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# Preview of Award 1237733 - Annual Project Report

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## Cover

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|---|---|
| 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<br>John H Porter, Co-Principal Investigator<br>Matthew A Reidenbach, Co-Principal Investigator<br>Patricia L Wiberg, Co-Principal Investigator |
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| Project/Grant Period: | 12/01/2012 - 11/30/2018 |
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| Submitting Official (if other than PD\PI): | John H Porter<br>Co-Principal Investigator |
| Submission Date: | 11/17/2016 |
| Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions) | John H Porter |

## Accomplishments

*** What are the major goals of the project?**

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 of 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: *Core Data Collection*

Collection of core long-term datasets: physical drivers (meteorology, tides, groundwater levels), marsh and seagrass biomass/production, coastal bay water quality and fish diversity/abundance, and the distribution/abundance of small mammals, mesopredators migratory shorebirds, and intertidal invertebrate prey for shorebirds on the barrier islands. We began testing if GPS measurements could be used to monitor marsh elevation change at large spatial scales with accuracy similar to measurements currently done with surface elevation tables at the plot scale.

*Mechanisms of non-linear state change*

Marshes: To examine the upland-marsh transition in response to sea-level rise and storms, we monitored wells on transects from salt marshes to agricultural fields and forests. We also measured leaf water potential of different tree species and light intensity. For the marsh-lagoon boundary, we used high-resolution field measurements and cellular automata simulations to study erosion by wave action. We have previously investigated biotic feedbacks of plant characteristics and invertebrate activity on erosion. We also established a new long-term experiment to address how oyster reefs affect marsh erosion. In response to the mid-term review, we added a new PI to study the role of ecological interactions – facilitation and grazing – on plant production and feedbacks on geomorphic processes (sediment trapping, organic matter production) that allow marshes to maintain elevation with rising seas. We surveyed 3 marshes to quantify the effect of fiddler crabs (facilitative species) and purple marsh crabs (herbivore) on soil strength and sediment deposition. These data will be used to design caging studies to test these species effects in isolation and together.

Coastal bays: We monitored seagrass biomass and temperature/light sensors that bracket the model-predicted depth threshold of seagrass distribution in the long-term, landscape-scale restoration experiment. These data will quantify minimum light requirements and temperature thresholds for our predictive hydrodynamic - seagrass growth model. We are determining the consequences of seagrass state change at population to ecosystem levels, including metabolism (using aquatic eddy covariance approach), carbon/nitrogen cycling and sequestration, and fish abundance/diversity.

Barrier islands: We continue to study the impacts of shrub expansion on mesopredator and nesting/migrant bird populations. Physiological and microclimate data were

collected inside and outside shrub thickets, and a shrub removal experiment was initiated. Predator and prey populations were monitored and related to shrub expansion. Landscape cellular automata modeling of shrub expansion that incorporates LiDAR elevation data and 30 years of satellite data of shrublands is proceeding.

Data on dune grass growth rates as a function of distance from the shoreline and elevation for 3 dune-building species from a multi-year experiment are being used to improve parameterization of our coastal dune model to assess the conditions under which barrier islands become bistable. We used the coastal dune model to assess the biological and physical factors that control whether dunes are continuous or discontinuous (therefore vulnerable to overwash in low areas).

We also developed and are running models linking island geomorphology, invertebrate prey and migrant shorebird populations using a long-term dataset to predict how climate variation affects trophic dynamics.

*Thresholds for state change*

Marshes: We coupled long-term measurements of marsh elevation change to numerical models and “marsh organ” experiments manipulating marsh elevation. We examined the role of root-zone processes in determining elevation change by quantifying root growth (computed tomography scans) and measuring organic matter decay. We used optical backscatter sensors to measure suspended sediment concentrations in 3 marshes that will be used in numerical models to predict threshold rates of sea-level rise for marsh survival. We are using remote sensing data to look at the historical relationship between barrier island upland and marsh transitions. We added wave edge erosion to GEOMBEST+ to assess the effect of backbarrier marsh edge erosion.

Coastal Bays: We used aerial photograph data of seagrass restoration plots (1 acre) over 15 years to determine if we there was an early warning indicator before marsh loss at sites below the depth threshold.

Barrier Islands: We used historical imagery and repeated field sampling to characterize the relationship between island habitat change and the distribution/abundance of mammals.

*Ecosystem Connectivity*

We coupled hydrodynamic modeling (FVCOM, Delft3D) with measurements of sediment characteristics in the coastal bays to address ecosystem connectivity via sediment transport. We developed a new method to estimate the spatial distribution of sediment properties in bays, which are important for seagrass state change, based on limited bed sampling and knowledge of the spatial distribution of water residence times (Wiberg et al. 2015).

We used Delf3D-SWAN to determine the long-term sediment budget of coastal bays. This was highlighted by the mid-term review committee as an opportunity to link state change dynamics between systems. We are determining what controls sediment flux from bays to the ocean through the inlets, and the relationship of this sediment flux to water residence time and resuspension. We are studying whether tropical cyclones/Nor’easters cause a net flux of sediments from ocean to bays or vice versa using a long-term data set of 52 historical storms occurring in the last 30 years.

We coupled models of vertical marsh accretion, erosion and transgression into uplands to determine how ecosystem connectivity influences marsh response to sea-level rise. We used historical maps and photographs to explore the connectivity between marshes and barrier islands, and completed a field experiment simulating hurricane overwash effects on marsh productivity. We continued our experiments on the salt-tolerant biofuel crop *K. pentacarpos* in agricultural fields abandoned due to saltwater encroachment.

We continued to study how elevation and roughness of natural and restored oyster reefs affect larval settlement, flow dynamics and wave attenuation. We used aquatic eddy covariance to determine controls and rates of metabolism. We measured wave attenuation by oyster reefs and marsh vegetation and sediment delivery onto the marsh platform. We are developing a new marsh vulnerability index that combines hydrodynamic conditions with marsh morphology (from LiDAR data) and historical rates of change.

We tested if the invasive macroalga *Gracilaria vermiculophylla* enhanced the spread and abundance of 2 pathogenic bacteria (*Vibrio parahaemolyticus, V. vulnificans*) with an algal removal experiment. We used surveys to assess if foraging of shorebirds - a possible vector for bacterial transmission - is increased on mudflats with algae.

Tidal channel networks mediate the exchange of water, nutrients and sediment between marshes and bays. Biology influences channel morphodynamics through flow and the cohesive strength of channel banks. Determining how biota affect channel networks is essential in understanding the functioning of intertidal ecosystems and their ecosystem services. We compared the channel networks of vegetated salt marshes to unvegetated systems in the Gulf of California and Yemen.

On the barrier islands, raccoon and red fox threaten beach-nesting and colonial waterbirds. The effectiveness of predator removal as a management strategy is often dependent on migration into removal areas. We used mobility data to apply cost-distance and least-cost path analyses to determine predator migration paths and sources of immigrants to barrier islands. We also used mitochondrial and nuclear DNA markers to identify sources and pathways of connectivity between populations.

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 is 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 is 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 are 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 and carbon sequestration.

Barrier Island Grassland vs. Shrub Thicket. Our objective is 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.

Barrier Island Geomorphology, “High” vs. “Low” Islands. Our objective is 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) is varied to evaluate the effect on island state (high vs. low).

*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 is 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 is 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. We are building an artificial seagrass bed to examine experimentally if the physical structure of seagrass shoots at these depths will allow colonization or successful growth..

Barrier Islands. Our objective is to continue monitoring fronts of shrub expansion to identify specific thresholds of change (i.e. introduction of nitrogen-fixer *Frankia* to the soils). We will identify changes in key ecosystem parameters along dune/swale transects and related these to elevation (nearness to groundwater). This will 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 is to quantify sediment fluxes from the tidal flat to the marsh at 2 sites in Hog Island Bay.

Seagrass – Marsh. Our objective is 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 is to perform a new long-term experiment in which we construct artificial oyster reefs and measure waves, mean currents, turbulence, suspended sediment concentrations and larval recruitment.

Barrier Island – Back-barrier Marsh. To explore couplings between barrier islands and back-barrier marshes, our objective is 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 is to assess how the invasion of the macroalgae, Gracilaria vermiculophylla, affects nitrogen subsidies and trophic dynamics in adjacent marshes and mudflats.

Subsidy support and expansion of aquaculture. Our objective is 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 Shange & Projected Climate/land-use Drivers*

Intertidal Habitats. To determine rates of transgression, our objective is to quantify historical rates of marsh expansion at the forest edge from aerial photographs.

Subtidal Habitats. Our objectives are to: 1) address how location affects habitat suitability for restoration and resilience of seagrass meadows, and 2) understand how meadow patchiness (size and configuration) affects vegetation feedbacks on sediment suspension, light attenuation, and state-change dynamics. Changes in land use will

affect nutrient loading to subtidal habitats, and our objectives are 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 streams.

Island Habitats. Building on our 30-yr historical analysis of vegetative cover change, our objectives are: 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 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. These remote-sensing analyses will be integrated with long-term data on species distributions and local-scale mechanisms to model vegetation change in the context of climate change scenarios of shoreline migration and sea-level rise.

Habitat/Vegetation/Faunal Analysis. Our objective is 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 1984-2010. The layers contain data for 14-22 land-cover classes with 30-m pixel resolution. For island faunal dynamics, our objectives are to: 1) determine species occupancy for evidence of local extinctions and/or colonizations, 2) determine genetic relationships among populations, 3) determine species diversity as evidence of community-level changes over time, 4) quantify the relationship between species diversity and island attributes such as size, isolation and habitat complexity which can be used to predict future distributions relative to changes in elevation and vegetation cover driven by climate, and 5) assess effectiveness of predator removal as a strategy for conservation management for waterbirds.

*Socio-ecological Drivers*

Our objective is 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 initiated a long-term experiment to explore the ecological and economic benefits of alternative biofuel crops in agricultural fields abandoned due to sea-level rise. Our objective is to determine if conversion of abandoned agricultural fields to salt marsh is facilitated by planting salt-tolerant agricultural crops.

Significant Results:

*Mechanisms of Non-linear State Change*

Coastal Bays. Seagrass state change results in restoration of ecosystem services. Compared to bare sediments: 1) carbon metabolism increases 10-25x (Fig. 1) and sediments bury "blue carbon" at rates similar to mature meadows after 10 yr; 2) denitrification rates are 3-4x higher indicating that seagrass are an effective nutrient filter; 3) biodiversity and abundance of fish and bivalves are increased. Blue carbon burial is spatially heterogeneous, and is driven by proximity to meadow edge. Resilience of seagrass systems is also hetereogeneous; loss and recovery are driven by temperature.

Marshes. Based on a large dataset of lateral erosion rates collected around the world and at VCR, we determined the response of marsh boundaries to wave action under normal and extreme weather conditions (Fig. 2, Leonardi et al. 2016). As wave energy increases, marsh response to wind waves remains linear, and there is not a critical threshold in wave energy above which marsh erosion drastically accelerates. Our results indicate that the transition from marshes to tidal flats driven by boundary erosion occurs with relatively constant rates. We have applied our general formulation for salt marsh erosion to historical wave climates at 8 locations affected by hurricanes in the United States, including PIE and VCR. At the upland border, experiments showed that

the salt-tolerant biofuel crop, *Kosteletzkya pentacapros* enhanced growth of high marsh plants.

Barrier Islands. We have identified plant functional types based on burial tolerance associated with differing dune topographic state that influence barrier island resilience to disturbance (Zinnert et al. 2016). We found that shrub establishment impacts microclimate and species composition by creating a feedback that further enhances shrub growth and productivity by moderating summer and winter temperatures (Fig. 3).

