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Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Award or Other Identifying Number Assigned by Agency:	1832221
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PD/PI Name:	Karen McGlathery, Principal Investigator Michael L Pace, Co-Principal Investigator John H Porter, Co-Principal Investigator Matthew A Reidenbach, Co-Principal Investigator Patricia L Wiberg, Co-Principal Investigator
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Accomplishments

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

Our overarching goal for VCR VII is to **understand, quantify, and predict how spatially integrated ecological and physical mechanisms drive ecosystem state change in coastal barrier systems in response to climate trends and variability, and to understand the consequences of these changes for ecosystem function.**

The vast undisturbed landscape of marshes, lagoons and barrier islands provides a unique opportunity to examine linkages among multiple ecosystems, in a way that cannot be done anywhere else in the US because of habitat fragmentation and the destruction of linkages by human activities. We take advantage of natural ‘experiments’ of pulse events (e.g., storm disturbance, marine heatwaves) that leverage our decadal-scale observations and experiments, and are conducting new experimental disturbances to investigate the sensitivity and resilience of the foundation species that dominate these ecosystems and their functions.

Our research questions are focused on four themes that build on recent findings and integrate existing long- and short-term studies with new observations, new experiments, and model development and testing.

Theme 1. Drivers and Patterns of Long-term Change: ***How have the distribution, spatial extent, and characteristics of ecosystems changed over time and how are these changes related to climate trends and variability?*** VCR research to date has identified climate-related forcing as having the greatest impact on ecological and physical processes that cause ecosystem state change. Changes in the trends and variability of storm frequency and intensity, sea-level rise, rainfall, and temperature have the potential to transform the coastal barrier landscape. Climate change may shift disturbance frequency (e.g., storms, high-temperature events) as well as mean climate state values.

Theme 2. Dynamics within Landscape Units: ***How do ecological and physical processes interact to maintain ecosystem states or facilitate transitions to new ones?*** We build on our long-term research to identify and test mechanisms that can lead to different possible trajectories (linear, threshold, regime shift). Long- and short-term data are used to parameterize, test, and evaluate mechanistic models. Natural disburbance events (high temperatures and storms)

provide valuable opportunities to test conceptual and theoretical models of state change and resilience in the context of climate-related forcing.

Theme 3. Dynamics between Landscape Units: ***How does connectivity influence ecosystem state change?*** The VCR is a model system in which to ask how ecosystems are connected through material and organismal transport and coupled state change dynamics. These integrated studies allow us to explore the relationship between local and broader-scale patterns and processes. Understanding how state change in one part of the landscape can propagate to another is critical to determining the holistic response of coastal barrier systems to present and future climate forcing.

Theme 4. Ecological Consequences of State Change: ***What are the consequences of ecosystem state change for ecosystem function?*** We focus on two important ecosystem functions of coastal barrier systems: carbon sequestration and habitat provisioning for consumers. Coastal systems are sites of high carbon sequestration, yet uncertainty exists on how ecosystem state change in response to climate forcing will affect carbon storage over the long term. Expansions of foundation species affect carbon cycling and also provide habitat for consumers that may alter predation, pathogens, and trophic dynamics. We address this question across multiple spatial and temporal scales, including mechanisms that can enhance responses to climate at the landscape scale. Our understanding of climate effects on ecosystem state change can inform management decisions that can avert undesirable changes (e.g., marsh loss) and reinforce positive ones (e.g., habitat restoration, wildlife conservation).

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

Major Activities:

Drivers of Long-term Change

Climate Drivers: Long-term data and analyses include 1) meteorological stations, tide and water temperature stations, groundwater wells; 2) a 40-yr record of storm surge events; and 3) VCR-wide simulations of storm surge during 4 large historic events.

Patterns of Change: Long-term data and experiments include: 1) satellite imagery, aerial photos, LiDAR, drone imagery, GIS layers, and structure-from-motion (SfM) technology to determine landscape change on islands, marshes and oyster reefs; 2) 2020 Landsat imagery and 2004 and 2021 NAIP aerial imagery data for barrier islands; 3) bathymetric measurements to quantify 20-yr changes in lagoon depth; and 4) continued experiments on seagrass and oyster reef restoration, marsh transgression, and island grass-shrub transitions; water quality monitoring; monitoring of shorebird and prey distributions and abundances on islands; and surveys of plant distributions.

Dynamics within Landscape Units

Upland: The long-term experiment to test the mechanisms underlying the forest-marsh response to sea-level rise (SLR) and storms includes monitoring tree water use and mortality, shrub growth, non-woody vegetation cover, litterfall, decomposition, groundwater, soil moisture, nutrients, salinity, light availability, canopy cover and invertebrate community structure/diet across an elevation gradient. We added 4 plots in the forest upslope to represent reference conditions and synthesized ecological, hydrological, and geomorphological baseline data to determine control-treatment plot pairings for the upcoming girdling disturbance experiment. We measured rates of elevation change across the marsh-forest boundary to quantify accretion and subsidence and analyzed the effect of tropical storm Melissa on groundwater salinity.

Intertidal: We continued long-term measurements of solar-induced chlorophyll fluorescence and canopy reflectance at our marsh eddy covariance tower to scale up to the landscape with remote sensing. For oyster reefs, we added elevation measurements to a hydrodynamic model linking flow and biogeochemical processes, and compared physical models of oyster habitat suitability for adults and juvenile recruits. Drone-based topographic measurements of 4 marshes were coupled with bathymetric measurements to quantify volumetric change in marsh and tidal flat

morphology at their boundary. We quantified wave attenuation over oyster reefs and the impact of reefs on adjacent marsh edge erosion rates.

Subtidal: For seagrass, we continued our long-term monitoring of the state-change restoration experiment (21 yr). We added continuous measurements of temperature to quantify heat stress, particularly marine heatwaves. We sampled leaves for disease analysis related to temperature. We added new measurements of seagrass epiphytes, benthic microalgae, and phytoplankton concentrations. Measurements of CO2, CH4, and N2O fluxes over the air-water interface were continued. At the broader lagoon scale, we 1) used high-resolution bathymetric measurements to quantify long-term (20 yr) and seasonal changes in meadow depth; 2) measured seasonal cycle of DIC and alkalinity; and 3) quantified effects of seagrass on hydrodynamics, sediment transport, and bivalve larval settlement using flow, optical backscatter sensors and sediment traps.

Barrier Island: We studied grasslands-shrub transitions by 1) monitoring of vegetation, microclimate, and soil characteristics in 3 swales that differ in dune elevation; and 2) continued monitoring grass-shrub ecotone for microclimate, water table, and vegetation composition; and examining drivers of shrub productivity. We extracted geomorphic metrics from LiDAR and combined these with dune height data to assess geomorphic thresholds for shrub growth in the island interior. To explore the feedbacks between plants and geomorphology, we 1) continued the dune grass planting experiment and long-term transect measurements of species composition and topographic evolution; and 2) continued our annual time series of multispectral and high-resolution optical drone surveys to characterize island vegetation and dune morphological change.

Dynamics Between Landscape Units

Transport of Sediment and Dissolved Constituents: We used the Delft3D model to quantify the importance of seasonal variations in seagrass density and storm winds on sediment retention in seagrass meadows and adjacent marshes and exchange between them.

Oyster Reef–Marsh Coupling: We continued our experiment with 8 constructed oyster reefs of different designs to determine effects on oyster populations (size, growth, density) and marsh erosion using field data and LiDAR imagery. We quantified wave attenuation, sediment deposition and marsh erosion for oyster reefs of two different substrate types.

Oyster Larval Transport and Population Dynamics: We continued our annual measurements of oyster recruitment and elevation at 12 sites over 250 km2. Using long-term data, we related elevation, rugosity, wind fetch, water residence time, and adult density to oyster recruitment and juvenile growth. We ran a caging experiment to test how depth and predators affect oyster growth and survival.

Seagrass–Marsh Coupling: We determined how seagrass restoration affects carbon (C) accumulation in adjacent salt marshes using stable isotopes, biomarkers, and 210Pb dating.

Barrier Island Ecosystem Coupling: On cross-island transects we measured plant cover, productivity, soil characteristics, and elevation, and characterized vegetation and topography using optical and multispectral drone imagery and SfM at 40–50 ha scales. We ran path cost analysis on dunes to determine resistance to seawater flow to the island interior for different storm surge scenarios. We added a shrub planting experiment to test if dune height affects shrub establishment, and used LiDAR to relate changes in dune height and shrub distribution. We analyzed dune profile and vegetation data to assess where *Spartina patens* grass is found relative to dune age to develop a conceptual model for its role in dune growth.

Cascading Effects: We completed model experiments that connect the coastal landscape from the shoreface to the mainland forest and identified conditions leading to state change in adjacent and non-adjacent ecosystems.

