Annual Report for Period: 12/2010 - 11/2011
Submitted on: 09/16/2011
Principal Investigator: McGlathery, Karen .
Award ID: 0621014
Organization: University of Virginia
Submitted By:
Porter, John - Co-Principal Investigator
Title:
Long-Term Drivers, State Change and Disturbance on the Virginia Coast Reserve: LTER V

Project Participants

Senior Personnel

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

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

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

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

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

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

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

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

and disturbance

Name: Christian, Robert

Worked for more than 160 Hours: Yes

Contribution to Project:

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

Name: D'Odorico, Paolo

Worked for more than 160 Hours: No

Contribution to Project:

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

Name: Day, Frank

Worked for more than 160 Hours: Yes

Contribution to Project:

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

Name: Dueser, Raymond

Worked for more than 160 Hours: Yes

Contribution to Project:

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

Name: Erwin, Russell

Worked for more than 160 Hours: No

Contribution to Project:

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

Name: Fagherazzi, Sergio

Worked for more than 160 Hours: Yes

Contribution to Project:

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

Name: Fuentes, Jose

Worked for more than 160 Hours: No

Contribution to Project:

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

Name: Galloway, James

Worked for more than 160 Hours: No

Contribution to Project:

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

Name: Macko, Stephen

Worked for more than 160 Hours: No

Contribution to Project:

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

Name: Mills, Aaron

Worked for more than 160 Hours: No

Contribution to Project:

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

Name: Moncrief, Nancy

Worked for more than 160 Hours: No

Contribution to Project:

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

Name: Oertel, George

Worked for more than 160 Hours: Yes

Contribution to Project:

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

Name: Reyes, Enrique

Worked for more than 160 Hours: Yes

Contribution to Project:

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

Name: Scanlon, Todd

Worked for more than 160 Hours: No

Contribution to Project:

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

Name: Shugart, Herman

Worked for more than 160 Hours: No

Contribution to Project:

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

Name: Smith, David

Worked for more than 160 Hours: No

Contribution to Project:

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

Name: Young, Donald

Worked for more than 160 Hours: Yes

Contribution to Project:

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

Name: Zieman, Joseph

Worked for more than 160 Hours: No

Contribution to Project:

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

Name: Schwarzschild, Arthur

Worked for more than 160 Hours: Yes

Contribution to Project:

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

Name: 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.

Name: Challard, Margaret

Worked for more than 160 Hours: No

Contribution to Project:

Ph.D student working 2010-2015 with PI Mills on stream nitrogen loading and denitrification. Supported by a UVA fellowship 2010.

Name: Kirwan, Matthew

Worked for more than 160 Hours: No

Contribution to Project:

Modeling of marsh and lagoon systems (2010-2012). USGS/BRD employee stationed at UVA.

Name: Mariner, Charlie

Worked for more than 160 Hours: Yes

Contribution to Project:

Northampton HS, 2011 worked with graduate student Gulbranson on her project looking at impacts of the invasive macroalgae

Post-doc

Name: Safak, Ilgar

Worked for more than 160 Hours: No

Contribution to Project:

2010-2012. Post-Doc for PI Wiberg, working on sedimentary geology in Hog Island Bay. Supported by UVA funding.

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; Thesis: Interisland variability in above and belowground plant biomass in interior marshes on the Virginia barrier islands

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 (2003-2010). Advisor: Macko; Ph.D Dissertation: An investigation of nutrient transfer in a restored eelgrass, Zostera marina, meadow

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 (2002-2008). 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 (2006-2009). Advisors: Blum, McGlathery & Wiberg; Spatial patterns of bacterial abundance in a seagrass restoration site on the Eastern Shore of Virginia (USA). MA thesis. University of Virginia, Charlottesville, VA.

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 (2006-2010). Advisor: Day; Thesis: Interisland variability of dune plant community structure on Virginia's 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: Yes

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; M.S. Thesis: Erosional processes along salt marsh edges on the Eastern Shore of Virginia.

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: Funk, Clara

Worked for more than 160 Hours: Yes

Contribution to Project:

M.S. Student (2008-2010). Advisor: Scanlon; Ph.D Dissertation: Factors contributing to spatial variability of N2O fluxes in a Virginia salt marsh.

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 PI D'odorico (2007-2011) Dissertation title: Stability and resilience of seagrasses in shallow coastal bays

Name: Wolner, Catherine

Worked for more than 160 Hours: Yes

Contribution to Project:

M.S. Student. University of Virginia. (2008-2011). Advisor: Moore. Thesis: Ecomorphodynamic feedbacks and barrier island evolution, Virginia Coast Reserve, USA

Name: Willis, Patricia

Worked for more than 160 Hours: Yes

Contribution to Project:

M.A. Student 2007-2009; Advisor Blum. Thesis:The effect of hydroperiod on surface elevation and sediment accumulation in Philips Creek Salt Marsh, Virginia, USA

Name: Kost, Elizabeth

Worked for more than 160 Hours: Yes

Contribution to Project:

VCU Biology MS student working with Don Young on studies on the shrubs on Hog Island 2010-2013.

Name: Rubis, Kathryn

Worked for more than 160 Hours: Yes

Contribution to Project:

VCU Biology MS student working with Don Young on studies on the shrubs on Hog Island 2010-2013.

Name: Greener, Jill

Worked for more than 160 Hours: Yes

Contribution to Project:

M.S. student working 2010-2013 with PI McGlathery on carbon cycling in seagrass.

Name: Taube, Sara

Worked for more than 160 Hours: No

Contribution to Project:

MS student working 2010-2013 with PI Wiberg on sediment distribution in salt marshes. Supported by a UVA fellowship 2010.

Name: Graziani, Dominic

Worked for more than 160 Hours: Yes

Contribution to Project:

ODU MS student (2011-2012) Advisor: Day working on island vegetation dynamics.

Name: Hansen, Jennifer

Worked for more than 160 Hours: Yes

Contribution to Project:

Ph.D student (2009-) Advisor: Reidenbach. Research related to flow and sediment dynamics within seagrasses.

Name: Whitman, Elizabeth

Worked for more than 160 Hours: Yes

Contribution to Project:

UVA M.S. Student (2008-2011). Advisor: Reidenbach. Thesis: Hydrodynamics affecting larval transport and settlement onto intertidal oyster reefs.

Name: Oster, Dana

Worked for more than 160 Hours: Yes

Contribution to Project:

M.S. Student (2009-2011) working with PI Moore studying beach dynamics on the barrier islands.

Name: McFarland, George

Worked for more than 160 Hours: Yes

Contribution to Project:

M.S. Student at UVA (2011-)working with PI's Mills and Herman on hydrogeochemistry of mainland creeks.

Name: Brenner, Owen

Worked for more than 160 Hours: Yes

Contribution to Project:

M.S. Student (2009-) at UVA working with PI Moore on beach dynamics.

Name: Challand, Maragaret

Worked for more than 160 Hours: No

Contribution to Project:

M.S. Student (2011-) at UVA working with PI Mills on Cobb Mill Creek watershed with support from other grants.

Name: Reid-Black, Kristina

Worked for more than 160 Hours: No

Contribution to Project:

M.S. Student (2008-) at UVA working with PI Mills on Cobb Mill Creek watershed with support from other grants.

Name: McFadden, George

Worked for more than 160 Hours: No

Contribution to Project:

M.S. Student (2009-) at UVA working with PI Mills and Herman on Cobb Mill Creek watershed. Supported by non-LTER funds.

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. BA Thesis 2009: Belowground production of the mixed high marsh plant community Spartina patens and Distichlis spicata. University of Virginia, Charlottesville, VA. Post graduation (2010-2012) worked on Information Management for the project with PI Porter.

Name: Wiles, Cory

Worked for more than 160 Hours: Yes

Contribution to Project:

2009-2010 ECU undergraduate student contributions to Haywood marsh study (faculty advisor, Christian)

Name: Ellis, Stuart

Worked for more than 160 Hours: Yes

Contribution to Project:

2009-2010 ECU undergraduate student contributions to Haywood marsh disturbance study and independent study project on below ground organic matter (faculty advisor, Christian)

Name: Walsh, Kate

Worked for more than 160 Hours: Yes

Contribution to Project:

Worked with PI Reidenbach on seagrass and oyster related research during 2010-2011.

Name: Starling, David

Worked for more than 160 Hours: Yes

Contribution to Project:

Worked with PI Young on studies of barrier island vegetation (2011)

Name: Luckenbach, Patrick

Worked for more than 160 Hours: Yes

Contribution to Project:

In 2011 worked with PI Schwarzschild. Assisted in the synoptic seagrass survey, assisted with pilot study to examine impacts of sediment organic matter on eelgrass morphology and minimum light requirements.

Name: Bruno, Gavin

Worked for more than 160 Hours: Yes

Contribution to Project:

In 2011 worked with PI Schwarzschild. Assisted in the synoptic seagrass survey, assisted with pilot study to examine impacts of sediment organic matter on eelgrass morphology and minimum light requirements.

Name: Anutaliya, Waen

Worked for more than 160 Hours: No

Contribution to Project:

Student at UVA working with PI Mills on Cobb Mill Creek watershed with support from other grants (2011).

Name: Hounschell, Alexandria

Worked for more than 160 Hours: No

Contribution to Project:

Student at UVA working with PI Mills on Cobb Mill Creek watershed with support from other grants (2011).

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

Name: Betancourt, Christopher

Worked for more than 160 Hours: Yes

Contribution to Project:

2010-. Lead programmer for PI Reyes VCR Landscape Model.

Name: Rodgers, Brooke

Worked for more than 160 Hours: Yes

Contribution to Project:

Collect data, maintain and operate monitoring equipment and boats at the Anheuser-Busch Coastal Research Center. (2011-2012)

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

Name: Deemy, James

Worked for more than 160 Hours: Yes

Contribution to Project:

VCU undergraduate, worked with Don Young on shrub-related projects in 2010.

Name: Austin, Jared

Worked for more than 160 Hours: Yes

Contribution to Project:

VCU undergraduate, worked with Don Young on shrub-related projects in 2010.

Years of schooling completed: Freshman

Home Institution: Other than Research Site

Home Institution if Other: Virginia Commonwealth University

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2010

REU Funding: REU supplement

Name: Hoffman, Ava

Worked for more than 160 Hours: Yes

Contribution to Project:

UVA undergraduate, worked with Don Young on shrub-related projects in 2010.

Name: Mische, Paige

Worked for more than 160 Hours: Yes

Contribution to Project:

In 2010 worked with PI McGlathery and graduate student Dana Gulbransen on a project studying the ecological impacts of the invasive macroalage Gracillaria

Name: Olcott, Chris

Worked for more than 160 Hours: Yes

Contribution to Project:

In 2010 worked with PI Linda Blum in studies of the effects of fertilizer additions to below ground growth in saltmarshes

Name: Weakley, Meredith

Worked for more than 160 Hours: Yes

Contribution to Project:

In 2010 worked with PI Wiberg and graduate student Wolner on a sediment survey of Hog Island

Name: Peterson, Nancy

Worked for more than 160 Hours: Yes

Contribution to Project:

Worked in 2011 with graduate student Dana Gulbransen under Karen McGlathery on Potential Ecological Impacts of invasion by a non-native macroalgae

Name: Emery, Kyle

Worked for more than 160 Hours: Yes

Contribution to Project:

In 2011 worked with graduate student Jill Griener under the supervision of PI's McGlathery and Wiberg. Topic: Carbon sequestration in sediments of restored seagrass meadows in the coastal bays

Organizational Partners

USGS Biological Resources Division

Co-PIs R. Michael Erwin and Matthew Kirwan are supported by USGS/BRD and are stationed at UVA.

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. In 2010 they provided $75K to assist us in a joint purchase of LiDAR data for the Eastern Shore of Virginia.

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)

Department of Army, U.S. Army Corp of Engineers

LiDAR expert John Anderson is supported during a sabbatical at UVA (2011-2012) and collaborates on studies of barrier island vegetation.

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:
EDUCATION AND OUTREACH ACTIVITIES

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 involve about 200 students each year in our Schoolyard LTER program, more than half of whom are representative of women and minority groups. 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

The goals of our education program are to: 1) involve and excite local school kids and teachers in marine science in general, and specifically about their local coastal barrier island system; 2) reach a broader audience of students through web-based resources; and 3) train undergraduate and graduate students through VCR research and involvement in national and internal collaborations. Our site director, A. Schwarzschild, is our current Education and Outreach Coordinator and works closely with local teachers and students. He also has forged new education collaborations with our partners at The Nature Conservancy and colleagues at Chesapeake Experience. 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.

1) 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 23 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, conductivity meters, 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. Students use these data to analyze 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 the 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.

2) Teacher training our partnership with Chesapeake Experience continued during the Spring of 2010, with the completion of another teacher training/ professional development program, entitled Coastal Bay Ecology. This three day, short course provided instruction in ecology and environmental science topics centered around the Eastern Shore Barrier islands, but applicable to other VA ecosystems. Nine teachers from the Hampton Roads area participated in the program, held at the ABCRC facilities. A. Schwarzschild was the main instructor, with assistance from Jill Bieri from Chesapeake Experience. Instruction was provided through a variety of formal lectures, discussion groups, kayak excursions and two walking trips, one on the mainland and one across Hog Island. During these experiences, the participants were introduced to the varied ecosystems found on the VA Eastern Shore, the ecosystem services they provide, and the impacts of climate change, sea-level rise and human activities on these ecosystems. Another three-day workshop focused on ecology of migratory birds was conducted in October.

3) Research internships ? Over the last 4 years we have involved 15 high school students in 8-week summer research 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. 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.

Six REHS interns were supported in 2007, 2 in 2008, 4 in 2009 and 3 in 2010. This summer The Nature Conservancy and Volgenau Foundation have again provided funding for 2 of the internships. Student projects this summer included an investigation of the ecological impacts of the invasive macroalgae G. vermiculophylla, assisting with our annual survey of seagrass restoration sites that examines the ecological implications of restoring eelgrass to the VA coastal bays, and a continuation of the SLTER water quality monitoring program to obtain summer time values to supplement academic year data taken by the Environmental Science II classes. The quality of the student involvement has been very high ? 2 students from last year were very motivated by their experiences, applied to and were accepted to UVA, joining a student from the summer of 2008 who is now a major in Environmental Sciences at UVA.

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, we provide some support for undergraduate assistants in PI laboratories during the academic year. This allows students to continue their involvement in the LTER program and to get more deeply involved in research projects than a single summer allows. Undergraduate students have also been successful in obtaining their own funding for LTER research. For example, two students in McGlathery's lab applied with their graduate student mentors and received $5000 research grants from UVA to continue their LTER work. One of these students is now a graduate student in Pace's lab.

The VCR site serves as a platform for field classes that have been run by LTER PIs at the field site. Table 5 below includes a list of undergraduate and graduate courses that are taught everyone 1-2 years at the LTER site.

Table: Undergraduate and graduate level courses currently run by LTER PIs at the VCR

COURSE	INSTITUTION	ENROLLMENT
Methods in Aquatic Ecology	University of Virginia	15
Estuarine Ecology	University of Virginia	15
Aquatic Ecology	University of Virginia	15
Marine Invertebrates	University of Virginia	15
Marsh Ecology	East Carolina University	15
Barrier Island Ecology	Old Dominion University	15
Coast Geomorphology	Randolph Macon University	25
Biological and Ecological Conservation in		

Chesapeake Bay   University of Virginia   20

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. Thus far during this funding cycling, 30 M.S. and Ph.D. theses have been completed.

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. A. Schwarzschild runs this series, which began in Fall 2007 supported by a partnership between the NOAA Coastal Zone Management Program/Seaside Heritage Program, the Department of Environmental Sciences and the VCR-LTER. 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. Past seminar topics covered have included, seagrass ecology, barrier island history, the seaside heritage program, oyster catcher ecology, sea turtle ecology, habitat restoration in support of migratory song birds, the VA natural heritage program, salt marshes and sea level rise, oyster restoration, seagrass restoration, hypoxia and dead zones in the Chesapeake Bay, impacts of climate change on the Eastern Shore, stream and catchment hydrology, and the ecology of barrier island upland communities.

In addition to school classes we have also hosted groups of the UVA Ecology Club, the VA Aquarium Mentoring Young Scientists program, the Eastern Shore chapter of the VA Mater Gardeners and Master Naturalists programs, and the Virginia Association of Biological Sciences.

VCR LTER investigators and graduate students frequently give presentations on topics of scientific interest to community groups and at scientific workshops. For example Ray Dueser and Nancy Moncrief made a presentation about predators on the Virginia barrier islands during a Virginia Coastal Zone Management workshop in December 2010 and made a presentation about predation management on the VCR during a meeting of the Virginia Chapter of the Wildlife Society in February 2011; and Matt Reidenbach gave a presentation on 'Following the Scent: Smelling and tracking of odors by animals' as part of the Long Term Ecological Research Public Seminar Series, Oyster VA, March 2011.

Information Management

We continue to fully participate in LTER Network activities, such as Ecotrends, ClimDB, SiteDB, all-site bibliography and personnel directory. All metadata are available as high-quality Ecological Metadata Language documents that are available from the LTERNET Metacat server. Our web server has provided over 5 Terabytes of information and responded positively to formal 860 data requests (See the 'Contributions to Resources for Research and Education' section for detailed statistics on data access and use.).

In addition to formal datasets, the VCR/LTER provides near real-time data in graphical and tabular forms to the scientific and local community. During 2009 and 2010 we upgraded our tide station in Oyster VA to use a more reliable tide sensor using radar to detect changes in tide levels. A new radar sensor was added to the Redbank, VA tide station in 2011 and a replacement meteorological station was added to Hog Island. 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 server. 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 any place in the world. Graphs and tables, along with updated data from these systems are placed on the public web several times each day.

International Outreach

The VCR/LTER has been active in international outreach, particularly in the East-Asia Pacific region in the area of Information Management and in Italy, focusing on comparisons of coastal systems.

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. In 2009 and 2010 we helped lead two workshops aimed at applying advanced ecoinformatics techniques to ecological data. Week-long workshops in Taiwan (2009) and Malaysia (2010) used Ecological Metadata Language and scientific workflow tools (e.g., Kepler) to analyze data from permanent plots at International LTER sites.

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) spent six months at Boston University working on modeling of intertidal hydrodynamics, and part of the dissertation of Mara Tonelli (PhD, University of Udine Italy) was based on the application of wave models to the VCR marshes.

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.'

Iris Anderson, Robert Christian and Karen McGlathery have begun a collaboration with Victor Camacho-Ibar on nitrogen cycling and ecosystem functions and hydrogeomorphology in San Quentin Bay, Mexico.

Network Activities

Karen McGlathery is a member of the LTER Network Advisory Board (2010-).

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.

John Porter has collaborated with other information managers on the creation of a controlled vocabulary for LTER data sets that was accepted by the LTER Executive Board in 2010. In 2011 he chaired two workshops that organized the controlled vocabulary into a thesaurus and with other members of the Controlled Vocabulary Working Group created web services that allowed the thesaurus to be used to enhance searching using the LTER Metacat server. The controlled vocabulary can be seen and used to search datasets at: http://vocab.lternet.edu

During 2010 the VCR/LTER participated in the MIRADA workshop, aimed at providing an environmental context for microbial genetics measurements, providing both microbial samples and associated environmental measurements.

VCRLTER Researchers are frequently chosen to participate in NSF site visits to other LTER sites. Karen McGlathery participated in the 2011 North Temperate Lakes Review and John Porter participated in 2009 reviews of Harvard Forest and Central Arizona Phoenix LTER sites.

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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 130 datasets using standard Ecological Metadata Language metadata. In addition to the VCR/LTER web site they are available through the national LTERnet, KNB, NASA Mercury and the National Biological Information Infrastructure data catalogs.

Sharing Information:

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

Details on this data use can be found in the "Contributions to Resources for Science and Technology" section of this report.

Product Type:

Audio or video products

Product Description:

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.

Sharing Information:

A compilation of these can be viewed at:
http://amazon.evsc.virginia.edu/video/scivee.html .
Additionally, brief video clips for inclusion in presentations are available at: http://amazon.evsc.virginia.edu/video .

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. The set-aside was renewed in 2010. The 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.

Our study of the coupling between biotic and abiotic processes controlling the dynamics of seagrass ecosystems has shown that:
1) The positive feedback that exists between seagrass and their light environment is strong enough to induce bistable dynamics within a limited depth range; and 2) Seagrasses within this depth range possess limited resilience, in that disturbances (high temperature events/poor growth conditions) may cause shift to stable bare sediment conditions.

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

Within the realm of coastal sciences, our work continues to show that barrier island plant communities are sensitive to climate change. These may serve as sentinels to climate change due to a rapid response to shoreline migration and storm related disturbances.
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 of 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.

On a broader scale, our long-term work continues to identify and quantify mechanisms for shrub expansion. Nearly all published studies have focused on the causes and consequences of woody expansion with a very limited understanding how or why species are so successful at expanding.

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:

The data compiled so far have enabled tests of previously recently developed untested conceptual models. Additionally, the data are contributing to a long-term predictive model of barrier island morphodynamics. These data will provide climate change assessments along one of the longest natural, mixed-energy barrier island systems in the world. We have coined the term 'maintainer feedback' to apply to processes that maintain low elevations (in contrast to the more typically considered 'dune-builder feedback,' which leads to increases in island elevation). Our work on the maintainer feedback has improved our understanding of the role of combined physical and vegetative processes in barrier island evolution. We have found evidence to suggest that this feedback, working in conjunction with physical processes alone, has the potential to accelerate large-scale shifts from dune-dominated to overwash-dominated barrier morphologies with climate change-induced increases in storm intensity and sea-level rise.

Modeling of northern and southern Metompkin Island has improved our understanding of how the Virginia barrier islands may evolve in the future. Results to date suggest that while island migration rates can be expected to accelerate, Metompkin Island (and islands having similar characteristics) is likely to avoid disintegration or inundation, remaining subaerial because of sufficient substrate sand quantities and an adequately upward sloping substrate, both of which reduce the amount of sand needed to keep up with sea level rise. (Brenner and Moore, 2010)The new ecomorphodynamic model of barrier island evolution synthesizes our work on physical and ecological barrier island processes and improves our ability to qualitatively predict future island evolution along the continuum from high islands to low islands.

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.

An important asset to support landscape modeling is LiDAR data obtained during 2010 that provides a highly accurate (18 cm or better) elevation data for all of Northampton and Accomac Counties. This data was purchased by the VCR/LTER and The Nature Conservancy under the condition that all the data be made available to other researchers and to the general public.

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.

Through our support and collaboration with resource economist Stephen Swallow at the University of Rhode Island, we have helped develop new understandings of the tradeoffs involved in environmental conservation. Some recent presentations include:
- 'Consumer Willingness-to-Pay for Coastal Restoration ? Ecosystem Services and Individualized Pricing' -- Presented at International Institute of Fisheries Economics and Trade Conference. Montpellier, France (2010)
-'Selling Ecosystem Services as Public Goods to Consumer-Beneficiaries: An Auction Experiment on Restoration of Seagrass and Bird Habitat in Virginia Coastal Reserve' --Presented at The Soil and Water Conservation Society Conference. St Louis, Missouri (2010)
-'Generating Revenues from WTP for Ecosystem Restoration: An Auction Experiment on Public Goods' Presented at The Agricultural & Applied Economics Association Conference. Denver, Colorado (2010)

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. Since the start of the current grant cycle over 5.1 terabytes of information have been downloaded by over 700,000 distinct clients (http://www.vcrlter.virginia.edu/analog/Nov2006toAug2010/). On a daily basis an average of over 3.7 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, Russia, Canada 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 860 formal data requests. Not surprisingly, roughly one half of the data requests (373, 43%) came from faculty and students in some way associated with the project, almost entirely for research purposes. However, researchers and students not associated with the VCR/LTER requested 300 datasets. Most (56%)were for educational use (class projects, etc.), with the remaining 44% for research uses. An additional 187 datasets were requested by automated programs using the LTER Data Access Server.

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.

PI Reidenbach and his students have developed new instrumentation to conduct underwater particle image velocimetry (commonly known as PIV). Particle image velocimetry (PIV) has been used for a number of years in laboratories to measure velocity and turbulence over an area ranging from square millimeters to square meters. This system uses a laser and optics to create a laser light sheet. This light illuminates suspended particles in the flow and, using a digital camera, particle motion is recorded. With the recent development of laser diodes, powerful yet energy efficient lasers can be placed in water tight housings and submersed underwater. The system developed uses a 250 mW laser with a wavelength of 532 nm (green light). A waterproof housing has been designed to hold both the laser and optics used to spread the beam into a narrow, yet wide sheet. The housing is sealed and the laser is pulsed on and off using a magnetic switch controlled from outside the housing. Imaging of the illuminated particles is done using a high definition camcorder (Sony HDR-HC7) that can obtain images up to 60 frames per second. Both the laser and camera are attached to a rigid frame and can be deployed in the coastal ocean where suspended sediment particles are tracked.

PI Berg has developed a new instrument to measure sediment-water column fluxes in aquatic habitats, based on eddy correlation. The new technique measures fluxes under true in situ hydrodynamic and light conditions.

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 (TNC).

We work closely with colleagues at the Virginia Institute of Marine Sciences and The Nature Conservancy to address issues relevant to sustainable restoration of seagrass and oysters in the VCR and in the mid-Atlantic region in general. Our models on bistable dynamics of seagrass meadows and the dependence on water depth provides useful information on regions within the VCR coastal bays that could potentially support seagrass habitats. We also are providing information on how the maximum depth limit for sustainable seagrass meadows could vary as a function of sediment conditions (organic content, grain size, hydrogen sulfide) and this helps managers identify areas that are most likely to support seagrass habitats over the long term. In addition, our work on hydrodynamic influences on oyster feeding and larval settlement is useful to practitioners in understanding how currents and exposure affect oyster growth and the persistence of oyster reefs.

In collaboration with the TNC, we have done a retrospective analysis of long-term trends in erosion and accretion of mainland marshes throughout the VCR from the 1950's to the presence. This is coupled with information on the presence of oyster reefs as a potential buffer to marsh erosion. Patterns of erosion were also overlain on maps of TNC-conserved lands to identify potential areas to study climate adaptation and the potential for marshes to transgress onto the mainland with predicted scenarios of climate change and sea-level rise.

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

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Christian, RR;Brinson, MM;Dame, JK;Johnson, G;Peterson, CH;Baird, D, Ecological network analyses and their use for establishing reference domain in functional assessment of an estuary, "APR, 2008", ECOLOGICAL MODELLING, 220 (22): 3113-3122 Sp. Iss. SI NOV 24 2009

Franklin, RB;Mills, AL, Importance of spatially structured environmental heterogeneity in controlling microbial community composition at small spatial scales in an agricultural field, "AUG, 2007", SOIL BIOLOGY & BIOCHEMISTRY, 41 (9): 1833-1840 SEP 2009

Special Requirements

Special reporting requirements: None

Change in Objectives or Scope: None

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

VCR-LTER ANNUAL REPORT 2010 - 2011
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)
Flux tower	nutrients, primary production	A, C (initiated in 2008)

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, and chlorophyll.
- *Stream water chemistry* is obtained quarterly from 4 tidal creeks.
- *Stream discharge* from 4 tidal creeks: Cobb Mill Creek, Bundick's Creek, Phillip's Creek, and Tommy's Ditch. These will be used to develop rating curves and estimates of nutrient discharge to coastal lagoons.
- *Meteorological stations* at Phillips Creek Marsh, Hog Island and Oyster, VA, for precipitation, temperature, wind and light data.
- *Tide stations* at Red Bank, Oyster and Hog Island.
- *Surface elevation tables (SET)* in Phillips Creek Marsh, and 5 other lagoon/mainland marshes 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 to 10 years since seeding.
- *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 October 2010 – September 2011 are detailed below.

Mainland Watersheds and Lagoon

Watershed nutrient loading

The watersheds of the VCR-LTER are small compared to the surface area of the neighboring lagoons, but beneath agricultural fields the surficial groundwater at the site contains a high concentration of dissolved inorganic nitrogen. As a result nitrogen transformation in streams is important for the maintenance of water quality of downstream lagoons. P.I. Aaron Mills and colleague Janet Herman have continued their work on estimating the annual nitrogen loading to the seaside lagoons from mainland watersheds. They have made several estimates since 2001; however, difficulties in scaling a few infrequent measurements of stream discharge and nitrate concentrations to an annualized loading created uncertainty in the estimates. This year they made a much more systematic survey of 17 streams draining watersheds of different contributing area and different land use. They placed continuously recording stage recorders on 4 of the 17 streams to get a detailed record of discharge. Additionally, they gauged the discharge in the 17 streams monthly. This has allowed them to construct annual discharge measurements for those streams that are much more reliable than taking the 12

Fig. A1. Eddy correlation instruments for measuring oxygen metabolism in watershed creeks.

monthly measurements and annualizing them by assuming the values to represent base flow for the entire month and summing them for the year. Additionally, they measured anions in each stream monthly to obtain values that could be used for combining with the discharge estimates to generate approximations of the nitrate flux from each of the streams and to extrapolate those fluxes across the 54 watershed that drain into the coastal lagoons.

Submarine groundwater discharge

Research on nitrogen processing in streambed sediments at the VCR has shown that bacterial activity may remove 90% or more of groundwater nitrogen in the final few centimeters of flow prior to discharge to streams. Highly effective nitrogen removal occurs in streams with lower nitrate loads, but as streams become eutrophic, they export a disproportionate amount of nitrate downstream. The mechanisms of this process are unclear, but nitrogen assimilation, transformation, storage, and denitrification are all components of, or are affected by, stream metabolism. Ph.D. student Dirk Koopmans and P.I. Peter Berg are applying the eddy correlation and open-water techniques to quantify metabolism in streams with different watershed nutrient loading and at different groundwater discharge rates through multiple tidal cycles before and after rain events (Fig. A1).

Diurnal patterns of groundwater discharge to streams - implications for nitrate removal

Mills and Herman also analyzed the relationship between the diurnal fluctuation in stream stage and the flux of NO_3^- from groundwater to the stream, and how this influenced diurnal cycling of NO_3^- concentration in the stream. They staged two campaigns (one of 10 days duration, another of 3 days) during which they made hourly measurements of NO_3^- concentration and continuous (10-min intervals) of stream stage. Simultaneously, they measured the discharge of water and NO_3^- from the groundwater to the stream using a spatial array of seepage meters in the stream bed.

They began two new projects this year in which they are examining 1) NO_3^- profiles and groundwater flow characteristics in sediments of a variety of streams in the VCR, and 2) the contribution of water column processes (viz., photosynthesis) as a control on NO_3^- concentration in the stream waters and the contribution of photosynthesis to the diurnal fluctuation of NO_3^- in Cobb Mill Creek and several others. The latter project tests the hypothesis that water column processes play a much larger role in controlling NO_3^- concentration in streams with no forest canopy.