Our simplified one-dimensional model of foredune height (Goldstein and Moore, 2016) corroborates the earlier findings of Duran and Moore (2015) indicating the tendency for local island elevation to exhibit bistability in certain regions. Model results match observations for the VCR and other areas on the U.S. East Coast. Analysis of biological and physical factors that control whether dunes are continuous or discontinuous (hummocky) shows that the time it takes for gaps between hummocks to anneal is longer when the lateral growth rate of dune-building vegetation is slower. This is likely because overwashing of low areas resets the dune-building process, leading to the tendency for gaps to persist. This biological control on hummockiness has key implications for the VCR because a transition from dominance of *Ammophila breviligulata* (rapid lateral growth; continuous dunes) to dominance of *Uniola paniculata* (slower lateral growth; hummocky dunes vulnerable to storm overwash) is anticipated with warming temperatures.

*Thresholds for State Change*

Marshes. Long-term Sediment Elevation Table (SET) data indicate that mainland marshes are building soil elevation at a rate similar to or exceeding the rate of relative sea-level rise, but lagoonal marshes are not. Plant root growth accounts for >50% of vertical elevation change. Numerical models of marsh accretion parameterized with suspended sediment concentrations measured at 4 sites predict mainland marshes should accrete in equilibrium with current sea-level rise rates, and are consistent with SET data. The models predict a threshold rate of sea-level rise, beyond which marshes convert to open water. Disturbance experiments in the marsh organs illustrate that the state change is preceded by critical slowing down (Kirwan et al. 2016).

Barrier Islands. Areas with little vegetative cover are actively migrating, whereas island areas with frequent transitions between states are experiencing shoreline erosion with little migration. Areas with expansion of woody vegetation exhibit resistance to change in short-term intervals. We are investigating if there is a threshold level of vegetation cover associated with state change. We are continuing to monitor and analyze threshold water levels for shrub productivity/expansion.

Coastal Bays. The 15-year aerial photographic record show signs of "flickering" as an early warning indicator of seagrass loss of meadows in the depth range where the numerical model shows that seagrass are bistable.

*Ecosystem Connectivity*

Natural and restored intertidal oyster reefs are effective at reducing wave energy for intermediate water depths, but are much less effective for deeper water (high tide and storm surge). This suggests a fringing reef may provide some benefit in reducing edge erosion for marshes with elevations close to mean sea level, such as are relatively common along the mainland, but are less likely to be benefit marshes located higher in the tidal frame (Fig. 4). At some sites, owing to wave conditions or reef design, we saw almost no effect of reefs on wave attenuation. This has led us to propose a new long-term study to compare the efficacy of differing constructed reef designs on wave attenuation, habitat provision, shoreline stabilization and sediment supply for marsh accretion.

Wave driven erosion of marsh edges leads to lateral marsh loss, but enhances the ability of the remaining marsh to survive sea level rise by providing sediment to build vertically. Migration of marshes into adjacent uplands can compensate for marsh loss from erosion or drowning, but this depends on connectivity between marsh and upland ecosystems.

Clam beds occupy only a small portion of bays, but have a large impact on ecosystem fluxes such as grazing on phytoplankton and transfer of carbon and nitrogen to sediments. Nitrogen release by clams and uptake by macroalgae represents a potential eutrophying process (Murphy et al. 2016).

Adding marsh edge erosion by wind waves in the barrier island GEOMBEST+ model results in wider, more resilient back-barrier marshes. Marsh edge erosion is a more important sediment source to the marsh platform than vertical erosion of a drowned marsh surface (Lauzon et al., in review). Where back-barrier marshes and bays are keeping up with sea level, and sediment is retained in the bays, the behavior of the marsh edge can be predicted by basin geometry and the sediment input. Islands with higher woody cover experience less conversion of marsh to upland.

Comparison between vegetated and unvegetated intertidal platforms shows that unvegetated systems are dissected by less efficient channel networks than marshes like those found at VCR and PIE. This reflects differences in branching and meandering of channels in the network, characteristics that are related to vegetation density. A high geometric efficiency — corresponding to a low unchanneled path length — means the fresher, oxidized region near channels covers a relatively larger area of the platform. Therefore, an efficient network should support more productive vegetation.

Aquatic eddy covariance measurements on intertidal oyster reefs showed that benthic metabolism scales linearly with population density as reefs grow and develop. Reef metabolism was found to be significantly dependent on both light and current velocity.

*State Change & Projected Climate/land-use Drivers*

Climate change is driving species range expansions. Life-history theory based on the enemy-release-hypothesis predicts that "vanguard" populations at the edge of expansion will invest more in growth and reproduction than enemy defense. The fiddler crab, *Uca pugnax*, has extended its range northward. As part of cross-site analyses we have collected *U. pugnax* from Florida to Massachusetts including PIE, GCE and VCR to analyze the diet, body size, and fecundity of fiddler crabs to address hypotheses about niche-widths and phenotypes.

Key outcomes or Other achievements:

VCR scientists have published 149 journal articles and 16 book chapters during this funding cycle. A complete list of publications can be found at http://www.vcrlter.virginia.edu/home1 /biblio.

*Mechanisms of State Change & Ecological Consequences*

Coastal Bays

Long-term data from landscape-scale seagrass restoration experiment supports model results of depth threshold for state change; potential for state change at landscape scale depends on water quality and sediment characteristics. Seagrass state change has ecological benefits: enhances metabolism, carbon and nitrogen sequestration, promotes biodiversity, and increases water quality. Coupled models predict that seagrass presence does not limit sediment supply for marsh accretion.

One of the primary potential impacts of climate change on seagrass is increasing water temperature. Days with water temperatures exceeding 28-30 C, particularly in early summer, can adversely affect growth rates and plant survival. Water temperature in the VCR bays is controlled by a combination of local heating/cooling and the regional sea-

surface temperatures (SST) of the mid-Atlantic water that exchanges with bay water through tidal exchange at the 12 inlets along the Virginia Delmarva coast. We have begun an analysis of remotely sensed SST from AVHRR satellites (~1 km resolution), which are available at several times every day - clouds permitting - for the Chesapeake Region (including the VCR) courtesy of the Coastal Ocean lab at Rutgers University (RUCOOL; (https://rucool.marine.rutgers.edu). A preliminary analysis showed that satellite-derived temperatures are in good agreement with in situ time series measurements at several locations (Fig. 5). We have just been given access to the considerable data archives maintained by RUCOOL and are beginning a systematic analysis of seasonal spatial patterns and variability of temperature in the bays.

Barrier Islands

Over the last 30 years, barrier island area (upland and marsh) has been reduced by 35%. This represents 1600 ha of backbarrier marsh loss. At the same time, woody cover increased by 40% across all islands (ZInnert et al. 2016, Fig. 6). Cross-island topography and species composition is integral in determining barrier island resilience to disturbance.

We have extended the 2 previously identified stability domains (high and low) to cross-island transects, and identified areas that are transitional between states. We have associated ecological characteristics and plant functional types that influence barrier island resilience. Low and high islands, or portions of islands are associated with unique shorebird prey and shorebird communities. Shrub establishment has an immediate effect on the environment, reducing species diversity and modifying the microenvrionment to enhance shrub growth. This has landscape-level consequences for barrier island migration.

The link between barrier island geomorphology and vegetation has trophic-level ecological consequences affecting mammals and nesting shorebirds and can be used to predict how changes in ocean temperatures and storminess will impact abundance and availability of invertebrate prey to spring migrant birds.

The distribution of raccoons on the islands has expanded over the past 30+ years, with islands near the mainland having greater recolonization. The minimum costs of immigration to specific islands vary >3 orders of magnitude, making some islands better targets for predator removal to aid recovery of shorebirds.

Tidal Marshes

Marshes tend to be stable in vertical dimension (i.e. build elevation with sea level rise), but with thresholds and warning signals. Threshold rate of sea-level rise between regions increases with sediment concentration and tidal range (Fig. 7). Marshes are inherently unstable at seaward and landward boundaries (erosion + migration). Physical and biological processes dictate the heterogeneity of marsh boundaries, and this heterogeneity drives non-uniform marsh erosion and state change between tidal flats and salt marshes. We can forecast the state change from marsh boundary variability.

The fate of marshes cannot be assessed without consideration of adjacent ecosystems (bays, uplands, barrier islands). If enough adjacent land to accommodate severe loss of existing marsh, expansion is possible. Marsh response to sea-level rise depends on human response - the interaction between sea-level rise and human impacts is more important than the rate of sea-level rise itself.

*Ecosystem Connectivity*

Restored oyster reefs attenuate wave energy at intermediate water depths but are significantly less effective for deeper water conditions that allow for the development of larger waves. Reefs remove sediment from the water column at moderate flow speeds

but can contribute sediment to the water column as flow speeds large enough to resuspend sediment from the reef structure.

Based on the analysis of two decades of data, we find that large storms and hurricanes contribute less than 1% to long-term salt marsh erosion rates. In contrast, moderate storms with a return period of 2.5 months cause most salt marsh deterioration. Therefore, salt marshes seem more susceptible to variations in mean wave energy rather than changes in the extremes (Leonardi et al. 2016).

For the sediment budget of the VCR lagoons, preliminary results with the numerical model Delft3D-SWAN indicate that energetic nor'easters and hurricanes produce a net flux of fine sediments (silt and clay) from the bays to the ocean, which correlates to the magnitude of the storm surge (Fig. 8).

*Coupled Nonlinear Dynamics of Adjacent Systems*

In systems with large fetch, like the VCR, seagrass meadows positively affect marshes by reducing wave energy acting on the marsh boundary. Increased sediment suspension from marsh erosion decreases light availability and has a negative feedback on seagrass ecosystems.

On barrier islands, storm overwash is the key mechanism linking marshes and barrier islands, and is important for maintaining narrow back-barrier marshes. Frequent thin deposition stimulates productivity and alleviates flooding stress. The presence of back-barrier marshes reduces island migration rate by about 30%. Extensive woody vegetation reduces overwash and transition of marsh to upland.

*Interacting Drivers, Future Scenarios and Resilience*

The barrier island response to climate change depends on plant species composition, overwash and barrier/marsh couplings. Barrier island vulnerability to storm overwash depends on the likelihood that dunes will re-establish prior to the next storm event. Range expansion of the southern dune-building grass could cause dunes to become discontinuous and hummocky. These changes increase vulnerability to overwash and island migration rates, with consequences for beach area, island vegetation, and habitat availability for predators and shorebirds.

The spatial extent of marshes under future scenarios of climate and land-use change is controlled by the balance between state changes at its boundaries (erosion at the bay-marsh interface and transgression of marsh into higher elevations at the forest-marsh interface). Marsh loss is inevitable unless erosion at the seaward edge is compensated by expansion of marshes into adjacent uplands, which can only occur in the absence of anthropogenic structures. Moderate sea-level acceleration will actually lead to net marsh expansion, although faster accelerations lead to net marsh loss.

Increased temperatures beyond threshold tolerances of seagrasses leads to seagrass loss, though the response in heterogeneous and appears to be related to local-scale temperature differences. Our long-term experiment (15 years) has captured a major temperature disruption that led to seagrass loss and this gives us a unique opportunity to measure recovery and resilience. Our data thus far indicate that seagrass meadows are resilient, and recovery rates are related to local-scale temperatures.

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

14 graduate students, 4 post-docs and 11 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.

Ongoing K-12 Activities.

