Annual Report for Period: 12/2008 - 11/2009 **Submitted on:** 09/30/2009

Principal Investigator: McGlathery, Karen . **Award ID:** 0621014

Organization: University of Virginia

Submitted By:

McGlathery, Karen - 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: Reidenbach, Matthew

Worked for more than 160 Hours: No

Contribution to Project:

Co-PI, University of Virginia; research focuses on sediment movements in the lagoon. Started 2008.

Name: Moore, Laura

Worked for more than 160 Hours: No

Contribution to Project:

Co-PI, University of Virginia; research on coastal geology and ecology using remote sensing. Started 2008.

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. (2006-2010) 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. Dissertation: Consequences of shrub encroachment: linking changes in canopy structure to shifts in the resource environment.

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 ? 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; Dissertation: Variation in the availability and utilization of dissolved organic nitrogen by the smooth cordgrass, Spartina alterniflora.

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 (2003-2009), Advisor: Shugart; Dissertation: Ecohydrology of Delmarva Peninsula barrier island forests and the application of lidar to measure and monitor forest structure.

Name: Poleto, Juliette

Worked for more than 160 Hours: Yes

Contribution to Project:

M.S. student (2007-2009). Advisor: Anderson; Thesis: Nutrient Loading and System Response in the Coastal Lagoons of the Delmarva Peninsula.

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; Thesis: Spatial analyses and repletion of Gargathy coastal lagoon.

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 (2006-2009). Advisors: Mills & UVA colleague Janet Herman; Thesis: Diurnal Variations in Nitrate Concentrations in the Cobb Mill Creek, VA

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.

Name: Carr, Joel

Worked for more than 160 Hours: Yes

Contribution to Project:

Ph.D student working with Wiberg and D'odorico (2008-) Modeling, hydrology

Name: Wolner, Catherine

Worked for more than 160 Hours: Yes

Contribution to Project:

M.S. Student. University of Virginia. (2008-). Advisor: Moore. Working on remote sensing of barrier island-lagoon system.

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.

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.

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:

The Virginia County (Northampton) that houses the VCR program is one of poorest counties in the Commonwealth. It has been our experience that the majority of primary and secondary school students on Virginia's Eastern Shore have never spent significant time on the water, and few have ever ventured into the marshes or mudflats. Consequently, our involvement with this audience is very important. We have worked closely with the science faculty at the county high school to develop environmental courses to educate students about local, regional, and national environmental issues. All students in the county high school take one, and sometimes two, SLTER-based courses before they graduate; thus we have a tremendous potential impact on the local schools. In addition, the VCR Program has helped outfit the science faculty at the county high school with badly needed computers, specialized software (e.g., GIS software), portable GPS units, supplies, reference material, etc.

EDUCATION

Schoolyard LTER ? Our Schoolyard LTER program is focused on local high schools in Northampton County and contains 3 main components: 1) curriculum development, 2) teacher training, and 3) high school student summer research internships.

Curriculum - We continue to work with science faculty at Northampton High School with the successful and popular Environmental Science II class. This class is built around water quality monitoring at 26 locations along the VCR, analogous to the water quality monitoring done as part of the VCR LTER data collection. Students learn basic laboratory techniques and are engaged in local environmental issues including: land use change and coastal eutrophication, sediment runoff, climate change and sea-level rise. SLTER support was used to purchase and maintain secchi tubes, thermometers, DO probes, refractometers, and Smart Colorimeters used by the students to measure water quality parameters including: turbidity, temperature (water and air), dissolved oxygen, salinity, nitrate/nitrite, ammonia and dissolved phosphorus. Using digital cameras and hand held gps units, also purchased for the school with SLTER support, the students take pictures of the area surrounding their monitoring sites and collect latitude and longitude positional data. They use this information along with GIS software and computers supplied with SLTER funding to create GIS maps of their study sites in order to characterize the potential impacts of varying land use patterns (i.e. agriculture, development, nature preserve, etc.) on the water quality parameters being monitored. After quality control screening of the student data it is entered into a long-term database so that the students can see how the data they collected compares to data collected by previous students, allowing for analysis of long-term trends in water quality criteria along the VCR. At the end of each semester the students describe their methods and results in a PowerPoint presentation.

LTER staff and science faculty at Northampton High School also have developed a new high school science class on Coastal Ecology. This class is focused on the locally relevant human activities impacting health, productivity and sustainability of coastal ecosystems along the VCR. We also make routine visits to Northampton High School to present guest lectures and assist in classroom instruction on such topics as gps technology, seagrass ecology and water quality in Earth Science, Chemistry and Marine Biology classes. Finally, we host field trips for a variety of visiting middle and high school classes and science groups ranging in size from 10-60 students. On average, 10 school groups visit the VCR each year from the VA Eastern Shore, Virginia Beach, Norfolk, Richmond and Charlottesville.

Research internships ? Over the last 3 years we have involved 12 high school students in 8-week summer research internships. Four interns were supported in 2009; The Nature Conservancy and Volgenau Foundation provided funding for 2 of the internships. The program partners qualified high school students with graduate students conducting summer fieldwork at the VCR-LTER, and was initially motivated by a REHS (Research Experience for High School Students) supplement in 2007. Participation in this program is merit based and determined through a competitive application process. A. Schwarzschild provides program oversight and project coordination on site. Participation in this program is merit based and determined through a competitive application process. Graduate students wishing to participate in the program are required to submit a proposal detailing their summer research objectives and indicating the role a high school intern would fill as a research assistant, along with a letter of support from their faculty advisor. All high school students wishing to apply are required to attend an orientation meeting in which they are introduced to the graduate students selected as mentors and presented brief summaries of the available research positions. The high school students then submit applications including: a prioritized list of the projects they would like to work on, a copy of their high school transcript, a letter of recommendation from at least one science teacher, and a an essay detailing why they wish to participate in the REHS program and what they hope to gain from the experience. They work under the direct supervision of their graduate student advisor on assigned tasks, and are also expected to conduct a related project of their own design. All participants gather for informal dinner meetings several times throughout the summer to discuss the progress of their projects. At the end of the summer each intern is required to make a public presentation of the results of their activities.

Undergraduate Research ? Each year the VCR LTER supports at least 2 undergraduate students with supplemental funding from the NSF Research Experience for Undergraduates (REU) program. Each student is partnered with a PI and graduate student as mentors for a 10-week field season. Students are based at the VCR site and assist with the ongoing research activities of their mentors, plus conduct a research project of their own. We expect students to present their work as a poster at the annual VCR LTER All Scientists meeting; UVA undergraduate students also typically make poster presentations at the annual Department of Environmental Sciences annual Graduate Student Symposium.

In addition to REU interns, undergraduate students have also been successful in obtaining their own funding for LTER research. This year, one student in McGlathery's lab applied with her graduate student mentor and received $5000 research grant from UVA to continue their LTER work.

Graduate Training ? Graduate student training is an important part of our education mission. Each year we provide support for approximately 20 students who conduct their research at the VCR LTER site; about half of these students work with UVA PIs and the other half work with VCR PIs at partnering institutions. All completed M.S. and Ph.D. theses are uploaded on our website: http://www.vcrlter.virginia.edu/thesis/thesis.html.

Outreach Activities:

The LTER has developed links with conservation organizations, and local, state, and federal agencies through outreach efforts. The LTER has a strong partnership with The Nature Conservancy (TNC), and through this we address the important management and conservation problems that face the region. This puts us in an excellent position to provide a solid, scientific foundation for making decisions related to planning, management, and ecosystem restoration. A good example of this is our collaboration with The Nature Conservancy (and VIMS) on the seagrass restoration in the VCR coastal lagoons. We provide key data (e.g., lagoon bathymetry) that facilitates the restoration program, and we also provide logistical support for the volunteer-driven TNC efforts on seagrass and oyster restoration.

An important part of outreach to the local community is a public seminar series hosted by the LTER and ABCRC, with monthly presentations by scientists working on the coastal barrier system. The purpose of the seminar series is to educate the local public about environmental research, management and restoration projects being conducted on the Eastern Shore of Virginia.

A new outreach partnership began in summer 2009 with the development of a teacher-training workshop hosted at the ABCRC and instructed by VCR-LTER field staff in conjunction with the staff of Chesapeake Experience, a non-profit organization specializing in outdoor environmental education programs (www.chesapeakeexperience.org). This 3-day mini-workshop was held in May and involved 10 teachers from school districts around the Williamsburg and Hampton Roads areas. Teachers kayaked through the coastal waters of the VCR, hiked through a slat marsh and visited a barrier island while being introduced to the environmental issues affecting ecosystems of the VCR. Discussion groups and a final workshop were used class to help the teachers develop ways to incorporate this information into their regular lesson plans. Our goal is to continue this partnership and host at least 2 workshops each year, one in the spring and one in the fall.

A monthly public seminar series was initiated at the Anheuser-Busch Coastal Research Center (field laboratory for the VCR/LTER) in September of 2007, and continued through 2008-2009. 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.

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 4 Terabytes of information and responded positively to formal 430 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 has begun to replace the VCR/LTER web server (currently running on a Sun workstation). Currently the main web page and MYSQL database have been moved to the new server, but specialized functions are still provided by the old serve. 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.

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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 120 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), storm disturbance, 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 the 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 most recent research has shown that nitrogen is retained in the sediments for a longer time than would be expected by turnover of plant biomass because nitrogen 'shuttles' back and forth between bacterial and benthic microalgal pools.

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 in 2007, 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. In addition, there may be landscape-level feedbacks where stabilization of the lagoon sediments by seagrass restoration may reduce the availability of sediments for marsh accretion. This may have implications for the ability of marshes to keep pace with increasing rates of sea-level rise.

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 changes in sedimentation and subsidence 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) and the feedbacks on sedimentation rates, 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 on mainland marshes, the rate of accretion is generally keeping pace with sea level rise, and that specific rates 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.

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 our work to date have increased our understanding of dynamic vegetation changes and their causes in coastal barrier island ecosystems. We have established that landscape position is they key factor controlling the pattern of plant community development and production on the islands, with distance from the shore (and susceptibility to salt spray and overwash disturbance) and elevation (and distance to the groundwater) as the important factors defining landscape position. 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 ofr 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.

We have used NOAA data to assess changes in land use/land cover in the VCR watersheds for the last 20 years. For all the VCR watersheds, we found that changes over time were typically very small, illustrating how little development pressure the VCR watersheds receive relative to other watersheds in the mid-Atlantic region. These watersheds can be compared with more developed watersheds in the mid-Atlantic region to compare the effects of different levels of development and eutrophication on coastal bay processes.

Our modeling of the evolution of barrier islands reveals that substrate composition, followed by sea-level rise rate, and sediment supply rate, is the most important factor in determining barrier island response to sea-level rise. These results suggest that although barrier island migration rates may increase significantly in the future, barrier islands with sufficiently thick and sandy substrates are likely to persist as long as landward migration is not impeded and shoreface erosion can occur quickly enough to liberate sand volumes necessary to maintain subaerial exposure. We are now building on this work to address the biotic feedbacks of island vegetation structure on the island geomorphodynamics.

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. He has continued work as an elected member of the LTER Network Information System Advisory Committee.

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. Each year, the VCR LTER supports approximately 20 graduate students who conduct their M.S. and Ph.D. projects at the VCR site.

Our SLTER program, and related activities, have helped introduce scientific concepts to K-12 students. All high school students take an LTER-based course before they graduate, and some take more than one course.

Contributions to Resources for Research and Education:

The VCR/LTER web page is widely used. Between the start of the current grant cycle and late July 2009, over 4 terabytes of information have been downloaded by over a half million distinct servers (http://www.vcrlter.virginia.edu/analog/Nov2006toJuly2009/). On a daily basis an average of over 4 gigabytes of information are transferred. However, such raw statistics can be misleading because search engines (e.g., Googlebot) make up a large number of the 'hits.' More telling is that users came from over 190 different countries or international organizations (as shown by network domains). Countries with over 100,000 requests included India, Switzerland, Netherlands, Czech Republic and China, and 32 additional countries each had over 10,000 requests. Similarly the large number of distinct hosts (550,000) reflects a wide user community.

A more important measure of impact is datasets that are formally downloaded. These formal data requests require users to fill out a data license form. During the current grant, we have had 430 formal data requests. Not surprisingly, roughly one half of the data requests came from faculty and students in some way associated with the project (51%), almost entirely for research purposes. However, researchers and students not associated with the VCR/LTER requested 207 datasets, most (68%)were for research use, with the remaining 32% for educational uses (class projects, etc.).

The VCR/LTER has provided a variety of video products, including interviews of seagrass researchers, field trips, data collection procedures and formal presentations on educational and video sharing sites such as SciVee and COSEE. A compilation of these can be viewed at: http://www.vcrlter.virginia.edu/video/scivee.html. Additionally, brief video clips for inclusion in presentations are available at: http://www.vcrlter.virginia.edu/video

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 ABCRC 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.

Conference Proceedings

Special Requirements

Special reporting requirements: None
Change in Objectives or Scope: None
Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Any Conference

VCR-LTER ANNUAL REPORT 2009 - ACTIVITIES

Long-term Data sets

We continue our collection of long-term data sets that constitute the core of our long-term monitoring. These are summarized in the table below:

Long-term data set	Core Area	Research Question
Groundwater levels	nutrients, disturbance	A, B
Meteorology	disturbance	A, B, C
Tides	disturbance	A, B, C
Lagoon water quality	organic matter, nutrients	A, B, C
Watershed stream nutrients/discharge	organic matter, nutrients	B
Marsh vegetation (EOYB)	primary production	A, C
Lagoon vegetation	primary production	A, C
Island vegetation	primary production	A, C
Sediment elevation tables	organic matter, disturbance	A, B
Mammals	trophic dynamics	A
Colonial waterbirds	trophic dynamics	A (data set maintained by VCAP)
Lagoon fish	trophic dynamics	A (initiated 2009)

Specific details about the location of sampling sites and the frequency of monitoring are listed below:

- *Water quality transects* in 2 focal lagoons, Hog Island Bay and South Bay, including analysis of light, dissolved oxygen, temperature, total suspended solids, inorganic and organic nutrients, chlorophyll
- *Meterological 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 at 9 sites to estimate annual productivity
- *Island vegetation biomass and percent cover* estimates along a chronosequence on Hog Island.
- *Seagrass biomass and productivity and sediment characteristics* in a seagrass chronosequence of restored meadows in Hog Island and South Bays, representing ages 0, (bare), 1, 2, 3, and 7 years, and a mature reference site.
- *Groundwater levels* at 10 stations on Hog Island in marsh and upland habitats, 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* in restored seagrass beds and adjacent bare sediments
- *Small mammal population surveys* 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

Research activities conducted over the period November 2008 – October 2009 are detailed below.

