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

Mechanisms and Consequences of State Change

Marshes: Along the marsh-upland boundary, we developed a new protocol for herbaceous, shrub, and tree monitoring to track the response of plant communities to sea-level rise in abandoned farmland and maritime forests. On the marsh-lagoon boundary, we examined the effects of the herbivorous purple marsh crab, *Sesarma reticulatum*, and the burrowing fiddler crab, *Uca pugnax*, on marsh plant growth, decomposition, soil strength and sedimentation. For the back-barrier marshes, we resampled the chronosequence across low marsh zones to assess predictions of state change made in the mid-1990s, and used fine-scale remote sensing and drones to assess relationships between plant community structure, biomass, and health.

Coastal bays: We continued to monitor the long-term, landscape-scale seagrass restoration experiment to determining the consequences of seagrass state change at population to ecosystem levels, including metabolism, carbon/nitrogen cycling and sequestration, and faunal abundance/diversity. The seagrass restoration dataset, now 17 years long, includes the period of ecosystem development (0-13 years), a high-temperature related die-off event in 2015, and recovery from 2016-2018. This gives an unprecedented opportunity to understand seagrass resilience. To determine the consequences of the seagrass landscape structure on invertebrate biodiversity, we began a new spatial time series of crab abundances at 16 sites and infaunal communities at 30 sites. We also started a new experiment to test how seagrass alters

the growth of juvenile clams via reductions in water flow. We quantified the effects of the invasive algae, Gracilaria vermiculophylla, on net ecosystem metabolism (using aquatic eddy covariance) and hydrodynamics. We digitized and mapped oyster cover using LIDAR altimetry data and ground-truthing, and quantified the relationship between oyster reef locations and the physical parameters.

Barrier islands: We continued to study the mechanisms of shrub expansion and the impacts on mesopredator and nesting/migrant bird populations. Species composition, stomatal conductance, microclimate, and water table data were collected in grassland, transition areas, shrub thicket and shrub removal plots. We measured productivity in these plots and collected soils to assess carbon stocks and nitrogen availability in grasslands and shrublands of different ages. We collected distribution data on shrub seedlings with respect to grass density, salinity, and elevation. We began marking Piping Plovers to track movements of birds in response to vegetation encroachment and geomorphic change and used models to link island geomorphology, invertebrate prey and migrant shorebird populations to predict how climate variation affects trophic dynamics. We also completed data collection, analysis and interpretation for our dune-grass transplant field experiment to determine the feedbacks of vegetation structure and growth on dune formation.

Thresholds for State Change

Marshes: We measured suspended sediment concentrations and water levels and used them in numerical models to predict threshold rates of sea-level rise for marsh survival. Remote sensing data were used to look at the historical relationship between barrier island upland and marsh transitions. We applied our spatial marsh accretion model to predict how VCR marsh area will change in response to sea-level rise and decisions related to upland land use. The model was parameterized using LTER datasets related to suspended sediment concentrations, elevation change, plant biomass, and LIDAR.

Coastal bays: We used aerial-photo data of eelgrass restoration plots to quantify the eelgrass environmental niche and evaluate the potential for state change. We analyzed survival/failure data with respect to water residence time, fetch length, water temperature, bathymetry and sediment grain size. We continue to investigate spatial and temporal patterns of sea-surface temperature, focusing on high-temperature events that might impact seagrass survival in restoration plots. We evaluated the dual role of seagrass and benthic microalgae in altering the seasonal threshold for sediment resuspension, a critical feedback that influences seagrass growth and state transitions. We measured all greenhouse gas stock and fluxes, and for the first time for a seagrass meadow, calculated the net greenhouse gas benefit from restoration.

Barrier islands: We continue to develop a model of dune growth and shrub expansion on islands subject to storm events. We also developed a coastal dune model with a more detailed vegetation module to examine how vegetation characteristics and species interactions may influence dune development. We modelled the change in overwash areas and corresponding change in abundance of nesting Piping Plovers, and compared this to similar geomorphic changes in New York and North Carolina.

Ecosystem Connectivity

We modeled the response of marshes at the global scale to changes in sea level-rise under different scenarios of coastal population growth and flood protection (e.g., levees) to explore coupling between marshes and adjacent uplands. For the mid-Atlantic, we used historical maps and photographs to assess model assumption that marshes migrate passively into retreating forests as a function of sea-level rise and topography. We continued our experiments on the salt-tolerant biofuel crop *K. pentacarpos* in agricultural fields abandoned due to saltwater encroachment.

For the marsh-lagoon boundary, we used high-resolution field measurements to study sediment exchange between tidal flats (with and without seagrass) and marshes. We also established a new long-term experiment in collaboration with TNC to address how restored oyster reefs affect marsh erosion by quantifying effects on larval settlement, oyster densities, infaunal communities, flow dynamics and wave attenuation. To better understand the controls on oyster population dynamics, we began measuring spatial variation in monthly and seasonal oyster larval settlement at 14 natural and restored oyster reefs. We used aquatic eddy covariance to determine rates of oyster metabolism.

We continued to to assess shorebird foraging as a vector for bacterial transmission. We amplified markers of the pathogen Vibrio 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.