Atmospheric N deposition

P.I. Jim Galloway and collaborator William Keene continued their monitoring of atmospheric deposition as an important exogenous source of nutrients and other chemical constituents entering LTER ecosystems. Projected increases in the creation rate of reactive nitrogen will lead to corresponding increases in both emissions of reactive N to the atmosphere and associated deposition from the atmosphere to ecosystems with major consequences for biogeochemical processes. Starting in March 1990, wet-deposition fluxes of major ionic species (including SO_4^{2-}, Cl^-, NO_3-, NH_4^+, Na^+, K^+, Mg^{2+}, Ca^{2+}, and H^+) were quantified as part of the LTER based on analysis of precipitation sampled weekly on Hog Island. To minimize breaks in the record resulting from logistical difficulties in servicing the sampling equipment (storms, tides, etc.), the station was relocated in June 1996 to the GATR site at the Eastern Shore of Virginia National Wildlife Center in Cape Charles. In September 2003, this sampling station was destroyed by Hurricane Isabel. At that time, it was decided to relocate the precipitation sampling equipment to the LTER's meteorological station at the new ABCRC in Oyster. During 2004, the damaged equipment and support facilities were repaired or replaced, the station was installed at the ABCRC, and the site operator was re-trained. Routine weekly sampling resumed in April 2005. At that time, the following constituents were added to the analytical suit: $HCOO^-$, CH_3COO^-, $CH_3SO_3^-$, $(COO)_2^{2-}$, and Br^-. Note that $HCOO^-$, CH_3COO^-, NH_4^+, and H^+ are not conservative against biological degradation in weekly samples and, consequently, concentrations of these analytes should be considered lower limits.

Lagoon hydrodynamics and sediment transport

P.I. Patricia Wiberg and post-doctoral associate Ilgar Salfak are using two open source models that account for circulation, surface waves, wave-current interaction, and sediment processes (FVCOM and Delft3D) to investigate hydrodynamics (wind- and tide-induced circulation, surface waves, particle residual time) and sediment transport due to combined wave-current flow in the barrier island-lagoon-marsh system of the Virginia Coast Reserve. FVCOM (Finite Volume Coastal Ocean Model, Chen et al., 2003) is an unstructured grid hydrodynamic model that is fully coupled with a surface wave model (Simulating WAves Nearshore "SWAN", Booij et al., 1999), a 3-D sediment transport model (Warner et al., 2008), and a 3-D Lagrangian particle tracking model. Delft3D (Lesser et al., 2004) has a stronger focus on morphodynamics, and version 4.0 has been open source since January 2011.

Following the setup, serial/parallel compilation on high-performance computing clusters, and testing of these two models with variable forcing (winds, tides, and waves), FVCOM was validated with one-week field observations of wind- and tide-induced water flow (water level and current velocities) in Hog Island Bay during a moderate storm (wind speed sometimes reaching 10-m/s) in winter 2002. They are currently working on testing these two models against more recent field measurements of waves and water levels at five locations within the Hog Island Bay in winter and early spring 2009.

Water and particle exchange within the VCR and between the VCR and the ocean was examined with the Lagrangian particle-tracking module of FVCOM. Three bays with strongly varying bathymetry and coastline geometry, which are also located along a gradient of nitrogen input to the system, were selected: Hog Island Bay, South Bay, and Magothy Bay. They are also investigating the effects of wave-current flow on sediment redistribution within the bays in response to storms over event and seasonal time scales.

Outputs from these modeling efforts are also being used in collaboration with other researchers in the project. So far, model results on circulation patterns (water flow, particle tracks under tide- and wind-induced flow) and wave energy have been provided to researchers some of which are working on:

- aquatic ecology of the Virginia Coast Reserve, namely, nutrient dynamics, algae and seagrass distritubtion (P.I. Karen McGlathery, Ph.D. students Dana Gulbransen, Luke Cole, Laura Reynolds)

- wave attenuation within the seagrass beds (P.I. Matthew Reidenbach, Ph.D. student Jennifer Hansen)
- wave-induced erosion at salt marsh boundaries (P.I.s Patricia Wiberg and Karen McGlathery, M. S. student Sean McLoughlin)
- effects of flow-induced sediment resuspension and light attenuation on stability of seagrass ecosystems (P.I.s Paolo D'Odorico, Karen McGlathery and Patricia Wiberg, Ph.D. student Joel Carr)

Seagrass restoration

A pandemic wasting disease coupled with a destructive hurricane in the 1930's, caused a large dieback of eelgrass (*Zostera marina*) in the Chesapeake Bay and the local extinction of eelgrass in the Virginia Coast Reserve (VCR) coastal bay system. Eelgrass recovered naturally in the Chesapeake Bay, but did not return to the VCR for over 60 years. Prompted by the discovery of small patches of eelgrass that naturally recruited into the VCR in the late 1990s, seeds from recovered Chesapeake Bay meadows were used in a very successful large-scale restoration effort in the VCR bays. The long-term monitoring of this large-scale seagrass restoration effort focuses on the ecosystem-level consequences of the state change from a bare unvegetated state to one dominated by seagrass. The work 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. This is a large interdisciplinary effort involving a number of P.I.s (Karen McGlathery, Patricia Wiberg, Peter Berg, Matthew Reidenbach, Paolo D'Odorico, Stephen Macko and Jay Zieman) and their students. Also, a number of undergraduate (REU) and high school students (REHS) are involved in the effort each year.

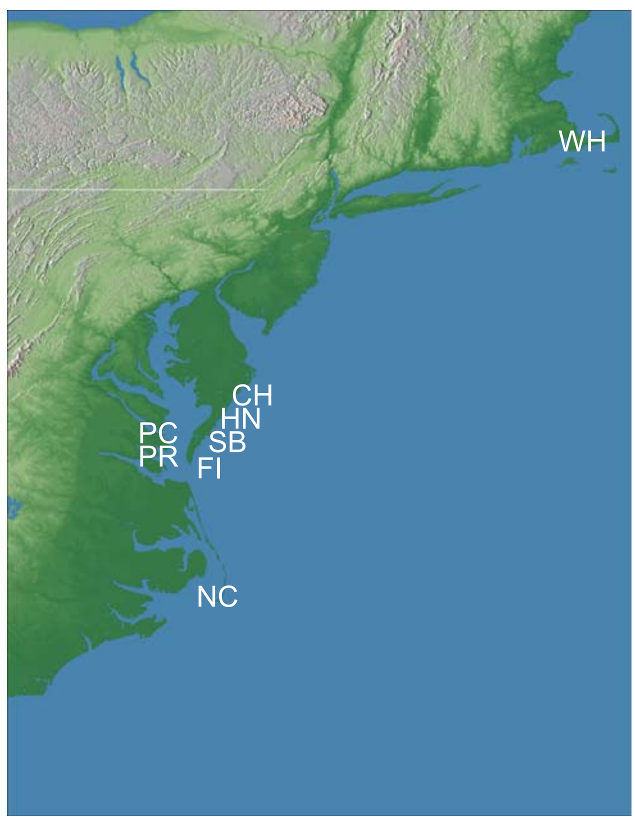

Fig. A2. Sampling sites for eelgrass genetic analysis

The work is a collaboration with Dr. Robert Orth of the Virginia Institute of Marine Sciences at the College of William and Mary and the Nature Conservancy. Orth has ~30 years of experience in seagrass restoration by seeding, and also has a large program in the Chesapeake Bay region. To date, the restoration has resulted in approximately 1821 ha of seagrass habitat from an original 81 ha seeded throughout the Virginia coastal bays The VCR researchers focus on the return of ecosystem services as seagrass revegetate the lagoon bottoms, including enhancement of water quality, sediment stabilization, carbon and nutrient sequestration, and trophic dynamics. The experiment design includes both following initial establishment of seagrass meadows and development through time, and comparing a chronosequence of meadows of different ages in the VCR bays. A special thematic issue of the journal *Marine Ecology Progress Series* will be dedicated in 2011 to the findings of this work.

Genetic studies: To assess the overall genetic diversity of restored populations and whether restoration by seeding reduced diversity relative to donor populations, Ph.D. student Laura Reynolds, working with P.I. Karen McGlathery, sampled seagrass shoots in 3 meadows that naturally recruited and 5 areas that were seeded for restoration. She also sampled shoots from 15 additional meadows from Woods Hole, MA to Beaufort, NC, concentrating on meadows in the nearby Chesapeake Bay. Samples were brought back to the lab and analyzed genetically using microsatellites.

Historical legacies of seagrass distribution: Ph.D. student Noah Egge and P.I. Stephen Macko are using sediment characterization ($\delta^{13}C$, $\delta^{15}N$ and TOC/TN) to assess the sources of organic matter in the coastal lagoons and to determine if isotopic tracers could indentify the historical distribution of seagrass in the coastal bays. Push cores were used to collect samples from sites that have different records of seagrass cover.

Restoration trajectories: P.I. Karen McGlathery and her students have been following restoration trajectories of numerous sediment and vegetation parameters in the restored seagrass meadows in two bays: Hog Island Bay and South Bay. Replicate large plots (0.2 – 0.4 ha) were restored by seeding in successive years, resulting in a chronosequence of sites from 0 (unvegetated) to 9 years since seeding. Meadows seeded in South Bay in 2001 were sampled 6 – 9 years after seeding; meadows seeded in Hog Island Bay in 2006 – 2008 were sampled 1 – 4 years after seeding. Vegetated sites were compared with nearby "bare" unvegetated plots (n=8, 4 at each site), which represented the initial condition (0 year time point). The *Z. marina* meadows were sampled annually during mid-summer (mid-June – mid-July) synoptic campaigns in 2007-2010 to follow the recovery of both functional (primary productivity, carbon and nitrogen sequestration, sediment deposition) and structural (shoot density, biomass, plant morphometrics) attributes of the meadows.

Nitrogen cycling: Ph.D. student Luke Cole, working with P.I. Karen McGlathery, determined if seagrass (*Zostera marina*) restoration in a shallow coastal bay system facilitated increasing rates of N_2 fixation as the meadows aged. Rates of N_2 fixation were measured in a system that had been devoid of seagrass following local extinction in the 1930s until restoration by seeding began in 2001. Restored Z. marina meadows of different ages (time since seeding) were compared with nearby bare sediment sites during times of summer peak metabolism over two years. In addition, he used the N_2:Ar technique to measure net N_2 fluxes seasonally across the chronosequence of restored seagrass (*Z. marina*) meadows, comparing bare sediment sites (n = 8) and nearby seagrass sites restored by seeding. Net N_2 fluxes infer the balance of N inputs via sediment N_2 fixation and losses via denitrification.

Carbon sequestration: Seagrass meadows are highly productive habitats and provide many important ecosystem services to the coastal zone, including carbon and nutrient sequestration. Although seagrass meadows represent only about 0.1 % of the area of the world's coastal oceans, seagrass have the potential of accumulating 10 to 18% of the total carbon buried by the ocean.

M.S. student, Jill Greiner, working with P.I. Karen McGlathery, has been evaluating the carbon accumulation rates of the large-scale seagrass restoration in the Virginia coastal bays. This is one of the first studies to address the potential importance of seagrass habitat restoration in enhancing carbon sequestration in the coastal zone. Samples were collected in restored *Z. marina* meadows at 4 and 10 years of age (time since restoration was initiated by seeding) and were compared with nearby bare sediments. Within each aged bed, 6 sites were selected that have been used in previous studies. At seagrass sites, seagrass densities were measured along transects at 4 locations running parallel with the ocean current, and sediment cores (20 cm to 25 cm depth) were collected at each of these sites. At bare sediment sites, only sediment was collected along transects. Each core was divided up into 1 cm intervals and weighed for bulk density. Sediment samples from core intervals are then allotted for soil moisture and loss on ignition measurements. Samples will also be run for percent carbon and nitrogen content as well as lead 210 for dating.

<u>Metabolism</u>: In shallow aquatic systems, benthic metabolism is one of the most important processes for total ecosystem metabolism and the presence of macroalgae and seagrasses have been shown to increase both the rates of benthic production and respiration. Historically, coastal systems have been ignored when concerning global carbon budgeting due to their small areal contribution; however, new studies have shown that near-shore systems may be much more important. The seagrass restoration project at the VCR-LTER provides a natural comparison of the two different benthic states observed across the entire lagoon system: seagrass-vegetated and bare sediment and provides an excellent opportunity to implications of a state change from a bare sediment to a seagrass-dominated state on carbon metabolism. M.S. student Jennie Rheuban, working with P.I.s Peter Berg and Karen McGlathery, is using the eddy correlation technique to determine seasonal benthic metabolism in late summer, early fall, early spring, and early summer in order to create an annual budget. Eddy correlation is unique in that it provides a truly in situ measurement of benthic O_2 metabolism with little to no disturbance of the natural hydrodynamics, temperature, or ambient light conditions, and integrates over a significantly larger measurement area then previous techniques for measuring metabolism.

Sustainable seagrass restoration

P.I.s Karen McGlathery, Patricia Wiberg, and Art Schwarzschild have received supplemental funding from the Virginia Sea Grant program to examine relationship between sediment characteristics/resuspension, water quality and minimum light requirement of eelgrass in the coastal bays of the VCR. In the summer 2011, Schwarzschild conducted a pilot study examining effects of varying sediment organic matter and light levels on eelgrass morphology, growth and survival. M.S. student Alia Al-Haj began in August 2011 and will conduct the field portion of this project, assessing water column and sediment characteristics in two bays that differ with respect to nutrient loading, and linking this to the maximum depth limits of the seagrass.

Hydrodynamics and sediment motion within seagrass beds

P.I. Matthew Reidenbach and his Ph.D. graduate student Jennifer Hansen continued their studies of boundary-layer flow dynamics and the deposition and erosion of sediments in the coastal bays. Seagrass meadows have been shown to alter their hydrodynamic environment by inducing drag on the flow, thereby attenuating wave energy and near bottom currents. This alters the turbulent structure and shear stresses within and around the seagrass bed that are responsible for the suspension and deposition of sediment. To quantify these interactions, velocity, pressure, and sediment measurements were obtained across a density gradient of a *Z. marina* seagrass bed within a shallow coastal bay (1-2 m depth).

This study was performed in one of the coastal bays of the VCR (South Bay) during three different times of the year: January, May and June 2011. Flow and sediment dynamics were quantified using Nortek acoustic Doppler velocimeters (ADVs) and optical backscatter systems (OBSs) deployed in tandem for 72 hours. Water velocity, turbulence, and wave dynamics were correlated with in situ turbidity and therefore sediment transport mechanisms were explored. One vector was placed with the sampling volume at 50 cm above the bed (cmab), above the seagrass meadow, and one with the sampling volume at 5 cmab within the meadow. Additionally, bulk fluid currents throughout the water column were quantified via high resolution Nortek Acoustic Doppler Profilers (aquadopps), which were placed in the seagrass meadow and at a bare site devoid of seagrass as a control site.

Coupled vegetation – hydrodynamic model

Ph.D. student Joel Carr, working with P.I. Paolo D'Odorico, coupled his hydrodynamic model of vegetation-sediment-water flow interactions (Carr et al. 2010) with a morphologic seagrass vegetation growth model (Carr et al. in review, a) that encompasses the changes in shoot and leaf density, leaf length, and rhizome biomass within a meadow (Fig. A3). The coupled model was used to investigate the resiliency of a seagrass meadow to changing environmental conditions both within a given year as well as across many years (Carr et al. in review, a). The coupled model was then used not only to explore the effects of climate change on seagrass resilience, but to identify possible leading indicators of regime shift (Carr et al. in review, b).

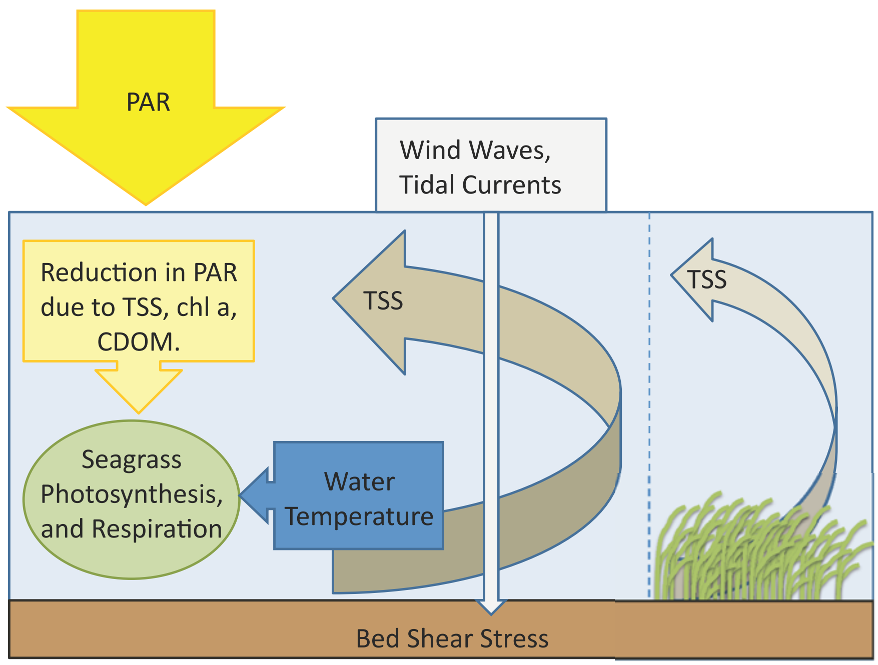

Fig. A3. Schematic of coupled hydrodynamic and vegetation growth model to determine seagrass distribution patterns and bistability depth ranges in the VCR coastal bays.

Flow dynamics and larval settlement onto intertidal oyster reefs and adjacent restoration sites

P.I. Reidenbach and M.S. student Elizabeth Whitman have been working with Barry Truitt of The Nature Conservancy (TNC) to determine how the composition, topography, and benthic roughness of the ocean floor impacts settling success of oyster larvae in restored oyster reefs.

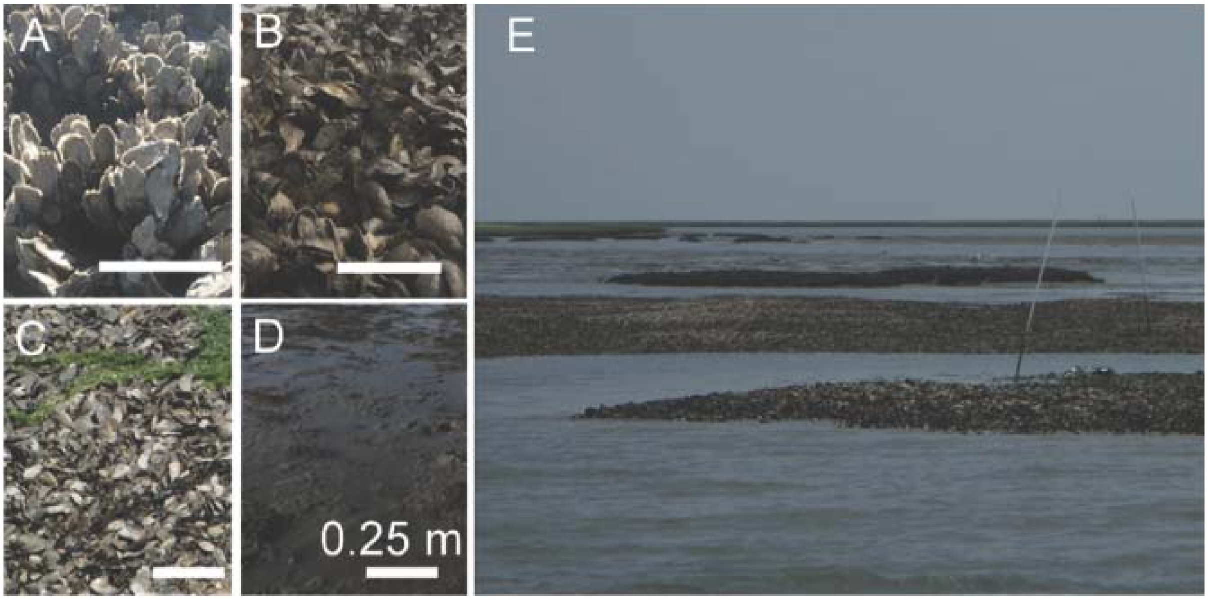

Fig. A4. Four oyster sites studied, comprised of (A) healthy oyster reef, (B) restoration site composed of fossil whelk shell, (C) restoration site composed of fossil oyster shell, (D) mud site. (E) Image showing from foreground to background, the oyster shell restoration site, whelk shell restoration site, and healthy oyster reef.

Larvae preferentially settle on existing oyster reefs due to a hard, stable substrate for firm attachment and topographic variability that prevents burial by sediments. Settlement success has been shown to be dependent upon their ability to quickly land, attach, and undergo metamorphosis before they are washed away by fluid stresses or transferred to areas where they can be buried by depositing sediments. The goal of the study is to understand both the large and small scale hydrodynamics involved in fluid transport and turbulent mixing over reefs, and how these dynamics impact larval transport and settlement on healthy and restoration reef areas. Studies were performed during May through November 2010 on an established *Crassotrea virginica* oyster reef and adjacent oyster restoration sites located approximately 1 km offshore from the mainland in the VCR coastal bays (Fig. A4). Nortek Aquadopp© Profilers (AQDPs) were deployed at various elevations on the sites to obtain velocity profiles throughout the water column. Concurrent with AQDP measurements, a Nortek Inc. Vectrino© (Acoustic Doppler Velocimeter) was used measure fine scale hydrodynamics adjacent to and between tightly spaced oysters at the *C. virginica* reef as well as over benthic surfaces at the restoration sites. Larval settlement plates composed of interlocking slate tiles of varying height:spacing ratios were created to test the effects of benthic roughness on recruitment of oyster larvae. Plates were deployed at the restoration sites for a 5-month period and larval recruitment counts were performed in Dec. 2010.

Trophic dynamics in clam aquaculture beds

The VCR supports extensive bivalve populations that provide important ecosystem services. They are studying the organic matter sources that provide support to aquacultured hard clams (*Mercenaria mercenaria*). P.I. Michael Pace and M.S. student Kelly Hondula are using stable isotopes of carbon (C-13), nitrogen (N-15), and hydrogen (H-2) to study contributions to clam diets including benthic microalgae, macroalgae, seagrass, marsh grass, and terrestrial material. In addition, they are interested in the more specific issue of whether deuterium (H-2) is a useful tracer for food web studies in the VCR and by inference in other coastal ecosystems. They are sampling for the above isotopes in source materials and clams over an annual cycle, to be completed in the fall of 2011. Because they are considering multiple sources and multiple isotopes, they are applying a Bayesian mixing model that formally incorporates uncertainty as well as other commonly used mixing models that can potentially explain clam isotopic composition.

Intertidal Marshes and Mudflats

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

<u>Erosion of marsh boundaries</u>: With supplemental funding from the DOE NICCR program, P.I.s Sergio Fagherazzi, Patricia Wiberg, and Karen McGlathery and their students (Sean McLauglin, Gulio Mariotti, Anthony Priestas) 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.

<u>Long-term change analysis</u>: M.S. student Sean McLauglin and P.I.s Karen McGlathery and Patricia Wiberg, worked with supplemental funding from The Nature Conservancy to quantify changes in the shorelines of mainland marshes in the VCR. Ten

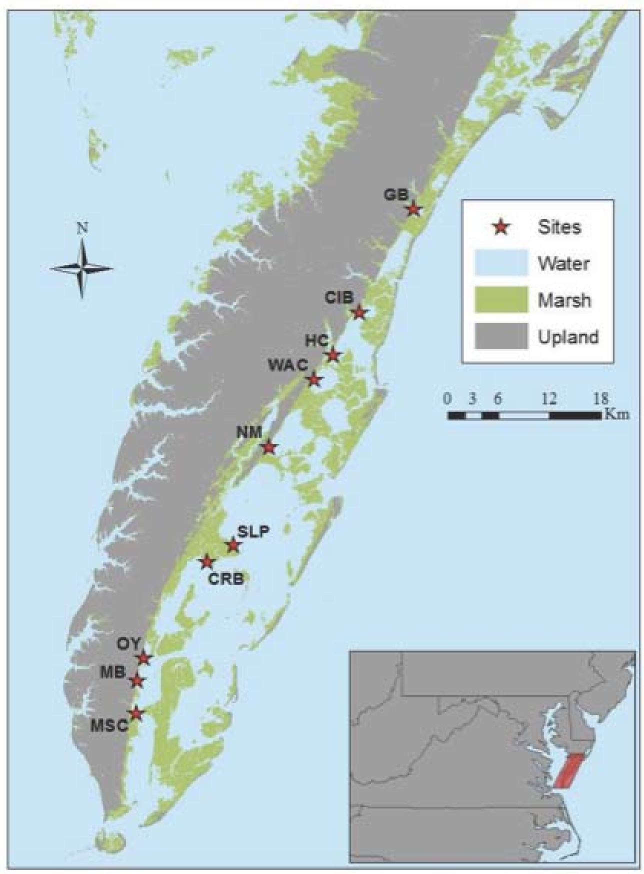

Fig. A5. Ten sites selected for analysis of long-term of mainland marsh shorelines in the VCR.

mainland marsh sites were chosen in the VCR to analyze temporal changes along their shorelines and determine their potential for upland transgression (Fig. A5). Sites were chosen primarily based on latitude, bay size, and whether they appeared to be eroding or prograding based on the morphology of their edge (eroding scarp vs. gently-sloping edge). These criteria were used in order to provide variability between the marsh sites, while still allowing comparisons to be made between sites. Aerial photographs were used to measure long-term changes along the marsh shorelines at the selected sites. Photographs were obtained for 1957, 1966, 1989, 2002, and 2009. While the 2002 and 2009 photographs were obtained as orthorectifications, the 1957, 1966, and 1989 photographs were rectified using the georeferencing tool in ArcGIS. At each of the ten sites, approximately 3-4 km of marsh edge was digitized for each aerial photograph to create a line segment marking the position of the edge. The digitized lines for each site were then overlaid in order to compute change statistics. Five line segments were created for each of the sites, with the exception of Short and Long Prong, Crabbing, and Mockhorn Bay marshes, for which 1966 photographs were either not available or not of a high enough quality for use. Rates-of-change along the marsh edges were computed using the Digital Shoreline Analysis System (DSAS), an ArcGIS extension (Thieler et al., 2009). DSAS works by casting transects off of a baseline layer that sits adjacent to the digitized shoreline features. Statistics are then calculated for the transects based on the positions of the shorelines. Transects were spaced at 10 m intervals at the marsh sites. The linear regression rate (LRR) was chosen as the best DSAS statistic to estimate rates-of-change along the marsh edge. Averaging the LRRs for each of the transects at a particular marsh site provided a mean rate-of-change for that site.

Oyster reef armoring of mainland marsh shorelines

M.S. student Sara Taube, working with P.I. Patricia Wiberg, is investigating the role of oyster reefs in the protection of mainland salt marshes. Previous studies have shown that oyster reefs can help to mitigate erosion of the marshes behind them, with some measured erosion rates that were negative (i.e., lateral accretion). They are investigating this further, looking at the potential for oyster reefs to allow for marsh expansion, not just erosion buffering. They have chosen four marsh sites along the mainland of the Virginia Eastern Shore to focus on, all of which face seaward onto open water but are partially blocked by oyster reefs. By characterizing each site based on sediment size, elevation, biomass density and species, crab burrow counts, on-coming wave energy, hydrodynamics around the oyster reef, and sediment deposition rates (using Pb^{210} dating), they hope to document whether oyster reefs offer protection, or even promote expansion, of the marshes they front. To delineate shoreline position through time, Sara is taking GPS surveys over the course of multiple months and analyzing digital photographs from as far back at 1956.

Marsh accretion relative to sea-level rise

P.I.s Linda Blum and Bob Christian continue the long-term monitoring of sediment accretion using surface elevation tables (SET) and end-of-year biomass (EoYB) on VCR salt marshes Increased effort this year was placed on analysis of the long-term records, which has resulted in one manuscript in preparation (Blum et al.) that synthesizes the SET data and related information. Blum has been collaborating with new P.I. Matthew Kirwan on a review that assesses the inter-annual and inter-site variation in EoYB of *Spartina alterniflora* in the context of a commonly-used model of primary production to inundation and resultant sustainability to sea-level rise (Kirwan et al. in review). Similar and extended efforts are ongoing for high marsh plants as part of a M.S. thesis project of Brooke Costanza is working with Bob Christian.

Blum continues her cross-site collaborative work examining the role of sediment deposition and plant production on marsh accretion. She is collaborating with others in the LTER network and at the USGS to synthesize and model long-term SET measurements of marsh elevation change.

Marsh transgression and state change

P.I.s Linda Blum and Robert Christian have also continued and supplemented their efforts on the influence of disturbance and nutrient availability (primarily N) on marsh primary production and ecosystem state. A field experiment that combines both factors is the primary component of a M.S. thesis project by John Haywood working with P.I.s Mark Brinson (now deceased), Christian and Blum. Two field experiments have tracked the response of primary production in the low marsh (Chris Olcott, undergraduate student working with Blum) and the high marsh (M.S. student Costanza working with Christian). The former study focuses on the dose response of plant production that is allocated to aboveground and belowground biomass. The latter study is designed to link to assessment of the relationship between N and production from the long-term monitoring of EoYB. In addition, undergraduate student Chase Crews, working with P.I. Enrique Reyes, completed a summer research project addressing the response of benthic primary productivity to fertilization. The experiment included locations representing different habitats; at each location 5 different nitrogen treatments were implemented. For each treatment, two soil samples were collected monthly and analyzed for chlorophyll content and, organic and inorganic matter. Finally, M.S. student Traci Davis, also working with Enrique Reyes, is studying marsh migration patterns in Phillips Creek Marsh, our primary mainland marsh study site.

Trophic interactions – environmental impacts of marsh change on waterbirds

Ph.D. student Charlie Clarkson, working with P.I. Michael Erwin, continued his project on the effects of habitat on waterbird growth. His research includes an evaluation of growth rates, diet, and feather dynamics (termed “ptilochronology”) of two nesting waterbird species, a generalist, the double-crested cormorant, and a specialist, the glossy ibis. The work is aimed at determining if feather growth of young birds can be used as a bioindicator of the quality of prey and hence, estuarine conditions, comparing a relatively pristine region (the VCR) with a highly disturbed and human-dominated landscape (the New York metro region). Fieldwork was conducted on the VCR LTER during the 2011 breeding season at two mixed-species of waterbird colonies along the Eastern Shore of Virginia. Feeding rates for two numerically dominant species (Great Egret: Ardea alba; Snowy Egret: Egretta thula) were determined over the course of the breeding season and regurgitant was collected from nestlings of observed nests (A. alba: n= 43, E. thula: n= 32). Prey species present in the regurgitant will be identified to species and combined with average feeding rates by adults to determine the relative biomass consumption of these species on a colony-wide basis. In addition, prey diversity indices and relative contributions of each prey item to total diet will be determined for both species.

Invasive species

Species invasions can have both positive and negative effects on trophic structure and habitat composition and function. Negative consequences include reductions in native biodiversity, declines in native habitat, and changes in productivity and food web dynamics. Invasive species can also be beneficial to native habitats where increased habitat complexity or the provision of new habitat facilitates native species, or where nutrient and food subsidies provided by invasive species enhance productivity. Marine macroalgal invaders have been shown to both positively and negatively affect recipient habitats through changes in biodiversity, trophic dynamics and rates of productivity. Previous work at the VCR has shown that *Gracilaria vermiculophylla* is a widespread invasive macroalga that is highly tolerant of stress and can therefore form dense aggregations in a variety of subtidal and intertidal habitats. Ph.D. student, Dana Gulbransen, working with P.I. Karen McGlathery is addressing on how the spread of this invasive macroalgae is affecting shorebird feeding rates and nitrogen subsidies on marshes and mudflats in the Virginia coastal bays. Dunlin and semipalmated sandpiper feeding substrate preferences were compared to amphipod prey abundance during the spring 2011 shorebird migration. In order to determine if *G. vermiculophylla* biomass subsidizes marsh and mudflat plants and invertebrates, they conducted two enrichment studies in summer 2010. *G. vermiculophylla* with elevated ^{15}N levels were placed in each system inside of cages and primary producers as well as invertebrate consumers were collected after a period of time.