Each year two professional development workshops for teachers on the Eastern VA Shore are held: Coastal Bay Ecology and Fall Migration Ecology professional development Workshops on the Eastern Shore. In addition to these science based workshop the VCR-LTER also supports two Art and Ecology based workshops each year. One couples instruction in Plein Aire Landscape painting techniques with an introduction to Salt Marsh Ecology. The other combines instruction in Observational Drawing techniques with an introduction to environmental monitoring programs and discussions of environmental issues impacting coastal ecosystems. Artwork and essays generated from the workshops were displayed in public exhibitions at the Barrier Islands Center Museum on the Eastern Shore and in the Science and Engineering library at the University of Virginia. We also run an Oyster Gardening Program that provides training and curriculum materials for local teachers along with classroom materials and field trips run in partnership with VA Oyster Reef Keepers. Together these programs impact over 45 teachers each year.

Summer Science Internships are offered for local high school students through our Research Experience for High School Students (REHS) program, made possible by leveraging SLTER Funds with additional support from The Nature Conservancy (TNC). We run a Water Cycle/Nutrient Dynamics field trip at the VCR for class groups from across Virginia.

Teachers from the Kiptopeke and Occohannock Elementary Schools Talented and Gifted Program (TAG) have received instructional training and supplies to participate in the Oyster Gardening Program. TAG groups at both schools grew and monitored batches of baby oysters during the school year. In 2015, 28 of these students participated in a half-day water quality and coastal habitat field trip on the Eastern Shore.

Working with our partners at TNC and Chesapeake Experience we support a 1-week coastal ecology camp for local 12-14 year old children in August. Participants use kayaks to explore coastal ecosystems and learn about environmental issues impacting the area.

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 underrepresented groups. Two VCR researchers are part of a collaborative team led by colleagues at the GCE LTER teaching a on-line distributed graduate course entitled "Sea level rise and saline intrusion into coastal habitats" that involves 14 institutions, and over 100 students and 15 researchers.

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

The VCR disseminates research findings and data through the VCR LTER website (www.vcrlter.virginia.edu). Use of the website is holding steady, with 21,423 page views in 6,336 sessions by 4,296 users during the period 2015-09-01 through 2016-08-31. During that same period, VCR/LTER data files were downloaded 5,827 times from the LTER Data Portal.

The VCR Science Education Coordinator along with PIs and graduate students are invited speakers for presentations at venues like the Barrier Islands Center Museum, Eastern Shore Community College, Science and Philosophy seminar series, Garden Club and Rotary club meetings. These presentations are open to the public and attended by local residents and county planners/administrators. VCR PIs and graduate students from UVA and our partner institutions also provide lectures to school and public groups in their areas.

The VCR Citizen Science Program includes collaborations with the VA Oyster Reef Keepers and the VA Master Naturalists.

Several VCR investigators and our Education/Outreach Coordinator serve on the Eastern Shore’s Climate Adaptation Working Group. We are partners with TNC and other regional universities on a Department of Interior (DOI) funded Coastal Resilience grant. Activities supported by leveraged funding from a NSF Coastal SEES project and the DOI Coastal Resilience project engage regional stakeholders and policy makers in visioning scenarios of climate change and in understanding the impacts of specific adaptation actions on wetland vulnerability and coastal resilience. Our Education/Outreach Coordinator is a science advisor to the Accomack- Northampton County Planning District Commission’s Hazard Mitigation Plan update and has been elected to their Resource Conservation and Development Committee. In 2014 we signed an MOU with the NASA Wallops Island Flight facility and partners from TNC, Virginia Institute of Marine Sciences, University of Maryland, University of Delaware, Old Dominion University and the Chincoteague Bay Field Station to form the Mid-Atlantic Climate Research Institute.

In 2015, the ABCRC hosted a visiting group from Panama to train researchers on methods to monitor carbon flux in coastal ecosystems using eddy covariance and a delegation from Ghana investigating the challenges of conserving barrier island-lagoon ecosystems facing climate change and sea-level rise.

The experimental work on planting salt-tolerant *K. pentacarpos* as an adaptation strategy for farmers to sea-level rise is being done as a demonstration project with TNC and colleagues at the University of Delaware. We have presented our work at the Virginia Tech Agricultural Experiment Station Field Days and our research was the topic of a feature article in The Delmarva Farmer, an American Farm publication. We plan to expand the demonstration projects in collaboration with Agricultural Extension Agents to engage more local farmers known to have abandoned fields adjacent to encroaching salt marshes.

Online curriculum for middle school students were created to meet Commonwealth of Virginia learning standards for Environmental Sciences. Two online modules were developed: (1) Sea-level rise impacts on coastal communities, and (2) Marine biology and coastal ecosystems. (http://www.wiseengineering.org)

VCR scientists are working with TNC to develop and test a new Coastal Resilience on-line decision-support tool for managers and the public to better understand and explore the effects of land-use decisions and climate change on flooding potential and shoreline erosion.

The VCR is a site in the NOAA Sentinel Site Program for the Chesapeake Bay Sentinel Site Cooperative to assess marsh response to sea-level rise.The Cooperative works to maximize the effectiveness of data collection, modeling, and synthesis of marsh responses to a changing climate. The VCR is hosting a SET workshop for Chesapeake Bay region scientists to discuss new ways to collaborate and synthesize data long-term marsh elevation, vegetation, and local sea-level change data sets.

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

In response to suggestions by the mid-term review team in 2015, we will continue to do the following: 1) develop a sediment budget for the VCR, which will be useful in linking subsystems across the landscape; 2) focus on biotic feedbacks on state change; in addition to our current activities, we have added a new PI, David Johnson, to address fauna-mediated feedbacks on plant production and geomorphology; and 3) assess carbon sequestration as consequence of ecosystem state change.

*Mechanisms of Non-linear State Change*

Marshes. We will continue to analyze high-resolution data of water levels and salinity and relate these to vegetation productivity at the marsh-upland boundary. This will be done 1) along the marsh-to-forest transition and 2) in a topographic depression where tree dieback occurred and a nearby convexity were trees survived hurricane Isabel. We will collect topographic data where tree dieback occurred throughout the VCR to scale up our results to the entire marsh-forest boundary.

Coastal Bays. We will continue our analysis of ecological implications of state change on carbon and nitrogen cycling, blue carbon sequestration, and faunal biodiversity. We will use the aquatic eddy covariance approach to study resilience of seagrass after loss from temperature stress.

Barrier Islands. We will continue measurements of physical and biotic factors in the grassland/shrubland transition zone. We will continue monitoring the shrub removal experiment and continue automating the transition matrices of land-cover change to capture changes for each of the time steps for which we have data. We are particularly interested in the trajectories and transition probabilities for upland areas. We will focus on transitions between sand, grassland, shrubland, and forest, as these are important for small mammals, mammalian predators and shorebirds.

We will use existing LiDAR data and time series for wind and water levels to analyze the likely number of ‘dune-building days’ for key locations in the VCR as a way to understand the time scales for dune recovery following storms.

*Thresholds for State Change*

Marshes. We will continue to integrate data from marsh SETs and field sampling of suspended sediment concentrations into our model of marsh state change and threshold responses. We will address this state change on a larger spatial scale, targeting specific locations in the VCR.

Coastal Bays. We will continue to monitor experimental seagrass plots to evaluate resilience to high-temperature events. We will use remotely sensed sea-surface temperatures from AVHRR satellites (~1 km resolution) to do a systematic analysis of

seasonal spatial patterns and variability of temperature in the bays. This will be used both to forecast future expansion of seagrass and hindcast the effects of past high-temperature events on seagrass distribution. We will initiate a new experiment of seagrass removal over different depths to determine if proximity to the critical threshold depth influences rates of recovery.

Barrier Islands. We will integrate species composition/cover and environmental variables to further develop our model of state change in grassland and shrubland. We are using historical remote sensing data to determine threshold levels of vegetative cover.

*Ecosystem Connectivity*

The Nature Conservancy constructed several artificial oyster reefs in 2015 - 2016 that we will use to monitor their role in stabilizing the marsh edge. A reef rebuilt in 2014 and 2015 will be the focus of long-term measurements of waves, currents, turbulence, and suspended sediment concentrations. Additional reefs over a range of ages (from 1 to 50 years) will be monitored to determine how wave attenuation is affected by reef morphology, water depth, incident wave height, and wind speed. Rates of accretion/erosion of the marsh edge will be monitored using aerial photography and surveying. We plan to begin a new long-term experiment with 5 different reef designs to monitor design effects on habitat provision and shoreline-erosion protection.

We will continue to address the relationship between vegetative cover, island width, and upland rollover onto the marsh by analyzing island segments. We are also constructing a carbon budget for the barrier island upland.

To examine the possibility of state changes in one landscape unit affecting the state of adjacent units through two-way couplings, we will extend our barrier island/back-barrier marsh work by adding seagrass dynamics to the GEOMBEST+ model.

To determine the long-term sediment budget of the VCR coastal bays, we will compute sediment fluxes with the numerical model Delft3D-SWAN under a variety of conditions, including storms and hurricanes. These fluxes will be integrated with measurements of erosion rates at marsh boundaries and accretion at the marsh surface.

*Subsidies*

We will test if macroalgal mats, by attracting invertebrates like amphipods, promote movement of *Vibrio* pathogens through bird foraging on amphipods. We will test for the abundance of the two *Vibrio* species in mats, amphipods, oysters, and bird feces on mudflats with high and low macroalgal densities and will also conduct experimental manipulations of *G. vermiculophylla* to test for its effects on pathogen abundance. For the aquaculture studies, we will continue to monitor trends in clam production using aerial photos taken annually. Studies of nutrient cycling related to aquaculture will also be continued. We will further explore the potential for impacts and subsidies, particularly the effects of enhanced nutrient fluxes in these oligotrophic bays.

*State Change & Projected Climate/land-use Drivers*

We are currently adding marsh edge erosion by waves into our coupled model of barrier island-marsh evolution. This work will be based on relatively simple relationships between erosion rate and wave power (McLoughlin et al. 2015), including the influence of tidal-flat fetch and depth on wave characteristics. The new model will consider connectivity between barrier islands, marshes, and tidal flats, and the impact of these couplings on system response to sea-level rise and storms. We will continue to monitor the dune grass transplantation experiment, the post-fertilized dune plots, and the expansion of *Uniola*, the grass species that could cause biotic feedbacks that make dunes more vulnerable to storm overwash To address the affects of shrub expansion on island fauna, we will 1) continue to relate long-term data on vegetation change, mammal predators and shorebird populations; 2) continue analysis of how climate-driven geomorphology changes affect shorebird abundance, habitat selection and prey availability; 3) add camera trapping for mammals on several islands; and 4) conduct additional trapping to assess changes in small mammal populations. We will add in manipulations of sea-level rise to the shrub/grass model.

Using the vulnerability index developed by Duran and Moore (2015) we will also model barrier island vulnerability to overwash as a function of the likelihood that dunes will re-establish prior to the next storm event.

*Socio-ecological Drivers*

In our studies of attitudes of the populace of the Eastern Shore, a second survey is being developed to consider choices from the perspective of the public’s willingness to ask owners of on-coast properties to change their planned responses to sea-

level rise.

We will continue our recently established (2012) long-term experiment designed to explore the ecological and economic benefits of *K. pentcarpos* in abandoned agricultural fields (e.g., nutrient and carbon sequestration, exclusion of invasive species). We will explore the ecological and economic benefits of *K. pentcarpos*. We are working with scientists at the Virginia Tech Agricultural Field Station to determine if growing alternative, salt resistant, crops provide can be used in Best Management Practices to reduce nitrogen runoff and store carbon in soils.

