorphic free surface changes and the ecological responses of state change on scales that vary from local to the entire coastal reserve. The model integrates physical and ecological processes over a grid of landscape cells. Each cell contains a unit ecosystem model that represents a certain habitat type and incorporates location-specific algorithms to quantify fluxes of materials between cells. Hydrodynamic, soil, and plant productivity modules are dynamically coupled via a unit ecosystem model (Reyes et al. 2000, 2004). The model also contains a habitat-switching module that tracks habitat characteristics for each land parcel within the model boundary, such that long-term processes and ecological responses can be examined.

Network modeling: Ecological network analysis is an effective tool for evaluating both the biogeochemical and trophic consequences of state We have used ecological network analysis at the VCR to evaluate nitrogen cycling within mainland marshes (Thomas and Christian 2001) and the lagoon (Voss et al. 2005) and also the food web structure of salt marsh ponds (Dame 2005). We are expanding this effort to include states across the entire VCR landscape to provide assessments of nitrogen cycling relative to the contributions of biomass storage, recycling, physical and biotic exchanges. In addition, co-PI Bob Christian has furthered the use of network analysis within the ecological community via publications and workshops sponsored by NSF biocomplexity and the LTER network. Several groups within and beyond the LTER network have begun using the tools.

Contributions to Other Disciplines:

The studies conducted by the VCR/LTER are inherently interdisciplinary or multidisciplinary. Our studies are being performed by an interdisciplinary team of ecologists, hydrologists, biologists, and physical oceanographers. When such collaborations take place, it is not unusual that each each group of scientists will gain greater insight into problems that may not be recognized within their own discipline.

Additionally, our workshops on network analysis have exposed a broad group of scientists to the field or network ecology. Social scientists have also used network analysis, and one of our accomplishments has been to bring awareness of the different approaches to the broader group.

Research on ecological information management has included computer scientists. The challenges posed by ecological data provide opportunities for innovation in computer science. Our work with development of wireless sensor networks, and processing of the massive data flows they can generate, contributes to better defining the cyberinfrastructure challenges that will confront us in coming decades. During 2006-2007 the VCR Information Manager participated in the Cyberinfrastructure-Core group and we hosted a modeling workshop that focused on the cyberinfrastructure needs of advanced ecological modleling.

Contributions to Human Resource Development:

As can be seen from the number of graduate and undergraduate students listed on our participant list, this project provides abundant opportunities for training. Moreover, the inter- and multi-disciplinary nature of the research teaches the students how to operate in a collaborative environment.

Our SLTER program, and related activities, have helped introduce scientific concepts to K-12 students. Additionally, an intensive 10-day workshop in July 2007 helped high school science teachers from counties on the Eastern Shore of Virginia in curriculum development activities.

Contributions to Resources for Research and Education:

Our WWW site (http://www.vcrlter.virginia.edu) provides access to a wide variety of information in text, graphical and video forms. Data are frequently downloaded for use by classes and researchers at institutions not associated with the VCR/LTER. Since the inception of VCR/LTER V in Nov. 2006, the web site has distributed 3.6 terabytes of information to over 379,000 different client computers. The site averaged over 27,000 requests per day. A detailed summary can be found at: http://www.vcrlter.virginia.edu/analog/Nov2006toSep2008/. To a large degree this increase was driven by increases in search engines indexing the web site, indicating that the site should be relatively easy to locate via Google and other search engines.

Contributions of VCR/LTER towards providing data can be more directly assessed by examining formal data download requests. Since 1 Nov. 2006, there have been 253 formal requests for data. 79% of the requests were for research purposes, with educational requests making up the remaining 21%. Requests by researchers from 'outside' the VCR/LTER research community accounted for 55% of all requests. These outside requests included numerous researchers from outside the US, including one or more requests from researchers in Italy, Australia, Canada, China, France, Iran, New Zealand, Philipines, South Africa, Thailand and Spain.

Through our Schoolyard LTER supplement, we have been able to provide equipment such as global positioning system, taxonomic guides and water chemistry analysis kits and equipment to the Northampton Co. VA Public Schools. This program now extends from grades K-12 through the Northampton Co. elementary, middle and high schools.

Work that we are currently doing at the VCR is of much interest to the Department of Environmental Quality of the State of Virginia, and in particular to the Water Conservation Districts located on the Eastern Shore. The major source of nitrogen to VCR coastal lagoons is agriculture. Proper management of agricultural activities and fertilization practices requires an improved understanding of nitrogen losses to the coastal lagoons via groundwater and surface water runoff.

Contributions Beyond Science and Engineering:

We have engaged in studies designed aid the conservation of avian fauna and better understanding of the extent and change in exotic plant species in the coastal zone in conjunction with The Nature Conservancy.

Knowledge of the relationship between land use, nutrient contamination of groundwater, groundwater export of nutrients to coastal lagoons, and the fate of nutrients within lagoons will be of benefit to state and federal agencies charged with managing coastal resources. This knowledge will be especially important given the ongoing return of seagrasses to large areas of the coastal bays, from which they have been absent for over 70 years. The VCR lagoons are also a model system to understand the important role of plants in mediating nutrient export from coastal watersheds to the open ocean (McGlathery et al. 2007).

Linking information about variation in microbial and fungal community structure and fungal and microbially controlled processes (e.g.,

nitrogen-fixation, decomposition), will allow prediction of how critical ecosystem processes will be affected by disturbances due to human activities in the coastal zone.

Activities with the UN programs on observing global change along coastal ecosystems have significance for broad aspects of public welfare and environmental protection. One of the greatest potential contributions from PI Christian's work at the VCR LTER are to the global observing systems and the ability to detect and assess global change in coastal ecosystems. The Coastal Module of GTOS is being developed to complement the Coastal GOOS program and highlights terrestrial, wetland, freshwater, and transitional ecosystems. Further and importantly it explicitly includes socio-economic components of global change in the coastal zone. This is the first significant introduction of the human dimension into the global observing systems.

Finally, we continue the monthly public seminar series begun in the summer of 2007 on environmental issues and research activities at the VCR/LTER was established with support from the Coastal Zone Management and Seaside Heritage Program of the Commonwealth of Virginia. During the seminars, VCR/LTER researchers provide information on their research to the general public.

Special Requirements

Special reporting requirements: None

Change in Objectives or Scope: None

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

VCR-LTER ANNUAL REPORT 2008 - ACTIVITIES

Long-term data sets

We continue our collection of long-term data sets that constitute the core of our long-term monitoring. These include:

- *Water quality transects* in 2 focal lagoons, including analysis of light, dissolved oxygen, temperature, total suspended solids, inorganic and organic nutrients, chlorophyll
- *Meteorological stations* at Phillips Creek Marsh, Hog Island and Oyster, VA, for precipitation, temperature, wind and light data
- *Tide stations* at Red Bank, Oyster and Hog Island
- *Sediment elevation tables (SET)* in Phillips Creek Marsh, and a lagoon marsh for detailed measures of marsh accretion or erosion
- *Atmospheric chemistry* – wet-deposition fluxes of major ionic species including SO_4^{2-}, Cl^-, NO_3-, NH_4^+, Na^+, K^+, Mg^{2+}, Ca^{2+}, and H^+, and also $HCOO^-$, CH_3COO^-, $CH_3SO_3^-$, $(COO)_2^{2-}$ and Br^-.
- *Marsh grass end-of-year biomass* sampling to estimate annual productivity
- *Island vegetation biomass and percent cover* estimates along a chronosequence on Hog Island bay
- *Seagrass biomass and productivity and sediment characteristics* in a seagrass chronosequence
- *Groundwater levels* at 10 stations on Hog Island and 5 stations in Phillips Creek Marsh
- *Creek flows and nutrient concentrations* in 3 tidal creeks draining mainland watersheds to estimate baseflow nitrogen loading related to watershed land use
- *Fish and invertebrate populations* are monitored annually in restored seagrass beds and adjacent bare sediments
- *Mammal population surveys* – small mammal populations are monitored semi-annually in fall and spring on 3 transects on Hog Island
- *Photographic records* – landscape changes and unusual events are monitored using web cameras that monitor over 150 locations on a daily basis

These long-term data sets serve as the foundation for the research activities for the 2007-2008 grant year that are detailed below.

Watersheds and Lagoons

Watershed nutrient loading

One of the main drivers of long-term change in the VCR is the change land-use (and associated population demography) in the coastal watersheds that influences nutrient loading to the coastal bays. The multiple watershed-lagoon systems within the VCR, and extending northward to the Maryland coastal lagoons, vary considerably with respect to watershed land use and nitrogen loading to the coastal lagoons, and they provide an ideal natural laboratory

that allows us to do comparative studies. A team of PIs and students (Karen McGlathery, Iris Anderson, collaborator Mark Brush, Ph.D. student Luke Cole, M.S. student Juliette Poleto) used a watershed nitrogen-loading model to estimate annual baseflow nitrogen loads from 8 watersheds within the VCR (Fig. 1). Baseflow nutrient data from their stream monitoring in several of these watersheds will be used to verify the model. These watershed nitrogen-loading estimates will then be compared to similar estimates in several Virginia and Maryland coastal lagoons outside the VCR to put our system within a regional perspective.

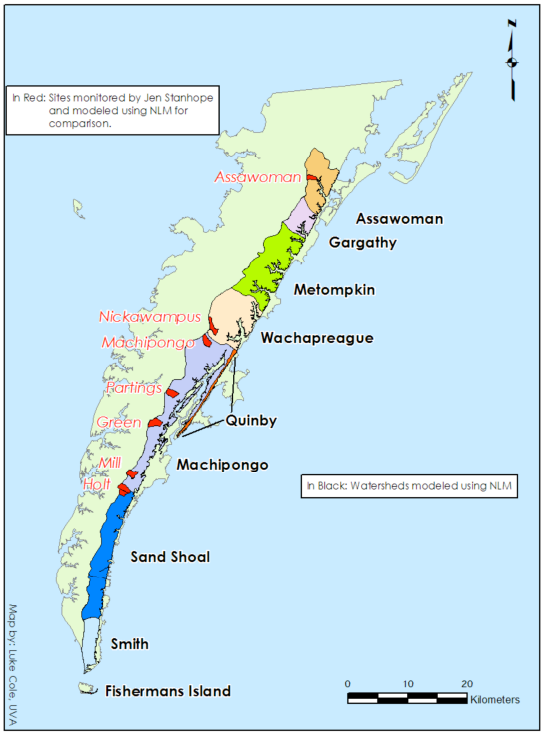


Fig. 1. VCR watersheds to which the Nitrogen Loading Model was applied to estimate baseflow nitrogen inputs based on watershed land use.

Aaron Mills and his collaborators (graduate students Paul Probasco and Wendy Robertson, colleague Janet Herman, and undergraduate research assistants) have been involved in 2 major projects: (1) They initiated a regional examination of low-relief coastal streams in the VCR coastal watersheds to determine the extent to which these other locations mimic the behavior observed in their primary research site, Cobb Mill Creek, where 80-90% of the nitrate discharging in groundwater entering the stream is removed before the water emerges from the stream-bed sediments. Permanent instrumentation (peizometers, survey monument, stream gauges) have been established on three additional streams draining each of the major study lagoon systems (Gargathy Bay, Smith Bay). (2) They began a study to obtain high frequency discharge and chemical data to test the hypothesis that decreased nitrate flux through the stream-bed represents an increased residence time in the active sediments that will cause a discernible diurnal variability in nitrate concentrations. This project developed from their observations that evapotranspiration in the riparian buffer exerts a strong effect on ground water fluxes to the stream at Cobb Mill Creek resulting in a strong diurnal fluctuation in stage.

Saline submarine groundwater discharge may be an important source of recycled nutrients in marine systems, but terrestrial groundwater discharge, including both fresh and brackish water, represents a new source of nutrients to marine systems. Ph.D. student Dirk Koopmans, working with Peter Berg, used radon mapping to do a preliminary investigation of potential locations of terrestrial submarine groundwater discharge along the primary channels of Hog Island Bay, Cobb Bay and the Intracoastal Waterway between them. Radon was enriched in surficial groundwater adjacent to the bays (3300 ± 1600 Bq/m^3, n = 7) making it a useful terrestrial groundwater tracer. Potential regions of terrestrial groundwater discharge were identified where surface water radon concentrations were in excess of the radon supplied by the decay of dissolved radium in surface waters and likely supply by radium decay in adjacent sediments. Regions that merit further investigation for terrestrial groundwater discharge include the northwest corner of Ramshorn Bay and the Machipongo Channel from Willis Wharf to inner Hog Island Bay.

Dirk Koopmans and Peter Berg also are modifying the eddy correlation technique developed by Berg for measuring sediment-water column oxygen fluxes to quantify terrestrial groundwater discharge *in situ* to Cobb Mill Creek.

Water vapor, carbon dioxide and nitrous oxide fluxes

Todd Scanlon is using a tunable diode laser trace gas analyzer as part of an eddy covariance system in the Cobb Mill Creek marsh to collect the first ecosystem-scale nitrous oxide fluxes to be measured in such a setting. The aim of this study is to establish if the marsh is a hotspot of nitrous oxide emissions and to determine what biogeochemical processes are responsible for the temporal variability of these fluxes. During the test phase of the eddy covariance tower on the Eastern Shore of Virginia, the high-frequency data were examined to characterize the correlation structure between water vapor and carbon dioxide time series. As part of this analysis, Scanlon developed a new technique to partition the fluxes of water vapor (into transpiration and direct evaporation components) and carbon dioxide (into photosynthesis and respiration components) by adapting flux-variance similarity theory combined with correlation-based arguments. The validity of this method was demonstrated using high-frequency measurements of water vapor (q) and carbon dioxide (c) concentrations collected over the course of a transition from dry to wet surface conditions in an agricultural setting on the Eastern Shore of Virginia. The new technique shows outstanding promise for estimating these components which heretofore had to be derived from isotopic measurements or more elaborate field instrumentation.

