Preview of Award 1237733 - Annual Project Report

Cover

Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Grant or Other Identifying Number Assigned by Agency:	1237733
Project Title:	LTER: Drivers, dynamics and consequences of non-linear change in coastal barrier systems
PD/PI Name:	Karen McGlathery, Principal Investigator John H Porter, Co-Principal Investigator Matthew A Reidenbach, Co-Principal Investigator Patricia L Wiberg, Co-Principal Investigator
Submitting Official (if other than PD\PI):	Karen McGlathery Principal Investigator
Submission Date:	11/03/2013
Recipient Organization:	University of Virginia Main Campus
Project/Grant Period:	12/01/2012 - 11/30/2018
Reporting Period:	12/01/2012 - 11/30/2013
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	Karen McGlathery

---

Accomplishments

* What are the major goals of the project?

MAJOR RESEARCH QUESTIONS/GOALS

1. Evaluate the existence of alternative stable states and threshold responses to environmental drivers as a unifying dynamic across the coastal barrier landscape, by integrating coordinated long-term observations and experiments that address the mechanisms of nonlinear change with models and new experimental studies. Relate ecosystem state change to key ecosystem processes, services and trophic dynamics.

2. Address how connectivity via transport of sediments and organisms influences alternative stable state dynamics of adjacent ecosystems (e.g., seagrass and oyster connectivity to marshes, island connectivity to backbarrier marshes) and if subsidies via organism fluxes between adjacent habitats influence key ecosystem processes, services and states.

3. Use future scenarios to explore how interacting drivers affect threshold behavior and resilience of ecosystem states at different spatial scales, including climate change and changes in land use and nutrient loading. Relate ecosystem state change to key ecosystem processes, services and trophic dynamics. Engage a diverse group of stakeholders to incorporate public valuation of ecosystem services and tradeoffs into quantitative models of future scenarios.

SPECIFIC QUESTIONS ADDRESSED

1a. What are the mechanisms of non-linear state change in coastal barrier landscapes in response to environmental drivers?

1b. Are there specific thresholds for ecosystem state change and leading indicators of proximity to that threshold?

2a. To what extent does connectivity of adjacent ecosystems via sediment fluxes affect responses to environmental change?

2b. Is there evidence of subsidies via organism fluxes between adjacent habitats that influence key ecosystem processes, services and states?

3a. How will ecosystem resilience and state dynamics vary in response to climate drivers across the landscape?

3b. How will changes in land use affect subtidal and intertidal ecosystems, and how will these drivers affect the resilience of ecosystems to climate change? How are state changes related to the delivery of to key ecosystem processes, services and trophic dynamics?

3c. How do regional attitudes and motives modify future scenarios?

*** What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?**

Major Activities: **Mechanisms of non-linear state change**

We identified 2 locations where marsh transgression into upland is occurring. We also began collaborating with USGS and NRL to use hyperspectral imagery for a large-scale pre- and post-Sandy analysis of marsh transgression.

We studied the dynamics of tidal flats bordering salt marshes by 1) determining changes in tidal-flat width from aerial photographs covering a 50-y period for 54 marsh basins along the US Atlantic Coast, and 2) numerical modeling to predict tidal flat width based on horizontal marsh migration and vertical adjustment of marshes and tidal flats. We also developed a morphological model for the long-term evolution of tidal flats. We quantified the effect of temperature on the influence of burrowing organisms on porewater exchange and oxygen dynamics in intertidal sediments, and developed a model for growth of benthic biofilms subjected to variable hydrodynamic disturbances (tidal currents and waves).

To assess seagrass effects on sediment suspension, we 1) quantified seasonal flow and sediment dynamics, 2) correlated water velocity, turbulence, and wave dynamics with in situ turbidity, 3) initiated a study of large-scale flow and wave attenuation, and 4) assessed the role of benthic microalgae on critical shear stress. Seagrass state change effects on production and biogeochemical cycling were determined by 1) seasonal benthic metabolism measurements, 2) bulk isotopes $\delta^{13}C$ and $\delta^{15}N$ in sediment cores, and 3) carbon burial rates related to meadow age and patch size. Effects on trophic dynamics are being assessed from long-term monitoring of fish populations and analyses of benthic foraminiferal communities.

On the barrier islands, a network of 50 wells was established at the interface where shrub thicket expansion is occurring for monitoring of salinity and depth to groundwater. The spatial extents of grassland and shrubland were quantified via remote sensing, and the NDVI was determined. Hyperspectral/Lidar data were obtained at the time of a field campaign that measured spatial variation in vegetation community composition, physiology of grasses and shrubs, and environmental variables along island-scale transects.

We developed a numerical ecomorphodynamic model that simulates the co-evolution of a sandy surface and vegetation, and ran simulations to assess both the role of vegetation in determining the maximum size of coastal foredunes and how changes in storm frequency and sea-level rise will likely impact dune recovery during storms, and thus barrier island state.

Thresholds for state change

In the marshes, we are studying 1) *Spartina alterniflora* production responses to the duration/frequency of flooding using marsh organs at 6 elevations, and 2) whether the phenomenon of “critical slowing down” can be used as an indicator of ecosystem collapse at the boundary between tidal flat and marsh. We measured the response to experimental disturbance (clipping) along a flooding gradient, and calculated recovery rates relative to undisturbed marsh.

In the subtidal, a network of light and temperature sensors were installed along the depth gradient that brackets the current threshold of the seagrass stable-bistable states predicted from the model.

On the barrier islands, we set up 100 seed traps at 50 m intervals along transects from the shrub-thicket edge. These were monitored monthly, and elevation, % cover and plant species composition were quantified in 5x5 m plots. Salinity and relative water content were measured in soil samples, and the relationship between aboveground decay and soil N and position of groundwater was investigated.

Ecosystem Connectivity

Controls on tidal flat-marsh sediment fluxes are influenced by waves (suspend sediment) and tides (sediment transport). We began documenting these complex controls with a series of field deployments of wave gauges, current meters and turbidity sensors at a more slowly eroding site and a more rapidly eroding site.

We used the 3-point dynamic model to examine potential trajectories of salt marshes, including those at the VCR, PIE, and GCE sites, to assess the effects of river sediment supply and sediment retention by seagrass.

Natural intertidal oyster and restored reefs were instrumented to quantify processes affecting boundary layer flow, suspended sediment deposition/erosion, and oxygen fluxes. We integrated ‘hitting rates’ with lab data on larval responses to turbulence and in situ flow velocity and turbulence profiles to calculate the probability of larvae settlement on 4 substrate types (mud, natural reefs, and restored reefs constructed from oyster or whelk shell) as a function of downstream distance.

We merged GEOMBEST and the marsh transect model to develop GEOMBEST+, the first model to simulate the coupled evolution of barrier islands and backbarrier marshes. GEOMBEST+ simulates the processes of barrier-island migration and marsh progradation, and includes the effect of storm-driven overwash deposition onto the marsh platform. We applied GEOMBEST+ to assess the impact of 1) overwash deposition on backbarrier-marsh morphology, and 2) marsh morphology and rates of barrier-island migration.

Subsidies

We 1) quantified macroalgal biomass in intertidal flats/marshes and used N-15 isotope tracer experiments to investigate nutrient subsidies to sediments, vegetation and higher trophic levels, 2) related these data to primary production and invertebrate abundance/diversity, and 3) assessed the “upward cascade” of subsidies to shorebird populations that feed on invertebrates.

We completed an isotope study on sources supporting clam production, and evaluated whether shells produced by aquaculture might be a C sink that contributes to so-called 'blue carbon'. Oyster reef and clam aquaculture beds were characterized with respect to sediments, water column and pore water nutrients and sulfide. Nutrient fluxes and N cycling processes were measured from clam beds, oyster reefs and bare sediments.

State change & projected drivers

To determine N loading to coastal bays, we 1) continue to monitor stream stage and N concentrations at fixed stations, and 2) measure N removal from sediments and water columns of streams draining watersheds. We developed a modeling approach to explore how patchy seagrass meadows affect sediment resuspension and light availability under tidal and wind-wave forcing.

