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Submitting Official (if other than PD\PI):	John H Porter Co-Principal Investigator
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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 are:

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 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, shrub biomass/production, coastal bay water quality and fish diversity/abundance, and distribution/abundance of small mammals, mesopredators, migratory shorebirds, and intertidal invertebrate prey for shorebirds on the barrier islands.

Mechanisms and Consequences of Non-linear State Change

Intertidal: 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 continued our experiments on marsh mallow, the salt-tolerant biofuel crop, in abandoned agricultural fields. We also measured leaf water potential of tree species, light intensity, and recruitment. At the marsh-lagoon boundary, we used high-resolution field measurements and cellular automata simulations to study erosion by wave action. We also conducted a caging experiment to quantify the effect of biotic feedbacks from fiddler crabs (facilitative species) and purple marsh crabs (herbivore) on soil strength and sediment deposition.

We tested if the invasive macroalga *Gracilaria vermiculophylla* enhanced the spread and abundance of 2 pathogenic bacteria (*Vibrio parahaemolyticus*, *V. vulnificans*) and assessed if foraging of shorebirds are a vector for bacterial transmission. We worked on a technique to amplify markers of *V. vulnificans* to test if amphipods in *Gracilaria* mats enhance pathogen abundance. We used aquatic eddy covariance and profiling ADVs to determine the impact of *Gracilaria* on benthic metabolism and vertical mixing.

Coastal bays: We studied the effects of seagrass state change at population to ecosystem levels in the long-term landscape-scale seagrass restoration experiment. This included studies on metabolism (using aquatic eddy covariance approach developed by VCR PI, extending our data base to a decade), carbon/nitrogen cycling and sequestration, and fish abundance/diversity. We tested prototypes of artificial seagrass beds to study feedbacks of the physical structure of the canopy on sediment suspension and light and on establishment of seagrass seedlings.

Barrier islands: We measured species composition, productivity, stomatal conductance, microclimate, and water table height in grasslands, transition areas, shrub thickets of different ages and experimental shrub removal plots to address biotic feedbacks on the grassland – shrubland transition. Predator and shorebird prey populations were monitored and soil carbon stocks were measured and related to shrub expansion. We conducted burial experiments of two dune-building grasses. 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, and what ecological and physical factors control whether dunes are continuous or discontinuous.

We are beginning to see a northward expansion of the southern dune grass (*Uniola paniculata*) that lab experiments show is competitively superior to local dune grasses. Integrating physiological data with an empirical process-based model predicts that this species shift and an increase in storm frequency will lead to more hummocky dunes, and increased vulnerability of islands to storm disturbance.

Thresholds for state change

Intertidal: We coupled long-term measurements of marsh elevation change to numerical models and “marsh organ” experiments manipulating marsh elevation. We continued to examine the role of root-zone processes in determining elevation change by quantifying root growth (computed tomography scans) and measuring organic matter decay. We developed a landscape scale numerical model of salt marsh accretion, and collected sediment cores to test its application.

Coastal Bays: We used aerial photograph data of seagrass 1-acre restoration plots over 15 years to determine if we there was an early warning indicator before seagrass loss at sites near the depth threshold. Data from AVHRR satellites were used to investigate spatial and temporal patterns of sea-surface temperature from 2006 until present. We focused on high-temperature conditions that might result in heat stress in seagrass restoration plots.

Barrier Islands: We used historical imagery and repeated field sampling to characterize the relationship between island habitat change and the distribution/abundance of mammals and migratory shorebirds. We conducted freezing experiments to determine the lower limits of shrub physiological functioning and developed a process based modeling framework showing the potential emergence of bistable dynamics (grassland vs. shrubland) as a result of positive feedbacks with microclimate conditions. We began development of a new empirical model of dune growth and shrub expansion on islands subject to storm events. The model is parameterized by existing VCR data, including use of a newly discovered dune-height threshold for shrub presence and additional archived data on shrub seed production, growth, seed dispersal, germination rates, wave and tide information (NOAA), dune growth rates.

Ecosystem Connectivity

Sediment flux by storm overwash increases the resilience of narrow (100-500 m) back-barrier marshes, allowing them to persist under conditions in which they would otherwise disappear. We added waves to the existing barrier-marsh model GEOMBEST+, which allowed us to assess the effect of backbarrier marsh edge erosion. Adding wave erosion to the coupled model increases resilience because sediment supplied by the eroding edge allows marshes to keep pace with sea-level rise.

We measured wave attenuation by oyster reefs and marsh vegetation and sediment delivery onto the marsh. We also continued studies of how elevation and roughness of natural and restored oyster reefs affect larval settlement and flow dynamics, and used aquatic eddy covariance to determine controls and rates of oyster metabolism. A new

index was developed to characterize marsh vulnerability throughout the VCR that combines wave exposure with marsh morphology (elevation, width and height of vegetation from LiDAR data) and historical rates of change.

On the barrier islands, raccoon and red fox threaten beach-nesting and colonial waterbirds. We used mitochondrial and nuclear DNA markers to identify sources and pathways of connectivity between populations, and camera trapping to assess the before-after impacts of predator removal.

Landscape Changes

A high-temperature disturbance in the coastal bays and localized die-off in 2015 provides a unique opportunity to study recovery and resilience of seagrass meadows and factors that lead to spatial heterogeneity in response. We quantified variations in sea surface temperature using automated sensors in coastal bays where seagrass have been restored, and related these to the known temperature threshold. Data were compared to eddy flux measurements, carbon burial and satellite temperature data. We determined spatial heterogeneity and drivers of carbon burial in seagrass meadow sediments by core data on burial rates, isotope analysis, Bayesian mixing models for carbon source, and spatial analysis.

We measured species composition, % cover, and functional traits along cross-island transects on two islands that differ in topography and disturbance regime based on recent LiDAR data. We continued our historical analysis of Landsat imagery from 1984, 1998, 2011, and 2016 to look at transitions between ecosystem state on barrier islands and transitions between upland communities (bare, grass, woody) and marsh. For individual islands, we looked at relationships between width, vegetation type and area, elevation, and marsh/upland boundary change between each image date.