Lagoon bathymetry and hydrodynamics

Students and VCR staff working with George Oertel completed bathymetric surveys of the Gargathy and Smith/Magothy Marsh-Lagoon systems that serve as the foundation for developing the hypsometric relationships and hydrodynamic models for these systems. We now have 3 systems surveyed in the VCR as part of our mainland-island box transects.

Echo-sounding surveys were conducted in the Gargathy Inlet marsh-lagoon system in the summer and fall of 2007, generating over 24,000 echosounding depths in tidal channels and

deep tidal flats. In spring and summer of 2008, Loreto Gomez (M.S. student at ODU) processed the data to convert variable-datum echosounding data to MLW-datum. In summer and fall of 2008, a composite depth-area hypsograph is being generated to determine the total capacity of the Gargathy marsh-lagoon system, hypsometric relationships, hydraulic turn over, and repletion times.

For the Smith-Magothy Lagoon system, Kathleen Overman and David Boyd (VCR-LTER technicians) located NAVD 1988 Benchmarks on Mockhorn Island. Elevations were then carried to temporary benchmarks (TBM's) in intertidal parts of the lagoon. Echosounding surveys of the Smith-Magothy system began on May 30, 2008 with 500 data points. Approximately 4,000 data points were collected on June 11 and 590 more on June12, 2008. Emmett Rafferty (M.S. student at ODU) is assisting in the field effort and has begun post-processing of data to convert echosounding data to depths correlated to vertical datum. In fall 2008, Rafferty will generate a bathymetric model of the Smith-Magothy system.

Masters student G. McLeod is working with George Oertel to compare flushing characteristics of 6 coastal lagoons (Chincoteague Bay, VA/MD; Gargathy Lagoon, VA; Great Machipongo Lagoon, VA; Smith-Magothy Lagoon, VA; Lynnhaven Bay, VA; and Garolim Bay, Korea) with different tidal and spatial characteristics. They are determining how basin dimensions and tides influence hypsometry (for distribution of benthic habitats), hydro-hypsometry (for distribution of water) and repletion of coastal lagoons. This study may also reveal relationships between boundary distance and natural repletion distance that can be used as a tool for evaluating basin flushing. Tidal ranges vary from 10 cm (Chincoteague Bay) to 600 cm (Garolim Bay, Korea). The lagoons range from mostly open-water basins (Inner Chincoteague, Great Machipongo and Garolim Bay Korea) to primarily marsh-choked basins with flows confined by tidal channels. Distances from the inlet to inner boundaries also vary considerably.

Sergio Fagherazzi has applied the two-dimensional final element numerical model developed by Carniello et al. (2005) to the VCR-LTER lagoons (Fig. 2). The model couples a hydrodynamic finite element module based on the shallow water equations with a finite volume module that accounts for the generation and propagation of wind waves. The wave module solves the wave action conservation on the same triangular mesh used in the hydrodynamic module, thus efficiently reproducing the physical relationships between waves and tide propagation. See D'Alpaos and Defina (2007) for the derivation of the equations. The model is particularly suitable for the highly irregular bathymetry of the Eastern Shore tidal basins, characterized by deep channels, emergent salt marshes, and extensive tidal flats. The hydrodynamic model allows the simultaneous quantification of both tidal fluxes and wind waves in the VCR tidal basins. Tidal and wave hydrodynamics are key factors for the resuspension of sediments in tidal flats, which regulates water turbidity and primary production in the water column as well as in benthic communities. Tidal fluxes also determine the morphological equilibrium of salt marshes and their resilience to climatic and anthropogenic modifications.

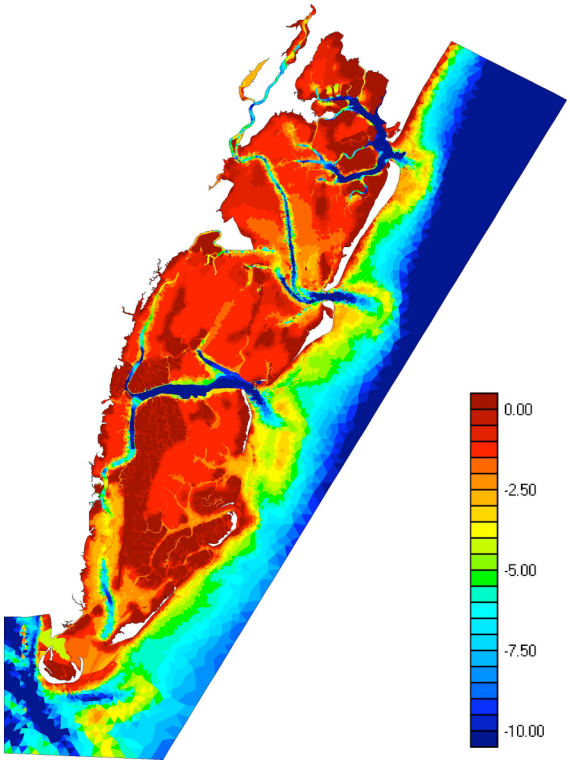


Fig. 2. Triangular mesh of the VCR lagoons used for the finite elements model.

Lagoon nitrogen and carbon dynamics

With supplemental funding from the NSF Ecosystems Program, Iris Anderson, colleagues Elizabeth Canuel (VIMS) and Craig Tobias (UNC), and Ph.D. student Amber Hardison, studied the uptake and fate of carbon and nitrogen in shallow sediments along a eutrophication gradient in the Virginia-Maryland coastal lagoons. Field monitoring of environmental variables and sediment characterization at 2 sites that represent end-members of the gradient were conducted over a two-year period. The Isle of Wight Bay watershed is impacted by agricultural and urban activities, notably poultry farms and wastewater discharges from Ocean City, Maryland. Hog Island Bay is a relatively unimpacted coastal lagoon in the VCR. The following parameters were measured: water column nutrient concentrations (dissolved inorganic nitrogen (DIN), phosphate (DIP), dissolved organic nitrogen (DON), dissolved organic carbon (DOC)), water column chlorophyll a and phaeophytin, total suspended solids and particulate organic matter, temperature, dissolved oxygen (DO), pH, salinity, light attenuation, sediment chlorophyll a and phaeophytin in three sediment horizons (0-0.3cm, 0.3-1cm, 1-2 cm), sediment particulate organic carbon (POC), total nitrogen (TN), bulk density, percent organic matter in three sediment horizons (0-1 cm, 1-2 cm, 2-5 cm), extractable nutrients (DIN, DIP) in two sediment horizons (0-2 cm, 2-5 cm), lipid biomarkers for algal and bacterial sources for the 0-1 cm depth section, and macroalgal biomass and taxa.

Iris Anderson and her colleagues also conducted a dual stable isotope ^{13}C and ^{15}N enrichment experiment in May-July 2007-2008 using a system that continuously perfused sediments with nutrients, dissolved inorganic carbon (DIC), and isotopic tracers. Using this approach they

were able to more realistically trace sediment process by directly labeling the porewater ammonium and DIC pools. Adding the tracer directly to the sediments also simplified interpretation of benthic tracer cycling because it was not confounded by uptake and cycling in the water column prior to introduction to the sediments. This experiment used sandy sediments collected from Hog Island Bay and included the following treatments: (1) delivery of labeled DIN and DIC through surface water or pore water; (2) incubation with and without added macroalgae; and (3) incubation under normal diel conditions vs. long-term dark conditions to separate autotrophic and heterotrophic pathways.

Masters student Juliette Giordano is working with Iris Anderson and collaborator Mark Brush (VIMS) to study the effects of nutrient loadings from watersheds on metabolic processes in 4 coastal bays along the VA and MD eastern shore (Hog Island Bay, Burton's Bay, Gargathy Bay, VA and Isle of Wight Bay, MD) using two oxygen-based methods, component and open-water methods. Sediment and water samples were collected at three sites, creek to inlet, in each bay, and incubated in a light gradient box for short incubations. Metabolism measurements were done by measuring changes in dissolved oxygen over the incubation period and creating production-irradiance curves. Sampling occurred monthly from July 2007 – November 2007; bi-monthly from Nov 2007 – May 2008 and monthly from May 2008-July 2008. From May 2008 – July 2008, macroalgal samples were collected for determination of macroalgal metabolism using short incubations in the light gradient box with dominant species (*Ulva* spp. and *Gracilaria* spp.) collected from each site within the bays. Datasondes deployed in Burton's Bay and Gargathy Bay at the time of sampling recorded diel dissolved oxygen changes, which serves as the open-water measure of ecosystem metabolism.

Bob Christian is using ecological network analysis to understand N cycling in Hog Island Bay in the VCR in comparison with other lagoonal systems that receive higher external nutrient loadings. He is doing this with Karen McGlathery, Iris Anderson, Christy Tyler (former VCR graduate student, now Assistant Research Professor at Rochester Institute of Technology), and Italian colleague Peir Luigi Viaroli. "Ecosystem Health" has been assessed through this mechanism.

Seagrass restoration

Karen McGlathery and her students continue the large-scale experiment on the ecosystem-level effects of the large-scale seagrass restoration in the VCR lagoons. This restoration represents a state-change from the current benthic-algal dominated system to a seagrass system that dominated the VCR lagoons prior to the disease and storm-driven seagrass extinction in the 1930's. In fall 2007, our colleague (Robert Orth), and his staff at the Virginia Institute of Marine Sciences, with help from VCR LTER personnel, broadcast some 2 million seeds in the 509-acre 'set-aside' in Hog Island Bay designated for seagrass restoration by the Virginia Marine Resources Commission. This brings the total seeds planted in this restoration site to 4 million and the total number of plots to 56. In 2007, the seeds were broadcast in the same factorial design as had been done in fall 2006, with 2 seed densities (50,000 and 100,000 per acre) and 2 plot sizes (0.5 and 1.0 acre), with 7 replicates per treatment (Fig. 3). In summer 2008, a team of 15 graduate, undergraduate and high school students, LTER technicians, and a high school teacher helped Karen McGlathery with the synoptic survey that is conducted

annually at the restoration sites as part of this long-term experiment. This included: density, canopy height, above- and below-ground biomass, growth, epiphyte biomass and tissue carbon and nitrogen contents of the seagrass. Sediment parameters measured included: benthic chlorophyll, organic content, grain size, porosity, and carbon and nitrogen contents. In 2009, we plan to add fish and invertebrate sampling to our annual synoptic survey. In spring 2008, a team of VCR LTER faculty, students and staff assisted the VIMS and The Nature Conservancy teams to collect seeds from the seagrass restoration site in South Bay for fall 2008 deployment in the VCR coastal bays. A UVA news story on this can be seen at: http://www.virginia.edu/uvatoday/newsRelease.php?id=5537.

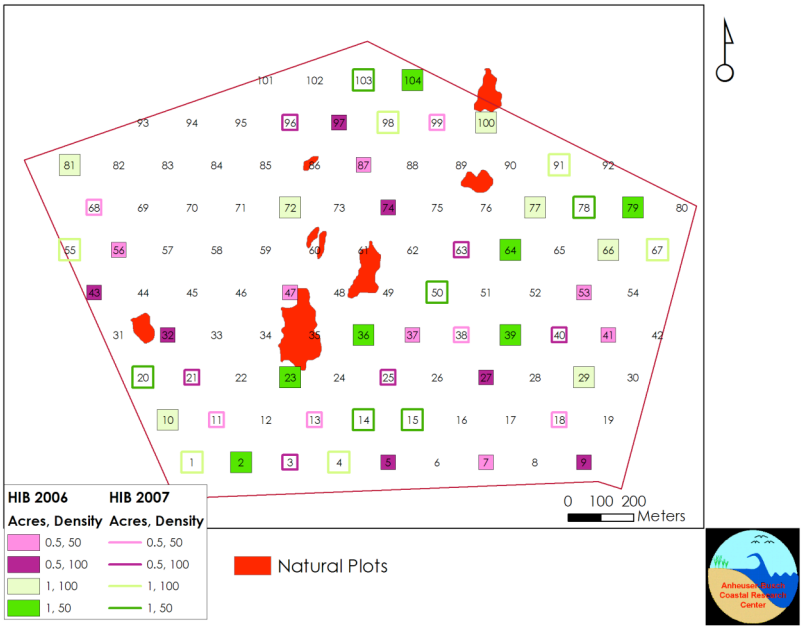


Fig. 3. Map showing treatment plots for the seagrass restoration experiment. For each of the years 2006 and 2007, 2 million seeds were broadcast into plots with the factorial design of 2 seed densities (50k, 100k per acre) and 2 plot sizes (0.5 and 1.0 acres).

In addition to following the factorial experiment over time, we have taken advantage of the different times that areas within the southern portion of the VCR have been seeded with seagrass to establish a chronosequence of seagrass sites. Ph.D. student Luke Cole (working with Karen McGlathery) is using the 1 acre, 100,000 seed treatment plots at sites in Hog Island Bay (<2 yr old), adjacent South Bay (5-6 yr old), and nearby reference sites (>10 yr old) at Fisherman's Island and Nassawadox, and unvegetated sediments to understand the role of seagrass in retaining and/or transforming watershed nitrogen as it passes through the coastal lagoons to the coastal ocean. He is specifically interested in the relationship between dentrification (loss), nitrogen fixation (additional source), and nitrogen assimilation and turnover by seagrasses (temporary retention).

There are several other graduate student projects that take advantage of the seagrass restoration program to understand the impacts of the return of this 'foundation' species on the coastal lagoons.