We added seagrass dynamics to the barrier island morphodynamic model, GEOMBEST+, using parameterizations for seagrass and morphologic conditions based on VCR data sets. We used the model to conduct experiments that examine the coupled interactions of the back-barrier bay with both adjacent (marsh) and non-adjacent (barrier) systems. On the barrier islands, raccoon and red fox threaten beach-nesting and colonial waterbirds. We used mobility data to apply cost-distance and least-cost path analyses to determine predator migration paths and sources of immigrants to barrier islands, and camera trapping to assess the before-after impacts of predator removal. We used these and other data in partnership with the USFWS, Manomet, USDA, and TNC to develop a plan for predation management.

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 State Change

Marshes: Our caging experiment suggests that fiddler crabs can ameliorate grazing effects of purple marsh crabs on *S. alterniflora*. When combined with fiddler crabs, purple marsh crabs had no effect on plant biomass. Resampling the South Hog Marsh Chronosequence after a period of 20+ years yielded results very similar to those found in the 1990s, with predictable increases in *Spartina alterniflora* biomass and tissue N, soil organic matter, N and C, and a decrease in grain size. While the invertebrate community continued to shift towards more “mud-loving” species, the population densities were significantly more patchy and higher. In our long-term study at the mainland-marsh boundary, marsh has encroached on an old field plant community over the last 6 years, reflecting an increase in average groundwater elevation and salinity. Plots planted with salt marsh mallow in 2014 showed that it facilitated the transition to high marsh including the pioneer species, *Distichlis spicata*, rather than the invasive *Phragmites* species.

Coastal bays: Seagrass restoration enhanced emission of greenhouse gasses CH4 and N2O release, however, this was offset by CO2 sequestration by 10:1. Enhanced production and burial within the meadow increased the net CO2-sequestration rate over time, which was calculated to be equivalent to the IPCC estimate for national GHG inventory accounting. Carbon storage in seagrass sediments varied spatially, with most carbon buried in areas of the meadow with low current velocities and fine-grained sediments. The seagrass meadow was in metabolic balance throughout our 11-year eddy covariance dataset. There were spatial patterns in consumer communities: bivalves and male crabs were more abundant in the meadow interior while female crabs were concentrated along meadow edges and outside the meadow. The invasion of tidal flats by the Japanese macroalga *Gracilaria vermiculophylla* has enhanced metabolism

and dampened flow, leading to a large reduction in bed shear stress. On oyster reefs, nighttime oxygen flux and day-night flux differences increased significantly with oyster density, the latter suggesting that as reefs matured they hosted greater quantities of benthic microalgae.

Barrier islands: Shrub seedlings establish within a narrow range of elevation and grass density. Shrublands invading grasslands modify the microclimate and reduce temperature extremes by 16℃ in the summer and ~2℃ in winter. Shrub presence of shrubs alters soil characteristics (bulk density, organic matter content, temperature) and community composition. Despite higher productivity in shrubs, carbon stock in sandy soils is low (<2%). Experimental transplantation of dune grasses shows that all 3 species tested increase sand deposition, providing evidence for the dune-building capacity. Based on transplant survival, the seaward limit of vegetation after 2 years was ~30 m from the shoreline (1.43m elevation), corresponding to < 7.5% inundation. Using our coastal dune model with a more-detailed vegetation module, we found that *S. patens* likely facilitates *A. breviligulata* establishment and thereby increases dune resilience following disturbance from overwash. We also found that hummocky foredunes coalesce to form continuous dune ridges, absent external forcing, over timescales that depend on initial plant dispersal and growth. The distribution and abundances of red knot shorebirds on barrier islands are partially explained by the abundances and distribution of food items. Other on-site (e.g. distance to predator-free roosting habitats) are important to predicting distribution and abundance. Stable isotope analysis indicates that one of the knots' key food items, *Mytilus edulis* spat, originates in non-estuarine waters and we are currently assessing its origin, which is key to understanding whether this prey will persist in the VCR under changing climate scenarios.

Thresholds for State Change

Marshes: Spatial model experiments at the VCR suggest that there are typically two phases of marsh response to sea-level rise, where marshes expand under low rates by migrating inland, but drown faster than they migrate under faster rates. Reconstruction of mid-Atlantic forest retreat rates derived from historical photographs and sediment cores, illustrate that marsh migration into forests has occurred in parallel with sea-level rise for the last 2000 years without significant lags or important thresholds.

Coastal bays: Recruitment site data indicate that the total habitable area for seagrass is smaller than that implied by the restoration plots, suggesting that meadows will continue to expand naturally but additional restoration effort would be necessary to maximize seagrass coverage. Analysis of sea-surface temperature in the coastal bays reveals persistently warmer regions and strong year-to-year variation in high-temperature conditions that are correlated with spatial variations in seagrass response and recovery.

Barrier islands: Long-term data records of air temperature show a warming trend since 1956 of 0.2°C/decade (annual max), 0.3°C/decade (annual min), and 0.6°C/decade (winter min). There are fewer freezing events below -15℃ since the 1970s. A ~-15℃ threshold for transition from grassland to shrubland was confirmed with experimental measurements on adult shrubs, and preliminary data suggest seedlings are more sensitive to freezing, with low survival at 10℃. Islands experiencing overwash and faster rates of landward migration have exposed peat banks that provide different species and abundances of prey for shorebirds than the more stable sandy intertidal zone habitats found on other islands. DNA analyses from migratory red knot fecal samples indicates that knots feeding on mid-tide, sandy intertidal zone habitats primarily consume *Diptera* and *Veneroida*, whereas knots feeding at low tide on exposed peat banks forage on *Amphipoda* and *Mytiloda*.