For the islands, 3 years of imagery (1984, 1998, 2011) were analyzed to quantify changes in island size and woody vegetation cover classes, and we began evaluating NDVI of woody and grass cover. We converted the NOAA C-CAP land cover data and simplified the classification scheme into 6 classes: bare, developed, herbaceous, woody, marsh and water. Activities completed to assess the “upward cascade” of vegetation to mammal and bird populations include: 1) mammal live-trapping campaigns at 21 island/marsh and 2 mainland sites to compare large, elevated, relatively stable islands with small, low-lying, geomorphologically unstable islands, 2) predator surveys on the 21 islands to quantify mobility, 3) analysis of raccoon movement, and 4) least-cost path analysis to determine an optimal strategy for mesopredator movement as an aid to avian habitat restoration.

Socio-ecological drivers

Six focus groups were held to identify how residents think about the benefits of ecosystem services and the undeveloped landscape that comprises much of the VCR. A survey was developed to evaluate 1) how individuals prefer different potential locations for economic development projects, and 2) the relative importance of defending farm, forest, or village areas from sea-level rise or storms. We identified a former agricultural field that was abandoned in 2006 due to soil salinization from Hurricane Isabel in which to initiate our experiment of planting salt-tolerant marsh mallow. Soil analysis has been completed and we have begun monitoring groundwater wells and surface water level monitors.

Specific Objectives:

Mechanisms of non-linear state change

Mainland Forest/Shrub vs. Marsh - The extent of marshland is controlled by changes at its terrestrial boundary, where complex interactions determine its landward-most extent. Our objective was to document transgression of this boundary.

Marsh vs. Tidal Flat - Positive feedbacks between vegetation growth and sediment transport promote the development of two alternative states: salt marshes and tidal flats. Our objective was to understand the ecological and physical connectivity between these two stable systems, and the mechanisms of state change that transform salt marshes in tidal flats and vice versa.

Seagrass vs. Unvegetated Seafloor - To further constrain and validate the stage-change model, and to investigate the resilience of seagrass meadows, our objectives were to: 1) continue long-term monitoring of seagrass morphology and meadow characteristics, and 2) evaluate the consequences of the seagrass state change for sediment suspension, biogeochemistry, carbon sequestration and trophic dynamics.

Barrier Island Grassland vs. Shrub Thicket - Our objective was to evaluate the relative importance of temperature and water-table feedback between grassland and shrubland by investigating: 1) how shrubs modify the local microclimate, particularly in the coldest months, 2) how shrubs lower the water table, 3) the cold sensitivity of shrubs, and 4) the sensitivity of shrubs to shallow water tables using field and remote sensing (spectral/Lidar) measurements. We assessed trophic implications of grassland to shrub transition by evaluating mammal populations and predation on waterbirds.

Barrier Island Geomorphology, "High" vs. "Low" Islands - Our objective was to develop a model of barrier-island dynamics from an existing model of dune growth that includes aeolian sediment transport and vegetation population dynamics. In model runs, forcing parameters (sea-level rise, overwash frequency, sediment-loss rates) varied to evaluate the effect on island state (high vs. low) using migration rate as an inverse proxy (e.g., low islands have high migration rates and vice versa).

Thresholds for state change

Intertidal Marshes - The ability of marshes to maintain elevation high in the intertidal zone determines if marshland will convert to subtidal mudflats. Our objective was to understand how marsh plant growth responses to duration and frequency of tidal inundation reveal if there are leading indicators of proximity to the threshold of change.

Seagrass - To refine the growth model that estimates the maximum depth threshold of seagrass, our objective was to install a network of light and temperature sensors along the depth gradient that brackets the current threshold of the stable-bistable states predicted from the model.

Barrier Islands - Our objective was to continue monitoring fronts of shrub expansion to identify specific thresholds of change (i.e. introduction of nitrogen-fixer *Frankia* to the soils). We planned to identify changes in key ecosystem parameters along dune/swale transects and related these to elevation (nearness to groundwater). This would provide a basis for predictions on a larger spatial scale of state transitions with changes in elevation (erosion, accretion, sea-level rise, groundwater fluctuation).

Ecosystem Connectivity

Sediment Redistribution - Our objective was to quantify sediment fluxes from the tidal flat to marsh at 2 sites in Hog Island Bay.

Seagrass/Marsh - Our objective was to develop a 3-point dynamic model, incorporating ecogeomorphological feedbacks between wind waves, vegetation, sediment loading and sea-level rise, to investigate how internal and external processes affect coupled marsh-mudflat systems.

Oyster/Marsh - Oysters reefs fringing marshes may impact erosion and sediment supply. Our objective was to start *a new long-term experiment* in which we construct artificial oyster reefs and measure waves, mean currents, turbulence, suspended sediment concentrations and larval recruitment.

Island/Back-barrier Marsh - To explore couplings between barrier islands and back-barrier marshes, our objective was to merge: 1) a barrier island model, GEOMBEST+, that incorporates sediment composition and supply rate to forecast barrier island evolution in response to sea-level rise and 2) a marsh transect model that predicts coupled marsh – tidal flat evolution in response to sea-level rise and storms.

Subsidies

Cross-Habitat Macrophyte Subsidies -Our objective was to assess how the invasion of the macroalgae, *Gracilaria vermiculophylla*, affected nitrogen subsidies and trophic dynamics in adjacent marshes and mudflats.

Subsidy Support and Expansion of Aquaculture - Our objective was to document sources of organic matter supporting clam production and changes in clam aquaculture over time, and to evaluate possible impacts of clams on biogeochemical and ecological processes.

State change & projected climate/land-use drivers

Intertidal Habitats - To determine relative rates of transgression, our objective was to incorporate historical observations of marsh expansion at the forest edge based on aerial photographs.

Subtidal Habitats -Our objectives were to address: 1) how location affects habitat suitability and resilience of seagrass meadows by considering variation in physical and chemical parameters and linking these with our model of state dynamics, and 2) understand how meadow patchiness (size and configuration) affects vegetation feedbacks to sediment suspension and light attenuation. Changes in land use will affect nutrient loading to subtidal habitats, and our objectives were to: 1) continue monitoring stream stage and nitrogen concentrations at fixed stations, 2) assess nitrate removal via denitrification from groundwater feeding streams, and 3) quantify nitrate removal from the stream.

Island Habitats - To build on our historical analysis of vegetative cover change, our objectives were 4-fold: 1) examine fine-scale changes in vegetation as a result of shoreline accretion/erosion, 2) use NDVI as a link between changes in woody cover due to hydrological patterns, 3) use LiDAR to determine the potential range of distribution based on habitat polygons, and 4) quantify changes in island shape and size and corresponding vegetative classes over 40 years using Landsat TM imagery. To explore future climate change scenarios of shoreline migration and sea-level rise, we integrated these remote-sensing analyses with long-term data on species distributions and local-scale mechanisms to model bistability and vegetation change.

Habitat/Vegetation Analysis. Our objective was to develop a temporal sequence of spatially explicit habitat descriptors for the islands based on the NOAA Coastal-Change Analysis Program (C-CAP) land cover data layers for 1984 - 2005. The layers contain data for 14-22 land-cover classes and a background class for areas outside the images on which the classification was based, with 30-m pixel resolution.

Mammal Distributions. Our objectives were to: 1) determine species occupancy to look for evidence of local extinctions and/or colonizations, 2) develop an "incidence function" for each species in terms of associated island attributes such as size, isolation and habitat complexity, 3) determine species diversity to look for evidence of community-level changes since the previous sampling, 4) quantify the relationship between species diversity and island attributes such as size, isolation and habitat complexity, and 5) collect tissue samples for analysis of genetic relationships among populations.