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 Change & 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 and Consequences of Non-linear State Change

Coastal Bays. Seagrass state change results in restoration of key ecosystem services. Carbon metabolism measured by eddy covariance is increased 10-25x; sediment carbon burial rates are similar to mature meadows after 12 years; denitrification rates are 3-4x higher and exceed external nitrogen inputs; and biodiversity and abundance of fish and bivalves are increased. Forty percent of the carbon buried is derived from seagrass, 10% is marsh carbon, and 50% is microalgal carbon produced mostly in situ.

Intertidal. Field experiments testing the biotic feedback between marsh crabs and sediment deposition show that fiddler crabs (e.g., *Uca pugnax*) can enhance *Spartina alternilfora* biomass, but not enough to result in increased sediment deposition. At the terrestrial boundary, sea-level rise and storm surge cause flooding and saltwater intrusion. Annual tree ring growth data combined with dendroclimatic and statistical modelling show that in some regions adult trees are resilient to storm surge, with recovery after 3 years, but that seedling mortality is high, limiting forest regeneration.

At the marsh edge, intertidal oyster reefs modulate the state change from marsh to tidal flat. Oyster reefs reduce wave energy that causes erosion for intermediate waves, but are less effective for deeper water (high tide and storm surge). We have initiated 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.

The fiddler crab is a climate migrant that recently expanded its range north of Cape Cod, MA. Data collected from 10 sites from Georgia to New Hampshire including PIE, GCE and VCR show that crabs in their expanded range (e.g., northern Massachusetts) have fewer parasites than those in their historic range (e.g., Virginia). These results support the hypothesis that range-expanded species can 'escape' their parasites.

Barrier Islands. Shrublands invading grasslands modify the microclimate and create temperature conditions for shrub persistence. During nighttime, shrubland is significantly warmer than grassland in winter by ~2℃. A small increase in near-surface temperature can induce a non-linear shift in ecosystem state from a stable grassland state to an alternative stable state dominated by the shrub *Morella cerifera.*

In the dune grass transplant experiment, two years of leaf growth and length data reveal that *Ammophila breviligulata* (American beachgrass) and *Uniola paniculata* (sea oats) grew more than *Spartina patens* (saltmeadow cordgrass) by 15% and 45%, respectively. Distance from the shoreline and elevation had no effect on transplant growth rate but did affect survival. This provides evidence that informs our empirical models for the dune-building capacity of all three species, and suggests *S. patens* is not a maintainer species as previously thought, but rather a moderate dune builder. Given sufficient time and absent external forcing, hummocky dunes coalesce to form continuous dune ridges. Model results also yield a predictive rule for the timescale of coalescing and the height of the coalesced dune.

Our landscape genetic analyses indicated that raccoons on barrier islands occur in semi-independent local populations that exhibit significant genetic structure and are characterized by historical and ongoing colonization events (Fig. 2).

Thresholds for State Change

Coastal Bays. Ground-truthing of satellite-derived sea-surface temperature against in situ temperature data indicates that the satellite data are able to capture spatial and temporal variations. Analysis of images for high-temperature conditions, e.g., pixels with temperature > 28 ℃ which is the temperature threshold of the seagrass, reveals regions of persistently warmer temperatures and strong year-to-year variation in high-temperature conditions across the bays. Spatial variation in the response and recovery of seagrass reflect differences in the duration of high temperatures above the threshold tolerance.

Intertidal. Long-term Surface 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. Plant root growth accounts for >50% of vertical elevation change. Models predict a threshold rate of sea-level rise, beyond which marshes convert to open water. Disturbance experiments in marsh "organs" indicate that the state change is preceded by "critical slowing down" as an early warning indicator.

Barrier Islands. Model results show that ~-15℃ is the threshold temperature that induces state change from grassland to shrubland (Fig 1). This was confirmed with experimental measurements showing that freezing-induced cavitation reduced hydraulic conductance of the stem at -15℃, down to 0 at -20 ℃. New analysis of archived VCR data for dune height and observations of shrub presence reveals a threshold minimum dune height on Hog Island (~1.75 m). Higher elevation dunes have increased species cover and functional composition of the community (i.e. higher specific leaf area and height), and higher woody vegetation cover.

Ecosystem Connectivity

Sediment Fluxes. From 2009 to 2016, 52 storms were identified and simulated using the fully coupled coastal hydrodynamic, sediment transport and wave model Delft3D-SWAN. Intense storms import sediment into the bays, determined primarily by the

duration and magnitude of storm surge. This increases the resilience of the coastal bay system by providing the sediment necessary to counteract sea-level rise.

Coupled Dynamics: Marsh-Bay. Wave attenuation by vegetation, when water depths are great enough to inundate the marsh, is more effective at reducing wave energy than wave attenuation by fringing oyster reefs. However, fringing oyster reefs may help to stabilize low-elevation marsh edges, thereby reducing marsh retreat. Oyster reefs in low velocity regions have a higher probability of self-colonization, while reefs found in higher velocity environments depend on connectivity with other areas.

Coupled Dynamics: Island-Marsh. Expansion of the coupled barrier island-marsh evolution model GEOMBEST+ to include the effects of wind waves on back-barrier marshes reveals that the addition of marsh edge erosion leads to wider, more resilient marshes and that horizontal erosion of the marsh edge is a more efficient sediment source to the marsh than vertical erosion of the marsh surface as it drowns. Where the net rate of sediment imported to (or exported from) the coastal bay is known, the behavior of the back-barrier marsh edge can be predicted knowing only the bay geometry and net sediment input.