Ecosystem Connectivity

In the VCR and globally, the single biggest factor influencing future wetland size is their ability to migrate inland in the face of flood control structures. Our modeling predicts wetlands will expand with sea-level rise if levees are limited to locations where future populations > 20 people/km2, but will contract with sea-level rise if levees are constructed in locations with ≤ 5 people/km2.

GEOMBEST+ simulations suggest that seagrass both reduces back-barrier marsh edge erosion rates and increases progradation rates when there is sediment export to the ocean. Addition of seagrass to the model reduces the amount of sediment available to the marsh until the bay reaches a new, shallower equilibrium depth, while removing seagrass liberates previously-sequestered sediment that is then delivered to the marsh. Seagrass reduces migration rates of barrier islands that lack a back-barrier marsh by filling accommodation space in the bay.

At the bay-marsh boundary, suspended sediment is exchanged between tidal flats and adjacent marsh when the marsh is flooded. Marsh deposition is sensitive to inundation frequency, underscoring the importance of nontidal controls on water surface elevation, such as storm surge, on marsh deposition rates. A sediment deposition model for marshes predicted that waves displace maximum deposition inland from the marsh edge, consistent with measured deposition patterns.

The presence of *Gracilaria* macroalgal mats affects shorebird foraging. Generalist shorebirds forage on invertebrates mudflats with *Gracilaria*. Specialist shorebirds preferentially forage on bare sections of mudflats. Differences in invertebrates communities on bare vs. macroalgal dominated flats influence shorebird diets. Pathogenic *Vibrio* bacteria were present in *Gracilaria* based on qPCR and present on amphipods based on plate count studies. Further method refinements are needed to trace pathogens on different intertidal organisms.

Key outcomes or Other achievements:

VCR scientists have published 205 journal articles and 25 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 19%. This represents ~1300 ha of marsh 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. Regional winter warming has limited

the frequency of extreme cold temperatures (-16 C) which maintain a grassland state. Shrub establishment has an immediate effect on the environment, reducing species diversity and modifying the microenvironment (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. Despite high ANPP from shrubs, soil C stocks are very low.

The link between barrier island geomorphology and vegetation has trophic-level ecological consequences affecting mammals and nesting and migrant 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%. Overwash frequency also affects vegetation composition in the swale and the lowers range of functional traits expressed and impacts the quantity and quality of habitat available for ground-nesting shorebirds.

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. Shrub presence is found behind larger dunes (>1.5m). The combined effects of dune ridges and shrub establishment may further affect overwash of sediments onto the marsh.

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?**

As demonstrated by 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. 35 graduate students, 4 post-docs, and 8 undergraduate students were trained this year through the VCR LTER program. VCR has a formal 'tiered' mentoring program that involves faculty, graduate students, and undergraduate students working together as a team on specific research projects.

Together with The Nature Conservancy we supported a 1-week coastal ecology summer camp for local upper elementary and middle school students. Camp was held at VCR research sites, and half of campers were recruited via the Boys and Girls Club and attended on SLTER scholarships. Campers explore terrestrial and marine environments while learning about environmental issues and natural processes.

The VCR LTER K-12 program is otherwise focused on teacher professional development. Sessions with varied focus impact a minimum of 45 teachers per year with a goal of increasing environmental literacy and strengthening STEM education in K-12 classes on the Eastern Shore and throughout Virginia. We 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. Class groups grew and monitored batches of baby oysters during the school year.

Each year VCR co-sponsors Coastal Bay Ecology (Spring) and Fall Migration Ecology professional development workshops on the Eastern Shore of Virginia. In 2018, Fall Migration was temporarily suspended to allow for additional professional development planning following new partnerships with The Nature Conservancy and Blandy Experimental Farm on two

NOAA grants awarded to support Meaningful Watershed Education Experience (MWEE) integration into K-12 curriculum in Northampton, Accomack, and Clarke County schools. Through SLTER, VCR will contribute to both teacher professional development and to assisting teachers with issue definition and results interpretation and synthesis before and after field experiences with MWEE partners, respectively.

VCR-LTER also supports two annual Art and Ecology workshops for teachers. Both focus on observation as the origination for both art and science. 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 in the Science and Engineering library at the University of Virginia and on the Eastern Shore of Virginia.

In 2018 “listening” emerged as a new theme in VCR research and outreach. Ph.D. Candidate M. Volaric collaborated with Eli Stine of the UVA Music Department to study sounds in relation to productivity of oyster reefs. Stine is now creating musical compositions with the reef sound data collected during research. The Environmental Humanities Conservatory was founded in association with VCR-LTER with an initial award based on ecoacoustic listening and an ultimate goal of launching an LTEReflections program that promotes collaborations between VCR researchers and scholars in the humanities. Associated outreach activities are in planning stages.