Ecological Consequences of State Changes

Carbon Sequestration:

We continued to monitor C stocks in the mainland uplands, lagoons and barrier islands. We synthesized C stocks and accumulation rates across each of these ecosystems to establish a landscape-scale C budget, measured the flux of carbon from eroding barrier islands, and are using our barrier island model to estimate C released by island migration under different SLR scenarios. We also conducted a 6 month decomposition study along the marsh-forest gradient. Deep sediment cores (2 m) were collected in seagrass beds and analyzed for blue carbon stored in the past 100 yr.

Consumer Dynamics:

In lagoons and on barrier islands, we 1) tested how invasive algae affect shorebird habitat selection on mudflats; 2) monitored spring migrant shorebirds and their prey (16 yr), and modeled factors affecting migrants; 3) analyzed spatial and temporal variation in two key shorebird prey; 4) monitored distribution and nesting success to link with geomorphology, predator and vegetation; 5) resighted banded birds to monitor movements, survival and reproduction related to changes in island geomorphology and vegetation; and 6) studied factors affecting Atlantic ghost crabs, a predator of shorebirds hypothesized to be more abundant due to warming.

In the intertidal, we continued tracking upland movement of grazing bands created by purple marsh crabs and looked at their impacts on carbon storage in marshes.

In the subtidal, we 1) continued the time series of seagrass epifauna, infauna, and fish; and 2) determined experimentally how food availability and predators control hard clam (*Mercenaria mercenaria)* growth and survival.

Specific Objectives:

Theme 1. Drivers and Patterns of Long-term Change: How have the distribution, spatial extent, and characteristics of ecosystems changed over time and how are these changes related to climate trends and variability?

Climate-related forcing has the greatest impact on ecological and physical processes that cause ecosystem state change. Changes in the trends and variability of storm frequency and intensity, sea-level rise, rainfall, and temperature can transform the coastal barrier landscape. Climate change may shift disturbance frequency (e.g., storms, hightemperature events) as well as mean climate state values.

Our specific objectives for this theme are:

(1) Track long-term changes in average and extreme climate conditions (sea-level rise, storms, temperature, precipitation) through measurements and, where appropriate, historical data compilation of storms (frequency and magnitude), sea-level rise rates, water temperature and chemistry, weather and groundwater levels.

(2) Describe trends and variation in ecosystem distribution, biogeochemical processes, organic matter, primary and secondary production, and community composition within the VCR domain. We do this through measurements of ecosystem state change using LiDAR, drone and remote sensing imagery, changes in land elevation, and process measurements.

(3) Evaluate how these processes and trends are related to climate drivers using longterm experiments.

Theme 2. Dynamics within Landscape Units: How do ecological and physical processes interact to maintain ecosystem states or facilitate transitions to new ones?

We identify and test mechanisms that can lead to state change (linear, threshold, regime shift).

Long- and short-term data are used to parameterize, test, and evaluate mechanistic models. Natural disburbance events (high temperatures and storms) provide valuable opportunities to test conceptual and theoretical models of state change and resilience in the context of climate-related forcing.

Our specific objectives for this theme are:

(1) Establish a new long-term disturbance experiment at the forest-marsh boundary to test feedbacks that govern this transition and to inform ongoing modeling.

(2) Continue to monitor marsh-edge retreat at mainland, marsh island, and back-barrier marsh sites using surveys and aerial photographs.

(3) Use repeated drone-based high-resolution photography coupled with structurefrommotion techniques to determine storm-driven change in the morphology of the marshtidal flat boundary, and relate to measured wave and tide guage monitoring of hydrodynamic conditions.

(4) Test the indirect effects on marsh sediment accretion by the two dominant marsh crabs, and incorporate into current geomorphic models of marsh response to sea-level rise.

(5) Expand the long-term seagrass restoration experiment to four additional bays, and quantify both threshold responses to high temperatures (marine heatwaves) and spatial resilience on metabolism, carbon storage, and biodiversity.

(6) Quantify plant feedbacks on dune morphology and development on the barrier islands, and the effects on island vulnerability to changes in storm frequency and sealevel rise.

(7) Through continued long-term measurements and new experiments, test microclimate feedbacks between grasslands and shrubs that enhance shrub expansion on the barrier islands.

Theme 3. Dynamics between Landscape Units: How does connectivity influence ecosystem state change?

The VCR is a model system in which to ask how ecosystems are connected through cross-sytem transport of materials and organisms and coupled state change dynamics, and how local and broader-scale patterns and processes are related. Understanding how state change in one part of the landscape can propagate to another is critical to determining the holistic response of coastal barrier systems to present and future climate forcing.

Our specific objectives for this theme are:

<u>Transport</u>:

(1) Use our hydrologic model to construct a sediment budget to study sediment transport from lagoons to marshes, the effects of seagrass meadows on sediment transport, and model marsh-edge morphodynamics.

(2) Relate sediment transport to organic carbon transfer between seagrass and marsh ecosystems.

(3) Examine how storm strength and frequency affect sediment import and redistribution within the entire VCR domain.

(4) Use drone imagery, structure-from-motion analysis, and hydrodynamic modeling to evalute oyster reef population dynamics, including fecundity, dispersal, settlement and survival.

Coupled dynamics:

(1) Use long-term seagrass and oyster restoration experiments to test effects on marsh edge erosion and vertical accretion using drone imagery, hydrodynamic measurements of waves and currents, and models of morphodynamics and plant-hydrodynamic coupling.

(2) Test the feedback between dune height and plant productivity and species composition (grass and shrubs in adjacent interior swales on barrier islands through LiDAR and remote sensing imagery.

(3) Use the coastal dune model to explore how storms and dune height affect shrub expansion on the islands.

(4) Explore how state change dynamics may cascade across the landscape using two process-based transect models driven by VCR data that connect adjacent and nonadjacent ecosystems.

Theme 4. Ecological Consequences of State Change: What are the consequences of ecosystem state change for ecosystem function?

We focus on two important ecosystem functions of coastal barrier systems: carbon sequestration and habitat provisioning for consumers. Expansions of foundation species (i.e., *Z. marina* seagrass, *M. cerifera* shrub, *C. virginica* oysters) affect carbon cycling and also provide habitat for consumers that may alter predation, pathogens, and trophic dynamics. Our specific objectives for this theme are:

Carbon cycling and sequestration:

(1) For sediment carbon stocks and accumulation rates, synthesize existing point-based estimates in each ecosystem and supplement with targeted measurements to extrapolate to the VCR landscape.

(2) Evaluate the connectivity of carbon pools between intertidal and subtidal ecosystems.

(3) Use our 1D transect model and measurements of carbon pools to evaluate how marsh transgression into mainland forests and marsh edge erosion affect carbon storage at the landscape scale.

Consumer responses:

(1) Assess how state change from bare subtidal and intertidal flats to seagrassand macroalgal-dominated ecosystems affects diversity and abundance of fauna, including invertebrates, bivalves, fish and shorebirds, and coastal foodwebs.

(2) Determine how climate-related ecosystem state change on islands (e.g., beach, marsh, grassland shrub thicket, forest) affects habitat generalists (e.g., racoons) vs. specialists (e.g., red fox).

(3) Determine how the abundance, distribution, and community structure of groundnesting shorebirds on barrier islands is affected by the relative availability of overwash and interdune areas, which is predicted by the frequency and extent of storms.

(4) Test if short-distance migrants that have a broader foraging niche compensate for changes in ecosystem state (e.g., marsh peat banks, sandy beaches) or prey resources by shifting foraging strategy and are less vulnerable to climate-driven changes than long-distance migrants.

Significant Results:

Drivers of Long-term Change

- From 1979-2021 there were 183 storm surge events affecting the VCR, with an annual average of 4.3 storm surge events per year, dominated by NE winds. There were no significant trends in their strength and duration apart from the increase in water levels due to sea-level rise.

Dynamics within Landscape Units

Upland–Marsh

- The marsh grass *Spartina patens* has a different morphology in shaded coastal uplands than in the open marsh, due primarily to phenotypic plasticity.
- SET measurements suggest that retreating coastal forests are not subsiding, and that the transition zone is accreting at rates similar to long-established high marsh vegetation.
- Tropical storm Melissa caused an increase in both groundwater level and specific conductivity above pre-storm levels, with time to recover 10 times greater for groundwater specific conductivity. The percent of time with salinization was higher for Melissa than for hurricanes.
- In the Linear Discriminant analysis water content in the soil and groundwater electrical conductivity were the main variables responsible for the hydrological difference among sites, with greater differences during winter.
- Landscape analysis (1984-2020) shows that barrier islands are keeping pace with sea-level rise by greater marsh to upland transitions (a sign of island rollover). Upland has been reduced by 22% since 1984, but most loss occurred between 1984-1998 and has stabilized since 2016. Woody cover has increased across the landscape; recent upland migration resulted in increased grassland in 2020.