Landscape Changes

Total island area (upland and marsh) was reduced by 18% between 1984 and 2016. The rate of marsh conversion to upland has increased in the last 5 years (67 ha yr-1) relative to the entire time period (~41 ha yr-1). Upland area increased by 10% between 2011 and 2016, possibly due to conversion of marsh to upland. The presence of woody vegetation significantly reduced landward migration of the marsh/upland boundary. Woody vegetation continues to expand across the landscape, with new populations establishing on islands that previously (1984-2011) had little to no woody cover.

Historical mapping across the Chesapeake region revealed that 100,000 acres of uplands have converted to marshes since the mid-19th century, and that rates of marsh migration into adjacent upland are correlated with slope and land use.

“Blue” carbon burial in seagrass sediments is spatially heterogeneous, and is driven by proximity to the meadow edge. Resilience of seagrass systems to high temperature events is also spatially heterogeneous, with greater sensitivity in areas with a longer water residence time and slower recovery in deeper waters closer to the depth threshold predicted by empirical models (Fig. 3).

Key outcomes or Other achievements:

VCR scientists have published 180 journal articles and 19 book chapters during this funding cycle. A complete list of publications can be found at https://www.vcrlter.virginia.edu/home2/?page_id=215.

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. High water temperatures have been suggested as a cause of die-off in subtidal seagrass meadows in shallow coastal bays. Satellite-based sea-surface temperature (SST) over the VCR indicates persistent regions of warmer than average summertime temperatures and large inter-annual variations in SST

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, with over 1300 ha transitioning to upland. At the same time, woody cover increased by 40% across all islands. 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 (including both temperature and depth to the water table) to enhance shrub growth and preventing catastrophic hydraulic failure. 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. 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

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.

For the sediment budget of the VCR lagoons, 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.

Measurements of wave attenuation over oyster reefs indicate that marshes with edge elevations close to mean sea level could benefit from reductions in wave energy associated with oyster reefs. In contrast, rates of marsh-edge retreat for marsh edges

characterized by large vertical scarps and marsh surface elevations well above mean sea-level are unlikely to be slowed by the presence of fringing reefs.

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. The seagrass meadow in South Bay is densest adjacent to the back-barrier marsh of Wreck Island. This will be a site of future work on connectivity and non-linear dynamics of adjacent systems.

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 is 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?**

31 graduate students, 4 post-docs and 28 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.

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 The Nature Conservancy 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 (https://www.vcrlter.virginia.edu). Use of the website has declined modestly over the last 12 months, with 10,481 page views in 4,100 sessions by 2,477. This decrease may reflect changes in the structure of the web page which reduce the number of clicks required. During that same period, VCR/LTER data files were downloaded 2,650 times from the LTER or Environmental Data Initiative Portals.

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 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.

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 islandlagoon 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 has hosted 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?**

Mechanisms of Non-linear State Change

Intertidal. 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. Records of seagrass meadow change at a range of sites in the Virginia coastal bays over the period of the satellite data record will be examined for large changes and compared to water temperatures at the same locations to determine whether there is evidence for a temperature threshold for seagrass die-off. Observed variations in temperature will also be compared with results of models that incorporate effects of heat stress on meadow growth.

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 continue to use historical and present-day imagery and LiDAR to model the relationships between island geomorphology, invertebrate prey, shorebird populations and predators.

We will continue to monitor dune growth and changes in vegetation cover density at the site of our field experiment using topographic data derived from structure-from-motion.

Thresholds for State Change

Intertidal. 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. In addition, we will determine long-term accretion rates from 16 recently collected sediment cores. We will address this state change on a larger spatial scale, targeting specific locations throughout the VCR domain.

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. We will also determine if artificial seagrass beds can effectively mimic the hydrodynamic impacts of restored seagrass beds and then test the ability of artificial beds to facilitate restoration below the seagrass depth limit.

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. We will also continue to develop the dune-shrub model, incorporating time series for total water level and wind as we conduct preliminary model experiments to test model outcomes against data for dune and vegetation growth in the VCR.

Ecosystem Connectivity

Working with The Nature Conservancy (TNC), along with their network of community volunteers, eight oyster reefs (of four differing designs) are being constructed using “oyster castles”. These four reef designs vary in both reef height (relative to mean sea level) and reef width. Oyster castles are made of concrete blocks with notches on top so that blocks can be

stacked and locked in place, defending the castles from wave energy. Previous results showed that restored oyster reefs promote vertical accretion and horizontal habitat once oysters are large enough and fall to the ground.

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.

We will continue to examine the possibility of state changes in one landscape unit affecting the state of adjacent units through two-way couplings through our consideration of barrier-marsh-bay processes. Because the effects of seagrass vary as a function of relative sea-level rise (RSLR) and back-barrier sediment import/export (BSF) our next step is to identify the approximate locations within the RSLR/BSF phase space that natural barrier systems tend to exist. This will help us more directly translate modeled results to the real world, giving us a better idea of the actual impacts (and magnitudes) of seagrass we can expect to see in natural systems.

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.

State Change & Projected Climate/land-use Drivers

We will continue our analysis of historical marsh/upland transitions. 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 hummocky and therefor more vulnerable to storm overwash. To address the effects 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; and 3) conduct additional trapping to assess changes in small mammal populations. We will add in manipulations of sea-level rise to the shrub/grass model.

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* (marsh mallow) in abandoned agricultural fields (nutrient and carbon sequestration, exclusion of invasive species). We are working with scientists at the Virginia Tech Agricultural Field Station to determine if growing alternative, salt resistant, crops can be used in Best Management Practices to reduce nitrogen runoff and store carbon in soils.

Supporting Files

Filename	Description	Uploaded By	Uploaded On
Figures_edited1.pdf	Figures for Accomplishments section of Annual Report	John Porter	11/27/2017

Products

Books

Book Chapters

Christian, R.R. and Camacho-Ibar, V.F. and Piehler, M.F. and Smyth, A. R. (2016). Improved understanding of nitrogen cycle through network models in coastal ecosystems. *Treatise on Estuarine and Coastal Science* Wolanski, E. and McLusky, D..