Site director and education and outreach coordinator C. Johnston stepped into the role of LTER Education and Outreach Committee co-chair for a 3-year term. A set of specific actions derived from the VCR Diversity Plan are being implemented to better support diversity in incoming cohorts, and VCR leadership agreed to extend the Diversity Plan to incorporate outreach audiences.

*** 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 7,9331 page views in 3,400 sessions. During that same period, VCR/LTER data files were downloaded 5,887 times from the LTER or Environmental Data Initiative Portals, which more than doubles the number of downloads during the same period in the previous year.

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?**

In response to suggestions by the mid-term review team in 2015, we will continue to do the following: 1) develop a sediment budget for the VCR, which will be useful in linking subsystems across the landscape; 2) focus on biotic feedbacks on state change; we have added two new PIs, David Johnson, to address fauna-mediated feedbacks on plant production and geomorphology, and Keryn Gedan, to investigate plant interactions and their effects on ecosystem transition at the marsh-upland boundary; and 3) assess carbon sequestration as consequence of ecosystem state change.

Mechanisms of Non-linear State Change

Marshes. Through field surveys and caging experiments, we will examine the effects of grazing by the purple marsh crab, *Sesarma reticulatum*, on the chemistry of *Spartina alterniflora*, the dominant marsh plant. We hypothesize that grazing will induce chemical defenses in *S. alterniflora*, thereby deterring further grazing. 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 along the marsh-to-forest transition and in a topographic depression where tree dieback occurred and a nearby convexity were trees survived hurricane Isabel. We will set up permanent monitoring plots that span the marsh-to-upland transition at several more sites.

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 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

Marshes. We will continue to integrate data from marsh SETs and field sampling of suspended sediment concentrations into our model of marsh state change and threshold responses. We will continue to use fine-scale remote sensing to develop improved algorithms for retrieval of plant biophysical characteristics, especially as related to plant stress, community shifts, and potential carbon sequestration, and will expand sampling to include seasonal variation and different types of marshes.

Coastal Bays. We will continue to monitor experimental seagrass plots to evaluate resilience to high-temperature events. We will complete our seagrass niche modeling 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. To understand the consequences of seagrass spatial structure on fauna, we will continue to sample communities of fish, infauna, and mobile consumers (e.g., crabs, whelks) across >30 seagrass sites

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

We will continue to monitor the constructed reefs that comprise our new long-term experiment addressing the effectiveness of 4 different reef designs on marsh erosion, larval settlement, oyster densities and infaunal communities. To determine the spatial environmental factors mediating oyster population dynamics, we will continue to measure oyster larval settlement and recruitment monthly and seasonally (May–September) at numerous sites across VCR.

We will be working to carry through to final publication stage, papers describing seagrass-marsh- barrier connections (using GEOMBEST+) and the likely facilitation of *A. breviligulata* by *S. patens*.

We will examine the impacts of interior vegetation cover on barrier overwash by installing measurement stations in areas to measure overwash flow and deposition during storms, and measure aggregated stratigraphic and topographic effects of past washover events in areas with and without shrubs using GPR and GPS surveying techniques. We will link these findings to ongoing monitoring of the distribution, abundance and productivity of shorebirds nesting in these areas. We plan to use these measured impacts in a coupled barrier island-shrub model to further investigate the role of interior land-covers differences on long-term (centennial-millennial) barrier evolution.

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.

We will continue to refine methods to measure if macroalgal mats, by attracting invertebrates like amphipods, promote the abundance of *Vibrio* pathogens. We will also assess bird biomass in relation to mudflat primary producers. Studies of nutrient cycling related to aquaculture will also be continued.

State Change & Projected Climate/land-use Drivers

We will continue our analysis of historical marsh/upland transitions, including a new focus on the carbon ramifications of marsh migration, using new measurements of above and belowground carbon stocks and rates of soil carbon burial across a marsh-to-upland chronosequence. We will continue the dune grass transplantation experiment, the post-fertilized dune plots, and the expansion of *Uniola*. We will 1) continue to relate long-term data on vegetation change, mammal predators and shorebird populations; 2) continue analysis of how climate-driven geomorphology changes affect shorebird abundance, habitat selection and prey availability; 3) conduct additional camera and manual trapping to assess changes in small mammal populations. We will add in manipulations of sea-level rise to the shrub/grass model. We will continue measurements of groundwater elevations and salinity, as well as plant community composition in our research plots at the boundary between high marsh and old field plant communities.

We will continue our 2012 experiment designed to explore the ecological and economic benefits of *K. pentcarpos* in abandoned agricultural fields (e.g., nutrient and carbon sequestration, exclusion of invasive species). We will explore the ecological and economic benefits of *K. pentcarpos*.

Products

Books

Laura J. Moore and Brad A. Murray (2018). *Barrier Dynamics and Response to Changing Climate* Springer, International Publishing A.G.. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; ISBN: 978-3-319-68086-6

Book Chapters

Christian, R.R. and Blum, L. K. and Ardón, M. and E.Leorri (2018). Sea-level change and its potential effects on coastal blue carbon. *A Blue Carbon Primer: The State of Coastal Wetland Carbon Science, Practice, and Policy* Windham-Myers, L. and

Crooks, S. and Troxler, T.. CRC Press. New York. 121-132. Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = No

Laura J. Moore and Evan B. Goldstein and Orencio Durán Vinent and David Walters and Matthew Kirwan and Rebecca Lauzon and A. Brad Murray and Peter Ruggiero (2018). The Role of Ecomorphodynamic Feedbacks and Landscape Couplings in Influencing the Response of Barriers to Changing Climate. *Barrier Dynamics and Response to Changing Climate* Moore, L.J. and Murray, A.B.. Springer International Publishing AG. 305-336. Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/978-3-319-68086-6_10.