**Supporting Files**

| Filename | Description | Uploaded By | Uploaded On |
|---|---|---|---|
| VCR LTER 2016 Annual Report Figures FINAL.pdf | Figures for the Significant Results and Key Outcomes sections | John Porter | 11/14/2016 |

## Products

### Books

### Book Chapters

Emery, Kyle A and Gephart, Jessica A and Wilkinson, Grace M and Besterman, Alice F and Pace, Michael L (2016). Exploring Trophic Cascades in Lake Food Webs with a Spreadsheet Model. *Learner-Centered Teaching Activities for Environmental and Sustainability Studies* Springer. 111-115. Status = PUBLISHED; Acknowledgement of Federal Support = No ; Peer Reviewed = No

Hayden, Bruce P. (2016). Networking: From the Long-Term Ecological Research Program to the National Ecological Observatory Network. *Long-Term Ecological Research, Changing the Nature of Scientists* Willig, Michael R. and Walker, Lawrence R.. Oxford University Press. New York. 375-380. Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes

Porter, John H (2016). Sharing information: many hands make light work. *Long-Term Ecological Research, Changing the Nature of Scientists* Willig, Michael R. and Walker, Lawrence R.. Oxford University Press. New York. 381-388. Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes

### Inventions

### Journals or Juried Conference Papers

Bissett, Spencer N and Zinnert, Julie C and Young, Donald R (2016). Woody expansion facilitates liana expansion and affects physical structure in temperate coastal communities. *Ecosphere*. 7 (6), e01383. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/ecs2.1383

Carr, J. A. and D'Odorico, P. and McGlathery, K. J. and Wiberg, P. L. (2016). Spatially explicit feedbacks between seagrass meadow structure, sediment and light: Habitat suitability for seagrass growth. *Advances in Water Resources*. 93 part 315-325. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.advwatres.2015.09.001

Elko, Nicole and Brodie, Kate and Stockdon, Hilary and Nordstrom, Karl and Houser, Chris and McKenna, Kim and Moore, Laura and Rosati, Julie and Ruggiero, Peter and Thuman, Roberta (2016). Dune management challenges on developed coasts. *Shore & Beach*. 84 (1), 15. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Emery, Kyle A and Wilkinson, Grace M and Camacho-Ibar, Victor F and Pace, Michael L and McGlathery, Karen J and Sandoval-Gil, Jose M and Hernández-López, Julieta (2016). Resource use of an aquacultured oyster (Crassostrea gigas) in the reverse estuary Bahia San Quintin, Baja California, Mexico. *Estuaries and Coasts*. 39 (3), 866-874. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s12237-015-0021-9

Fagherazzi, Sergio and Edmonds, Douglas A and Nardin, William and Leonardi, Nicoletta and Canestrelli, Alberto and Falcini, Federico and Jerolmack, Douglas J and Mariotti, Giulio and Rowland, Joel C and Slingerland, Rudy

L (2015). Dynamics of river mouth deposits. *Reviews of Geophysics*. 53 (3), 642-672. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2014RG000451

Fenster, Michael S. and Dolan, Robert and Smith, Jodi Jones (2016). Grain-size distributions and coastal morphodynamics along the southern Maryland and Virginia barrier islands. *Sedimentology*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1111/sed.12239

Ganju, Neil K. and Kirwan, Matthew L. and Dickhudt, Patrick J. and Guntenspergen, Glenn R. and Cahoon, Donald R. and Kroeger, Kevin D. (2015). Sediment transport-based metrics of wetland stability. *Geophysical Research Letters*. 42 (19), 7992-8000. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2015GL065980

Goldstein, Evan B and Moore, Laura J (2016). Stability and bistability in a one-dimensional model of coastal foredune height. *Journal of Geophysical Research: Earth Surface*. 121 (5), 964-977. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2015JF003783

Greiner, JT and Wilkinson, GM and McGlathery, KJ and Emery, KA (2016). Sources of sediment carbon sequestered in restored seagrass meadows. *Marine Ecology Progress Series*. 551 95-105. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.3354/meps11722

Henriques Antão, Laura and Connolly, Sean R and Magurran, Anne E and Soares, Amadeu and Dornelas, Maria (2016). Prevalence of multimodal species abundance distributions is linked to spatial and taxonomic breadth. *Global Ecology and Biogeography*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1111/geb.12532

Hubbard, A. and Reidenbach, M.A. (2015). The effects of larval swimming behavior on the dispersal and settlement of the eastern oyster, Crassostrea virginica. *Marine Ecology Progress Series*. 535 161-176. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.3354/meps11373

Kearney, William S. and Fagherazzi, Sergio (2016). Salt marsh vegetation promotes efficient tidal channel networks. *Nature Communications*. 7 12287. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1038/ncomms12287http://www.nature.com/articles/ncomms12287#supplementary-information

Kirwan, Matthew L and Walters, David C and Reay, William G and Carr, Joel A (2016). Sea level driven marsh expansion in a coupled model of marsh erosion and migration. *Geophysical Research Letters*. 43 (9), 4366-4373. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2016GL068507

Kirwan, Matthew L. and Temmerman, Stijn and Skeehan, Emily E. and Guntenspergen, Glenn R. and Fagherazzi, Sergio (2016). Overestimation of marsh vulnerability to sea level rise. *Nature Clim. Change*. 6 (3), 253-260. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1038/nclimate2909http://www.nature.com/nclimate/journal/v6/n3/abs/nclimate2909.html#supplementary-information

Leonardi, Nicoletta and Defne, Zafer and Ganju, Neil K and Fagherazzi, Sergio (2016). Salt marsh erosion rates and boundary features in a shallow Bay. *Journal of Geophysical Research: Earth Surface*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2016JF003975

Leonardi, Nicoletta and Ganju, Neil K and Fagherazzi, Sergio (2016). A linear relationship between wave power and erosion determines salt-marsh resilience to violent storms and hurricanes. *Proceedings of the National Academy of Sciences*. 113 (1), 64-68. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1073/pnas.1510095112

Lunstrum, Abby and Aoki, Lillian R (2016). Oxygen interference with membrane inlet mass spectrometry may overestimate denitrification rates calculated with the isotope pairing technique. *Limnology and Oceanography: Methods*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/lom3.10101

Mariotti, G and Kearney, WS and Fagherazzi, S (2016). Soil creep in salt marshes. *Geology*. 44 (6), 459-462. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1130/G37708.1

Marsh, Amanda and Blum, Linda K and Christian, Robert R and Ramsey, Elijah and Rangoonwala, Amina (2016). Response and resilience of Spartina alterniflora. *Journal of Coastal Conservation*. 20 (4), 335-350. Status = PUBLISHED;

Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s11852-016-0445-9

Moore, Laura J and Vinent, Orencio Duran and Ruggiero, Peter (2016). Vegetation control allows autocyclic formation of multiple dunes on prograding coasts. *Geology*. 44 (7), 559-562. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: DOI: 10.1130/G37778.1

Murphy, A.E. and Anderson, I.C. and Luckenbach., M. W. (2015). Enhanced nutrient regeneration at commercial hard clam (Mercenaria mercenaria) beds and the role of macroalgae. *Marine Ecology Progress Series* . 530 135-151. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.3354/meps11301

Murphy, Anna E and Emery, Kyle A and Anderson, Iris C and Pace, Michael L and Brush, Mark J and Rheuban, Jennie E (2016). Quantifying the Effects of Commercial Clam Aquaculture on C and N Cycling: an Integrated Ecosystem Approach. *Estuaries and Coasts*. 1-16. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s12237-016-0106-0

Murphy, E.A. and Reidenbach, M.A (2016). Oxygen transport in periodically ventilated polychaete burrows. *Marine Biology*. 163 208. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s00227-016-2983-y

Nardin, W and Edmonds, DA and Fagherazzi, S (2016). Influence of vegetation on spatial patterns of sediment deposition in deltaic islands during flood. *Advances in Water Resources*. 93 236-248. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.advwatres.2016.01.001

Pace, Michael L and Gephart, Jessica A (2016). Trade: A Driver of Present and Future Ecosystems. *Ecosystems*. 1-10. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s10021-106-0021-z

Priestas, Anthony M and Mariotti, Giulio and Leonardi, Nicoletta and Fagherazzi, Sergio (2015). Coupled Wave Energy and Erosion Dynamics along a Salt Marsh Boundary, Hog Island Bay, Virginia, USA. *Journal of Marine Science and Engineering*. 3 (3), 1041-1065. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.3390/jmse3031041

Reynolds, Laura K and Waycott, Michelle and McGlathery, Karen J and Orth, Robert J (2016). Ecosystem services returned through seagrass restoration. *Restoration Ecology*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1111/rec.12360

Schepers, Lennert and Kirwan, Matthew and Guntenspergen, Glenn and Temmerman, Stijn (2016). Spatio-temporal development of vegetation die-off in a submerging coastal marsh. *Limnology and Oceanography*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/lno.10381

Vinent, Orencio Durán and Moore, Laura J (2016). Reply to'Bistability and the future of barrier islands'. *Nature Climate Change*. 6 (1), 6-6. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1038/nclimate2803

Walters, David C. and Kirwan, Matthew L. (2016). Optimal hurricane overwash thickness for maximizing marsh resilience to sea level rise. *Ecology and Evolution*. 6 (9), 2948-2956. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/ece3.2024

Wiberg, Patricia L and Carr, Joel A and Safak, Ilgar and Anutaliya, Arachaporn (2015). Quantifying the distribution and influence of non-uniform bed properties in shallow coastal bays. *Limnology and Oceanography: Methods*. 13 746-762. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi: 10.1002/lom3.10063

Zinnert, Julie C and Brantley, Steven T and Young, Donald R (2016). Bistability and the future of barrier islands. *Nature Climate Change*. 6 (1), 5-6. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1038/nclimate2802

Zinnert, Julie C and Shiflett, Sheri A and Via, Stephen and Bissett, Spencer and Dows, Benjamin and Manley, Paul and Young, Donald R (2016). Spatial–Temporal Dynamics in Barrier Island Upland Vegetation: The Overlooked Coastal Landscape. *Ecosystems*. 19 (4), 685-697. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s10021-016-9961-6

**Licenses**

**Other Conference Presentations / Papers**

**Other Products**
*Databases.*

The VCR/LTER publishes 198 individual datasets comprised of over 200 GB of data. Many datasets span multiple decades of research. Data are also available through the LTER Data Portal (https://portal.lternet.edu) and DataONE.org (https://dataone.org).