Watersheds and Lagoons

Watershed nutrient loading

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. In 2007-2008, a team of PIs and students (K. McGlathery, I. Anderson, collaborator M. Brush, students L. Cole and J. Poleto) used a watershed nitrogen-loading model to estimate annual baseflow nitrogen loads from 8 watersheds within the VCR (Fig. 1). We adapted the Nitrogen Loading Model (NLM) that was developed and validated by Valiela et al. (1997, 2000) for a Massachusetts coastal bay system. In 2008-2009, we compared our watershed nitrogen-loading estimates to similar estimates in several Maryland and Delaware coastal lagoons to put the VCR within a regional perspective.

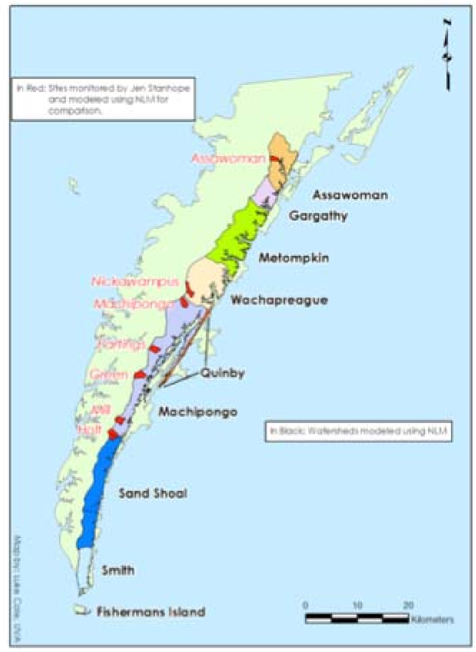


Fig. 1. Watersheds in the VCR used for the Nitrogen Loading Model estimates.

In the model, nitrogen enters the system via three inputs: atmospheric deposition, fertilizer application (agricultural and residential) and wastewater from septic systems. Inputs are then subject to a series of reductions as they travel through different land covers, the vadose zone, and the aquifer, eventually arriving at a total nitrogen load entering the receiving water body from the groundwater (Valiela et al. 1997). Land cover categories in the model that influence these reductions include agriculture, residential turf, natural vegetation and impervious surfaces. The model was modified to include crop specific fertilization rates, areal extent of crop, and calculations for crop nitrogen removal and attenuation for additional nitrogen (Cole 2005).

PI A. Mills and his collaborators (graduate students P.Probasco and W. Robertson, colleague J. Herman) have continued their work on a regional examination of low-relief coastal streams in the VCR coastal watersheds to determine the extent to which these stream systems remove nitrate discharging from groundwater. In addition, permanent instrumentation (peizometers, survey monument, stream gauges) has been set up at three streams draining each of the major study lagoon systems (Gargathy Bay, Smith Bay) to monitor base flow, storm flow and nutrient discharge via streams to the coastal lagoons. (2) They began a study to obtain high frequency discharge and chemical data to test the hypothesis that decreased flux 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, we began a study

Nitrous oxide and water vapor fluxes

PI T. Scanlon and his students are 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.

In addition to the TGA, he has instrumented the site with an acoustic sensor at the outlet of the marsh, which measures bidirectional discharge in response to tidal fluctuations, and a stilling well and pressure transducer upstream of the marsh to measure inflow. Much of this instrumentation has been purchased through an NSF CAREER grant to Scanlon, and is connected to our wireless network to allow for continuous monitoring. To supplement the TGA work, Student C. Funk began a chamber study in summer 2009 to characterize the temporal and spatial variability of N_20 fluxes from the marsh surface within the flux tower footpring.

Lagoon bathymetry and hydrodynamics

Students and VCR staff working with PI G. Oertel have completed bathymetric surveys of the Gargathy and Magothy bays that serve as the foundation for developing the hypsometric relationships, hydrodynamic and seagrass restoration models for these systems. We now have 3 systems surveyed in the VCR as part of our mainland-island box transects.

We have previously assessed the potential for seagrass recolonization and survival by coupling high-resolution measurements of water column turbidity, wave height and currents with a mechanistic, system-wide model that describes the amount and variability of light reaching the seafloor (Lawson et al., 2007). The Lawson et al. (2007) model estimates sediment resuspension by combining a two-dimensional finite element hydrodynamic model for tidal and wind-driven currents with a wave model; both are both forced with wind data and compared with our Acoustic Doppler Profiler (ADP) measurements of turbidity, currents and wave height (Lawson et al. 2007). PIs Fagherazzi and P. Wiberg are now using the finite element model IMAGE, also used in the Venice lagoon, to simulate hydrodynamics (coupled tides, wind-driven currents and waves) in the VCR. From the simulated distribution of bottom shear stresses, sediment resuspension and light attenuation can be calculated as in Lawson et al (2007). We are applying this model to examine light attenuation and water residence times in two other lagoons in our new box transects – Gargathy Bay and Magothy Bay – that vary with respect to geomorphology and nutrient loading. The accuracy of modeled currents, waves and resuspension is sensitive to the bathymetry/topography of the VCR landscape.

Hydrodynamic modeling provides a valuable tool for filling in the spatial and temporal picture of flow and estimating residence times. There are a number of hydrodynamic models that could be used in our system, including Bellamy (Ip et al, 1998) used to evaluate residence times in Hog Island, FV-COM which is being used in the PIE-LTER (Chen et al 2007) and ROMS which has been applied to a range of estuarine and shelf sites (Warner et al 2008). After considering a number of models, we decided to use the IMAGE model (Carniello et al. 2005), a 2D (depth-averaged) finite-element model that resolves tides, wind-driven currents and waves. 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, similar to the morphology of Venice lagoon. PIs P. Wiberg and S. Fagherazzi are collaborating with the Italian scientists who are developing the model to share model testing and new algorithms.

The IMAGE 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, solved on the same triangular mesh (D'Alpaos and Defina 2007). We have developed a preliminary grid for the VCR based on NOAA bathymetric charts and detailed bathymetric measurements in Hog Island Bay. Because of the shallow depths characterizing much of the VCR bays and the extensive salt marshes, calculated flow fields – and particularly wave fields – are sensitive to details of topography/bathymetry. One of the most significant steps forward we will take in the near future is the acquisition of LIDAR data for the VCR.

The application of IMAGE to the VCR was tested using field measurements of waves and tidal elevations. Water levels and wave regime were measured using high resolution pressure transducers (three RBR TGR 2050P and two Nortek Aquadop), deployed simultaneously in five sites within Hog Island Bay from January to March 2009. The model was run to simulate two storm events in this period: one from 01/31/09 to 02/05/09, and one from 03/01/09 to 03/02/09. The wind measured at the Wachapreague NOAA station (ID8631044) was used as input for the model. The model reproduces the water level at all sites as well as wave regime. In particular the model captures the wave dependency on wind speed, fetch, and water depth.

Lagoon nitrogen cycling and system metabolism

PI I. Anderson and student A. Hardison conducted a series of stable isotope tracer experiments to understand N uptake and retention by the sediment microbial community, the influence of living and decaying macroalgal biomass on microbial N cycling, in our focal lagoon, Hog Island Bay. Stable isotope tracers (^{15}N, ^{13}C) are particularly useful for tracking C and N through the sediment microbial pool because microbial biomass is difficult to separate from the sediment matrix. Compound specific isotope analysis (CSIA) is perhaps one of the most powerful geochemical tools available to unambiguously trace C and N through a system. CSIA is commonly used in microbial ecology because it provides the best tool for tracing C into microbial fatty acid biomarkers. Amino acids (AA) have an advantage over lipids because they allow both C and N to be analyzed using CSIA. Specifically, D-amino acids (D-AA) from peptidoglycan, a cell wall component found uniquely in almost all species of bacteria, have been used as bacterial biomarkers since bacteria are the only organisms to incorporate D-AA into their biomass; all other organisms utilize only L-amino acids (L-AA). Using bulk sediments and AA biomarkers, we conducted two ^{15}N isotope tracer experiments in HIB to study N cycling within the sediment microbial community. In the first experiment, they tracked the uptake and retention of ^{15}N-labeled DIN ($DI^{15}N$) by benthic microalgae and bacteria in the presence or absence of bloom-forming nuisance macroalgae (*Gracilaria*) to assess the direct and indirect effects of macroalgae on bacteria-benthic microalgae coupling (Hardison et al. *In prep-b*). In the second experiment, they tracked the fate of macroalgal-bound ^{15}N after a simulated macroalgal die-off using sediments and macroalgae from HIB and Isle of Wight Bay, Maryland to evaluate the role of the sediment microbial community in retaining N following a macroalgal die-off (Hardison et al. *In prep-a*).

We take advantage of the multiple watershed-lagoon systems in the VCR to assess patterns of net ecosystem metabolism (NEM) in relation to nutrient loading and water residence time. Student J. Giordano, PI I. Anderson, and collaborator M. Brush measured NEM using a component approach in 4 lagoons -- 3 in the VCR and 1 in southern Maryland. We plan to extend this work by linking the patterns of production to the estimates we will make of water residence times.

PI B. 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 K. McGlathery, I. Anderson, C. Tyler (former VCR graduate student, now Assistant Professor at Rochester Institute of Technology), an Italian colleague P. Luigi Viaroli, and a new international colleague Victor Camacho-Ibar. "Ecosystem Health" of coastal lagoons in response to external nutrient loading is being assessed through this modeling effort.

As the VCR coastal bays shift from a benthic algal to a seagrass-dominated state, we expect changes in nitrogen cycling processes. Specifically, we would expect an increase in the retention of nitrogen in plant-bound biomass, an increase in nitrogen fixation due to the positive feedback of DOC release from plant roots on bacterial nitrogen fixers, little change in nitrogen loss via denitrification because of nitrogen limitation from continued competition with benthic plants, and a decrease in mineralization rates (McGlathery et al. 2007; McGlathery 2009). We are focusing our current seagrass N cycling studies on N fixation and denitrification in the chronosequence of seagrass meadows. Our first year of results on N fixation show a trend of increasing rates for both epiphytes on the seagrass leaves and heterotrophic bacteria in the sediments as the meadows age (student L. Cole, PI K. McGlathery). Interestingly, the intermediate-aged meadows have N fixation rates similar to the reference site. We began our studies of denitrification and nitrogen retention/turnover in seagrass biomass in summer 2009.

Seagrass Restoration

We continue our 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. We have worked with Orth to design a restoration program for seagrass meadows in the VCR lagoons that allows us to track experimentally the ecosystem consequences of the return of this important species to the VCR. Orth has ~30 years of experience in seagrass restoration by seeding, and also has a large program in the Chesapeake Bay region. In fall 2006 and again in 2007, 1.5 million seeds were broadcast in the 509-acre 'set-aside' in Hog Island Bay. In both years, the seagrass was broadcast in a 2 x 2 factorial design, with 2 seed densities (50,000 and 100,000 per acre) and 2 plot sizes (0.5 and 1.0 acre), with 6-7 replicates per treatment; in 2008, 6 plots were added with 100,000 seeds in 1-acre plots. This is the bay where we have focused our production and nitrogen process studies in the algal-dominated state for the last decade, and we can now compare changes in sediment, nutrient, plant and animal characteristics of the system as it moves to a seagrass-dominated state. This experimental design also allows us to address issues of scale and density, and to follow changes in state variables over the long-term in a time-series analysis. In addition, we take 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 using replicate 100,000 seed – 1 acre plots of different age classes. The chronosequence includes at this time: 0 (bare), 1, 2, 3, and 7 year plots, and a mature reference site.

Our work on the seagrass state change is integrative and involves: 1) monitoring state variables related to nutrient cycling, primary production, and trophic relationships; 2) process studies on nitrogen cycling, net ecosystem metabolism, and sediment transport; 3) genetic studies relating genetic diversity to regional patterns and restoration success; and 4) modeling the dynamics of state transitions in the system (see also Question A1). This is a large interdisciplinary effort involving a number of PIs (K. McGlathery, P. Wiberg, P. Berg, M. Reidenbach, P. D'Odorico, L. Blum) and their students (9 in total). Also, we have involved REU, high school students (REHS) and high school teachers in the effort each year (UVA news story: http://www.virginia.edu/uvatoday/newsRelease.php?id=5537).

A number of students have their thesis projects focused on the seagrass state change:

• Ph.D. student L. Cole is working with K. McGlathery on the consequences of the seagrass state change on nitrogen cycling. Specifically, he is looking at processes of N fixation, denitrification, and N assimilation in the seagrass-vegetated in the chronosequence compared nearby bare sediments colonized only by benthic algae.

• Ph.D. student L. Reynolds is also working with K. McGlathery and PI J. 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 one of the foremost experts on seagrass genetics.

• J. Carr (Ph.D student) is working with PIs Paolo D'Odorico, P. Wiberg, and K. McGlathery to develop a state change model incorporating the dynamics of seagrass on modifying the fluid environment to investigate whether the seagrass system in Hog island bay exhibits unistable or bistable behavior. Combined wave and current shear stress, an active bed layer formulation and vertical diffusivity is used to calculate suspended sediment across grain size classes. 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. The model is used to explore of the effects of grain size, shoot density and canopy height, water depth, water temperature, eutrophication, and relative storminess on the light necessary for sea grass growth/maintenace.

• Ph.D. student J. Romanowich is working with PI Matt Reidenbach to understand how seagrass beds within South Bay affect boundary-layer flow dynamics and how this impacts the deposition and erosion of sediments within the lagoon. Dense seagrass beds create regions of reduced flow that promote sedimentation and the retention of particles, however we know little about the effects of shoot density on this process. 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. Deployments of multiple profiling and single point acoustic velocimeters are being used along with sediment sensors to calculate the flux of sediment above and within the seagrass bed. They are also developing an in situ underwater laser-based velocity measuring system. Particle image velocimety (PIV) has been used for a number of years in laboratories to measure velocity and turbulence over an area ranging from mm^2 to m^2. This system uses a laser and optics to create a laser light sheet that illuminates suspended sediment particles, and then sediment motion is recorded using a digital camera. A two dimensional map of sediment velocities is obtained using software that tracks particle motions over time. These data are being used in conjunction with the longer-time series data obtained from the acoustic velocimeters to determine how fine scale shear impacts sediment entrainment and distribution around seagrass blades.