Andrew Hume completed his M.S. (with Peter Berg and Karen McGlathery) using the novel eddy correlation technique to measure community metabolism in a restored (5 yr old) seagrass

meadow and a nearby bare sediment substrate. The non-invasive and *in situ* nature of the eddy correlation technique allowed dissolved oxygen (DO) fluxes to be measured at a high temporal resolution (64 Hz) and represented an integrated DO flux measurement for an area of approximately 400 m^2. High variations in these measurements, both within a daily cycle and between days, highlighted the importance of measuring ecosystem metabolism under natural environmental conditions over a large spatial scale.

Sarah Lawson (Ph.D. student with Patricia Wiberg and Karen McGlathery) completed her studies examining the physical and biological couplings controlling the movement of sediment and nutrients across the sediment-water interface the shallow VCR lagoons. Her work addressed the following questions: (1) How does the density of primary producers (seagrass and macroalgae) affect sediment and nutrient transport across the sediment-water interface? (2) What is the relative importance of porewater advection and desorption across a range of fine to coarse-grained sediment? (3) What controls sediment erodibility and nutrient fluxes across a range of sites and seasons? She used a Gust erosion microcosm (Gust and Muller 1997) to expose sediment cores to controlled shear stresses representative of the in situ flows. Measurements were made over a growing season (mid-April to Mid-November) to reflect temporal variability in nutrient cycling and primary productivity. She also used controlled experiments on desorption and porewater advection, along with numerical modeling, to gain further insight into the controls on nutrient fluxes.

Ph.D. student Laura Reynolds is working with Karen McGlathery and Jay Zieman to understand both the genetic basis of successful seagrass restoration in the VCR lagoons, and the source of natural populations that have become established in one of the lagoons adjacent to the restored sites. She is also collaborating with a colleague in Australia, Michelle Waycott, who is a well-known expert on seagrass genetics.

Travis Robertson (M.S. student with Linda Blum, Patricia Wiberg, Karen McGlathery) is looking at changes bacterial community composition in both the sediment and water column that occur with seagrass restoration. He is particularly interested in the spatial scale over which significant changes in community composition occur, as previous studies suggest that this scale is smaller than typical sampling strategies can resolve.

Joel Carr (Ph.D student), working with Paolo D'Odorico, has developed a model of the effects of sea grass dynamics on modifying the fluid environment in shallow coastal bays. They are using the model to investigate whether the sea grass system in Hog Island Bay exhibits unistable or bistable behavior under regular conditions. Drag on sea-grass stems creates a shear layer in the flow, with a modified logarithmic velocity profile above the canopy and exponential decay within the canopy. The model includes attenuation of wave orbital velocities due to the sea grass canopy, combined wave and current shear stresses, and an active bed layer formulation. An empirical relationship defining the light attenuation coefficient from total suspended solids, chl a and gilven is used to calculate PAR at the canopy surface from incident solar radiation at the water's surface; compensation and saturation values of PAR are calculated based on water temperature. The model allows for the exploration of the effects of grain size, stem density, canopy height, water depth, water temperature, eutrophication, and relative storminess on the light necessary for sea grass growth/maintenace. A sea-grass growth

model was developed to capture the inter-seasonal dynamics of rhizome storage and remobilization of carbon into new shoot structures, with intra-seasonal variations of productivity due to light availability and temperature, rhizome biomass, stem density and single stem biomass; above ground biomass is the product of stem density and single stem biomass.

Matt Reidenbach started a new project with his Ph.D. student Jennifer Romanowich and an REU student from UVA, Savanna Berry, with the goal of understanding how seagrass beds within South Bay are affecting boundary-layer flow dynamics and how this impacts the deposition and erosion of sediments within a barrier island lagoon. Seagrass beds create regions of reduced flow that promote sedimentation and the retention of particulate nutrients. However, depending upon the density of vegetation, increased sediment movement may occur due to increases in turbulence formed around individual plant stems. Whether bulk flow is able to move through the seagrass bed or is diverted above and around it may be dependent on bed spatial heterogeneity. Three separate 1 week experiments were conducted in June and July 2008 to measure how seagrass patch size, density of shoots, and physical environment (such as water depth, exposure to waves, and magnitude of tidal currents) influences sediment suspension and deposition within the South Bay coastal lagoon. Deployments of multiple profiling and single point acoustic velocimeters were used along with sediment sensors to calculate the flux of sediment above and within the seagrass bed.

Along with these measurements, Peter Berg and his graduate student Andrew Hume concurrently measured oxygen flux from the seagrass beds using an eddy-correlation system which simultaneously measured oxygen and water velocities. The combination of flow, sediment, and oxygen measurements should provide net photosynthetic activity of the seagrasses and how sediment dynamics, due to light attenuation, may be impacting rates of photosynthesis within these shallow lagoon systems. Separate measurements were conducted in open lagoon areas devoid of seagrasses to provide a baseline comparison for in-situ estimates of bio-physical feedbacks between flow, seagrass structure, and sediment dynamics.

An additional focus of this work was the development of an underwater laser-based velocity measuring system. Particle image velocimetry (PIV) has been used for a number of years in laboratories to measure velocity and turbulence over an area ranging from square millimeters to square meters. Essentially this system uses a laser and optics to create a laser light sheet which illuminates suspended sediment particles and, using a digital camera, sediment motion is recorded. A laboratory PIV system was modified and waterproofed and was deployed within the seagrass bed in natural flow conditions. The benefit of this system is that sediment motion directly adjacent to the seafloor and within the seagrasses can be quantified spatially over tens of cm simultaneously. Using software that tracks particle motions over time, a two dimensional map of sediment velocities was obtained and is being used in conjunction with longer-time series data obtained from the acoustic velocimeters.

Flow dynamics and metabolism of oyster reefs

A new collaborative project was begun between Matthew Reidenbach and Peter Berg, and Barry Truitt at The Nature Conservancy, to measure flow, sediment uptake and net metabolism

concurrently at oyster reefs (*Crassostrea virginica*) in the VCR lagoons. It is known that filtration by oysters not only increases light availability to the benthos, and that biodeposition of sediments can enhance the flux of C, N, and P to the benthos. This increases benthic-pelagic coupling in coastal and estuarine ecosystems and, in coastal waters subject to anthropogenic N and P inputs, it can also be ecologically beneficial by functioning as a bio-filter for nutrients. Although numerous mesocosm studies have been performed to determine rates of filter feeding and biodeposition by oysters, few studies have been conducted *in situ* to determine how natural variability in climate and physical conditions may affect rates of filtration and biodeposition. For a 2-week period in June 2008, an oyster reef just off-shore from the town of Oyster, VA was instrumented with sensors to measure flow, sediment flux, and the uptake of oxygen by the oysters.

Filtration and siphon currents of the hard clam, Mercenaria mercenaria

A laboratory study was initiated to determine how clam size and spacing affects filtration of the hard clam, *Mercenaria mercenaria*. Suspension-feeding bivalves filter the water column to acquire phytoplankton, and this filtration plays an important role in controlling phytoplankton abundance and altering nutrient cycling. Additionally, hard clams are the most commonly cultured of the bivalve species in the United States. Although many measurements of filtration have been conducted on this species, little is known about the hydrodynamics of their siphon currents and how incurrent and excurrent flows through their siphons are impacted by clam size and spacing between clams. The objective of this work was to determine uptake rates of phytoplankton by hard clams and to directly measure filtration velocities of their incurrent and excurrent siphons. This research was primarily conducted by an REU student, Savanna Barry, working with Matthew Reidenbach who measured filtration rates and conducted particle image velocimetry around the incurrent and excurrent siphons of the clams.

Tidal Marshes

Marsh accretion relative to sea-level rise and related marsh studies

Linda Blum, Mark Brinson, and Bob Christian now have a 10-year database on salt marsh accretion in relation to sea-level rise at our core mainland marsh site, Phillips Creek Marsh. Sediment Elevation Tables (SETs) and root-zone SETs are monitored twice a year at low-, mid- and high-marsh sites. Surface accretion is measured using feldspar marker layers. Biomass is surveyed annually. Of particular interest are the relationships among marsh elevation/accretion and plant biomass, groundwater elevations, patterns of tidal flooding, and rainfall. Work also continues on the effects of disturbance, processes leading to elevation change, vegetation and ground cover change, and experimental effects of flooding increase on high marsh plants. Analysis of the ground cover changes from 1990 until 2007 has been improved and a geospatial analysis is underway. Bob Christian, with the assistance of an REU, Jessica Pendergrass, is assessing the genetic makeup of *S. alterniflora* to determine if the tall and short growth forms do in fact have a genetic component.

Marsh erosion and changes in marsh area

With supplemental funding from the DOE NICCR program, Sergio Fagherazzi, Patricia Wiberg, Karen McGlathery and their students are investigating rates of erosion or accretion of the marsh-tidal flat boundary and the processes that control the evolution of that boundary. The study combines modeling and fieldwork. During summer and fall 2007, they established 4 sites in Hog Island Bay where they are monitoring marsh erosion or accretion over at least a 3-year period (Fig. 4). Three of the sites are erosional, reflecting the dominance of erosional sites in this system. One site, located behind a protective ridge of sand and oyster rock, appears to be accretional. In each site they established 2 shore-perpendicular transects extending from ~50m into the marsh to ~50 m into the adjacent tidal flats. These transects were resurveyed 3 times during 2008 and will continue to be surveyed at least annually.

Fig. 4. Focus sites for DOE/NICCR study of marsh edge dynamics in Hog Island Bay. The Hog Island (HI), Chimney Pole Marsh (CP) and Upshur Creek (UC) sites have erosional marsh edges; the marsh edge at the Fowling Point (FP) site appears to be accreting.

To establish the relationship between marsh erosion and wind waves, two Nortek ADCP and one TWR2050 wave recorder were deployed at two marsh locations for a period of three months during the spring and summer of 2008 (Fig. 5). The instruments recorded tidal elevation, wave characteristics, and currents every 30 min.

Fig. 5. Deployment of a Nortek ADCP near an eroding marsh boundary in Chimney Pole Marsh, Hog Island Bay.

During the same period changes in the marsh boundary were measured using a high-resolution survey that combined total station and erosion pin data. The goal is to relate the erosion of the marsh boundary to wave activity. In a first phase the study examined the feedbacks between wave characteristics and wind velocity, fetch distance, and tidal flat morphology. In a second phase wave activity will be coupled to the erosion of the marsh boundary. The PIs are also creating a biophysical model, incorporating marsh plant characteristics, to predict the response of the marsh boundaries to future scenarios of sea-level rise and storminess.

Marsh carbon and nitrogen dynamics

Several related studies investigated physiological or biogeochemical processes that influence the productivity and distribution of tidal marsh plants.

Ph.D. student Tom Mozdzer, working with Jay Zieman and Karen McGlathery, investigated how diurnal tides and the resulting submergence of plants influenced nutrient uptake and photosynthesis of the dominant salt marsh cordgrass, *Spartina alterniflora.* Experiments were conducted to test if *S. alterniflora* plants can assimilate both inorganic and organic nutrients through their leaves when they are submerged. Using flooding mesocosms, they submerged plants with ^{15}N-enriched treatments to determine foliar N uptake rates. They are currently developing a model to determine the relative importance of foliar nutrient uptake based upon plant growth rate, duration of flooding, plant location, and seasonal nutrient availability using data from the water quality monitoring program. To determine how tidal inundation affects photosynthesis, a Diving-PAM fluorometer was used to measure the change in relative electron transport rates, a proxy for photosynthesis, throughout the course of the day while the plants are submerged and exposed.

In 2007, Jose Fuentes and his Ph.D. student James Kathinlankal installed a 6.7-m tower with an eddy covariance system in a lagoonal salt marsh dominated by *S. alterniflora* to study carbon dynamics (Fig. 6). These studies continued through 2008. The flux tower site (37°24'39.85"N, 75°50'0.53"W) is located near Fowling Point, about 2.2 kilometers away from the mainland and 10.7 kilometers away from Hog Island, the nearest barrier island, and is situated at about 80 meters away from the creek edge. The eddy covariance system consists of a three dimensional sonic anemometer which measures the components of the wind velocity along with virtual temperature and an open path gas analyzer which measures the concentration of carbon dioxide and water vapor in the air. These measurements were used to estimate the fluxes of carbon dioxide, latent heat, and sensible heat. The microclimate over the canopy was

quantified by a variety of sensors mounted on the flux tower. Temperature measurements were made at three different heights above the canopy. Humidity measurements were made at two different levels. The radiation measurements included net radiation, along with incoming and reflected photosynthetic active radiation at 5.2 m above the surface. Wind direction and speed were measured using a propeller anemometer that was installed at 7 m from the surface. The flow of heat into and out of soil was estimated using two soil heat flux plates installed at 2 cm below the sediment surface. The temperature profile of the soil was monitored using three soil thermometers, installed at 5, 10, and 25 cm depths. Rainfall estimates were obtained using a tipping bucket rain gauge. A water level recorder was used to measure tidal fluctuations over the marsh surface. A set of 5 thermocouples were used to estimate temperature changes within the plant canopy. All instruments were power with a combination of batteries and solar panels. Instruments acquire data continuously and the resulting information is stored on a computer which is linked to the internet.

Fig. 6. Flux tower (6.7m) on Fowling point marsh at high, with solar panels that power instruments.