Barrier Islands

Vegetation dynamics

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. Thus storm-related effects should vary among islands as a function of island size and topography. We have now obtained LIDAR imagery for all islands, and this database will provide spatial variations in elevation distance to the shoreline for each island that can be related to vegetation communities and to predicted changes in island geomorphology.

P.I. Don Young and his students have continued their research on landscape-level comparisons of vegetation dynamics across the terrestrial portions of the VCR barrier islands. Their objectives are to understand and quantify important fluxes among the VCR landscape units, to remain inclusive of all barriers within the VCR system and to place their results in the context of the knowledge base for other barrier systems and terrestrial ecosystems in general. This year they have focused on mechanisms related to the expansion of shrub thickets on barrier islands and also the potential responses of island thickets to climate change.

M.S. student Dominic Graziani, working with P.I. Frank Day, is addressing the fine-scale mechanisms that related to thresholds of state change on the barrier islands. He has established 3 fine-scale transects over a dune line (from marsh on one side to shrub thicket on the other). He installed leaf litter bags and wooden dowels at different elevation stations along the transects and is measuring decomposition rates from marsh over the dune to the thicket. He is also quantifying water level, soil N, and vegetation transitions, and will expand this study to include NPP and other process rates in the next several years. Ultimately the measurements will be correlated with elevation so the results can be extrapolated to a larger spatial scale.

Day also continues to monitor vegetation dynamics in the permanent vegetation plots on Hog Island. Next spring he plans to complete a synthesis of over 20 years of data from these plots.

Vegetation-predator-bird interactions

P.I.s Ray Dueser, John Porter and Bruce Hayden developed a Markov model of terrestrial landscape dynamics on the Virginia barrier islands. This transition matrix model provides a statistical approach to estimating future landscape structure, and is described in more detail in the landscape analysis section of this report. The model will be extended to predict the occurrence of both mammals and birds on the islands. At the whole island level, records of observations of vertebrates will be coupled to island properties (e.g., island area, elevation, woody area) to identify threshold levels of habitat needed to support populations of particular species. Rapidly changing islands near the identified thresholds will be subjected to additional monitoring, because they may be in a bi-stable region of state space. For example, they predict that the threshold island area associated with local extinction of a species will be lower than the threshold area required for successful immigration of that same species. Further integration of vertebrate data with the landscape model will be achieved by using vertebrate distributional data to quantify species/land cover relationships. Data for this integration will come from existing long-term small mammal trapping efforts coupled to new camera traps to monitor larger animals (e.g., deer, foxes, raccoons and rabbits). Analysis of long-term data on locations of small mammals (using a 22-year record of small mammal captures and vegetation on Hog island) relative to vegetation, elevation and land cover data will enable us to predict where small mammals will be found on future landscapes based on habitat availability. Addition of camera traps will provide information on the utilization of different habitat types by a wider array of fauna such as mesopredators, rabbits and deer. Additionally, they have observed that beach-nesting birds avoid islands with substantial shrub cover. Whether removing the shrubs would improve the bird habitat depends on whether the shrubs are only an indicator of a level of island stability that could support predators, or whether the shrubs themselves provide habitat needed to support predator populations. If predators are seldom found in the shrubs, it would argue the former.

Landscape Genetic Analyses to Indirectly Assess Movement of Raccoons

As part of the efforts aimed at predator removal on the VCR, P.I.s Nancy Moncrief, Ray Dueser, and John Porter are engaged in a collaborative effort with Eric Hallerman of Virginia Tech to investigate movement of raccoons to the islands from the mainland and among the islands. Like most mammals, direct observation of movement by raccoons is logistically difficult and cost prohibitive. Therefore, landscape genetics techniques are being used in conjunction with GIS Modeling results to test specific hypotheses of how particular environmental and landscape features influence the spatial distribution of neutral genetic variation in this meso-predator on these islands. Using funds awarded by the Virginia Department of Game and Inland Fisheries, 379 raccoons from 26 localities on the islands and adjacent mainland are being genotyped for 14 microsatellite DNA loci.

Ecomorphodynamic Controls on Barrier Island Evolution in Response to Sea-Level Rise

P.I.s Laura Moore and Don Young received supplemental funding from the DOE NICCR program to investigate the potential influence of ecomorphodynamic feedbacks on overwash persistence and barrier island evolution in the VCR. Several students (Cat Wolner, Spencer Bissett, Dana Oster) have been conducting this interdisciplinary research.

<u>Ecomorphodynamic feedbacks and overwash persistence</u>: Two morphologically distinct barrier islands were studied, Hog Island (dune-dominated, rotating) and Metompkin Island (overwash-dominated, transgressing). At 6 representative sites on each island, they collected and analyzed vegetative (quadrat), topographic (GPS), and sedimentological (grab sample) data associated with cross- and alongshore transects to assess the relationship between species composition and morphology. They also considered factors other than vegetation that may influence dune recovery/overwash persistence, including beach width (a proxy for sand supply to the dunes) and sediment properties (particularly the presence of shell armoring, which can inhibit aeolian sand transport). To evaluate overwash persistence on the scale of decades to centuries, they analyzed orthorectified historical aerial photos (determining spatial and temporal overlap of overwash zones), collected ground-penetrating radar (GPR) data and sediment cores (looking for stratigraphic evidence of dune recovery/overwash persistence).

<u>Lidar-based analysis of barrier island resilience</u>: Along Smith, Hog, and Metompkin Islands, they are comparing lidar data collected immediately following Hurricane Bonnie in 1998 with a calm-weather survey collected in 2005; our objective is to characterize changes in beach features and to assess alongshore variations in response and recovery to storm events. At 10 m alongshore intervals in each lidar survey, they have extracted morphological characteristics of the beach and dune (e.g., foredune toe and crest elevations, foreshore slope, beach width, etc.) to quantify overwash probability (applying methods described in Stockdon et al., 2009, and based on the Storm Impact Scale defined by Sallenger, 2000). They have defined alongshore “resilience,” or relative localized recovery, as the change in probability of overwash between the post-storm lidar survey (1998) to the more recent calm-weather lidar survey (2005). They hypothesize that the rate and degree of localized barrier island recovery, or resilience, is likely related to local morphological characteristics. They are using wavelet coherence analysis to determine the alongshore positions and spatial scales at which changes in beach morphology covary with resilience. This analysis of alongshore coherence will allow us to infer the processes that are important in determining barrier island resilience in the VCR.

Morphological-behavior modeling of barrier island vulnerability to increased rates of sea-level rise

To better understand the potential impacts of sea-level rise (SLR) on the VCR barrier islands, M.S student Owen Brenner and P.I. Moore are using GEOMBEST, a 2-D morphological behavior model (e.g., Moore et al., 2010), to characterize the late-Holocene evolution of Metompkin Island, as well as its potential response to SLR through the year 2100. To understand why the northern and southern halves of Metompkin Island have evolved differently, they have created representative initial conditions for each half of the island and simulated past and potential future evolution of each half independently. After developing a plausible initial island stratigraphy and morphology based on the best available literature, they calibrated GEOMBEST simulations of late Holocene (4600 years BP–present) evolution and performed a comprehensive sensitivity analysis to evaluate the relative importance of key physical variables (e.g., backbarrier environment, stratigraphy, sediment supply) in determining Metompkin Island's response to SLR. Using SLR predictions for the year 2100, they are carrying out a series of simulations to assess the potential range of future barrier island responses to expected SLR.

Conceptual model of barrier island evolution in response to climate change

P.I.s Moore, Young, ROA collaborator Michael Fenster, and former student Steven Brantley have developed a new conceptual framework for considering the evolution of barrier island systems arises from interdisciplinary collaborative LTER research focused on understanding barrier island geomorphology and ecology. Moore is leading development of a synthesis paper (to be submitted to *Bioscience*) describing the conceptual, predictive geomorphic and ecological model.

Landscape analysis

Landscape-scale models of ecosystem state change

The Markov model of terrestrial landscape dynamics of the VCR barrier islands developed by P.I.s Dueser, Hayden and Porter is a transition matrix model that provides a statistical approach to estimating future landscape structure. The model is based on the NOAA Coastal Change Analysis Program (CCAP) preliminary hyperspectral data base for 1984 and 1988 (14 land-cover classes) and the refined CCAP data base for 1992, 1996, 2001 and 2005 (23 land cover classes). During the past year they assembled the data and began reconciling terminological differences between the preliminary and refined cover classes. They have also developed a preliminary set of codes and labels for basic habitat types (Open, Herbaceous, Woody, Marsh, Water) and an even more simplified one (Upland, Wetland, Water). They have overlain the data layers to create a file that contains the land cover code for each year, for each polygon, along with an indication of which of the terrestrial/marine watersheds the polygon falls into. They have also developed a layer that outlines each individual island. They are now developing an algorithm for differentiating mainland, mainland marsh, lagoonal marsh and barrier islands. Once this task is completed, they will superimpose that layer onto the CCAP/watershed layer, and begin generating system-wide statistics for zones within the landscape for each time period. They will then be able to stratify cover classes based on elevation, and link cover projections to geomorphic and shoreline change models.

P.I. Enrique Reyes continues to develop the Virginia Landscape Model (VLM) that incorporates hydrodynamics, transport of water-borne particles (salt and sediments) and plant biomass growth over a grid of landscape cells, and focuses on intertidal marshes. 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 m2 “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. Reyes’ research efforts were to implement solutions to long-term water movement, particle distribution and plant production for long-term model stability. They have solved those long-stability problems. The hydrodynamic module, for example, calculates water movement on time intervals of less than an hour. Previous test runs were limited to 10 simulated years; presently the simulation interval is up to 25 years.

Morphodynamic changes of barrier island shorelines

ROA collaborator Fenster completed his field work on quantifying the tidal prism of selected VCR coastal bays and offshore bathymetry, and is using those data to drive an empirically-driven expert systems model (e.g., Bayesian) capable of predicting the landscape changes that will occur with predicted climate change scenarios. These projects included a field test of the runaway barrier island transgression model (e.g., FitzGerald et al., 2007) and the production of a high-resolution bathymetric map and side-scan sonar mosaic of the nearshore zone off the coast of four of the barrier islands. Ultimately, he plans to analyze bottom surface changes over time (i.e., the locations and volumes of sediment gains and losses of the shoreface sediment over time), analyze sea-level rise impacts on coastal ecosystems, and create a more accurate bathymetric grid needed for wave refraction modeling.

Fenster surveyed three tidal inlets (Quinby Inlet, Wachapreague Inlet and Metompkin Inlet) for more than a half tidal cycle (13 hr) with a downward-looking ADCP and three bottom-mounted, bottom-deployed, upward-looking acoustic Doppler current profilers (ACDPs) to obtain cross-sectional areas and tidal discharges. He then used these data to quantify the tidal prism and examine changes to the tidal prism over time. To quantify offshore bathymetry, he used a digital, high-accuracay, single-beam survey echo sounder and side-scan sonar system to produce bathymetric maps and side-scan mosaics of the nearshore from the breaker zone to the 15 m isobath along an approximately 60 km reach of coast.

Multi-sensor remote sensing analysis of land topography and vegetation

In June 2011, P.I. Charles Bachmann led a multi-sensor airborne remote sensing campaign at the VCR with a coordinated ground and water calibration and validation effort. NRL was the lead institution in a team of researchers and students that also included participants from George Mason University, Cornell University, Princeton University, Stephen F. Austin State University, NASA Goddard, and Virginia Commonwealth University) with logistical support from both the University of Virginia and The Nature Conservancy. Remote sensing imagery acquired during the ten-day exercise included hyperspectral imagery (NRL CASI), topographic LiDAR, and thermal infra-red imagery, all acquired simultaneously from the same aircraft. Airborne synthetic aperture radar (SAR) data acquisition is planned for a smaller subset of sites later in the year. The primary focus areas of this most recent campaign were properties of beaches and tidal flats and barrier island vegetation and, in the water column, shallow water bathymetry and water column properties.

The airborne remote sensing portion of the VCR'11 campaign, June 22-30, 2011, covered all of the barrier islands from Smith Island through Parramore Island as well as large segments of the VCR shallow lagoon system and the mainland marsh system.

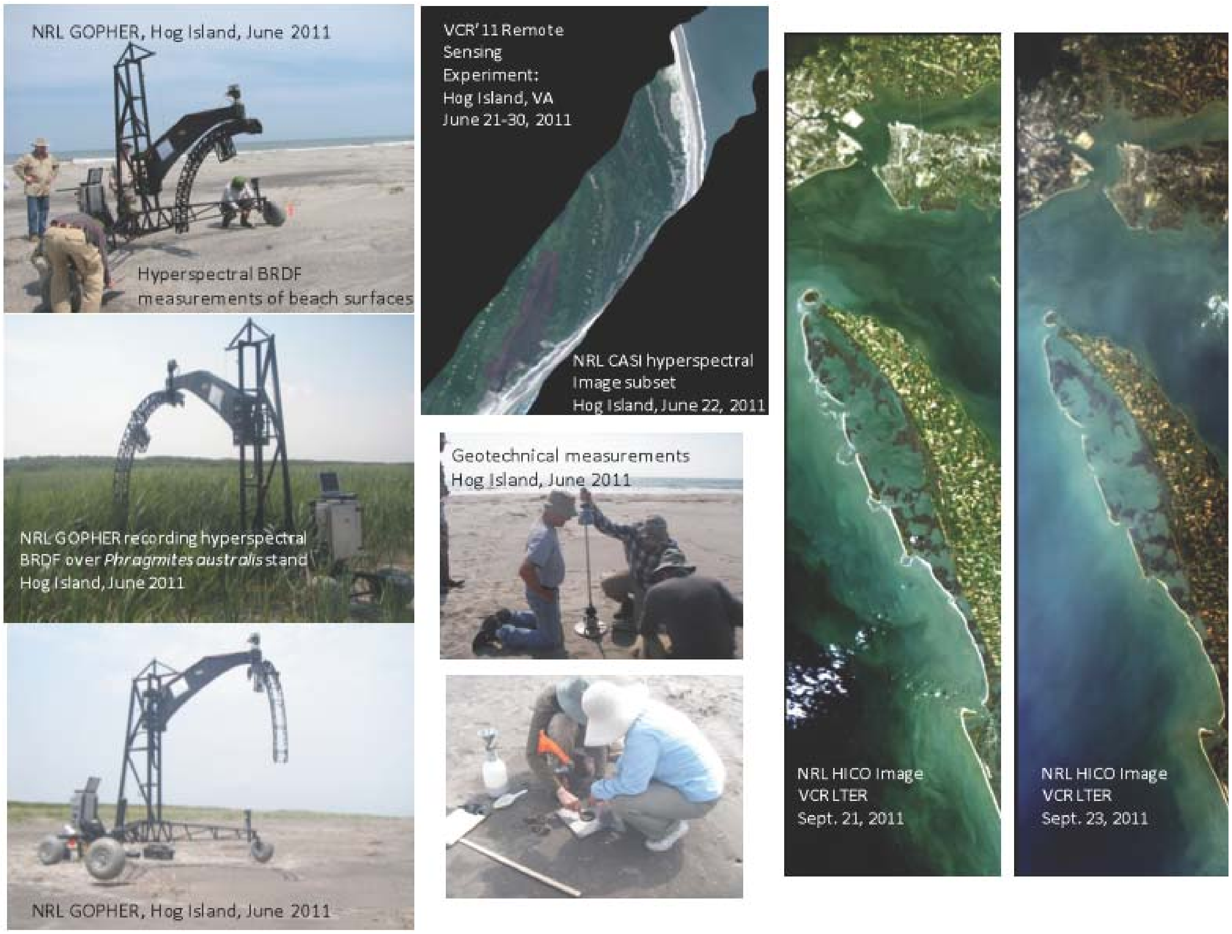

Fig. A6. (Left column) Photos of the NRL Goniometer for Outdoor Portable Hyperspectral Earth Reflectance (GOPHER) recording hyperspectral BRDF measurements on Hog Island during the VCR'11 remote sensing campaign. (Center) Examples of NRL CASI airborne hyperspectral imagery acquired during VCR'11, showing subsets over Hog Island, and photos of geotechnical measurements coordinated with GOPHER BRDF at all transect positions. (Right) A pair of HICO scenes of the VCR taken two days apart in September 2010, showing dramatic differences in the water column immediately after a storm event and two days later after subsidence.

On land, calibration and validation activities focused primarily on properties of beaches and tidal flats, including: composition, grain size distributions, density, moisture content, and other geotechnical properties such as shear and bearing strength (dynamic deflection modulus) were related directly to hyperspectral measurements taken with the new NRL Goniometer for Outdoor Portable Hyperspectral Earth Reflectance (GOPHER). The NRL GOPHER (Figure X) consists of a SpectraVista HR-1024 full-range (visble, near infra-red, and short-wave infra-red) hyperspectral sensor mounted on a rotating quarter arc track. The spectrometer can move along the track, and the arc rotates a full 180 degrees in azimuth, allowing this instrument to measure the full hyperspectral bi-directional reflectance distribution function (BRDF). The goal is to relate these geotechnical measurements to hyperspectral remote sensing, building on an earlier study conducted at the VCR LTER in 2007 which focused on beach properties (Bachmann, Nichols, et al, 2010) and shallow water bathymetry (Bachmann, Montes, et al, 2010).

A priority for this campaign was to collect and model relationships between hyperspectral imagery, acquired from the aircraft at a variety of different phase angles, and geotechnical properties of beaches and tidal flats as well as biophysical properties of vegetation. The phase angle is the angle between the vectors linking the positions of the sun and the sensor to a particular point on the ground. In addition to characterizing the BRDF, detailed measurements of the so-called "hot spot" (vegetation) or "opposition effect" (granular surfaces) were emphasized. This phenomenon is the well-known increase in reflectance in the vicinity of zero phase angle (the retro-reflectance direction). The shape of the hyperspectral reflectance about the retro-reflectance direction is closely related to important geophysical parameters such as grain size and density (for granular surfaces) and biophysical parameters such as biomass and leaf area index (LAI) for vegetation.

Network modeling

P.I Robert Christian continues to use network analysis to synthesize information on a variety of systems. He is combining the use of ecological and social network analysis in the studies of N cycling and food webs. And he is collaborating with others in the LTER network to further analysis of collaboration within the LTER program.

Social Science

Public valuation of ecosystem services

Using supplement funding, we have developed a collaboration with Stephen Swallow, a natural resource economist at the University of Connecticut, and his Ph.D. student Elizabeth Smith, to study the public valuation of seagrass, oyster, and bird habitat restoration. Increased demands on our coastal ecosystems, due to increased development and population growth, are threatening many environmental goods and the amenities associated with well-functioning ecosystems. While few to no markets exist for ecosystem services that provide public goods and are not traditional commodities, such as habitat services provided by healthy sea grass beds or water quality benefits associated with clam populations, consumer preferences can provide insight to managers and policymakers on how to prioritize limited funding and make trade-offs between coastal restoration priorities. Yet economic theory suggests consumers will not actually pay their full marginal value in support of provision of public goods. This is a multi-year project that examines methods to implement an individualized pricing auction (IPA) approach to public good provision, grounded in Lindahl's marginal benefit theory. They evaluate how different payment rules and incentive mechanisms impact individual's marginal decision making in a public goods environment. The research concerns a basic-science test of Lindahl's theory for pricing public goods and the economists' consensus of its impracticality, while also providing broader impacts with respect to a better understanding of the potential to implement market based approaches ion support of public goods, such as key ecosystem services.

They focus on ecosystem valuation and market approaches that have potential to provide public goods, examining the potential to generate revenues for public goods from consumers. While willingness-to-pay techniques have been used to estimate preferences for many environmental goods, this study goes a step further to explore auctions that generate actual revenues sufficient to pay for restoration activities. They compare field experiments conducted in coastal Virginia with induced-value laboratory experiments in order to evaluate the performance of auction mechanisms in generating revenues relative to potential (Hicksian) willingness to pay for marginal increments in public goods.

This year they concluded the induced-value lab experiments which allow for a test of the mechanisms in a controlled, experimental economics laboratory environment, examining how individuals respond to the incentives without the possible bias associated with preconceived notions about the specific public good's environmental or social impacts. The design of the induced-value experiment follows the literature testing mechanisms intended to fund public goods. In the laboratory experiments, groups of 8 to 14 participants are assembled and asked to make a series of decisions regarding how much money they are willing to allocate, on a per-unit basis, towards provision of incremental units of a public good.

The field execution of this experiment conducted in 2008 and 2009 involves residents of Virginia's eastern shore and local public goods. Data was collected using a field experiment employing an individualized price auction approach with mechanisms to reduce free riding often seen in the experimental economics literature. These incentive mechanisms are applied to individual restoration activities and marginal willingness to pay estimates are compared to a baseline choice experiment (CE) that employs an incentive compatible, majority vote mechanism and actual (not hypothetical) money payments. They take estimates from both utility models, including confidence intervals constructed under a Krinsky-Robb approach, to compare payments and values generated from the individualized price auction with the incentive compatible approach. The field application involves half-acre increments of ecosystem restoration for sea grass habitat in coastal lagoons, plantings for migratory bird habitat, and, in some auctions, clam-based increments of water quality services, defined as delaying the harvest of clams for six months beyond normal harvest by an existing aquaculture firm. To perform these tasks, participants are provided a budget, between $100-$150.The auctioneer describes for participants the ecosystem services that may result from additional ecosystem restoration associated with each activity. For instance, these ecosystem services may include the additional habitat and oxygen resulting from additional sea grass restoration or the critical migratory sites and ecotourism opportunities resulting from bird habitat or the increased water clarity resulting from delayed clam harvests.

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FINDINGS

Mainland Watersheds and Lagoon

Watershed nutrient loading

Using the N loading model, we determined that agricultural fertilizer was the dominant terrestrial N source to the VCR coastal bays, though deposition of rainfall to the surface of the bays was the largest overall source of N. On average, Virginia coastal bays received 7.2 x 10^4 kg N y^{-1} or 2.11 g N m^{-2} y^{-1}, markedly lower than most other shallow coastal waterways in temperate systems (Fig. F1, McGlathery 2007). This is potentially due to the low watershed:bay areas, the low population density, and the absence of high-concentration poultry and livestock farming which is prevalent in the Maryland, Delaware, and North Carolina systems (Cole and Nixon *submitted*, USDA NASS 2009). In Virginia, the north to south decreasing N input rate (g N m^{-2} y^{-1}) is likely a combination of the low land:water area and the overall low population density, particularly at the southern tip of the Delmarva Peninsula (Fig. F1).

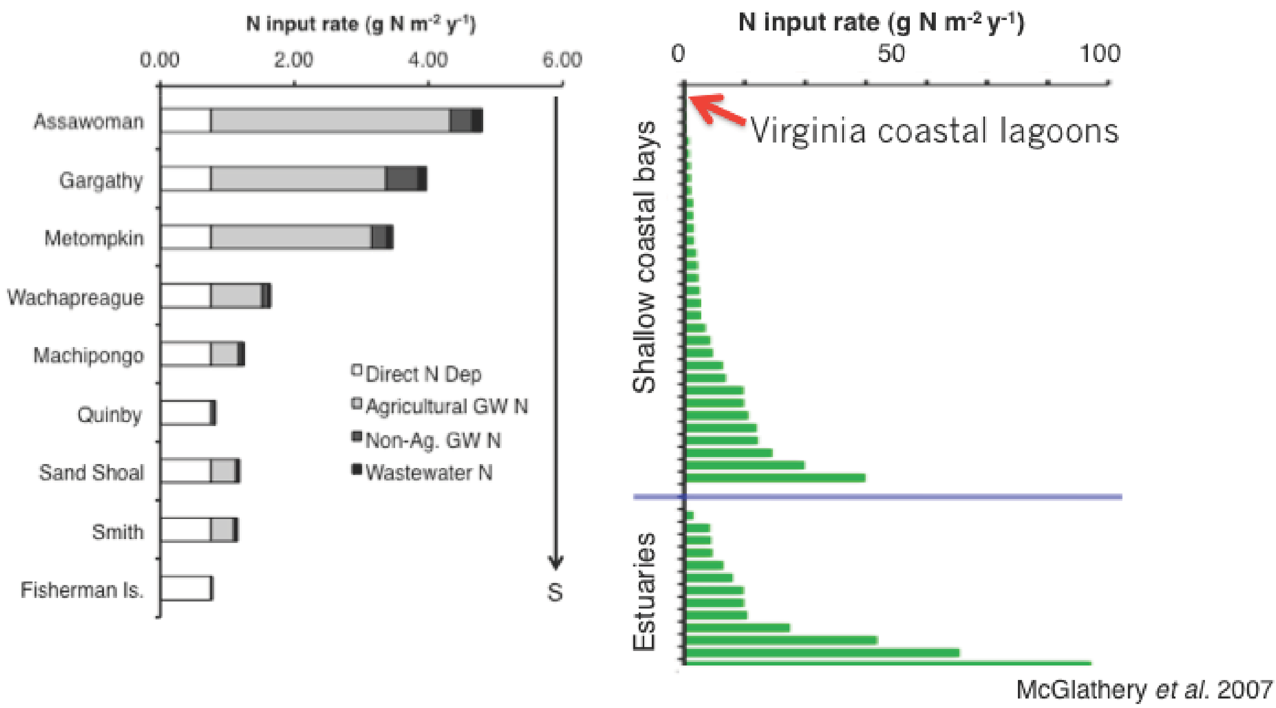


Fig. F1. Annual nitrogen loading estimates to from individual watersheds to the VCR coastal bays (left panel), and N loading in the context of published estimates to other coastal bay and estuarine systems (right panel).

Estimates from the stream monitoring data suggest the N loading for the total VCR coastal bay system is between 2 x 10^5 and 3 x 10^5 kg NO_3^- -N/yr.

Submarine groundwater discharge

The eddy correlation technique and a conventional open water technique were used to determine the factors influencing stream metabolism over hourly, daily, and seasonal scales in a representative stream at the VCR. The two techniques are complementary. The eddy correlation technique can be used to determine the oxygen flux at a high temporal resolution and without correction for the air-water exchange, while the conventional open water technique can be used to determine the oxygen flux over longer time scales than eddy correlation allows. The eddy correlation technique is based on the simultaneous measurement with an acoustic Doppler velocimeter and a Clark-type oxygen microelectrode in the same measurement volume in the water column (Berg et al., 2003). Turbulence is responsible for the mixing of surface waters in most natural systems. Because of this, eddy correlation measurements of the instantaneous deviation of the vertical velocity and oxygen concentration at the same point in the water column can be used to calculate the oxygen flux through the water. Oxygen flux is a proxy for net stream ecosystem metabolism. Stream ecosystem metabolism is determined from the conventional open water technique as the sum of the change in dissolved oxygen concentration over time and the

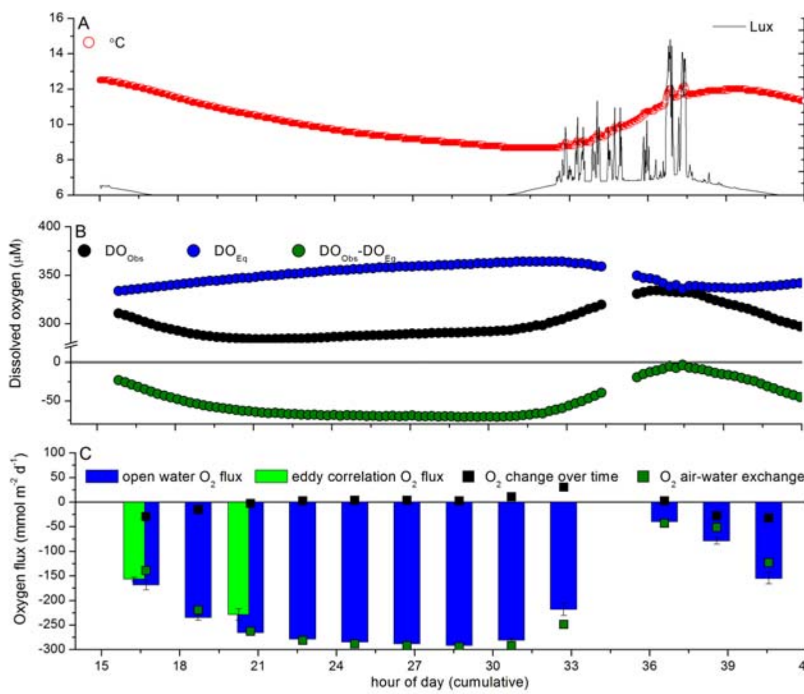


Fig. F2. Oxygen fluxes in Rattrap Creek determined by the eddy correlation technique and a conventional open water technique; A, water temperature and sunlight penetration to the stream bed; B, observed and equilibrium dissolved oxygen concentrations; and C, the oxygen flux calculated using the different techniques. The open water calculation includes the oxygen change over time and the air-water exchange.

exchange of oxygen across the air-water interface. Exchange across the air-water interface is the product of the oxygen deficit and a gas transfer coefficient.

Comparative measurements of stream metabolism made with the two techniques on November 11th and 12th of 2010 in freshwater Rattrap Creek near Locustville, VA, are given in Fig. F2. The temperature of the stream dropped from a daytime high of 12.5 °C to a nighttime low of 8.7 °C (Panel A), while the dissolved oxygen concentration in the creek climbed steadily during the night as a function of the increased solubility of oxygen in water due to the decrease in temperature (Panel B). The difference between the equilibrium dissolved oxygen concentration and the observed concentration was consistently negative, indicating that the net oxygen flux across the air-water interface was towards the water (Panel C). The air-water exchange constituted most of the oxygen flux measured with the open water technique, but the results were similar to the oxygen flux calculated with the eddy correlation technique (Panel C). These results indicate that this stream is highly heterotrophic, with a net heterotrophic ecosystem metabolism even under peak sunlight. The observed nighttime oxygen consumption rate exceeded the mean respiration rate of Walker Branch, a low gradient (0.04 m m^{-1}) first-order mountain stream (104 mmol O_2 m^{-2} d^{-1}; Mulholland et al., 1997), and was similar to the mean respiration rates of a moderately steep (0.13 m m^{-1}) gravel-bed second order mountain stream (244 mmol O_2 m^{-2} d^{-1}; Mulholland et al., 1997), and a low gradient (0.001 m m^{-1}), sand-and-gravel bed, Virginia coastal plain blackwater stream (215 mmol O_2 m^{-2} d^{-1}; Fuss and Smock, 1996). High rates of respiration in stream bed sediments are linked to high rates of nitrogen removal through mineralization and denitrification (Mulholland et al., 2008).

Diurnal patterns of groundwater discharge to streams - implications for nitrate removal

There were diurnal fluctuations in stream stage in summer months in Cobb Mill Creek (Fig. F3) when trees were leafed out, and there was no similar cycle in the months in which leaves were absent from the trees. The high frequency fluctuations have an autocorrelational lag of exactly 24 hours (144 10-minute sampling periods, Fig. F4).