• Ph.D. student D. Gulbransen is working with K. McGlathery on the impacts of the invasive seaweed, *Gracilaria vermiculophylla*, on seagrass and marsh ecosystems in the VCR. This 'super invader' is tolerant of a wide range of environmental conditions, and may impact seagrass restoration success.

• M.S. student T. Robertson (working with PIs L. Blum, P. Wiberg, and K. McGlathery) is finishing his work on 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.

Flow dynamics and metabolism of oyster reefs

In addition to our work on seagrass, M. Reidenbach and M.S. student E. Whitman began a collaborative project with TNC in 2009 to measure flow, sediment uptake and net metabolism by restored oyster reefs (*Crassostrea virginica*). The oysters were once prominent along the lagoonal land margin in the VCR and our partners at TNC are doing large-scale restoration of oyster reefs in the area. Filtration by oysters increases light availability to the benthos, and biodeposition of sediments is an effective bio-filter for nutrients. An oyster reef just off-shore from the LTER lab in Oyster was instrumented with sensors to measure flow, sediment flux, and the uptake of oxygen by the oysters

Tidal Marshes

Marsh accretion relative to sea-level rise

PIs L. Blum, M. Brinson, and B. Christian now have a 12-year data base on salt marsh accretion in relation to sea-level rise at our core study site, Phillips Creek Marsh. Sediment Elevetation 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. They are particularly interested in the relationships between marsh elevation/accretion and plant biomass, groundwater elevations, patterns of tidal flooding, and rainfall. We also monitor SETs in several other lagoonal and mainland marshes as part of studies on sea-level rise effects on colonial waterbird nesting (M. Erwin) and climate change effects on marsh areal extent (S. Fagherazzi, P. Wiberg, K. McGlathery).

Past efforts at the VCR, as well as in the broader coastal wetland research community, to understand the potential for belowground processes to contribute to vertical accretion have focused primarily on *S. alterniflora* or, less often, on *J. roemerianus*. In the VCR and other U. S. Atlantic coast salt marshes, a significant proportion of marsh area is colonized by *S. patens* and *D. spicata*. An important gap in our ability to predict marsh response to long-term drivers (sea level, eutrophication) is knowledge about belowground processes in this plant community. We currently are measuring root growth of the *S. patens* and *D. spicata* community and comparing these to *S. alterniflora* and to previous measurements in *S. alterniflora* and *J. roemerianus* (Blum 1991, Blum and Christian 2004). This work compliments our studies on the role of nutrients in marsh transgression and state change.

Changes in marsh spatial coverage in response to climate change (sea-level rise, storms)

With supplemental funding from the DOE NICCR program, PIs S. Fagherazzi, P. Wiberg, K. 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. Extensive field measurements in Hog Island Bay are being coupled with modeling efforts at several scales to understand the physical and biological mechanisms responsible for marsh edge erosion and the coupled evolution of salt marshes and tidal flats in intertidal environments. The goal of the modeling is to predict changes in areal extent of marshes under different 100-yr climate change scenarios of increased sea level and storminess. The field component includes monitoring of 4 marsh boundaries with measurements of scarp erosion, vegetation and sediment characteristics, crab-burrow and bivalve density, and flow conditions (waves and tides) just lagoon-ward of the marsh edge. 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.

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 J. Zieman and K. McGlathery, continued his work on 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. In addition, Mozdzer continued his studies on nitrogen and carbon metabolism of the non-native genotype of *Phragmites australis* at the VCR, a species that is replacing native marsh species that have very different physiognomies (*Spartina patens, Distichlis spicata*) in mid and high marsh zones (Mozdzer 2009).

Barrier Islands

Island vegetation

The barrier islands represent a collection of land forms that are both independent and dependent on one another. Our past work has shown that each island may respond in a unique fashion to sea level rise; however, sediment movement among islands and island position dictate that islands are affected by their neighbors. This is true of both physical processes (e.g sediment transport) and biological processes (e.g. movement of propagules, including organisms, seeds, and pollen). Our goal is to link the external drivers of storm disturbance (overwash, sand desposition, flooding, salt spray) that modify the land surface and water table to patterns of vegetation on the barrier islands. We are building on our long-term work on Hog Island, including permanent plots in the dune chronosequence, to include islands in the 2 new box transects. Our earlier work has shown that there is predictable spatial variation across the island landscape due to differences in microtopography and the decrease in disturbance magnitude and frequency with distance from the beach face, which result in different vegetation patterns across the islands (Fahrig et al. 1993). Thus storm-related effects should vary among islands as a function of island size and topography.

Any position on an island, indeed any individual plant, should be influenced by a suite of physical factors that are dictated by the distance from the ocean shoreline (e.g. sea spray) and elevation above sea level (e.g. flooding, water water availability, etc.). Through hyperspectral imagery and ground truthing we have assembled an array of data sets to describe spatial variations in vegetation within and among the VCR barrier islands. In the near future, LIDAR imagery will be obtained for all of the islands. The multi-return LIDAR data will provide spatial variations in elevation over each island. Based on the LIDAR imagery, we can then place an elevation and distance to the ocean shoreline for any and all locations/vegetation communities on the islands. We will be able to assign landscape polygons based on ranges of elevation and distance from the shoreline, for communities and in many cases individual species. Thus, based on predicted storm surges and ranges of sea-level rise we are able to assess spatial variations in threats to the resident biota on the VCR islands. In addition, comparing the landscape polygons to current distribution patterns for communities and/or species, we will be able to identify stable and unstable locations across the VCR landscape.

Shrub thickets provide important habitat for predators and are expanding on the islands. We continue to add to our long-term data set on the expansion of *Morella* sp. thickets on the VCR islands. In addition, to documenting changes in shrub area, we have begun to focus on ecological changes associated with the expansion. We quantified seasonal variation in litterfall and litter N concentration in *M. cerifera* shrub thickets to assess changes in litterfall and associated N input after shrub expansion. We also used the natural abundance of ^{15}N to estimate the proportion of litterfall N originating from symbiotic N fixation.

Vegetation-predator-bird interactions

The interaction of physical processes with the biotic feedbacks provides stability to ecological communities but may also lead to a transition to another stable state. Across the VCR landscape there is tripartite interaction among vegetation structure and species composition, the presence of predators, and the abundance and nesting success of shore birds. These biotic interactions are also subject to physical forcing factors, especially storm related overwash and shoreline change. Our goal is to quantify these synthetic interactions and determine their spatial variation across the landscape. We and our collaborators continue to build on our long-term (20 year) data sets on shrub expansion, predator presence and colonial waterbird abundance on the VCR barrier islands. In addition, we continue to quantify spatial/temporal variations in the distribution of the dominant woody community on the VCR islands –*M. cerifera* shrub thickets – and the changes in associated ecological processes as a result of conversion of island grassland to shrub thickets. These biotic processes will be coupled with barrier island evolution predictions based on a DOE-NICCR collaborative project of PIs L. Moore and D. Young.

PI M. Erwin (Erwin et al. 2001) noted that the distribution of raccoons on islands was inversely related to the number of colonies of beach-nesting and colonial waterbirds on those islands, and that there was an overall decline in the abundance of many species of birds. There are many potential factors that dictate the relative suitability of an island for raccoons, including the relative isolation, areas of suitable habitats, and the availability of food sources (especially in seasons when birds are not nesting). PIs R. Dueser and N. Moncrief are focusing on the roles that relative isolation and land cover play, including the relative importance of colonization from the mainland, vs. "island hopping" from other insular populations. With support from the Coastal Zone Management Program (CZMP) at the Virginia Department of Environmental Quality, in 2008 we integrated a variety of trapping and track-survey datasets to provide a comprehensive picture of raccoon monitoring and removal activities, which allowed us to create GIS data layers for 1999-2005. With student J. Martin, we have also developed field techniques for reducing predation by raccoons on nests based Conditioned Food Aversion techniques. We created artificial nests using birds' eggs that were treated so that they were indistinguishable from untreated eggs and were also distasteful to raccoons.

Seed dispersal via birds

PI D. Young and his students are quantifying seed disperal via birds which will contribute to their understanding of patch dynamics and variations in vegetation community structure across the landscape. Microsites favorable for germination are continually being created and destroyed in coastal ecosystems, so seed dispersal to multiple patches is essential for survival and growth. They are focusing on three VCR barrier islands: Metompkin, Hog, and Smith, which represent a range of size, topographic complexity and species richness. Artificial perches with an attached fecal seed trap were installed along transects on the islands.

Barrier island evolution

Rising relative sea level and potentially increasing storm activity will cause barrier islands to overwash more frequently, thus altering their stability in the future. Changes in plant species composition, such as the prevalence and distribution of dune-building grasses, are also expected as climate warms. Underlying these changes in physical and biological forcing is the potential for non-linear feedbacks between geomorphic and biological processes, associated with overwash and dune-building, to reinforce and expand the presence of overwash zones. PIs L. Moore and D. Young recently were awarded funding from the DOE-NICCR program to investigate the existence of these biogeomorphic feedbacks in the VCR and to assess how they might respond to changes in physical and biological forcing thereby affecting future island stability. Specific questions they plan to address within VCR include: 1) How do morphological zones and plant species composition co-vary? 2) Are overwash and dune areas persistent through time and can this be tied to species composition? 3) What is the current status of barrier island vulnerability to storm impacts, how is this different from a decade ago and is there a relationship with changes in species composition?, 4) How do changes in vulnerability compare to those we would expect given shifts in physical and biological forcing alone?, and 5) Given current topography and species composition, potential feedbacks, and a range of anticipated changes in physical and biological forcing, what are likely barrier island responses in the future? The questions are being addresses using a combination of remote sensing, geophysical and numerical modeling methods including aerial photo analysis, ground-penetrating radar and sediment coring.

Landscape Analysis

We are using 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 landscape. The goal of this modeling effort is to predict the ecosystem responses to long-term environmental change and short-term disturbance events to predict areas of high vulnerability on the landscape. Our work on this question focuses on developing 1) landscape models of ecosystem state change; 2) geomorphic models of landscape change; and 3) large-scale hydrodynamic models to which sediments and nutrients will be added.

An important first step in our landscape modeling effort is to generate a complete hypsometric curve for each of the two new box transects, as we have done previously for the Machipongo box transect. This relationship links the vertical elevation of the land surface (including lagoon bottom) with the areal extent of that elevation to allow us to map the positions of ecosystems on the landscape. The bathymetric data will be used as the basis for hydrodynamic models, for models to determine the potential areas for seagrass recovery, and for models of the general distribution of benthic habitats. By the end of 2009, we will obtain LIDAR imagery for much of the VCR. This will allow us to better resolve the elevation of the marshes and islands in the VCR, which is critical for landscape modeling.

Landscape-scale models of ecosystem state change

Observed decadal trends in landscape change - We assessed landscape change for all the VCR marine watersheds using published land cover data layers from the NOAA Coastal Change Analysis Program (CCAP). PI J. Porter compiled data for five dates (1984, 1988, 1996, 2001 and 2005). The 1984-1988 data shared a common set of categories and methodologies, and the 1996-2005 data shared a different (but similar) set of categories and methods. Data layers were recoded to a common classification scheme that provided a coarse, but useful, categorization of land cover in the two watersheds. These were "Developed", "Bare", which includes sandy beaches; "Cropland" which includes agricultural fields on the mainland and upland grasslands on the islands, "Woody", which includes both deciduous and evergreen forests on the mainland and shrublands on the islands; and "Marshes."

Landscape modeling - We have focused our initial efforts on adapting the modeling framework of PI E. Reyes (Reyes et al. 2000, 2004) to the VCR landscape. This will incorporate the conceptual model of state change for mainland marshes we have developed previously (Brinson et al. 1995,Christian et al. 2000) based on free surface interactions (land, sea and groundwater)and the flux of materials. Processes that facilitate change include brackish water intrusion, tidal creek encroachment, erosive currents, waves and increased water depth. Those that maintain a state include forest floor shading, water table dynamics, rainfall and evapo-transpiration, organic matter accumulation, sediment redistribution and resuspension.

As a starting point for our modeling, we assumed that sea-level rise would generate the observed spatial and temporal patterns of coastal vegetation at the VCR. We recognize that pulsing events (e.g., storms that deposit sediment and wrack, and cause erosion) are also important to state change and plan to include this in future versions of the model. At present the landscape model only incorporates the interactions of two free surfaces (land and sea). We also recognize the importance of groundwater (most notably its effect on barrier island communities), and will incorporate this free surface in future modeling efforts.

The Virginia Landscape Model (VLM) is a regional model that incorporates hydrodynamics, transport of water-borne particles (salt and sediments) and plant biomass 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 (Boumans and Sklar 1990; Fitz et al. 1996). Feedback between the processes occurring within the cells and the landscape allows both the landscape and the processes affecting it to change over time. The VLM represents habitat changes at a 275 m^2 "pixel" for a total of 100,189 active cells, and produces daily values for water depth, salinity, sediment concentration and plant above- and below-ground biomass.

The NOAA C-CAP maps (1989, 1996, 2001 and 2005)were used as a basis for habitat classification. We recoded the habitat types for our study area and defined model domain boundaries. Eight habitat types were included in the model: four for marsh, two for forested areas and one for upland/develop areas.

Calibration - For calibration purposes, the VLM simulated processes over a 10-year time scale using a sea-level rise rate of 2 mm yr^{-}1 (~ eustatic) as a conservative estimate (Ray et al. 1992). The regional model spatial calibration was performed in three steps. First, the model was run repeatedly using the 1996 initial forcing functions until the land/water ratio matched the original habitat map (2005). Then the habitat type proportions were calibrated, and finally the habitat distribution was determined.

The spatial calibration included a goodness-of-fit analysis (Costanza 1989) between the 2005 model results and the corresponding C-CAP reclassified map. The model was run repeatedly, varying the initial spatial parameters (e.g., initial elevation) until the overall fit improved to 85 or better using the criteria established by Reyes (Reyes et al. 2004; Reyes et al. 2000). The calibrated base case simulations yielded a fit of 98.82 for the 2005 simulated VLM. Total habitat results are presented on Table 3.