Elsevier. Amsterdam, Netherlands. . . Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = No

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 = Yes ; Peer Reviewed = No

Macko, Stephen A. and Fantasia, Christina and XUE, Guifang (Julia) (2017). Potential Global Economic Impacts of Ocean Acidification. *International Marine Economy: Law and Policy* 20. Nordquist, Myron H. and Moore, John Norton and Long, Ronán. Brill | Nijhoff. Leiden, The Netherlands. 79-97. Status = PUBLISHED; Acknowledgement of Federal Support = No ; Peer Reviewed = No

Porter, John H. and Lin, Chau-Chin (2017). Chapter 24: Ecoinformatics: a new paradigm for ecology. *Ecology: Concepts and Practices (Traditional Chinese Edition) 7e.* Manuel C. Molles, Jr.. McGraw-Hill International Enterprises. Taipei, Taiwan. 555-568. Status = PUBLISHED; Acknowledgement of Federal Support = No ; Peer Reviewed = No

Inventions

Journals or Juried Conference Papers

Berg, Peter and Delgard, Marie Lise and Glud, Ronnie N and Huettel, Markus and Reimers, Clare E and Pace, Michael L (2017). Non-invasive flux Measurements at the Benthic Interface: The Aquatic Eddy Covariance Technique. *Limnology and Oceanography e-Lectures*. 7 (1), 1-50. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/loe2.10005

Berg, Peter and Koopmans, Dirk J and Huettel, Markus and Li, Hua and Mori, Kosuke and Wüest, Alfred (2016). A new robust oxygen-temperature sensor for aquatic eddy covariance measurements. *Limnology and Oceanography: Methods*. 14 (3), 151-167. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/lom3.10071

Deaton, Charles D and Hein, Christopher J and Kirwan, Matthew L (2016). Barrier island migration dominates ecogeomorphic feedbacks and drives salt marsh loss along the Virginia Atlantic Coast, USA. *Geology*. G38459. 1. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1130/G38459.1

Dugan, JE and Emery, KA and Alber, M and Alexander, CR and Byers, JE and Gehman, AM and McLenaghan, N and Sojka, SE (2017). Generalizing Ecological Effects of Shoreline Armoring Across Soft Sediment Environments. *Estuaries and Coasts*. 1-17. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: DOI:10.1007/s12237-017-0254-x

Fagherazzi, S. and Viggato, T. and Vieillard, A.M. and Mariotti, G. and Fulweiler, R.W. (2017). The effect of evaporation on the erodibility of mudflats in a mesotidal estuary . *Estuarine, Coastal and Shelf Science*. 194 118–127. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.ecss.2017.06.011

Ganju, Neil K and Defne, Zafer and Kirwan, Matthew L and Fagherazzi, Sergio and D'Alpaos, Andrea and Carniello, Luca (2017). Spatially integrative metrics reveal hidden vulnerability of microtidal salt marshes. *Nature communications*. 8 ncomms14156. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1038/ncomms14156

Ganju, Neil K and Defne, Zafer and Kirwan, Matthew L and Fagherazzi, Sergio and D'Alpaos, Andrea and Carniello, Luca (2017). Spatially integrative metrics reveal hidden vulnerability of microtidal salt marshes. *Nature communications*. 8 ncomms14156. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1038/ncomms14156

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

Goldstein, Evan B and Moore, Laura J and Durán Vinent, Orencio (2017). Vegetation controls on maximum coastal foredune 'hummockiness' and annealing time. *Earth Surf. Dynam. Discuss.,*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.5194/esurf-2017-2

Kearney, William S and Mariotti, Giulio and Deegan, Linda A and Fagherazzi, Sergio (2017). Stage-discharge relationship in tidal channels. *Limnology and Oceanography: Methods*. 15 (4), 394-407. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/lom3.10168

Lefcheck, Jonathan S and Marion, Scott R and Orth, Robert J (2017). Restored eelgrass (Zostera marina L.) as a refuge for epifaunal biodiversity in mid-Western Atlantic coastal bays. *Estuaries and Coasts*. 40 (1), 200-212. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s12237-016-0141-x

McCann, Michael J and Able, Kenneth W and Christian, Robert R and Fodrie, F Joel and Jensen, Olaf P and Johnson, Jessica J and López-Duarte, Paola C and Martin, Charles W and Olin, Jill A and Polito, Michael J (2017). Key taxa in food web responses to stressors: the Deepwater Horizon oil spill. *Frontiers in Ecology and the Environment*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/fee.1474

Moncrief, Nancy D and Roberts, James H and Hallerman, Eric M and Van Den Bussche, Ronald A and Porter, John H and Dueser, Raymond D (2017). Landscape genetics of a raccoon (Procyon lotor) metapopulation in an undeveloped coastal island system. *Journal of Mammalogy*. 98 (4), 1137-1155. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1093/jmammal/gyx056

Oreska, M. J. P., K. McGlathery, G. Wilkinson, M. Bost, and B. McKee (2017). Allochthonous carbon contributions to seagrass bed blue carbon. *Limnology and Oceanography*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/lno.10718

Oreska, Matthew PJ and Truitt, Barry and Orth, Robert J and Luckenbach, Mark W (2017). The bay scallop (Argopecten irradians) industry collapse in Virginia and its implications for the successful management of scallop-seagrass habitats. *Marine Policy*. 75 116-124. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: http://dx.doi.org/10.1016/j.marpol.2016.10.021

Reynolds, P., J. Stachowicz, K. Hovel, C. Bostrom, K. Boyer, M. Cusson, J. Eklof, F. Engel, A. Engelen, B. Ericksson, J. Fodrie, J. Griffin, P. Jorgensen, C. Hereu, M. Hori, T. Hanley, M. Ivanov, C. Kruschel, K.-S. Lee, K. McGlathery, P. O. Moksnes, M. Nakoaka, F. Nash, M. O'Connor, N. O'Connor, R. Orth, F. Rossi, J. Reusink, E. Sotka, R. Unsworth, M. Whalen, and J. E. Duffy (2017). Latitude, temperature regime and habitat complexity predict predation pressure in eelgrass across the Northern Hemisphere. *Ecology.*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/ecy.2064