Socio-ecological drivers

Our objective was to develop a survey of public valuation of ecosystem services to incorporate input from multiple stakeholder perspectives into future scenario planning related to climate and land-use change. We also planned to initiate a *new long-term experiment* to explore the ecological and economic benefits of an alternative biofuel crop in agricultural fields abandoned due to sea-level rise.

Significant Results: **Mechanisms of non-linear state change**

Volumetric (but not lateral) erosion rates of marsh edges were positively correlated with incident wave energy flux. For marshes with sufficient vertical accretion to maintain elevation as sea level rises, increases in volumetric erosion rates expected to result from deeper water depths and larger waves may be offset by taller marsh-edge scarps such that lateral erosion rates remain relatively constant. Biostabilization introduces a hysteresis on tidal flats: given a disturbance with the same intensity, biofilm is eroded or not depending on its current state. Without wind waves the only stable configuration is a channel without tidal flats, for intermediate wave conditions, the stable equilibrium is a channel flanked by tidal flats, and intense waves suppress the channelization process, and a flat bed becomes then only equilibrium solution. Sea-level rise allows the coexistence of channels and tidal flats, even in absence of waves.

Eelgrass meadows reduced current velocities compared to unvegetated seafloor, dampened wave heights for all seasons except winter when seagrass biomass was lowest, and orbital wave motions in winter enhanced bottom shear stress. Metabolism switched from heterotrophy in bare sediments to autotrophy in 5-y sites back to heterotrophy in 11-y sites. Seagrass sediments were significant stores of “blue carbon”, with rates of C sequestration similar to natural meadows by 12 y.

The conversion of grassland to shrubland is explained in part by elevation. Results from the ecomorphodynamic models indicate that 1) plant zonation is the main factor controlling the maximum size of foredunes and thus the amount of sand stored in a coastal dune system, and 2) aeolian sand supply to dunes determines the time scale of foredune formation. Barrier islands can undergo rapid deterioration in response to gradual changes in forcing. Strong storms can trigger a shift from a high-elevation state (resistant to storms) to a low-elevation state (prone to storm overwash).

Thresholds for state change

There is a threshold width for tidal flats bordering salt marshes. Once this threshold is exceeded, irreversible marsh erosion takes place even in the absence of sea-level rise. This catastrophic collapse occurs due to positive feedbacks among tidal flat widening by wave-induced marsh erosion, tidal flat deepening driven by wave bed shear stress, and local wind waves.

Island vegetation surveys indicate that elevation and distance to groundwater are important drivers ecosystem process rates (e.g, decomposition) and thresholds of state change from grasslands to shrublands. In areas in which expansion of the shrub *Morella* sp. is occurring, seed dispersal decreased exponentially with distance from the source thicket, and influences shrub establishment.

Ecosystem Connectivity

Preliminary data on sediment redistribution show complex controls on wave conditions at the marsh edge that are strongly influenced by water depth, wind speed and wind direction. Waves are attenuated, but persist, in the near-edge region of the marsh (where vegetation is sparse or stunted), limiting deposition and promoting erosion close to the edge. Deposition rates are expected to be highest along tidal creeks.

A comparison of coupled marsh-seagrass dynamics indicates for the 3 Atlantic coastal LTER sites shows that while though rates of sea-level rise are similar, responses are different. For marsh systems without seagrass or significant riverine sediment supply (PIE,) marsh horizontal retreat is triggered by large mudflats and strong winds, whereas small mudflats and weak winds reduce the sediment supply and increase vulnerability. Marsh expansion and an eventual lateral equilibrium are possible only with large allochthonous sediment supply. High riverine sediment supply directly to the marsh (GCE) reduces the importance of waves, and infilling or retreat become are predicted. Seagrass (VCR) decrease near-bed shear stresses and sediment flux to the marsh, but also reduce wave energy and reduce marsh boundary erosion.

Oyster reefs dissipate wind-wave energy depending primarily on water depth above the reef and significant wave height. We have identified an ideal range of depths at which reefs most effectively protect adjacent marshes from wave energy. Although waves grow with deeper water related to strong winds and storm surge, the decay in orbital motion with depth makes reefs less effective at dissipating storm wave energy. Sediment deposition to the reef increased linearly for lower current velocities up to a threshold, beyond which it decreased due to bed shear stresses that exceeded the critical threshold for erosion. This suggests that the best way to maximize settlement on restored reefs is to construct patches of optimal length for the water depth.

Simulations indicate that islands backed by marsh platforms transgress more slowly and that overwash deposition provides backbarrier marshes with an important source of sediment that maintains narrow marsh platforms within a range of conditions of sea-level rise rates and sediment supply.

Subsidies

Intertidal sediment, marsh cordgrass, and mudflat invertebrates all incorporated nitrogen of *Gracilaria vermiculophylla* origin, indicating that the macroalga is an important mediator of nutrient transfers. On mudflats the presence of *Gracilaria* increased oxic-anoxic heterogeneity in the sediment and coupled nitrification-denitrification, and though there was an increase in invertebrate biomass, but this did not translate to increases in shorebird foraging.

There is a subsidy of algae to subtidal clam beds from adjacent mudflats and marshes, and that clams are potentially significant C sinks. Long-term expansion of clam beds may influence water and sediment quality and potentially compete with seagrasses. Rates of denitrification in clam beds were low and similar to bare sediments.

State change & projected climate/land-use drivers

There has been an upward trend in marsh retreat over the last 52 years correlated with an increase in storm frequency. Preliminary measurements in “marsh organs” indicate that the recovery rate of biomass postdisturbance decreases linearly with flooding frequency, providing general support for critical slowing down theory. Production in the undisturbed organs showed that at high elevations productivity increased with flooding frequency even as recovery rates declined.

Seagrass-vegetated areas influence a larger area than they footprint, including a barren adjacent downstream area which exhibit reduced shear stresses. Understanding how the patchy structure of meadows affects sediment resuspension and the consequent light environment must include the presence of this sheltered region.

From 1984 to 2011, the 7 islands analyzed have all shown some loss of total upland area. Woody vegetation has increased on 5 of the 7 islands with a corresponding loss of grassland. We have quantified conversion of grassland to shrubland and other land cover changes at the island chain scale. These data will be made available to other PI’s and TNC for scaling up trophic levels to historical changes in bird and mammal populations.

The distribution of raccoons has expanded on the islands over the past 30+ years. Islands near the mainland had greater re-colonization. Raccoons are highly mobile within an island, but are less mobile between islands. The minimum costs of immigration to specific islands vary >3 orders of magnitude, making some islands better targets for removal of predators. This suggests that implementation of staged predator management effort is likely to be most effective and cost efficient in aiding the recovery of beach-nesting and colonial waterbirds.

Discharge rates influence NO_3^- lost from coastal streams by denitrification; longer residence times result in more higher denitrification rates. Preliminary data suggest that this is not affected by temperature.

Key outcomes or Other achievements:

Mechanisms of non-linear state change

The dynamics of the marsh boundary is primarily controlled by sediment supply rather than relative sea level rise. We propose that lack of sediment supply, often associated with human activities, is a major driver of marsh loss at the study sites and generates effects at least comparable to the accelerating sea-level rise due to global warming. This finding advocates for salt marsh preservation projects based on the restoration of the natural sediment supply at the coastline by dam removal and controlled river diversions.

A new method, computer-aided-tomography, for measuring marsh root and rhizome volume is being tested using samples collected in VCR marshes. Development of this method will advance our understanding of how salt marsh plant roots and rhizomes contribute to the maintenance of salt marsh structural integrity, and affect marsh surface elevation, and therefore, geomorphic patterns.

'Blue' carbon systems play a large role in global carbon sequestration, which impacts climate change and sea level rise. We are the first to show the importance of seagrass restoration in sequestering carbon and as a result have been chosen to develop the methodology for determining greenhouse gas benefits of seagrass restoration by the Verified Carbon Standards VCS program.

The ecomorphodynamic model of dune growth on barrier islands fills a gap in the field of coastal geomorphology and simulations thus far have resulted in new ideas, including that vegetation (not sediment supply) determines the maximum size of coastal foredunes and that barrier islands are bistable.