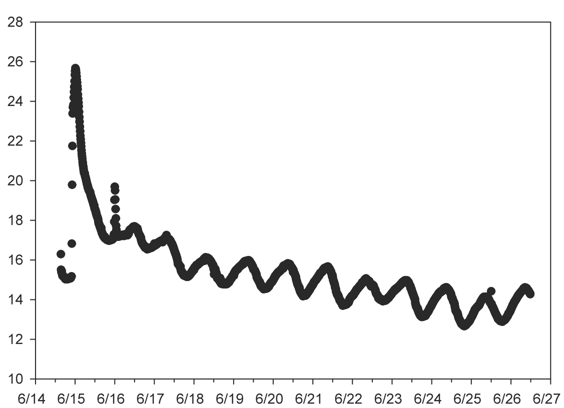


Fig F3. Diurnal fluctuation in stream stage at Cobb Mill Creek. Data collected in June 2010

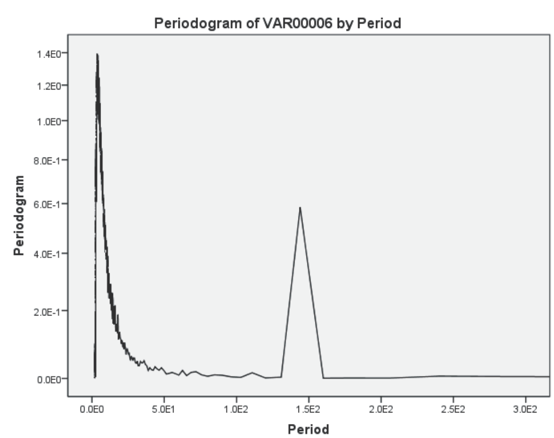


Fig. F4 Results of spectral analysis of June stage data showing the strength of the diurnal signal.

Nitrate concentrations taken on an hourly basis also showed a similar diurnal signal, although there were a large number of samples with lower concentration of NO_3^- than the samples considered to display the pattern (Fig. F5). The curious distribution of NO_3^- concentrations remains unexplained, even though the fluctuation could be seen, and was demonstrated in an earlier 3-day experiment. Again, no such fluctuation was seen in the March examination when the trees had not yet opened their leaves.

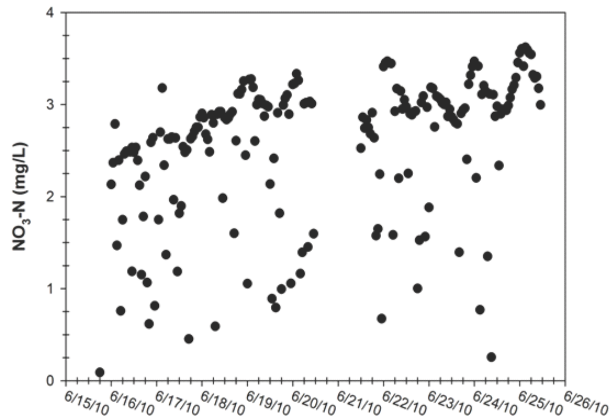


Fig F5. Nitrate concentrations in water column samples collected hourly with an ISCO sampler. The line was added by hand simply to help visualize the fluctuating pattern of the NO_3^- concentration. The break in the data between 6/20 and 6/21 was a result of the failure of the sampler to collect water.

Modeling of PET, in combination with a 1-D model of denitrification developed for Cobb Mill Creek showed that the discharge of NO_3^- to the creek, and the resulting concentration of NO_3^- in the creek can be controlled by the hydrological process of evapotranspiration. On a system basis, we are confident of the control on the process, although we have yet to show the definitive link experimentally.

Lagoon hydrodynamics

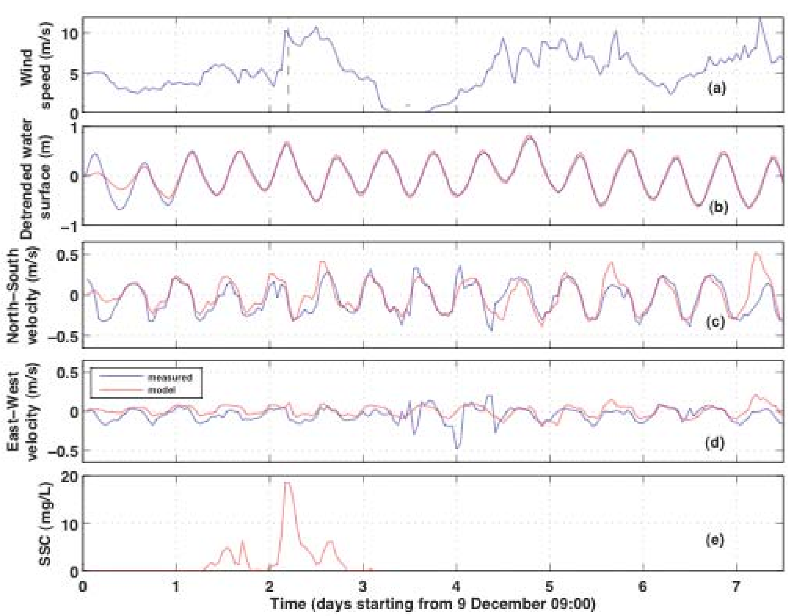


Fig. F6. (a) Wind speed at Kiptopeke, and ADP measurements (blue) and model calculations (red) of (b) water surface elevation, (c) N-S component of velocity (positive = Northward) and (d) E-W component of velocity (positive = Eastward), and (e) suspended sediment concentration. Sediment model was run only for days 1-3.5.

A hydrodynamic model was implemented to study residence time, sediment transport and wave energy impacting tidal marshes in the coastal bays of the VCR. Following setup of the model, serial/parallel compilation on high-performance computing clusters, and testing of these two models with variable forcing (winds, tides, and waves), FVCOM was validated with one-week field observations of wind- and tide-induced water flow (water level and current velocities) in Hog Island Bay during a moderate storm (wind speed sometimes reaching 10-m/s, Fig. F6a) in winter 2002. At the peak of the storm, wave heights calculated at the tidal flats at the Hog Island

Bay exceeded 30-cm. Surface waves were observed to make a significant contribution on the sediment resuspension. During high-tide phases, suspended sediment concentration within the model domain calculated by accounting for waves was more than one-order of magnitude larger than suspended sediment concentration within the domain calculated by neglecting waves. The comparison of measured and calculated water levels and current velocities (Fig. F6b-d) shows that the model captures the general trend of water flow during this event fairly well. Modeled suspended sediment concentrations during the wind event on day 2 reached 20 mg/L at the site of our ADP measurements, in general agreement with measured values. (Note that the period between days 0-1 is where the model is ramped up). The distributions of significant wave height and suspended sediment concentration within the system at the peak of the storm (dashed line in Fig. F6a) are shown in Fig. F7.

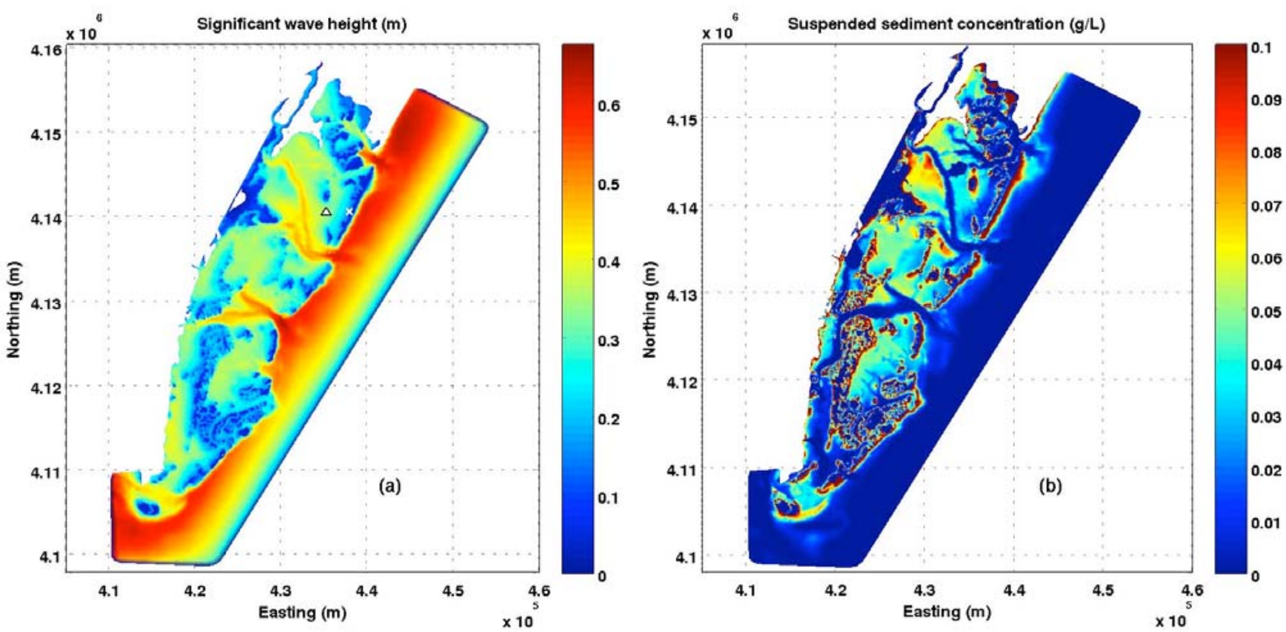


Fig. F7. Distribution of (a) significant wave height, and (b) near-bed suspended sediment concentration at VCR during the peak of the December 2002 storm at high-tide (see the dashed line in Fig. F6).

Residence time was calculated for three bays with strongly varying bathymetry and coastline geometry: Hog Island Bay, South Bay, and Magothy Bay (Fig. F8). Particles released close to the channels have residence times of few hours, whereas those that were released far from the inlets and closer to the land boundaries are likely to reside in the system for periods reaching two-weeks (>300 hours). Future runs will include sediment particles to assess sediment transport in the coastal bays.

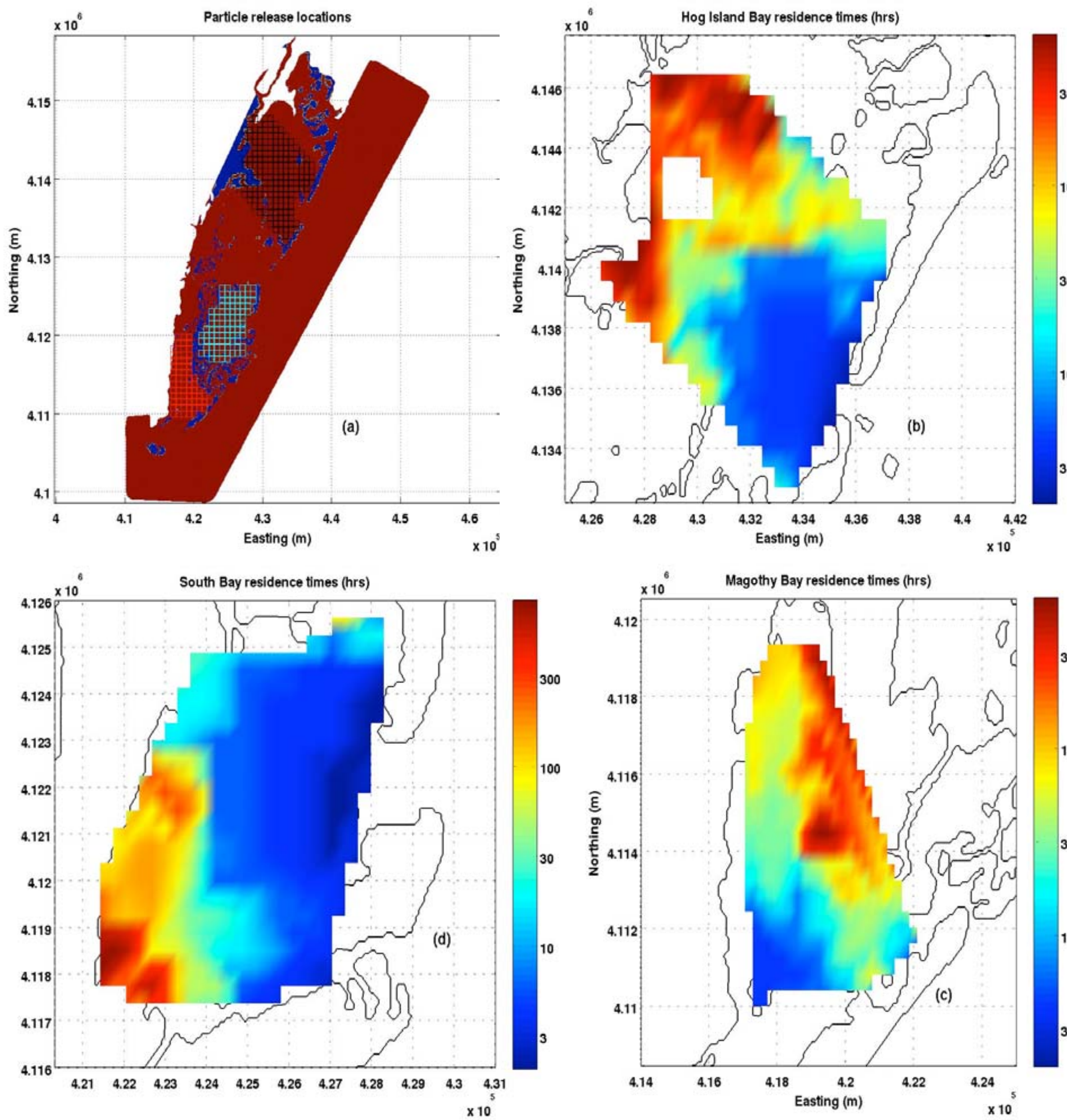


Fig. F8. (a) Particle release locations at Hog Island Bay (black), Magothy Bay (red) and South Bay (cyan). (b-d) Residence time of particles at these three bays of interest. The scale of the color bar is in hours.

The eroding impact of surface waves on the marsh boundaries (Chimney Pole, Fowling Point, Matulakin, Hog Island) was quantified through Wave Power Factor at the marsh Boundary (WFB; Mariotti et al 2010) for idealized wind conditions. WFB values obtained from the 48 idealized simulations (four wind speeds (5, 10, 15, 20 m/s) and 12 directions (30^o discretization)) are weighted by the probability of occurrence of each wind speed/direction. To evaluate the effect of higher water levels, the simulations were repeated by increasing the water level by 60-cm throughout the model domain, reflecting mean high water conditions. Evaluation of the results together with the field estimations of erosion rates at these marsh sites suggests that wave energy is not the only mechanism that controls erosion rates (McLoughlin et al., in revision), but additional characteristics of the marsh appear to play a role as well.

Coupled vegetation – hydrodynamic model

Shallow coastal bays provide habitat for diverse fish and invertebrate populations and are an important source of sediment for surrounding marshes. The sediment dynamics of these bays are strongly affected by seagrass meadows, which limit sediment resuspension thereby providing a more favorable light environment for their own survival and growth. Due to this positive feedback between seagrass and light conditions, it has been suggested that bare sediment and seagrass meadows are potential alternate stable states of the benthos in shallow coastal bays (Fig. F9). To investigate the stability and resilience of seagrass meadows subjected to variation in environmental conditions (e.g., light, temperature), a coupled model of vegetation-sediment-water-flow interactions and vegetation growth was developed (Carr et al. in review, a). The model was applied to Hog Island Bay, a shallow coastal bay within the VCR where seagrass restoration efforts are ongoing. The model was used to examine the effect of dynamically-varying seasonal and interannual seagrass density on sediment resuspension, water column turbidity, and the subsequent light environment on hourly time steps and then run over decadal time scales. A daily growth model was designed to capture both belowground biomass and the growth and senescence of aboveground biomass structural components (e.g., leaves and stems). This allowed us to investigate how the annual and seasonal variability in shoot and leaf density within a meadow affects the strength of positive feedbacks between seagrass and their light environment. The model demonstrates both the emergence of bistable behavior from 1.6-1.8

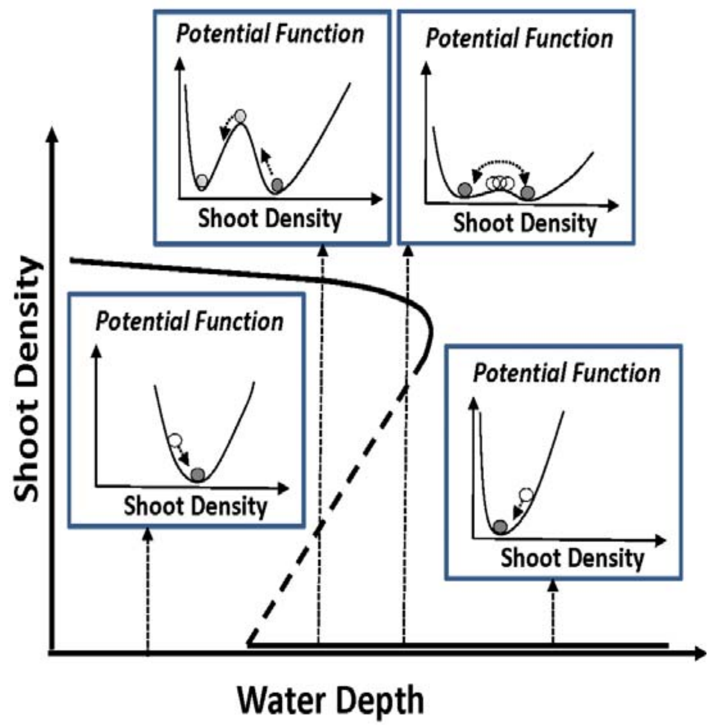


Fig. F9. Schematic representation of the "fold-type" bifurcation of seagrass dynamics. Stable (solid) and unstable (dashed) states of the system are shown as a function of water depth. In shallow waters the light environment is sufficient for seagrass establishment and survival regardless of the initial existence of a seagrass canopy stabilizing the benthic sediments. In relatively deep waters the light penetrating through the water column is insufficient for seagrass growth. In intermediate conditions the system may be stable either with or without a seagrass bed. These stability and bistability conditions are shown in terms of minima of the potential function which is qualitatively plotted in the insets. Close to the critical fold bifurcation point the potential barrier between the stable states is small and the system may repeatedly fluctuate between these two states ("flickering").

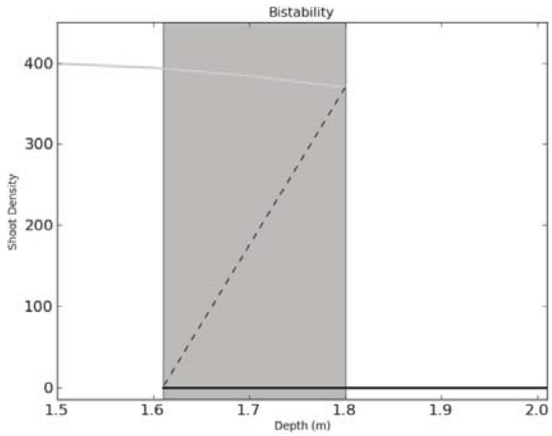


Fig. F10. Fold bifurcation plot exhibiting the bistable depth range for *Zostera marina* as a function of water depth and wintering shoot density (shoots m^{-2}), under random drivers. Meadows at water shallower than 1.6 m MSL exhibit a single attraction domain of a dense meadow state (gray line). Meadows initiated deeper than 1.8 m MSL display a single attraction domain of the bare sediment state (black line). In between 1.6 and 1.8 m MSL, depending on shoot density, depth and environmental forcing conditions, a meadow may be within the attractive domain of either the dense meadow state or the bare sediment state (shaded area).

meters mean sea level due to the strength of the positive feedback (Fig. F10), as well as the limited resilience of seagrass meadows within this bistable range (Fig. F11).

The coupled vegetation-growth hydrodynamic model was also used to investigate seagrass stability and leading indicators of ecosystem shift under the effects of sea-level rise and increases in water temperature associated with climate change (Fig. F12) (Carr et al. in review, b). The results indicate that while extant seagrass meadows are likely to tolerate sea-level rise, an increase in the frequency of days when summer water temperature exceeds 30°C will cause more frequent summer die offs. This increase in the number of higher temperature disturbance events is likely to push a dense meadow initially located within the bistable depth range (1.6 – 1.8 m mean sea level) toward and eventually past a critical bifurcation point, from which recovery is not possible. We identified two leading indicators of a meadow nearing this bifurcation point, both associated with the number of leaves per shoot: "flickering", which reflects conspicuous fluctuations from one attractor to the other across the threshold, and "slowing down", which is the increased persistence of the fluctuations as a system gets close to a threshold due to its inability to recover (Fig. F13). The model indicates that the seagrass in these coastal bays have limited resilience

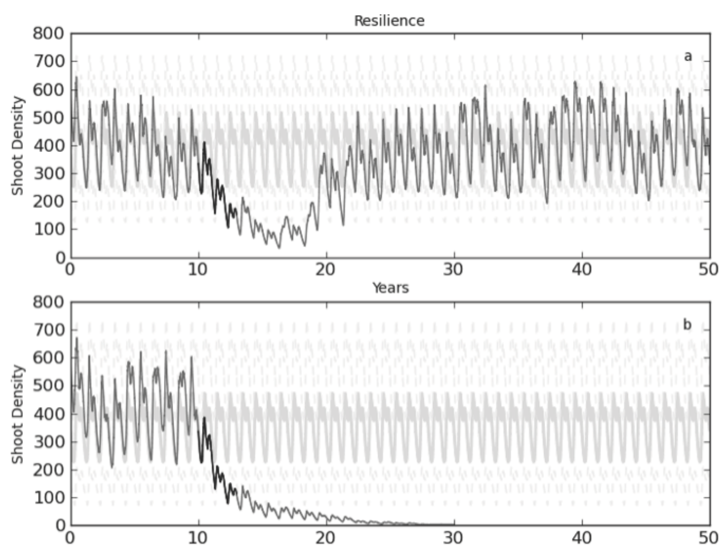


Fig. F11. a) Resilience of an initially dense meadow at 1.6 m MSL under three consecutive bad years initiated at simulation year 10. b) Collapse of a meadow at 1.8 m MSL undergoing the same three consecutive poor years. Gray solid line indicates shoot densities corresponding to the seasonal mean with gray dashed lines indicating plus or minus two standard deviations.

to increases in water temperatures predicted from current climate change models.

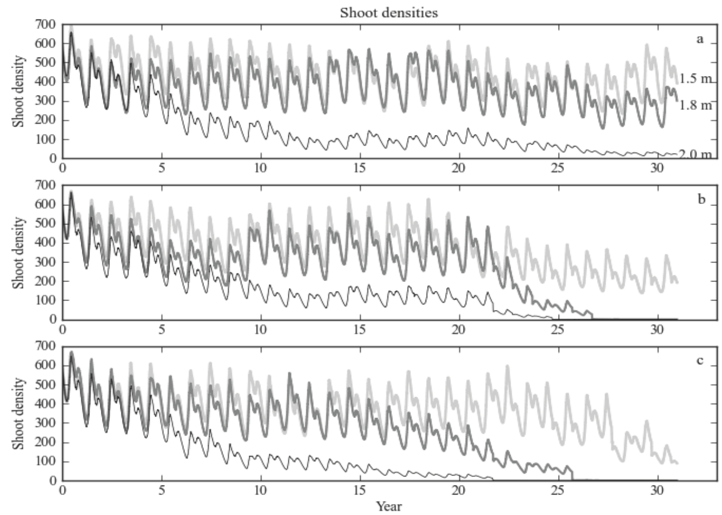


Fig. F12. *Zostera marina* shoot densities averaged over all runs initiated at water depths 1.5, 1.8 and 2.0 m MSL, under a) increase in sea-level b) increase in temperature and c) both increased temperature and sea-level.

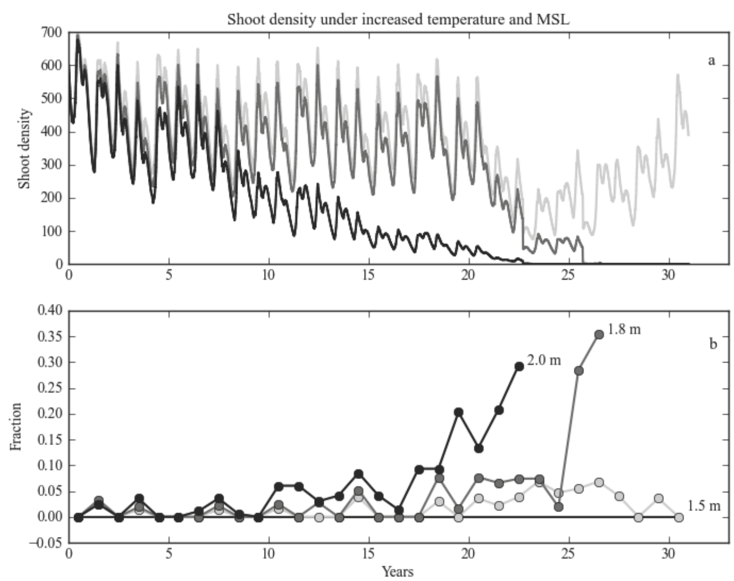


Fig. F13. a) *Zostera marina* shoot densities for meadows initiated at 1.5, 1.8 and 2.0 m MSL under increased temperature and sea-level. b) The appearance of flickering and slowing down prior to loss for the meadows initiated at 1.8 and 2.0 m MSL. Flickering, slowing down, but then recovery of the meadow initiated at 1.5 m MSL.

Seagrass Restoration

Genetics: Restored seagrass populations showed high genetic variation, and were similar to the geographically distinct populations sampled. A Bayesian cluster analysis in STRUCTURE (Pritchard et al. 2000) followed by a delta K analysis (Evanno et. al 2005) found 5 distinct genetic clusters among the 23 geographically separated populations sampled. The restored populations in the Virginia coastal bay populations were quite similar to Chesapeake Bay populations, from which seeds were originally taken to restore these populations. The meadows that naturally recruited into the Virginia coastal bays, however, varied. Two of those populations, one in Hog Island Bay (HN) and Fisherman Island near the mouth of the Chesapeake (FI) look more like populations to the north: Chincoteague Bay (CB) and Woods Hole (WH) respectively. The third naturally-recruited population, South-south Bay (SSB), which had anomalously low diversity, grouped in its own distinct cluster. It did not look like any of the other meadows sampled (Fig. F14). We conclude that natural recruitment is likely from the north, which is the same direction as dominant long-shore transport. The individuality of the anomalous natural site (SSB) suggests that this recruitment event is either old and has undergone genetic drift so that it no longer resembles the seed source or that source of the seeds was from outside of our sampling area.

The area of natural recruitment into the VCR over the last 60 years pales in comparison to the current estimate of over 1800 ha of seagrass coverage resulting in the addition of seeds via restoration that has occurred over the last 10 years (Orth et al. in revision). In addition, natural recruited meadows are lower in genetic diversity (Fig. F15), which suggests that they may be less fit and less resistant to disturbances. It is probable that natural recruitment would eventually result in the same area of seagrass; however, the time scale of recovery would be decades longer. While the southern Virginia coastal bays have good water quality and can support seagrass expansion, coastal bays to the north of the region are experiencing large declines in seagrass primarily due to water quality. Because of the time require for natural restoration, these bays may cease to produce the necessary propogules before restoration is complete. Artificial, anthropogenic restoration may in many ways be more successful than natural recruitment.

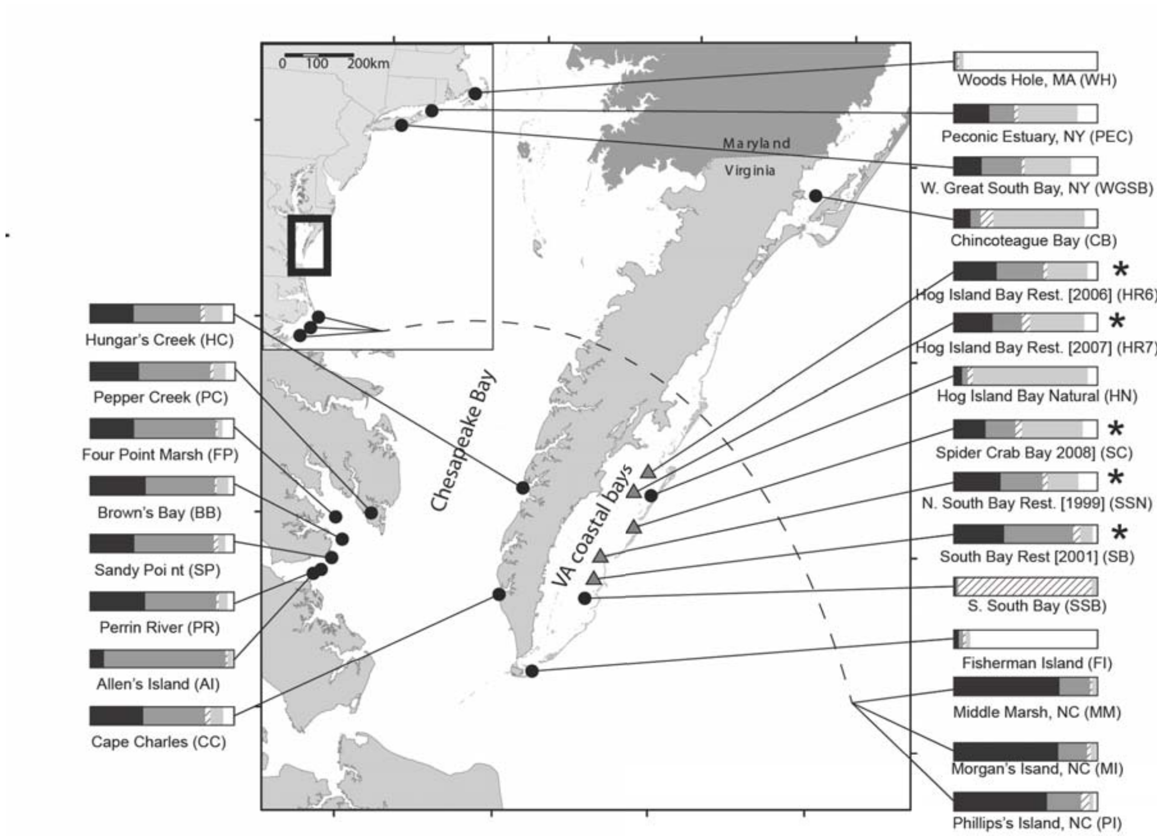


Fig. F14. Genetic variation in 23 geographically separated populations based on Bayesian cluster analysis.