Table 3. Habitat types for VLM. Initial map is 1996. For Calibration the resulting map (2005VLM) was compared with the 2005 map. The 2005VLM5 results indicate a change in SLR to 5 mm/yr. Pixel resolution is 275 sq. m. R-Sim indicates difference.

Habitat Type	1996	%	2005	%	2005 VLM	R - Sim	%	2005 VLM5	R - Sim	%
Brackish high marsh	49	0.05	56	0.06	49	7	0.05	51	5	0.05
Freshwater high marsh	18	0.02	9	0.01	22	-13	0.02	30	-21	0.03
Wetland forest	1200	1.20	1169	1.17	1190	-21	1.19	1190	-21	1.19
High marsh	1	0.00		0.00	3	-3	0.00	7	-7	0.01
Low marsh	3621	3.61	3603	3.60	4153	-550	4.15	4203	-600	4.20
Open water	89009	88.84	89079	88.91	88585	494	88.42	88521	558	88.35
Upland	4686	4.68	4726	4.72	4686	40	4.68	4686	40	4.68
Forest	1159	1.16	1141	1.14	1157	-16	1.15	1157	-16	1.15
Canals	226	0.23	227	0.23	226	1	0.23	226	1	0.23
Barren or sandy areas	220	0.22	179	0.18	118	61	0.12	118	61	0.12
Fit Index					98.82			98.78		

Geomorphic models of landscape change

Evolution of marshes and tidal flats - A one-dimensional numerical model for the coupled long-term evolution of salt marshes and tidal flats has been developed by PI S. Fagherazzi and one of his students. The model framework includes tidal currents, wind waves, sediment erosion and deposition, as well as the effect of vegetation on sediment dynamics. The model is used to explore the evolution of the marsh boundary under different scenarios of sediment supply and sea level rise.

Evolution of barrier islands - As sea level rises, a barrier island will respond by migrating landward across the underlying substrate to higher elevations, by disintegrating if there is no longer sufficient sand volume and relief above sea level to prevent inundation, or by drowning in place and transforming into a marine sand body. A recent study of barrier island response to sea-level rise by PI L. Moore using the morphological-behavior model GEOMBEST(Stolper et al., 2005; Moore et al., 2007; Moore et al., accepted), explores the sea-level rise response of a complex coastal environment (North Carolina Outer Banks) to changes in a variety of factors, yielding general insights into barrier island evolution.

PI Moore and ROA M. Fenster are beginning to build upon this previous work by investigating the past and potential future evolution of Metompkin, Hog and Cobb Islands (which exhibit a range of morphologies, orientations and evolutionary histories) using a combination of field observations and numerical model experiments. Field observations will be conducted using a series of geophysical and sedimentological methods including collection of ground penetrating radar surveys, boomer and chirp sub-bottom profiles, vibracores (back-barrier environments) and sediment cores to better understand the geologic framework of the VCR barrier islands. Laboratory methods will be employed for sedimentological and biofacies analysis of cores along with optically stimulated luminescence and radiocarbon dating of critical stratigraphic layers to provide chronology. The field-based methods will provide important constraints and input parameters to a morphological-behavior model, GEOMBEST which will be used to run inverse and forward simulations of barrier island evolution. In addition, because marshes and barrier islands evolve interdependently, PIs Moore and Fagherazzi will be seeking funding in the next year to couple GEOMBEST with the one-dimensional model of long-term marsh evolution described above. The resulting two-way coupled model system will be the first to explore the co-evolution of marshes and barriers and will be particularly useful in understanding landform evolution in the LTER where marsh and barrier interrelationships are especially important. Field observations will be employed iteratively with barrier island (and eventually, with coupled barrier island/marsh) model experiments to provide geometric tests of plausible evolutionary scenarios and allow the development of hypotheses regarding the geometric and stratigraphic relationships that result from different scenarios.

In a related effort led by Moore, simulations of barrier island and marsh evolution will be used to develop maps of potential landscape changes associated with likely future sea-level rise scenarios for the LTER and adjacent mainland. To date, maps depicting sea-level-rise-induced changes in the coastal landscape are static, reflecting only the potential submergence of land by a rise in water level. Such maps do not take into account the dynamic nature of coastal landforms. By combining the results of our landform evolution experiments with more traditional inundation models (where they are appropriate) we will develop more realistic predictions of sea-level-rise- induced landscape change.

ROA M. Fenster and colleagues are developing an empirically-driven expert systems model (e.g., Bayesian) capable of predicting the landscape changes that will occur with predicted climate change scenarios. The work involves: 1) compilation of an empirical database of all factors (sediment supply, storms, tides, tidal inlets, waves, sea-level fluctuations (rise), and antecedent geology) that produce morphologic and geologic changes along the VCR; 2) geophysical work to provide a seismic facies analysis capable of analyzing the nearshore record of longer-term ($10^5 – 10^3$ yr) environmental changes; 3) an upgrade of the shoreline change GIS database for the entire VCR to include shoreline positions of all islands through 2009; 4) assessment of the impact of short-term disturbances (i.e., coastal storms) on the Virginia barrier islands using a method that compares the shoreline position outliers to the magnitude and timing of the largest storm prior to a photo date; 5) use of a densely gridded wave refraction model developed by the Spanish Ministry of Environment and the University of Cantabria (González et al., 2007) to examine the role of both long-term wave climate and short-term wave (storm) disturbances on controlling the barrier-tidal inlet morphodynamics of the VCR; and 6) development of a sediment budget to enable determination of the sources that feed the Virginia Barrier Island sand prism and the sinks that remove sand from the system.

Social Science Research

Using supplement funding, we have developed a collaboration with S. Swallow, a natural resource economist at the University of Rhode Island, and his Ph.D. student E. Smith, to study the public valuation of seagrass, oyster, and bird habitat restoration. The work examines ways to generate revenues for public goods by: 1) exploring individual willingness-to-pay for specific ecosystem restoration activities; 2) determining methods (test markets) by which such willingness-to-pay might be translated into revenues for these restoration activities; and 3) examining trade-offs that individuals make between heterogeneous public goods. The importance of ecosystem restoration may be identified through the dollars spent each year by government mandated action and philanthropic efforts or by the documented links between humans and natural systems. Efforts to value public goods in economic terms have been plagued by free riders and lack of property rights; one of the main challenges faced by economists and policy-makers is to determine how to link the value of ecosystem services and restoration to people and to integrate these values into the economy.

Two field experiments involving local citizens were conducted. The first gave participants a choice to spend $100 on alternative restoration activities involving half-acre increments of a) half-acre increments of seagrass habitat; b) 12,000-seed increments of clams for water filtration and c) half-acre increments of habitat for fall-migrating birds. Decisions between restoration bundles allowed us to test whether these activities (and ecosystem-services) were viewed as substitutes or complements while also providing an opportunity to compare the outcomes of incentive mechanisms. The second experiment used a process to identify marginal (or individualized) prices for increments of each of the ecosystem restoration activities. This was done by asking participants to complete a series of decisions to offer a per-increment price for additional units of restoration with the researcher evaluating whether the sum of per-unit prices exceeded the costs of providing each unit. As in the first session, participants were given a $100 endowment or budget to use. Our data show that participants did support higher quantities (e.g., more acres) of ecosystem restoration, yet the average individual did not show a statistically significant difference in value for alternative restoration types. Preliminary results and participant feedback indicate that factors beyond the purely theoretical assessment of incentive compatible properties (e.g. framing effects or science-information) may have played an integral role in individuals' choices (votes). Also, we found that as the number of increments increased, participants' offered price declines, consistent with the concept of diminishing marginal benefits.

This work will contribute to understanding economic incentive mechanisms as an alternative to government action or voluntary fundraising by non-profit organizations as a viable approach to conservation (broader impacts) and private provision of public goods (basic science)**.** The scope of this work has implications for the private provision of public goods, impacting government, non-profits, opportunity for private organizations and local citizens, as well as economic theory. Our work will provide insight on local residents' relative values for ecosystem restoration and their willingness to pay for restoration activities. Examining ways that private action may provide for public goods has theoretical merit, but is also useful for local non-profits, such as TNC (a collaborator in this research), who work to further the ecological restoration in this area.

VCR-LTER ANNUAL REPORT 2009 - FINDINGS

Watersheds and Lagoons

Watershed nutrient loading

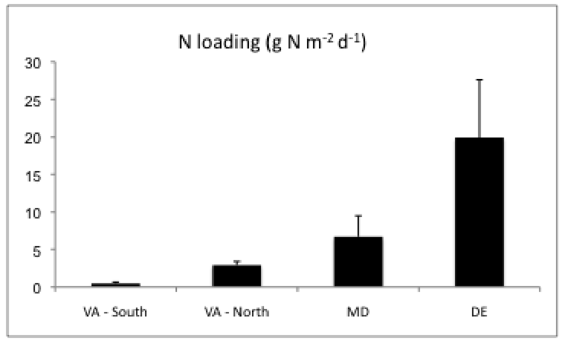


Fig. 1. N loading estimates to mid-Atlantic coastal bays. Data for Maryland from Boynton et al. (1996) and Wazniak et al. (2007), and for Delaware from Nixon et al. (2001).

Annual nitrogen loading to the VCR coastal bays expressed as a load per bay area varied by over an order of magnitude, from a low of 0.1 g N m^{-2} y^{-1} to a high of 4.4 g N m^{-2} y^{-1}. The more northern bays had higher nutrient loading rates (average 2.9 g N m^{-2} y^{-1}) than the southerly bays (average 0.5 g M m^{-2} y^{-1}), which we attribute to differences in land use, including increased suburbanization and poultry farming, and to the smaller size of the receiving bay. Compared to the Maryland and Delaware coastal bays, nutrient loading to the VCR coastal bays is very low, especially for the more southerly VCR bays. There is a general regional trend of increasing N loading as one moves northward from Virginia to Delaware (Fig. 1).

Our work indicates that the sediments in low relief coastal streams are a critical filter for groundwater NO_3^-, provided there is an adequate input of organic matter from the surrounding riparian zone. In Cobb Mill Creek, 80-90% of the nitrate discharging in groundwater entering the stream is removed before the water emerges from the stream sediments. Piezometers indicate that NO_3^- is removed within a zone of 1 m below the stream sediment surface. Enumeration of denitrifiers using molecular genetic methods, probing of the nitrous oxide reductase (*nos*) gene in a dilution-extinction mode, showed substantial numbers of the organisms coinciding with maximum nitrate removal. Acetylene-block measurements yielded the highest denitrification potential coincident with the nitrate disappearance. High organic matter concentrations derived from riparian vegetation and buried in the sediments (up to 20%w/w) were co-located with the zone of active denitrification.

We have found that by influencing residence time, hydrology is a critical factor controlling the amount of nitrate removed from groundwater via denitrification. During small storms, the passage of a flood wave associated with storms over stream sediments can cause changes in groundwater discharge to the stream that range from a transient reduction in the discharge rate to a reversal of flow and temporary storage of stream water in the stream sediments, which would allow a greater reaction time for nitrate removal. During large storms, the flow rate increases substantially, and the solute residence time in the reactive zone is shortened resulting in a lesser extent of reaction, such that more NO_3^- is delivered to the stream water. In field measurements of storm events, large quantities of NO_3^- were quickly transferred due to the large volume of water albeit with low NO_3^- concentrations flowing in the stream Herman et al. (2008).

Riparian vegetation has an important influence the water flow to these tidal streams. During the summer, stage varies up to 5 cm over a 24-hour period. In contrast, there is no diurnal fluctuation in stream stage or in the concentrations of nitrate or chloride during colder part of the year and before the trees and understory develop leaves.

Nitrous oxide fluxes from the marsh surface

Half-hourly average N_2O concentrations indicate that there may be significant N_2O emissions from the marsh, as buildups are observed during the night followed by depletions during the morning.

Net ecosystem metabolism

Our regional comparison of net ecosystem metabolism (NEM) of different lagoons that varied with respect to nutrient loading showed that based on summertime NEM, system autotrophy increased with nutrient load, peaking at an intermediate load, then decreased in the two most enriched systems (Fig. 2). We had expected that lagoons that currently receive low-moderate nutrient loading would be net autotrophic and that there would not be a shift to net hetrotrophy until the systems become heavily eutrophied.

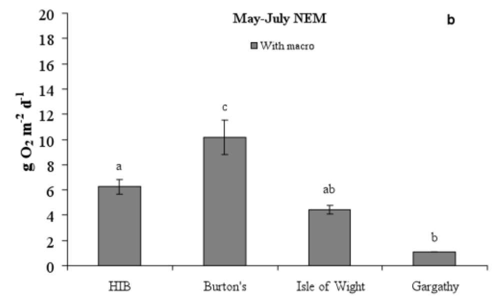


Fig. 2. Net ecosystem metabolism measured in VA and MD bays that vary in nutrient loading rates (HIB – low, Gargathy – high)

Lagoon hydrodynamics

The completed bathymetric data are shown in Fig. 3. The two systems – Gargathy Bay and Magothy Bay –vary with respect to geomorphology and nutrient loading. Together with the bathymetry of Hog Island Bay, we now have full bathymetry for 3 coastal lagoons in the VCR.

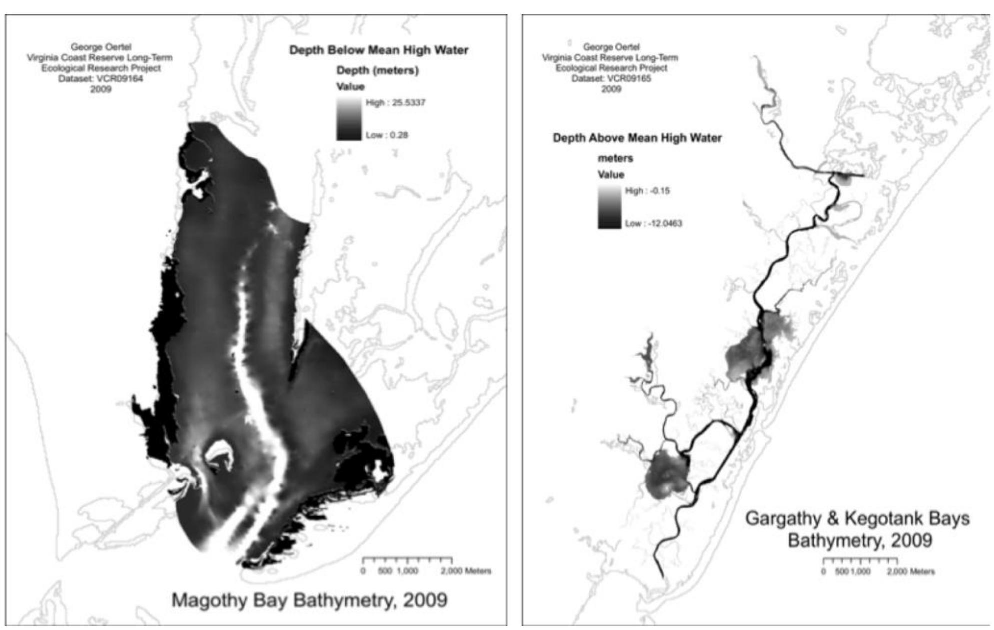


Fig. 3. Bathymetry of Magothy and Gargathy Bays.