Sedghi, Nathan and Adams, Emily C. and Day, Frank P. (2017). Carbon Input and Accumulation in Freshwater to Brackish Marshes on the Barrier Islands of Virginia, USA. *Wetlands*. 37 (4), 729-739. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s13157-017-0905-5

Smith, Matthew L. and Day, Frank P. (2017). Groundwater Thresholds for Root Decomposition and the Relation to Barrier Island Plant Communities. *Wetlands*. 37 (5), 851-860. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s13157-017-0918-0

van Belzen, Jim and van de Koppel, Johan and Kirwan, Matthew L and van der Wal, Daphne and Herman, Peter MJ and Dakos, Vasilis and Kéfi, Sonia and Scheffer, Marten and Guntenspergen, Glenn R and Bouma, Tjeerd J (2017). Vegetation recovery in tidal marshes reveals critical slowing down under increased inundation. *Nature Communications*. 8 ncomms15811. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1038/ncomms15811

Vanderbilt, Kristin and Porter, John H and Lu, Sheng-Shan and Bertrand, Nic and Blankman, David and Guo, Xuebing and He, Honglin and Henshaw, Don and Jeong, Karpjoo and Kim, Eun-Shik (2016). A prototype system for multilingual data discovery of International Long-Term Ecological Research (ILTER) Network data. *Ecological Informatics*. 40 93–101. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.ecoinf.2016.11.011

Xu, Meng (2016). Ecological scaling laws link individual body size variation to population abundance fluctuation. *Oikos*. 125 288–299. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1111/oik.03100

Yousefi Lalimi, F and Silvestri, S and Moore, LJ and Marani, M (2016). Coupled Topographic and Vegetation Patterns in Coastal Dunes: Remote Sensing Observations and Ecomorphodynamic Implications. *Journal of Geophysical Research: Biogeosciences*. 122 119-130. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2016JG003540

Zinnert, Julie C and Stallins, J Anthony and Brantley, Steven T and Young, Donald R (2016). Crossing Scales: The Complexity of Barrier-Island Processes for Predicting Future Change. *BioScience*. biw154. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1093/biosci/biw154

Licenses

Other Conference Presentations / Papers

Other Products

Other Publications

Patents

Technologies or Techniques

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 LTER
https://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 202 datasets that are also published on the Environmental Data Initiative and LTER Data Portals and DataONE.org.

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
McGlathery, Karen	PD/PI	2
Porter, John	Co PD/PI	9
Reidenbach, Matthew	Co PD/PI	1
Wiberg, Patricia	Co PD/PI	1
Anderson, Iris	Co-Investigator	1

Name	Most Senior Project Role	Nearest Person Month Worked
Bachmann, Charles	Co-Investigator	1
Berg, Peter	Co-Investigator	1
Blum, Linda	Co-Investigator	3
Carr, Joel	Co-Investigator	1
Christian, Robert	Co-Investigator	1
D'Odorico, Paolo	Co-Investigator	1
Dueser, Raymond	Co-Investigator	1
Fagherazzi, Sergio	Co-Investigator	1
Fenster, Michael	Co-Investigator	1
Fuentes, Jose	Co-Investigator	1
Hayden, Bruce	Co-Investigator	1
Johnson, David	Co-Investigator	1
Karpanty, Sarah	Co-Investigator	1
Kirwan, Matt	Co-Investigator	1
Macko, Stephen	Co-Investigator	1
Mills, Aaron	Co-Investigator	1
Moncrief, Nancy	Co-Investigator	2
Moore, Laura	Co-Investigator	2
Pace, Michael	Co-Investigator	1
Schwarzschild, Arthur	Co-Investigator	5
Smith, David	Co-Investigator	1
Sojka, Sarah	Co-Investigator	1
Swallow, Stephen	Co-Investigator	1
Young, Donald	Co-Investigator	1

Name	Most Senior Project Role	Nearest Person Month Worked
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)	4
Goldstein, Evan	Postdoctoral (scholar, fellow or other postdoctoral position)	5
Woods, Natasha	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Boyd, David	Technician	8
Doucette, Danielle	Technician	1
Lee, David	Technician	7
Parker, Steve	Technician	3
Walters, David	Technician	3
Aoki, Lillian	Graduate Student (research assistant)	3
Berger, Amelie	Graduate Student (research assistant)	3
Besterman, Alice	Graduate Student (research assistant)	6
Brown, Joseph	Graduate Student (research assistant)	4
Castagno, Katie	Graduate Student (research assistant)	3
Coleman, Daniel	Graduate Student (research assistant)	4
deVries, Elsemarie	Graduate Student (research assistant)	6
Ferguson, Amy	Graduate Student (research assistant)	4
Fernandes, Arnold	Graduate Student (research assistant)	4
Flester, Jessica	Graduate Student (research assistant)	4
Heller, Erin	Graduate Student (research assistant)	6
Jiménez Robles, Alfonso	Graduate Student (research assistant)	4
Kearney, William	Graduate Student (research assistant)	4

Name	Most Senior Project Role	Nearest Person Month Worked
Lauzon, Rebecca	Graduate Student (research assistant)	1
Leonardi, Nicoletta	Graduate Student (research assistant)	2
Long, E.	Graduate Student (research assistant)	8
Lunstrum, Abby	Graduate Student (research assistant)	3
Moulton, Ashley	Graduate Student (research assistant)	4
Nettleton, Benjamin	Graduate Student (research assistant)	4
Oreska, Matthew	Graduate Student (research assistant)	3
Palazzoli, Irene	Graduate Student (research assistant)	6
Reeves, Ian	Graduate Student (research assistant)	7
Ruiz-Plancarte, Jesus	Graduate Student (research assistant)	4
Schieder, Nathalie	Graduate Student (research assistant)	1
Sebillian, Serina	Graduate Student (research assistant)	1
Sinclair, Michael	Graduate Student (research assistant)	4
Sun, Chao	Graduate Student (research assistant)	4
Williams, Bethany	Graduate Student (research assistant)	4
Wood, Lauren	Graduate Student (research assistant)	4
Zhang, Xiaohe	Graduate Student (research assistant)	3
Zhu, Qingguang	Graduate Student (research assistant)	1
Baucom, Caroline	Undergraduate Student	3
Chan, Abigail	Undergraduate Student	2
Cobb-Davis, Tyrah	Undergraduate Student	2
Eddy, Dale	Undergraduate Student	2
Exline, Elizabeth	Undergraduate Student	2
Failon, Caroline	Undergraduate Student	1