Barrier Islands

Island geomorphology

Michael Fenster has worked with several colleagues toward developing an empirically-driven expert systems (e.g., Bayesian) model capable of predicting barrier island landscape dynamics as a function of spatial and temporal variations in sediment supply, storms, tides, tidal inlets, waves, sea-level, and antecedent geology. He has been supported primarily through ROA

supplement funds. Other collaborators on this project include Robert Dolan (UVA faculty), Jodi Jones-Smith (UVA Ph.D. student), Brian Rizzo (University of Mary Washington), and Mauricio González and Raúl Medina (University of Cantabria, Spain). The initial work focused primarily on quantifying modern (centennial) sea-level trends and the coastal storm wave and wind climatology. They continue to develop tropical and extratropical storm inventories that include hindcast wave energies (or an erosion potential index) associated with each storm.

The team used a densely-gridded wave refraction model to examine the role of both long-term wave climate and short-term storm disturbances in controlling the morphodynamics of the Virginia barrier islands (VBIs). The wave data came from the Wave Information Studies (WIS) hindcast database spanning the period 1980-1999. The National Geophysics Data Center of the National Oceanographic and Atmospheric Administration supplied the bathymetric data. Wave propagation and wave-induced currents were determined by the Coastal Modeling System (SMC) developed by the Spanish Ministry of Environment and the University of Cantabria (González et al., 2007). In addition, they related the interactive wave and tidal current fields to historical shoreline dynamics, observed grain size distributions and developed a preliminary model for tidal inlet migration stability (as opposed to inlet opening and closure) and barrier island dynamics. This model has provided a storm-driven mechanism for inlet-barrier sediment exchange along mixed-energy tidal inlets.

In 2008 they also began analyzing the impact (residual and outlier detection) of coastal storms on shoreline migration prediction uncertainty (based on a method developed by Fenster et al., 2001 and Fenster et al., 2003). They used an *a posteriori* means of assessing the impact of a storm on shoreline position by comparing the outliers to the magnitude and timing of the largest storm prior to the photographic date used for digitizing each shoreline. Analyses of the outliers relative to two storm indices, wave energy and erosion potential have provided additional evidence regarding the important role of storms in controlling both the short- and long-term morphodynamics of these islands (i.e., storm shoreline positions are not outliers). Our outlier analysis currently involves assessing the spatial and temporal distributions of shoreline residuals along the Virginia barrier islands.

The shoreline change analysis has benefitted greatly from collaboration with Dr. Brian Rizzo, Director of the Remote Sensing Laboratory at the University of Mary Washington. In short, they have transferred the cumbersome COASTS shoreline and vegetation line data from a Fortran-based program to a Geographic Information Systems (GIS) data base for the entire VBIs (1949-1989). In addition, they are in process of adding shorelines from Geographic Positioning Systems (GPS) and aerial photographs that span the period 1990 – present thereby updating the shoreline/vegetation line inventory. Once completed, they plan to provide a new and updated shoreline change analysis of the Virginia barrier islands.

Vegetation dynamics

Frank Day has continued the annual monitoring of permanent vegetation plots (fertilized and unfertilized) and groundwater wells on Hog Island. A major new phase of their work involves expanding quantification of key parameters to other islands to evaluate generality and

variability in their data. Continued fieldwork and analyses this summer involved the study of plant biomass on grassy dunes and interdunal marshes on multiple islands of the Virginia Coast Reserve (Hog, Parramore and Smith).

Don Young and his students have completed a season of collecting avian dispersed seeds from nearly 80 'seed traps' that are placed on Metompkin, Hog, and Smith Islands on open dunes and in wooded areas. In addition, they have initiated seasonal measurements of spatial variations in soil respiration. They continue to monitor spatial variations in shrub growth and have linked these long term data with recent experimental work to identify shrub stress and the cause of stress using hyperspectral imagery.

Predator-prey interactions

A team of PIs (Ray Dueser, Nancy Moncrief, John Porter) and student J. D. Martin are working both to test their hypothesis about the pathways of gene flow between raccoon populations and to develop behavioral approaches to enhance avian habitat protection on the Virginia barrier islands. The Virginia barrier islands provide nesting habitat for 27 species of beach-nesting and colonial waterbird species. Mammalian predators, including the raccoon (*Procyon lotor*) and red fox populations (*Vulpes vulpes*), have been identified as a primary source of habitat degradation for beach-nesting and colonial waterbirds on the islands. The U.S. Fish and Wildlife Service (USFWS), The Nature Conservancy (TNC) and the Virginia Department of Game and Inland Fisheries (VDGIF) currently employ removal of raccoons and red foxes as a tool for habitat restoration. This procedure has proven to be labor intensive and only temporarily effective, with frequent colonization of removal islands by (apparently) new immigrant animals. Raccoons have not been permanently removed from any of the occupied islands. Dueser and his colleagues have used mitochondrial DNA of 100 removed raccoons to describe several pathways of raccoon movement between the mainland and islands, and between islands. They also ran a field trial in 2006 to test the feasibility of an estrogen-induced conditioned food aversion (CFA) as a management tool to reduce egg predation by any remaining or newly-arrived raccoons. This trial, which both confirmed the potential effectiveness of CFA and reaffirmed the vital importance of identifying pathways of predator movement between islands, is the basis for educational materials currently under development.

The team has worked during 2008 to (1) compile an extensive GIS database of predator capture locations and dates on the islands for the period 2003–2007, and (2) produce a set of web-based education materials documenting both our criteria for site selection for a CFA field trial/management application and our lab and field methodology for implementing such a strategy on the islands. These materials are designed to aid managers in identifying areas on the islands where a CFA strategy might reasonably be employed and assist managers in the effective implementation of such a strategy. Although additional tests and refinements of the CFA technology remain to be run, we are at a point where written guidelines and instructions and video documentation of the methodology are appropriate.

Waterbird studies

Michael Erwin conducted waterbird breeding surveys in the northern section of the Virginia Coast Reserve as part of a cooperative 5-year comprehensive waterbird project coordinated with The Nature Conservancy, U.S. Fish & Wildlife Service, Virginia Game Commission, and College of William and Mary. In Fall 2007, Ph.D. student Charles Clarkson began his studies, which focus on the role of wading bird energetics in the VCR.

Landscape Analysis

Sergio Fagherazzi and Patricia Wiberg are modeling the feedbacks between wave height and marsh landforms at the VCR. In the first phase of this work, they analyzed the response of the VCR lagoons to wind events, focusing on how the distribution of wind-wave-generated bottom shear stresses is influenced by the effect of the distribution of channels, salt marshes, and tidal flats on fetch and water depth. These two parameters, together with wind speed and direction, were then used to determine the wave height in each basin location through equations commonly used in the literature.

Enrique Reyes is producing an integrated forecast of environmental consequences of long-term effects of sea level rise and state change for the habitats of the VCR. One of the goals is to identify hot spots of vulnerability to climate-related changes in sea level and storm events. The model integrates a large-scale hydrodynamic model with a series of ecological sub-models that represent the VCR lagoons. He also initiated the development of an ecological model for the VCR wetlands and uplands. This model was designated as the VCR Landscape Model (VLM).

Data capture for the landscape model was expanded to grey literature and non-electronic sources. A quality control of meteorological and environmental data compiled from NOAA weather service archives was done. Historical sea level and tide records were collected for Chesapeake Bay Bridge Tunnel and Kiptopeke to be used as calibration and verification data. They prepared a data set for VCR topography and baythmetry using extrapolation and krigging techniques. They also began the classification of VCR time series data, which later were used for the generation of meteorological and tidal complete time series data. We proceeded with the testing of river discharge and sediment load implementation for the VLM. Boundary conditions were expanded and this required the use of new offshore tidal data. Lack of empirical information and the need to comply with National Standards guided our efforts to use synthetic data as generated by the ADCIRC project (http://www.nd.edu/~adcirc/index.htm). As part of VLM testing several runs were implemented. One test included the distribution of habitat types for the study area and boundary conditions for landscape model. Preliminary simulations for 5 and 50 years were done using a stability criterion. After these, we proceeded with a modification of the VLM to include additional habitats, potential implementation of subtidal habitats. Several software utilities were developed to aid on the data pre-processing of new information. These included the development of a utility to reformat tide information for input to the VLM. Other activities included the development of a utility to reformat tide information for input to mode and several tools to split and merge large maps so that they can be manipulated with spreadsheet programs. In parallel they began writing detailed documentation of the tools and utilities developed.

In the fall of 2007, Chip Bachmann of the Naval Research Laboratory (NRL) led a partnership of multiple institutions (including the VCR/LTER), to undertake a combined airborne multi-sensor remote sensing campaign and *in situ* validation effort (Fig. 7). For VCR'07, NRL mounted three remote sensing instruments in a de Havilland Twin Otter : a CASI-1500 , which is a visible near infra-red (VNIR) hyperspectral camera operating in the 0.38-1.04 μm spectral range, a Surface Optics hyperspectral short-wave infra-red (SWIR) camera operating in the 0.9-1.7 micron range, and a single channel mid-wave infra-red (MWIR) camera operating in the 3-5 μm range. Additional data were also obtained during the last few days of the exercise by coincident flights of the NASA EAARL LIDAR and the NRL multi-sensor instrument suite.

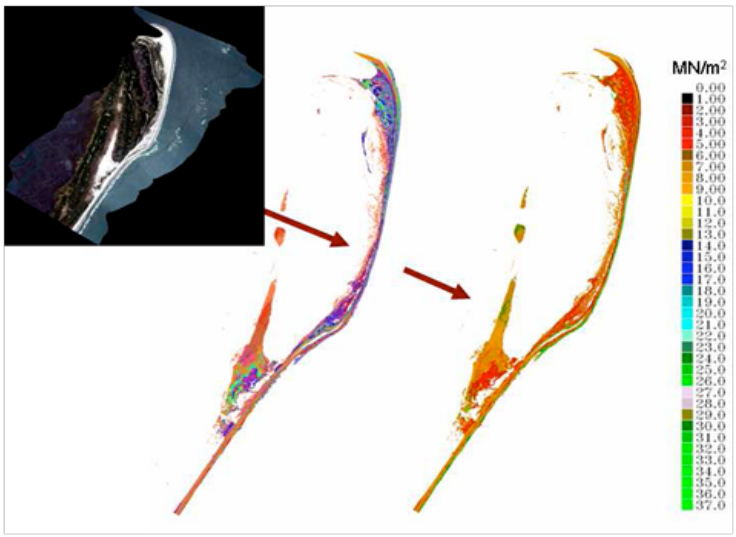


Fig. 7. Retrieval of bearing strength from CASI Imagery. (Left) CASI image of Hog Island, Sept 7, 2007; (middle) color-coded closest matched spectrum in the LUT; (right) retrieved bearing strength from LUT in MN/m^2 .

Social Science Research

Stephen Swallow and graduate student Elizabeth Smith (URI) are developing an economics experiment focused on identifying the value of ecosystem services associated with the VCR and developing and testing economic theory and methods for private delivery of public goods through market or market-like mechanisms. The experiment is planned for Fall (October) 2008. This project is funded through the 2007 social science supplement. Three areas of progress include: negotiation of cooperation with environmental managers or organizations capable of implementing small-scale actions (acre-scale) affecting ecosystem structure for production of ecosystem services; adaptation of the delivery plan for these management actions to facilitate transformation of monetary payments into actions salient to the public; preliminary design of a choice experiment suitable for testing alternative economic mechanisms (rules of payment) for generating revenues in support of ecosystem services. They have a verbal agreement with a non-profit organization involved in restoring coastal bird habitat for delivery of acre-scaled units of restoration at an acceptable cost.

They have also been exploring activities linked to seagrass restoration and shellfish (oyster or clam) restoration; however, due to the nature of current restoration efforts, which involve extensive use of volunteer labor in the VCR area, a simple payment of around $1200 for seeding of one acre of sea grass is not an acceptable arrangement for restoration leaders. The experimental plan will therefore be adapted to focus public attention on creating an earmarked

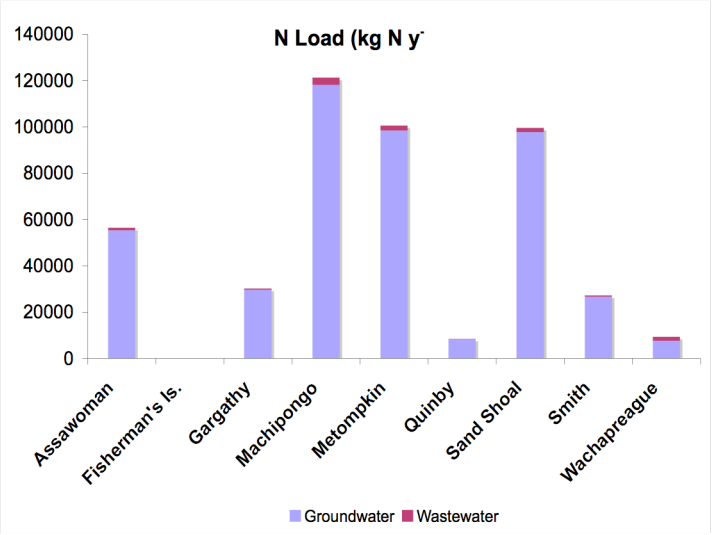
fund, dedicated to sea grass, oysters or clams that is on the scale needed to pay for an acre of restoration, but without specifically contracting for acres. Such a fund would potentially enable a larger acreage of restoration through leveraging money with volunteer labor. Work is now proceeding on an experimental design and presentation that will give individuals choices to allocate money between bird habitat restoration and funds for one or more estuarine restoration activities. In order to address choices by low-income participants, the experiment will not request payment from personal household funds. Rather, current plans will give experiment-participants choices where funds not allocated to an ecosystem service (or restoration) activity will be directed by default to generic (probably county) government purposes. These default option will simulate the opportunity cost (or alternative use) of funds allocated to ecosystem services. The economic mechanisms (rules of payment) will be chosen through end of summer and fall, but will be informed by data and newly-available results from an experimental market for grassland bird habitat in Rhode Island.