Intertidal

- Reefs constructed at high elevations (near mean-water level) were more effective at attenuating waves and fostering oyster growth. Oysters atop high elevation reefs were twice as dense and 20% larger than those on low-elevation designs; reef width had a minimal effect on density. In-situ measurements of reef-lined and un-lined marshes showed reefs significantly reduced rates of marsh edge erosion.
- Erosion rates of marsh scarps and tidal flats indicate that the tidal flat may release as much or more sediment per year as the scarp when considering the total area of the marsh edge.

Subtidal

- Seagrass were resilient to a marine heatwave, with recovery within 2-4 yr; landscape position modulates heat stress. Spatial variation in resilience was driven by both temperature (loss) and recovery (hydrodynamics).
- On meadow edges, flow velocities were reduced 30-75% within 1 m, and bivalve recruitment increased. No differences in wave activity and sediment suspension were observed within 5 m of edges.
- 20-yr differences in bathymetry in a largely unvegetated bay indicate strong spatial patterning of erosion and deposition related to the presence of a deep tidal channel.

Multi-year differences in bathymetry in a largely vegetated bay are linked to vegetation density.
- 210Pb dating revealed a long-term (1860-present) average sedimentation rate of 0.54 cm/yr similar to modern (20-yr) rates. Large amounts of legacy blue carbon were found below modern seagrass beds.
- Bubble trap measurements over dense seagrass meadows showed that emissions of greenhouse gasses (CO2 and CH4) are significant.
- Analysis of high-resolution sonde time-series of water quality data indicated that long-term, lower-frequency VCR water quality time-series likely capture well the climatological seasonal cycle.

Barrier Island

- Dune grass species differences in cover and lateral expansion rates affect sediment accumulation and explain dune shape and size. Spatial patterns of *Spartina patens* suggests that this grass colonizes following overwash, builds elevation until it is outcompeted by other dune-building grasses, and then remains at the heel of more established foredune.
- Dune formation (hummock vs. ridge) affects storm surge, plant community composition of adjacent swales, productivity, soil carbon stocks and shrub survival. A dune height of 1.7m and interior island width of greater than 150m is necessary for shrub growth.
- Dunes grow lower and wider when marsh wrack containing propagules is present, and high-marsh grass speeds up dune-building by enhancing deposition so grasses can become established sooner.
- Shrub edge increased 233% in 27 yr resulting in a moderated microclimate that enhances grassland biomass and cover. Traits of grassland species at the shrub edge are altered, likely due to higher shade and soil nitrogen.

Dynamics between Landscape Units

Sediment Transport

- Seagrass boosted sediment retention in tidal flat-marsh systems by facilitating a tenfold increase in sediment deposition on the flats and served as a sediment source for adjacent marshes during winter senescence but not during the growth season.

Exchange of Dissolved Constituents

- Wind-driven fluxes control transport and concentrations within bays. Variations in tidal phase and amplitude promote flushing of bays, with average flushing time of 24–27 days.

Oyster Population Dynamics

- Survival is determined by oyster life stage, landscape location, and depth.
- Recruitment showed unimodal relationships with fetch, increased with elevation, and had no relationship with water residence time.
- Predation on juvenile oysters increased in the subtidal (vs. mid-intertidal and upper-intertidal).

Coupled State Change Dynamics

- Islands with shrubs migrate landward more slowly, are more likely to migrate in a discontinuous manner, and are more vulnerable to drowning. Shrubs expand more slowly on islands experiencing greater dune erosion and overwash disturbance.
- Landward island migration is the main cause of back-barrier marsh loss, and periods of island stability can allow recovery. Bay extent is insensitive to sea-level rise because increased island migration (bay narrowing) offsets increased marsh edge erosion (bay widening).

Ecological Consequences of State Changes

Carbon Sequestration

- Barrier island transgression leads to an annual organic carbon release. Recent (1994–2017) beach and shoreface carbon erosion rates exceed annual accumulation rates in adjacent backbarrier ecosystems by ~30%. Erosion of lagoon sediments (up to 8 m) accounts for >80% of total carbon losses, despite those deposits having lower carbon content than overlying salt marsh peat.
- Decomposition rates vary little across the forest-marsh ecotone gradient, despite microclimate differences, but rapid decomposition rates in the transition zone and minimal litter fall suggest that little leaf litter carbon is preserved as forests are inundated by seawater.
- A spatially-explicit geomorphic model showed that landscape connectivity, carbon accumulation and landscape-scale carbon stock all peak at intermediate sea-level rise rates. Loss of forests with higher sea-level rise shifts the system from being dominated by tree biomass carbon to marsh soil carbon maintained by recycling between marshes and lagoons.

Consumer Dynamics

Islands

- Migrant shorebird distribution and abundance are driven by 3 prey (coquina clams, blue mussel spat, crustaceans). Some migrants use prey resources on lagoonal mudflats in addition to beach invertebrates whereas others appear specialized on prey found only on beaches.
- Predation by Atlantic ghost crabs, Peregrine falcons and owls is impacting survival of pre-fledgling American Oystercatchers and driving declining productivity. Chicks are selecting vegetation-free areas closer to marshes to be near to foraging adults.
- Long-term data on beach geomorphology and vegetation (2004 – 2021) show system-wide stability in island length, and width/length of available peat bank habitat. Substrate available for nesting increased by 39% from 2004 to 2021, and prey use was influenced by geomorphology (island and beach width) and time since storms.

Intertidal

- Grazing fronts of the purple-marsh crab (*Sesarma*) continue to move at a rate of ~1 m/y, leading to carbon loss of ~40-70%.

Subtidal

- Food availability to clams is greater inside seagrass meadows, enhancing clam growth.

Key outcomes or Other achievements:

VCR scientists have published 163 journal articles and 28 theses/dissertations through the 5th year of this funding cycle. A complete list of publications is at https://www.vcrlter.virginia.edu/home2/?page_id=215.

Drivers of Long-term Change

Climate Drivers of Change

There have been an average of 4.3 storm surge events per year for the last 40 years; for 33 days during this period storm surge exceeded 1.5m (water levels >3 times normal high tide levels). There have been no significant trends in the strength and duration of storm surge events apart from the increase in mean sea level and flooding due to sea-level rise.

Patterns of Change

There was a 22% net loss of barrier islands between 1984 and 2020. Long-term data on beach geomorphology and vegetation (2004 – 2021) show system-wide stability in

island length. Substrate available for nesting birds increased by 39% from 2004 to 2021.

Increasing rates of landward barrier island migration are influenced by dune elevation and island vegetation. Winter warming has resulted in 41% increase in woody vegetation in protected, low elevation areas.

Bathymetric changes in a largely unvegetated lagoon over the last 20 yr suggests that the bed is eroding in addition to increase in depth due to sea-level rise.

Dynamics within Landscape Units

Forest-Marsh

The dominant high marsh grass, *Spartina patens*, fails to flower and changes morphology in low-light understory of the forest transition; growth here is due to recruitment by seeds dispersed from outside the zone and clonal expansion. Once light becomes available through canopy tree mortality, it can quickly return to a marsh growth-form. With forest dieback, understory shrubs also increase. The saltmarsh amphipod, *Orchestia grillus*, indicates marsh migration into the forest, and is found ahead of major loss of the tree canopy.

Storms occurring every 1–2 years lead to a salinization period longer than energetic hurricanes. Given the high frequency of these events, and the long time needed for groundwater conditions to return to normal, these increasingly frequent moderate storms will have the most impact on vegetation.

Limited subsidence or accretion in the retreating coastal forest suggests that static inundation models may be appropriate for forecasting marsh migration. Accretion rates in the transition zone are similar to adjacent marshes, suggesting the impact of marsh migration on elevation is rapid.

Subtidal

Our landscape seagrass restoration experiment, now in its 22nd year, shows that ecosystem services are reinstated within a decade. Meadows were resilient to a marine heatwave, with plant biomass recovering within 2-4 yr, although lost sediment carbon took longer. Spatial variation in resilience was driven by both temperature (loss) and recovery (hydrodynamics). Seagrass meadows influence flow and sediment movement: currents and turbulence are influenced at short spatial scales (<10 m), and changes to sediment deposition/suspension only occur over large distances (~100 m).

Intertidal

Oyster reefs constructed along a marsh edge dissipated wave energy, but only when water depths were near or below reef crest heights. Reef-lined marshes had lower erosion rates but this protection varied depending on marsh elevation relative to reef elevation and marsh orientation relative to wave energy.

Barrier Island

Dune shape and size are influenced by dune grass species cover and lateral expansion rates. The grass *Spartina* is important to the growth of dunes in early stages of dune-building and less so in later stages. Geomorphic thresholds in dune height and interior island width are necessary for shrub establishment and expansion.