**Other Publications**

**Patents**

**Technologies or Techniques**

MODELS:

Walters, D., **Moore, L.J.**, *Durán Vinent, O., Mariotti, G. and Fagherazzi, S., 2015. GEOMBEST-Plus (Geomorphic Model of Barrier and Estuarine Translations- Plus Dynamic Marsh), v.1.0, DOI: 10.5281/zenodo.16576

Durán Vinent, O. and **Moore, L.J.**, 2015. Coastal Dune Model, v1.0. DOI:10.5281/zenodo.16161

**Thesis/Dissertations**
Jones, M.J.. *Considering holistic coastal response to climate-change induced shifts in natural processes and anthropogenic modifications*. (2016). University of North Carolina at Chapel Hill. Acknowledgement of Federal Support = Yes

Harris, April. *Differential responses of barrier island dune grasses to species interactions and burial* . (2016). Virginia Commonwealth University. Acknowledgement of Federal Support = Yes

Brown, Joseph. *Emergent interactions influence functional traits and success of dune building ecosystem engineers*. (2016). Virginia Commonwealth University. Acknowledgement of Federal Support = Yes

Smith, Matthew L. . *Groundwater Thresholds for Root Decomposition and the Relation to Barrier Island Ecological State Changes*. (2015). Old Dominion University.. Acknowledgement of Federal Support = Yes

Thompson, Joseph. *Mechanisms of native shrub encroachment on a Virginia barrier island*. (2016). Virginia Commonwealth University. Acknowledgement of Federal Support = Yes

**Websites**
*Virginia Coast Reserve Long-Term Ecological Research*
http://www.vcrlter.virginia.edu

Central web site for the VCR/LTER. It includes information about the research, data, documents (including full-text of student theses), photographs and videos. Data include 198 datasets that are also published on the LTER Data Portal and DataONE.org

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## Participants/Organizations

**Research Experience for Undergraduates (REU) funding**

| | |
|---|---|
| Form of REU funding support: | REU supplement |
| How many REU applications were received during this reporting period? | 12 |
| How many REU applicants were selected and agreed to participate during this reporting period? | 7 |
| REU Comments: | |

**What individuals have worked on the project?**

| Name | Most Senior Project Role | Nearest Person Month Worked |
|---|---|---|
| McGlathery, Karen | PD/PI | 9 |
| Porter, John | Co PD/PI | 9 |
| Reidenbach, Matthew | Co PD/PI | 3 |
| Wiberg, Patricia | Co PD/PI | 3 |
| Anderson, Iris | Co-Investigator | 1 |
| Bachmann, Charles | Co-Investigator | 1 |
| Berg, Peter | Co-Investigator | 2 |
| Blum, Linda | Co-Investigator | 5 |
| Carr, Joel | Co-Investigator | 1 |
| Christian, Robert | Co-Investigator | 1 |
| D'Odorico, Paolo | Co-Investigator | 1 |
| Day, Frank | Co-Investigator | 1 |
| Dueser, Raymond | Co-Investigator | 3 |
| Fagherazzi, Sergio | Co-Investigator | 2 |
| Fenster, Michael | Co-Investigator | 2 |
| Fuentes, Jose | Co-Investigator | 1 |
| Galloway, James | Co-Investigator | 1 |
| Hayden, Bruce | Co-Investigator | 1 |
| Johnson, David | Co-Investigator | 1 |
| Karpanty, Sarah | Co-Investigator | 2 |
| Kirwan, Matt | Co-Investigator | 2 |
| Lawson, Sarah | Co-Investigator | 1 |
| Macko, Stephen | Co-Investigator | 1 |
| Mills, Aaron | Co-Investigator | 2 |

| Name | Most Senior Project Role | Nearest Person Month Worked |
|---|---|---|
| Moncrief, Nancy | Co-Investigator | 2 |
| Moore, Laura | Co-Investigator | 2 |
| Pace, Michael | Co-Investigator | 1 |
| Schwarzschild, Arthur | Co-Investigator | 12 |
| Smith, David | Co-Investigator | 1 |
| Swallow, Stephen | Co-Investigator | 1 |
| Young, Donald | Co-Investigator | 2 |
| Zinnert, Julie | Co-Investigator | 2 |
| Delgard, Marie Lise | Postdoctoral (scholar, fellow or other postdoctoral position) | 4 |
| Duran, Orencio | Postdoctoral (scholar, fellow or other postdoctoral position) | 12 |
| Goldstein, Evan | Postdoctoral (scholar, fellow or other postdoctoral position) | 2 |
| Smyth, Ashley | Postdoctoral (scholar, fellow or other postdoctoral position) | 6 |
| Boyd, David | Technician | 12 |
| Crowley, Cynthia | Technician | 1 |
| Maben, John | Technician | 1 |
| Walters, David | Technician | 12 |
| Aoki, Lillian | Graduate Student (research assistant) | 4 |
| Berger, Amelie | Graduate Student (research assistant) | 4 |
| Besterman, Alice | Graduate Student (research assistant) | 4 |
| Brown, Joseph | Graduate Student (research assistant) | 4 |
| Castagno, Katie | Graduate Student (research assistant) | 3 |
| Coleman, Daniel | Graduate Student (research assistant) | 6 |
| deVries, Elsemarie | Graduate Student (research assistant) | 4 |
| Dows, Benjamin | Graduate Student (research assistant) | 4 |

| Name | Most Senior Project Role | Nearest Person Month Worked |
|---|---|---|
| Ferguson, Amy | Graduate Student (research assistant) | 4 |
| Fernandes, Arnold | Graduate Student (research assistant) | 5 |
| Harris, April | Graduate Student (research assistant) | 4 |
| Heller, Erin | Graduate Student (research assistant) | 4 |
| Jiménez Robles, Alfonso | Graduate Student (research assistant) | 6 |
| Jones, Margaret | Graduate Student (research assistant) | 9 |
| Kearney, William | Graduate Student (research assistant) | 4 |
| Lauzon, Rebecca | Graduate Student (research assistant) | 4 |
| Leonardi, Nicoletta | Graduate Student (research assistant) | 2 |
| Long, E. | Graduate Student (research assistant) | 4 |
| Lunstrum, Abby | Graduate Student (research assistant) | 4 |
| Moulton, Ashley | Graduate Student (research assistant) | 4 |
| Murphy, Elizabeth | Graduate Student (research assistant) | 4 |
| Oreska, Matthew | Graduate Student (research assistant) | 4 |
| Palazzoli, Irene | Graduate Student (research assistant) | 5 |
| Reeves, Ian | Graduate Student (research assistant) | 1 |
| Ruiz-Plancarte, Jesus | Graduate Student (research assistant) | 4 |
| Schieder, Nathalie | Graduate Student (research assistant) | 3 |
| Sebillian, Serina | Graduate Student (research assistant) | 1 |
| Smith, Matt | Graduate Student (research assistant) | 1 |
| Thompson, Joseph | Graduate Student (research assistant) | 4 |
| Williams, Bethany | Graduate Student (research assistant) | 1 |
| Yue, Ian | Graduate Student (research assistant) | 4 |

| Name | Most Senior Project Role | Nearest Person Month Worked |
|---|---|---|
| Bissett, Spencer | Non-Student Research Assistant | 4 |
| Deaton, Charles | Undergraduate Student | 2 |
| Flester, Jessica | Undergraduate Student | 4 |
| Grimaudo, Alex | Undergraduate Student | 3 |
| Houghland, Callie | Undergraduate Student | 3 |
| Knepper, Sean | Undergraduate Student | 3 |
| Lipford, Aylett | Undergraduate Student | 3 |
| Longmire, Katherine | Undergraduate Student | 1 |
| Nicks, David | Undergraduate Student | 4 |
| Pirault, Tiffanie | Undergraduate Student | 3 |
| Thuma, Jessie | Undergraduate Student | 4 |
| Zhang, Jiaya | Undergraduate Student | 1 |
| Bartenfelder, Amy | Research Experience for Undergraduates (REU) Participant | 4 |
| Edwards, Lindsay | Research Experience for Undergraduates (REU) Participant | 4 |
| Himmelstein, Joshua | Research Experience for Undergraduates (REU) Participant | 4 |
| Holmes, Grace | Research Experience for Undergraduates (REU) Participant | 4 |
| Kremer, Marnie | Research Experience for Undergraduates (REU) Participant | 4 |
| Price, Taylor | Research Experience for Undergraduates (REU) Participant | 2 |
| Spady, Katie | Research Experience for Undergraduates (REU) Participant | 5 |
| Cook, Allice | Other | 1 |
| Sorabella, Laurie | Other | 1 |

**Full details of individuals who have worked on the project:**

**Karen J McGlathery**
**Email:** kjm4k@virginia.edu
**Most Senior Project Role:** PD/PI
**Nearest Person Month Worked:** 9

**Contribution to the Project:** Project leader, seagrass research

**Funding Support:** NSF

**International Collaboration:** Yes, Denmark
**International Travel:** Yes, Denmark - 0 years, 0 months, 7 days

**John H Porter**
**Email:** jhp7e@virginia.edu
**Most Senior Project Role:** Co PD/PI
**Nearest Person Month Worked:** 9

**Contribution to the Project:** Information management, sensor systems, population and community ecology of insular small mammals

**Funding Support:** NSF

**International Collaboration:** Yes, China
**International Travel:** Yes, China - 0 years, 0 months, 10 days

**Matthew A Reidenbach**
**Email:** reidenbach@virginia.edu
**Most Senior Project Role:** Co PD/PI
**Nearest Person Month Worked:** 3

**Contribution to the Project:** Research on oyster reef establishment and consequences

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

**Patricia L Wiberg**
**Email:** pw3c@virginia.edu
**Most Senior Project Role:** Co PD/PI
**Nearest Person Month Worked:** 3

**Contribution to the Project:** Studies of sediment dynamics and water movements

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

**Iris Anderson**
**Email:** iris@vims.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Studies of nitrogen and phosphorus cycling and clam aquaculture

**Funding Support:** SeaGrant, VIMS

**International Collaboration:** No
**International Travel:** No

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**Charles Bachmann**
**Email:** bachmann@cis.rit.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Use of hyperspectral remote sensing

**Funding Support:** Office of Naval Research

**International Collaboration:** No
**International Travel:** No

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**Peter Berg**
**Email:** pb8n@virginia.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Aquatic flux measurements

**Funding Support:** NSF, UVA Dean's office

**International Collaboration:** No
**International Travel:** No

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**Linda K. Blum**
**Email:** lkb2e@virginia.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 5

**Contribution to the Project:** Study of linkages between ecological and geomorphological process in salt marshes focused primarily on soil organic matter accumulation and thus plant belowground production and decomposition

**Funding Support:** UVA

**International Collaboration:** No
**International Travel:** No

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**Joel Carr**
**Email:** jac6t@Virginia.EDU
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Modeling of coastal lagoons focusing on the physical conditions associated with seagrass growth

**Funding Support:** USGS

**International Collaboration:** No
**International Travel:** No

**Robert R Christian**
**Email:** CHRISTIANR@ecu.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Network analysis, studies of marsh macrophytes

**Funding Support:** Personal

**International Collaboration:** Yes, Italy
**International Travel:** No

**Paolo D'Odorico**
**Email:** pd6v@virginia.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Modeling of coastal lagoons

**Funding Support:** UVA

**International Collaboration:** No
**International Travel:** No

**Frank Day**
**Email:** fday@odu.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Long-term studies of vegetation dynamics and water relations on barrier islands

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

**Raymond D Dueser**
**Email:** ray.dueser@usu.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 3

**Contribution to the Project:** Mammalian population and community studies

**Funding Support:** USU

**International Collaboration:** No
**International Travel:** No

**Sergio Fagherazzi**
**Email:** sergio@bu.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Modeling of coastal lagoon water and sediment dynamics

**Funding Support:** NSF, USGS

**International Collaboration:** No
**International Travel:** No

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**Michael Fenster**
**Email:** mfenster@rmc.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Monitoring of shoreline change

**Funding Support:** Randolph-Macon College

**International Collaboration:** No
**International Travel:** No

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**Jose Fuentes**
**Email:** jdfuentes@psu.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Marsh carbon fluxes

**Funding Support:** Penn State, NSF

**International Collaboration:** No
**International Travel:** No

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**James N Galloway**
**Email:** jng@virginia.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 1

**Contribution to the Project:** working on N cycling in coastal systems

**Funding Support:** UVA

**International Collaboration:** No
**International Travel:** No

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**Bruce P. Hayden**
**Email:** bph@virginia.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Climatology research, work on LTER Climate Ecosystems Dynamics blog and VCR Synthesis volume

**Funding Support:** UVA

**International Collaboration:** No
**International Travel:** No

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**David S Johnson**

**Email:** dsjohnson@vims.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Ecological control of geomorphology

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Sarah M. Karpanty**
**Email:** karpanty@vt.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Studies of birds on the Virginia Coast

**Funding Support:** Virginia Tech

**International Collaboration:** No
**International Travel:** No

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**Matt Kirwan**
**Email:** kirwan@vims.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Modeling marsh formation, marsh-barrier couplings