VCR-LTER ANNUAL REPORT 2008 - FINDINGS

Watersheds and Lagoons

Watershed nutrient loading

The VCR consists of some 54 tidal streams that drain small coastal watersheds and feed into the lagoons systems. Modeled nitrogen loading to the VCR watersheds based on watershed land use indicate that while there is significant variation between sites, N loading rates to all the VCR sites are significantly lower than in more urbanized watersheds to the north (Figs 1, 2).



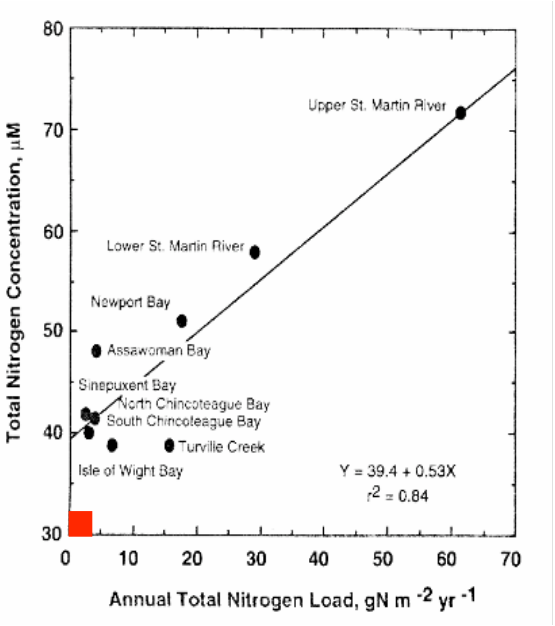


Fig. 1 (above) Modeled baseflow N loading (kg/yr) to the VCR coastal lagoons.

Fig. 2 (left) Calculated N loading to Maryland and Virginia coastal bays by Boyton et al. (1996). The red square indicates the N loading and N concentrations in the VCR coastal lagoons.

Our process work in one of these streams -- Cobb Mill Creek -- has shown that in areas where nitrate concentrations are high, and groundwater flow to the stream moves through the bed sediments, nitrate concentrations in the stream are lower than in the groundwater, and the difference cannot be accounted for by dilution alone. Process-level studies indicate that nitrate is removed by denitrification in the streambed sediments. In situations in which either the nitrate concentration in the groundwater is low or the water does not discharge vertically through the sediments, the nitrate concentration in the stream is similar to or higher than the concentration in the ground water. Storm events reduce the proportion of nitrate that is removed from the groundwater because flow-time through the beds is faster.

Riparian vegetation strongly controls the water flow to these tidal streams. During the colder part of the year and before the trees and understory develop leaves, there is no diurnal fluctuation in stream stage or in the concentrations of nitrate or chloride. In the summer, stage varies by 2-5 cm over each 24-hr period. Chloride shows a slight diurnal signal. Nitrate samples have yet to be analyzed, but a preliminary look at selected samples suggest that if fluctuation occurs, it may be too small to detect.

The vertical heat flux measured overnight in Cobb Mill Creek from a footprint approximately 5 m long using the eddy correlation system was used to calculate specific groundwater discharge to the creek. The fast temperature sensor measures changes in temperature that reflect the flux of cold groundwater into the overlying seawater (Fig. 3). Mean groundwater discharge calculated by eddy correlation was 6.8 ± 3.2 cm/d. Seepage meters installed 30 m upstream of the footprint measured a mean groundwater discharge of 5.8 ± 3.3 cm/d (Fig. 4). Future applications of eddy correlation to measure groundwater discharge will include co-location with seepage meters in some of the VCR coastal bays.

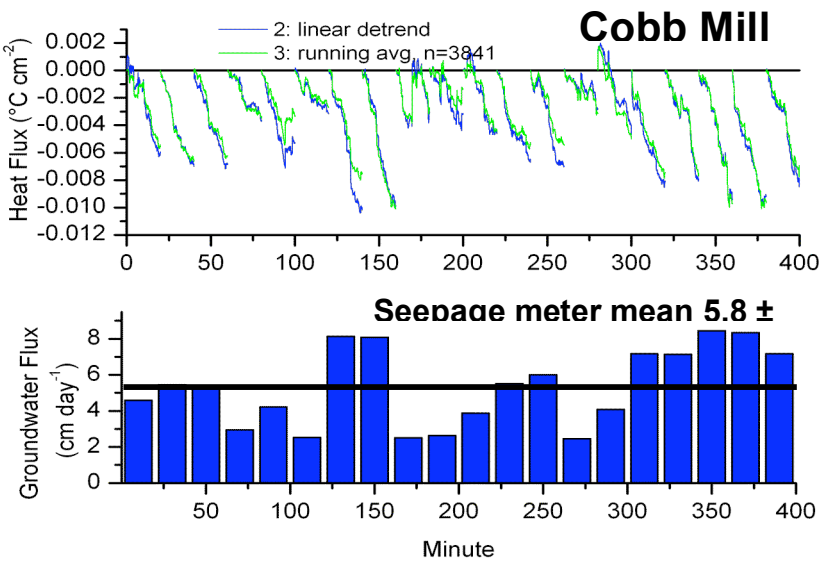


Fig. 3 (left). The eddy correlation system for measuring groundwater fluxes from the sediment to the overlying water consists of an Accoustic Doppler Velocimeter (ADV) and a fast conductivity and temperature sensor (PME). Fig. 4 (right). The groundwater flux can be determined by the heat flux over a 5-long footprint.

Water vapor and carbon dioxide fluxes

Todd Scanlon's new technique to partition fluxes of water vapor (into transpiration and direct evaporation components) and carbon dioxide (into photosynthesis and respiration components) by adapting flux-variance similarity theory combined with correlation-based arguments yielded some exciting results. The partitioning method assumes that surface-layer correlations are

influenced by the non-identical source-sink distributions of the water vapor and carbon dioxide fluxes and the relative magnitude of their constituent fluxes. The method applies flux-variance similarity assumptions separately to the stomatal and the non-stomatal exchange. Water use efficiency for the vegetation, and how it varies with respect to vapor pressure deficit, is the only input needed for this approach that uses standard eddy covariance measurements. The mathematical intricacies involved in the approach belie its conceptual simplicity, and reasonable estimates yielded by this technique when applied to the contrasting wet and dry days demonstrate its potential for flux partitioning (Fig. 5). In this example, increases in direct evaporation and respiration coincide with the onset of wet conditions.

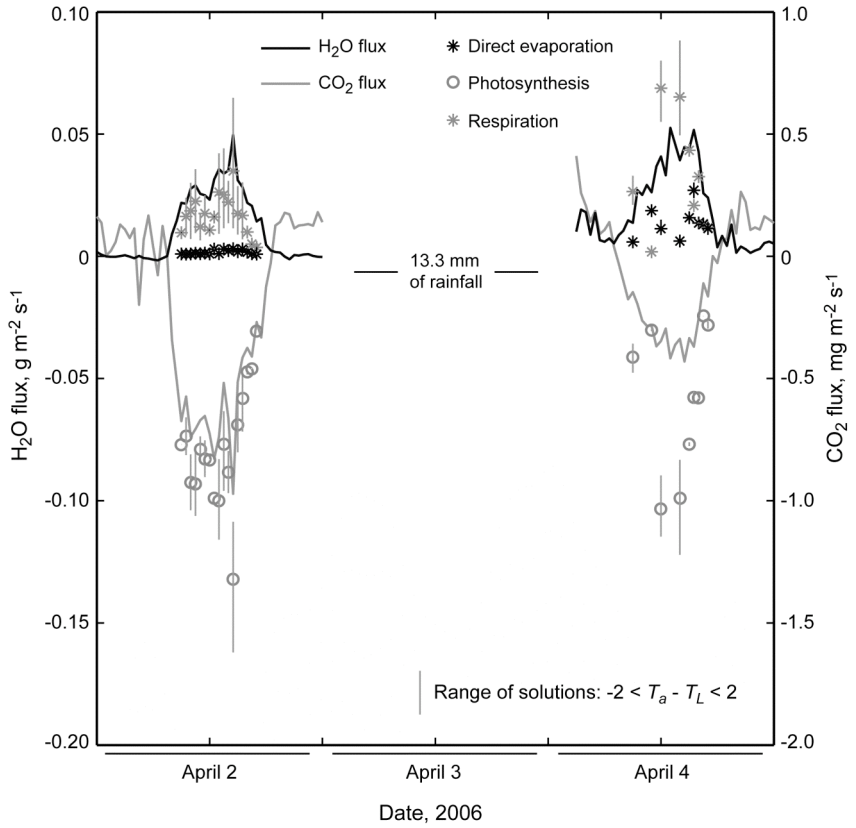


Fig. 5. Water vapor and carbon dioxide fluxes, together with their estimated components derived from flux-variance similarity theory and correlation analysis. Vertical bars represent the range of solutions obtained when foliage temperature (T_L) was allowed to vary within ±2°C of the measured air temperature (T_a).

This method can be a useful tool for interpreting measurements and improving models of water vapor and carbon dioxide exchange between the land surface and the atmosphere. Existing procedures for handing direct evaporation within soil-vegetation-atmosphere transfer (SVAT) models, in particular, are relatively crude and are especially unsatisfactory when it comes to partitioning the direct evaporation and transpiration fluxes following rainfall events. Further applications of this separation technique to field data will help improve such models. Future steps will also include verifying the results obtained by this method with independent estimates

derived, for example, from oxygen or carbon isotopic approaches that are now being used to generate the same flux partitioning information.

Lagoon hydrodynamics

Our lagoon hydrodynamic model allows us to simultaneous quantify both tidal fluxes and wind waves in the VCR tidal basins. Tidal and wave hydrodynamics are key factors for the resuspension of sediments in tidal flats, which regulates water turbidity and primary production in the water column as well as in benthic communities. Tidal fluxes also determine the morphological equilibrium of salt marshes and their resilience to climatic and anthropogenic modifications. We have run the model with different tidal and wind conditions to quantify the response of the lagoon substrate (in terms of erosion and sediment resuspension) to different external forcing. In Fig. 6 we show a comparison between wave shear stresses generated by a wind of 15 m/s blowing from North and by a wind of same intensity blowing from South. Departures from a symmetrical configuration are due to the distribution of marshes and tidal flats in the basins that affect wind fetch.

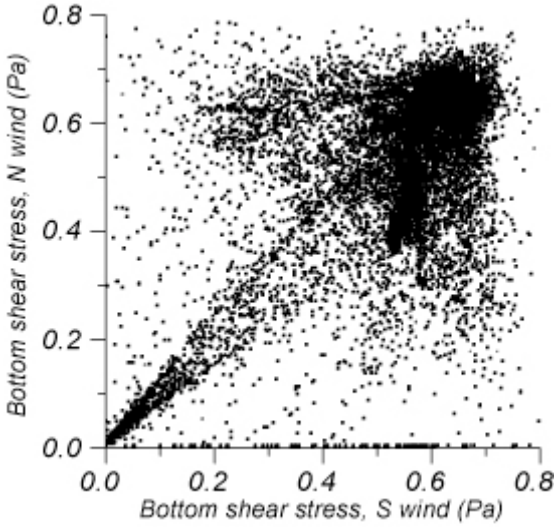


Fig. 6. Comparison of bottom shear stresses produced by waves for a wind of 15 m/s blowing from South and from

Lagoon nitrogen and carbon dynamics

Our mesocosm experiment on the uptake and fate of carbon and nitrogen in shallow sediments of lagoons along the eutrophication gradient on the Delmarva Peninsula yielded the following results:

(1) $\delta^{15}N$ and $\delta^{13}C$ analyses for TOC and TN samples from pre-labeling and the initial labeling period showed significant uptake in bulk sediments (including benthic microalgae and microbes) in the light treatments.

(2) Changes in ammonium and nitrate concentrations strongly suggest that nitrification was occurring in either the water column or porewater throughout the duration of the experiment, even in dark incubations where benthic microalgae would not be producing oxygen to fuel nitrification.

(3) The sediment-water column flux data also suggest that nitrification occurred in the long-term dark treatment, perhaps because of perfusion through the sediment of oxic pore water nutrients. In the diel light treatment, uptake was similar in the presence and absence of macroalgae. Benthic macroalgae reduce the flux of inorganic nitrogen mineralized in the sediment into the water column. We suggest that benthic microalgae also play an important role in uptake of inorganic nitrogen, either by direct removal to build biomass, stimulation of heterotrophic uptake by release of DOC, or by stimulation of coupled nitrification – denitrification.

(4) We measured fluxes of both DIC and DO in order to calculate gross primary production

(GPP), net ecosystem metabolism (NEM), respiration (R), and the production : respiration (P/R) ratio. As in many shallow coastal systems, we found that the activity of the micro- and macroalgae caused the benthic system to be net autotrophic.

(5) Coupled nitrification-denitrification determined using the $^{15}N_2$ technique showed that there was significantly more N removal via denitrification when autotrophs (microalgae and macroalgae) were not present. Some of this effect was the result of N competition between nitrifier/denitrifiers and autotrophs. It appears that benthic autotrophy does not enhance true N removal via denitrification, but instead primarily acts as an agent of N recycling.

Seagrass restoration

All restored plots in 2008 had successful germination, at rates of 5 – 10%, which is typical of a 'successful' year using the seed hand-broadcast technique. These results are similar to the results from the previous year's restoration plots. As expected, shoot densities were lower in the newly restored (1-2 yr old) plots compared to the reference sites (20 – 40 shoots per m^2 vs. 400 – 750 shoots per m^2). However, it is noteworthy that the primary production rate per shoot was equivalent between the newly restored and older reference sites. Our colleagues at VIMS have determined that over the 8 years of restoration efforts, 200 acres of seeding with eelgrass has results in some 1400 acres of total coverage in the lagoons.