Typically, large-scale die-backs and restoration efforts result in decreased genetic diversity compared to healthy populations. However, a survey of genetic diversity in meadows from both locations using microsatellite markers unexpectedly revealed very high levels of genotypic diversity, allelic richness, and heterozygosity (Fig. F14, F15). We hypothesize that the mechanisms responsible for generating this high level diversity are an increase in sexual reproduction and seed production due to stress, and adequate open space for seedlings to germinate and survive due to disturbance. We saw evidence for these mechanisms at 3 spatial scales. In Chesapeake Bay, genetic analysis of meadows before and after a temperature-driven dieback showed no reduction in diversity (Fig. F16), and in the VCR bays, 1 acre plots planted over a depth gradient showed an increase in diversity in deeper waters where plants often experience light stress (Fig. F17). Furthermore, a regional survey showed that plant diversity increased at the geographical margin where plants are often stressed and regularly die back in the fall due to high temperature (Fig. F18). In North Carolina, at the very southern limit, plants often completely die back each year. Meadows that are closer to the geographical

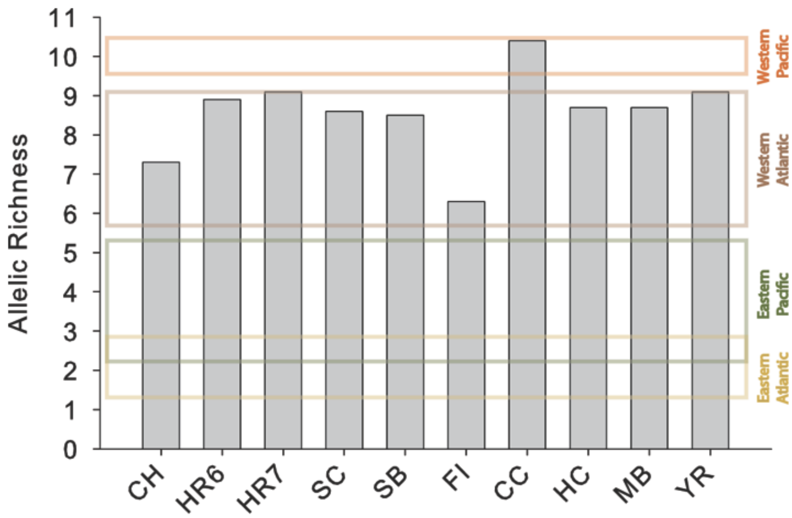


Fig. F15. Allelic richness (a mesure of gentic diversity) of sites along the x-axis, which are seagrass meadows in Chesapeake Bay and the Virginia coastal bays. Additional bars are measures of allelic richness from meadows worldwide

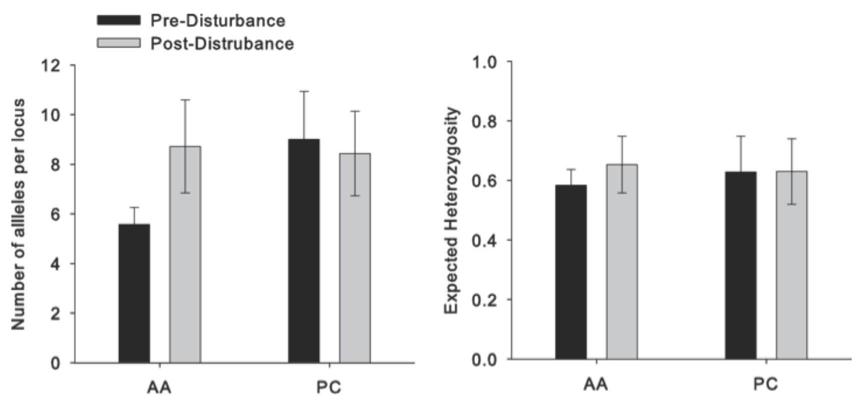


Fig. F16. The genetic diversity of meadows in Chesapeake Bay both before and after a large biomass loss due to high temperatures.

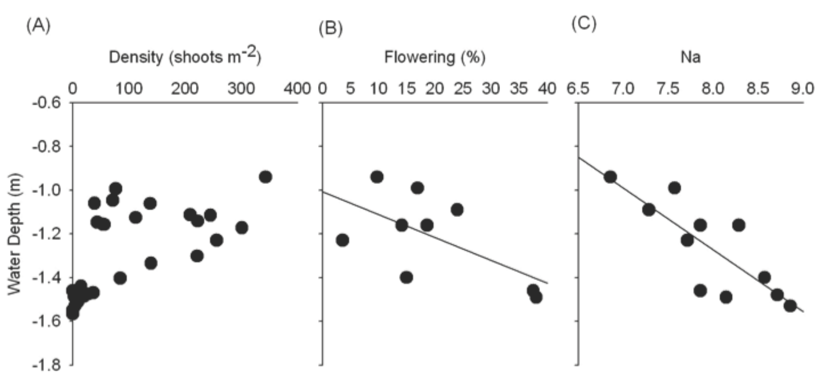


Fig. F17. (A) Seagrass shoot density decreases with water depth, likely on account of a light stress (R^2=0.4,p=0.0004). (B) The stressed plants put a larger effort in to sexual reproduction as opposed to clonal elongation, evident by a larger proportion of flowering shoots (R^2=0.4,p=0.06), which results in (C) a larger genetic diversity in plants that are stressed by deeper watD(R^2=0.6,p=0.0002).

margin are often stressed are more diverse.

The high levels of Chesapeake Bay diversity were maintained when seeds were used to restore the VCR bays. Adding a large number of seeds to a suitable habitat via restoration is similar to natural processes that maintain genetic diversity (increase reproductive effort with suitable open space).

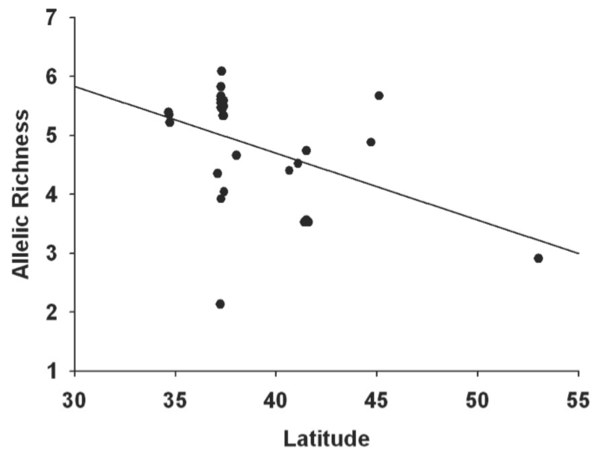


Fig. F18. Plants which are closer to the southern geographical margin are often stressed by high water temperatures.

Restoration trajectories: We have followed the recovery of both functional (primary productivity, carbon and nitrogen sequestration, sediment deposition) and structural (shoot density, biomass, plant morphometrics) attributes of *Zostera marina* meadows in replicate large plots (0.2 – 0.4 ha) restored by seeding in successive years, resulting in a chronosequence of sites from 0 (unvegetated) to 9 years since seeding. Shoot density was the structural metric that changed most significantly, with an initial 4-year lag, and a rapid, linear increase in plots 6 – 9 years after seeding (Fig. F19). Changes in *Z. marina* aerial productivity, sediment organic content and exchangeable ammonium also showed a similar trend with an initial 4-year lag period before differences were observed from initial bare sediment conditions. After 9 years, *Z. marina* meadows had 20 times higher rates of areal productivity than 1 – 3 year old meadows, had double the organic matter (Fig. F20) and exchangeable ammonium concentrations, had sequestered 3 times more carbon and 4 times more nitrogen, and had accumulated and retained finer particles than bare, unvegetated sediments. These results demonstrate the reinstatement of key ecosystem services – primary productivity, carbon and nutrient sequestration, and sediment deposition – with successful large-scale restoration initiated by seeding. None of the parameters we monitored reached an asymptote after 9 years, indicating that at least a decade is required for these attributes to be restored, even in an area with high habitat suitability. Survivorship along a depth gradient showed that ~1.6 m MSL (mean sea level) is the maximum depth limit for *Z. marina*

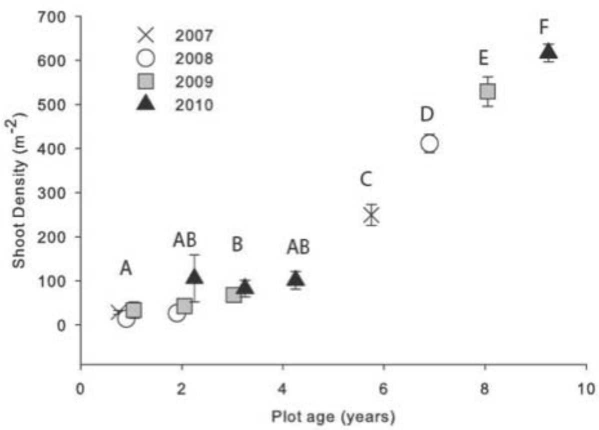


Fig. F19. Change in shoot density in restored seagrass meadows.

in the regions where restoration has occurred, which matches the ‘tipping point’ for *Z. marina* survival predicted for this system from a non-linear hydrodynamic/seagrass growth model. Changes in environmental factors related to climate and land-use (light, temperature, nutrients, storm disturbance) will alter the maximum and minimum depth limits of *Z. marina*, and will likely reduce the areal extent of potentially suitable habitat (see discussion of coupled hydrodynamic-growth model).

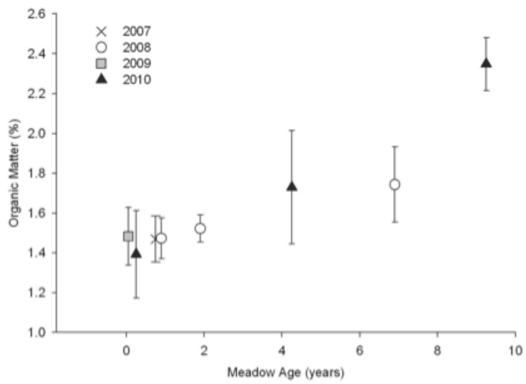


Fig. F20. Percent organic matter accumulated in seagrass meadows of different ages.

Nitrogen cycling: In the restored seagrass meadows, nitrogen fixation (N_2 fixation) rates were significantly higher compared to bare sediment and decreased with sediment depth. Furthermore, the older seagrass meadow (8 years old; seeded in 2001) fixed significantly more N_2 than the younger meadow (3 years old; seeded in 2006) and bare sediment. N_2 fixation rates in the older meadow and bare sediment were comparable to other *Z. marina* and bare sediment systems, respectively. N loss via denitrification increased as seagrass meadows aged, and were correlated to increases in sediment organic matter. The N removal capacity of bare sediment was half of the total N loading rate into the bays (1 g N m^{-2} y^{-1}), and vegetated sediments removed 3.9–5.8 g N m^{-2} y^{-1}, supporting the concept of seagrass beds as a “nutrient sponge”.

Carbon sequestration: Depth profiles of organic matter in 10-year old restored seagrass meadows had higher organic matter in the top 5 cm than the 4-year old restored meadows (Fig. F21). Further analysis will be done to measure organic matter, percent carbon, and lead 210 at these sites to quantify the effects of seagrass restoration on carbon burial in these shallow coastal systems.

Sediments dominated by seagrass contain organic matter enriched in 13C relative to autochthonous algal sources. Within the sediment record, there were two distinct regions of enriched organic matter within the sediment record—one near the surface and another at lower depths. Organic matter

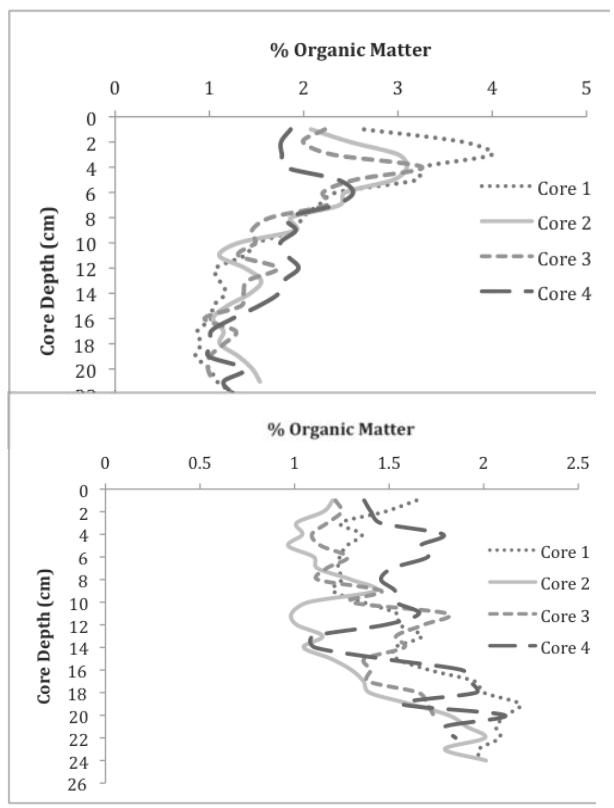


Fig. F21. Percent organic matter in sediments from 10-year old (top panel) and 4-year old (lower panel) seagrass meadows.

enriched in 13C near the surface is likely from current seagrass cover. Similar characteristics of sediment deeper in the core imply that the area was previously dominated by comparable vegetation. These results may be used as a proxy to infer the spatial extent of the historic (prior to 1930) presence of seagrass and guide future restoration efforts. Sediments dominated by seagrass (*Z. marina*) contain organic matter enriched in 13C relative to autochthonous algal sources.

<u>Metabolism</u>: Initial results suggest that metabolic rates of the 10-year old restored seagrass meadows during the late summer can be twice to four times the O_2 metabolic rates for unvegetated sediments. These metabolic rates are larger than measured by a previous study of Hume et al. (2011 during an earlier stage of restoration. Fig. F22 shows two 24 hour deployments as a comparison of O_2 fluxes (mmol O_2 m^{-2} day^{-1}) measured at a 15-minute resolution from the mature seagrass meadow and the bare sediments. Panel A and B show fluxes and photosynthetically active radiation (PAR, µm photons m^{-2} s^{-1}) from the surface of the seagrass meadow, and C and D show fluxes and PAR measured just above the bare sediments. It is surprising that significantly more light reached the benthic surface at the vegetated site in the presence of seagrass, as shown in panels B and D; this may be due to light flickering related to the presence of the seagrass. Measurements will be made again in October, March, and June.

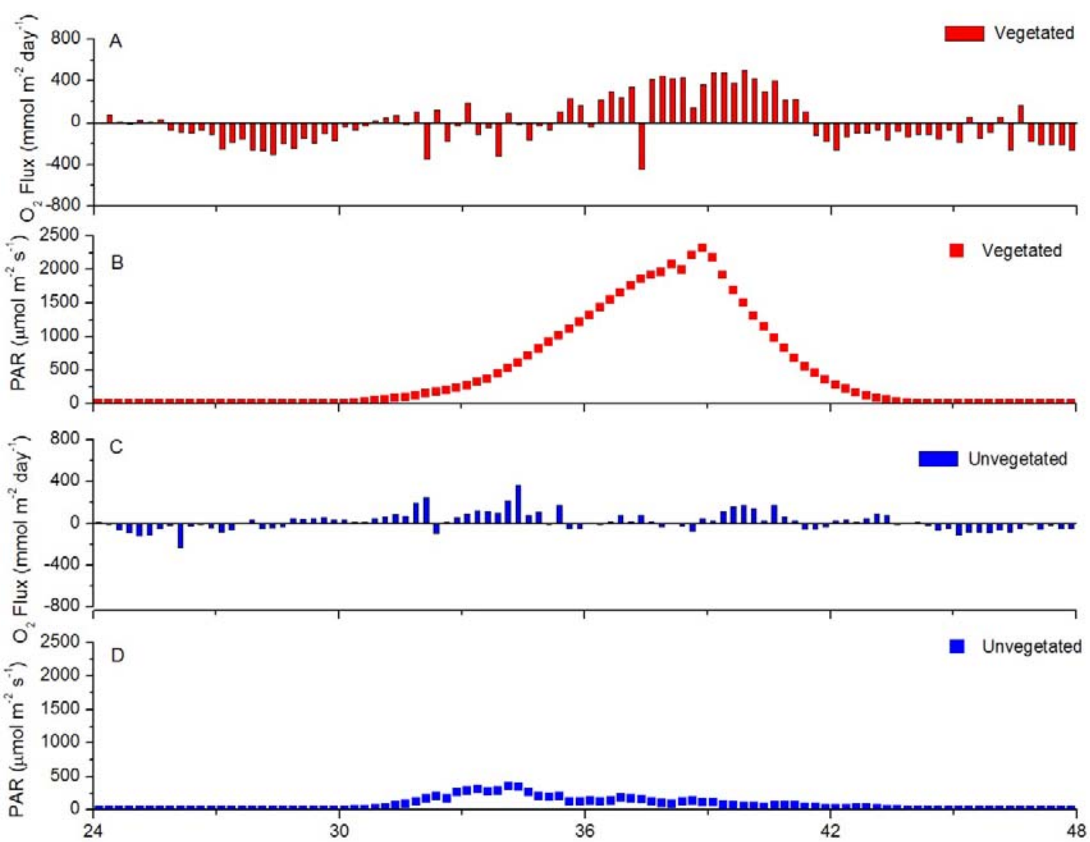


Fig. F22. Comparison of 15 minute O_2 fluxes over a 24 hour period from a vegetated, ten year old restored seagrass bed, to unvegetated bare sediments under similar ambient environmental conditions.

Hydrodynamics and sediment motion within seagrass beds

Zostera marina meadows reduced near-bottom mean velocities by 70-90% (Fig. F23), while wave heights were reduced 45-70% compared to an adjacent unvegetated region. Three seagrass sites, labeled sites 1, 2, and 3 in Fig. F23, contained *Z. marina* of varying densities of 560±70, 390±80, and 150±80 shoots m^{-2} respectively. Wave orbital velocities within the seagrass bed were reduced by 20% compared to flow above the bed, primarily acting as a low-pass filter by removing high frequency wave motion (Fig. F24). However, relatively little reduction in wave energy occurred at lower wave frequencies suggesting that longer period waves were able to effectively penetrate the seagrass meadow. Average bottom shear stresses (t_b) at the unvegetated

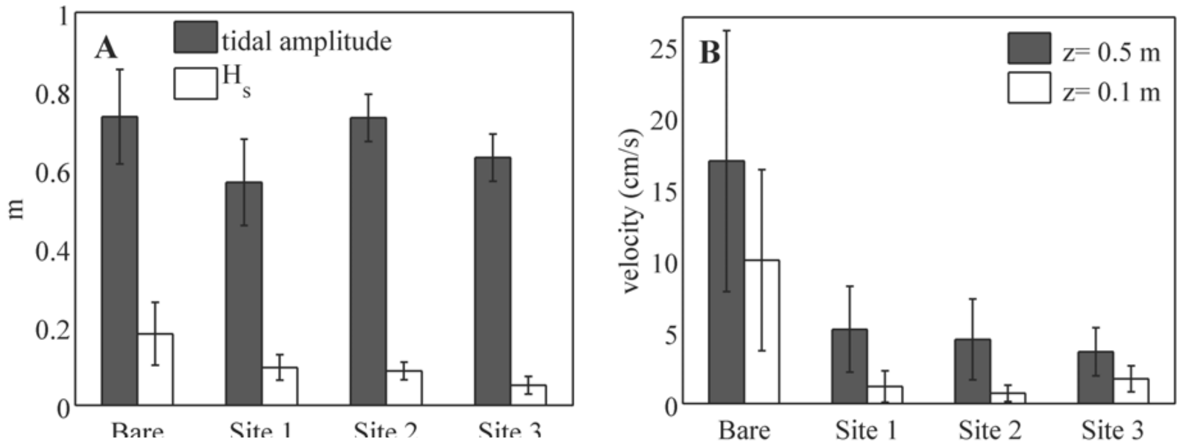


Fig. F23. (A) Average tidal amplitudes with error bars representing ±1 standard deviation. The average over all sites was 0.65 ± 0.11 m. (B) Time averaged velocity magnitude of the study sites during tidally dominate flow conditions (± 1 s.d.).

region were τ_b= 0.17±0.08 N m^{-2}, significantly larger than the critical stress threshold necessary for sediment entrainment of 0.04 N m^{-2}. Within the *Z. marina* meadow, τ_b= 0.03±0.02 N m^{-2} and stresses were below the critical stress threshold during 80% of the time period of measurement (Fig. F25). Expansion of *Z. marina* within the coastal bay has thus altered the dynamics of the seafloor from an erosional environment to one that promotes deposition of suspended sediment, enhancing light penetration throughout the water column and creating a positive feedback for seagrass growth.

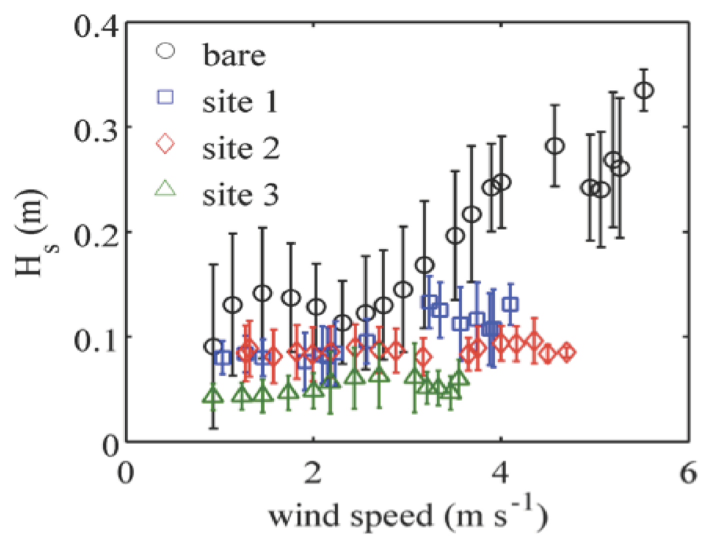


Fig. F24. Significant wave height (H_s) as a function of mean wind speed. Bars represent ±1 s.d. Estimates of H_s were computed as a running mean over a ±0.5 m s^{-1} averaging window of wind speed.

Flow dynamics and larval settlement onto intertidal oyster reefs

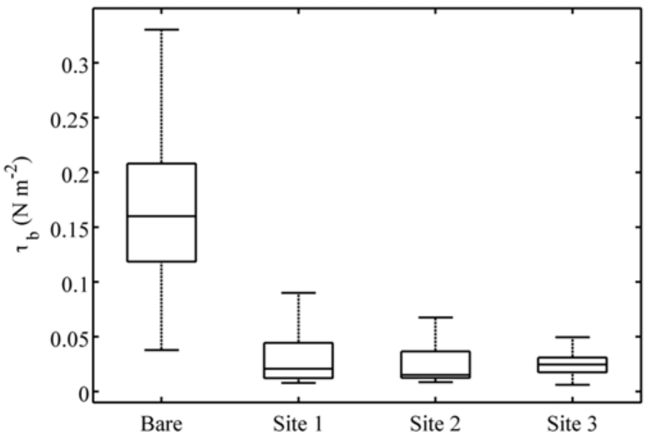


Fig. F25. Bottom shear stress (τ_b) at each site calculated as the square of the sums of the wave and current bottom stresses. Horizontal line within the box indicates median τ_b, while the lower and upper edges of the box represent the 25th and 75th percentiles respectively. Vertical lines extending from the box indicate the minimum and maximum measured τ_b.

Velocity and turbulence data were collected over multiple intertidal benthic surfaces including a healthy *Crassotrea virginica* oyster reef, two restoration sites comprised of either fossil *C. virginica* oyster shell or the relatively larger *Busycom canliculatum* whelk shell, and a mud bed, in order to determine how flows differ between sites and how benthic flow processes impact rates of larval recruitment. Mean estimates of the coefficient of drag, C_D, over a healthy reef were found to be up to 47% greater than those at restoration sites (Table 1). Enhanced shear increased both turbulent mixing and drag above the reef, but within the interstitial areas between individual oysters, mean velocities and turbulent motions were reduced. Larval settling-plates of varying benthic roughness height and spacing were deployed on the restoration sites and used to mimic variability found along the reef. The greatest larval recruitment corresponded to plates with largest height:spacing ratios (Fig. F26), and greater recruitment was found on the top half of the structure (peaks) than the bottom half (valleys) where sediment typically accumulated. Hydrodynamic drag and lift forces along the plate surfaces, measured in a recirculating water flume, decreased with increasing height:spacing ratios. Regions of high larval recruitment closely matched regions of low lift and drag forces. These results suggest that restoration efforts should consider both vertical elevation and the complex 3-dimensional topography of benthic substrates, similar to those found on healthy oyster reefs, to provide suitable hydrodynamic conditions that promote larval recruitment, prevent burial by sediment, and provide refuge from predation.

Table 1. Mean velocities and drag parameters calculated for the study sites. *U* is the velocity at *z*= 0.4 m, and elevations are relative to the mud site.

Location	Elevation (cm)	U (cm s^{-1})	u_* (cm s^{-1})	z_0 (cm)	C_D
C. virginica reef	0	11.3	1.9	1.7	0.017±.007
Whelk site	-31	16.3	1.8	1.5	0.013±.005
Oyster site	-1	9.6	0.9	0.4	0.009±.001
Mud site	-37	17.9	1.1	0.3	0.004±.001

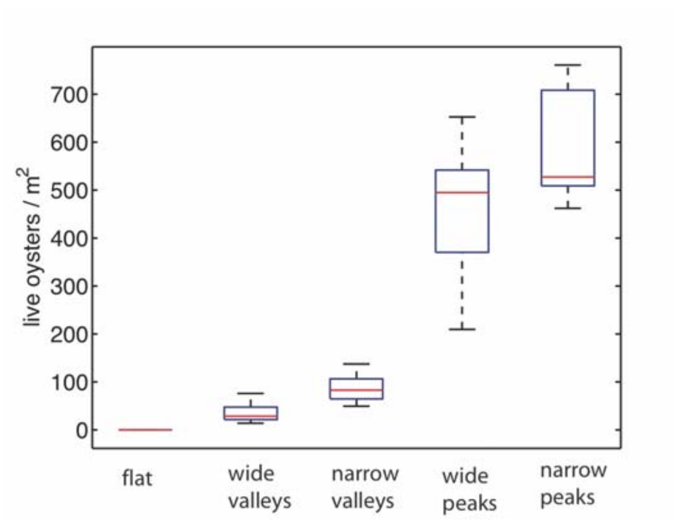


Fig. F26. Recruitment of juvenile oysters on settlement plates. Horizontal line within the box indicates median live oysters m^{-2}, while the lower and upper edges of the box represent the 25th and 75th percentiles respectively. Vertical lines extending from the box indicate the minimum and maximum measured live oysters m^{-2} of 5 replicates. The peaks of structures (upper half of roughness elements) with narrowly spaced peaks had the greatest recruitment and the valleys of structures (lower half of roughness elements) with widely spaced peaks had the least recruitment. No recruitment was found on the flat tiles.

Trophic dynamics in clam aquaculture beds

Stable isotope studies of the organic matter sources (benthic microalgae, macroalgae, seagrass, marsh grass, and terrestrial material) that provide support to aquacultured hard clams (*Mercenaria mercenaria*) in the VCR indicate significant distinctions among source materials in their isotopic composition. Deuterium is a useful isotope for separating sources and serving a tracer of clam resources in the VCR. Because we are considering multiple sources and multiple isotopes, we are applying a Bayesian mixing model (Fig. F27) that formally incorporates uncertainty as well as other commonly used mixing models that can potentially explain clam isotopic composition. Initial application of the Bayesian model indicates that clams rely largely on benthic microalgae and to a lesser extent on macroalgae (Fig. F27). Benthic microalgae are largely made available to these filter feeders via resuspension due to wind and turbulence. Hence, we hypothesize that resuspension is an important process supporting aquaculture in the VCR.

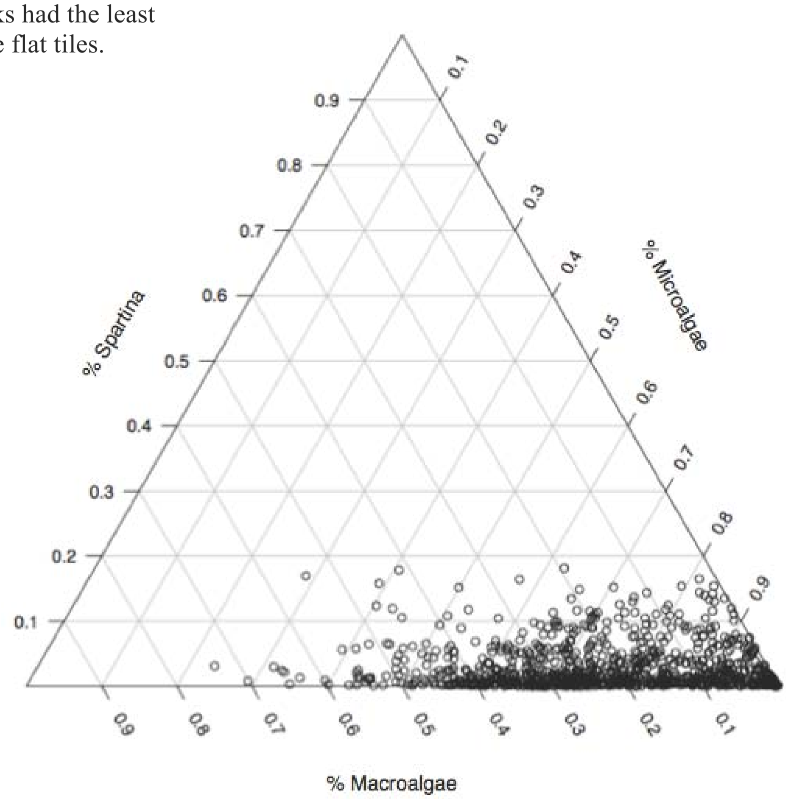


Fig. F27. Results of Bayesian model runs for the contribution of three sources to clams. Each point represents a solution to the model that incorporates variability in sources, water use, and trophic fractionation. Note the importance of microalgae in all runs.

Intertidal Marshes and Mudflats

Mechanisms of marsh erosion

Marsh boundary erosion: Measurements taken since summer 2007 reveal that the marsh boundary is retreating at a rate of approximately 0.5 – 1.5 m per year in 3 of 4 field sites studied in Hog Island Bay (Table 2). Boundary retreat for each site is reported in terms of mean cumulative erosion (m) and the estimated retreat rate (m/yr) derived from pin measurements, boundary surveys, and aerial photos. Estimates from erosion pins may underestimate the erosion while the boundary surveys and photos may overestimate the erosion, since the boundary was defined where vegetation was present, which will often recede much faster than the boundary of the scarp; therefore, we also report the average retreat rate derived from the three methods. Overall, the shoreline along Upshur Neck eroded the fasted, averaging 1.52 m/yr followed by Chimney Pole (1.09 m/yr) and Hog Island (0.69 m/yr).

Table 2. Marsh boundary retreat at three sites within the VCR

	Upshur Neck			*Chimney Pole*			*Hog Island*		
Method	*Cumulative (m)*	*Duration days*	*Rate (m/yr)*	*Cumulative (m)*	*Duration days*	*Rate (m/yr)*	*Cumulative (m)*	*Duration days*	*Rate (m/yr)*
Pins	1.68	825	0.74	1.87	958	0.71	0.85	958	0.32
Survey	3.71	705	1.92	2.71	705	1.4	1.77	705	0.91
Photos	13.24	2557	1.89	8.18	2557	1.17	5.98	2557	0.85
Average			**1.52**			**1.09**			**0.69**

The action of waves on the marsh boundary produces a series of alongshore undulations previously described as wave-cut gullies, and the rate at which the marsh boundary recedes, may therefore be a function of shoreline sinuosity. To test this hypothesis, shoreline surveys at each location were divided into either 5 or 6 sections roughly 20 m in length, and the erosion for each was estimated between the first and last surveys (May 2008 – April 2010). The cumulative retreat was then correlated with respect to the sinuosity of the initial (May 2008) survey.

The cumulative erosion for each site is plotted as a function of sinuosity in Fig. F28. There is a high degree of correlation between the total distance the marsh retreated and the sinuosity of the initial survey. With the exception of one outlying point in the Upshur Neck data, the greater the sinuosity the more the marsh boundary retreated. The strengths of the relationships are reported as r-values in Table 2, and with the exception of Upshur Neck, are statistically significant at the 95% confidence interval.