Laura J. Moore and Murray, A. Brad (2018). Geometric Constraints on Long-Term Barrier Migration: From Simple to Surprising. *Barrier Dynamics and Response to Changing Climate* Moore, L.J. and Murray, A.B.. Springer International Publishing AG. 211-241. Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes ; ISBN: 978-3-319-68086-6.

Oreska, M. P. J. and McGlathery, K. J. and Orth, R. J. and Wilcox, D. J. (2018). Seagrass mapping: A survey or recent seagrass distribution literature. *A Blue Carbon Primer* Crooks, S. and Troxler, T. and Windham-Myers, L.. CRC Press. 352. Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes ; ISBN: 978-1-49-876909-9.

Porter, J.H. (2018). Chapter 3: Scientific Databases for Environmental Research. *Ecological Informatics: Data Management and Knowledge Discovery 3.* Recknagel, Friedrich and Michener, William. Springer Nature. Switzerland. 27-54. Status = PUBLISHED; Acknowledgement of Federal Support = No ; Peer Reviewed = No ; DOI: 10.1007/978-3-319-59928-1.

Inventions

Journals or Juried Conference Papers

Aoki, Lillian R and McGlathery, Karen J (2018). Restoration enhances denitrification and DNRA in subsurface sediments of Zostera marina seagrass meadows. *Marine Ecology Progress Series*. 602 87-102. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: https://doi.org/10.3354/meps12678

Besterman, Alice F and Pace, Michael L (2018). Do Macroalgal Mats Impact Microphytobenthos on Mudflats? Evidence from a Meta-Analysis, Comparative Survey, and Large-Scale Manipulation. *Estuaries and Coasts*. 1-13. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s12237-018-0418-3

Castagno, Katherine A and Jiménez-Robles, Alfonso M and Donnelly, Jeffrey P and Wiberg, Patricia L and Fenster, Michael S and Fagherazzi, Sergio (2018). Intense Storms Increase the Stability of Tidal Bays. *Geophysical Research Letters*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: https://doi.org/10.1029/2018GL078208

Day, Frank P and Adams, Emily C and Gibala-Smith, Leah A and Graziani, Dominic J and McMillan, Brett and Sedghi, Nathan and Shafer, Justin and Smith, Matthew (2018). Determining Change in Coastal Barrier Island Dune Vegetation Following a Decade of Nitrogen Fertilization. *Journal of Coastal Research*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.2112/JCOASTRES-D-17-00190.1

Donatelli, Carmine and Ganju, Neil Kamal and Fagherazzi, Sergio and Leonardi, Nicoletta (2018). Seagrass Impact on Sediment Exchange Between Tidal Flats and Salt Marsh, and The Sediment Budget of Shallow Bays. *Geophysical Research Letters*. 45 (10), 4933-4943. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1029/2018GL078056

Dornelas, Maria and Antao, Laura H and Moyes, Faye and Bates, Amanda E and Magurran, Anne E and Adam, Dušan and Akhmetzhanova, Asem A and Appeltans, Ward and Arcos, Jose Manuel and Arnold, Haley (2018). BioTIME: A database of biodiversity time series for the Anthropocene. *Global Ecology and Biogeography*. 27 (7), 760-786. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: https://doi.org/10.1111/geb.12729

Fernandes, Arnold and Rollinson, Christine R. and Kearney, William S. and Dietze, Michael C. and Fagherazzi, Sergio (2018). Declining Radial Growth Response of Coastal Forests to Hurricanes and Nor'easters. *Journal of Geophysical Research: Biogeosciences*. 123 (3), 832-849. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1002/2017JG004125

Goldstein, Evan B and Moore, Laura J and Durán Vinent, Orencio (2017). Lateral vegetation growth rates exert control on coastal foredune hummockiness and coalescing time. *Earth Surface Dynamics*. 5 (3), 417-427. Status = PUBLISHED;

Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.5194/esurf-5-417-2017

Horton, Benjamin P and Shennan, Ian and Bradley, Sarah L and Cahill, Niamh and Kirwan, Matthew and Kopp, Robert E and Shaw, Timothy A (2018). Predicting marsh vulnerability to sea-level rise using Holocene relative sea-level data. *Nature communications*. 9 (1), 2687. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1038/s41467-018-05080-0

Lauzon, Rebecca and Brad Murray, A and Moore, Laura J and Walters, David C and Kirwan, Matthew L and Fagherazzi, Sergio (2018). Effects of marsh edge erosion in coupled barrier island-marsh systems and geometric constraints on marsh evolution. *Journal of Geophysical Research: Earth Surface*. 123 (6), 1218-1234. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1029/2017JF004530