Name	Most Senior Project Role	Nearest Person Month Worked
Grimaudo, Alex	Undergraduate Student	1
Himmelstein, Joshua	Undergraduate Student	3
Houghland, Callie	Undergraduate Student	2
Kamani, Amitav	Undergraduate Student	2
Kerns, Kylor	Undergraduate Student	2
Knepper, Sean	Undergraduate Student	3
Longmire, Katherine	Undergraduate Student	1
Nicks, David	Undergraduate Student	1
Olivares, Philip	Undergraduate Student	2
Soghomonian, Shane	Undergraduate Student	1
Stachowiak, Jacob	Undergraduate Student	1
Thuma, Jessie	Undergraduate Student	2
Tuley, Philip	Undergraduate Student	3
Walker, Rosemary	Undergraduate Student	1
Yu, Viola	Undergraduate Student	1
Zhang, Jiaya	Undergraduate Student	3
Daly, Elizabeth	Research Experience for Undergraduates (REU) Participant	3
Flick, Rebekah	Research Experience for Undergraduates (REU) Participant	3
Long, Edward	Research Experience for Undergraduates (REU) Participant	3
Martin, Damien	Research Experience for Undergraduates (REU) Participant	3
Price, Taylor	Research Experience for Undergraduates (REU) Participant	3

Name	Most Senior Project Role	Nearest Person Month Worked
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 McGlathery
Email: kjm4k@virginia.edu
Most Senior Project Role: PD/PI
Nearest Person Month Worked: 2

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 Manager for project data

Funding Support: NSF

International Collaboration: Yes, Taiwan
International Travel: No

Matthew A Reidenbach
Email: reidenbach@virginia.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Environmental Fluid Mechanics

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: 1

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

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

Peter Berg
Email: pb8n@virginia.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Aquatic flux measurements

Funding Support: NSF, UVA Dean's office

International Collaboration: No
International Travel: No

Linda K. Blum
Email: lkb2e@virginia.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 3

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

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: No
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

Raymond D Dueser
Email: ray.dueser@usu.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Mammalian population and community studies

Funding Support: NSF, USU

International Collaboration: No
International Travel: No

Sergio Fagherazzi
Email: sergio@bu.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

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

Funding Support: NSF, USGS

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

Michael Fenster
Email: mfenster@rmc.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Monitoring of shoreline change

Funding Support: Randolph-Macon College

International Collaboration: No
International Travel: No

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

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

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

Sarah M. Karpanty
Email: karpanty@vt.edu

Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

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

Funding Support: Virginia Tech

International Collaboration: No
International Travel: No

Matt Kirwan
Email: kirwan@vims.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

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

Funding Support: VIMS, NSF, USGS

International Collaboration: Yes, Australia, Belgium
International Travel: No

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

Aaron Mills
Email: alm7d@virginia.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Worked on streambed biogeochemistry

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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: No

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

Arthur C Schwarzschild
Email: arthur@virginia.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 5

Contribution to the Project: Educational Coordinator, Site Manager

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

International Collaboration: No
International Travel: No

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

Sarah Sojka
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

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

Donald R Young
Email: dryoung@vcu.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

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

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

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

Orencio Duran Duran
Email: odvinent@vims.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
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

Evan Goldstein
Email: ebgold@live.unc.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 5

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

Natasha Woods
Email: nnwoods@vcu.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 1

Contribution to the Project: Worked with Zinnert on landscape dynamics of barrier islands

Funding Support: NSF, Ford Foundation

International Collaboration: No
International Travel: No

David M Boyd
Email: dmb4dd@cms.mail.virginia.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 8

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

Danielle Doucette
Email: doucettedn@gmail.com
Most Senior Project Role: Technician
Nearest Person Month Worked: 1

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

Funding Support: NSF, VIMS

International Collaboration: No
International Travel: No

David Lee
Email: ddk5e@virginia.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 7

Contribution to the Project: Drives boats, collects data

Funding Support: NSF

International Collaboration: No
International Travel: No

Steve C Parker
Email: scp3t@virginia.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 3

Contribution to the Project: Boat driving, equipment maintenance

Funding Support: UVA, NSF

International Collaboration: No
International Travel: No

David C Walters
Email: dcwalters@vims.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 3

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Lillian Aoki
Email: lra53@cornell.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Amelie C Berger
Email: acb4rk@virginia.edu

Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

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

Alice F Besterman
Email: afb5kg@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Daniel J Coleman
Email: djcoleman@vims.edu
Most Senior Project Role: Graduate Student (research assistant)
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

Elsemarie deVries
Email: elsemar@live.unc.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

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

Funding Support: NSF, UNC-CH

International Collaboration: No
International Travel: No

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

Arnold Fernandes
Email: arnold26@bu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: Volunteer

International Collaboration: No
International Travel: No

Jessica A. Flester
Email: jaf3bc@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
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: NSF, UVA

International Collaboration: No
International Travel: No

Erin Heller
Email: elheller@vt.edu

Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

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

Funding Support: NSF GRFP

International Collaboration: No
International Travel: No

Alfonso M Jiménez Robles
Email: mjralfonso@gmail.com
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: Spanish Government

International Collaboration: Yes, Spain
International Travel: No

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

Rebecca Lauzon
Email: Rebecca.lauzon@duke.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