Cold temperatures limit shrub survival of both seedlings and adults and grasses provide insulation to shrub seedlings. Shrubs modify microclimate and bring the water table

closer to the surface and enhance grassland cover at the edge, but reduce diversity and alter plant and soil characteristics.

Dynamics between Landscape Units

Sediment Transport

Restoration should target coastal erosion before the vegetated surface becomes too small compared to the basin area.

Coupled State Change Dynamics

Subtidal - Intertidal Coupling

Oysters currently occupy 12% of the suitable intertidal area in the VCR, suggesting that there is area for future restoration that will impact both biodiversity and marsh erosion. Multi-year oyster recruitment data suggest that larvae are not limiting. Reef elevation is important for restoration, with oyster densities increasing as elevations approach sea level at the reef crest. These reefs are also more effective at attenuating wave energy than lower-elevation reefs. Increases in reef %cover and/or area were correlated with finer sediment grain size, higher organic matter and lower flow.

Barrier Island Ecosystem Coupling

The new barrier island model, Barrier 3D, and Barrier 3D with shrubs, has been contributed to the Community Surface Dynamics Modeling System repository and GitHub where it can be accessed by researchers. It is the only barrier island evolution model that includes dune dynamics. Dune elevation and shape provide resistance to storm surge and influence plant species composition and annual net primary productivity in adjacent low-elevation swales.

Coupling Between Non-adjacent and Adjacent Systems

Blue crabs are dominant predators in the mid-Atlantic where they are a link moving productivity from the benthos to pelagic fishes. Their distribution is influenced by both habitat connectivity and local seagrass conditions. Oyster reefs create a ‘halo’ of higher infaunal communities to a distance of ~40 m, occuring within 3 yr of reef restoration.

Ecological Consequences of State Changes

Carbon Sequestration

Numerical modeling indicates that landscape connectivity, carbon accumulation and landscape-scale carbon stock all peak at intermediate sea-level rise. Loss of forests with higher sea-level rise shifts the system from being dominated by tree biomass carbon to marsh soil carbon maintained by recycling between marshes and lagoons. These results suggest that climate change strengthens connectivity between adjacent coastal ecosystems, but with tradeoffs that include a shift towards more labile carbon, smaller marsh and forest extents, and carbon accumulation in parts of the landscape more vulnerable to sea-level rise and erosion.

Barrier island transgression leads to annual organic carbon release. Recent (1994–2017) beach and shoreface carbon loss exceed accumulation in adjacent backbarrier ecosystems by ~30%. Erosion of lagoon sediments (up to 8 m) accounts for >80% of total carbon losses. Together, these results suggest that landscape-scale carbon budgets that assume only shallow erosion depths of carbpon-rich sediment may overstate the coastal carbon sink. However, analysis of deep sediment cores revealed large amounts of legacy seagrass blue carbon buried in sediments that date back to at least the 1700s.

Bubble trap measurements showed that emissions of greenhouse gasses (CO_2, CH_4) should be accounted for when evaluating seagrass meadows as blue carbon systems.

Consumer Dynamics

Barrier islands: Monitoring of shorebirds and their prey reveals responses to climate drivers. Piping plovers (ground-nesting shorebird) have population irruptions following storm events. Two invertebrate prey (crustaceans, coquina clams) used by migratory shorebirds are influenced by island and beach width, and time since storms. Predation by Atlantic ghost crabs, Peregrine falcons and owls is now impacting survival of pre-fledgling shorebirds.

Intertidal: Long-term recruitment data show that restored oyster reefs have less juvenile recruitment than reference reefs. Our discovery of blue crab ambushing juvenile fiddler and purple-marsh crabs has implications for marshes as nursery habitats.

Subtidal: Restoration of seagrass meadows increases fish abundance by 6.4x and biodiversity by 2.4x; these benefits may be dampened by ocean warming and sea-level rise.

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

VCR LTER continues our strong tradition of training undergraduate and graduate researchers through a tiered mentoring program; this year 47 graduate students, 3 post-docs and 3 undergraduate REUs at the VCR site. conducted research through the program. The inter- and multi-disciplinary nature of the research teaches the students how to operate in a collaborative environment.

Our Fundamentals of Learning for Science Mentors course was offered for the 4th continuous year, with seven registered participants from three institutions. Mentors trained in the course continue to contribute to both RET and REU programs; they report feeling more prepared and better able to meet their mentees needs using approaches from the course. Course instructor and co-developer Baird began work with other UVA field stations and LTER sites to adapt the course for broader mentorship training across institutions and career stages.

A pilot RaMP project was awarded to VCR (PI Johnson and collaborators), creating a cross-LTER network initiative with all four east coast LTERs to enhance the participation of underrepresented groups. The award supports post-bac internships where participants receive research experience in addition to professional development (e.g., applying to graduate school, grants, government jobs).

We continued supporting excellent undergraduate education by hosting REUs, continuing our partnership with Eastern Shore Community College, and sharing VCR research findings and field methods with undergraduate classes from five regional universities, including PUIs. Students from Moravian College also conducted research with VCR through the DURSiE program with PI Woods.

The Research Experiences for Teachers (RET) program continued as a hallmark of K-12 engagement at VCR. Three teachers from two counties completed the science professional development in 2023, expanding our community of practice to 6 current teachers that reach 4 elementary schools across the full geographic extent of our districts. Leveraging the classes of RETs, VCR staff helped bring science directly to students by introducing all 4th and 5th graders at Kiptopeke Elementary to the process (and mindset) of science investigation. They also completed hands-on project-based water quality analysis with all 6th grade students in Northampton County Schools, introducing them to the tools (and faces) of real scientists. Reprising a successful 2020 program, all 8th grade art students at Nandua Middle School completed an HSI-inspired abstraction unit; the resulting art was showcased at Title I family night. Working across grade levels reinforces associations with scientists and encourages science identity among students.

One of our PhD students worked with a local school teacher in our underserved area to develop lesson plans for K-12 education. In Spring 2023, the student presented this work at an international conference in Spain (ASLO). The resulting publication will now be included as a chapter in the student’s PhD dissertation and count toward earning a PhD degree.

The 2023 workplace climate and culture assessment revealed that encounters with harassment, discrimination, and bullying have decreased since 2020 (down 8%), and that the number of people unsure of how to report incidents decreased by more than half since implementing our Code of Conduct and associated trainings. Field staff also completed mental health first aid training for the first time. To help address disparities in use of field safety planning tools provided by VCR, we host field safety discussions with every research group prior to field season. These sessions improved information and resources sharing and will be continued annually.To further improve information sharing and preparedness, all resource documents - from field safety to data policies - are now provided on a single page of the VCR website.

Six members of the VCR project received training in Trimble GPS survey methods. Our drone surveying program was formalized by a leading staff member to facilitate surveys across research groups.

*** Have the results been disseminated to communities of interest? If so, please provide details.**

The VCR disseminates research findings and data through the VCR LTER website (https://www.vcrlter.virginia.edu) with 8,600 page views in 5,300 sessions by 3,600 distinct users from Nov. 1, 2022 to Oct.31, 2023, also VCR/LTER data files were downloaded 1,745 times from the Environmental Data Initiative portal and 7,685 times from the VCR/LTER data portal.

Media and Public Presentations

Public engagement during a workshop for the co-produced Climate Equity Atlas was profiled in the local newspaper (Eastern Shore Post) and UVA Today.

Karen McGlathery was featured on UVA's Hoos in Stem podcast, covering research, policy, and career.

Matt Kirwan contributed to coverage on coastal change and resilience on CBS Mornings.

Staff contributed to a public media documentary about changing water and life on the Eastern Shore of VA.

Max Castorani was interviewed by Mongabay for a story about our meta-analyses describing the success of oyster reef restoration in recovering ecosystem services.

Matt Kirwan and Keryn Gedan were interviewed for a PNAS article on ghost forests.

VCR PIs and students contributed research and outreach presentations at national and international conferences including AGU, ASLO, BEM, CERF, ESA, OBFS, The Wildlife Society, WSN.

PI Fagherazzi and his group gave two presentations at the American Geophysical Union Fall Meeting in 2022 and one at the EGU General Assembly Conference in 2023

PI Reidenbach presented oyster and marsh research at the Association of Sciences in Limnology and Oceanography meeting in 2023.

PI Gedan presented rates of coastal forest tree mortality at the Reunión Argentina de Ecología in 2023 and also in the seminar series of another NSF REU site, Blandy Experimental Farm.

PI Castorani presented research in two workshops at the LTER All Scientists Meeting and helped organize a workshop on the role of drones in LTER research.

PI Castorani was invited to speak at the World Seagrass Conference

PI Moore presented VCR-LTER research at Coastal Sediments 2023 and the monthly Eurocoast Zoominar series, and a member of her research group presented VCR-LTER results at the AGU Fall Meeting.