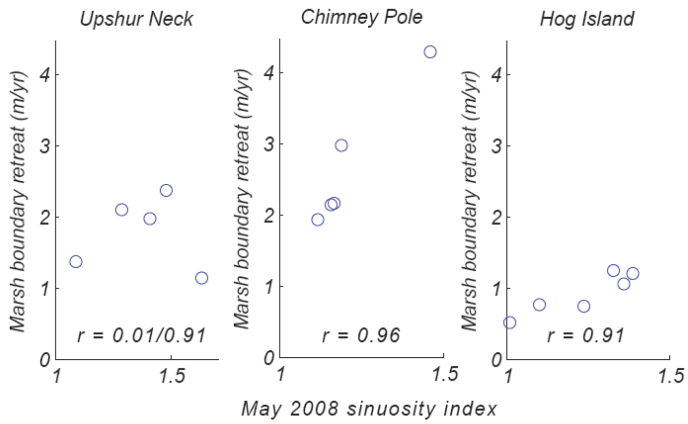


Fig. F28. Marsh boundary erosion as a function of sinuosity

Marsh boundary retreat and wave energy: The total amount of work done (cumulative wave energy) at each site for each measurement period is shown in Fig. F29a, and it was derived from numerical simulations of wave formation and propagation with the model VENICE. In Fig. F29b we present the relationship between the work done and average cumulative erosion. Intriguingly, while the model determined that the Hog Island site received the greatest cumulative wave energy, this did not translate into predicting the greatest amount of erosion. Instead, Chimney Pole, which received only 40 % of the wave energy that Hog Island received, eroded at a rate nearly double that of Hog Island. This seemingly inverse relationship may be explained by local factors such as differences in sediment composition, belowground biomass, organic content, the extent and magnitude of burrowing crabs and differences in marsh elevation. Based on the work of Tonelli et al. (2010), marsh elevation may exert particular control over erosion rates by regulating the force of wave impact based on changing water levels; i.e., a water level greater than the marsh elevation quickly attenuates the force of wave impact on the scarp.

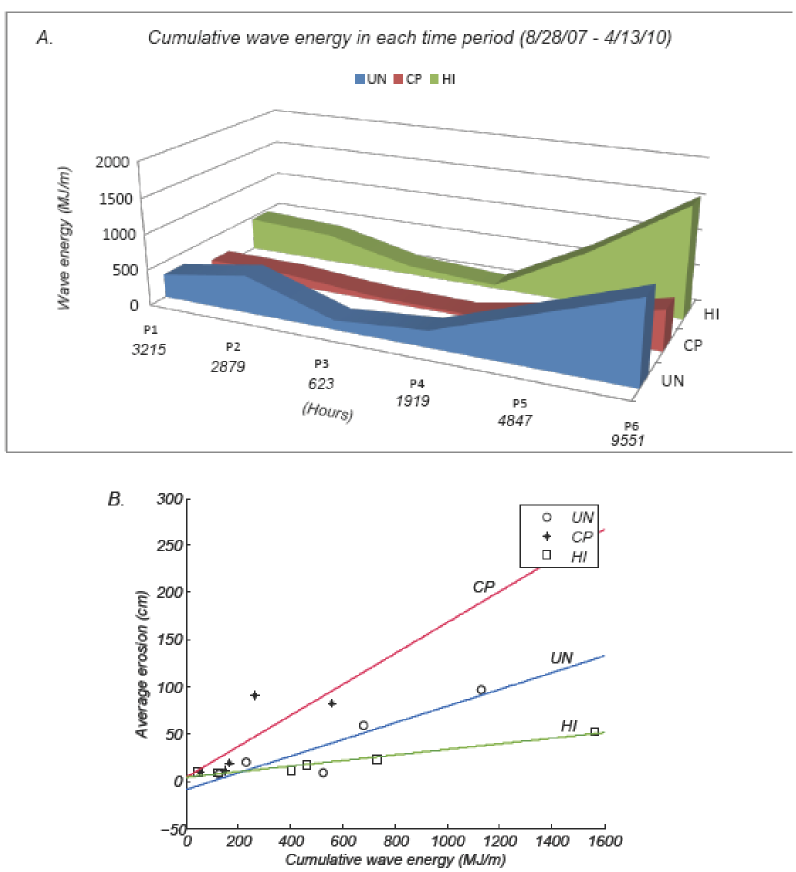


Fig. F29. A. Cumulative wave energy for each site. B. relationship between the work done and average cumulative erosion

Erosion rates derived from aerial photography**:** The average erosion rate derived from aerial photography along 32 sites of Hog Island Bay over a seven year period (2002-2009) was 1.47 ± 1.03 m/yr with 75 % of the values distributed between 1.0 and 2.0 m/yr; only 12 % of the values exceeded 2.5 m/yr (Fig. F30). Upshur Neck had the highest average retreat rate at 1.89 m/yr followed by Chimney Pole (1.17 m/yr) and Hog Island (0.85 m/yr).

Using our calibrated model results, we suggest that marsh boundary retreat is a linear function of the duration and magnitude of wave impact, or total wave power. The linear regression equation predicts that an average wave power of 12 W/m gives rise to an erosion rate of 1.52 m/yr, equivalent to

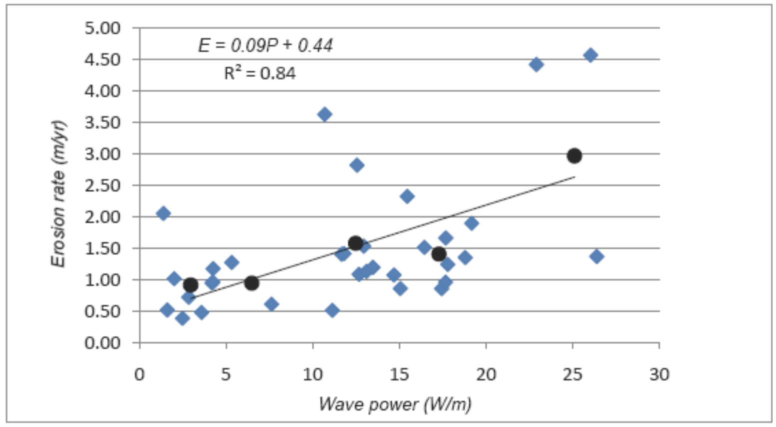


Fig. F30. Erosion rate measured from aerial photographs at 32 sites as a function of wave power measured with the model Venice

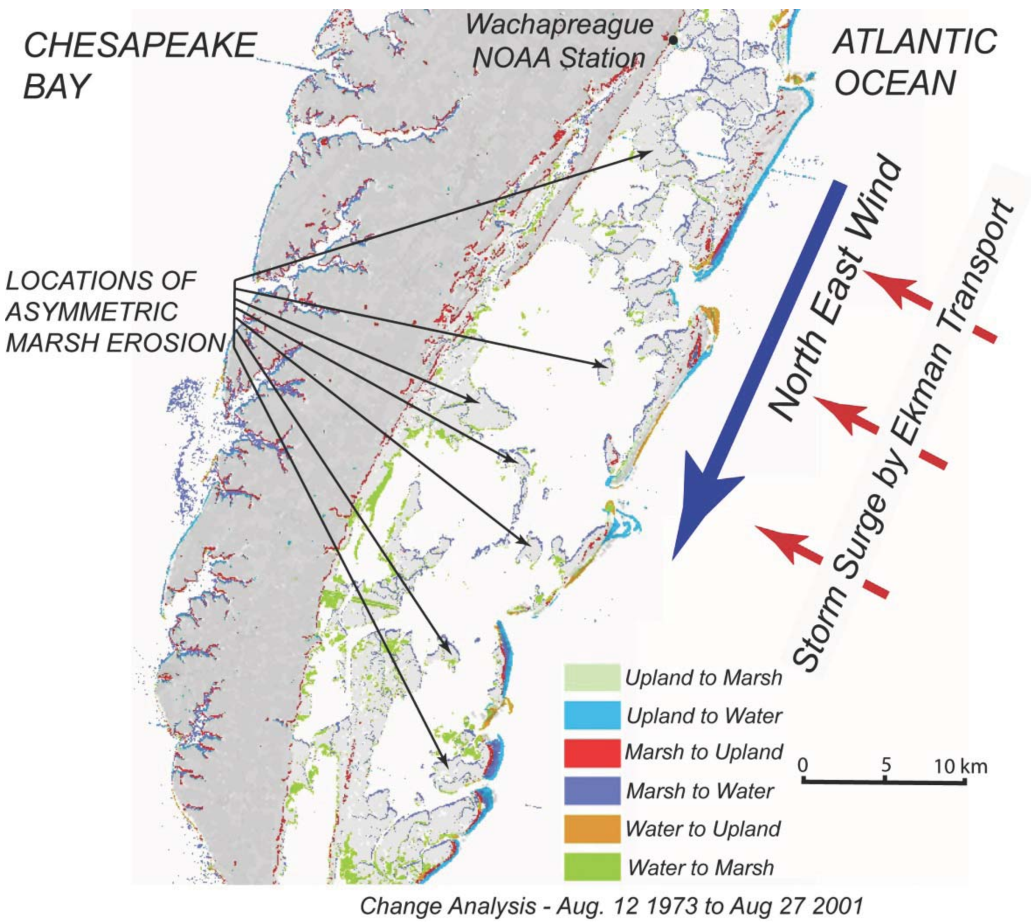


Fig. F31. Intense winds from the northeast often produce storm surges within the VCR. The figure also displays land change in the VCR from Aug 12 1973 to Aug 27 2001. The boundary migration was calculated comparing two Landsat classified images (NOAA Coastal-Change Analysis Program C-CAP). At several locations the salt marshes oriented toward northeast eroded whereas those oriented toward southwest accreted. This asymmetric marsh erosion is particularly evident in the marsh islands in the middle of the bays that can be attacked by waves from all directions.

the average erosion rate estimated at Upshur Neck (Table 2). The high degree of variability is most likely due to a combination of factors such as sediment composition, marsh elevation, and the extent of burrowing crabs at each site.

<u>Wave energy asymmetry in shallow bays</u>: Storm surges along the coastline of the United States are often driven by alongshore winds triggering cross-shore Ekman transport. We showed that this mechanism creates ideal conditions for large wave events in the shallow bays characterizing the VCR (Fig. F31). A positive feedback enhances wave formation during along-shore wind events, affecting the spatial distribution of waves and wave-forced erosion in shallow bays at a continental scale (see Fagherazzi et al. 2010).

<u>Morphology and hydrodynamics of wave-cut gullies</u>: Wave-cut gullies are sub-triangular incisions common along deteriorating marsh scarps. Wave gullies may be equi-spaced to quasi-equi-spaced and enlarge in time, incising the marsh boundary. A high-resolution survey was provided for ten wave gullies (Fig. F32). The measurements capture the morphologic character, evolution, and erosion rates of wave-cut gullies over a two-month period. The data relate changes in morphology to geometric factors and shoreline retreat. Finally, the first analysis of wave data measured by acoustic Doppler velocity profilers was presented to show how propagating waves are

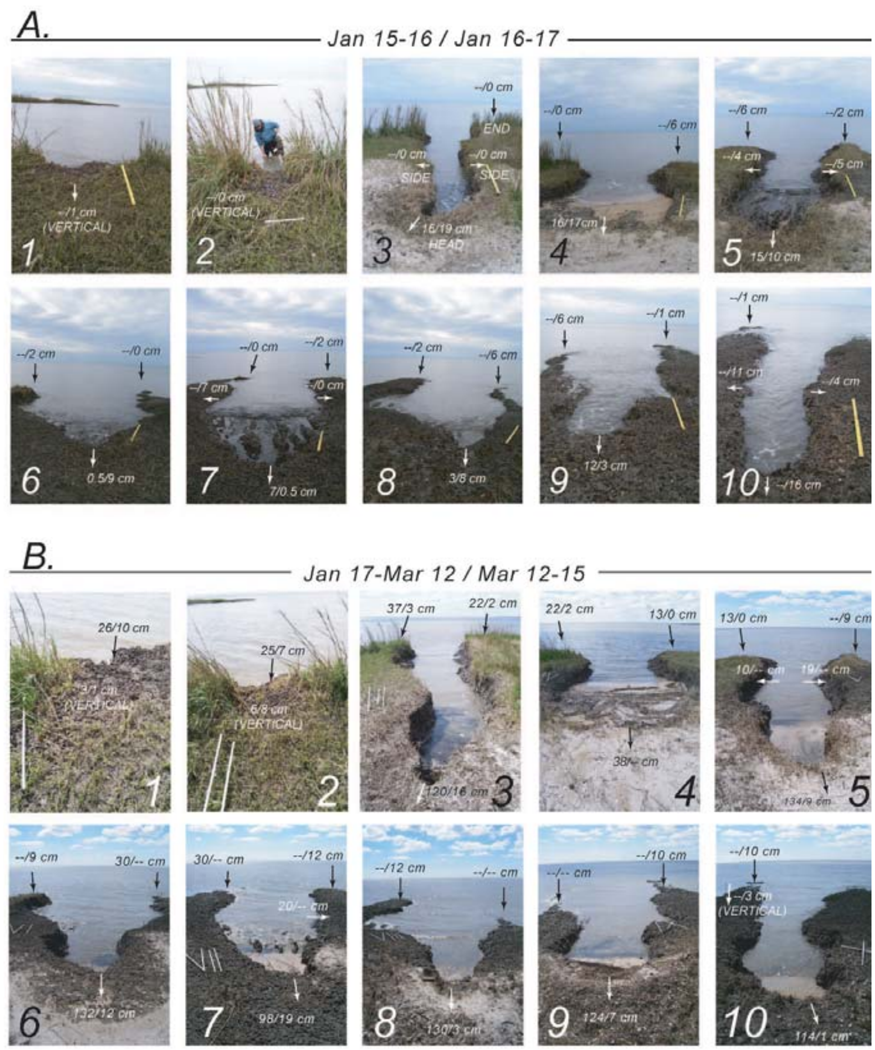


Fig. F32. Morphology of ten wave gullies and related erosion rates. The gullies are numbered from East to West reflecting increase in age. The two photo sets were taken on January 15 2008 (a) and on March 13 2008 (b). Erosion rates measured with erosion pins are also reported, and refer to four different periods, two per figure: (a) 01/15/08 to 01/16/08 (left number) 01/16/08 to 01/17/08 (right number); (a) 01/17/08 to 03/12/08 (left number) 03/12/08 to 03/15/08 (right number). The double dash indicates when the erosion pin went missing.

transformed inside a wave-cut gully in order to describe the processes leading to their formation. Results show that waves of intermediate period (4–6 s) yield very strong swash currents that hit the gully head, detaching marsh substrate and triggering headward erosion. A conceptual model of wave gully evolution was presented as an explanation for this non-uniform, episodic shoreline erosion (see Priestas and Fagherazzi 2011).

Changes in boundaries of mainland marshes

Long-term changes: Aerial photographs were used to measure long-term changes along the marsh shorelines at 10 selected sites in the VCR. Photographs were obtained for 1957, 1966, 1989, 2002, and 2009. There was considerable spatial variation in rates-of-change within individual sites (Fig. F33). No spatial trends were evident between the sites in the rates-of-change; however, the majority of the sites experienced erosion. Erosion rates varied an order of magnitude from ~0.1 to 1.0 m per year (Fig. F34; Tables 3-4). The high standard deviations indicate that there was high variability in the rates-of-change at several sites.

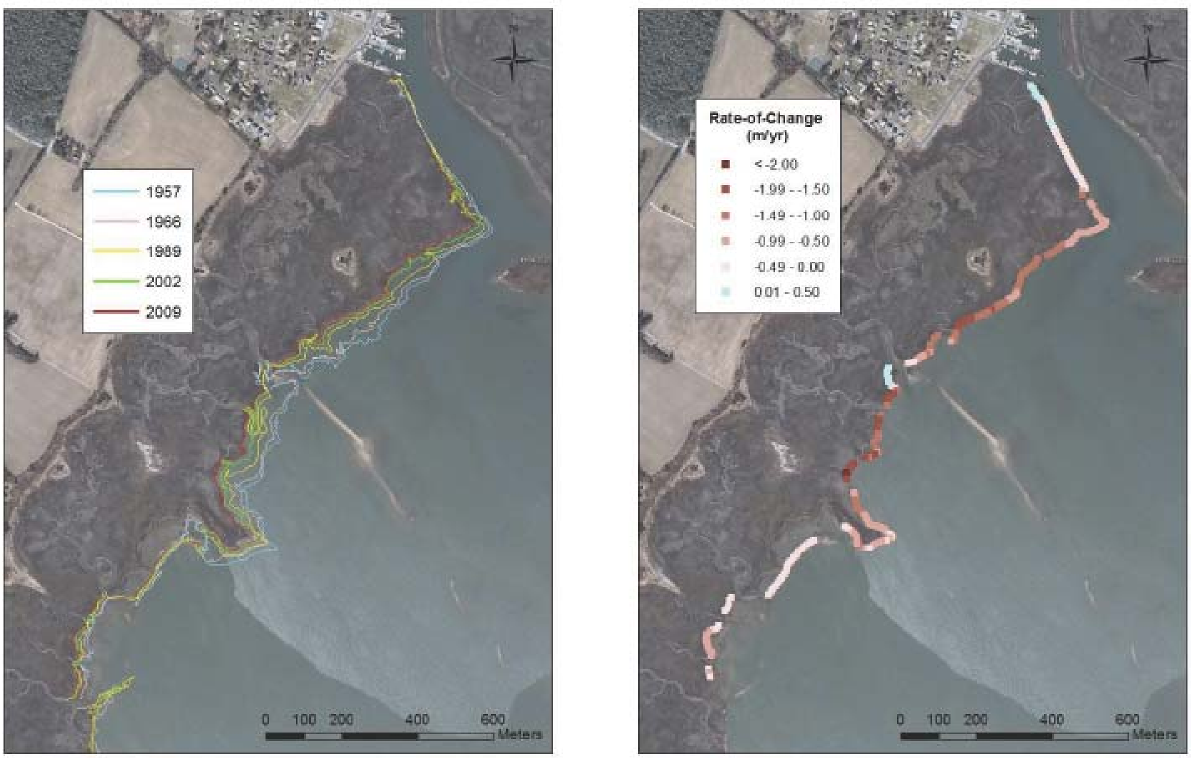


Fig. F33. Rates of shoreline change for Wachapreague, VA, as an example of the intrasite variation, which at some sites was of similar magnitude as the variation between sites in the VCR.

Short-term changes: Changes along mainland marsh shorelines between 2002 and 2009 were calculated for the entire length of the VCR. The same methods used to examine long-term trends at the ten study sites were employed for this broader analysis. However, only photographs from the two most recent years were used. Results show that there was a mean rate of erosion of -0.2 m/yr at mainland marshes along the entire length of the VCR. This does not necessarily indicate a net loss in salt marshes in the VCR, as it does not include lagoonal marshes or marshland gained through transgression. It does, however, show that marsh shorelines along mainland marshes have experienced greater amounts of erosion than progradation over the length of the peninsula. There were no significant spatial trends in rates-of-change between the northern and southern parts of the peninsula nor was there a clear correlation between rates and the size of the adjacent bays.

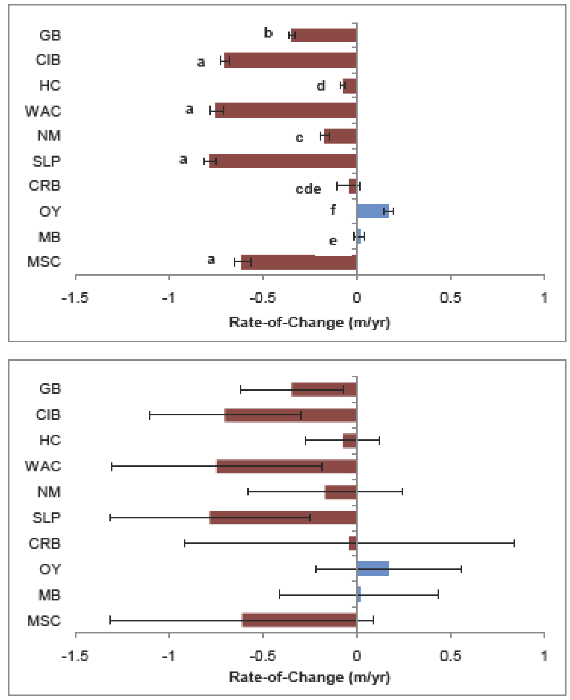


Fig. F34. Mean annual rates of change for 10 mainland marshes in the VCR 1957 – 2009. Error bars indicated standard error (top) and standard deviation (bottom).

Land coverage was analyzed using the 2005-era land cover data generated by NOAA's Coastal Change Analysis Program to identify potential areas for marsh transgression. In ArcGIS, the data was reclassified into twelve classifications, from the original twenty-two, based on similarities in land type. The land-use types that were thought to be most suitable for marsh transgression to occur were estuarine forested and shrub wetlands, palustrine wetlands, scrubs and shrubs, and forests. Although marsh transgression is capable of occurring over cultivated land or pastures (collectively grouped as agricultural land), it was theorized that farmers or landowners are likely to take preventative actions to halt transgression at the loss of valuable agricultural property. Therefore, these land types were not considered suitable locations for transgression in this analysis. Fig. F35 shows the distribution of the potential 34,632 ha area where transgression could occur in the VCR.

Table 3. Mean rates of marsh shoreline change, 1957-2009.

Marsh Site	Mean Change (m/yr)	Standard Error	Standard Deviation
Gargathy Bay	-0.35	0.02	0.28
Cedar Island Bay	-0.70	0.02	0.41
Hummock Cove	-0.07	0.01	0.20
Wachapreague	-0.75	0.04	0.56
North Matulakin	-0.17	0.03	0.41
Short and Long Prong	-0.78	0.03	0.53
Crabbing	-0.04	0.06	0.88
Oyster	0.17	0.03	0.39
Mockhorn	0.01	0.03	0.42
Marion Scott Cove	-0.61	0.04	0.70

Table 4. Variation in rates of change of mainland marsh shorelines between successive data sets.

Marsh Site	Rate-of-Change (m/yr)			
	1957-1966	1966-1989	1989-2002	2002-2009
Gargathy Bay	-0.3	-0.3	-0.3	-0.4
Cedar Island Bay	-0.7	-0.8	-0.7	-0.6
Hummock Cove	0.1*	-0.1*	-0.1	-0.1
Wachapreague	-0.7	-0.7	-0.8	-0.9
North Matulakin	0.1	-0.4	0.1	-0.1
Oyster	0.4	0.3	-0.3	0.4
Marion Scott Cove	-0.6	-0.4	-0.9	-0.8

* Photograph taken in 1967

Marsh Site	Rate-of-Change (m/yr)		
	1957-1989	1989-2002	2002-2009
Short & Long Prong	-0.4	-1.8	-1.0
Crabbing	0.1	-0.3	-0.2
Mockhorn Bay	-0.1	0.1	0.7

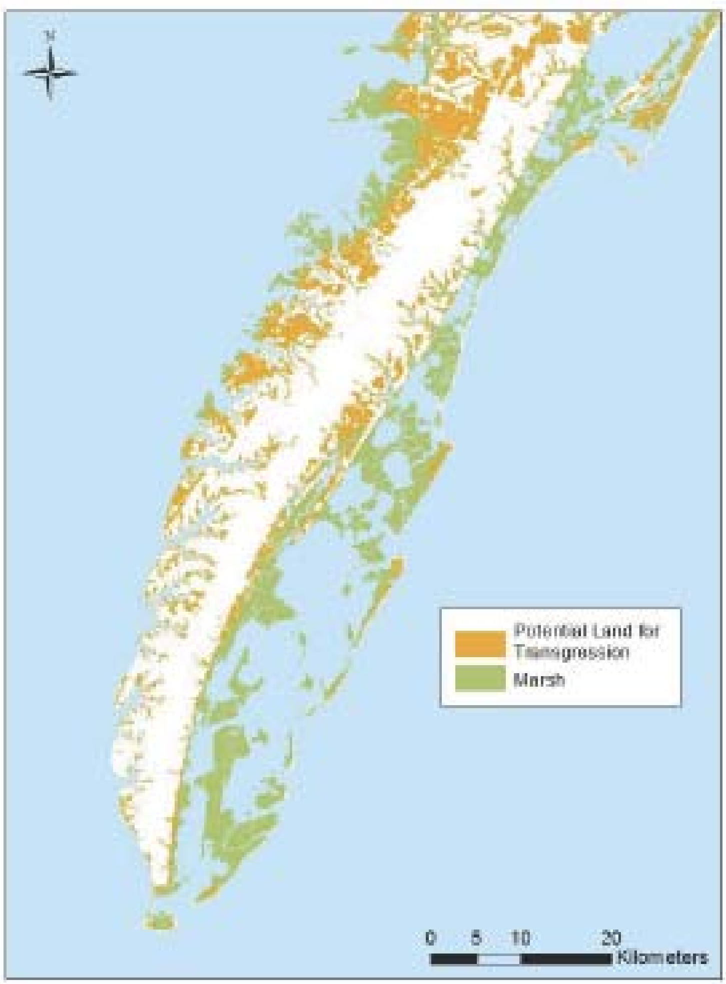


Fig. F35. Potential land area for marsh transgression on the Delmarva Peninsula.

Marsh productivity and relative sea-level rise

The salt marshes of the VCR have a relatively large range of elevations, with most mainland marshes being high in the tidal range and infrequently flooded, and back-barrier island and marshes being low in the tidal frame. Production rates in higher elevation marshes have a more muted response to inundation frequency than those at lower elevations (Fig. F36).

Aboveground primary production of marsh plants shows a dose response to N additions. This occurs in both the low and high marsh, although belowground productivity responses are less evident. Both above- and below-ground plant tissues were enriched in nitrogen in proportion to the amount of fertilizer the plants received (Fig. F37) suggesting the potential for faster decomposition of the N-enriched plant litter and an impact on the marsh surface elevation.

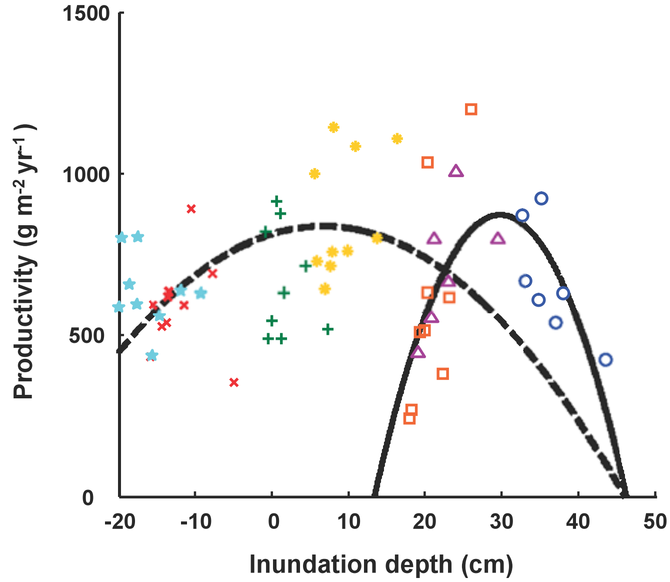


Fig. F36. Interannual production at each site as a function of inundation depth at mean high tide (related to elevation). Solid, narrow parabola refers to the best fit through the mid intertidal, high slope marshes (open markers) (r=.641, p=.001). Dashed, broad parabola indicates the best fit through the high intertidal, low slope marshes (solid markers) (r=.317, p=.034). Marsh identity as follows: red x = GATR; orange square = Indiantown; gold sunburst = Oyster; green plus sign = Phillips Creek; purple diamond = North Hog; blue circle = South Hog; and cyan star = Steelman's.

Trophic interactions – environmental impacts of marsh change on waterbirds

A 2-year study was completed investigating the pervasiveness of methylmercury (MeHg) in the Virginia barrier island complex and the bioaccumulation risk to fish-eating waterbirds nesting in the Hog Island and Chincoteague Bays. The study focused on two species of waterbirds: Glossy Ibis (*Plegadis falcinellus*) and Double-crested Cormorants (*Phalacrocorax auritus*), which represented opposite ends of a foraging habitat-use spectrum.

Feather MeHg concentrations were higher in 2009 than 2010 for both species (Fig. F38). Findings indicate that, in both years of the study and for both species,

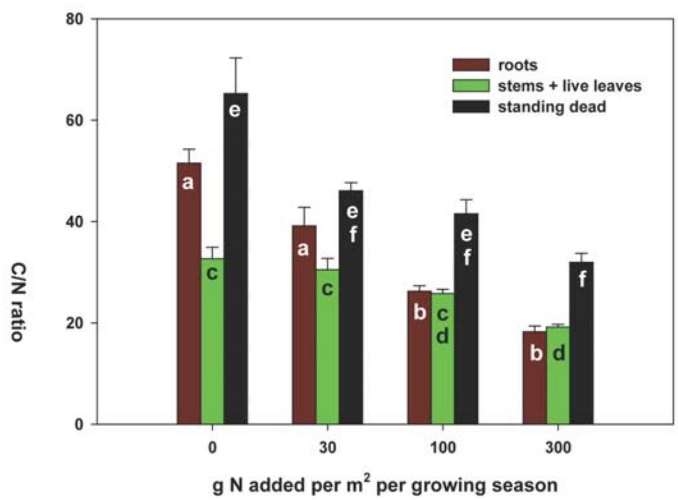


Fig. F37. Carbon-to-nitrogen ratio of roots (brown bars), live aboveground foliage and stems (green bars), and standing dead foliage (black bars) as a function of four fertilization levels (0, 30, 100, 300 g N m^{-2}) for n = 3. Error bars are one standard error. Letters within similar colored bars indicate significant differences at a = 0.05 based on a one-way ANOVA analysis and Tukey's posthoc test.

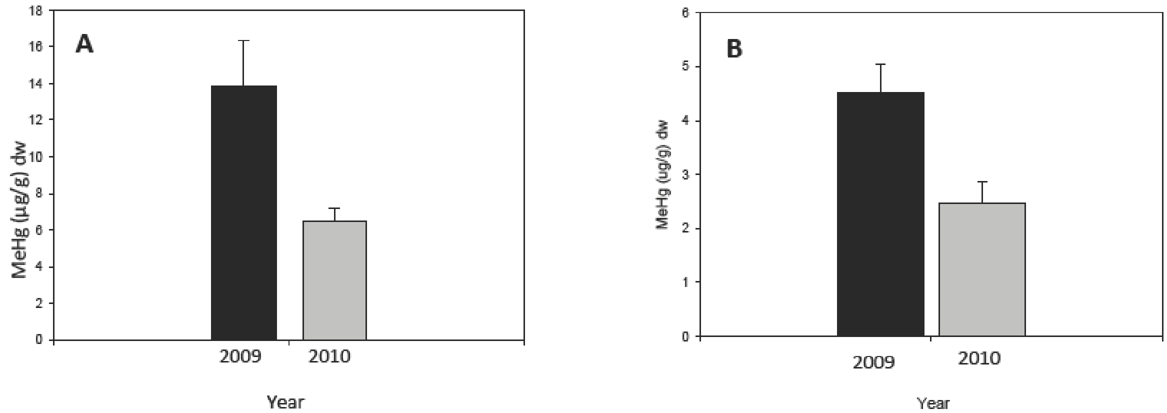


Fig. F38. Methylmercury (MeHg) concentration in: A) Double-crested Cormorant (*Phalacrocorax auritus*) and, B) Glossy Ibis (*Plegadis falcinellus*) chick feathers from the 2009 and 2010 breeding seasons.

developing chicks that experience higher accumulation of MeHg through diet tend to develop their juvenile flight feathers slower (Fig. F39). An information-theoretic approach was used to determine that the average growth rate of a feather can be used to predict the MeHg content a developing chick experiences through diet (AIC Parameter Likelihood: 0.77).