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

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

E. Victoria Long
Email: evl5yz@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 8

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

Abby M Lunstrum
Email: aml3ra@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

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

Funding Support: NSF, UVA

International Collaboration: No
International Travel: No

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

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

Contribution to the Project: Worked with Zinnert on landscape dynamics of barrier islands

Funding Support: NSF

International Collaboration: No
International Travel: No

Matthew P Oreska
Email: mpo4zx@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

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

Irene Palazzoli
Email: irene.palazzoli@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: NSF

International Collaboration: No
International Travel: No

Ian Reeves
Email: irbreeves@gmail.com
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 7

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

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

Nathalie W Schieder
Email: nwschieder@vims.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

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

Funding Support: Dominion Foundation

International Collaboration: No
International Travel: No

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

Michael Sinclair
Email: sinclairmn@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Worked with Zinnert on landscape dynamics of barrier islands

Funding Support: NSF

International Collaboration: No
International Travel: No

Chao Sun
Email: sunchaonju@yeah.net
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Fagherazzi on marsh migration

Funding Support: NSF

International Collaboration: No
International Travel: No

Bethany Williams
Email: bwilliams@vims.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Lauren Wood
Email: woodlk@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

Xiaohe Zhang
Email: zhangbu@bu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Working with PI Fagherrazi on marsh migration

Funding Support: NSF

International Collaboration: No
International Travel: No

Qingguang Zhu
Email: qz3cp@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Working with P. Wiberg

Funding Support: NSF

International Collaboration: No
International Travel: No

Caroline Baucom
Email: baucomcm@mymail.vcu.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 3

Contribution to the Project: Worked with Zinnert on landscape dynamics of barrier islands

Funding Support: NSF, VCU

International Collaboration: No
International Travel: No

Abigail Chan
Email: awc4ey@Virginia.EDU
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Tyrah Cobb-Davis
Email: tacobb@randolphcollege.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: Worked with S. Sojka on artificial seagrass project

Funding Support: Randolph College, Virginia Foundation for Independent Colleges

International Collaboration: No
International Travel: No

Dale Eddy
Email: dje5pe@virginia.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Elizabeth Exline
Email: eaexline@randolphcollege.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: Worked with S. Sojka on artificial seagrass project

Funding Support: Randolph College

International Collaboration: No
International Travel: No

Caroline Failon
Email: cmfailon@email.wm.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, VIMS

International Collaboration: No
International Travel: No

Alex Grimaudo
Email: alexg8@vt.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

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

Funding Support: Virginia Tech

International Collaboration: No
International Travel: No

Joshua D Himmelstein
Email: jdhimmelstein@email.wm.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 3

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Callie Houghland
Email: cbh5mb@virginia.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

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

Funding Support: none

International Collaboration: No
International Travel: No

Amitav Kamani
Email: aak7uz@Virginia.EDU
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Kylor Kerns
Email: kk2kq@Virginia.EDU
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

David Nicks
Email: dwnicks@vims.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: DOE

International Collaboration: No
International Travel: No

Philip Olivares
Email: pmo5fm@Virginia.EDU
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Shane Soghomonian
Email: scsoghomonian@randolphcollege.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Worked with S. Sojka on artificial seagrass project

Funding Support: Randolph College

International Collaboration: No
International Travel: No

Jacob Stachowiak
Email: jpstachowiak@randolphcollege.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Worked with S. Sojka on artificial seagrass project

Funding Support: Randolph College

International Collaboration: No
International Travel: No

Jessie A. Thuma
Email: jat7jw@virginia.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

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

Philip Tuley
Email: tuleypa@vcu.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 3

Contribution to the Project: Worked with Zinnert on landscape dynamics of barrier islands

Funding Support: NSF

International Collaboration: No
International Travel: No

Rosemary Walker
Email: rosemaryw151@gmail.com
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Worked with M. Kirwan on marsh process studies

Funding Support: none

International Collaboration: No
International Travel: No

Viola Yu
Email: vy33@cornell.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, VIMS

International Collaboration: No
International Travel: No

Jiaya Zhang
Email: jzhang15@email.wm.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 3

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

Funding Support: Volunteer

International Collaboration: No
International Travel: No

Elizabeth Daly
Email: ejd5yd@Virginia.EDU
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

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: 2017

Rebekah Flick
Email: rmf5xb@Virginia.EDU
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Worked with PI Mike Pace and graduate student Alice Besterman on effects of invasive macroalgae

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: 2017

Edward Long
Email: longea3@mymail.vcu.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Worked with Zinnert on landscape dynamics of barrier islands

Funding Support: NSF

International Collaboration: No
International Travel: No
Year of schooling completed: Junior
Home Institution: VCU
Government fiscal year(s) was this REU participant supported: 2017

Damien Martin
Email: dm2vj@Virginia.EDU
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Worked with PI Mike Pace and graduate student Alice Besterman on effects of invasive macroalgae

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: 2017

Taylor Price
Email: pricetl@vcu.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

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: 2017, 2016

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: Junior
Home Institution: UVA
Government fiscal year(s) was this REU participant supported: 2017

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
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.

VCR research has contributed to the development of ecological theory on ecosystem state change dynamics, specifically involving foundation species. We have made significant contributions to understanding leading indicators of threshold responses and biotic feedbacks that either maintain or facilitate transitions in ecosystem states. 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. This knowledge is transferrable to other coastal systems globally.

The VCR domain provides us with a unique opportunity to address how connectivity among ecological systems on the landscape (coastal bays, intertidal marshes, barrier islands) affects state change. Our work to date has shown that state change dynamics among adjacent systems is coupled, where state in one system can propagate to the other.

WATERSHEDS AND COASTAL BAYS

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. We have collaborated with colleagues at the VIMS and TNC 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 – 16 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. Our research has also shown that the state change to seagrass dominance alters local hydrodynamics and switches 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%). This has important implications for long-term carbon burial in coastal sediments. At VCR LTER, we were the first to show the role of restoration in reinstating carbon storage capacity, similar to how reforestation reinstates carbon storage on terrestrial landscapes.