PI Berg and co-workers' findings on legacy blue carbon found below modern seagrass beds were featured in UVA Today. Berg also presented this work at the 2023 Ocean Science Meeting in Spain.

VCR researchers also presented research for the Garden Club of the Eastern Shore and during certification trainings for regional Master Naturalists and the Virginia Association for Environmental Educators (VAEE).

Virtual and Distributed Platforms

Our repeat photography community science installations continue to accumulate public engagement. 609 photos have been submitted by 257 unique visitors; 58 people have submitted more than one photo; three users have submitted more than a dozen photos. Submissions peak on weekends, suggesting contributions by recreational visitors. Processes are ongoing for turning the resulting time lapse images into data sources for k-12 and public learning engagements.

Our virtual Ghosts of the Coast (https://www.coastaleducation.virginia.edu/wp/?page_id=1389) collaboration between artists and scientists stimulated the creation of a community science mapping project (https://storymaps.arcgis.com/stories/12863715c76a40d8928e467845801b03) hosted by PI Gedan.

Partnerships

We continue to build a partnership with the Science Department of Eastern Shore Community College to link VCR research and local ecosystems to student learning, especially via the newly adopted capstone project requirement. Partnerships with S&WCD, Virginia Eastern Shore Land Trust, and TNC have continued through informal education, resilience planning, and other efforts. In summer 2023, we established a partnership with the local public library and town to seine on the public beach monthly, bringing marine scientists and ecosystems into view for visitors and residents (focused on kids). We also deepened collaborations with UVA's Equity Center toward co-producing climate equity maps informed by Eastern Shore community needs. To enhance that project and other VCR modeling efforts, we initiated a partnership with Wetlands Watch and are now using their flood mapping phone app to enable community science that will improve hydrology and flood modeling in our region; local data contributions tripled the first year of our partnership. We continue to contribute to the local Climate Adaptation Working Group, which advises and supports the community on resilience issues, and to work with The Nature Conservancy to provide a scientific basis for some of their land management decisions.

In 2023, VCR began the strategic engagement planning process as a case study in the Advancing Public Engagement Across LTERs (APEAL) program (AISL grant). The results, expected by summer 2024, will shape partnerships priorities for the VCR.

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

Theme 1: Drivers of Long-term Change

Climate Drivers: We will continue our analysis of historical temperature records, marine heatwaves and their effects on seagrass and associated fauna, with a focus on spatial patterns of heating. To improve the accuracy of our predictive modeling of coastal water clarity, we will use imagery gathered by the Sentinel II system.

Patterns of Change: Much of our analysis of landscape change will involve drone imagery, structure-from-motion analysis (SfM), and aerial and satellite imagery. This year we will: 1) develop drone methods to measure macroalgae, oyster reefs and tidal flats, and determine geomorphological change on days-year scales and relate to biodiversity; 2) combine drone-based mapping of interannual and storm-driven changes in the morphology of the marsh-tidal flat transition with bathymetric change measurements to develop a sediment budget for Hog Island Bay; 3) analyze state change in 2020 imagery and relate to previous years imagery; 4) interpret LiDAR data to map distribution of Phragmites australis on the mainland forest edge.

Theme 2: Dynamics within Landscape Units

Upland - Marsh: We will continue our new long-term experiment on the forest-marsh transition with the following activities: 1) monitor tree and shrub survival and growth in experimental plots spanning a ghost forest to healthy forest transition, and track herbaceous vegetation and tree seedlings; 2) measure transpiration continuously using sap flux sensors; 3) continue to measure SETs located on the marsh-forest gradient; 4) create drone-based image mosaics; 5) sample invertebrates; 6) analyze high-resolution salinity and groundwater data at 8 stations with 16 wells, compare hydrological data to ecological data; and 7) assess occupancy of small mammals both inside the plots and in the surrounding landscape. We will plan tree girdling activities, the experimental treatment within this large-scale experiment, to be implemented at the end of 2024. In preparation for the tree girdling experiment, we will install six more hydrological stations and three more SET stations in our Marsh-Forest experimental sites. We will keep collecting and analyzing ecological, hydrological, invertebrate and geomorphic data.

Intertidal: We will complete an analysis of the seasonal cycle of water column DIC and alkalinity, and will continue to monitor CO2 exchanges and salt marsh photosynthesis using eddy covariance and solar-induced chlorophyll fluorescence. We will continue to monitor the movement of the grazing front of the purple-marsh crab in the salt marshes. For oysters, we will continue to quantify the effects of oyster reef elevation and proximity to marsh edges on sedimentation dynamics. This will be conducted using a suite of hydrodynamic, suspended sediment, and novel sediment deposition instrumentation.

Subtidal: We will continue the long-term seagrass restoration/resilience experiment (yr 22), including measurements of biomass, sediment organic matter, carbon and nitrogen stocks, O2, CO2 and methane fluxes, and sediment and water temperatures. We will relate continuous temperature data with measurements of seagrass biomass, carbon accumulation, and disease prevalence. We will continue to apply new techniques and sensors to measure emissions of greenhouse gasses (CO2, CH4, N2O), and underwater sound recording to quantify CH4 bubble release from seagrass. We will analyze data on epiphytes, benthic chlorophyll, and phytoplankton. Barrier Island: We will use repeat drone imagery to evaluate changes in shrub expansion into grassland, and annual optical and multispectral drone flights and SfM analysis of 2 islands to develop vegetation models (NDVI). We will continue to monitor species composition change and topographic evolution along newly established transects on 2 islands using vegetation surveys, RTK surveys and repeat drone flights to generate high resolution DEMs and collect multi-spectral data. We will continue our measurements along the shrub-grass ecotone, in the swales spanning different dune heights, and the dune planting experiment.

Theme 3: Dynamics between Landscape Units

Oyster Larval Transport and Population Dynamics: We will continue long-term measurements of oyster recruitment and size at 12 sites. We will continue to develop a hydrodynamic model to study larval connectivity between the coastal lagoons and among the intertidal regions.
Coupled State Change Dynamics: Wave heights, bed shear stress and suspended sediment concentrations will continue to be measured adjacent to a marsh edge behind constructed oyster reefs and at adjacent sites to determine impacts on marsh erosion.

Barrier Island Ecosystem Coupling: We will analyze topographic changes from drone data over the last 3 years and relate to changes in vegetation along cross-island transects, and will work to quantify the temporal lag between shrub expansion and dune elevation.

Ecological Consequences of State Changes

Carbon (C) Sequestration:

We will continue to measure soil and groundwater C in island grass and shrub habitats, in the long-term seagrass restoration experiment, and across the marsh-forest boundary. We are continuing our work on C connectivity between seagrass and adjacent marshes. We will run simulations in our barrier island model to estimate the likely impact of future barrier island migration on the VCR C budget. We will complete a two-year decomposition experiment investigating the effects of litter type and overstory species for three common species on litter decay rate in the coastal forest. This experiment is designed to test how one of these species, the N-fixing shrub *Morella cerifera*, may enhance ecosystem processes such as decomposition by altering nitrogen cycling.

Consumer Dynamics:

Barrier islands: We will collect our 17th year of spring migrant shorebird data including samples of prey, and complete analyses of dietary and habitat selection of long- vs. short-distance migrants related to island geomorphology and sandy beach, peat bank habitats, and intertidal mudflats. In the next year, we will conduct a 5th year of nesting shorebird monitoring and relate distribution and abundance and movements of marked piping plovers to island geomorphology and vegetation

characteristics; and 2) complete analyses of the factors affecting reproduction and survival of American Oystercatcher, addressing the influences of predation and flooding and changing island geomorphology and vegetation.

Subtidal: We will continue our time series collection of epifauna, infauna, and fish at 24–50 seagrass sites across 5 bays. We will analyze data from clam sclerochronology, clam growth, and survival experiments.Intertidal: In the intertidal, we will continue tracking upland movement of grazing bands created by purple marsh crabs.

Products

Books

Book Chapters

Inventions

Journals or Juried Conference Papers

View all journal publications currently available in the NSF Public Access Repository for this award.

The results in the NSF Public Access Repository will include a comprehensive listing of all journal publications recorded to date that are associated with this award.

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Coleman, Daniel J. *The Role Of Suspended Sediment In Assessing Coastal Wetland Vulnerability*. (2020). Virginia Institute of Marine Science, William and Mary. Acknowledgement of Federal Support = Yes

Websites or Other Internet Sites

Coastal Education
https://www.coastaleducation.virginia.edu

Coastal Education: Supporting, engaging, and informing a resilient coastal community. Provides materials for educators, students and the general public.
Virginia Coast Reserve Long-Term Ecological Research
https://www.vcrlter.virginia.edu

The VCR/LTER web site provides access to a wide variety of data (329 formal datasets), images, maps, documents and interactive data displays.