Fagherazzi and Wiberg (2009) used a simple parametric wave model for shallow water to estimate sediment erosion potential in shallow tidal basins caused by wind-wave events in coastal bays like those of the VCR. Their method determines the aggregate response of the entire basin, combining in a simple framework the contribution from different landscape units. They have run the model with different tidal and wind conditions to quantify bed shear stresses and erosion potential of the lagoon bottom under different forcing conditions. As an example, the average wave height over a tidal cycle is reported as a function of wind direction in Fig. 4 for the four sites in Hog Island Bay where we are monitoring marsh edge erosion. They found maximum wave heights and erosion potential for winds oriented along the axis of the basin (NNE-SSW) and water depths between 0.3-0.9 m above MSL (MHHW ≈ 0.7m) (Fig. 5).

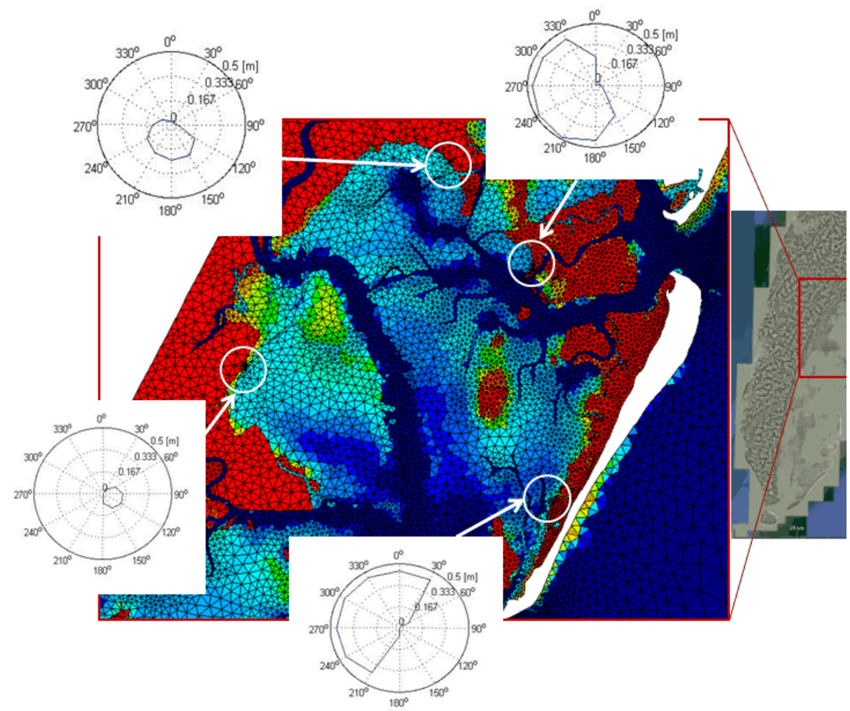


Fig. 4. Maximum wave height calculated with the model IMAGE during a tidal cycle at the four marsh boundary locations of figure 3. The simulations were carried out with a wind of 15m/s blowing from 12 different directions.

At greater depths (deeper parts of the basin or during meteorologically enhanced peak tidal elevations), wave orbital motion decays moderately or completely (i.e. deep-water wave conditions) before reaching the lagoon bottom so that wave-generated shear stresses become small and tidally-generated stresses dominate. At shallower depths, wave-generated shear stresses are significantly larger than those due to tide, (deeper parts of the basin or during meteorologically enhanced peak tidal elevations), wave orbital motion decays moderately or completely (i.e. deep-water wave conditions) before reaching the lagoon bottom so that wave-generated shear stresses become small and tidally-generated stresses dominate. At shallower depths, wave-generated shear stresses are significantly larger than those due to tides (Lawson et al 2007).

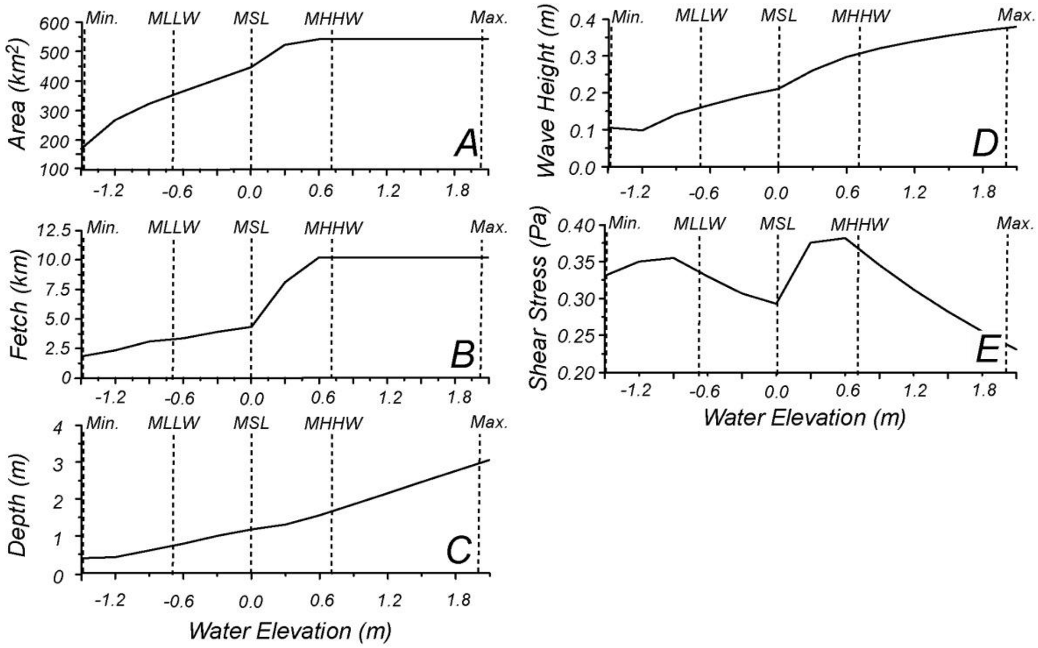


Fig. 5. Aggregated physical parameters driving sediment resuspension at the Virginia Coast Reserve: a) basin area, b) average fetch, c) average depth, d) average wave height, and e) average bottom shear stress as a function of water elevation for a wind blowing from North with a speed of 15 m/s.

Lagoon nitrogen and carbon dynamics

Recent work by PI I. Anderson and student A. Hardison using biomarkers has changed our view of N retention in the sediments. The general finding of their work is that while N turnover is high in the sediments, shuttling between bacterial and benthic microalgae enhances retention substantially. Competition for light by macroalgal blooms interrupts this linkage and enhances N turnover. This work was largely funded by an NSF grant to Anderson and an EPA STAR fellowship to Hardison.

In Fig. 6, the ratio of ^{15}N label in the bacterial biomarker, D-Ala, versus that in L-Ala indicates the relative importance of bacterial uptake to total microbial uptake. The observed ratio suggests that bacteria were responsible for the initial isotopic uptake; however, as bacteria remineralized macroalgal biomass, benthic microalgae incorporated relatively more ^{15}N. They used sediments and macroalgae from HIB as well as Isle of Wight Bay, Maryland, and found similar results for both systems. This suggests that the results are likely applicable to other shallow coastal lagoons. In the presence and absence of living macroalgae, bacterial activity was dependent on benthic microalgal activity, suggesting that bacteria used benthic microalgal-derived metabolites to support some portion of their production. But for a brief time period following the macroalgal die-off, benthic microalgae depended on bacteria to remineralize organic matter into inorganic substrates.

PI R. Christian used N process measurements measured by PIs I. Anderson and K. McGlathery to develop an ecological network analysis model and to compare this with the hypereutrophic Sacca di Goro in Italy (Christian et al., 2009). This work was funded in part by an international supplement, and with new supplement money, we now plan to extend this analysis to include San Quintin Bay, Mexico, where N inputs come primarily from upwelling, in collaboration with Victor Camacho-Ibar.

Seagrass restoration

We began our annual synoptic monitoring of the newly seeded sites and the chronosequence sites in summer 2007. This marks the start of a new long-term data set that includes seagrass variables (density, canopy height, above- and below-ground biomass, productivity, epiphyte biomass, and tissue carbon and nitrogen contents), sediment variables (benthic chlorophyll, organic content, grain size, porosity, and carbon and nitrogen contents) and macroalgae biomass. In the Hog Island Bay restoration plots, germination rates and seedling survival is 7-12%, which is on par with what has been found in other regions, such as Chesapeake Bay and the Maryland coastal bays(R. Orth, pers. com.), and density has increased annually (Fig. 7). Our preliminary data show that rates of productivity, faunal density and diversity (per shoot) are similar between treatments in the 1-2 year old meadows in Hog Island Bay, and between these meadows and the older (7 and >10 years) meadows in the chronosequence, suggesting that the change in seagrass density is the important driver of state changes in the system.

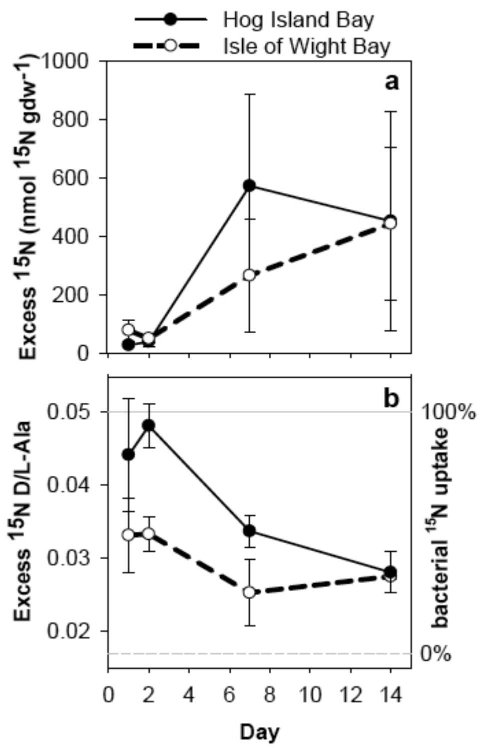


Fig. 6. Results of isotope labeling experiment showing tight coupling between benthic microalgae and bacterial pools of N.

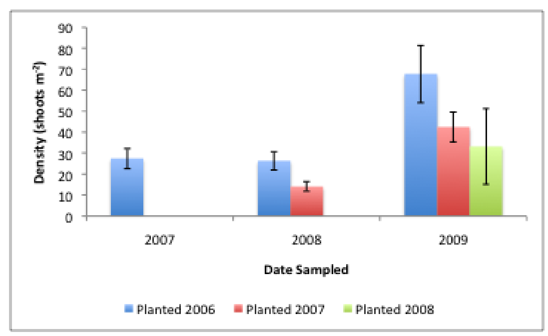


Fig. 7. Seagrass shoot density has increased in restored meadows in Hog Island Bay.

The results of the lagoon stability model indicate that under typical conditions the system is bistable; seagrass is stable in water depths < 2.2 m (51% of the bay bottom deep enough for seagrass growth) and bistable conditions exist for depths of 2.2 – 3.6 m (23% of bay), where the preferred state depends in initial seagrass cover. The remaining 26% of the bay is too deep to sustain seagrass (Fig. 8). Decreases in sediment size and increases in water temperature and degree of eutrophication shift the bistable range to shallower depths, with more of the bay bottom unable to sustain seagrass (Carr et al, in review).

We plan to build on this modeling effort and the model of Lawson et al (2007) to develop a population model that will incorporate patch dynamics, the lateral expansion of seagrass by clonal growth, and seed production and germination. Students L. Reynolds and K. Hondula have collected detailed data from the site on rhizome growth and branching patterns and seed production/germination that can be used to parameterize the model.

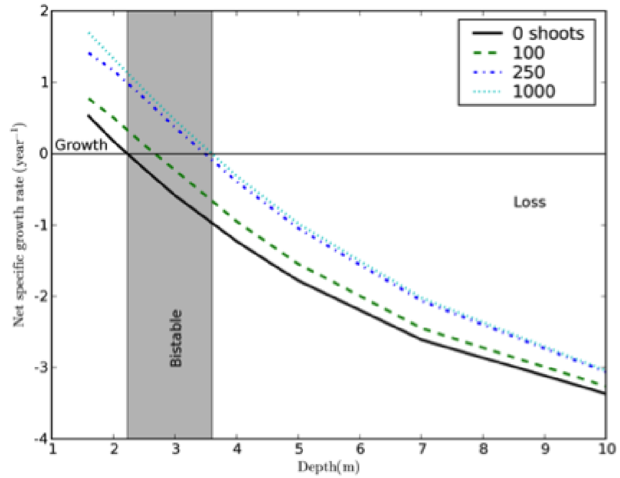


Fig. 8. Specific growth rate as a function of depth for varying shoot densities. Conditions suitable/unsuitable for seagrass establishment and growth were evaluated by looking at the sign of the net annual growth rate. Positive (negative) values were associated with favorable

Genetic studies

Genetic diversity, structure, and population connectivity are important to the restoration success and stability of seagrass populations. The challenge for restoration efforts is to minimize the loss of genetic diversity due to collection of donor material from a limited area and low transplant survival and to understand the connectivity with extant populations. For the restored seagrasses in the VCR lagoons, we are using microsatellite techniques to: 1) assess the genetic diversity of the seagrass meadows on a local (VCR coastal lagoon) and latitudinal metapopulation (Eastern Atlantic Coast) scale to determine connectivity between meadows, 2) determine if using seeds from a broad range of donor sites increases the genetic diversity of restored seagrasses and if this is related to metrics of restoration success, and 3) identify the origin of the plants naturally recruiting to the area. The genetics work is in its early stages; the preliminary data indicate that the restored seagrass meadows in the VCR lagoons do not lack genetic diversity relative to other seagrass meadows along the US East Coast (Fig. 9). In 2007, we set up an experiment to test whether increased genetic diversity of donor populations increases restoration success using the metrics of seagrass density, productivity, and also invertebrate density and nitrogen retention as proxies for ecosystem functions. The experiment was also designed to test for stresses associated with light limitation by blocking the plots along a

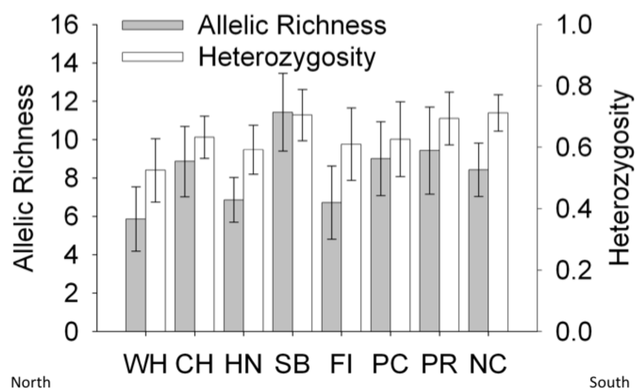


Fig. 9. Genetic diversity is similar along the U. S. East coast between Massachusetts and North Carolina. HB and SB are seagrass meadows in the VCR.

depth gradient. Our preliminary data indicate that the higher-diversity plots have a marginally higher seagrass density. We will continue to follow these plots through 2010.