Our model of ecosystem stability, which incorporates the feedback of seagrass on fluid flow, bed shear and suspended sediment concentrations, demonstrates that the Hog Island Bay is not bistable (with respect to the presence or absence of seagrass) under typical conditions. While presence of a seagrass meadow further enhances the ability of that meadow to thrive via reduction of bed shear, suspended sediment concentrations and the resultant reduction in suspended sediment light attenuation, we find that even under bare sediment conditions there is enough light for growth and maintenance of a seagrass meadow. Specifying a finer-grained (muddier) lagoon bottom pushes the system towards bistability but not enough to induce bistability. Adding eutrophication in the system can induce bistability, where a bare sediment surface or a seagrass meadow will maintain their respective states under typical temperature, sediment, current and wave conditions. The combination severe eutrophication and a muddy lagoon bottom can induce a system with a single stable bare bed state at low water depths to return to bistability at deeper water depths.

Sediment and nutrient fluxes at the sediment-water interface

Fluxes of sediment and nutrients between the sediment bed and the water column are regulated by complex interactions of physical and biological controls. These have often been considered separately, with sediment suspension controlled by physical forcing and nutrient flux controlled by biological activity. Our studies have shown that sediment suspension and nutrient flux are to a large extent controlled the density of benthic primary producers (seagrass and macroalgae) in shallow coastal lagoons. For nutrient fluxes, sediment grain size controls the relative importance of desorption and porewater advection while the magnitude and direction of the flux is controlled by biological uptake and nutrient availability.

Previous research has shown that high-density populations of benthic primary producers stabilize sediment and decrease near-bed hydrodynamic activity. Our study is the first to show that low-density populations affect the hydrodynamics differently, resulting in an increase in sediment suspension (Fig. 7). This mechanism of enhanced sediment suspension in low-density seagrass beds is analogous to results seen with other emergent features, such as polycheate tubes. These features can divert flow around rather than over the feature creating enhanced erosion. Low-density populations of macroalgae can be transported as bedload material, acting as a tool to dislodge particles, thereby increasing erosion. With macroalgae and seagrass, the key feature leading to decreased sediment suspension and bed forcing is likely the development of skimming flow, in which water is directed away from the sediment bed. The effect of low-density populations of primary producers on sediment and nutrient fluxes shows that studies of fully-developed, high-density populations can not be used to explain developing or declining populations where densities are lower. Our results have important implications for seagrass restoration efforts or for areas that have low seagrass densities due to anthropogenic or natural stresses (e.g. eutrophication, disturbance). Sediment destabilization by low-density seagrass meadows and macroalgal mats likely increases the vulnerability of these populations to light limitation during forcing (e.g. wind) events.

We also used controlled erosion experiments to determine changes in erodibility and nutrient release at three from early spring to late fall. These sites included a fine-grained mainland creek site, an intermediate-grain-size mid-lagoon shoal site, and a relatively coarse-grained back-barrier island site. Two sites showed significantly greater sediment erosion during experiments conducted on sediment cores collected during the summer months (0.07 kg m^{-2} Island, 0.15 kg m^{-2} Shoal) than the rest of the year (0.01 kg m^{-2} Island, 0.03 kg m^{-2} Shoal). Erosion at the Creek site showed no temporal variability (0.03 kg m^{-2} average for all time periods). Variations in erodiblity among sites were caused largely by differences in grain size. While the periods of high erodibility coincided with higher organic content, preceding wind speed, and temperature (Shoal only), the measured sediment characteristics and meteorological data did not explain the seasonal variability in erodibility well. Examination of further data

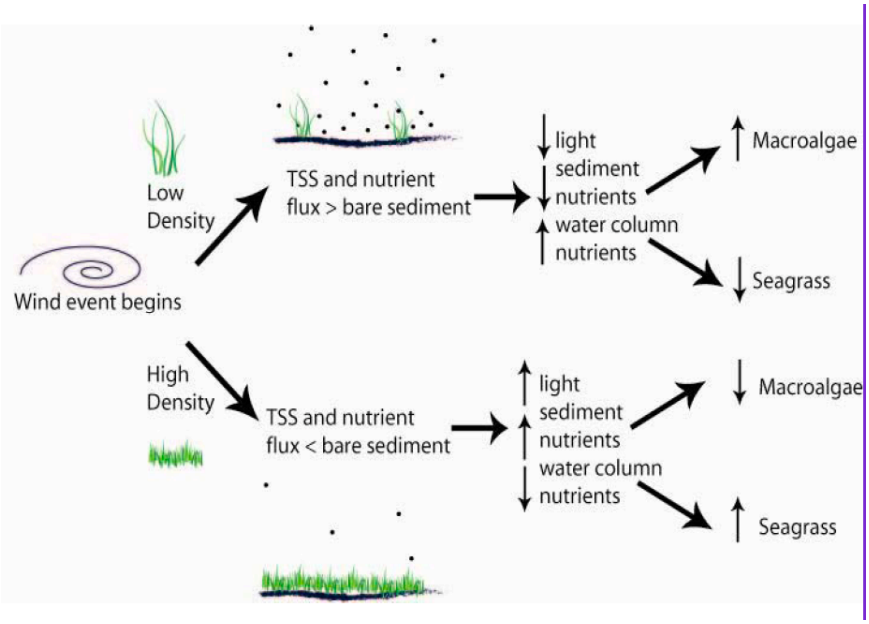


Fig. 7. Response of low vs. high density populations of benthic primary producers in response to episodic forcing caused by wind events.

available for the sites indicated that the summer increase in erodibility at the shoal and island sites is likely due to trapping of fine material by seasonal accumulations of macroalgae and increased invertebrate density during the summer months. Nutrient fluxes were almost an order of magnitude greater, both in terms of efflux and uptake, than those measured in previous low-flow incubations of cores taken at the same site. The results suggest that nutrient transport was controlled in part by desorption from suspended particles at the fine-grained site (Creek) and porewater advection at the coarse-grained site (Island). Both processes were important at the intermediate Shoal site. Nutrient flux at the Creek and Island sites was also affected by the preceding wind conditions, which may have caused breakdown of the benthic microalgal biofilm at the fine-grained site and a flushing of available porewater nutrients at the coarse-grained site.

Tidal Marshes

Marsh accretion relative to sea-level rise and related marsh studies

Ten years of salt marsh surface-elevation data obtained with soil elevation table (SET) methods show that for diurnally- and springtide-flooded areas, rates of surface-elevation change (5.8 and 4.4 mm yr^{-1}) matched or exceeded those of sea-level rise (~4 mm yr^{-1}) (Fig. 8). Change well below rates of sea-level rise were observed in storm-tide-flooded areas (2.2 mm yr^{-1}) and the long-term elevation deficit would have been even greater except that soil accretion and root zone processes appeared to partially offset the deficit. A 2-year-long drought midway through the study yielded puzzling dynamics. Pre-drought elevation changes were 6.5, 4.3, and 2.2 mm yr^{-1}. Post-drought rates were 6.7 and 5.4 mm yr^{-1} in the springtide- and storm-tide-flooded areas, whereas post-drought and pre-drought change was similar in diurnally-flooded areas. Collectively, these results suggest that the influence of severe drought on marsh elevation is substantial in some areas of the marsh and may persist well beyond the end of the drought period. In storm-tide-flooded areas, the increased rate of elevation change post-drought may be sufficient to allow these areas to

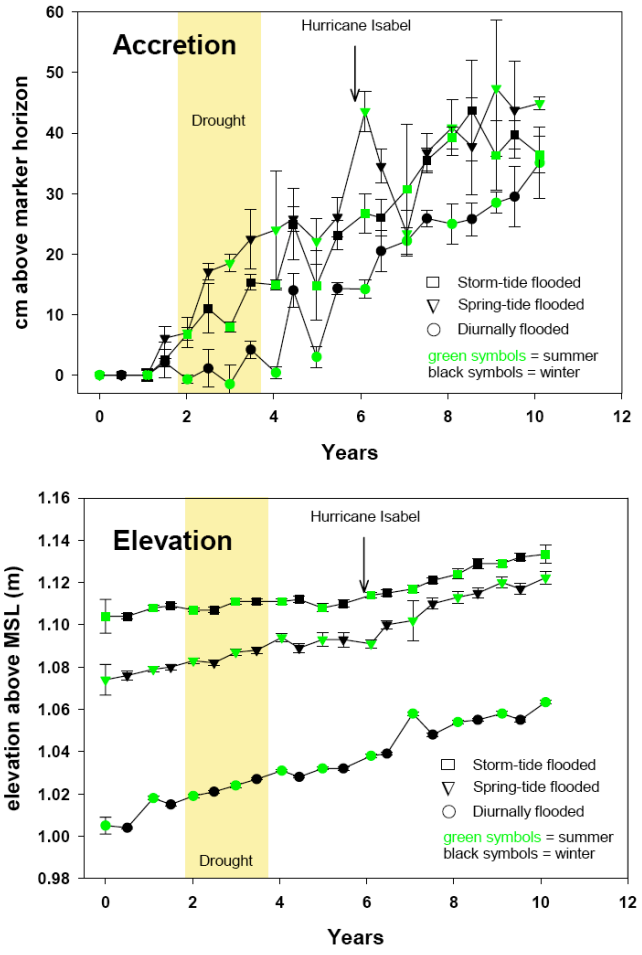


Fig. 8. Marsh surface accretion (top) and total elevation change (bottom) in Phillips Creek marsh over the last 10 years.

survive current sea-level rise. Additionally marsh surface dynamics were not correlated with marsh grass productivity measured as end-of-year-biomass.

It is becoming more evident that ecosystem states demonstrate hysteresis. They appear to be able to remain in hydroperiods of greater flooding frequency than would be expected based on their ability to establish in such regimes. Disturbance may override the hysteresis. Furthermore, in high marshes the amount of hysteresis depends on depth and extent of organic soil. This in turn depends on the age of the marsh and pattern of the antecedent surface.

Marsh erosion and changes in marsh area

Our analysis of the response of the shallow tidal basins of the Eastern Shore to wind wave events specifically focused on the interplay of basin morphology, tidal elevation and wind direction on depth, fetch and the resulting wave-generated shear stresses. The results indicate that the potential for erosion is the highest when the salt marshes are submerged. Under these conditions the direction of the wind is critical, with maximum wave heights and erosion potential occurring for winds blowing along the barrier islands of the basin (NNE-SSW) (Fig. 9).

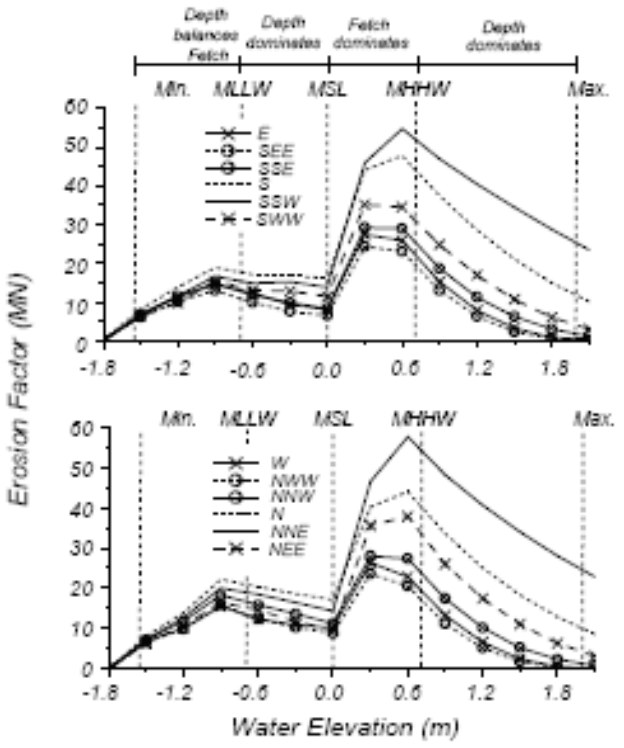


Fig. 9. Erosion factor (a measure of the potential erosion of the bay bottom) for a wind of 15 m/s as a function of tidal elevation and wind direction in the Virginia Easter Shore lagoons

We identify four bottom shear stress regimes produced by wind waves in the Virginia Coastal Reserve as a function of water elevation. For elevations between MLLW and MSL the increase in water depth dominates the increase in wave height thus reducing the bottom shear stresses. For elevations between MSL and MHHW the flooding of the salt marshes increases fetch, wave height and bottom shear stresses, producing the largest resuspension events in the bay. Finally, for elevations above MHHW, the increase in depth reduces the average bottom shear stresses, thus reducing possible erosion in the tidal flats.

Marsh carbon and nitrogen dynamics

The eddy covariance data from the flux tower allowed us to quantify the atmospheric forcings on the seasonal rates and amounts of carbon assimilation by a *Spartina alterniflora* dominated inter-tidal salt marsh. Also, the responses of the salt marsh ecosystem to tidal activity were studied to quantify the influences of tides on net carbon ecosystem exchange (NEE). In

addition to the eddy covariance data, two other data sets were used to study carbon exchange in the Fowling Point marsh system: (1) diurnal variations in plant physiological characteristics of *S. alterniflora* to establish how the leaf-level assimilation rates depend on prevailing environmental conditions, and (2) plant physiological quantities to be utilized as inputs to canopy biophysical models.