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
McGlathery, Karen	PD/PI	2
Pace, Michael	Co PD/PI	1
Porter, John	Co PD/PI	9
Reidenbach, Matthew	Co PD/PI	1
Wiberg, Patricia	Co PD/PI	1
Bachmann, Charles	Co-Investigator	1
Baird, Cora	Co-Investigator	12
Berg, Peter	Co-Investigator	1
Berger, Amelie	Co-Investigator	1
Carr, Joel	Co-Investigator	1
Castorani, Max	Co-Investigator	1
Doney, Scott	Co-Investigator	1
Dueser, Raymond	Co-Investigator	1
Fagherazzi, Sergio	Co-Investigator	1
Fenster, Michael	Co-Investigator	1
Gedan, Keryn	Co-Investigator	1
Johnson, David	Co-Investigator	1
Karpanty, Sarah	Co-Investigator	1
Kirwan, Matthew	Co-Investigator	1

Name	Most Senior Project Role	Nearest Person Month Worked
Macko, Stephen	Co-Investigator	1
Moncrief, Nancy	Co-Investigator	1
Moore, Laura	Co-Investigator	1
Pusede, Sally	Co-Investigator	1
Smith, David	Co-Investigator	1
Sojka, Sarah	Co-Investigator	1
Tyler, Christy	Co-Investigator	1
Woods, Natasha	Co-Investigator	1
Yang, Xi	Co-Investigator	1
Young, Donald	Co-Investigator	1
Zinnert, Julie	Co-Investigator	1
Donatelli, Carmine	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Ewers Lewis, Carolyn	Postdoctoral (scholar, fellow or other postdoctoral position)	7
Zhu, Quingguang	Postdoctoral (scholar, fellow or other postdoctoral position)	12
Burkett, Thomas	Technician	12
Doughty, Albert	Technician	6
Goetz, Emily	Technician	12
Gustafson, Gunnar	Technician	3
Hoffman, Sophia	Technician	12
Lee, David	Technician	1
Martinez-Soto, Kayla	Technician	6
Miller, Margot	Technician	10

Name	Most Senior Project Role	Nearest Person Month Worked
Atchley, Savannah	Graduate Student (research assistant)	1
Barksdale, Mary	Graduate Student (research assistant)	1
Barnes, Tyler	Graduate Student (research assistant)	4
Bramehy, Emma	Graduate Student (research assistant)	2
Brideau, Lauren	Graduate Student (research assistant)	4
Call, Mikayla	Graduate Student (research assistant)	4
Cornish, Michael	Graduate Student (research assistant)	4
Cortese, Luca	Graduate Student (research assistant)	4
Franklin, Benton	Graduate Student (research assistant)	4
Giovanna, Nordio	Graduate Student (research assistant)	4
Goldsmith, Sarah	Graduate Student (research assistant)	4
Granados, Paola	Graduate Student (research assistant)	4
Granville, Kayleigh	Graduate Student (research assistant)	4
Groff, Luke	Graduate Student (research assistant)	4
Gurevich, Sofia	Graduate Student (research assistant)	1
Hardison, Sean	Graduate Student (research assistant)	4
Harless, Kaitlyn	Graduate Student (research assistant)	1
Ingram, Brianna	Graduate Student (research assistant)	4
Jobe, Justus	Graduate Student (research assistant)	4
Kerns, Kylor	Graduate Student (research assistant)	4
Lapenta, Kristy	Graduate Student (research assistant)	4
Lapszynski, Chris	Graduate Student (research assistant)	4
LaRoche, Carly	Graduate Student (research assistant)	4
Leff, Riley	Graduate Student (research assistant)	4

Name	Most Senior Project Role	Nearest Person Month Worked
Long, Edward	Graduate Student (research assistant)	1
Martinez, Juan	Graduate Student (research assistant)	1
Mast, Hannah	Graduate Student (research assistant)	4
Messershmidt, Tyler	Graduate Student (research assistant)	4
Miller, Avery	Graduate Student (research assistant)	4
Molino, Grace	Graduate Student (research assistant)	1
Noori, Amirhossein	Graduate Student (research assistant)	1
Nur, Nayma	Graduate Student (research assistant)	1
Ortiz-Miller, Isabellla	Graduate Student (research assistant)	1
Pant, Manisha	Graduate Student (research assistant)	4
Rafael Palacios Gonzalez, Jordi	Graduate Student (research assistant)	1
Riffe, Emily	Graduate Student (research assistant)	4
Sabo, Alex	Graduate Student (research assistant)	4
Say, Caitlin	Graduate Student (research assistant)	1
Sciolino, Anne	Graduate Student (research assistant)	1
Smith, Alex	Graduate Student (research assistant)	4
Tabor, Charles	Graduate Student (research assistant)	0
Tassone, Spencer	Graduate Student (research assistant)	4
Tedford, Kinsey	Graduate Student (research assistant)	4
Turrietta, Elise	Graduate Student (research assistant)	4
White, Drew	Graduate Student (research assistant)	4
Yates, Griffin	Graduate Student (research assistant)	2
Yiyang, Xu	Graduate Student (research assistant)	4

Name	Most Senior Project Role	Nearest Person Month Worked
Hutchinson, Jonah	Research Experience for Undergraduates (REU) Participant	3
McBride, Desraeli	Research Experience for Undergraduates (REU) Participant	3
Shapiro-Tamir, Noa	Research Experience for Undergraduates (REU) Participant	3
Fauber, Donna	Other	12

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 Leadership. Seagrass research

Funding Support: NSF

Change in active other support: No

International Collaboration: No
International Travel: No

Michael L Pace
Email: pacem@virginia.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Studies of clam aquaculture in coastal lagoons

Funding Support: NSF

Change in active other support: Yes

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: Project Information Management, mammalian studies, monitoring stations

Funding Support: NSF

Change in active other support: No

International Collaboration: No
International Travel: No

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

Contribution to the Project: Works on studies of oyster reefs

Funding Support: NSF

Change in active other support: Yes

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: Works on studies of sediment dynamics

Funding Support: NSF

Change in active other support: No

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

Cora Johnston Baird
Email: caj2dr@Virginia.EDU
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 12

Contribution to the Project: Site Manager, Education Specialist

Funding Support: NSF, UVA

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

Amelie C Berger
Email: acb4rk@virginia.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Working with PIs McGlathery and Berg on studies of seagrass metabolism using eddy covariance techniques and management of research operations at the field station

Funding Support: NSF

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 C N Castorani
Email: castorani@virginia.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Biodiversity of seagrass meadows and oyster reefs; oyster population dynamics and connectivity; remote sensing of islands, mudflats, marshes; seagrass resilience experiment

Funding Support: NSF

International Collaboration: No
International Travel: No

Scott Doney
Email: scd5c@virginia.edu

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

Contribution to the Project: Works on issues of global change related to coastal aquatic systems

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
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

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

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

Matthew 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: NSF

International Collaboration: No
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

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 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, barrier and bay

Funding Support: NSF

International Collaboration: No
International Travel: No

Sally Pusede
Email: spusede@virginia.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Atmsopheric fluxes

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

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

Contribution to the Project: Remote sensing of biogeochemistry of wetlands

Funding Support: NSF

International Collaboration: No
International Travel: No

Natasha Woods
Email: nnwoods@vcu.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Works on landscape dynamics of barrier islands in cooperation with PI Zinnert

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 Young
Email: dyoung@vcu.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, barrier and bay

Funding Support: NSF

International Collaboration: No
International Travel: No

Julie C Zinnert
Email: jczinnert@vcu.edu

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

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: No
International Travel: No

Carmine Donatelli
Email: dcarmine@bu.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 1

Contribution to the Project: Working with PI Fagherazzi

Funding Support: NASA

International Collaboration: No
International Travel: No

Carolyn Ewers Lewis
Email: ce8dp@virginia.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 7

Contribution to the Project: Works with PIs McGlathery and Berg on seagrass

Funding Support: NSF

International Collaboration: No
International Travel: No

Quingguang Zhu
Email: qz3cp@virginia.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 12

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

Funding Support: NSF, COPE

International Collaboration: No
International Travel: No

Thomas Burkett
Email: pnj9ud@virginia.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 12

Contribution to the Project: Technical staff of field station, boat operations, data collection

Funding Support: NSF

International Collaboration: No
International Travel: No

Albert Doughty
Email: ad7rw@virginia.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 6

Contribution to the Project: Boat driving, equipment maintenance

Funding Support: UVA, NSF

International Collaboration: No
International Travel: No

Emily Goetz
Email: emgoetz@vims.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 12

Contribution to the Project: Working with PI Castorani

Funding Support: NSF

International Collaboration: No
International Travel: No

Gunnar Gustafson
Email: tkf8hn@virginia.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 3