Sediment fluxes

The combination of flow, sediment, and oxygen measurements provides relationships between net photosynthetic activity of the seagrass and how flow and sediment dynamics (due to light attenuation) may be impacting the rate of photosynthesis within these shallow lagoon systems. Our comparison of flow velocities and sediment suspension from open lagoon areas devoid of seagrass and seagrass meadows of ~400 shoots m-2 provide a baseline comparison for in situ estimates of feedbacks between seagrass density, flow, and suspended sediment concentrations (Fig. 10). We are continuing this study with measurements in meadows that vary in density to address where a threshold occurs between destabilizing effects on sediment suspension associated with low-density seagrass meadows to stabilizing effects associated with high-density meadows.

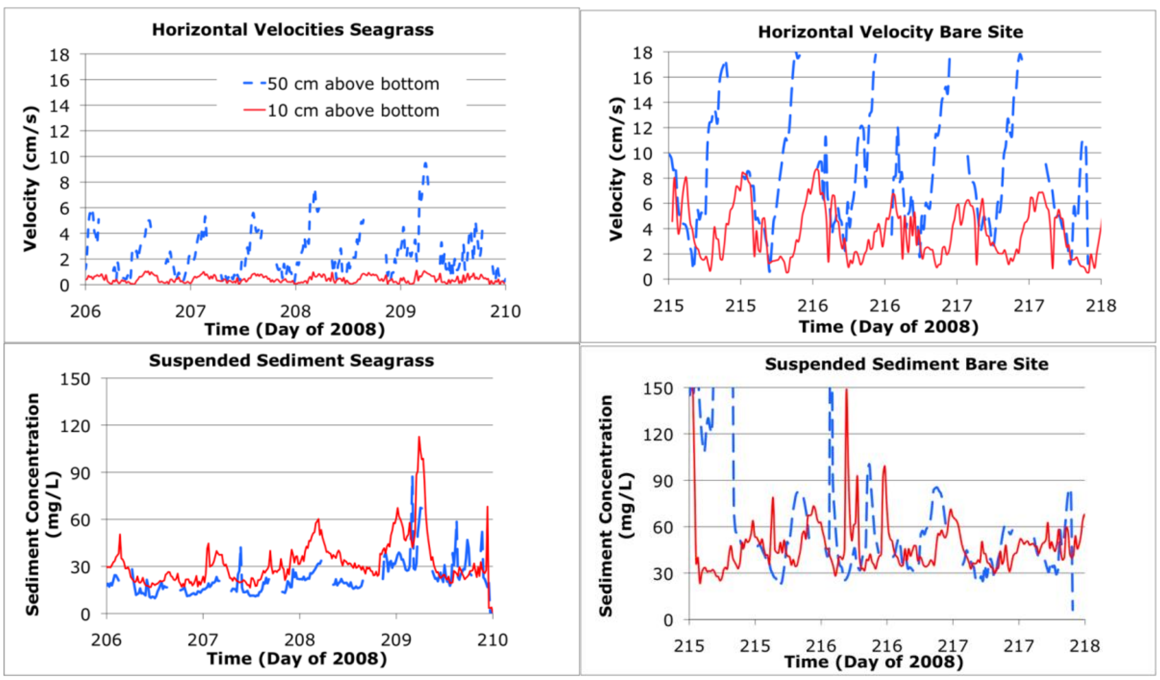


Fig. 10. Horizontal velocities and suspended sediment concentrations for a dense seagrass bed and a bare site devoid of seagrasses in South Bay. Height of the seagrass is ~30 cm. Time is reported as the day within 2008 from Jan 1.

Flow dynamics and metabolism of oyster reefs

Results indicate that oysters exert a strong influence on reducing suspended sediment concentrations, and both their net oxygen uptake and sediment filtration increases with increased flow. Mean sediment uptake by the reef was measured to be 270 $g/m^2/day$, which is equivalent to the reef completely filtering an approximately 5 m deep water column on a daily basis, and this increased to a maximum of 1500 $g/m^2/day$ (~25 m/day of water cleared) with increased flow. This value is similar to maximum filtration rates of water masses (through measured uptake rates of phytoplankton) measured over a coral reef in the Red Sea and dense patches of benthic filter feeders within San Francisco Bay. Further measurements of phytoplankton flux over the oyster reef will be necessary to determine if the enhanced metabolism and sediment flux with velocity is due to greater food availability.

Tidal Marshes

Marsh accretion relative to sea-level rise

The capacity of marshes to survive rising sea level depends upon two interdependent processes: the vertical accretion of marsh surface and the balance between shoreline change and the landward migration. The landward migration determines marsh area, while the vertical component depends upon (1) deposition of suspended sediments transported and deposited on marsh surfaces and (2) belowground processes such as root/rhizome production, organic matter decomposition, and bioturbation. We have used surface elevation tables (SETs) to measure overall elevation change, root SETs (RSETs) to measure change associated with root zone, marker horizons for estimating surface accretion, and belowground litter bags and ingrowth bags to measure dynamics of root growth and decomposition. This work is ongoing, building on previous studies (Blum 1993, Erwin et al. 2004, 2006, Blum and Christian 2004) and represents a 12-year record of marsh accretion (Fig. 11) from which we can examine the potential effects of multi-year trends in external drivers, such as the lunar nodal cycle of sea level (Chamber et al. 2003) and freshwater input (Craft 2007). River discharge is unlikely to be important given the small amount of runoff at the VCR, but some evidence exists that prolonged drought and major storms may impact elevation changes. We are in the process of examining the impact of the lunar nodal cycle evident in water level records on our SET data.

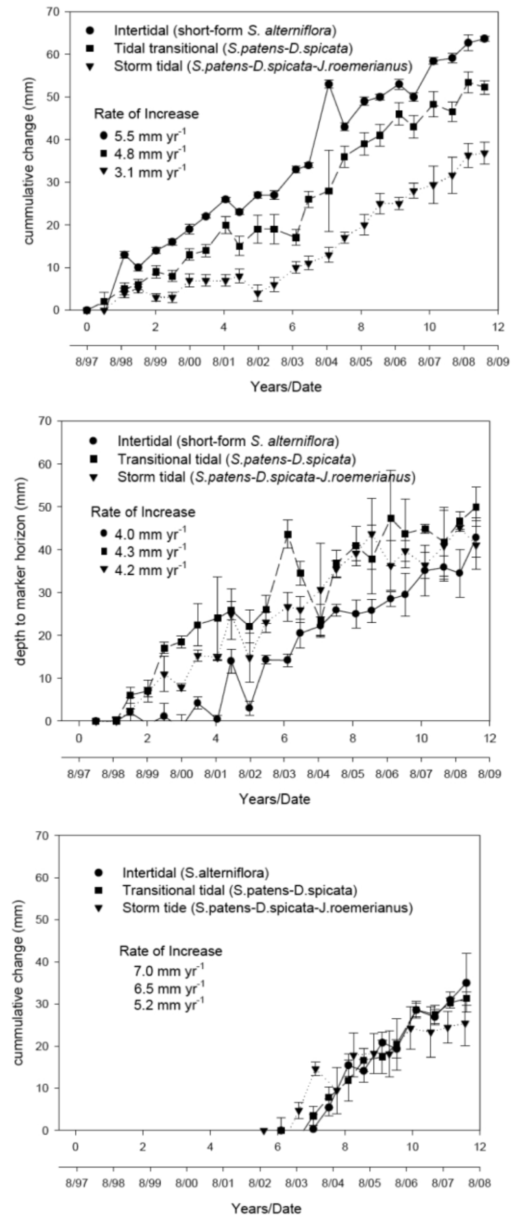


Fig. 11. Marsh elevation change in 3 hydrogeomorphic zones in Phillips Creek marsh. Top panel: total elevation change from SET data integrating both surface and subsurface processes. Middle panel: surface accretion measure by deposition over feldspar marker layer. Bottom panel: RSET data integrates root zone processes above and below the feldspar layer. Note that rates of RSLR in region are estimated to be 3.8-4.0

Marsh erosion and changes in marsh area

Measurements taken since summer 2007 reveal that the marsh boundary is retreating at a rate of approximately 0.5-1.5 m/yr in 3 of the 4 field sites (Fig. 12). This is consistent with longer-term (40 yr) rates determined from aerial photo comparisons. Erosion rates depend on a variety of factors including frequency of wave attack, tidal inundation period, above- and below-ground (root) biomass and structure, sediment characteristics geotechnical properties and effects of macroinvertebrates that live near the marsh edge, especially crabs, mussels, oysters and snails.

Fig. 12. An ArcGIS image depicting the marsh edge at Chimney Pole marsh in 1968, 2001, and 2007 based on aerial photos. The edge at Chimney Pole has been eroding about 1.57 m/yr from 1968 to 2007 and about 1.21 m/yr

The primary mechanisms of marsh boundary erosion within Hog Island Bay are slumping, undercutting, and root scalping (removal of the active root layer to form a denuded terrace) as a direct result of wave attack (Fig. 13). Our initial findings suggest that most of the erosion is not associated with extreme storms, but rather is driven by small waves, 20-40 cm in height, during regularly occurring wind events. Stabilization by marsh vegetation slows the erosion at the edges of marshes and results in a style of erosion characterized by the detachment of blocks of marsh sediment and roots that can slump into the intertidal zone or be washed back onto the marsh surface. Preliminary observations have noted that the failure (separation of a marsh block from the intact marsh) can occur along a pathway connecting a series of crab burrows, suggesting that the development of weakness at the marsh edge could be related to macroinvertebrate density and activity. Our sampling this summer includes measurements of burrow density and size. In addition, we are deploying a webcam at one of the eroding marsh sites to document the timing and mechanisms of marsh edge erosional processes.

Fig. 13. Different mechanisms of marsh boundary degradation by wave erosion: a) slumping; b) undercutting; c) root scalping (removal of the active root layer forming a denudated terrace).

Tidal water variations control the elevation at which waves pound against the marsh edge and condition the propagation and transformation of wave trains as they move towards these boundaries. We used a high-resolution wave model developed at the University of Udine, Italy, which couples a finite-volume shock-capturing numerical scheme with the Boussinesq equations to investigate the effect of wave action on marsh boundaries as a function of tidal elevation and wave height, for different edge configurations. In order to link numerical simulations to field conditions, the model inputs are based on topographical and hydrodynamic surveys conducted at the VCR study site. Model results show that the wave thrust on the marsh scarp depends strongly on tidal levels. The thrust increases with tidal elevation until the marsh is submerged, then it rapidly decreases. The wave thrust is maximum for a vertical scarp and minimum for a terraced scarp. Similarly, wave energy dissipation is maximized just above the marsh platform elevation, when wave reflection is reduced and wave breaking occurs at the marsh edge (Tonelli et al, in review).

Carbon and nitrogen dynamics

Work by student T. Mozdzer and PIs J. Zieman and K. McGlathery (Mozdzer et al. (in review), Mozdzer and Zieman (in review) at the VCR, helps to explain rapid expansion of the non-native, invasive type into high marsh zones in part due to its ability to be competitive when N availability is high. Ecophysiological properties of the non-native *Phragmites* combine with natural drivers (wrack distribution and disturbance) and human drivers (nitrogen enrichment and historical introduction of the non-native form to North America) to modify microhabitat conditions (i.e., elevation, microrelief, salinity, redox) of high marsh surfaces. The consequence of these modified conditions is the creation of an alternate stable state that is maintained by biological feedbacks of *Phragmites*. In the long term, this could have implications for rising sea levels, suggesting that coastal marshes with non-native *Phragmites* may be less vulnerable to rising sea level than native marsh species. Other factors, such as the consequences of elevated atmospheric CO_2 concentrations contribute to the uncertainty of the long-term effects of this invasive species. Our monitoring of EOYB in high marsh zones at the LTER-VCR megasite will allow us to follow *Phragmites* invasion at larger spatial scales in the future.

Barrier Islands

Island vegetation

The barrier islands represent a collection of land forms that are both independent and dependent on one another. Our past work has shown that each island may respond in a unique fashion to sea level rise; however, sediment movement among islands and island position dictate that islands are affected by their neighbors. This is true of both physical processes (e.g sediment transport) and biological processes (e.g. movement of propagules, including organisms, seeds, and pollen). Our goal is to link the external drivers of storm disturbance (overwash, sand desposition, flooding, salt spray) that modify the land surface and water table to patterns of vegetation on the barrier islands. We are building on our long-term work on Hog Island, including permanent plots in the dune chronosequence, to include islands in the 2 new box transects. Our earlier work has shown that there is predictable spatial variation across the island landscape due to differences in microtopography and the decrease in disturbance magnitude and frequency with distance from the beach face, which result in different vegetation patterns across the islands (Fahrig et al. 1993). Thus storm-related effects should vary among islands as a function of island size and topography.