**Funding Support:** VIMS, NSF, USGS

**International Collaboration:** Yes, Australia, Belgium
**International Travel:** Yes, China - 0 years, 0 months, 14 days

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**Sarah Lawson**
**Email:** ssojka@randolphcollege.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Work in collaboration with Karen McGlathery on seagrass research

**Funding Support:** Randolph College

**International Collaboration:** No
**International Travel:** No

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**Stephen Macko**
**Email:** sam8f@virginia.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Research using stable isotopes

**Funding Support:** UVA

**International Collaboration:** No
**International Travel:** No

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**Aaron Mills**
**Email:** alm7d@virginia.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Worked on streambed biogeochemistry

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Nancy Moncrief**
**Email:** nancy.moncrief@vmnh.virginia.gov
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Mammalian population ecology and genetics studies

**Funding Support:** Virginia Museum of Natural History

**International Collaboration:** No
**International Travel:** No

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**Laura J Moore**
**Email:** moorelj@email.unc.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Leading investigations of barrier island bi-stability and couplings between marsh and barrier

**Funding Support:** NSF, UNC-CH

**International Collaboration:** Yes, Portugal
**International Travel:** Yes, Portugal - 0 years, 0 months, 6 days

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**Michael L Pace**
**Email:** mlp5fy@virginia.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Studied Role of clam aquaculture in VCR

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Arthur C Schwarzschild**
**Email:** arthur@virginia.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 12

**Contribution to the Project:** Educational Coordinator, Site Manager

**Funding Support:** UVA, W. Buckner Clay Endowment for the Humanities

**International Collaboration:** No
**International Travel:** No

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**David E Smith**
**Email:** des3e@virginia.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Aquatic vertebrates and education

**Funding Support:** UVA

**International Collaboration:** No
**International Travel:** No

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**Stephen Swallow**
**Email:** stephen.swallow@uconn.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Social science research related to environmental value systems

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Donald R Young**
**Email:** dryoung@vcu.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Investigating the mechanisms relating to shrub expansion across the VCR landscape

**Funding Support:** NSF, Army Research Office

**International Collaboration:** Yes, Spain
**International Travel:** No

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**Julie C Zinnert**
**Email:** jczinnert@vcu.edu
**Most Senior Project Role:** Co-Investigator
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Linking remote sensing to environmental and ecological functioning at the VCR island chain scale and spatial-temporal variability in vegetation hyperspectral indices to characterize terrain state

**Funding Support:** Army Corps of Engineers

**International Collaboration:** Yes, Spain
**International Travel:** No

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**Marie Lise Delgard**
**Email:** mld4n@Virginia.EDU
**Most Senior Project Role:** Postdoctoral (scholar, fellow or other postdoctoral position)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Worked with PIs Berg and McGlathery on lagoon and seagrass research

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Orencio Duran Duran**
**Email:** odvinent@vims.edu
**Most Senior Project Role:** Postdoctoral (scholar, fellow or other postdoctoral position)
**Nearest Person Month Worked:** 12

**Contribution to the Project:** Works with PI Kirwan on marsh modeling & process studies

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Evan Goldstein**
**Email:** ebgold@live.unc.edu
**Most Senior Project Role:** Postdoctoral (scholar, fellow or other postdoctoral position)
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Working with L. Moore on: Contributing to study of biological and physical processes involved in dune building

**Funding Support:** NSF

**International Collaboration:** Yes, Germany
**International Travel:** No

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**Ashley Smyth**
**Email:** arsmyth@email.unc.edu
**Most Senior Project Role:** Postdoctoral (scholar, fellow or other postdoctoral position)
**Nearest Person Month Worked:** 6

**Contribution to the Project:** Working with I. Anderson on nitrogen and phosphorus cycling

**Funding Support:** David H. Smith Conservation Research Fellowship

**International Collaboration:** No
**International Travel:** No

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**David M Boyd**
**Email:** dmb4dd@cms.mail.virginia.edu
**Most Senior Project Role:** Technician
**Nearest Person Month Worked:** 12

**Contribution to the Project:** Maintain rain gauge network and boats, transport researchers to field sites by boat

**Funding Support:** NSF, UVA

**International Collaboration:** No
**International Travel:** No

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**Cynthia Crowley**
**Email:** cmcrowley@vims.edu
**Most Senior Project Role:** Technician
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Working with D. Johnson on environmental control of isotopic niche width

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**John R Maben**
**Email:** jrm@virginia.edu
**Most Senior Project Role:** Technician
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Analyze precipitation sampled weekly for major ionic constituents

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**David C Walters**
**Email:** dcwalters@vims.edu
**Most Senior Project Role:** Technician
**Nearest Person Month Worked:** 12

**Contribution to the Project:** Works with PI Kirwan on marsh modeling & process studies

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Lillian Aoki**
**Email:** lra53@cornell.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Worked with PI s Peter Berg and Karen McGlathery on seagrass

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Amelie C Berger**
**Email:** acb4rk@virginia.edu

**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Working with PIs McGlathery and Berg on studies of seagrass metabolism using eddy covariance techniques

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Alice F Besterman**
**Email:** afb5kg@virginia.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Worked with PI Pace on macroalgae, invertebrate, bird and bacteria interactions

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Joseph Brown**
**Email:** brownjk5@vcu.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Worked with PIs Young and Zinnert on landscape dynamics of barrier islands

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Katie Castagno**
**Email:** katiecastagno@gmail.com
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 3

**Contribution to the Project:** Worked with PI Fagherazzi on hydrodynamic and morphodynamic modeling

**Funding Support:** WHOI

**International Collaboration:** No
**International Travel:** No

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**Daniel J Coleman**
**Email:** djcoleman@vims.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 6

**Contribution to the Project:** Works with PI Kirwan on marsh modeling & process studies

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Elsemarie deVries**
**Email:** elsemar@live.unc.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Working with PI Moore on coastal dynamics

**Funding Support:** NSF, UNC-CH

**International Collaboration:** No
**International Travel:** No

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**Benjamin Dows**
**Email:** dowsbl@vcu.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Worked with PIs Young and Zinnert on landscape dynamics of barrier islands

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Amy Ferguson**
**Email:** aef2wa@virginia.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Working with Pat Wiberg on coastal resilience

**Funding Support:** TNC

**International Collaboration:** No
**International Travel:** No

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**Arnold Fernandes**
**Email:** arnold26@bu.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 5

**Contribution to the Project:** Worked with PI Fagherazzi on forest response to hurricanes

**Funding Support:** Volunteer

**International Collaboration:** No
**International Travel:** No

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**April Harris**
**Email:** harrisal22@mymail.vcu.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Worked with PIs Young and Zinnert on landscape dynamics of barrier islands

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Erin Heller**
**Email:** elheller@vt.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Works with PI Karpanty on bird and predator studies

**Funding Support:** NSF GRFP

**International Collaboration:** No
**International Travel:** No

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**Alfonso M Jiménez Robles**
**Email:** mjralfonso@gmail.com
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 6

**Contribution to the Project:** Worked with PI Fagherazzi on hydrodynamic and morphodynamic modeling

**Funding Support:** Spanish Government

**International Collaboration:** Yes, Spain
**International Travel:** No

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**Margaret Jones**
**Email:** mbj@live.unc.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 9

**Contribution to the Project:** Working with PI Moore on landscape dynamics

**Funding Support:** The Nature Conservancy

**International Collaboration:** No
**International Travel:** No

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**William Kearney**
**Email:** wkearn@bu.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Working with S. Fagherazzi on modeling of coastal lagoon water and sediment dynamics

**Funding Support:** NSF, BU, ACS

**International Collaboration:** No
**International Travel:** No

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**Rebecca Lauzon**
**Email:** Rebecca.lauzon@duke.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Contributing to investigation of barrier-marsh couplings and assisting with field work with L. Moore

**Funding Support:** Duke Univ.

**International Collaboration:** No
**International Travel:** No

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**Nicoletta Leonardi**
**Email:** N.Leonardi@liverpool.ac.uk
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Worked with PI Fagherazzi on hydrodynamic and morphodynamic modeling

**Funding Support:** NSF/USGS

**International Collaboration:** No
**International Travel:** No

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**E. Victoria Long**
**Email:** evl5yz@virginia.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Worked with L. Blum on salt marsh transgression into abandoned agricultural fields

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Abby M Lunstrum**
**Email:** aml3ra@virginia.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Working with K. McGlathery on nitrogen cycling in seagrass beds

**Funding Support:** NSF, UVA

**International Collaboration:** No
**International Travel:** No

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**Ashley Moulton**
**Email:** moultana@vcu.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Worked with PIs Young and Zinnert on landscape dynamics of barrier islands

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Elizabeth Murphy**
**Email:** eakmurphy@gmail.com
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Working with M. Reidenbach on fluid dynamics in oyster reefs and burrowing biomechanics

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Matthew P Oreska**
**Email:** mpo4zx@virginia.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Working with K. McGlathery on assessing environmental change impacts on ecosystem services

**Funding Support:** NSF, UVA

**International Collaboration:** No
**International Travel:** No

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**Irene Palazzoli**
**Email:** irene.palazzoli@gmail.com
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 5

**Contribution to the Project:** Worked with PI Fagherazzi on hydrodynamic and morphodynamic modeling

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Ian Reeves**
**Email:** irbreeves@gmail.com
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Working with PI Moore on couplings between seagrasses, marshes and barrier islands

**Funding Support:** NOAA

**International Collaboration:** No
**International Travel:** No

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**Jesus Ruiz-Plancarte**

**Email:** jzr201@psu.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Working with PI Fuentes on carbon fluxes in salt marshes

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Nathalie W Schieder**
**Email:** nwschieder@vims.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 3

**Contribution to the Project:** Works with PI Kirwan on marsh modeling & process studies

**Funding Support:** Dominion Foundation

**International Collaboration:** No
**International Travel:** No

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**Serina Sebillian**
**Email:** sseblia@mail.sfsu.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Working with D. Johnson on environmental control of isotopic niche width

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Matt Smith**
**Email:** msmit211@odu.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Works with F. Day on vegetation dynamics on the barrier island dunes

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Joseph Thompson**
**Email:** thompsonja5@vcu.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Worked with PIs Young and Zinnert on landscape dynamics of barrier islands

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Bethany Williams**
**Email:** bwilliams@vims.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Working with D. Johnson on ecological control of geomorphology

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Ian Yue**
**Email:** ian.yue@uconn.edu
**Most Senior Project Role:** Graduate Student (research assistant)
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Worked with S. Swallow on social science research. He worked on a first-round survey of residents' preferences and values for ecosystem services affected by the location of sea walls, living shorelines , or the lack of adaptation for Sea Level Rise, including data analysis and 2 conference presentations listed in publications/presentations.