Contribution to the Project: Boat driving, equipment maintenance

Funding Support: NSF

International Collaboration: No
International Travel: No

Sophia Hoffman
Email: pbe8et@virginia.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 12

Contribution to the Project: Technical staff of field station, boat operations, data collection

Funding Support: NSF

International Collaboration: No
International Travel: No

David Lee
Email: ddl5e@virginia.edu

Most Senior Project Role: Technician
Nearest Person Month Worked: 1

Contribution to the Project: Drives boats, collects data

Funding Support: NSF

International Collaboration: No
International Travel: No

Kayla Martinez-Soto
Email: ksmartin@vims.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 6

Contribution to the Project: Working with DS Johnson on saltmarsh invertebrates

Funding Support: NSF, VIMS

International Collaboration: No
International Travel: No

Margot Tabb Miller
Email: mtm3hq@virginia.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 10

Contribution to the Project: Chemical analyses

Funding Support: UVA, NSF

International Collaboration: No
International Travel: No

Savannah Atchley
Email: zmv4ah@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Working with PI Reidenbach on oyster studies

Funding Support: NSF, UVA

International Collaboration: No
International Travel: No

Mary Bryan Barksdale
Email: mbarksdale@vims.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Working with PI Kirwan on marsh studies

Funding Support: NSF

International Collaboration: No
International Travel: No

Tyler Barnes
Email: teb5g@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Wiberg on VCR sediment budget

Funding Support: NSF

International Collaboration: No
International Travel: No

Emma Bramehy
Email: eb2vw@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 2

Contribution to the Project: Working with PI Doney on analysis of high-resolution automated water quality instrumented time-series

Funding Support: UVA

International Collaboration: No
International Travel: No

Lauren Brideau
Email: ysd4wx@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Castorani on studies of seagrass fauna biodiversity

Funding Support: NSF (VCR LTER), UVA

International Collaboration: No
International Travel: No

Mikayla Call
Email: mncall@vt.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Karpanty on shorebird studies

Funding Support: NSF and Virginia Tech

International Collaboration: No
International Travel: No

Michael R Cornish
Email: mcornish@virginia.edu

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

Contribution to the Project: Works with PI Castorani on oyster reef and seagrass meadow community ecology

Funding Support: NSF

International Collaboration: No
International Travel: No

Luca Cortese
Email: lucacort@bu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Fagherazzi on salt marsh studies

Funding Support: NASA

International Collaboration: No
International Travel: No

Benton Franklin
Email: wbenton@email.unc.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Nordio Giovanna
Email: nordiog@bu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Sarah Goldsmith
Email: sbg4917@rit.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Paola Granados
Email: xac4ke@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Berg on greenhouse fluxes

Funding Support: NSF LTER

International Collaboration: No
International Travel: No

Kayleigh Granville
Email: keg8fb@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with Berg on flux measurements

Funding Support: NSF

International Collaboration: No
International Travel: No

Luke Groff
Email: hmq2xm@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with Karen McGlathery and Peter Berg on carbon sequestration in seagrass meadows

Funding Support: NSF

International Collaboration: No
International Travel: No

Sofia Gurevich
Email: gis@unc.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Working with PI Moore on island geology/vegetation interactions

Funding Support: NSF

International Collaboration: No
International Travel: No

Sean Hardison
Email: sh5rs@virginia.edu

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

Contribution to the Project: Works with PI Castorani on remote sensing

Funding Support: NSF

International Collaboration: No
International Travel: No

Kaitlyn Harless
Email: harlesskb@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Working with PI Young on studies of shrubs on islands

Funding Support: NSF

International Collaboration: No
International Travel: No

Brianna Ingram
Email: ingrambc@email.unc.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Justus Jobe
Email: jjobe@gwu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: working with Keryn Gedan on the forest disturbance experiment

Funding Support: NSF, GRF

International Collaboration: No
International Travel: No

Kylor Kerns
Email: kk2kq@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Kristy Lapenta
Email: kristyl@vt.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Karpanty on shorebird studies

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: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Carly LaRoche
Email: ckl6be@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Scott Doney on lagoon inorganic carbon dynamics and air-sea CO2 exchange

Funding Support: NSF

International Collaboration: No
International Travel: No

Riley Leff
Email: rileyleff@gwmail.gwu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with Gedan on sap flow and tree mortality

Funding Support: NSF CZN

International Collaboration: No
International Travel: No

Edward Long
Email: longea3@vcu.edu

Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Working with PI Zinnert on island vegetation studies

Funding Support: NSF

International Collaboration: No
International Travel: No

Juan Martinez
Email: juan.martinez@gwmail.gwu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Working with PI Gedan on coastal forests

Funding Support: NSF

International Collaboration: No
International Travel: No

Hannah Mast
Email: hm4vd@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with Yang and Pusede on CO2 fluxes and SIF observations

Funding Support: NSF

International Collaboration: No
International Travel: No

Tyler C Messershmidt
Email: tcmesserschmidt@vims.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Kirwan on marsh-forest couplings

Funding Support: NSF, VIMS

International Collaboration: No
International Travel: No

Avery Miller
Email: axm9863@rit.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with C. Tyler on remote sensing of Spartina biomass

Funding Support: Nat. Geog., RIT

International Collaboration: No
International Travel: No

Grace Molino
Email: gdmolino@vims.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Worked with PI Kirwan on forest migration

Funding Support: USGS, VIMS

International Collaboration: No
International Travel: No

Amirhossein Noori
Email: amir1996@bu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Working with PI Faherazzi on lagoon studies

Funding Support: NSF

International Collaboration: No
International Travel: No

Nayma Binte Nur
Email: nn6721@rit.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Working with PI Bachmann on remote sensing of soil moisture

Funding Support: RIT

International Collaboration: No
International Travel: No

Isabellla Ortiz-Miller
Email: ortizmili@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Working with PI Young on studies of shrubs on islands

Funding Support: NSF

International Collaboration: No
International Travel: No

Manisha Pant
Email: mpant@vims.edu

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

Contribution to the Project: Working with DS Johnson on saltmarsh invertebrates

Funding Support: NSF, VIMS

International Collaboration: No
International Travel: No

Jordi Rafael Palacios Gonzalez
Email: jordipg@bu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Working with PI Faherazzi on lagoon studies

Funding Support: NSF

International Collaboration: No
International Travel: No

Emily Riffe
Email: riffee2@mymail.vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Worked with PI Zinnert and Moore on dune grass dynamics

Funding Support: VCU

International Collaboration: No
International Travel: No

Alex Sabo
Email: saboab@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Works with PI Zinnert on barrier island landscape dynamics

Funding Support: VCU, NOAA

International Collaboration: No
International Travel: No

Caitlin Say
Email: saycn@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Working with PI Zinnert on island vegetation studies

Funding Support: NSF

International Collaboration: No
International Travel: No

Anne Sciolino
Email: sciolinoam@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Working with PI Zinnert on island vegetation studies

Funding Support: NSF

International Collaboration: No
International Travel: No

Alex J. Smith
Email: ajsmith@vims.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Kirwan on carbon cycling

Funding Support: NSF

International Collaboration: No
International Travel: No

Charles Tabor
Email: cat6660@rit.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: Works with C. Bachmann on Remote Sensing

Funding Support: RIT

International Collaboration: No
International Travel: No

Spencer Tassone
Email: sjt7jc@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Pace on VCR primary producers

Funding Support: UVA, NSF

International Collaboration: No
International Travel: No

Kinsey N Tedford
Email: ktedford@virginia.edu

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

Contribution to the Project: Works with PI Castorani on oyster reef and seagrass meadow community ecology

Funding Support: NSF

International Collaboration: No
International Travel: No

Elise Turrietta
Email: emt4ze@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Reidenbach on seagrass resilience

Funding Support: NSF

International Collaboration: No
International Travel: No

Drew White
Email: aewhite@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Works with PI Zinnert on dune grass dynamics

Funding Support: NSF, Army Corps of Engineers

International Collaboration: No
International Travel: No

Griffin Yates
Email: gby3jr@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 2

Contribution to the Project: Working with PI Reidenbach on oyster dynamics

Funding Support: NSF LTER

International Collaboration: No
International Travel: No

Xu Yiyang
Email: Yiyangxu@bu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: USGS, Chinese Scholarship

International Collaboration: Yes, China
International Travel: No

Jonah Hutchinson
Email: jhutchsd@gmail.com
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Working with PI Gedan on forest disturbance

Funding Support: NSF

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

Desraeli McBride
Email: desraeli.mcbride@gmail.com
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Working with PI Karpanty on avian studies

Funding Support: NSF

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

Noa Shapiro-Tamir
Email: nshapiro@oberlin.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Working with PI Gedan on forest disturbance

Funding Support: NSF

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

Donna Fauber
Email: dhf4k@Virginia.EDU
Most Senior Project Role: Other
Nearest Person Month Worked: 12

Contribution to the Project: Educational coordination

Funding Support: NSF

International Collaboration: No
International Travel: No

What other organizations have been involved as partners?