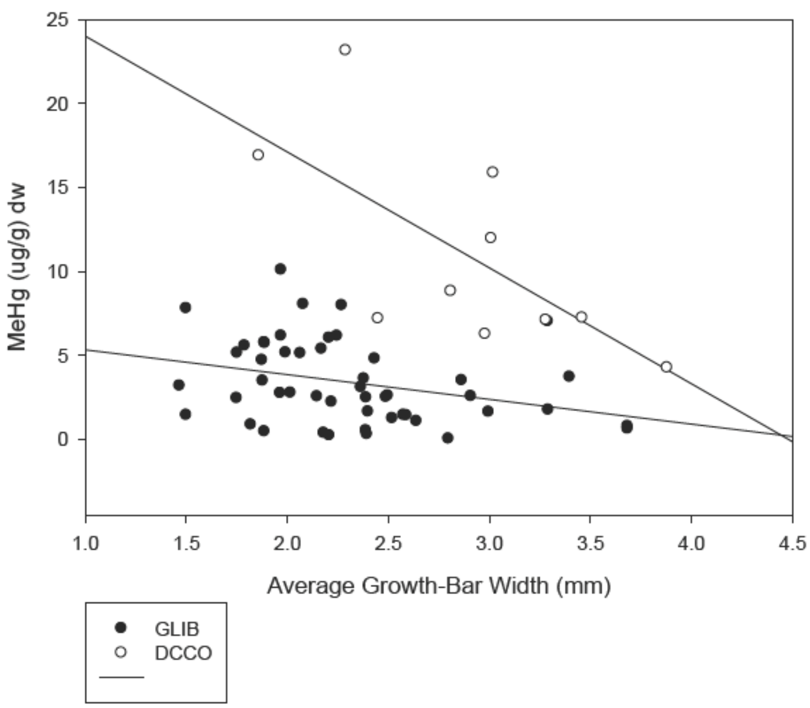


Fig. F39. Average feather Growth-bar width and MeHg concentration in Glossy Ibis (*Plegadis falcinellus*, GLIB) ($P < 0.05$, $R^2 = 0.10$) and Double-crested Cormorant (*Phalacrocorax auritus*, DCCO) ($P < 0.05$, $R^2 = 0.46$) chick feathers.

Invasive species

Data from the past 15 years show that the density of the invasive macroalgae *Gracilariea vermiculophylla* has greatly increased on mudflats (Fig. F40), and that it is prevalent in regions of the marsh where other macroalgal species are susceptible to temperature and dessication stresses (Fig. F41). These macroalgal accumulations can have a negative upward cascading effects on shorebird foraging. Although potential prey (amphipods) were most abundant in high-density macroalgal mats, shorebirds preferred to feed in low-density mats (Fig. F42). Shorebirds may choose to avoid high-density patches because of their inability to reach prey within the mats or because they can become entangled in the algal thalli. Macroalgae accumulations can also have a positive effect, up to a point, by subsidizing mudflat food webs. Based in 15N levels in experiments where labeled algae were added to mudflats and salt marshes, we concluded that on the marsh, sediment and the cordgrass *Spartina alterniflora* absorbed *G. vermiculophylla* nitrogen, but snails (primarily *Littorina littorea*) did not (Fig. F43). Mudflat results show that sediment, amphipods, snails (primarily *Ilyanassa obsoleta*), and a tube decorating polycheate *Diopatra cuprea* absorbed *G. vermiculophylla* nitrogen (Fig. F44). *G. vermiculophylla* can release nitrogen during both growth and decomposition. This nitrogen can then be utilized by benthic microalgae and in turn eaten by marsh and mudflat invertebrates.

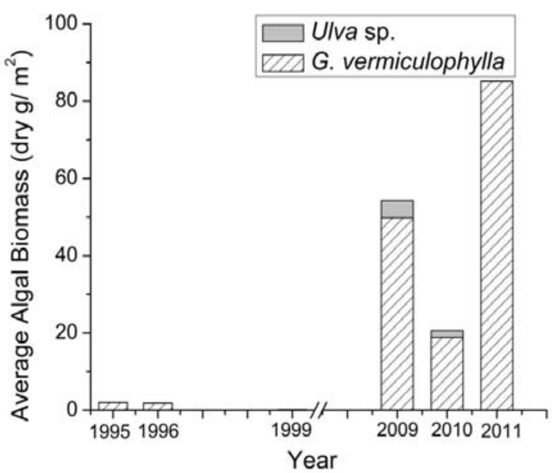


Fig. F40. *Gracilaria vermiculophylla* biomass on Virginia coastal bay mudflats. Data reported for 1995, 1996, 1999, 2009, 2010, and 2011.

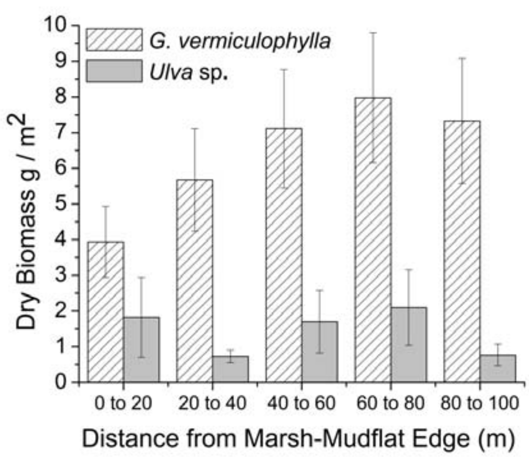


Fig. F41. *G. vermiculophylla* is able to proliferate in areas where other macroalgae cannot on Virginia coastal bay

Littorina littorea did not eat benthic microalgae as readily as *Ilyanassa obsoleta*, so it makes sense that their ^{15}N levels would not indicate use of *G. vermiculophylla* nitrogen. We are currently using natural abundance isotopes to further explain *G. vermiculophylla* nitrogen subsidies.

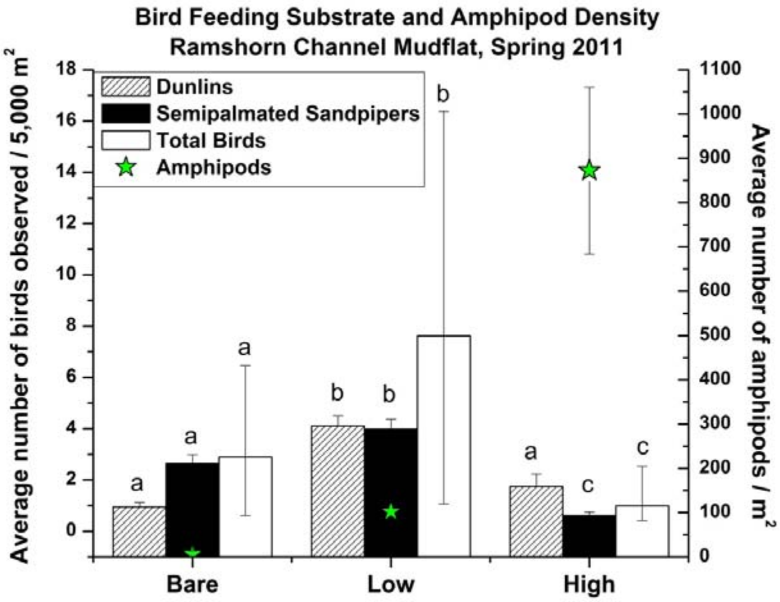


Fig. F42. Shorebird feeding substrate and invertebrate biomass.

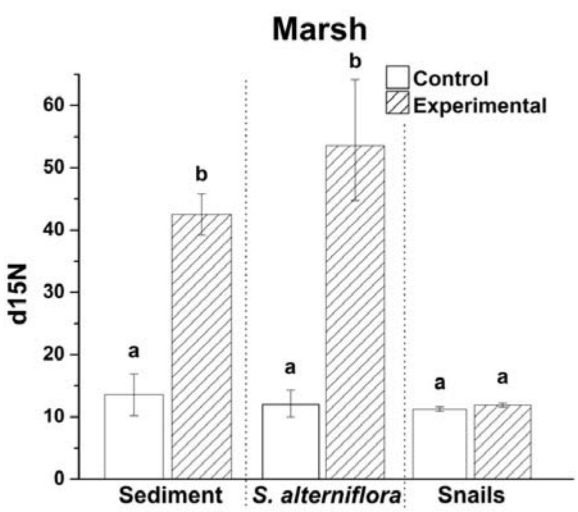


Fig. F43. Trophic transfer of 15N in marsh enrichment experiment.

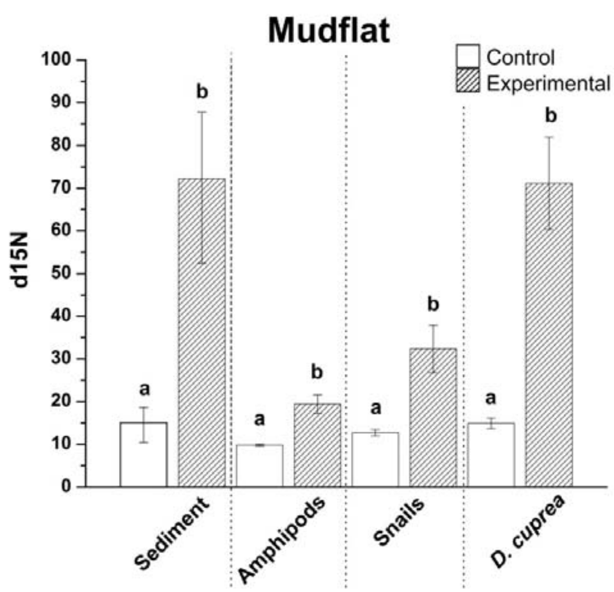


Fig. F44. Trophic transfer of 15N in mudflat enrichment experiment.

Barrier Islands

Vegetation dynamics

Changes in the *Morella cerifera* photosynthesis rates, chlorophyll content and N content as a function of leaf age were determined to assess variation in productivity across the VCR landscape where it is the dominant shrub species. *M. cerifera* is an evergreen N-fixer via a symbiotic association with the actinomycete *Frankia*. Regardless of position on the VCR landscape, we determined that leaf development varies throughout the spring and summer months, depending on temperature and available moisture. Leaf pigmentation and photosynthetic rate vary throughout the year in response to light and temperature. Further, as light becomes limiting along growing branches leaves are dropped. Thus, whole shrub photosynthesis remains at a high efficiency throughout the year. These characteristics may enhance the success of *M. cerifera* on barrier islands.

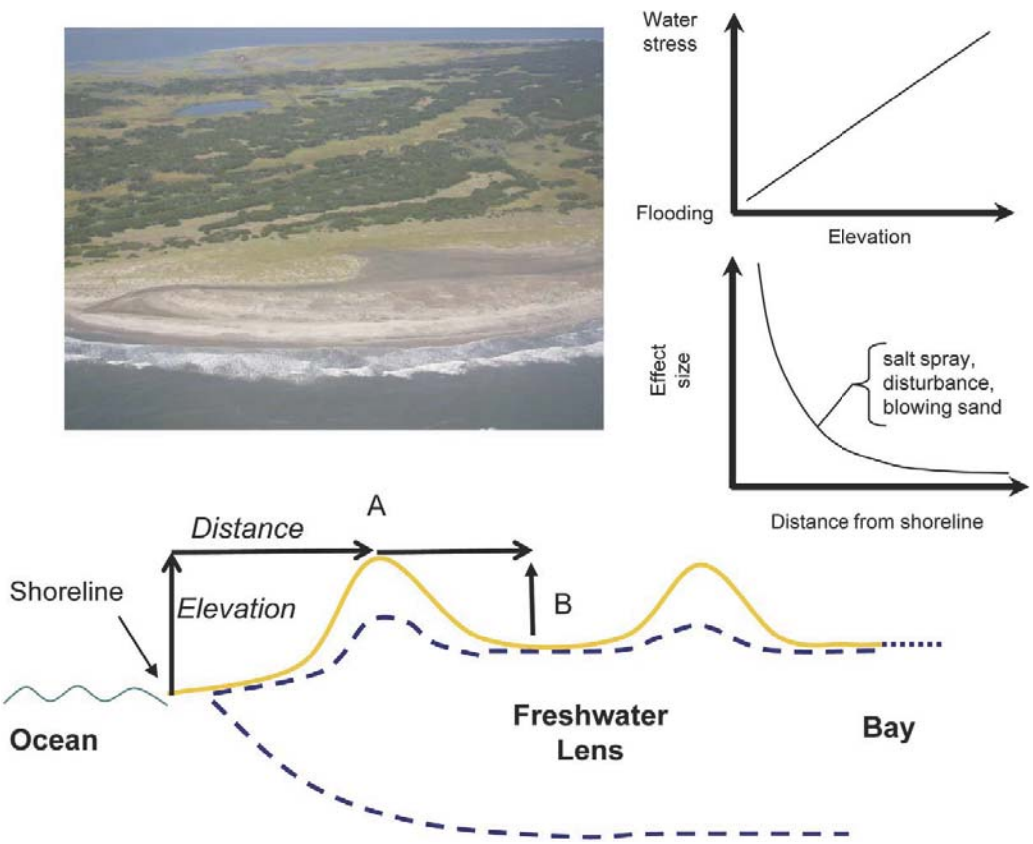


Fig. F45. Conceptual model of the importance of landscape position on barrier island vegetation highlights distance from the ocean and elevation above sea level as main determinants of species distribution patterns.

Our understanding of the importance of landscape position on barrier islands has culminated in the development of a concept paper that explains the importance of distance from the ocean and elevation above sea level as the key components of landscape position (Figs. F44, F45). Further, a collection of landscape positions for a species can be considered as a habitat polygon. These may represent functional groups and can be used to determine vulnerability to shoreline migration associated with climate change. In addition, our work highlights the dynamic nature of landscape position in coastal environments.

In an effort to synthesis our past work with existing hyperspectral imagery and Light Detection and Ranging (LiDAR) data, we examined island-scale conversion of land (i.e. sand to grassland to woody cover) while relating the importance of climate variables on rate of woody expansion (Fig F46). LiDAR was used to

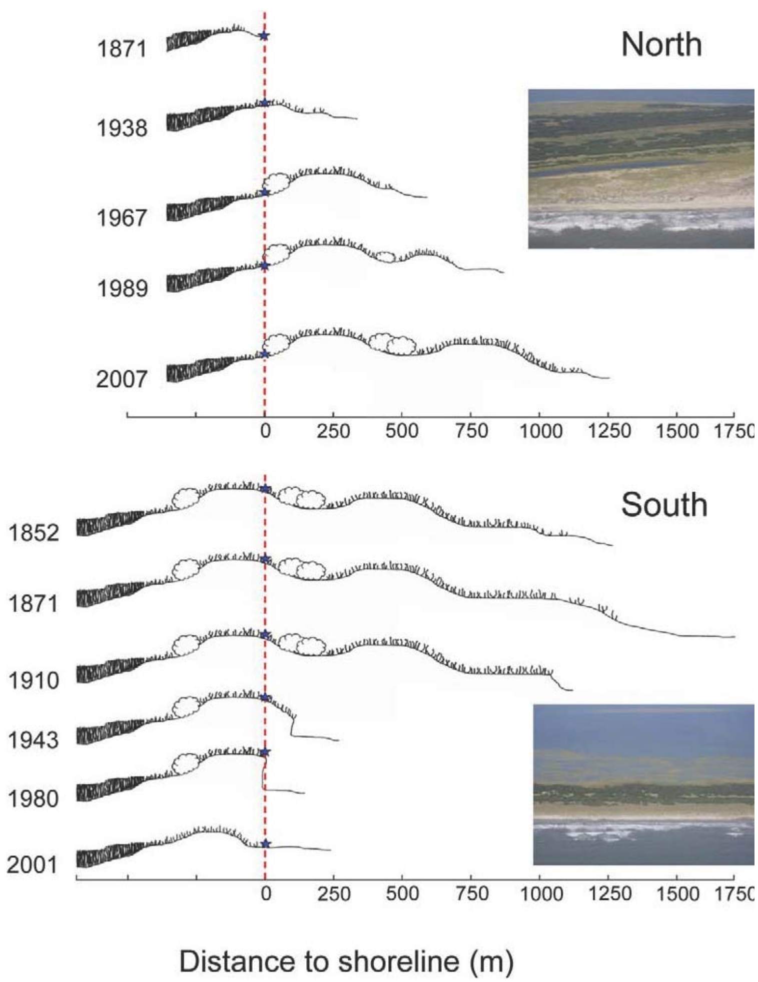


Fig. F45. Changes is vegetation with distance from shoreline as revegetation occurs following overwash on the barrier island.

evaluate potential distribution of woody species based on distance to shoreline and elevation. Using Landsat TM imagery, we monitored changes in island size and vegetation classes (1984 – 2010). These comparisons revealed conversion of grassland to woody cover (285% increase) was closely linked to air temperature, precipitation, and atmospheric [CO_2]. LiDAR data indicated that woody species have not expanded completely into the potential range. Our results suggest that woody species are responsive to climate change, thus serving as sentinels on Virginia barrier islands (Fig. F47).

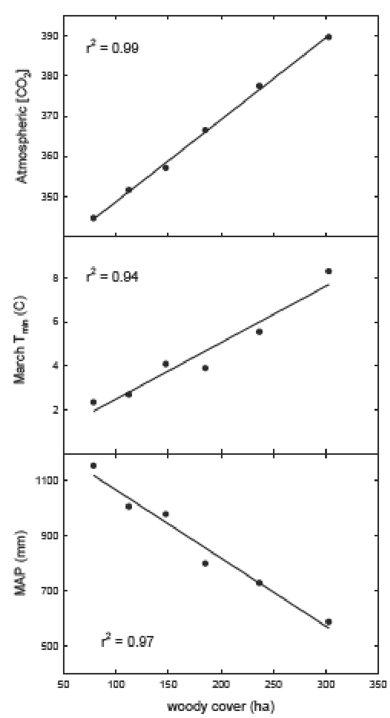
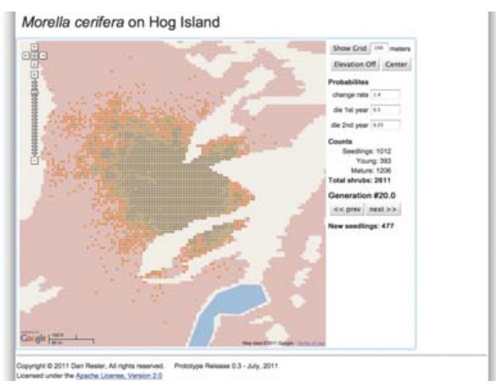
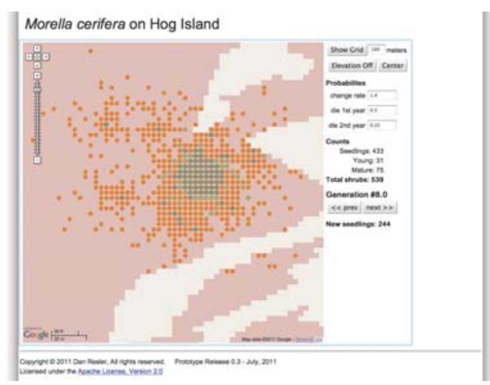


Fig. F46. Woody plant expansion as a function of climate change variables.

Fig. F47. Conversion of grassland to woody coverage (red) based on Landsat TM Imagery show an increase in shrub vegetation of 285% from 1984 – 2010.

We also continue to develop our cellular automata model to simulate shrub expansion on barrier islands, with a goal of predicting shrub response to climate change induced shoreline migration (Fig. F48).





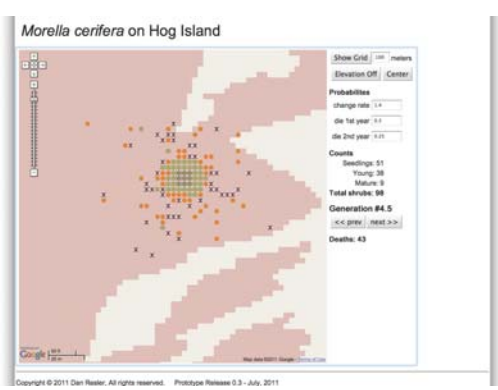


Fig. F48. Results of cellular automata model simulating *Morella cerifera* expansion on Hog Island.

Landscape genetic analyses of mammal movement

Genetic analyses were used to indirectly assess the movement of raccoons on the VCR barrier islands. Preliminary analyses indicate that most raccoons on two northern islands (Cedar and Metompkin) dispersed from the mainland, rather than from nearby Parramore and Revel islands. Additionally, preliminary data indicate that most raccoons on one of the southern islands (Myrtle) dispersed from a nearby island (either directly from Mockhorn Island, or from Mockhorn Island by way of Smith Island). More definitive statements can be made after genotyping has been completed and landscape genetic analyses have been conducted on the entire dataset.

Ecomorphodynamic Controls on Barrier Island Evolution in Response to Sea-level Rise

Ecomorphodynamic conceptual framework: Dune-building grasses (e.g., *Ammophila breviligulata*) aid accretion by trapping sand as they grow upward, thereby expanding the high-relief habitat in which they thrive (dune-builder feedback). Following overwash, this feedback

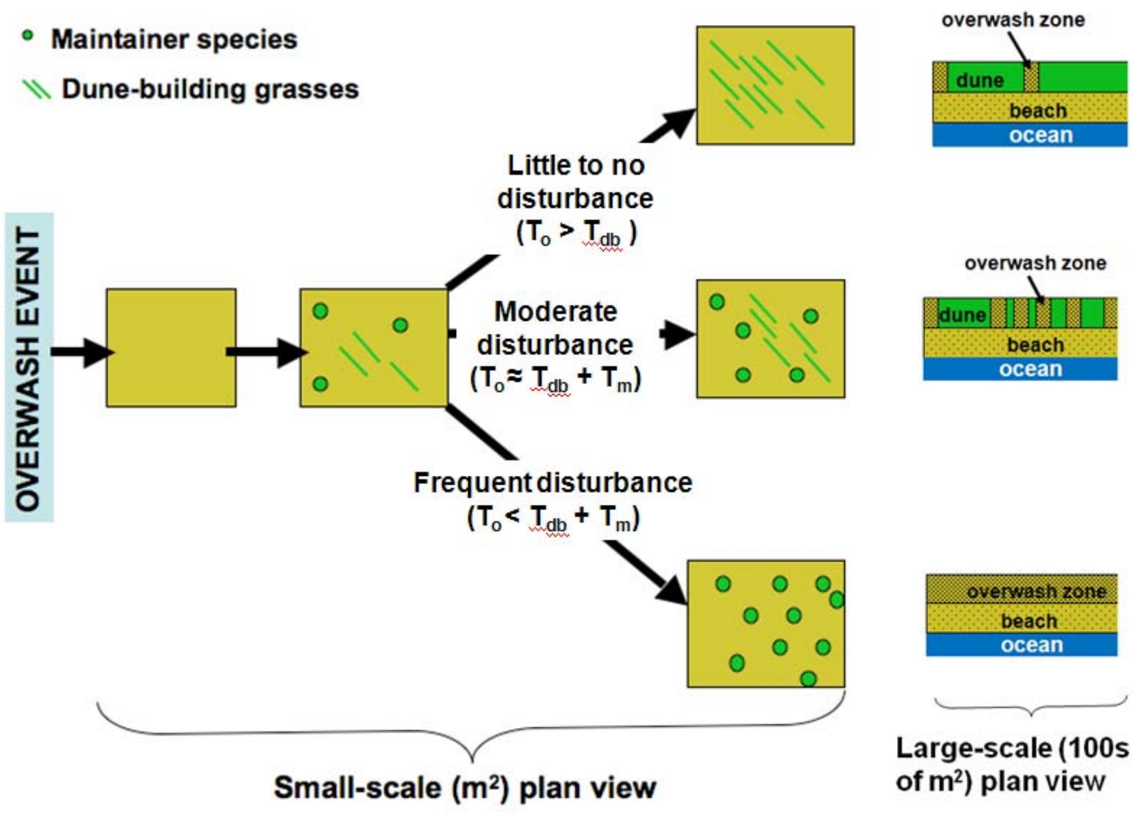


Fig. F49. Possible scenarios for ecomorphodynamic response to overwash when both continuous dune builders (e.g., *A. breviligulata*) and overwash-adapted maintainer species (e.g., *S. patens*) are present, where To = time between overwash events, Tdb = time needed for dune-building grasses to restore topographic relief, and Tm = time added to topographic recovery by the preferential survival of overwash-adapted maintainer species, which stabilize low topography and render sand unavailable for dune building. After overwash (left), both types of vegetation are likely to recolonize the area, but we hypothesize that subsequent disturbance frequency may determine which species ultimately becomes dominant (small-scale plan view). The right-most column (large-scale plan view) shows the implications for barrier island morphology associated with each scenario.

can restore dunes, given sufficient sand supply. However, if overwash recurs before dunes have reestablished, overwash-adapted "maintainer" species (e.g., *Spartina patens*) may preferentially survive. Maintainer species preserve low, flat topography by stabilizing the sediment surface and rendering sand unavailable for dune building, thereby lengthening the time needed for dune recovery and reinforcing continued disturbance (maintainer feedback—see Godfrey et al, 1979; Stallins and Parker, 2003; Stallins, 2005), often in conjunction with physical factors that also limit dune recovery (e.g., shell armoring, critically low elevations). Over time, this feedback (together with physical factors) may lead to overwash persistence, ultimately influencing large-scale morphological changes (Figs. F49, F50).

Combined topographic and vegetation surveys show that on Hog Island (high-relief, rotating, infrequently disturbed), where dunes built by *A. breviligulata* are ubiquitous, overwash is currently limited in extent and related to beach width rather than dominance by the maintainer species *S. patens*. Historical aerial photos and stratigraphic evidence (ground-penetrating radar, cores) indicate that gradual recovery has taken place after overwash events on Hog Island, except where the beach is narrow and eroding (limiting sand supply to the dunes). Conversely, on Metompkin Island (low-relief, transgressing, frequently disturbed), widespread overwash that

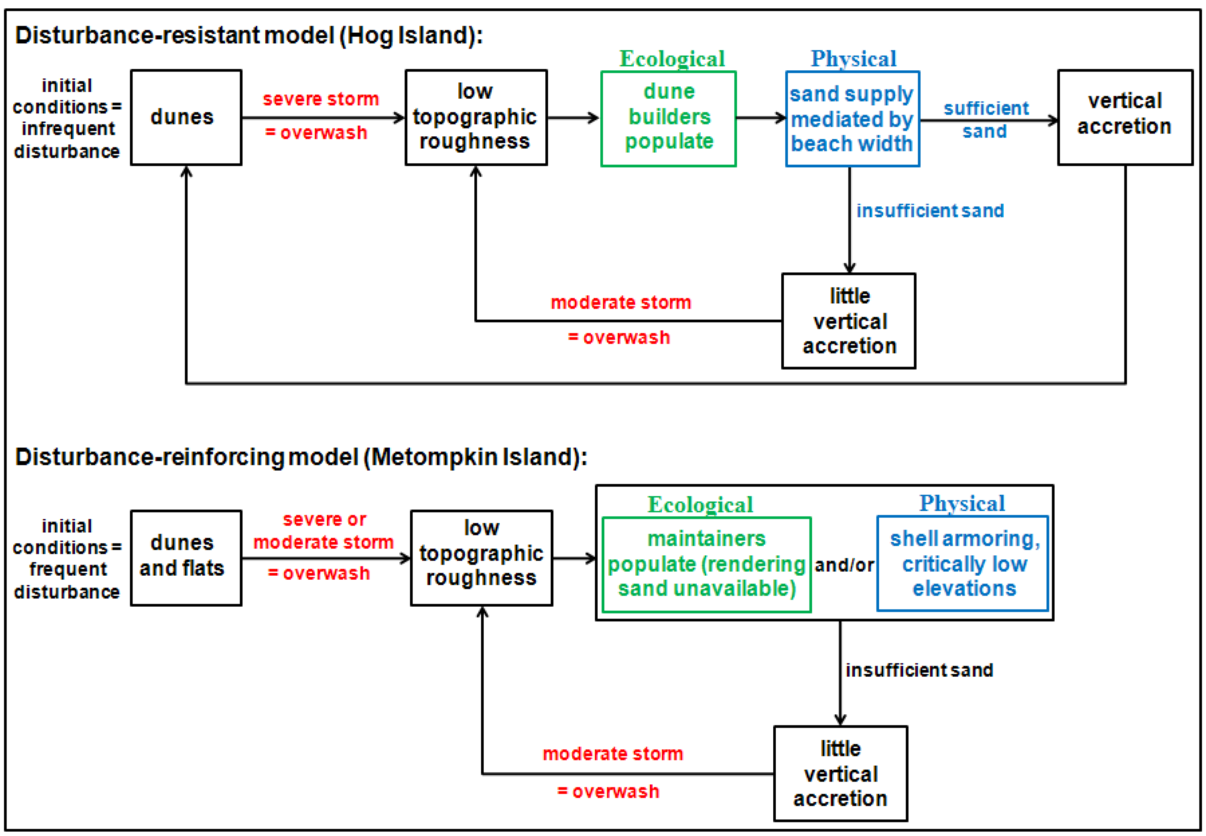


Fig. F50. Ecomorphodynamic conceptual models of barrier island susceptibility and response to overwash, developed based on data from the VCR (Hog and Metompkin Islands). Initial conditions (disturbance regimes) are set by physical factors such as relative sea level rise rate, antecedent geology and topography, sediment supply, wave climate, shoreline orientation, etc. In the top panel (disturbance-resistant model), dunes typically recover after disturbance via the dune-builder feedback, except in relatively isolated instances where physical factors (in this case, beach width) limit sand supply. In the bottom panel (disturbance-reinforcing model), insufficient sand supply is caused by a combination of ecological and physical factors, all of which reinforce continued overwash on comparatively broad spatial scales.

has been persistent on annual-decadal time scales is strongly associated with *S. patens* and shell armoring (northern half of island), as well as critically low elevations (southern half of the island). Results also suggest that spatially heterogeneous disturbance patterns on Metompkin Island may increase vegetative compositional variability relative to Hog Island. In aggregate, our findings suggest that within barrier island systems like the VCR in which both dune-building grasses and overwash-adapted maintainer species are common, the maintainer feedback is likely to be a more important dynamic on islands that are already susceptible to frequent disturbance due to physical and geological factors. This feedback therefore has the potential to accelerate large-scale shifts from dune-dominated to overwash-dominated barrier morphologies as overwash becomes more frequent as a result of climate change-induced increases in storm intensity and sea-level rise (see Figs. F49, F50).

Morphological-behavior modeling of barrier island vulnerability to increased rates of sea-level rise

Results thus far indicate that island migration requires an underlying unit rich in sand-sized sediment. Due to variable underlying stratigraphy, the size of this sand supply unit differs along northern and southern Metompkin Island. Simulations of future island response to SLR suggest that while island migration can be expected to accelerate, Metompkin Island is likely to avoid disintegration or inundation and remain sub-aerial, due to sufficient substrate sand quantities and an adequately landward sloping substrate, which help to sustain vertical island position during migration.