Our long-term data collection on vegetation patterns has focused on Hog Island. We are now expanding this effort to include to additional islands -- Smith, Parramore and Metompkin – that vary in their topographic complexity. PI F. Day and his students have characterized biomass patterns for both dunes and marshes, depth to groundwater, salinity, soil organic matter, total N and total plant N. They found that aboveground biomass was greatest on intermediate dunes, followed by older dunes, with the young dunes having the least biomass due to frequent disturbance. As expected, the oldest dunes displayed the highest levels of soil N, followed by the intermediate and young dunes. We find that for the marsh community the root to shoot ratios arevariable across the three islands, with greatest root biomass on Hog Island marshes

A B

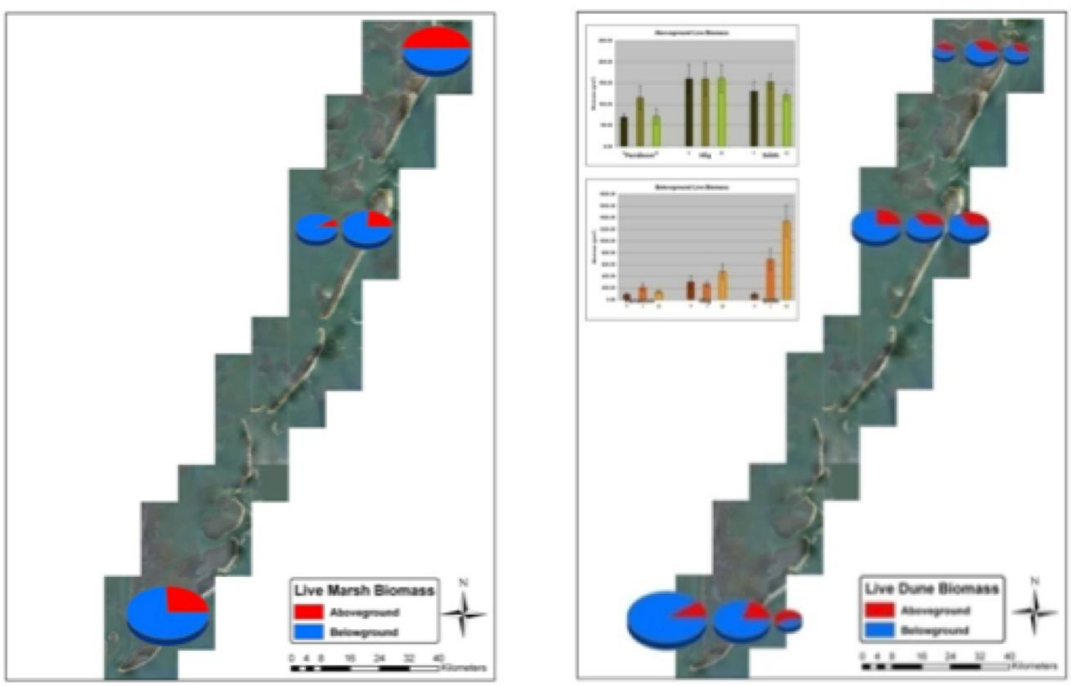


Fig. 14. Root to shoot ratios for marsh plants (A) and dune plants (B) on the islands in the 3 VCR box transects.

and least on Metompkin (Fig. 14a). In comparison there is much less variation in root to shoot ratios for dune plants (Fig. 14b).

Shrub expansion – Our data indicate that the shift from grassland to shrub thicket on barrier islands results in a substantial increase in litterfall and foliar nitrogen concentration that will likely have a major impact on the size and cycling of ecosystem carbon and nitrogen pools. PI D. Young and his students have found that litterfall for shrub thickets ranged from 8991 ± 247 to 3810 ± 399 kg ha^{-1} yr^{-1} and generally declined with increasing thicket age. Litterfall in three of the four thickets exceeded previous estimates of aboveground annual net primary production (ANPP) in adjacent grasslands by 300-400%. Leaf nitrogen concentration was also higher after shrub expansion and, coupled with low nitrogen resorption efficiency and high litterfall, resulted in a return of as much as 169 kg N ha^{-1} yr^{-1} to the soil (Fig. 15). We estimated that ~70% of nitrogen returned to the soil was from symbiotic nitrogen fixation resulting in an ecosystem input of between 37 and 118 kg N depending on site. Considering the extensive cover of shrub thickets on Virginia barrier islands, nitrogen fixation by shrubs is likely the largest single source of nitrogen to the system. Increasing carbon and nitrogen availability in these nutrient-poor soils is likely to permanently reduce cover of native grasses and alter community structure by favoring species with greater nitrogen requirements.

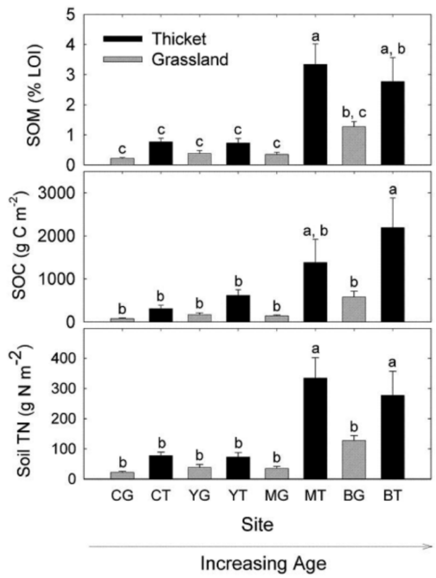


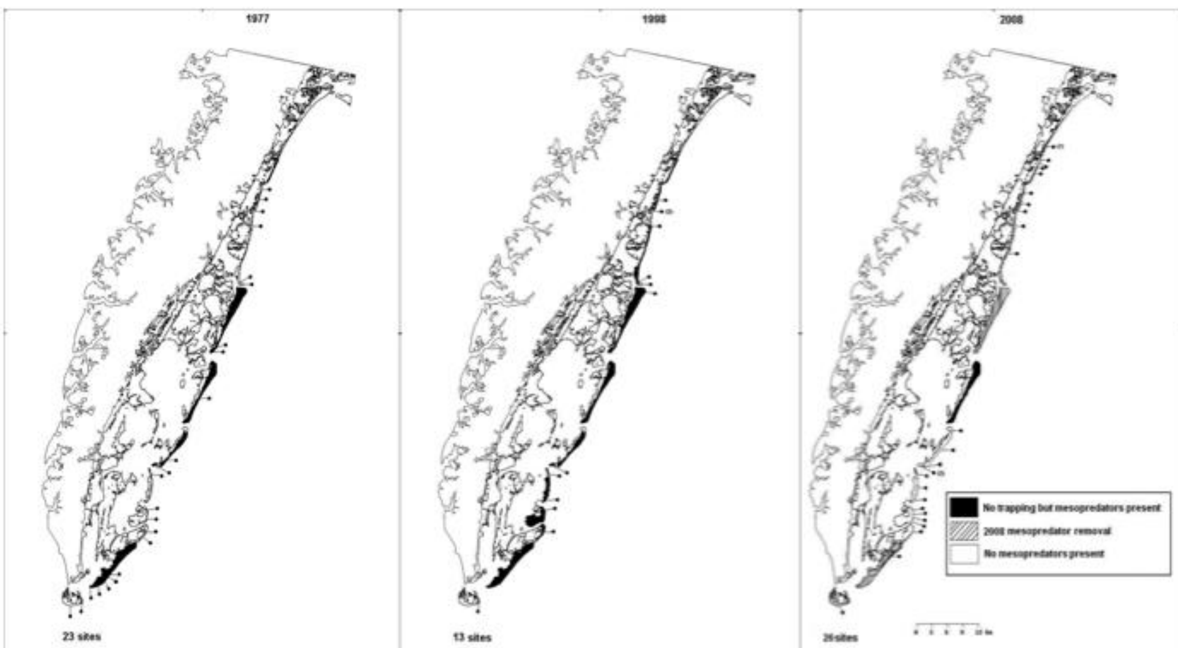
Fig. 15. Variations in soil organic matter, soil organic carbon and total soil nitrogen across the North Hog Island chronosequence. Carbon and nitrogen accumulation is much higher beneath shrub thickets indicating that shrub encroachment could be a major factor in regional C and N budgets.

Predator-prey interactions

The analysis by R. Dueser and N. Moncrief on predator migration from mainland habitats to the barrier islands (Fig. 16) has many implications for management, including the expected effectiveness of predator removals and the identification of "hotspots" where dispersing raccoons might be intercepted before they can immigrate onto islands that are important habitats for breeding birds.

Fig. 16. Least cost path analysis showing probable movement of raccoons.

Work by PI M. Erwin and colleagues have shown that there have been decadal changes in the distribution of abundance of colonial waterbirds in the VCR (Erwin et al. 2001, 2003, 2007). Of most conservation concern is the decline of 8 of 10 wading bird (egrets, herons) species, and marked decreases in 5 of 8 species of terns (including black skimmers). There has been a shift for two of the most abundant terns, royal and common, where birds have moved from barrier island nesting into the Chesapeake Bay region,which is believed to be the result of expansions of ranges of raccoons and foxes on the barrier islands (Erwin et al. 2001, 2003). The data set relating colonial waterbirds to predators has now been extended to cover a 30-year period (Fig. 17). In 2001, TNC, USFWS, and USDA Wildlife Services expanded removal efforts of foxes and raccoons at a number of islands. The most recent map (2008) in Fig. 16 indicates where trapping occurred in spring and summer of 2008. The pattern suggests that the trapping has had a positive influence on the numbers of colonies of these seabirds, especially in the northern region.



Data from 2008 provided by The Nature Conservancy (B. Truitt, A. Wilke), Virginia Department of Game and Inland Fisheries (R. Boettcher), U.S. Fish and Wildlife Service (P. Denmon), with assistance from Virginia Department of Conservation and Recreation (D. Field), Utah State University (R. Dueser), and USDA Wildlife Services personnel.

Fig. 17. The barrier island distribution changes in mammalian predators (red fox, raccoon) and colony sites (indicated by dots) of ground-nesting terns (least, common, royal, sandwich, gull-billed) and black skimmer from 1977 to 2008.

Seed dispersal via birds

Given the low woody-species richness on Metompkin Island and the lack of structural diversity, D. Young and his students expected to find only a few bird-dispersed seeds at the woody site and none at the graminoid. Therefore, birds may not be the main contributing factor in the initial stages of the expansion of woody species on this island. Fecal traps on Hog Island captured more seeds and more species than either of the other two islands, a result attributed to the diversity of woody species on Hog Island, as well as its relative successional and geomorphic maturity compared to Metompkin Island (Fig. 18). Smith Island captured only a small number of *Morella* spp. seeds. Because Smith Island has higher woody species diversity than Hog Island, we expected collected seed diversity to be higher than we observed.

The results on Smith Island are an indication of the importance of location of the artificial perches relative to small-scale patches. The sites chosen on north Hog Island were either within or very near the bands of dense shrub thickets, whereas the northernmost transect on Smith was not as close to the dense thickets. These results indicate that while the role patches play in influencing seed dispersal is related to island position and location on a given island, we may need to define patches in greater detail to accurately predict which locations will receive the most bird-dispersed seeds. Although spatial variation is an important factor in seed dispersal, we need to have a better understanding of precisely what kind of spatial variation exists and how to better quantify such variation in order to make more accurate predictions about the future community composition of the Virginia barrier islands.

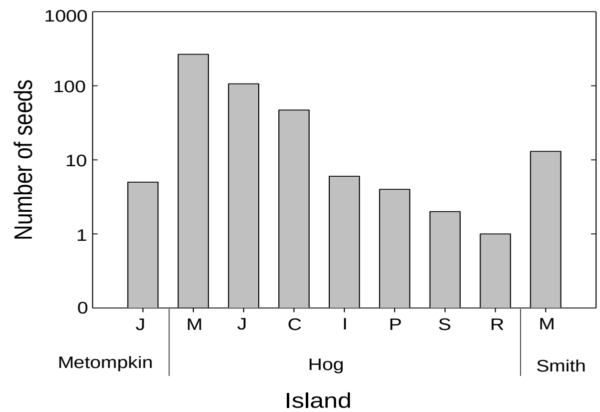


Fig. 18. Abundance of seeds collected from artificial perches across all transects on Metompkin, Hog and Smith Islands from July 2007-June 2008. J = *Juniperus virginiana*, M = *Morella* spp. including *Morella cerifera* and *Morella pensylvanica*, C = *Callicarpa americana*, I = *Iva frutescens*, P = *Parthenocissus quinquefolia,* S = *Sassafras albidum*, and R= *Rubus sp.*

In a related study, we examined the potential for passerines to disperse viable propagules of *Frankia*, the bacterium the forms a N fixation symbiosis with *Morella sp.* The results supported the hypothesis that *Frankia* propagules are consumed and transported by passerines to barrier islands, and deposited by defecation (Table 2). Fecal samples, whether collected directly or indirectly, contained sufficient *Frankia* material for nodulation, though samples

Table 2: Results of *Frankia* bioassay of Coastal Virginia Wildlife Observatory fecal material. Samples were pooled by species, and introduced to roots of one or more sterile *Morella cerifera* seedlings.

Bird Species	Samples pooled	Seedlings tested	Seedlings nodulated
American Redstart	9	3	1
American Robin	1	1	0
Black-and-white Warbler	1	1	0
Black-throated Blue Warbler	1	1	0
Common Yellowthroat	2	1	0
Gray-cheeked Thrush	1	1	0
Gray Catbird	7	2	0
House Wren	7	2	1
Northern Mockingbird	1	1	0
Northern Waterthrush	1	1	1
Pine Warbler	1	1	1
Red-breasted Nuthatch	1	1	1
Slate-colored Junco	1	1	1
Song Sparrow	3	1	1
Swamp Sparrow	9	3	2
Veery	1	1	0
Winter Wren	2	2	2
Western Palm Warbler	6	3	0
White-throated Sparrow	2	1	0
Yellow-rumped Warbler	28	2	1

collected directly from birds were more likely to induce nodule development on sterile *Morella cerifera* roots. While avian transport may not be the dominant mode of dispersal across small scales, bird dispersal in this environment appears viable, and likely provides an important mechanism for initial arrival of *Frankia* and landscape colonization by *M. cerifera*.