**Funding Support:** NSF, USDA National Institute for Food and Agriculture (NIFA), UConn Hatch Grant from the UConn Agricultural Experiment Station

**International Collaboration:** No
**International Travel:** No

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**Spencer Bissett**
**Email:** bissetsn@vcu.edu
**Most Senior Project Role:** Non-Student Research Assistant
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Worked with PIs Young and Zinnert on landscape dynamics of barrier islands

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Charles Deaton**
**Email:** ccdeaton@wm.edu
**Most Senior Project Role:** Undergraduate Student
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Senior thesis working with Matt Kirwan on marsh migration

**Funding Support:** none

**International Collaboration:** No
**International Travel:** No

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**Jessica A. Flester**
**Email:** jaf3bc@virginia.edu
**Most Senior Project Role:** Undergraduate Student
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Worked with L. Blum to compare approaches for measuring marsh surface elevation change rates

**Funding Support:** UVA

**International Collaboration:** No
**International Travel:** No

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**Alex Grimaudo**
**Email:** alexg8@vt.edu
**Most Senior Project Role:** Undergraduate Student
**Nearest Person Month Worked:** 3

**Contribution to the Project:** Working with S. Karpanty on bird studies

**Funding Support:** Virginia Tech

**International Collaboration:** No
**International Travel:** No

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**Callie Houghland**
**Email:** cbh5mb@virginia.edu
**Most Senior Project Role:** Undergraduate Student
**Nearest Person Month Worked:** 3

**Contribution to the Project:** Worked with PI Karen McGlathery on seagrass state change

**Funding Support:** none

**International Collaboration:** No
**International Travel:** No

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**Sean Knepper**
**Email:** spk23457@email.vccs.edu
**Most Senior Project Role:** Undergraduate Student
**Nearest Person Month Worked:** 3

**Contribution to the Project:** Worked with PI Karen McGlathery on seagrass state change

**Funding Support:** VA-NC Alliance Minority Fellowship

**International Collaboration:** No
**International Travel:** No

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**Aylett Lipford**
**Email:** aylettva@vt.edu
**Most Senior Project Role:** Undergraduate Student
**Nearest Person Month Worked:** 3

**Contribution to the Project:** Working with S. Karpanty on bird studies

**Funding Support:** Virginia Tech

**International Collaboration:** No
**International Travel:** No

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**Katherine Longmire**
**Email:** klongmire@vims.edu
**Most Senior Project Role:** Undergraduate Student
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Working with D. Johnson on ecological control of geomorphology

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**David Nicks**
**Email:** dwnicks@vims.edu
**Most Senior Project Role:** Undergraduate Student
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Works with PI Kirwan on marsh modeling & process studies

**Funding Support:** DOE

**International Collaboration:** No
**International Travel:** No

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**Tiffanie Pirault**
**Email:** ptiff95@vt.edu
**Most Senior Project Role:** Undergraduate Student
**Nearest Person Month Worked:** 3

**Contribution to the Project:** Working with S. Karpanty on bird studies

**Funding Support:** Virginia Tech

**International Collaboration:** No
**International Travel:** No

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**Jessie A. Thuma**
**Email:** jat7jw@virginia.edu
**Most Senior Project Role:** Undergraduate Student
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Worked with L. Blum to support Jessica Flester's marsh surface elevation change project

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

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**Jiaya Zhang**
**Email:** jzhang15@email.wm.edu

**Most Senior Project Role:** Undergraduate Student
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Works with PI Kirwan on marsh modeling & process studies

**Funding Support:** Volunteer

**International Collaboration:** No
**International Travel:** No

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**Amy Bartenfelder**
**Email:** ANB7PA@VIRGINIA.EDU
**Most Senior Project Role:** Research Experience for Undergraduates (REU) Participant
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Worked on data collection with VCRLTER investigators and graduate students

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No
**Year of schooling completed:** Junior
**Home Institution:** University of Virginia
**Government fiscal year(s) was this REU participant supported:**

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**Lindsay Edwards**
**Email:** lle8kk@virginia.edu
**Most Senior Project Role:** Research Experience for Undergraduates (REU) Participant
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Worked with PI Karen McGlathery on seagrass state change

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No
**Year of schooling completed:** Junior
**Home Institution:** University of Virginia
**Government fiscal year(s) was this REU participant supported:**

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**Joshua D Himmelstein**
**Email:** jdhimmelstein@email.wm.edu
**Most Senior Project Role:** Research Experience for Undergraduates (REU) Participant
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Works with PI Kirwan on marsh modeling & process studies

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No
**Year of schooling completed:** Junior
**Home Institution:** William & Mary
**Government fiscal year(s) was this REU participant supported:**

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**Grace Holmes**

**Email:** holmesge2@mymail.vcu.edu
**Most Senior Project Role:** Research Experience for Undergraduates (REU) Participant
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Worked with PIs Young and Zinnert on landscape dynamics of barrier islands

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No
**Year of schooling completed:** Junior
**Home Institution:** Virginia Commonwealth University
**Government fiscal year(s) was this REU participant supported:**

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**Marnie R Kremer**
**Email:** mrk2dt@Virginia.EDU
**Most Senior Project Role:** Research Experience for Undergraduates (REU) Participant
**Nearest Person Month Worked:** 4

**Contribution to the Project:** Worked with PI Reidenbach on oyster metabolism

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No
**Year of schooling completed:**
**Home Institution:**
**Government fiscal year(s) was this REU participant supported:**

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**Taylor Price**
**Email:** pricetl@vcu.edu
**Most Senior Project Role:** Research Experience for Undergraduates (REU) Participant
**Nearest Person Month Worked:** 2

**Contribution to the Project:** Worked on data collection with VCRLTER investigators and graduate students on investigations of island vegetation

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No
**Year of schooling completed:** Junior
**Home Institution:** Virginia Commonwealth University
**Government fiscal year(s) was this REU participant supported:**

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**Katie O Spady**
**Email:** kos5ft@virginia.edu
**Most Senior Project Role:** Research Experience for Undergraduates (REU) Participant
**Nearest Person Month Worked:** 5

**Contribution to the Project:** Worked with L. Blum on technical support for EoYB monitoring. Research for supervised research course credit on salt marsh mallow seed banks.

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

**Year of schooling completed:**
**Home Institution:**
**Government fiscal year(s) was this REU participant supported:**

**Allice McEnerney Cook**
**Email:** acook6@verizon.net
**Most Senior Project Role:** Other
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Art instructor for the Art and Ecology workshops with PI Schwarzschild

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

**Laurie Sorabella**
**Email:** oysterreefkeeper@yahoo.com
**Most Senior Project Role:** Other
**Nearest Person Month Worked:** 1

**Contribution to the Project:** Provides instruction for an Oyster Gardening educational program with PI Schwarschild

**Funding Support:** NSF

**International Collaboration:** No
**International Travel:** No

**What other organizations have been involved as partners?**

| Name | Type of Partner Organization | Location |
|---|---|---|
| Chesapeake Experience | Other Nonprofits | York County, VA |
| Deakin University | Academic Institution | Australia |
| University of Antwerpen | Academic Institution | Belgium |
| University of Bremen | Academic Institution | Germany |
| Virginia Institute of Marine Sciences | Academic Institution | Gloucester Point, VA |
| Dickinson College | Academic Institution | Carlisle, PA |
| East China Normal University | Academic Institution | China |
| Monash University | Academic Institution | Australia |
| Northampton County Public Schools | School or School Systems | Eastville, VA |
| Old Dominion University | Academic Institution | Norfolk, VA |
| Royal Netherlands Institute for Sea Research | Academic Institution | The Netherlands |

| Name | Type of Partner Organization | Location |
|---|---|---|
| Smithsonian Environmental Research Center | State or Local Government | Edgewater, MD |
| The Nature Conservancy | Other Nonprofits | Nassawadox, VA |

**Full details of organizations that have been involved as partners:**

**Chesapeake Experience**

**Organization Type:** Other Nonprofits
**Organization Location:** York County, VA

**Partner's Contribution to the Project:**
Collaborative Research

**More Detail on Partner and Contribution:** We collaborate on joint educational programs for K-12 and public groups.

**Deakin University**

**Organization Type:** Academic Institution
**Organization Location:** Australia

**Partner's Contribution to the Project:**
Personnel Exchanges

**More Detail on Partner and Contribution:** PI Kirwan hosted a visit by Dr. Peter Macreadie to the VCRLTER in 2016

**Dickinson College**

**Organization Type:** Academic Institution
**Organization Location:** Carlisle, PA

**Partner's Contribution to the Project:**
Collaborative Research

**More Detail on Partner and Contribution:** Thomas Arnold collaborates on carbon flux studies

**East China Normal University**

**Organization Type:** Academic Institution
**Organization Location:** China

**Partner's Contribution to the Project:**
Personnel Exchanges

**More Detail on Partner and Contribution:** PI Kirwan visited for two weeks in 2016

**Monash University**

**Organization Type:** Academic Institution
**Organization Location:** Australia

**Partner's Contribution to the Project:**
Collaborative Research

**More Detail on Partner and Contribution:** Working with PI Kirwan on marsh research

**Northampton County Public Schools**

**Organization Type:** School or School Systems
**Organization Location:** Eastville, VA

**Partner's Contribution to the Project:**
Collaborative Research

**More Detail on Partner and Contribution:** We collaborate with the Northampton Public School system on Schoolyard LTER activities for K-12 students.

**Old Dominion University**

**Organization Type:** Academic Institution
**Organization Location:** Norfolk, VA

**Partner's Contribution to the Project:**
Collaborative Research

**More Detail on Partner and Contribution:** Richard Zimmerman collaborated on development of bathymetric data layers

**Royal Netherlands Institute for Sea Research**

**Organization Type:** Academic Institution
**Organization Location:** The Netherlands

**Partner's Contribution to the Project:**
Collaborative Research

**More Detail on Partner and Contribution:** Working with PI Kirwan on marsh processes and sea level rise

**Smithsonian Environmental Research Center**

**Organization Type:** State or Local Government
**Organization Location:** Edgewater, MD

**Partner's Contribution to the Project:**
Collaborative Research

**More Detail on Partner and Contribution:** Whitman Miller collaborates on carbon flux studies

**The Nature Conservancy**

**Organization Type:** Other Nonprofits
**Organization Location:** Nassawadox, VA

**Partner's Contribution to the Project:**
Facilities

**More Detail on Partner and Contribution:** The Virginia Coast Reserve of The Nature Conservancy (TNC) is our primary research site. TNC allows us access to the islands for our research.

**University of Antwerpen**

**Organization Type:** Academic Institution
**Organization Location:** Belgium

**Partner's Contribution to the Project:**
Personnel Exchanges

**More Detail on Partner and Contribution:** PI Kirwan hosted a visit by Lennert Scheppers during 2016

**University of Bremen**

**Organization Type:** Academic Institution
**Organization Location:** Germany

**Partner's Contribution to the Project:**
Collaborative Research

**More Detail on Partner and Contribution:** L. Moore has collaborated with Orencio Duran Vinent

**Virginia Institute of Marine Sciences**

**Organization Type:** Academic Institution
**Organization Location:** Gloucester Point, VA

**Partner's Contribution to the Project:**
Collaborative Research

**More Detail on Partner and Contribution:** Collaborate with Robert J. Orth on seagrass restoration and Mark Luckenbach on invertebrate population montoring

**What other collaborators or contacts have been involved?**
Nothing to report

## 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 climate and land-use change (sea-level rise, storm disturbance, coastal eutrophication), habitat restoration (seagrass, oyster), expanding aquaculture, invasive species (including management of human-commensal predators), controls on plant production, determinants of faunal biogeography in an island system, and prediction of future state change.

We have established that ecological changes in the coastal barrier system are non-linear, with gradual changes punctuated by abrupt transitions to another ecosystem state. The effects of these dynamic relationships influence vegetation patterns and productivity, nutrient cycling and faunal relationships in ecosystems (upland, marsh, tidal flat, coastal bay) on the landscape. We have developed quantitative models and that include threshold responses, which trigger rapid ecosystem state change, for intertidal wetlands, subtidal seagrass meadows and barrier islands.