Thresholds for state change

The phenomenon of critical slowing down has been proposed as a leading indicator of ecosystem collapse, where recovery to disturbance slows as an ecosystem approaches a critical threshold. Our work provides important 'real world' support for this ecological theory, which is primarily grounded in numerical models and highly controlled experiments.

Our results offer a potential explanation for the empirical relation between beach type and foredune size, in which large (small) foredunes are found on dissipative (reflective) beaches: higher waves on dissipative beaches increase salinity at the backshore which leads to a wider plant zonation and thus larger foredunes. In this scenario, plants play a much more active role in modifying their habitat, and altering coastal vulnerability, than previously thought. At this point, the probability of returning to the high-elevation state decreased exponentially as a function of increasing storm frequency, rising sea level and physical and biological factors that slow dune formation. Such rapid, and potentially permanent, shifts in island state have the potential to initiate changes across the broader coastal system via connections to adjacent marsh and lagoon environments.

Ecosystem connectivity

Across all systems and with current sea-level rise, retreat is a more likely marsh loss modality than drowning. However, marsh retreat increases the system resilience, allowing the marsh platform to temporarily keep pace with elevated sea level rise.

Oyster reefs may not be effective as previously thought at dissipating the largest waves that accompany storms with strong winds and storm surge. Oysters have a significant positive effect on the deposition of suspended sediment in shallow coastal environments, thereby decreasing turbidity and enhancing light penetration through the water column and productivity of benthic primary producers.

For a single patch of oyster reef, the optimal habitat configuration is independent of larval concentration, but in a metapopulation the relative success of individual patches will depend on larval supply and the distribution of source and sink populations. The optimal distribution of patches may also depend on the dispersal distance during the larval development time or the degree of isolation needed to minimize the spread of disease or predators among patches. To better meet management goals, this and other optimization approaches should be combined in a spatially explicit metapopulation framework.

Subsidies

Cross-habitat subsidies in the coastal barrier system influence the provision of ecosystem services. Macrophyte subsidies from subtidal to intertidal habitats enhance nitrogen supply to primary producers and consumers, which can translate to enhanced primary and secondary production, and stimulate the removal of N via denitrification. The latter effect has implications for the role of lagoons and marshes as a filter for watershed N inputs. Macrophyte subsidies also enhanced biodiversity and abundance on intertidal mudflats.

Clam aquaculture is a growing industry and is subsidized by adjacent mudflats and intertidal marshes. Sustaining clam and oyster aquaculture requires information on positive and negative impacts on the benthic environment.

State change & projected climate/land-use drivers

Understanding the mechanisms responsible for marsh stability or deterioration is therefore a key issue for society. RSLR is often viewed as the main driver of salt marsh deterioration. While salt marshes can reach equilibrium in the vertical direction, they are inherently unstablein the horizontal direction. Marsh expansion driven by sediment supply rarely matches lateral erosion by waves, creating a dynamic landscape. Recent results show that marsh collapse can occur in the absence of sea level rise if the rate at which sediment is eroded at marsh boundaries is higher than the input of sediment from nearby rivers or from the continental shelf. We propose that the horizontal dynamics and related sediment fluxes are key factors determining the survival of salt marshes. Only a complete sediment budget between salt marshes and nearby tidal flats can determine the fate of marshes at any given location, with sea level rise being only one among many external drivers. Long-term observations of the position of borders of *Juncus roemerianus* patches have been tracked since 1990 and a picture is emerging as how hydroperiod and disturbance contribute to the adundance of this species.

Seagrasses are important foundation species in shallow coastal ecosystems that provide critical ecosystem services including stabilizing sediment, sequestering carbon and nutrients, and providing habitat and an energy source for a diverse fauna. Our project represents the world's largest successful seagrass restoration, and demonstrates the reinstatement of key ecosystem services with successful large-scale restoration within a decade.

Our work has broad application to all coastal LTER sites as well as federal, state and private natural areas/parks along the Atlantic coast. Historical understanding of land cover change along the VCR which can be linked with environmental drivers to fully understand mechanisms of change will be broadly applicable to coastal managers and planners for predicting future vulnerability due to climate change and other natural disturbances.

Socio-ecological drivers

As sea level rises, Eastern Shore communities face three choices; retreat inland and abandoned their farmland allowing conversion to barren areas that are quickly colonized by invasive plant species, harden the shoreline with structures to delay upland submergence leading to serious detrimental impacts on the regions natural resources and fisheries, or adopt alternative strategies such as planting salt tolerant crops to support the local economy. Planting native marsh halophytes, such as *K. virginica*, in fields no longer capable of supporting traditional crops would limit soil erosion and potentially provide ecologic and economic benefits while the land undergoes state change to high marsh or wetland forest.

* What opportunities for training and professional development has the project provided?

37 graduate students and about 15 undergraduate students were trained this year through the VCR LTER program. VCR has a formal 'tiered' mentoring program that involves faculty, graduate students, undergraduate students and high school students working together as a team on specific research projects. Five VCR LTER researchers are collaborating with

other faculty around the country, including those from all LTER Atlantic coastal sites, to offer a massive online graduate course. The course, “Linking biology and geomorphology in coastal wetlands (and other habitats)” is being offered for credit at 9 universities. Over 140 people are participating, including graduate students and faculty members at over 30 academic institutions, and staff at 9 National Estuarine Research Reserves and 2 Federal Agencies. The course is interdisciplinary, providing background on biological, geological and hydrological processes in wetlands, and considering how these processes interact to affect wetland structure and function. Lectures are being delivered online by 15 scientists from around the country.

VCR is represented on the LTER Education and Communication Committee. The VCR Education Coordinator participated in the 2013 International LTER meeting in Korea.

Ongoing K-12 activities include: Coastal Bay Ecology and Fall Migration Workshops on the Eastern Shore, professional development workshops for area K-12 teachers; Oyster Gardening Program which provides training and curriculum materials for local teachers along with classroom materials and field trips for participating classes run in partnership with VA Oyster Reef Keepers; Summer Science Internships for local high school students through our Research Experience for High School Students (REHS) program made possible by levering SLTER Funds with additional support from TNC; and our Water Cycle/Nutrient dynamics field trip at the VCR-LTER run on request for class groups from across VA. VCR researchers and staff work with the science faculty at Northampton High School, giving guest lectures and assisting with curriculum development. *Every one of the 200 high school student in the county is exposed to VCR research at least once in their high school career; over 50% of these students are from traditionally under-represented groups.*

Two professional development classes for art teachers were offered involving VCR researchers: 1) an observational Drawing workshop held in October for local Art Teachers that links Art with place based science, and 2) continuation of the Plein Aire and Marsh Ecology workshop held each spring. Exhibitions are currently planned at our local Barrier Islands Center Museum and the Brown Science & Engineering Library on the grounds of UVA. This year 45 area art teachers participated in the classes.

SLTER funds were leveraged with support from TNC and the Volgenau Foundation to develop a Kayak and Ecology summer camp program for local middle school students. Ten at-risk/low income students from Northampton and Accomack Counties received free tuition to this week-long program during which they used kayaks to explore the local waterways while learning about coastal ecosystems, including the ecology of critically important species like oysters, seagrass and blue crabs.

* How have the results been disseminated to communities of interest?

The VCR holds a monthly public seminar series at the Anheuser-Busch Coastal Research Center, which is attended by 20-50 local residents and planners.

VCR scienctists are members of 1) the Eastern Shore Climate Adaptation Working group, a partnership between TNC, local, regional and federal agencies, and 2) a regional committee formed to examine current zoning regulations and the potential economic and ecological impacts of developing commercial poultry production. The VCR Citizen Science Program includes colaborations with the VA Oyster Reef Keepers and the VA Master Naturalists. The VCR lab is a demonstration site for local vegetation.