Ecomorphodynamic model of barrier island evolution in response to climate change

Within this conceptual framework, the height and width of a barrier island are both an outcome and driver of physical and biological processes, and the coupled interactions and feedbacks arising among them (Fig. F51). The framework provides a means for capturing and summarizing these intimate connections to consider both the current state of a barrier island and the likelihood that a change in island behavior, or a change in island state will be catalyzed by climate-change induced alterations to physical and biological forcing. Within this framework islands fall on a continuum between “high” and “low,” determined based on island relief, which determines island elevation relative to short-term (e.g., storms) and long-term (e.g., sea-level rise) fluctuations in sea level, the maximum level of wave impact and species-specific elevation limits on vegetation growth. Island relief is critical in determining the physical and biological processes, and characteristics, that dominate a barrier island landform. We hypothesize that through time islands may evolve anywhere along the continuum with changes in physical processes (e.g., affecting the sediment budget) and biological processes (e.g., affecting vegetation), and or feedbacks between physical and biological processes, causing island an island to evolve more toward one end member or the other (Fig. F51). This framework represents a new way of considering barrier island evolution and provides the basis for future work that will utilize this framework to quantitatively address the likelihood of future changes in barrier island evolution as a result of climate change impacts.

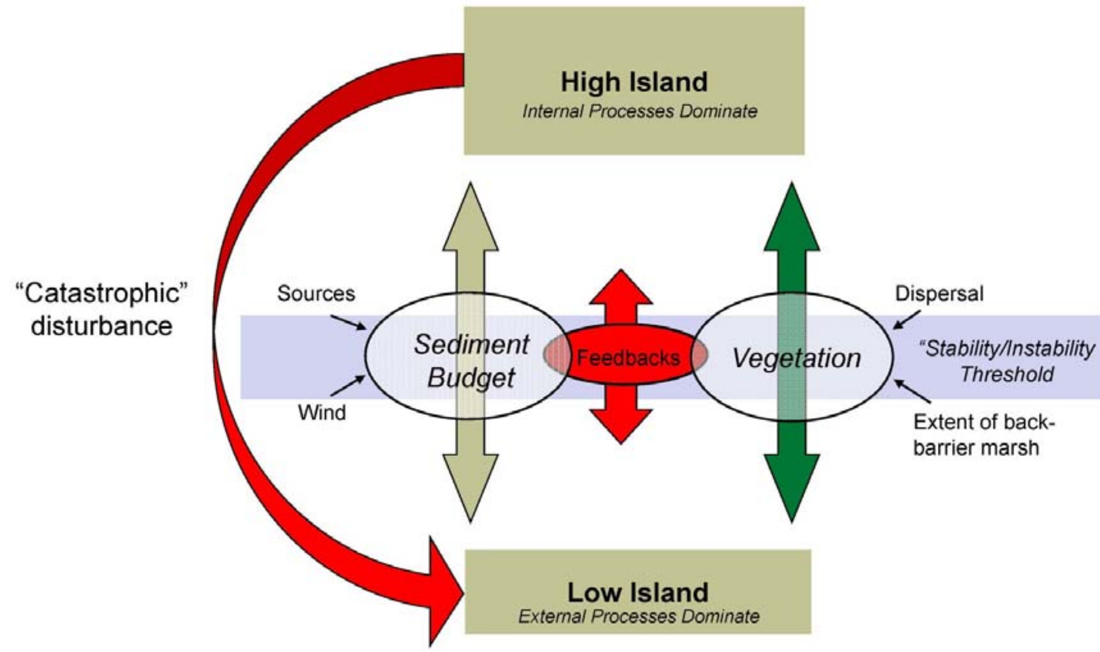


Fig. F51. Schematic representation of the evolving "Ecogeomorphic Framework for Barrier Island Evolution" arising from interdisciplinary, collaborative work in the LTER-VCR.

Landscape analysis

Virginia landscape model

The exchange of water between the islands and the open ocean has proven critical for model stability. Several test runs were done and vector images were created to detect areas of main circulation (Fig. F52).

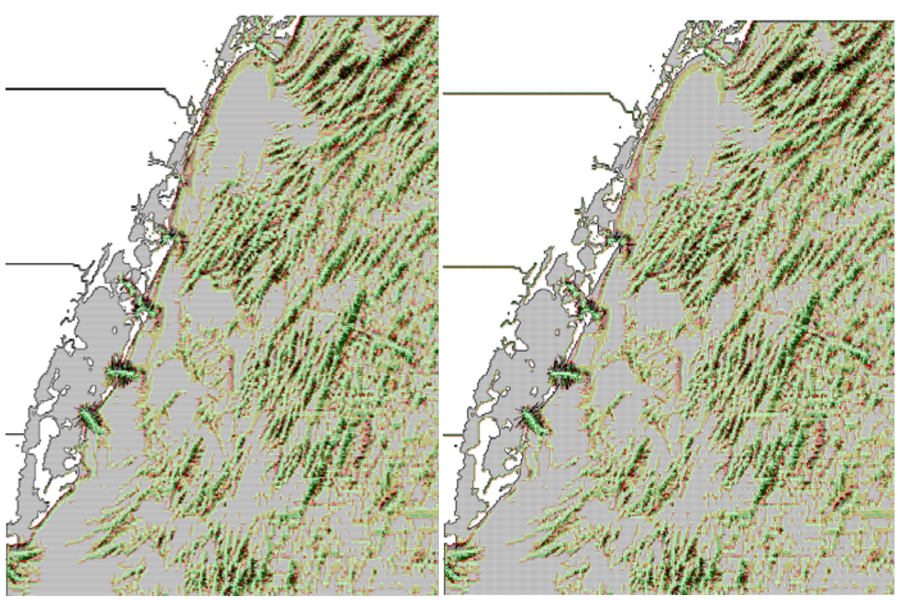


Fig. F52. Model domain circulation vectors for year 1 day 1 and year 1 day 365.

These results were used to complete runs for 25 years. In these runs, salinity distribution was examined to understand dispersal rates and salt water interactions (Fig. F53).

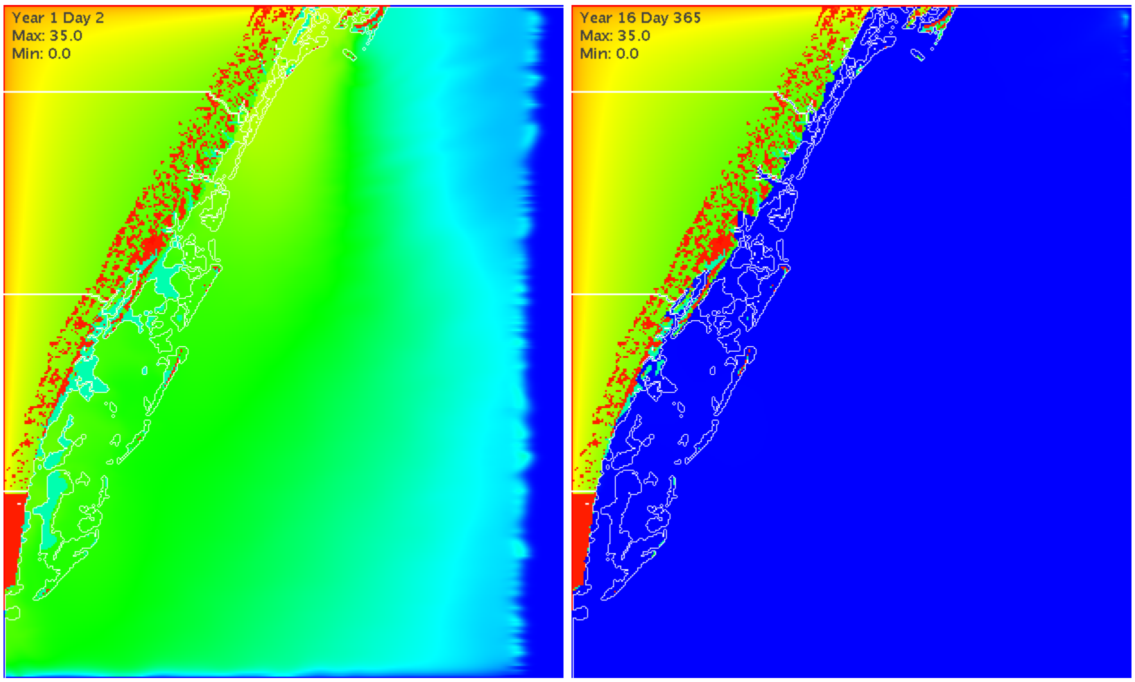


Fig. F53. Salinity distribution for initial conditions to day 365 of year 16.

The stability of the physical parameters allowed us to examine in detail the distribution of the mainland marshes. A base case scenario was run using present environmental conditions and

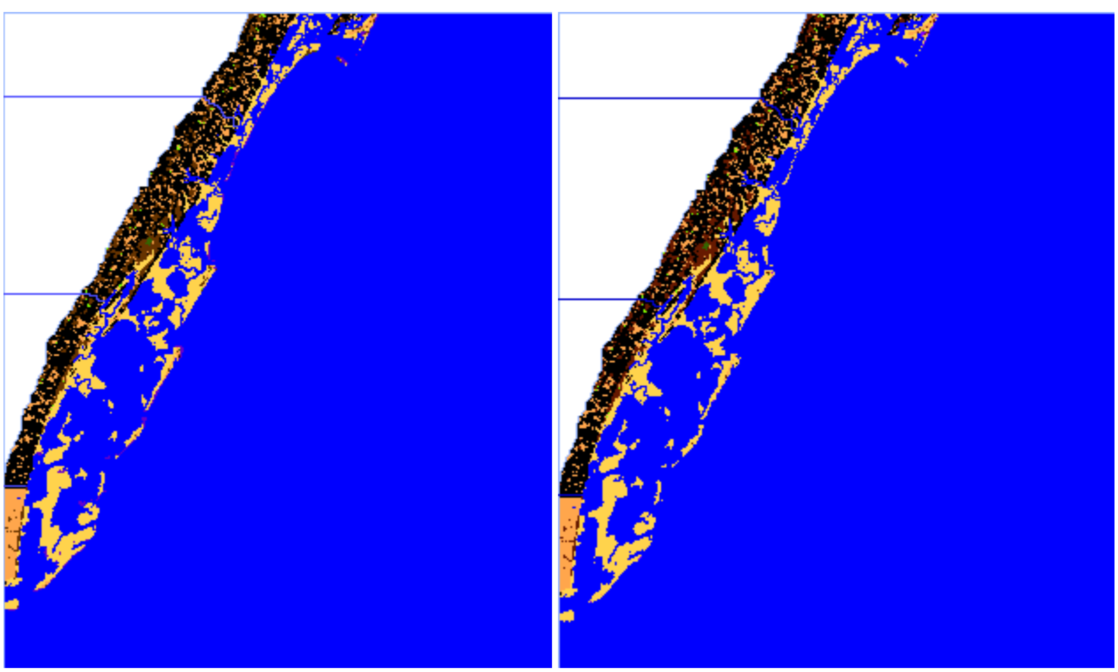


Fig. F54. Habitat initial conditions (1996) and simulated habitat conditions for year 25.

rates of RSLR for 25 years (Fig. F54). The resulting fit index (92.72) suggests that minimal changes will occur for the VCR area at current sea-level rise rates. The total number of cells that convert to water is 103 while the number of cells that convert to land is 240. This last number indicates also the conversion of a marsh type to another. Future simulations will include different scenarios of sea-level rise, and we will incorporate disturbance magnitudes and probabilities into our model simulations.

Barrier island transgression model

The field test of the runaway barrier island transgression model showed that the tidal prism at Wachapreague Inlet increased by approximately 25% over a 38 year period from 1972 – 2010 when comparing the value obtained by DeAlteris and Byrne (1975) to the calculated April 2010 tidal prism of Richardson and McBride (pers comm) and the dynamically calculated August 2010 tidal prism. However, the tidal prism only increased approximately 12% when comparing the average April value to the DeAlteris and Byrne (1975) value. These findings have raised questions about the use of the various methods employed to compute tidal prism and call for a closer examination (and sensitivity analysis) of the phenomena and methods that result in spatial and temporal variation in tidal prism. However, the preliminary results indicate that sea-level rise may be impacting sedimentation patterns and island morphodynamics in this region. Final results are pending the sensitivity analyses. Table 5 and Fig. F55 provide values for the tidal prism calculations.

Table 5. Area and Tidal Prism Calculations for Wachapreague Inlet

Date	**Area (m^2) with ± 1 s**	**Tidal Prism ($x10^7$ m^3), O'Brien with ± 1 s**
August, 2010	5,014 (± 214)	6.31 (± $2.5x10^6$)
April, 2010 (one cross-section)	4,975 (± 214)	6.26 (± $2.5x10^6$)
April, 2010 (average)	4,521	5.73
1972	4,047	5.16

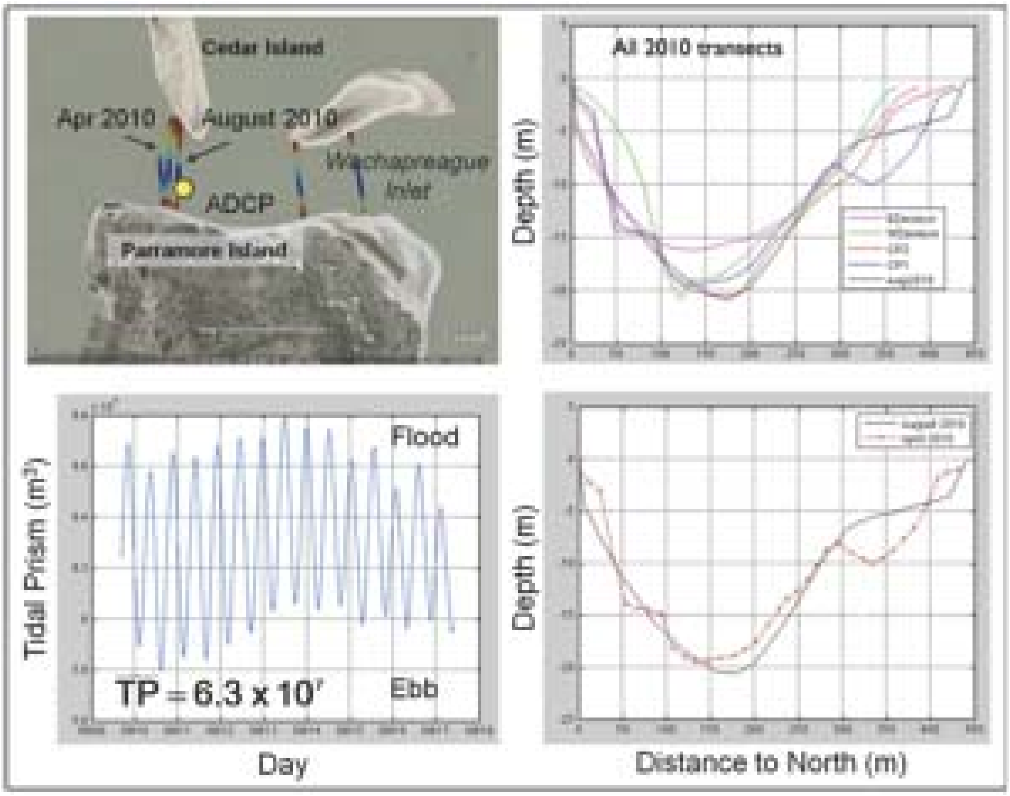


Fig. F55. Cross-section locations (top left), profiles (top right, bottom right), and dynamic tidal prism calculated on August 15, 2010 for Wachapreague Inlet.

Preliminary results from the bathymetric data and side-scan sonograms indicate a highly variable nearshore zone in terms of relief and substrate type. While we are still post-processing the data collected July 2011, preliminary contour maps indicate the importance of the ebb-tidal deltas and inlet retreat paths in controlling island morphodynamics.

Multi-sensor remote sensing analysis of land topography and vegetation

The remote sensing campaign was designed to collect data to explore the synergy of different remote sensing modalities to provide complementary information regarding these applications, for example, to obtain complementary information regarding substrate layering from thermal contrast imaging at different times of day, and volumetric soil moisture estimates from SAR. Similarly, the simultaneous acquisition of LiDAR also aids modeling of vegetation by providing information about topography and canopy height, and for beaches and flats, slope and roughness information which can be fed into models of grain size distributions, that up to now have relied on only hyperspectral imagery (Fig. F56).

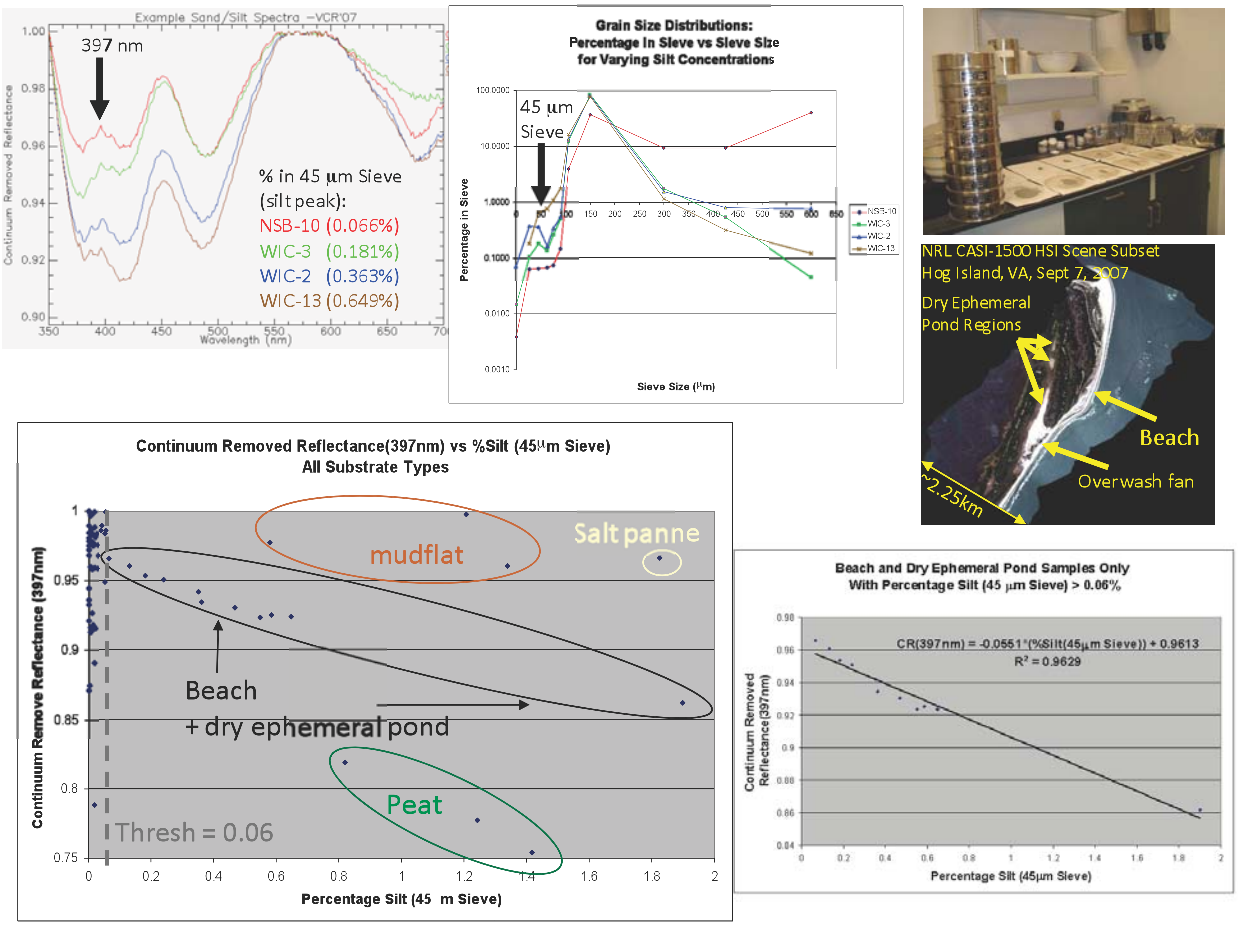


Fig. F56. Correlation of 45 mm grain size (silt particles peak) with reflectance at 397 nm (blue portion of EM spectrum). (Upper left) Continuum removed *in situ* reflectance measurement (VNIR portion of spectrum) showing local maximum at 397 nm for various silt concentrations in 45 mm sieve. (Upper middle) grain size distributions for the corresponding samples on log scale. (Upper right) Photo of sieve set used at the VCR LTER and NRL CASI hyperspectral scene highlighting beach and overwash fans. (Bottom) Silt concentration, along with moisture, plays a significant role in determining bearing strength (dynamic deflection modulus) of the beach; the 397nm spectral feature is highly correlated to the amount of silt present (after Bachmann, Nichols, et al, 2010).

To support validation of bathymetry retrieval from hyperspectral imagery, during the VCR'11 experiment, soundings were conducted by boat using a SonarMite echosounder in the vicinity of Wreck and Cobb Islands, including Sand Shoal Inlet, and portions of Cobb Bay, South Bay, Red Drum Drain, and Black Rock Channel. Previous hyperspectral bathymetry retrievals emphasized primarily the very shallow limit, < 1-2m depth (Bachmann, Montes et al, 2010; Fig. F57), however, hyperspectral imaging can be used to retrieve to significantly greater depth. The sounding data will support validation of retrievals in both shallow and deeper waters from both the airborne CASI hyperspectral imagery as well as from hyperspectral imagery obtained by the NRL Hyperspectral Imager for the Coastal Ocean (HICO) aboard the International Space Station (ISS) (Fig. F57; http://www.nrl.navy.mil/pao/pressRelease.php?Y=2009&R=90-09r).

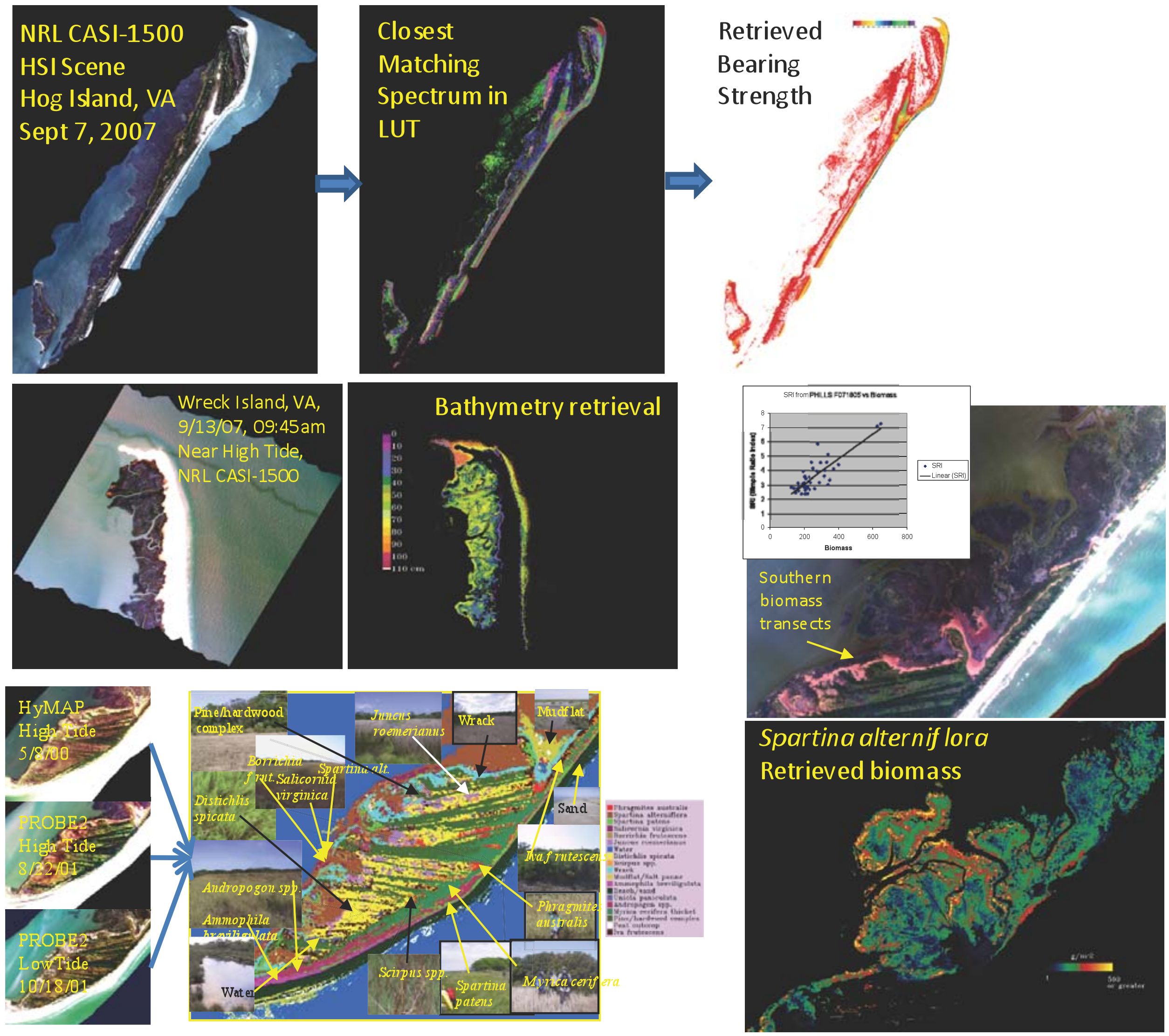


Fig. F57. Retrieved products from hyperspectral imagery: (top row) estimated bearing strength after (Bachmann, Nichols, et al, 2010); (middle, left) bathymetry retrieval after Bachmann et al. (2010); (bottom, left) species level vegetation map derived from multi-season hyperspectral imagery after Bachmann et al. (2003); (bottom and middle, right) *Spartina alterniflora* biomass retrieval after Bachmann et al. (2007).

Compared with the airborne imagery that we have been acquiring at the VCR LTER site since 2000, HICO provides synoptic scale hyperspectral imagery with a ground sample distance of 95m at nadir. HICO is a VNIR (visible and near infra-red) hyperspectral imager designed especially for coastal science applications. Since HICO was delivered to ISS in September 2009, HICO has acquired a time series of imagery over the VCR LTER. A pair of images taken two days apart in September 2010 shows the dramatic differences in the water column visible directly after a storm and two days later after subsidence (Fig. F57). HICO offers many advantages; in addition to the fact that it was designed for coastal applications, it also provides us with the ability to look at hyperspectral imagery from multiple scales for both land and water applications (comparing it with our airborne hyperspectral imagery time series) and to image the VCR LTER environment throughout the year.

The VCR LTER has deployed datasondes in the shallow water lagoons, and during the VCR'11 campaign, the NRL sensor suite was flown repeatedly over one of these datasondes, deployed at Red Bank. This data will be used in water column property modeling for the hyperspectral imagery collected during the campaign, and long term the deployment of the datasondes will be used to develop correlational models with the NRL HICO hyperspectral imagery being collected from the ISS.

The VCR'11 campaign will further overall objectives for coastal characterization (Fig. F57; Bachmann et al. 2010; Fusina et al. 2010) and monitoring of change at the VCR LTER, building on previous remote sensing experimentation conducted by NRL there for the past 11 years. Fig. F57 shows a variety of coastal products that NRL has worked on at the VCR LTER during this period.

Social Science

Public valuation of ecosystem services

The individualized price auction framework, IPA, was designed to gather information on the marginal decision-making of participants. We examined the changes in marginal willingness to pay across units, under different incentive structures, in order to determine if public good provision can be established, in a manner similar to Lindahl's theoretical approach. This framework is meant to encourage people to reveal their full marginal value for a public good while simultaneously collecting funds from a given group (or market) for public good provision. Results from the induced value laboratory experiments (Table 6) indicate that participants respond to the decision-making unit as well as the rules on the infra-marginal unit. In addition, the pivotal mechanism treatment (PivMech) garners higher offers on initial units.

Table 4: Results of Induced Value Laboratory Experiments

Variables affecting mWTP	B	(SE)	P <
LNUnits	-2.860	(1.139)	0.012
Induced Value	0.540	(0.055)	0.001
Dummy Female	1.963	(0.379)	0.001
Dummy Grad Student	-3.394	(0.509)	0.001
Dummy PivMech Trtmt	1.981	(0.846)	0.019
Dummy Rev Trtmt	1.200	(0.439)	0.006
Dummy Eight Unit Trtmt	-2.028	(0.551)	0.001
Constant	9.108	(2.189)	0.001
LR chi2	2036.86		0.001
(df)	(7)		n=3118

In the field we evaluated estimates produced under this new approach (IPA) with those from an incentive compatible approach (CE). If the IPA produces offers that are a good approximation to Hicksian value at the margin, and if the CE choice framework generates estimates of value under conditions of incentive-compatibility, then marginal estimates from the individualized price model should equal marginal estimates from the CE choice model. We examined the confidence intervals constructed for both approaches to determine if our results suggest IPA offers are expected to be within the 95% confidence interval of the CE offers. Figure F58 depicts this comparison graphically between the IPA and CE estimates for seagrass restoration. Our results show that both bird and seagrass restoration estimates under the IPA fall within the CE interval estimates, near the lower bound. These results suggest the individualized pricing auction approach does produce marginal offers consistent with an incentive compatible approach. This result is contrary to that expected by the conventional wisdom in economics that a Lindahl-inspired approach cannot generate marginal offers consistent with Hicksian willingness to pay.

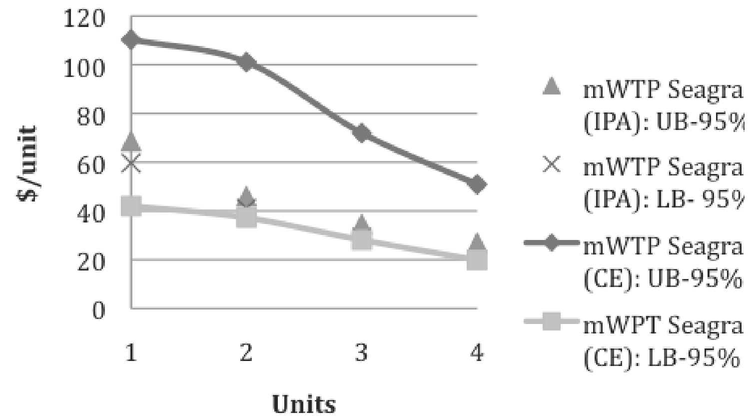


Fig. F58. Treatment comparison (IPA vs CE) of seagrass.

The study was intended to test hypotheses regarding feasibility and development of new approaches for financing public goods, beyond government and philanthropic efforts. Individualized pricing based on a Lindahl-type approach has long been considered impractical in microeconomics. This study initiates a direct test of this long-held assumption in the economics literature. Our results indicate that participants make decisions consistent with Lindahl's framework, while simultaneously generating adequate funds to provide the public goods. Regarding broader impacts, the methods explored in this study may be most appropriate for localized public goods, but there is potential to adapt such incentive mechanisms for use with existing programs by which government pays landowners for ecosystem services. Auction methods could serve as an alternative (or complementary approach) to stated preference methods as a means for guiding the investment of public funds for ecosystem services or other public goods. Thus, individualized pricing displayed through our IPA model supports the potential that Lindahl-inspired methods can generate revenues to fund public goods, at least when implemented with rebate mechanisms such as those found in the experimental literature.