WATERSHEDS AND LAGOON

The eelgrass (*Zostera marina*) that once carpeted the seafloor of the VCR coastal bays and supported a thriving economy became locally extinct in the early 1930s as a result of disease and storm disturbance, causing a catastrophic shift to an unvegetated state. We have collaborated with colleagues at the Virginia Institute of Marine Sciences and The Nature Conservancy in a large-scale ecosystem-level experiment to reverse the state change. This has resulted in >25 km2 of

restored habitat in a chronosequence of seagrass meadows 0 – 15 years since seeding. At least a decade is required for primary productivity, carbon and nitrogen sequestration, increased water column clarity, and sediment stabilization to be fully restored. The expansion of seagrass represents an additional filter for nutrient inputs, with enhanced rates of nitrogen removal through denitrification.

Seagrass expansion has altered local hydrodynamics and switched the seafloor from an erosional environment to one that promotes deposition of suspended sediment by reducing near-bottom velocities (70-90%) and wave heights (45-70%). Coupled bay-marsh modeling results indicate that the presence of seagrass can be both beneficial and detrimental to marshes depending on tidal flat extent, either attenuating wave energy that would erode the marsh edge or reducing sediment supply required to keep pace with RSLR.

Our conclusions regarding the importance of macroalgae and seagrass helps to explain the role of the bay as an active mediator between mainland nutrient sources (e.g., agricultural fields) and the coastal ocean. The discovery that the dominant macroalga in the bays is an exotic (rather than its native congener), has highlighted the importance of this invasive macroalgae in subsidizing nutrients and habitat in intertidal marshes and mudflats.

WETLANDS

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. Critical slowing down is evident in marshes, and the response is consistent between extremely diverse systems (VCR vs. Dutch Schelde Estuary).

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. 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. In lagoon marshes, sea-level rise may be exceeding the ability of the marshes to accrete. Coupled lagoon-marsh modeling results show that the presence of seagrass can act both beneficially and detrimentally to the lagoon marshes depending on tidal-flat extent.

In recent years, there has been a flurry of restoration projects aimed at mitigating the impact of coastal storms using salt marshes and vegetated surfaces (called “living shorelines”). Based on a large dataset of salt marsh erosion and wave measurements collected all around the world, we found that erosion rates of marsh boundaries and incident wave energy collapse into a unique linear relationship. Long-term salt marsh deterioration is dictated by average wave conditions, and it is, therefore, predictable. Violent storms and hurricanes contribute less than 1% to long-term salt-marsh erosion rates.

BARRIER ISLANDS

Our long-term data illustrate that barrier island plant and shorebird invertebrate prey communities serve as sentinels to climate change. Our work has demonstrated that two alternate ocean intertidal habitat states, sand vs. exposed peat substrates, host unique invertebrate communities of equal, complementary importance to migratory shorebird populations, and ongoing work is modeling how these habitats and invertebrate communities will respond to warming ocean temperatures and cascade to impact higher trophic levels.

Cross-scale interactions are at the cutting edge of spatial and ecological sciences. By exploring the complex roles of biological (e.g. vegetation and invertebrate succession dynamics) and physical (e.g. sediment composition and erosion) processes in the historical analysis of barrier island evolution, we are advancing our fundamental understanding of barrier dynamics and response to changing climate. Our work is contributing to the global body of research regarding ecosystem state change, stability domains and coupling of biotic and physical phenomena, and has also resulted in the development of models that are being used by the broader scientific community.

We have established that long-term and landscape-scale vegetation patterns on the islands reflect non-linear dynamics and threshold responses to environmental drivers. We coined the term 'maintainer feedback' to apply to processes that maintain low elevations (in contrast to 'dune-builder feedback,' which leads to increases in island elevation). 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. Sand delivered to back-barrier marshes by overwash processes allows back-barrier marshes to persist under conditions in which they would otherwise disappear, leading to increased island resilience. The newly recognized importance of two-way couplings between the sandy component of barrier islands and back-barrier marshes is redefining the way in which barrier island response to changing conditions is assessed.

Controls on plant community distribution can be explained by two key environmental parameters: distance from the shoreline (and thus overwash disturbance) and elevation above sea level (a surrogate for distance to groundwater). However, we are also showing the importance of biotic interactions in determining species composition as well as the interaction of different vegetation with the environment. We have also demonstrated the effect of changing species composition on alongshore dune morphology with a resulting effect on island vulnerability to overwash during storms.

We have documented a dramatic increase in shrub thickets (>400%) as shrubs encroach onto grasslands that is due to a decrease in precipitation and increases in winter temperatures and atmospheric CO2 concentrations. Increased shrubland has ecosystem level consequences by preventing transition of marsh to upland (e.g. migration). New shrubs immediately modify the microclimate and biogeochemical cycling. Aboveground net primary productivity (ANPP) results in a 5-fold increase in ANPP, from ~300 g m-2 in grassland to ~1500 g m-2 in woody communities. Large-scale expansion of *Morella cerifera* (N-fixing shrub) results in increased soil organic N, leaf %N, and net N mineralization rates.

**What is the impact on other disciplines?**

The studies conducted by the VCR/LTER are inherently interdisciplinary including ecologists, hydrologists, biologists, geomorphologists and physical oceanographers. When such collaborations take place, it is not unusual that 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.

As part of our collaboration in the LTER sponsored Ecological Reflections program we held two Art and Ecology professional Development workshops for public school Art Teachers. Along with faculty from the Science Technology and Society program in the UVA School of Engineering we hosted a Nature Writing workshop for undergraduate Engineering Students. These workshops introduce participants to the place-based science being conducted at the VCR-LTER. Participants are encouraged to find new ways to incorporate environmental issues/themes in their artwork and classroom projects. Paintings, drawings, essays, poems and short fiction created during the workshops are used to generate public Art and Ecology exhibitions displayed at the local Barrier Islands Center Museum and on the grounds of UVA.

**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 REU and REHS activities provide graduate students mentorship training as they supervise and support the work of undergraduate and high school student interns.

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. Our Professional Development workshops help train >45 school teachers/year, introducing them to the key environmental issues impacting our coastal ecosystems.

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. These activities were the inspiration for the development of a Diversity Plan for the site (now posted on the VCR web site). This plan can serve as a model for other LTER sites.

Our outreach and education activities include a series of professional development workshops for school teachers and educators. Each year these programs impact a minimum of 45 teachers with a goal of increasing environmental literacy and strengthening STEM education in K- 12 classes on the Eastern Shore and throughout Virginia. In addition, online curriculum has been developed for middle school students to meet Commonwealth of Virginia learning standards for Environmental Sciences. Two online modules were created: Sea-level rise impacts on coastal communities, and Marine biology and coastal ecosystems. (http://www.wiseengineering.org).

**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. Imaging of the illuminated particles is done using a high definition camera to obtain images up to 60 frames per second. The system is attached to a rigid frame and can be deployed in the coastal ocean where suspended sediment particles are tracked. This PIV system has recently been coupled with a planar-optode system that utilizes thin oxygen sensitive foils to quantify oxygen fluxes at the sediment water interface. This coupled system enables researchers to quantify the interactive effects of hydrodynamics and biological activity (such as burrowing) on oxygen exchange across the seafloor.

Berg has pioneered the approach of underwater eddy correlation to measure oxygen fluxes in benthic systems. This technique has the advantage over conventional techniques of measuring dynamic fluxes with a high temporal resolution (64 hz), and over a large spatial scale (10-100 km2), which captures natural heterogeneity in these systems. Novel results obtained from the application of this technique are the identification of multiple time-scale processes that drive seagrass metabolism and a hysteresis in seagrass metabolism that occurs over the day.

**What is the impact on institutional resources that form infrastructure?**

LTER researchers form the core of a monthly seminar series offered at 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.

Our wireless network provides real-time access to remote monitoring locations in and around Hog Island. Researchers from other universities/programs have access to this data, and our network is also used to support collection of images by other user groups like the Center for Wildlife Conservation at the College of William and Mary, which uses our wireless infrastructure to monitor peregrine flacon nesting activity on Cobb Island. Streaming video is made available to the general public during the nesting/fledging season.

**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).

The VCR/LTER shares 198 online datasets with an aggregate volume of approximately 230 GB. These are published via the VCR/LTER web site, the LTER Data Portal and DataOne Search. The datasets are frequently downloaded for use by researchers and students. During the period from 9/1/15 to 8/30/15 VCR/LTER data files have been downloaded at 5,827 times via the LTER Data Portal (19,125 times since the initiation of the grant in Nov. 2012). For most downloads no information regarding by whom or why data was downloaded is available. However, of the 115 downloads for which a reason was given, the vast majority of downloads were for research (93%), with 7% for education (e.g., student class projects). As noted below, we provide code generation web services that are used in the LTER Data Portal to generate statistical programs for using LTER data.

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.

The VCR/LTER developed code-generation tools that transform EML Metadata into usable programs for analysis in the R, SAS and SPSS statistical languages (and in collaboration with the GCE LTER, Matlab). These are provided as a web service and used in our local web data catalog and on the LTER Data Portal. Many of the models developed in the course of LTER-VCR efforts are readily available to the scientific community via the Community Surface Modeling Dynamics System, including the coastal dune model (Duran and Moore 2013;2015), GEOMBEST (Brenner et al., 2015) and GEOMBEST+ (Walters et al., 2014; Lauzon et al., in review).

PI Reidenbach developed online curriculum for middle school students to meet Commonwealth of Virginia learning standards for Environmental Sciences. Two online modules were developed: Sea-level rise impacts on coastal communities, and Marine biology and coastal ecosystems. (http://www.wiseengineering.org)

**What is the impact on society beyond science and technology?**

The high historic rate of sea-level rise (~4mm yr-1) within the Virginia Coast Reserve make it a bell-weather 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.

Our ability to make fine-scale, site-specific predictions of island geomorphology and Piping Plover habitat suitability in response to SLR and shoreline change is novel and will be useful managers coast-wide as application of the models is expanded geographically. Our findings related to SLR and beach management strategies at Assateague Island, where models were developed and first tested, have relevant implications for policy-makers today. For example, we found that a beach management strategy that involved annual sand nourishment along the sections of Assateague Island would result in vegetation encroachment and reduce the area of habitat suitable for Piping Plovers as compared to a scenario of modest SLR (3-4 mm yr-1) and no sand nourishment. While there is no such identical management strategy currently proposed for Assateague Island, targeted sand placement in order to stabilize barrier islands is a commonly discussed management strategy along the U.S. Atlantic Coast.

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 collaborating with respect to data, models and tools to address coastal resilience 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.

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 (http://maps.coastalresilience.org/virginia/).

Knowledge of the relationship between land use, nutrient contamination of groundwater, groundwater export of nutrients to coastal bays, and the fate of nutrients within bays 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. In the decade of seagrass restoration, ecosystem services have been reinstated, including increased water quality and clarity (decreased sediment suspension), and increased biodiversity (foraminfera), and faunal abundance (introduced scallops). The VCR coastal bays are also a model system to understand the important role of plants in mediating nutrient export from coastal watersheds to the open ocean.

Barrier islands are heavily developed landforms that are highly vulnerable to changing climate conditions. Concepts such as green and nature-based solutions are gaining attention within the coastal management and engineering community. Our work contributes to understanding how upland communities contribute to the overall resilience of barrier islands and how they will respond to climate change —including the mechanisms influencing and driving future island response—which is a prerequisite to sustainable coastal management. Upland communities are overlooked and we do not fully understand the ecosystem services they provide. Our work is bringing attention to these vulnerable landscapes.

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## Changes/Problems

**Changes in approach and reason for change**

In response to suggestions by the mid-term review team in 2015, we will continue to do the following: 1) develop a sediment budget for the VCR, which will be useful in linking subsystems across the landscape; 2) focus on biotic feedbacks on state change; in addition to our current activities, we have added a new PI, David Johnson, to address fauna-mediated feedbacks on plant production and geomorphology; and 3) assess carbon sequestration as consequence of ecosystem state change.

**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.