We work with UVA’s Institute for Environmental Negotiation on “listening sessions” to assess local citizen responses to climate change issues (http://ien.arch.virginia.edu/projects-current/virginia-sea-level-rise).

The VCR seagrass restoration project has been highlight in the public media with 2 stories highlighting Lead P.I. McGlathery's research on Virginia Public Radio.

The VCR disseminates research findings and data through the VCR LTER website (www.vcrlter.virginia.edu). Use of the website continues to increase.

In collaboration with The Nature Conservancy we have established a *new long-term ecosystem-level experiment* to determine how oyster reefs fringing marsh edges impact erosion and sediment supply to the marshes by constructing

1.5 acres of replicate artificial reefs composed of shell material adjacent to a mainland marsh.

'Blue' carbon systems play a large role in global carbon sequestration, which impacts climate change and sea level rise. VCR scientists are the first to show the importance of seagrass restoration in sequestering carbon and as a result have been chosen to develop the methodology for determining greenhouse gas benefits of seagrass restoration by the Verified Carbon Standards VCS program.

* What do you plan to do during the next reporting period to accomplish the goals?

Mechanisms of non-linear state change

We will establish two wells at the boundary between forest and salt marsh to measure the long-term oscillations in water levels and salinity. We will map areas of tree dieback along the boundaries of the VCR lagoons and relate these areas to the local vegetation characteristics and landscape morphology. Using the hyperspectral imagery, we will analyze the shoreward transgression of marsh at the mainland forest/shrub vs. marsh interface pre- and post- Hurricane Sandy. We will develop hyperspectral imagery tools that can be used generally to look at vegetation patterns following future storm/disturbance events.

We will continue our long-term study of the dynamics of the marsh boundary, trying to understand the complex feedbacks between marsh erosion, waves, and sea level rise. We will also continue research on burrowing mechanics of worms and will do field studies to determine pumping rates by burrowing worms and how this alters oxygen levels in intertidal sediments. This dynamic will be related to rates of nutrient turnover and mineralization in highly burrowed and non-burrowed regions intertidal flats.

For the subtidal systems, we will continue our long-term monitoring of plant, sediment and faunal parameters in the restored seagrass meadows. In addition, we will quantify meadow edge effects carbon sequestration and sources of buried carbon. We will validate our alternative-state change model with data on light, sediment characteristics and temperature, and use these to modify our model of habitat suitability for seagrass restoration in the VCR lagoons. Studies on nitrogen cycling (denitrification, dissimilatory nitrate reduction to ammonium, and nitrogen fixation) will be initiated in the seagrass meadows and in regions where clam beds and seagrass meadows co-occur. Metabolism studies using the eddy correlation approach will be expanded.

On the barrier islands, we will refine our bistability model experiments to assess the range of conditions under which barrier islands are bistable. We will trap mammals on islands where predators are transient, on islands where they are resident (i.e., source islands), and on islands that represent special cases (e.g., islands that might serve as bridges between source and transient islands).

Thresholds for state change

Monitoring of hydroperiod effects on *Spartina alterniflora* growth is planned for 2014. Experiments to determine the effect of N-fertilization are planned for subsequent years. We have just finished a second season of experimental disturbance in the marsh organs, and are in the process of comparing these results to those from a field based experiment that takes advantage of a naturally occurring gradient in elevation and flooding frequency. We will also compare our results to similar experiments conducted in the Netherlands.

We will test the theory of slowing down as an indicator of ecosystem resilience experimentally in the seagrass system. This will be done by expanding our experimental transplant studies and initiating new studies where meadows are disturbed and the recovery time is followed along a stress gradient (water depth) where resilience is expected to differ based on the alternative stable state model.

On the barrier islands, periodic monitoring of the wells for depth and salinity will begin summer 2014. Hobo packs will be ordered and deployed Fall/Winter 2013. Spatial variation in physiology will be linked to water table depth and linked to airborne imagery for developing models between ET and freshwater availability. We will quantify the fine-scale relationship of belowground (root) decay along a dune/swale transect. Belowground responses are expected to be more sensitive to changes in elevation and nearness to ground water.

Ecosystem Connectivity

At marsh sites, a 2-3 week late-fall/winter deployment of wave, current and turbidity sensors will be carried out. This deployment will have a large emphasis on quantifying suspended sediment concentrations and transport in response to wave and tidal forcing.

We will finalize data analysis regarding the impacts of seagrass growth on wave attenuation and sediment resuspension and will continue to take seasonal benthic biomass measurements of total biomass and extracellular polymeric substances (EPS) in an attempt to relate these measurements to critical shear stresses necessary for sediment resuspension. We will develop a cellular automata model to address sediment transport and redistribution in the context of marsh vulnerability to RSLR.

In the next year, we will compare long-term data sets (e.g., overwash frequency, historical barrier island shoreline change, and marsh width and edge erosion, etc.) in the VCR to patterns that arise in our model runs. These comparisons will inform model development, but also potentially lead to new interpretations of existing data.

Subsidies

Our main focus in the coming year on subsidies and expansion of aquaculture will be on refining estimates of areal coverage and further evaluating the subsidy questions via stable isotope studies. Additional flux experiments and site characterization studies are planned for 2013-2014. These data will allow us to assess if clam aquaculture is expanding as well as to document changes in the location of operations. Over the long-term we envision this data as important in evaluating relative coverage of bottom habitat by aquaculture and sea grasses. Eventually, there may be conflicts and trade-offs involved in these two uses of benthic habitat.

State change & projected climate/land-use drivers

We will continue to validate the alternative stable state model with field data on light attenuation, water temperature, depth of productive seagrass meadows. The modified model will be run with future scenarios of eutrophication and climate change, and will incorporate the coupling of seagrass and marsh habitats. This is a novel approach to understanding state change dyamics.

For the barrier islands we are developing a rules-based cellular automata model that simulates shrub thicket dynamics within the context of bistability at several spatial scales: swale, cross-island, island, and island chain. We will use the model to predict shrub expansion (or contraction) in response to increases in sea level and to changes in storm frequency, associated variations in shoreline migration, and availability of groundwater from the freshwater lens. We will continue quantifying changes in NDVI for grass and shrub cover and extract the potential range for shrubs on each island based on habitat polygons (using Lidar data). We will begin development of the model.

We plan to summarize the National Atmospheric Administration (NOAA) Coastal-Change Analysis Program (C-CAP) land cover information for each island to provide a statistical basis for modeling island occupancy by small mammals. We do occupancy analysis of the mammal data during autumn 2013, and relate them to the habitat/vegetation analysis in 2014. We will continue our 24-year semi-annual small mammal sampling on Hog Island in November 2013 and April 2014 and initiate a camera-trap study of predator movement relative to nesting bird colonies on the islands in 2014.

For the watershed nutrient loading estimates, we will determine estimates of nitrate loading from watersheds of differing land use/land cover. This will allow prediction of hydrological controls on the fluxes as well as an upper limit on the capacity of the streams to provide buffering and protection to the coastal waters.

In cooperation with a local high school we will germinate and grow seedlings of the salt-tolerant *K. virginica* that we will transplant to the old field in spring of 2014 and the plant communities will be monitored. Planting, vegetation characterization, and soils analyses are being carried out as a 3-year long 'senior' undergraduate thesis project at UVA. We will measure groundwater salinity at the sites monthly.

Products

Journals

Alber, M., D. Reed, and K. McGlathery (2013). Coastal long term ecological research: Introduction to the special issue. *Oceanography*. .

Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; DOI: http://dx.doi.org/10.5670/oceanog.2013.40

Berg, P., M. H. Long, M. Huettel, J. E. Rehuban, K. J. McGlathery, R. W. Howarth, K. H. Foreman, A. E. Giblin, and R. Marino (2013). Eddy correlation measurements of oxygen fluxes in permeable sediments exposed to varying current flow and light. *Limnology and Oceanography*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.4319/lo.2013.58.4.1329

Blum, L. K., and E. Davey (2013). Below the Salt Marsh Surface: Visualization of Plant Roots by Computer-Aided Tomography. *Oceanography*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: http://dx.doi.org/10.5670/oceanog.2013.49

Campbell, J. L., L. E. Rustad, J. H. Porter, J. R. Taylor, E. W. Dereszynski, J. B. Shanley, C. Gries, D. L. Henshaw, M. E. Martin, W. M. Sheldon, and E. R. Boose (2013). Quantity is Nothing without Quality: Automated QA/QC for Streaming Environmental Sensor Data. *Bioscience*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1525/bio.2013.63.7.10

Christian, R. R., and D. M. Allen (2013). Linking hydrogeomorphology and food webs in intertidal creeks. *Estuaries and Coasts*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: DOI:0.1007/s12237-013-9657-5

Duke, C. S., and J. H. Porter (2013). The Ethics of Data Sharing and Re-use in Biology. *Bioscience*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1525/bio.2013.63.6.10

Dueser, R. D., N. D. Moncrief, O. Keišs, J. D. Martin, J. H. Porter, and B. R. Truitt (2013). Overwater Movement of Raccoons (Procyon lotor) in a Naturally Fragmented Coastal Landscape. *Northeastern Naturalist*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Fagherazzi, S., G. Mariotti, P. L. Wiberg, and K. J. McGlathery (2013). Marsh collapse does not require sea level rise. *Oceanography*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: http://dx.doi.org/10.5670/oceanog.2013.47

Fagherazzi, S., P. L. Wiberg, S. Temmerman, E. Struyf, Y. Zhao, and P. A. Raymond (2013). Fluxes of water, sediments, and biogeochemical compounds in salt marshes. *Ecological Processes*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1186/2192-1709-2-3

Flewelling, S. A., G. M. Hornberger, J. S. Herman, A. L. Mills, and W. M. Robertson (2013). Diel patterns in coastal-stream nitrate concentrations linked to evapotranspiration in the riparian zone of a low-relief, agricultural catchment.

Hydrological Processes. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: DOI: 10.1002/hyp.9763

Fuchs, H. L., and M. A. Reidenbach (2013). Biophysical Constraints on Optimal Patch Lengths for Settlement of a Reef-Building Bivalve. *PLoS ONE*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1371/journal.pone.0071506

Gulbransen, D. J., and K. J. McGlathery (2013). Nitrogen transfers mediated by a perennial, non-native macroalga: A 15N tracer study. *Marine Ecology Progress Series*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.3354/meps1028

Greiner, J. T., K. J. McGlathery, J. Gunnell, and B. A. McKee (2013). Seagrass restoration enhances “blue carbon” sequestration in coastal waters. *PLoS ONE*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1371/journal.pone.0072469

Hardison, A., E. Canuel, I. Anderson, C. Tobias, B. Veuger, and M. Waters (2013). Microphytobenthos and benthic macroalgae determine sediment organic matter composition in shallow photic sediments. *Biogeosciences*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.5194/bgd-10-2791-2013

Hansen, J. C. R., and M. A. Reidenbach (2013). Seasonal growth and senescence of a Zostera marina seagrass meadow alters wave-dominated flow and sediment suspension within a coastal bay. *Estuaries and Coasts*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1007/s12237-013-9620-5

Hampton, S. E., C. A. Strasser, J. J. Tewksbury, W. K. Gram, A. E. Budden, A. L. Batcheller, C. S. Duke, and J. H. Porter (2013). Big Data and The Future for Ecology. *Frontiers in Ecology and the Environment*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: http://dx.doi.org/10.1890/120103

Howarth, R. W., M. Hayn, R. M. Marino, N. Ganju, K. H. Foreman, P. Berg, A. E. Giblin, K. J. McGlathery, and J. D. Walker (2013). Metabolism of a nitrogen-enriched coastal marine lagoon during summertime. *Biogeochemistry*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: DOI 10.1077/s10533-013-9901-x

Holzer, K. H., D. A. Seekal, and K. J. McGlathery (2013). Bucktooth parrotfish Sparisoma radians grazing on Thalassia in Bermuda varies seasonally and with background nitrogen content. *Journal of Marine Biology and Ecology*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1016/j.jembe.2013.02.031

Mariotti, G., and S. Fagherazzi. (2013). Critical width of tidal flats triggers marsh collapse in the absence of sea-level rise. *Proceedings of the National Academy of Sciences of the United States of America*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi/10.1073/pnas.1219600110

McGlathery, K. J., M. A. Reidenbach, P. D'Odorico, S. Fagherazzi, M. L. Pace, and J. H. Porter (2013). Nonlinear dynamics and alternative stable states in shallow coastal systems. *Oceanography*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: http://dx.doi.org/10.5670/oceanog.2013.66

Michaels, R. E., and J. C. Zieman (2013). Fiddler crab (Uca spp.) burrows have little effect on surrounding sediment oxygen concentrations. *Journal of Experimental Marine Biology and Ecology*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: http://dx.doi.org/10.1016/j.jembe.2013.06.020

Rheuban, J. E., and P. Berg (2013). The effects of spatial and temporal variability at the sediment surface on aquatic eddy correlation flux measurements. *Limnology and Oceanography*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: DOI_10.4319/lom.2013.11.351

Shiflett, S. A., J. C. Zinnert, and D. R. Young (2013). Changes in composition and structure during restoration of maritime communities.. *Journal of the Torrey Botanical Society*. 140 89.

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Voss, C. M., R. R. Christian, and J. T. Morris (2013). Marsh macrophyte responses to inundation anticipate impacts of sea-level rise and indicate ongoing drowning of North Carolina marshes. *Marine Biology*. .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s00227-012-2076-5

Swallow, S. K (2013). Demand-side Value for Ecosystem Services and Implications for Innovative Markets: Experimental Perspectives on the Possibility of Private Markets for Public Goods. *Agricultural and Resource Economics Review*. 42 33.

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Graziani, D. and F.P. Day (). Thresholds of change in decomposition rates along a dune/swale transect on a Virginia barrier island. *Journal of Coastal Research*. .

Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Canestrelli, A., S. Fagherazzi, and S. Lanzoni (). A mass-conservative centered finite volume model for solving two-dimensional two-layer shallow water equations for fluid mud propagation over varying topography and dry areas. *Advances in Water Resources*. .

Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Clarkson, C. E., and A. Riscassi (). Using ptilochronology to determine daily mercury deposition in feathers of nestling waterbirds. *Environmental Toxicology and Chemistry*. .

Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Clarkson, C. E., R. M. Erwin, and A. Riscassi (). The use of novel biomarkers to determine dietary mercury accumulation in nestling waterbirds. *Environmental Toxicology and Chemistry*. .

Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Erwin, R., P. McGowan, and J. Reese (). Predator removal enhances waterbird restoration on a large dredged material island in Chesapeake Bay. *Ecological Restoration*. .

Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Fagherazzi, S., and A. M. Priestas (). Backbarrier Flooding by Storm Surges and Overland Flow. *Earth Surface Processes and Landforms*. .

Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Gulbransen, D. J., K. J. McGlathery, M. Marklund, J. N. Norris, and C. F. D. Gurgel (). Gracilaria vermiculophylla (Rhodophyta, Gracilariales) in the Virginia (VA) coastal bays, USA: Cox1 analysis reveals the genetic richness and diversity of an invasive macroalga. *Journal of Phycology*. .

Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Gulbransen, D. J., A. R. Smyth, M. F. Piehler, and K. J. McGlathery (). Mats of the non-native macroalga, Gracilaria vermiculophylla, alter net denitrification rates and nutrient fluxes on intertidal mats. *Limnology and Oceanography*. .

Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Hayn, M., R. W. Howarth, R. Marino, N. Ganju, P. Berg, K. H. Foreman, A. E. Giblin, and K. J. McGlathery (). Exchange of nitrogen and phosphorus between a shallow seagrass-dominated lagoon and coastal waters. *Estuaries and Coasts*. .

Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Kirwan, M. L., and J. P. Megonigal (). Tidal wetland stability in the face of human impacts and sea level rise. *Nature*. .

Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Mariotti, G., and S. Fagherazzi (). Channels-tidal flat sediment exchange: the channel spillover mechanism. *Journal of Geophysical Research*. .

Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Reynolds, L. K., M. Waycott, K. J. McGlathery, and R. J. Orth (). Restoration recovers population structure and landscape genetic connectivity in a dispersal-limited ecosystem. *Journal of Ecology*. .

Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Thomsen, M. S., M. F. Muth, and K. J. McGlathery (). Facilitation of soft-bottom species via control of structural elements by the tube-dwelling polycheate Diopatra cuprea. *Estuarine, Coastal and Shelf Science*. .

Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Vick, J. K., and D. R. Young (). Comparative responses of a non-N-fixing shrub and an actinorhizal N-fixing shrub to N fertilization. *Plant and Soil*. .

Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Wolner, C. V., L. J. Moore, D. R. Young, S. T. Brantley, S. N. Bissett, and R. A. McBride (). Ecomorphodynamic feedbacks and barrier island response to disturbance: Insights from the Virginia Barrier Islands, Mid-Atlantic Bight, USA. *Geomorphology*. .

Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Books

Book Chapters

Fagherazzi, S., D. M. FitzGerald, R. W. Fulweiler, Z. Hughes, P. L. Wiberg, K. J. McGlathery, J. T. Morris, T. J.

Tolhurst, L. A. Deegan, and D. S. Johnson (2013). Ecogeomorphology of Tidal Flats. *Ecogeomorphology* Academic Press. San Diego. .

Status = PUBLISHED; Acknowledgement of Federal Support = No ; Peer Reviewed = No

Fagherazzi, S., D. M. FitzGerald, R. W. Fulweiler, Z. Hughes, P. L. Wiberg, K. J. McGlathery, J. T. Morris, T. J. Tolhurst, L. A. Deegan, and D. S. Johnson (2013). Ecogeomorphology of Salt Marshes. *Ecogeomorphology* .

Status = PUBLISHED; Acknowledgement of Federal Support = No ; Peer Reviewed = No

Feldman, S. H., and J. H. Porter (2013). Chapter 64: Syphacia. *Molecular detection of human parasitic pathogens* .

Status = PUBLISHED; Acknowledgement of Federal Support = No ; Peer Reviewed = Yes

Porter, J. H., and C. C. Lin (2013). Hybrid Networks and Ecological Sensing. *Wireless Sensor Networks & Ecol. Monitoring* Springer-Verlag. Berlin. .

Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = No ; DOI: DOI: 10.1007/978-3-642-36365-8_4.

Smith, E. C., and S. K. Swallow (2013). Lindahl Pricing for Public Goods and Experimental Auctions for the Environment. *Encyclopedia of Energy, Natural Resource, and Environmental Economics* Elsevier. Amsterdam. .

Status = PUBLISHED; Acknowledgement of Federal Support = No ; Peer Reviewed = No

Borrett, S. R., R. R. Christian, and R. E. Ulanowicz (). Network Ecology. *Encyclopedia of Environmetrics* A. El-Shaarawi and W. W. Pierogorsch. John Wiley & Sons, Ltd.. .

Status = ACCEPTED; Acknowledgement of Federal Support = No ; Peer Reviewed = No

Brinson, M. M (). Classification of wetlands. *Wetlands: A Multidisciplinary Perspective* B. A. Lepage. Springer. .

Status = ACCEPTED; Acknowledgement of Federal Support = No ; Peer Reviewed = No

Thesis/Dissertations

Hansen, J. *The effects of waves and turbulence on sediment suspension and mixing in seagrass systems*. (2013). University of Virginia.

Acknowledgment of Federal Support = Yes

Mariotti, G.. *Morphodynamics of shallow coastal bays*. (2013). Boston University.

Acknowledgment of Federal Support = Yes

McFadden, G. S.. *Streambed Sediments of Virginia Eastern Shore Streams are Poised for Pore-Water Dentrification*. (2013). University of Virginia.

Acknowledgment of Federal Support = Yes

Conference Papers and Presentations

Other Publications

Technologies or Techniques

Nothing to report.

Patents

Patent Abstract: Patent Application 12/653,125 filed December 8, 2009 Associated with NSF grant

No DEB0621014 (LTER-VCR) (USPTO Allowance issued 1/16/2013).

Patent Title: Revenue Raising Auction Processes for Public Goods

Patent Number: 8,429,023 B2

Country: UNITED STATES

Application Date: 12/08/2009

Patent Status: Granted

Date Issued: 01/16/2013

Inventions

Licenses

Websites

Title: Virginia Coast Reserve Long-Term Ecological Research

URL: http://www.vcrlter.virginia.edu

Description: Main web site for the VCR/LTER research project. Provides access to research summaries, data and images.

Other Products

Product Type: Databases

Description: The VCR/LTER shares 155 GB of data in 167 individual datasets via its web site and the LTER Network Data Portal and new PASTA data system. These include core long-term datasets and shorter-term, project-specific or baseline data. Data can be viewed and downloaded at:

http://www.vcrlter.virginia.edu/home1/dataCatalog

Data are provided along with metadata using Ecological Metadata Language (EML). Since Nov. 1, 2012, 1,656 dataset downloads were logged.

The VCRLTER also contributes data to the LTER ClimDB Climate Database: http://www.fsl.orst.edu/climhy/http://www.fsl.orst.edu/climhy/

Other:

Participants

Research Experience for Undergraduates (REU) funding

How many REU applications were received during this reporting period? 10

How many REU applicants were selected and agreed to participate during this reporting period? 2

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Michael L Pace	Co-Investigator	1
Kyle A Emery	Graduate Student (research assistant)	6
Peter Berg	Co-Investigator	4

Jennie Rheuban	Graduate Student (research assistant)	6
James N Galloway	Co-Investigator	1
Matt Kirwan	Co-Investigator	1
Arthur C Schwarzschild	Co-Investigator	12
John H Porter	Co PD/PI	12
David L Richardson	Technician	6
Christopher R Buck	Technician	12
Brooke Rodgers	Technician	3
David M Boyd	Technician	12
Patrick J Luckenbach	Technician	4
James Sparks	Technician	3
David Munoz	Technician	3
Stephen Swallow	Co-Investigator	1
Ian Yue	Graduate Student (research assistant)	6
Donald R Young	Co-Investigator	4
Paul Vaughan Manley	Technician	2
Stephen M Via	Graduate Student (research assistant)	1
Raymond D Dueser	Co-Investigator	8
Robert R Christian	Co-Investigator	1
Sherer Etheridge	Graduate Student (research assistant)	6
Janet S Herman	Co-Investigator	1
Dirk J Koopmans	Graduate Student (research assistant)	12
Sara R Taube	Graduate Student (research assistant)	8
Melissa Duvall	Graduate Student (research assistant)	8

Patricia L Wiberg	Co PD/PI	2
Matthew A Reidenbach	Co PD/PI	2
Frank Day	Co-Investigator	3
Dominic Graziani	Graduate Student (research assistant)	3
Linda Blum	Co-Investigator	4
Aaron Mills	Co-Investigator	2
Kirstina Reid Black	Graduate Student (research assistant)	2
Margaret P Challand	Graduate Student (research assistant)	5
Anne Dunkel	Graduate Student (research assistant)	8
Cassandra L Cosans	Undergraduate Student	2
Benjamin Pickus	Undergraduate Student	2
Iris Anderson	Co-Investigator	1
Charles Bachmann	Co-Investigator	1
Paolo D'Odorico	Co-Investigator	1
Sergio Fagherazzi	Co-Investigator	1
Michael Fenster	Co-Investigator	1
Jose Fuentes	Co-Investigator	1
Bruce Hayden	Co-Investigator	1
George S McFadden	Graduate Student (research assistant)	8
Stephen Macko	Co-Investigator	1
Nancy Moncrief	Co-Investigator	1
Laura J Moore	Co-Investigator	1
Todd Scanlon	Co-Investigator	1
David E Smith	Co-Investigator	1