Our studies showed that *S. alterniflora* leaves had low light saturation capacity which we attribute to the likely carbon dioxide limitation rather than light stress, as higher light saturation quantities were observed under elevated carbon dioxide levels. Second, the maximum carboxylation reaction rates in *S. alterniflora* leaves had a higher optimum temperature (>35°C), which indicates that plants can become more efficient in a scenario of increased temperatures and carbon dioxide concentrations. Third, due to tidal activity, submergence can significantly reduce the assimilation capacity of *S. alterniflora* leaves. High tides contributed to 3-91% reduction in midday NEE, with an average loss of about 46±26 percent (Fig. 10). In a scenario of rapid sea level rise, which can increase the hydro-period over marshes, the carbon fixing capability of *S. alterniflora* leaves *c*an be lowered.

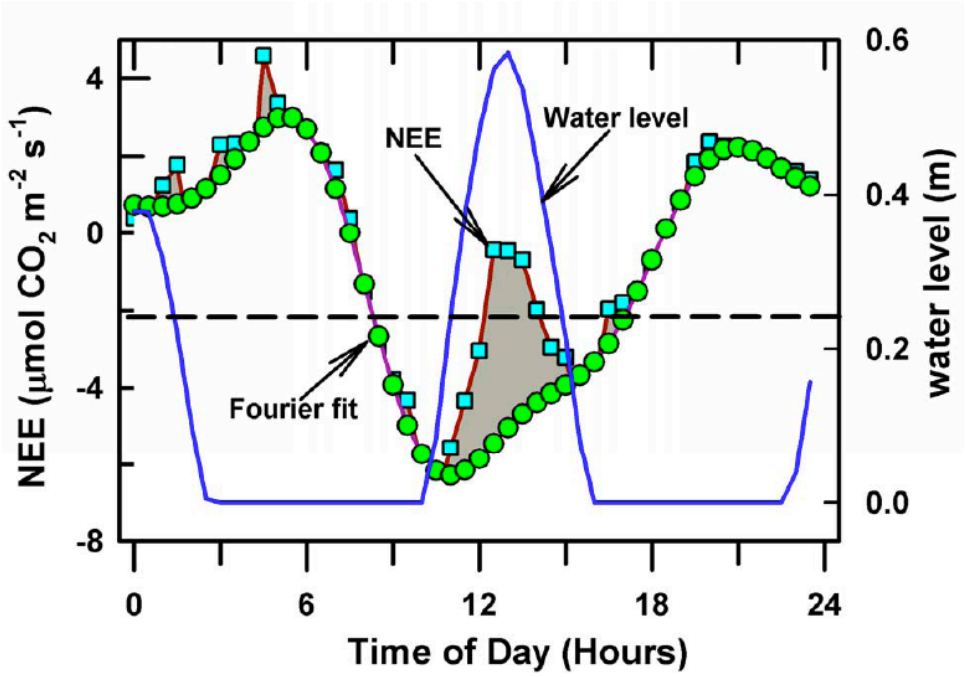


Fig. 10. Carbon fluxes, water level and Net Ecosystem Metabolism (NEE) over a diel cycle.

We also found that on a diurnal scale the NEE was controlled mainly by the quantity and quality of photosynthetic photon flux density. The comparatively inefficient light interception apparatus in *S. alterniflora* allowed light saturation under low light levels, hence light never became a limiting factor with the progress of the growing season. On a seasonal basis, changes in air temperature and specific humidity exerted strong control on NEE. The salt marsh assimilated 133 gm^{-2} during the growing season. Even though this amount is considerably lower compared to forests (600-800 gm^{-2}), the leaf area of this ecosystem was nearly half that observed for different forest ecosystems.

Using pulse-amplified fluorometry (PAM), on *S. alterniflora* plants in the flux tower footprint, our physiological studies corroborated the flux tower data. We found that that *Spartina* continues to photosynthesize underwater, however, at reduced rates compared to unsubmerged plants. We also found that flooded plants had a photosynthetic maximum at noon, while unflooded plants had photosynthetic maxima in the morning, indicating a potential interaction between CO_2 availability, diurnal patterns, light availability, and/or potential temperature stress. As long as leaves were partially exposed to the air, they maintained higher rates of photosynthesis than completely submerged leaves. We showed experimentally that *S. alterniflora* plants can assimilate NH_4, NO_3, and amino acids through their leaves, which may enhance photosynthetic efficient if no internal nutrient transport is needed during submergence to support photosynthesis.

Our continuing research on the dynamics of dissolved organic nitrogen (DON) in tidal marshes has indicated that DON use may be a factor facilitating the invasion *P. australis* into tidal marsh habitats, where it is displacing *S. alterniflora*. We also have found significant differences in N uptake in native and introduced *P. australis* lineages, suggesting that the introduced species is better adapted to take advantage and exploit N rich environments

Barrier Islands

Island geomorphology

We used long-term sea-level rise data and then compared the observed shoreline change rates for the period 1949-1989 (R. Dolan's COASTS data base) to determine standard 1-D modeling results that predict shoreline migration as a function of sea-level rise (Bruun, 1962). We did this for the following data sets: (1) the entire Virginia barrier island system, (2) one island from each of the LTER landscape box transects (Smith Island, Hog Island, and Metompkin Island), and (3) the six geomorphologic reaches along Hog Island (Harris, 1992). In all cases, the landward trend predicted by the Bruun Rule does not match the observed shoreline trends found along the Virginia barrier islands. These results support the finding that shorter-term processes, such as storms and tidal inlet dynamics, control Virginia barrier island morphodynamics.

The model for tidal inlet migration stability (as opposed to inlet opening and closure) and barrier island dynamics is based on the wave and tidal current fields, historical shoreline dynamics and observed grain size distributions. This model has provided a storm-driven mechanism for inlet-barrier sediment exchange along mixed-energy tidal inlets (Fig. 11).

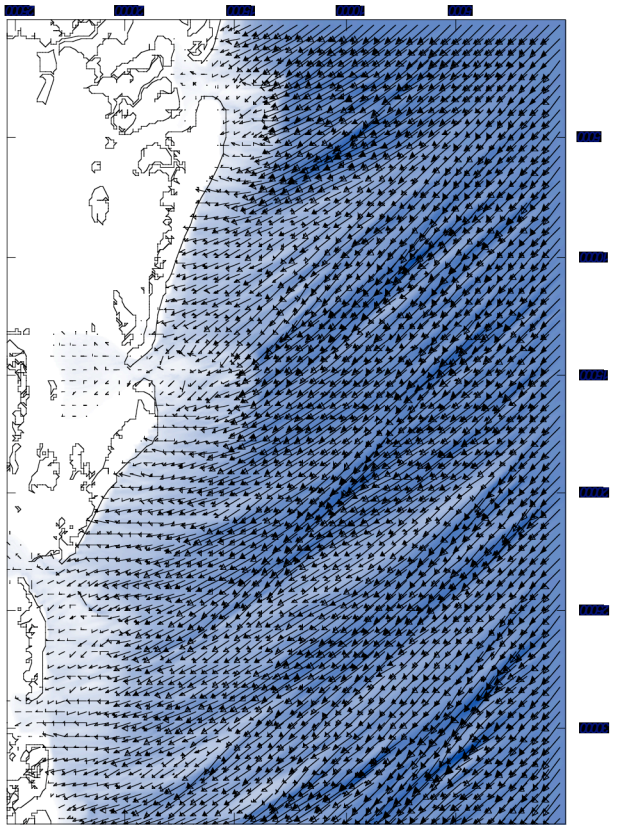


Fig. 11. Wave refraction results from a storm wave condition: ENE wave approach and deep water waves heights = 3 m. Note the concentration of refracted wave rays in the vicinity of tidal inlets. These results reveal the influence of nearshore bathymetric controls such as tidal inlet retreat paths.

The preliminary development of a sediment budget has enabled us to speculate on the sources that feed the Virginia barrier island sand prism and the sinks that remove sand from the system. The design, density, and scale of the grain size sampling program conducted along the Virginia barrier island, Assateague, and active shoreface has provided one of the most robust data sets available in North America. The combination of the sampling design and data analyses has added insight into Virginia barrier islands morphodynamics and includes the role of large shoals (i.e., Fishing Point, Chincoteague and Wachapreague Inlets) and the shoreface in controlling morphodynamics along the entire barrier island chain. In short, analyses of the offshore and onshore island data suggest that: (1) a southward fining in grain size exists along the barrier island and (2) statistically significant subsets or "pockets" of islands exist with a larger, regional trend most likely produced by differences in sediment sources and the influence of sediment sinks.

With funding from an NSF Major Research Instrumentation grant (M. Fenster), we will be purchasing the geophysical equipment needed to quantify the geometries and volumes of the offshore surficial sediments (side-scan sonar and seismic reflection profiler).

Finally, we completed a study that used non-linear modeling techniques to quantify the long-term ecotone displacement trends and the relationship between ecotone displacement and shoreline migration history on Hog Island, Virginia. The results showed that long-term trends in ecotone displacement and shoreline movement are nonlinear for over three-fourths of the Hog Island coast. On average, the shoreline and vegetation line experienced reversals in 1972 and 1974, respectively. Rarely did the ecotones and shorelines move in tandem or synchronously. Concavity tests indicated that most of the shoreline and ecotone are currently moving seaward and the distance between the shoreline and vegetation line is decreasing through time. The ecotone and shoreline trends apparently correspond to tidal inlet dynamics, individual storm events, storm climate, inherited topography (e.g., dune), and vegetation type.

Vegetation dynamics

We completed our study on shrub expansion on the VCR islands and published the results in a special issue of Ecosystems. Our study showed that intermediate-scale transfer processes, especially sediment transport and the interaction with island size, link fine-scale processes to observed broad-scale patterns of shrub expansion (Figs 12, 13).

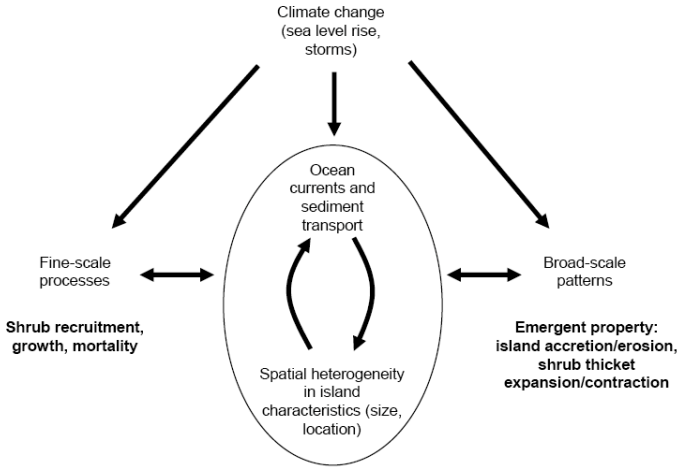
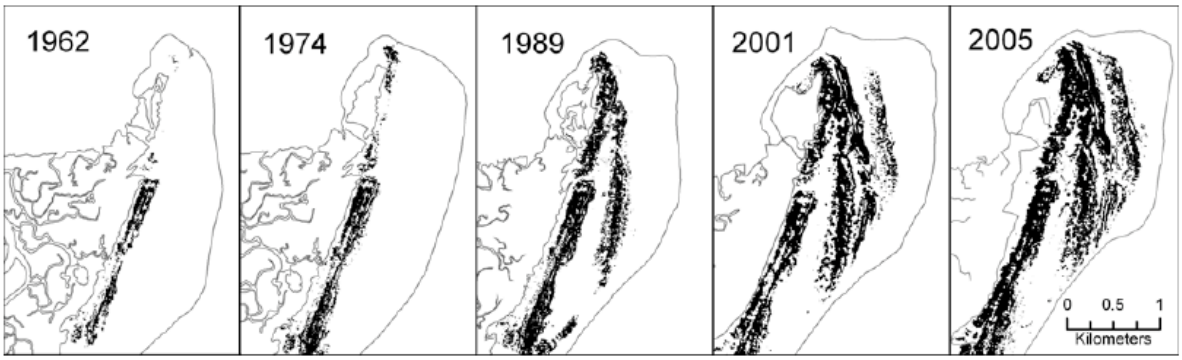


Fig. 12. (right) Conceptual model showing the relationships between climate change, fine-scale processes and broad-scale patterns.

Fig. 13 (below) Shrub expansion on Hog Island between 1962 and 2005



We continue to study the variation in biomass and diversity of dune and interdunal marsh communities on the Hog Island terrestrial chronosequence and other islands in the VCR. Grassy dunes of young, intermediate and old age were sampled on Smith, Hog, and Parramore Islands. Data were also collected for depth to groundwater, salinity, soil organic matter, total soil nitrogen and total plant nitrogen to determine the effect these parameters may have on biomass and diversity. Variation in mean aboveground biomass was evident among the islands: Hog (248 g/m^2), Smith (238 g/m^2), and Parramore (128 g/m^2). Variation in belowground biomass was even greater: Smith (796 g/m^2), Hog (375 g/m^2), and Parramore (155 g/m^2). Results also provide evidence of variation in biomass among the different age dunes. Aboveground biomass was greatest on intermediate dunes (286 g/m^2), followed by the older dunes (177 g/m^2). As may be expected, the young dunes, constantly disturbed by overwash, had the least aboveground biomass (151 g/m^2). Greater variation in belowground biomass was

also found among the different age dunes. The oldest dunes had the highest biomass (734 g/m^2), followed by the intermediate (286 g/m^2), and young (171 g/m^2) dunes.