Landscape studies

Landscape-scale models of ecosystem state change

Observed decadal trends in landscape change - An example of the data analysis that was done for the all watersheds in the VCR is given in Fig. 19 for the Hog Island Bay watershed. For this and all the VCR watersheds, we found that changes over time were typically very small, illustrating how little development pressure the VCR watersheds receive relative to other watersheds in the mid-Atlantic region. The Hog Island Bay watershed had relatively minor areas of developed or bare land cover classes (totaling < 5%), while cropland, marsh and woody were major elements. The largest observed shift was for cropland, and this was only 523 ha – less than 4% of the total area.

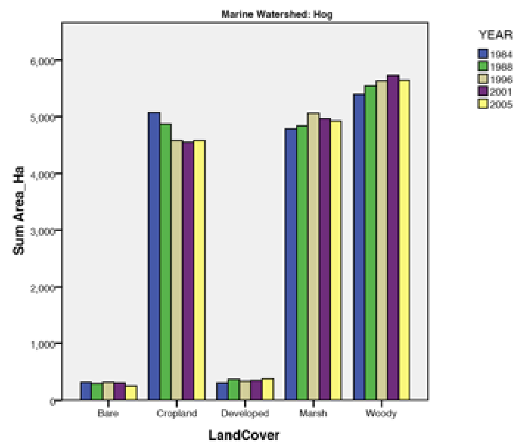


Fig. 19. 20-year landscape change analysis of the Hog Island Bay watershed based on NOAA CCAP data.

Landscape modeling - After calibration of the habitat-switcher model, a future scenario was developed by PI E. Reyes to investigate potential consequences of sea level rise. This scenario tested the response to a sea-level rate of 5 mm yr^{-1}. The simulation run was initiated in 1996 and ran for just 10 years. This allowed us to examine differences at two points in time. The resulting image at time 2005 was then compared using our fit statistic against the 2005 habitat classified image (Fig. 20). Table 4 shows the comparison between habitat classified maps and simulated maps. Our preliminary results indicate that under asea-level rise rate of 2-5 mm y^{-1}, habitat changes will continue to occur along barrier island shoreline and overland migration will follow the topographic gradient, and as expected, we did not see a significant change in habitat distribution. Our plan is to continue with calibration and validation efforts for VLM using the point data available for wetland water levels, sedimentation and EOYB biomass. In addition, as soon as we obtain the LIDAR data for the region, we will rerun the model with more precise topographic and bathymetric data.

The basis for the model lies in the mainland tidal wetland environment. Work in the future will focus on improving the representation of the other types of ecosystems on the landscape, e.g., barrier islands and subtidal habitats. Future simulations will include different scenarios of sea-level rise, and we will incorporate disturbance magnitudes and probabilities into our model simulations.

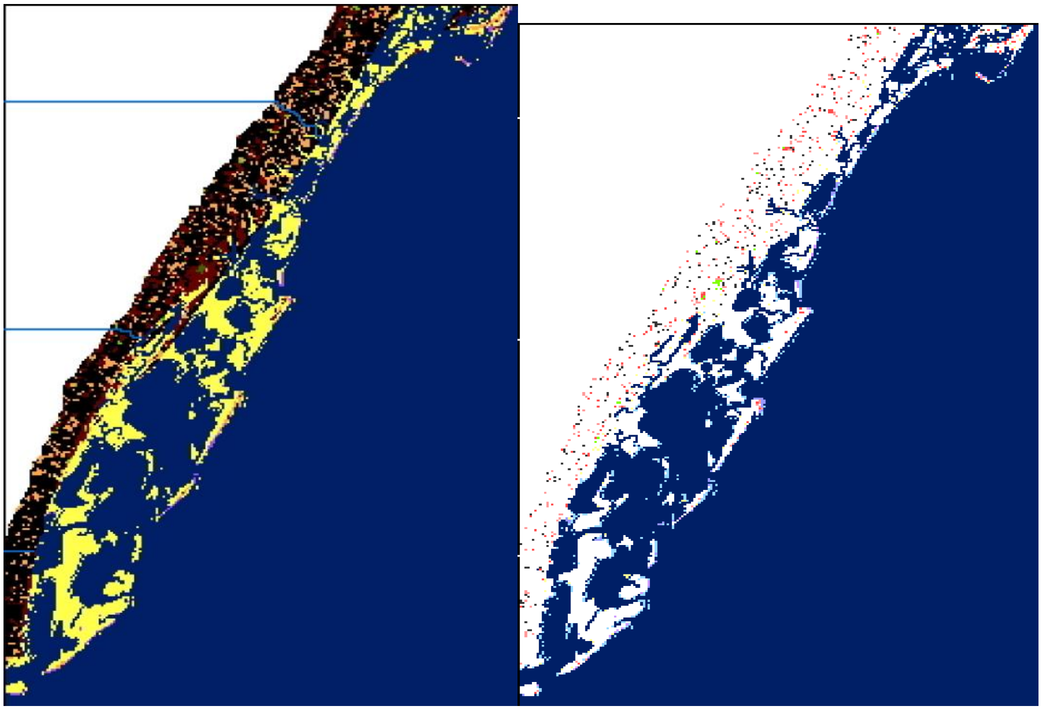


Fig. 20. Virginia Coastal Reserve Landscape Model Double SLR rate Scenario. Panel A shows habitat classified simulated image for 2005. Panel B shows difference map between habitat classified simulated image for 2005 and scenario results. Legend: Brackish high marsh; Freshwater high marsh; Wetland forest; High marsh; Low marsh; Open water; Upland; Forest; Canals; Barren or sandy areas.

Geomorphic models of landscape change

Evolution of marshes and tidal flats - Numerical results show that vegetation determines the rate of marsh progradation and regression, and plays a critical role in the redistribution of sediments within the intertidal area. Simulations indicate that the scarp between salt marsh and tidal flat is a distinctive feature of marsh retreat. For a given sediment supply, the marsh can prograde or erode as a function of sea-level rise. A low rate of sea-level rise reduces the depth of the tidal flat increasing wave dissipation. Sediment deposition is thus favored and the marsh boundary progrades. A high rate of sea-level rise leads to a deeper tidal flat and therefore higher waves that erode the marsh boundary, leading to erosion. When the rate of sea-level rise is too high the entire marsh drowns and is transformed in a tidal flat (Fig. 21; Mariotti and Fagherazzi, in revision).

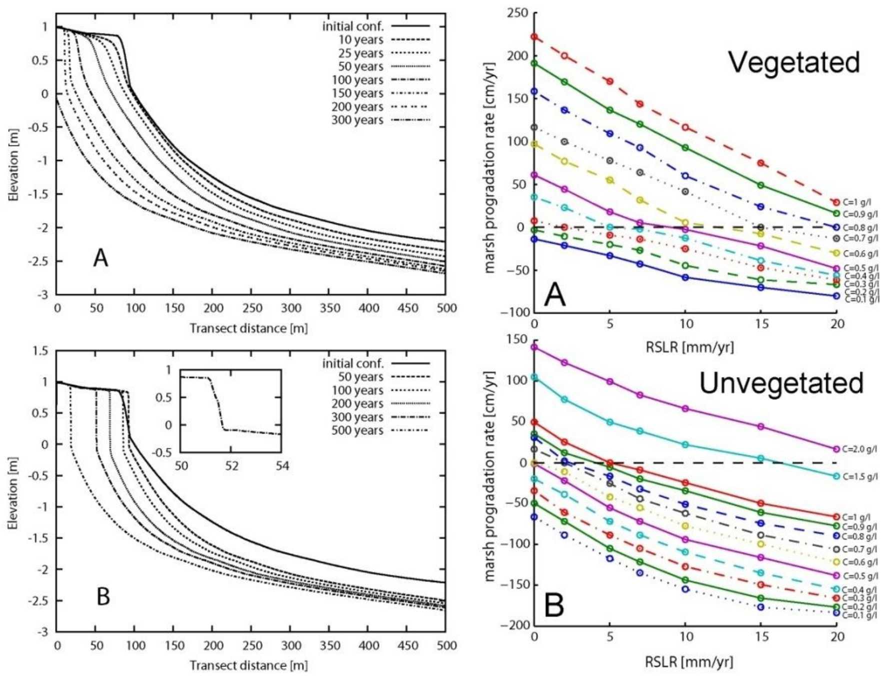


Figure 21. Left: Long-term numerical simulation of salt marsh deterioration. The evolution of the profile starts from a fully developed salt marsh, imposing a sediment concentration equal to 0.1 g/l at the seaward boundary: a) without vegetation, b) with vegetation; Right: Progradation and erosion rates of marsh boundary as function of Relative Sea Level Rise (RSLR) and sediment concentration. Positive values indicate progradation, negative values indicate erosion. A) With vegetation. B) Without vegetation.

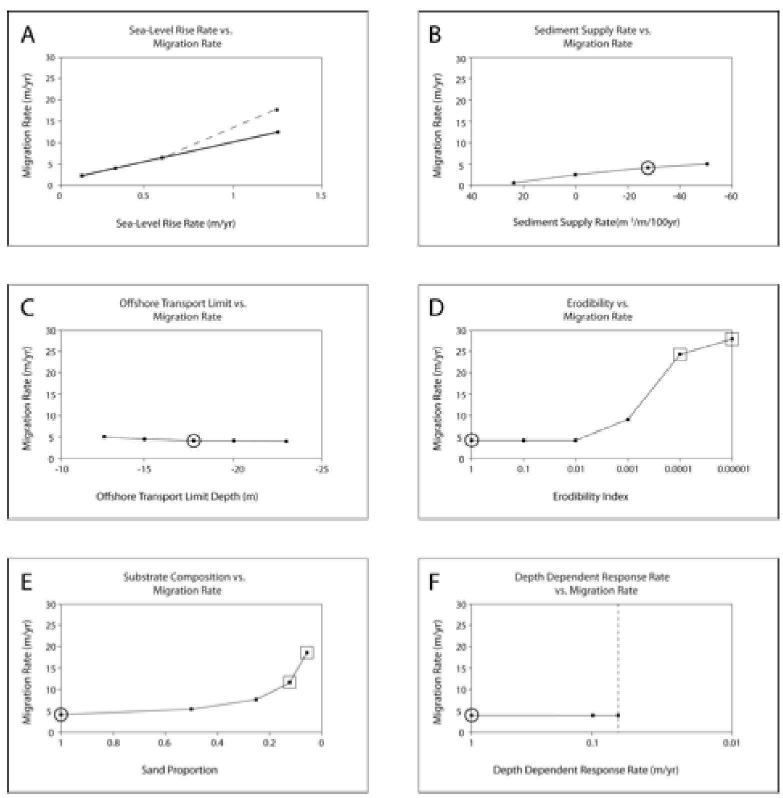


Fig. 22. Results of sensitivity analyses showing the effect of changes in six different input parameters on barrier island migration rate. In plot A a solid line denotes results of constant total sea-level rise simulations while a dashed line denotes results of constant duration simulations. Base-case simulation values are indicated by an open circle.

Evolution of barrier islands - Sensitivity analyses reveal that substrate composition, followed by sea-level rise rate, and sediment supply rate, is the most important factor in determining barrier island response to sea-level rise (Moore et al., accepted) (Fig. 22). The results of this study suggest that although barrier island migration rates may increase significantly in the future, barrier islands with sufficiently thick and sandy substrates are likely to persist as long as landward migration is not impeded and shoreface erosion can occur quickly enough to liberate sand volumes necessary to maintain subaerial exposure (Moore et al., accepted). Moore et al. (accepted) also apply insights from their sensitivity analyses along with additional geologic constraints to develop a Holocene simulation of barrier island evolution that closely reproduces the modern morphology and stratigraphy in the study area (Fig. 23).

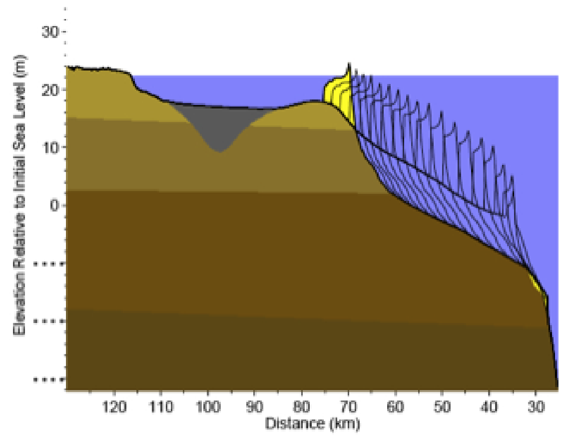


Fig. 23. The final time step in an 8500-year Holocene simulation for a study area in the North Carolina Outer Banks. Each trace represents a 500-year time increment and the modern barrier island appears in yellow. The initial surface is shown as a thin black line above the bold black line, which represents the modern shelf surface.

The design, density, and scale of the grain size sampling program done for the sediment budget analysis conducted by ROA M. Fenster and colleagues have provided one of the best data sets available in North America. This analysis has shown that large depocenters associated with Fishing Point, the Chincoteague Inlet flood-tidal delta, and the Wachapreague Inlet ebb-tidal delta control morphodynamics along the Virginia barrier islands over 10^2-10^0 time scales. Results from the outlier analysis indicate that the timing and magnitude of a storm prior to a photo date and its magnitude do not predict the variability in shoreline position residuals well. Consequently, storms are not outliers and thus do not increase uncertainty in, or change the shoreline rate-of-change. These results point toward the important role of storms – both the magnitude and cumulative frequency – in driving long-term shoreline changes along this coast. Analysis of the wave refraction model results showed that a dynamic equilibrium of tidal inlets (no net migration during 10^2-10^0 yr) in the vicinity of Hog Island can be explained by the local dynamics (seasonal wave- and tidal-current variations) interacting with the exterior (10-15 km offshore) and local (inshore ebb tidal delta and inlet channel configuration) bathymetric features. While the concentration of wave energy has stayed focused on the tidal inlets during the past 150 yr as they refract around large, stable nearshore features (i.e., shoreface-connected ridges and tidal-inlet retreat paths), mean wave conditions produce a slow, southward migration of the island-inlet systems. This situation results from downdrift barrier island erosion and updrift barrier island accretion (via tidal inlet bypassing processes). However, northeast storm waves reverse the direction of sediment transport as they refract around nearshore bathymetric features (e.g., ebb-tidal deltas). This seasonal variability in sediment flux in response to storm vs. mean wave conditions result in dynamic tidal inlet stability.