Leorri, Eduardo and Zimmerman, Andrew R. and Mitra, Siddhartha and Christian, Robert R. and Fatela, Francisco and Mallinson, David J. (2018). Refractory organic matter in coastal salt marshes-effect on C sequestration calculations. *Science of the Total Environment*. 633 291-398. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.scitotenv.2018.03.120

Nardin, William and Larsen, Laurel and Fagherazzi, Sergio and Wiberg, Patricia (2018). Tradeoffs among hydrodynamics, sediment fluxes and vegetation community in the Virginia Coast Reserve, USA. *Estuarine, Coastal and Shelf Science*. 210 98-108. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.ecss.2018.06.009

Needelman, Brian A and Emmer, Igino M and Emmett-Mattox, Stephen and Crooks, Stephen and Megonigal, J Patrick and Myers, Doug and Oreska, Matthew PJ and McGlathery, Karen (2018). The Science and Policy of the Verified Carbon Standard Methodology for Tidal Wetland and Seagrass Restoration. *Estuaries and Coasts*. 1-13. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s12237-018-0429-0

Schieder, Nathalie W and Walters, David C and Kirwan, Matthew L (2018). Massive upland to wetland conversion compensated for historical marsh loss in Chesapeake Bay, USA. *Estuaries and Coasts*. 41 (4), 940-951. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s12237-017-0336-9

Schuerch, Mark and Spencer, Tom and Temmerman, Stijn and Kirwan, Matthew L and Wolff, Claudia and Lincke, Daniel and McOwen, Chris J and Pickering, Mark D and Reef, Ruth and Vafeidis, Athanasios T (2018). Future response of global coastal wetlands to sea-level rise. *Nature*. 561 (7722), 231. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1038/s41586-018-0476-5

Sun, Chao and Fagherazzi, Sergio and Liu, Yongxue (2018). Classification mapping of salt marsh vegetation by flexible monthly NDVI time-series using Landsat imagery. *Estuarine, Coastal and Shelf Science*. 213 61-80. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: https://doi.org/10.1016/j.ecss.2018.08.007

Zeigler, Sara L and Thieler, E Robert and Gutierrez, Benjamin T and Plant, Nathaniel G and Hines, Megan and Fraser, James D and Catlin, Daniel H and Karpanty, Sarah M (2017). Smartphone technologies and Bayesian networks to assess shorebird habitat selection. *Wildlife Society Bulletin*. 41 (4), 666-677. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/wsb.820

Licenses

Other Conference Presentations / Papers

Other Products

Other Publications

Patents

Technologies or Techniques

Thesis/Dissertations

Oreska, M. P. J.. *Blue Carbon Benefits of Seagrass Restoration*. (2018). University of Virginia. Acknowledgement of Federal Support = Yes

Websites
VCR LTER Web Site
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 233 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
Bachmann, Charles	Co-Investigator	1
Berg, Peter	Co-Investigator	1
Blum, Linda	Co-Investigator	1
Carr, Joel	Co-Investigator	1
Castorani, Max	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
Gedan, Keryn	Co-Investigator	1
Johnson, David	Co-Investigator	1
Johnston, Cora	Co-Investigator	7

Name	Most Senior Project Role	Nearest Person Month Worked
Karpanty, Sarah	Co-Investigator	1
Kirwan, Matt	Co-Investigator	1
Macko, Stephen	Co-Investigator	1
Mills, Aaron	Co-Investigator	1
Moncrief, Nancy	Co-Investigator	1
Moore, Laura	Co-Investigator	1
Pace, Michael	Co-Investigator	1
Smith, David	Co-Investigator	1
Sojka, Sarah	Co-Investigator	1
Swallow, Stephen	Co-Investigator	1
Tyler, Christy	Co-Investigator	1
Yang, Xi	Co-Investigator	1
Young, Donald	Co-Investigator	1
Zinnert, Julie	Co-Investigator	2
Aoki, Lillian	Postdoctoral (scholar, fellow or other postdoctoral position)	4
Delgard, Marie Lise	Postdoctoral (scholar, fellow or other postdoctoral position)	4
Goldstein, Evan	Postdoctoral (scholar, fellow or other postdoctoral position)	4
Woods, Natasha	Postdoctoral (scholar, fellow or other postdoctoral position)	4
Lee, David	Technician	12
Parker, Steve	Technician	3
Berger, Amelie	Graduate Student (research assistant)	3
Besterman, Alice	Graduate Student (research assistant)	3
Biel, Reuben	Graduate Student (research assistant)	3
Brown, Joseph	Graduate Student (research assistant)	3