Joseph C Zieman	Co-Investigator	1
Spencer Bissett	Graduate Student (research assistant)	6
Emily C Adams	Graduate Student (research assistant)	6
Benjamin Dows	Graduate Student (research assistant)	6
Molly Hokkanen	Graduate Student (research assistant)	6
Nathan Sedghi	Graduate Student (research assistant)	6
Sheri Shiflett	Graduate Student (research assistant)	6
Matt Smith	Graduate Student (research assistant)	2
Alia N Al-Haj	Graduate Student (research assistant)	8
Traci Davis	Graduate Student (research assistant)	8
Katarina Doctor	Graduate Student (research assistant)	8
Lillian R Aoki	Graduate Student (research assistant)	1
Talia N Dibbell	Graduate Student (research assistant)	5
Noah E Egge	Graduate Student (research assistant)	8
Jill T Greiner	Graduate Student (research assistant)	4
Dana J Gulbransen	Graduate Student (research assistant)	4
Jennifer Romanowich Hansen	Graduate Student (research assistant)	4
John M Haywood	Graduate Student (research assistant)	8
Theo Jass	Graduate Student (research assistant)	1
Jennifer Johnson	Graduate Student (research assistant)	8
William Kearney	Graduate Student (research assistant)	1
Allison M Leach	Graduate Student (research assistant)	8
Nicoletta Leonardi	Graduate Student (research assistant)	8
Abby M Lunstrum	Graduate Student (research assistant)	1

Paul Manley	Graduate Student (research assistant)	6
Giulio Mariotti	Graduate Student (research assistant)	1
John McLeod	Graduate Student (research assistant)	8
Anna Murphy	Graduate Student (research assistant)	8
Elizabeth Murphy	Graduate Student (research assistant)	8
Matthew P Oreska	Graduate Student (research assistant)	8
Anthony Michael Priestas	Graduate Student (research assistant)	6
Emily L Thomas	Graduate Student (research assistant)	8
Ross Timmerman	Graduate Student (research assistant)	8
Jackie Vick	Graduate Student (research assistant)	4
Tammy Viggato	Graduate Student (research assistant)	3
David Walters	Graduate Student (research assistant)	8
Mark Wejrowski	Graduate Student (research assistant)	8
Ashley Smyth	Postdoctoral (scholar, fellow or other postdoctoral position)	12
Orencio Duran	Postdoctoral (scholar, fellow or other postdoctoral position)	12
Julie C Zinnert	Co-Investigator	6
Victoria Long	Undergraduate Student	4
William Clemo	Research Experience for Undergraduates (REU) Participant	4
Arianna Sherman	Research Experience for Undergraduates (REU) Participant	4
Karen McGlathery	PD/PI	3

What other organizations have been involved as partners?

Name	Location

Chesapeake Experience	York County, VA
Dickinson College	Carlisle, PA
Northampton County Public Schools	Eastville, VA
Old Dominion University	Norfolk, VA
Smithsonian Environmental Research Center	Edgewater, MD
The Nature Conservancy	Nassawadox, VA
Virginia Institute of Marine Sciences	Gloucester Point, VA

Have other collaborators or contacts been involved? N

Impacts

What is the impact on the development of the principal discipline(s) of the project?

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.

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. Our 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. We have shown the importance of this invasive macroalgae in subisidizing nutrients and habitat in intertidal marshes and mudflats.

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.

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.

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.

The conversion of grasslands to shrubs has significant cascading effects on trophic dynamics. We have shown that increased shrub cover provides refuge for mammalian predators that impact migratory waterbird populations. VCR scientists are working with regional managment agencies on novel predator management techniques.

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.

What is the impact on 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.

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.

What is the impact on the development of human resources?

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 25 graduate students who conduct their M.S. and Ph.D. projects at the VCR site and approximately 15 undergraduate students work each year as research assistants in the field and laboratory.

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. More than half of these students are from traditionally underrepresented groups.

Day was a member of a diversity working group that received funding from the LTER office and met in Albuquerque to address LTER related diversity issues. That group has now been appointed as an LTER standing committee, and he is developing a diversity plan for the VCR LTER site.

What is the impact on physical resources that form infrastructure?

The VCR/LTER is the principal user of the Anheuser-Busch Coastal Research Center (ABCRC) of the University of Virginia and provides, through user fees, resources that allow the center to support a substantial housing, lab and boat infrastructure. The ABCRC provides facilities for a number of smaller, more limited projects and educational programs.

Reidenbach has developed an underwater laser-based velocity measuring system. Particle image velocimetry (PIV) has been used for a number of years in laboratories to measure velocity and turbulence over an area ranging from square millimeters to square meters. 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.

What is the impact on institutional resources that form infrastructure?

LTER researchers form the core of a monthly seminar series offered at the the Anheuser-Busch Coastal Research Center (ABCRC) of the University of Virginia. Additionally, ecological science programs in the Northampton County High School are highly dependent on resources and facilities provided through our SLTER program.

What is the impact on information resources that form infrastructure?

This project provides a wide array of information resources to the larger scientific community through our formal datasets, which are available via our site data catalog (http://www.vcrlter.virginia.edu/cgi-bin/browseData.cgi), LTER Network, and affiliated data centers (e.g., KNB, DataOne).

Since 11/1/12, 1,656 datasets were downloaded. Of the 539 downloads where the user was identified, 200 (37%) were by users external to the VCR/LTER project. The majority of external downloads were for research (82%), with 18% for education (e.g., student class projects).

Additionally, on our website (http://www.vcrlter.virginia.edu) we provide access to maps, photographs, documents, publication lists and research descriptions.

What is the impact on technology transfer?

The VCR/LTER organized and hosted a workshop in 2013 that enhanced the LTER Controlled Vocabulary, a tool that is used to improve data discoverability. The LTER Controlled Vocabulary has been integrated into other systems, such as the European LTER ENVTHES project.

What is the impact on society beyond science and technology?

The high historic rate of sea-level rise (~4mm/yr) within the Virginia Coast Reserve make it a bellweather site for assessing the probable impacts of global sea-level changes. Our results concerning the response of salt marshes, upland and lagoon systems can provide insights that extend to other systems that are only now beginning to experience heightened sea level. VCR researchers work with regional planners and decision-makers in the Mid-Atlantic Climate Adaptation Working Group. In addition, VCR researchers are working The Nature Conservancy to develop a web-based decision tool for coastal resilience that includes natural and social science data to visualize future scenarios of climate change and sea-level rise.

The VCR LTER (UVA) has joined a consortium of institutions in the Mid-Atlantic, including NASA - Wallops Island, University of Delaware, University of Maryland, and the Virginia Institute of Marine Sciences to establish the Mid-Atlantic Coastal Resilience Institute, with the purpose of colloborating with respect to data, models and tools to address coastal reslience in response to climate change.

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.

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.

Recent VCR research is the first the importance of restored seagrass meadows in sequestering carbon and highlighted the role of habitat restoration in mitigation of rising atmospheric CO2 levels. Because the scale and success of seagrass restoration, VCR scientists have been chosen to write the international protocol for the Verified Carbon Standards program on to assign carbon credits on international trade markets for seagrass restoration.

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 present. 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.

Changes

Changes in approach and reason for change

We have added a new P.I. Sarah Karpantry from Virginia Tech to address questions related to barrier-island geomorphology and trophic dynamics. Dr. Karpantry has worked for a number of years on shorebird populations on Mid-Atlantic barrier islands and strengthens the VCR team with respect to trophic dynamics.

Actual or Anticipated problems or delays and actions or plans to resolve them

Nothing to report.

Changes that have a significant impact on expenditures

Nothing to report.

Significant changes in use or care of human subjects

Nothing to report.

Significant changes in use or care of vertebrate animals

Nothing to report.

Significant changes in use or care of biohazards

Nothing to report.