Our research on the invasive macroalga, *Graciliaria vermiculophylla*, is widely recognized as an example of how species introductions can lead to novel habitats. *Gracilaria* now dominates intertidal flats and marshes that previously did not support macroalgal populations. The presence of *Gracilaria* has both positive and negative impacts on the system. *Gracilaria*

subsizes nutrients to the intertidal zone, supports novel invertebrate communities, and enhances nitrogen removal through denitrification. At the same time, it is associated with the pathogenic bacteria *Vibrio* spp. that is a public health hazard, and may impede shorebird foraging in intertidal flats if macroalgal densities are high.

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 different systems (VCR vs. Dutch Schelde Estuary).

Surface Elevation Tables (SETs) are used to quantify changes in sedimentation and subsidence that ultimately will determine the fate of marshes in the face of sea level rise. Numerical models, parameterized in part from VCR data (sediment, biomass, erosion), predict marshes will respond to sea-level rise by building sediment at progressively faster rates until a threshold sea-level rise rate is exceeded. These models have been applied to the VCR, PIE and GCE LTER sites. Short-term experiments and long-term biomass records indicate that productivity and its effect on salt marsh accretion respond non-linearly to changes in sea level/flooding duration. 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.

There are many restoration projects aimed at mitigating the impact of coastal storms using salt marshes and vegetated surfaces (i.e., “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 loss by erosion is dictated by average wave conditions, and is, therefore, predictable. Moderate storms with a return period of 2.5 months drive erosion; large 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. We have 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 impact higher trophic levels.

By exploring the complex roles of biological and physical 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 of island geomorphology and vegetation feedbacks 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. Processes that maintain low elevations, termed 'maintainer feedback', has the potential to accelerate large-scale shifts from dune-dominated to overwash-dominated barrier island morphologies with climate change-induced increases in storm intensity and sea-level rise. We have shown how vegetation composition affects dune morphology with a resulting effect on island vulnerability to overwash during storms. 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 generally 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) as well as biotic feedbacks that maintain ecosystem states. We have documented a dramatic increase in shrub thickets (>400%) as shrubs encroach onto grasslands. Increased shrubland has ecosystem level consequences by preventing transition of marsh to upland (e.g. migration). Individual shrubs and thickets alter the microclimate, causing warmer winter and cooler summer temperatures, and fewer extreme damaging temperatures. This increases annual net primary productivity, evapotranspiration, and soil organic matter, nitrogen and carbon.

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. Our strength is our integrated approach linking ecological and physical

(geomorphology, hydrology) processes that are critical to ecosystem dynamics in coastal systems. For example, biotic feedbacks in seagrass ecosystems on sediment deposition and resuspension by currents and waves measured by physical scientists are critical to understanding growth and population dynamics. Through this collaboration, we have created a novel model coupling hydrodynamics with vegetation growth that describes the non-linear state-change dynamics in seagrass ecosystems.

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.

Science – arts/humanities collaborations are a key component of our education and outreach programs. As part of our collaboration in the LTER sponsored Ecological Reflections program we hold two Art and Ecology Professional Development workshops for public school Art Teachers annually. We also host a Nature Writing workshop for undergraduate Engineering Students with faculty from the Science Technology and Society program in the UVA School of Engineering. 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. More recently, we have initiated a Humanities Lab focused on “listening” in the coastal zone. These workshops all introduce participants to the place-based science being conducted at the VCR-LTER and explore interdisciplinary collaborations.

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 ~50 school teachers per year, introducing them to the key environmental issues impacting our coastal ecosystems. These workshops have the potential to impact more than 8000 students per year throughout the state of Virginia. In collaboration with Web-based Interactive Science and Engineering Learning Tool (NSF), Consortium for Ocean Science Exploration and Engagement, and VA Sea Grant we have developed on-line teaching modules that are available globally. This online curriculum has been developed for middle school students to meet Commonwealth of Virginia learning standards for Environmental Sciences. Two modules were created: Sea-level rise impacts on coastal communities, and Marine biology and coastal ecosystems. (http://www.wiseengineering.org).

VCR was the first LTER site to develop a Diversity Plan. This plan is serving as a model for other LTER sites.

What is the impact on physical resources that form infrastructure?

The VCR/LTER is the primary 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, oyster, and algal 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 periodic 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 falcon 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 202 online datasets with an aggregate volume of approximately 349 GB. These are published via the VCR/LTER web site, the Environmental Data Initiative Data Portal and DataOne Search. The datasets are frequently downloaded for use by researchers and students. During the period from 9/1/16 to 8/30/17 VCR/LTER data files have been downloaded at 2,650 times via the LTER and Environmental Data Initiative Data Portals (22,831 times since the initiation of the grant in Nov. 2012). An additional 452 data entities were downloaded directly from the VCRLTER . For most downloads no information regarding by whom or why data was downloaded is available. However, of the 84 downloads for which a reason was given, the vast majority of downloads were for research (91%), with 9% 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.

A map of the Marsh Vulnerability Index for the VCR has been incorporated into TNC’s Coastal Resilience online decision-support tool, where it can be queried and analyzed with other geospatial data to visualize risk and evaluate effectiveness of nature-based solutions for coastal protection.

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 (TNC) 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/).

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.

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. Our work on how restored oyster reefs affect marsh edge erosion is key to developing living shorelines in Virginia and throughout shallow coastal regions in the U.S. and abroad. Our findings 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.

VCR research is the first to show 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 wrote the international protocol for the Verified Carbon Standards program on to assign carbon credits on international trade markets for seagrass restoration.

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

Knowledge of the relationship between land use, nutrient contamination of groundwater, groundwater export of nutrients to coastal 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.

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 to collaborate on data, models and tools to address coastal resilience to climate change.

Changes/Problems

Changes in approach and reason for change
Nothing to report.

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.