Name	Most Senior Project Role	Nearest Person Month Worked
Coleman, Daniel	Graduate Student (research assistant)	3
Eon, Rehman	Graduate Student (research assistant)	3
Ferguson, Amy	Graduate Student (research assistant)	3
Fernandes, Arnold	Graduate Student (research assistant)	3
Flester, Jessica	Graduate Student (research assistant)	3
Goldsmith, Sarah	Graduate Student (research assistant)	3
Heller, Erin	Graduate Student (research assistant)	3
Holstein, Dawn	Graduate Student (research assistant)	3
Jiménez Robles, Alfonso	Graduate Student (research assistant)	3
Kearney, William	Graduate Student (research assistant)	3
Kirschner, Audrey	Graduate Student (research assistant)	3
Lapszynski, Chris	Graduate Student (research assistant)	3
Lauzon, Rebecca	Graduate Student (research assistant)	3
Leonardi, Nicoletta	Graduate Student (research assistant)	3
Long, E.	Graduate Student (research assistant)	3
Lunstrum, Abby	Graduate Student (research assistant)	3
Nettleton, Benjamin	Graduate Student (research assistant)	3
Oreska, Matthew	Graduate Student (research assistant)	1
Palazzoli, Irene	Graduate Student (research assistant)	3
Reeves, Ian	Graduate Student (research assistant)	3
Ruiz-Plancarte, Jesus	Graduate Student (research assistant)	3
Schieder, Nathalie	Graduate Student (research assistant)	3
Sebillian, Serina	Graduate Student (research assistant)	3

Name	Most Senior Project Role	Nearest Person Month Worked
Sinclair, Michael	Graduate Student (research assistant)	3
Sun, Chao	Graduate Student (research assistant)	3
Tedford, Kinsey	Graduate Student (research assistant)	3
Tuley, Philip	Graduate Student (research assistant)	3
Williams, Bethany	Graduate Student (research assistant)	3
Wood, Lauren	Graduate Student (research assistant)	3
Zhang, Xiaohe	Graduate Student (research assistant)	3
Zhu, Quingguang	Graduate Student (research assistant)	3
Longmire, Katherine	Undergraduate Student	3
Nicks, David	Undergraduate Student	3
Barbour, Graham	Research Experience for Undergraduates (REU) Participant	3
Baucom, Caroline	Research Experience for Undergraduates (REU) Participant	3
Bieri, Elizabeth	Research Experience for Undergraduates (REU) Participant	3
Daly, Elizabeth	Research Experience for Undergraduates (REU) Participant	3
Kerns, Kylor	Research Experience for Undergraduates (REU) Participant	3
Wheeler, Maya	Research Experience for Undergraduates (REU) Participant	3
Cook, Allice	Other	1
Fauber, Donna	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: No
International Travel: No

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

Funding Support: NSF

International Collaboration: Yes, Taiwan
International Travel: Yes, Taiwan - 0 years, 0 months, 14 days

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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, UVA

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: 1

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

Max Castorani
Email: castorani@virginia.edu

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

Contribution to the Project: Coastal Marine Ecosystems Research

Funding Support: NSF

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

Keryn Gedan
Email: kgedan@email.gwu.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Studies marsh/upland interface

Funding Support: NSF

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

Cora Johnston
Email: caj2dr@Virginia.EDU
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 7

Contribution to the Project: Site Manager, Education Specialist

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: 1

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: 1

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

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

Christy Tyler
Email: actsbi@rit.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Biogeochemistry of wetlands

Funding Support: NSF

International Collaboration: No
International Travel: No

Xi Yang
Email: xy4f@Virginia.EDU
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Remote sensing, atmospheric fluxes

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

Lillian Aoki
Email: lra53@cornell.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
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

Evan Goldstein
Email: ebgold@live.unc.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 4

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: 4

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 Lee
Email: ddl5e@virginia.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 12

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

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: 3

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Reuben Biel
Email: reuben.biel@unc.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Works with PI Moore on beach and dune dynamics

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: 3

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

Daniel J Coleman
Email: djcoleman@vims.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Rehman Eon
Email: rse4949@rit.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Works with investigator Tyler on biogeochemistry of wetlands

Funding Support: NSF

International Collaboration: No
International Travel: No

Amy Ferguson
Email: aef2wa@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

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: 3

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: 3

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

Sarah Goldsmith
Email: sbg4917@rit.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Works with investigator Tyler on biogeochemistry of wetlands

Funding Support: NSF

International Collaboration: No
International Travel: No

Erin Heller
Email: elheller@vt.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

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

Funding Support: NSF GRFP

International Collaboration: No
International Travel: No

Dawn Holstein
Email: dnholstein@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Works with PI s Zinnert and Young on shrub dynamics

Funding Support: NSF

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: 3

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: 3

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

Audrey Kirschner
Email: kirschneras@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Works with PI s Zinnert and Young on shrub dynamics

Funding Support: NSF

International Collaboration: No
International Travel: No

Chris Lapszynski
Email: csl3172@rit.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Works with investigator Tyler on biogeochemistry of wetlands

Funding Support: NSF

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: 3

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: 3

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: 3

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

Benjamin Nettleton
Email: nettletonbp@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
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

Matthew P Oreska
Email: mpo4zx@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

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: 3

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: 3

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: 3

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: 3

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: 3

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: 3

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: 3

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Kinsey Tedford
Email: Ktedford@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Works with PI Castorani

Funding Support: NSF

International Collaboration: No
International Travel: No

Philip Tuley
Email: tuleypa@vcu.edu

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

Contribution to the Project: Works with PI s Zinnert and Young on shrub dynamics

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: 3

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

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: 3

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

Quingguang Zhu
Email: qz3cp@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Works with PI Wiberg on sediment dynamics

Funding Support: NSF

International Collaboration: No
International Travel: No

Katherine Longmire
Email: klongmire@vims.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 3