Among islands, species richness was found to be highest on Smith (40 species sampled), followed by Hog (35 species) and Parramore (33 species). Among dune positions, the older dunes displayed the greatest species richness (17 species on average), followed by the intermediate dunes (11 species) and the youngest dunes (10 species). As was expected due to typical soil development on barrier islands, the oldest dunes displayed the highest levels of total soil nitrogen, followed by the intermediate and young dunes. Smith Island in particular showed significantly larger values on the oldest dunes (.27%) and the intermediate dunes (.09%), compared to averages of .03% and .02% respectively for those positions on Hog and Parramore Islands. Initial results show that total soil nitrogen may have a significant correlation with belowground biomass. The tall intermediate dunes had the greatest mean depth to the freshwater table (2.1 m), followed by the more weathered older dunes (1.8 m), and the newly formed primary dunes (1.1 m). Initial results show possible correlations between depth to water and biomass. Further processing is ongoing to determine values for organic matter and plant nitrogen concentrations (roots and shoots), the latter focused on *Spartina patens*, the most evenly distributed of the dominant species among the islands and dune positions.

Hog Island had the freshest interior marshes (0 and 0.7 ppm), but the least aboveground biomass (193 and 35 g/m^2). Smith and Parramore Islands were more saline (18.6 and 19.8 ppm) and had higher biomass (424 and 457 g/m^2). The saltiest marsh, Parramore Island, also had the most soil nitrogen and the most aboveground biomass. Using regression analysis, salinity and soil nitrogen were found to influence biomass (both above and belowground). Most root biomass was found in the top 20 cm of the soil and was allocated to fine roots. The depth of the water table did not seem to be strongly related to biomass allocation. Substantial variation in these parameters does exist in these marshes, making them of interest for further study.

Seed dispersal by birds is a key factor linking vegetation patterns among islands. We found that seed dispersal varied seasonally, with most dispersal occurring during the spring. Seed deposition was greatest on Hog Island and least on Metompkin. *Myrica* spp. accounted for 62% of all seeds collected and is also the most abundant woody species on the Virginia barrier islands. Two species, *Callicarpa americana* and *Sassafras albidum*, were not identified as growing near any of the seed traps and are, therefore, considered as representative of large distance avian dispersal. Passerine birds appear to be important for seed dispersal among the islands but avian dispersal is influenced by spatial variations in island topography, existing vegetation structure, and island position.

Our preliminary measurements of soil respiration indicate that immediately after shrub expansion into formerly grass dominated swales, soil respiration beneath shrub thickets is 3-4 times higher than adjacent grasslands, primarily due to increased moisture beneath thickets. However, as thickets and grasslands age, differences in respiration are reduced suggesting little long-term change in soil C loss.

Our combined field and laboratory studies of shrub (*Myrica* spp.) stress and detection have focused on the ability to identify stress based on salinity vs. drought. We have successfully linked lab measurements of physiological stress to fluoresence and reflectance spectral variation. In addition, we have linked the lab results with the field results. Thus, hyperspectral data collected over Hog Island in September of 2007 has been analyzed to identify areas of salt stress relative to drought stress.

Predator-prey interactions

The yearly trapping data for the islands have been analyzed on an annual basis, and we are now in the process of compiling the data into a landscape-level master database. Such a database will be critical for implementing either field-scale testing or management application of estrogen-based aversive conditioning as a non-lethal deterrent to mammalian predation on ground nests. We are now compiling an extensive database of GPS locations where trapping has been attempted and where the target species (raccoon or red fox) have been captured, in collaboration with The Nature Conservancy, USFWS, VDGIF and USDA Wildlife Services. When completed in fall 2008, this work will (1) provide a test of the putative pathways of raccoon movement between islands that were suggested by our earlier DNA analyses, (2) enable us to identify where on the islands the predator "hot spots" are located both geographically and in relation to active and former avian beach-nesting locations, and where removal trapping has been most effective in reducing predator incidence, and (3) produce a set of web-based education materials designed to aid managers in identifying areas on the islands where a CFA-based strategy might reasonably be employed and assist managers in the effective implementation of such a strategy.

Habitat restoration for beach-nesting and colonial waterbirds is a critical conservation challenge on the Virginia barrier islands. Mammalian predation management currently emphasizes broad-scale trapping and removal of raccoons and red foxes. We conducted a field trial in 2006 which tested the potential of using an induced (i.e., learned) conditioned food aversion (CFA) as a localized, non-lethal management tool. Our study results confirmed that relatively small doses of oral estrogen were effective in producing a CFA against egg consumption by free-ranging raccoons (J.D. Martin, M.S. thesis). Raccoons that consumed estrogen-injected (i.e., model) eggs on 2-4 occasions "learned" to avoid eating untreated (i.e., mimic) eggs. These animals even tended to shift their areas of activity away from treatment sites (i.e., artificial nest colonies). A host of innovative lab and field procedures were developed during this study, many of which were critical to the success of the field trial and are likely to be important to any field-scale management application. These procedural developments were relatively technical, but are readily teachable to novice field assistants. We concluded that CFA has real potential for field-scale application, but that the effectiveness would likely depend significantly on the use of these relatively refined techniques.
We are working in 2008 to produce a set of educational materials to aid in the implementation and further testing of this management tool. Specifically, we are working on (1) written guidelines for site selection and site set-up for optimal application of a CFA treatment, (2) written instructions for egg preparation and deployment, (3) written instructions for camera operation and artificial colony maintenance, and (4) videos illustrating the actual techniques and methods involved in applying such a treatment.

Waterbird studies

Our recent synthesis of waterbird populations (Erwin et al. 2008) has revealed that a number of species of breeding waterbirds have experienced both population changes and shifts in distribution in the coastal bays of Virginia and Maryland. Largely due to predator pressures, the VCR has seen many species consolidate into fewer, larger colonies on just a few barrier islands. Foxes and raccoons are the major predators. While wading birds have largely declined in numbers, both ibis species (glossy and white) have increased both numerically, and white ibis have expanded northward. The federally threatened Piping plovers are increasing, due largely to effective predator control on the northern barrier islands.

Landscape studies

Paleo-reconstruction

Over a decade of investigations into geologic lithosomes and stratigraphy in the LTER-VCR were summarized in a paper published in the Journal of Southeast Geology (Oertel et al, 2008). Late Holocene sea levels and paleo-drainage patterns were used to reconstruct paleogeography of the Delmarva coast and the origin of Virginia barrier islands. The barrier islands along the coast of Virginia's Eastern Shore have considerably different ages and have undergone very different migrations histories over the past 5,000 years. The origin of the barrier islands is directly linked to the marine exposure of headlands on the western side of an ancient Chincoteague paleovalley. The eastern interfluve of a Chincoteague paleovalley shielded many of the headlands during lower stands of sea level. As sea level rose, the distal end of eastern interfluve submerged exposing the southernmost headlands to the coastal ocean. The oldest islands originated on the southern coast of an Eastern Shore that was located significantly seaward of the present coastline. These barrier islands had relatively long migration tracks to their present positions. Islands get progressively younger in a northward direction with the precursors of Metompkin, Assawoman and Wallops being some of the last islands to form. The northern islands are younger and have migrated relatively shortest distances to their present locations.

Landscape model

Using the available NOAA C-CAP historical data for 1996 and 2005, a comparative map was created for the purpose of determining *a priori* hot spots or areas subject to rapid land change (Fig. 15).

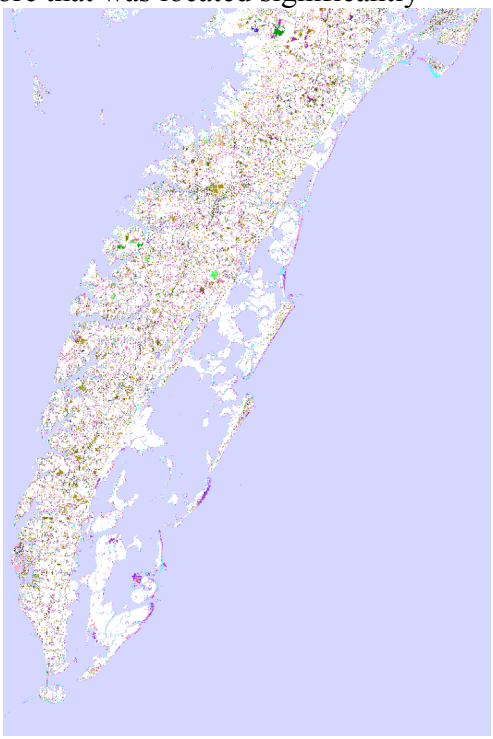


Fig. 15. VML comparative map for differences on habitat distribution between initial conditions (1996) and end results (2005).

Only subtle differences were detected within the coastal zone. However, the majority of changes appear to have occurred along the upland area. Shoreline erosion on the oceanfront is extensive and areas developed increased by almost a 40% (Table 1).

Table 1. Comparative Analysis for VCR Landscape.

Habitat	% Converted
Developed	39.08
Cultivated / Pasture	20.64
Evergreen Forest	21.87
Palustrine Wetland	68.89
Estuarine Scrub	59.23
Estuarine Wetland	0.79
Open Water	0.64

We concluded our test runs for the 10-year simulations and the 50-year test runs are in progress. Preliminary results are presented on Table 2 and Fig. 16 for 10-year simulations.

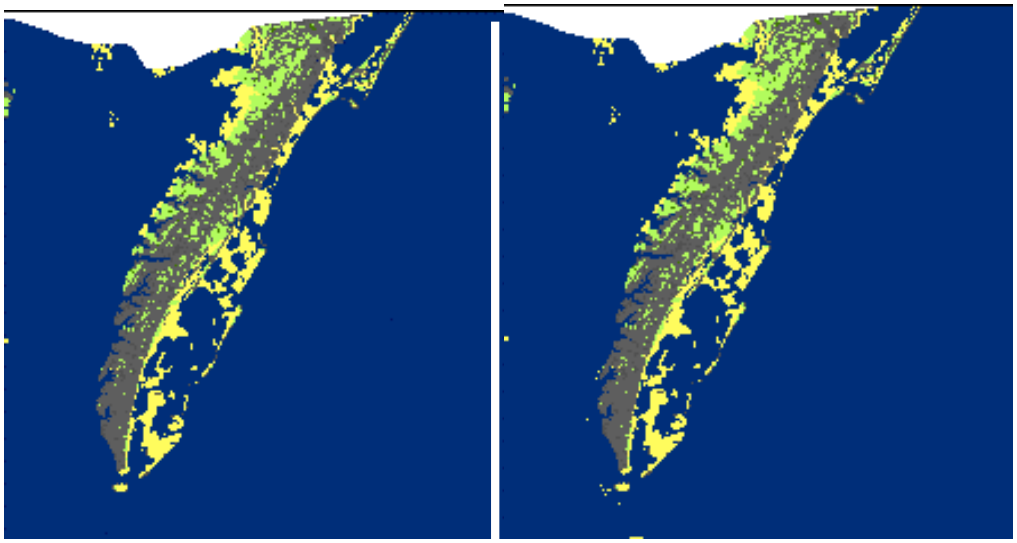


Fig. 16. VML preliminary simulation results for habitat distribution between initial conditions (1996) and end results (2005).

Table 2. Comparative Analysis of Preliminary simulation 10 yr runs for VCR Landscape Model. Units are km^2. 2005R are the actual changes determined from satellite images; 2005S are the simulated results.

	1996	2005R	2005S
Shrub wetland	0.16	0.19	0.15
High marsh	4.90	4.89	4.93
Low marsh	7.20	7.14	7.28
Open water	156.07	156.22	156.78
Forest	1.52	1.51	1.93

Remote Sensing

Applications of the NASA EAARL LIDAR and the NRL multi-sensor data thus far include development of a spectral look-up table for soil bearing strength (subsequently used to create maps of substrate bearing strength directly from the CASI hyperspectral remote sensing imagery), and development of hyperspectral models to predict very shallow water bathymetry (< 2 m) (Bachmann et al. 2008a,b). Operational LIDAR systems such as SHOALS do not produce reliable retrievals in the very shallow water regime, but at the VCR/LTER there are large areas of shallow water that play ecologically significant roles (e.g., seagrass habitat) (Fig. 17).

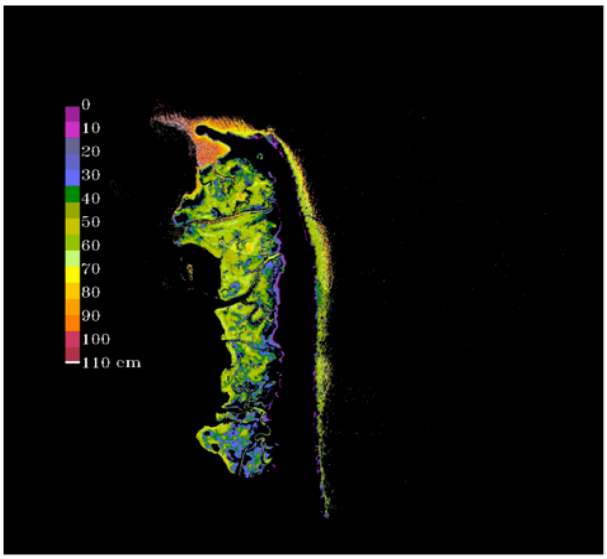


Fig. 17. Mapped shallow water depth on Wreck Island in Sept. 2007. Retrieved depth using the 810nm regressions for each bottom type determined in preprocessing from the spectral libraries. Depth is quantized in the color scale, but retrieval is continuous.

Network Activities

Bob Christian's network analysis has shown that the LTER network has demonstrated greater cohesion as it has developed since the early 1980's. Initially, no interaction between sites was seen via inter-site joint publications. In the latter 1980's and early 1990's such publications joined sites into small weakly linked groups. In the latter 1990's and on the network of sites demonstrated a strong and cohesive whole with few to no sites not interacting