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: 3

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

Funding Support: DOE

International Collaboration: No
International Travel: No

Graham F Barbour
Email: gfb7yd@Virginia.EDU
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Working with PI McGlathery on seagrass studies

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:

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

Contribution to the Project: Working with PI Zinnert

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:

Elizabeth Bieri
Email: bieril@g.cofc.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Working with PI Castorani on coastal marine study

Funding Support: NSF

International Collaboration: No
International Travel: No
Year of schooling completed: Sophomore
Home Institution: College of Charleston
Government fiscal year(s) was this REU participant supported: 2018

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

Contribution to the Project: Working with PI McGlathery on seagrass studies

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:

Kylor C Kerns
Email: kk2kq@virginia.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Working with PI Berg and graduate student Berger on flux study

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:

Maya Wheeler
Email: mwheeler@randolphcollege.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Working with Sarah Sojka

Funding Support: NSF

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

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Donna Fauber
Email: dhf4k@Virginia.EDU
Most Senior Project Role: Other
Nearest Person Month Worked: 1

Contribution to the Project: Educational coordination

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 ABCRC Site Manager Johnston

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

Name	Type of Partner Organization	Location
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.

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

WATERSHEDS AND LAGOON

The eelgrass (*Zostera marina*) that once carpeted the seafloor of the VCR coastal bays and supported a thriving economy became locally extinct in the early 1930s as a result of disease and storm disturbance, causing a catastrophic shift to an unvegetated state. We have collaborated with colleagues at the Virginia Institute of Marine Sciences and The Nature Conservancy in a large-scale ecosystem-level experiment to reverse the state change. This has resulted in >25 km2 of restored habitat in a chronosequence of seagrass meadows 0 – 15 years since seeding. At least a decade is required for primary productivity, carbon and nitrogen sequestration, increased water column clarity, and sediment stabilization to be fully restored. The expansion of seagrass represents an additional filter for nutrient inputs, with enhanced rates of nitrogen removal through denitrification.

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

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

WETLANDS

The phenomenon of critical slowing down has been proposed as a leading indicator of ecosystem collapse, where recovery to disturbance slows as an ecosystem approaches a critical threshold. Critical slowing down is evident in marshes, and the response is consistent between extremely diverse systems (VCR vs. Dutch Schelde Estuary).

Surface Elevation Tables (SETs) are used at numerous VCR/LTER research sites to quantify changes in sedimentation and subsidence. On mainland marshes, the rate of accretion is generally keeping pace with sea level rise, and specific rates are position dependent, with the upper marsh receiving less input. In lagoon marshes, sea-level rise may be exceeding the ability of the marshes to accrete. Coupled lagoon-marsh modeling results show that the presence of seagrass can act both beneficially and detrimentally to the lagoon marshes depending on tidal-flat extent.

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

BARRIER ISLANDS

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

By exploring the complex, cross-scale roles of biological (e.g. vegetation and invertebrate succession dynamics) and physical (e.g. sediment composition and erosion) processes in the historical analysis of barrier island evolution, we are advancing our fundamental understanding of barrier dynamics and response to changing climate. Our work is contributing to the global body

of research regarding ecosystem state change, stability domains and coupling of biotic and physical phenomena, and has also resulted in the development of models that are being used by the broader scientific community.

We have established that long-term and landscape-scale vegetation patterns on the islands reflect non-linear dynamics and threshold responses to environmental drivers. We coined the term 'maintainer feedback' to apply to processes that maintain low elevations (in contrast to 'dune-builder feedback,' which leads to increases in island elevation). This feedback, working in conjunction with physical processes alone, has the potential to accelerate large-scale shifts from dune-dominated to overwash-dominated barrier morphologies with climate change-induced increases in storm intensity and sea-level rise. Sand delivered to back-barrier marshes by overwash processes allows back-barrier marshes to persist under conditions in which they would otherwise disappear, leading to increased island resilience. The newly recognized importance of two-way couplings between the sandy component of barrier islands and back-barrier marshes is redefining the way in which barrier island response to changing conditions is assessed.

Controls on plant community distribution can be explained by two key environmental parameters: distance from the shoreline (and thus overwash disturbance) and elevation above sea level (a surrogate for distance to groundwater). We have developed a conceptual framework based on the interaction between topography and vegetation for understanding connectivity across the barrier island landscape (disturbance-reinforcing and disturbance-resisting). The importance of biotic interactions in determining species composition as well as the interaction of different vegetation with the environment may be stronger in disturbance-resisting landscapes.. We have also demonstrated the effect of changing species composition on alongshore dune morphology with a resulting effect on island vulnerability to overwash during storms.

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

What is the impact on other disciplines?

The studies conducted by the VCR/LTER are inherently interdisciplinary including ecologists, hydrologists, biologists, geomorphologists and physical oceanographers. 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., EDI, DataOne).

The VCR/LTER shares 233 online datasets with an aggregate volume of approximately 430 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 10/1/17 to 9/30/18 VCR/LTER data files have been downloaded at 5,887 times via the LTER and Environmental Data Initiative Data Portals (28,718 times since the initiation of the grant in Nov. 2012). An additional 393 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 54 downloads for which a reason was given, almost all stated a research-related pupose. 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 Environmental Data Initiative and LTER Data Portals.

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.