Name	Type of Partner Organization	Location
Accomack Co. Public Schools	School or School Systems	Accomack Co., VA
Agricultural Research and Extension Centers - Virginia Tech	Academic Institution	Blacksburg, VA
Barrier Islands Center	Other Nonprofits	Eastville, VA
Environmental Education Council of the Eastern Shore	Other Nonprofits	Virginia
Northampton County Public Schools	School or School Systems	Northampton Co, Virginia
SouthWings	Other Nonprofits	Norfolk, VA
The Nature Conservancy	Other Nonprofits	USA/Virginia
Virginia Institute of Marine Sciences	Academic Institution	Gloucester Point, VA

Full details of organizations that have been involved as partners:

Accomack Co. Public Schools

Organization Type: School or School Systems
Organization Location: Accomack Co., VA

Partner's Contribution to the Project:
Personnel Exchanges

More Detail on Partner and Contribution: Collaboration on the Schoolyard LTER work

Agricultural Research and Extension Centers - Virginia Tech

Organization Type: Academic Institution
Organization Location: Blacksburg, VA

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution: Helped REU complete a project in 2019

Barrier Islands Center

Organization Type: Other Nonprofits
Organization Location: Eastville, VA

Partner's Contribution to the Project:
Financial support
Facilities

More Detail on Partner and Contribution: Provided a venue for our outreach program, and supported advertising

Environmental Education Council of the Eastern Shore

Organization Type: Other Nonprofits
Organization Location: Virginia

Partner's Contribution to the Project:
In-Kind Support

More Detail on Partner and Contribution: We partner on outreach, share outreach equipment and mailing lists, etc.

Northampton County Public Schools

Organization Type: School or School Systems
Organization Location: Northampton Co, Virginia

Partner's Contribution to the Project:
Personnel Exchanges

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

SouthWings

Organization Type: Other Nonprofits
Organization Location: Norfolk, VA

Partner's Contribution to the Project:
In-Kind Support

More Detail on Partner and Contribution: Provide access to overflights to support environmental outreach

The Nature Conservancy

Organization Type: Other Nonprofits
Organization Location: USA/Virginia

Partner's Contribution to the Project:
Facilities
Collaborative Research

More Detail on Partner and Contribution: Research is conducted on TNC-owned land. We also collaborate on establishment and monitoring of experimental oyster reefs

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

Were other collaborators or contacts involved? If so, please provide details.
Nothing to report

Impacts

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

VCR research has contributed to theoretical advances in understanding complex dynamics of state change in ecosystems dominated by foundation species. The VCR is the most extensive stretch of undisturbed coastal barriers in the world, and is an ideal model for assessing climate impacts and ecosystem state change in shallow coastal systems.

Our research focuses on barrier islands, maritime forests, salt marshes, and coastal lagoons with seagrass meadows and oyster reefs that comprise the VCR and the connections between them. We link ecological and physical (geomorphic, hydrologic) processes that are critical to ecosystem dynamics. For example, sediment transport and deposition allows marshes to keep pace with rising seas, oyster reefs and seagrass affect marsh erosion during storms, and vegetation (shrubs, grass) affects how barrier islands build elevation and migrate inland in response to sea-level rise and storms.

We have made significant contributions to understanding ecological and physical processes, feedbacks that either maintain or facilitate transitions in ecosystem states, and have identified leading indicators of threshold responses. We are leaders in developing and testing mechanistic models with long- and short-term observations and experimental data, and using these to project state change and its ecological consequences. Our work on seagrass meadows and oyster reefs influence general knowledge in restoration ecology.

The VCR domain provides a unique opportunity to address how connectivity among ecological systems on the landscape affects state change. Our work to date has shown that state change dynamics among adjacent systems are coupled, where state in one system can propagate to the other. This integrated long-term research informs management and conservation of coastal ecosystems at the VCR, and through synthesis and comparative work our research impact extends globally.

COASTAL BAYS

The eelgrass (Zostera marina) that once carpeted large areas of the seafloor of the VCR 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. Now due to restoration, over 35 km2 have been restored to seagrass habitat, and is considered the largest seagrass restoration in the world. This 20-yr landscape-level experiment has shown that within a decade ecosystem services – primary productivity, carbon and nitrogen sequestration, increased water column clarity, sediment stabilization, and biodiversity – biodiversity are reinstated. VCR scientists were the first to show the role of seagrass restoration in reinstating ‘blue’ carbon storage capacity and our work has both informed VA state policy and set global standards for issuing carbon credits in the voluntary carbon market for seagrass restoration.

Understanding how seagrass restoration and marine heatwaves affect ecologically and economically important fishes has implications for recreational and commercial fishing communities that directly or indirectly rely on these species for their livelihoods and/or for food security. Our study of blue crabs suggests that the restoration of seagrass meadows alters the distribution of blue crabs, and that seascape habitat connectivity had equally strong effects on crab densities.

Our study of oyster reef restoration addresses a key gap in restoration ecology by identifying the recovery timelines for restored oyster reefs and their associated ecosystem services, as well as the physical factors that mediate restoration success. This body of work provides evidence to support the value of continuing oyster restoration efforts by illustrating functional equivalence of restored and natural reefs over time. VCR scientists wrote a policy brief to NOAA about necessity of

long-term monitoring for oyster restoration based on our research highlighting the need for managers and conservation practitioners to increase monitoring time frames and include appropriate reference sites in monitoring programs to clarify recovery timelines and assess functional equivalence of restored and natural ecosystems.

We developed methods to quantify marsh edge morphology using airborne LiDAR data and validated these methods with in situ observations. In the oyster restoration experiment, we are using these to compare morphology and retreat at paired reef-lined and control marsh edges at ten different marsh sites.

WETLANDS AND MARITIME FOREST

Tidal wetlands exist in the narrow band of elevation affected by tides; their distribution is fundamentally defined by the limits of the sea and extremely responsive to changes in sea level. Coastal storms and daily wave energy affect their distribution through erosion at the seaward edge and migration into maritime forest on the upland edge. At the VCR, elevation measurements and coupled models are used to predict changes in marsh and forest habitat area and carbon sequestration benefits that can translate into carbon accounting efforts and species survival analysis. Ecological monitoring is being used to understand the succession that occurs during coastal habitat state change from forest to marsh. A widespread invasive species, the common reed, is of particular management concern for wildlife habitat quality. Understanding forest retreat is of interest to the US Forest Service and land trusts including The Nature Conservancy (TNC). Based on our research, we have provided input on state and federal agencies' saltwater intrusion plans and public manuals.

BARRIER ISLANDS

Barrier island plants and shorebirds and their invertebrate prey communities serve as sentinels to climate change. Habitat classification studies and documented changes in island geomorphology explain shifts in nesting success and our understanding of how imperiled shorebirds respond to climate- and storm-driven changes inform planning and management decisions by Virginia DWR, USFWS, and TNC.

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

We have established that long-term and landscape-scale vegetation patterns on the islands reflect nonlinear dynamics and threshold responses to environmental drivers. We coined the term 'maintainer feedback' to apply to processes that maintain low elevations (vs. '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 island morphologies with climate change-induced increases in storm intensity and sea-level rise. We have shown how vegetation affects dune morphology island vulnerability to overwash during storms. Sand delivered by overwash allows back-barrier marshes to persist under conditions in which they would otherwise disappear, leading to increased island resilience. The importance of this coupling is redefining the way barrier island response to changing conditions is assessed.

What is the impact on other disciplines?

VCR LTER research integrates ecology, hydrology, geomorphology, atmospheric science, and physical and chemical oceanography. Our strength is our integrated approach linking ecological and physical processes that are critical to ecosystem dynamics in coastal systems. This has leveraged recent support from NSF to establish a Critical Zone Observatory network in the Coastal Mid-Atlantic that includes the VCR and builds on our research questions. The Coastal CZO studies links between ecological and geomorphological changes documented by VCR LTER studies with hydrological and biogeochemical changes in the coastal zone resulting from sea-level rise and saltwater intrusion.

VCR scientists also have received funding for two Coastlines and People Focused Hubs, one starting in 2021 and one in 2022. Both Hubs leverage VCR research to address climate equity issues on the coast.

Physical scientists and ecologists work together to understand biotic feedbacks in seagrass ecosystems on sediment deposition and resuspension by currents and waves that are critical to understanding both responses to climate drivers (sea-level rise and storm disturbance) and the connectivity between seagrass meadows and adjacent tidal marshes.

Research on ecological information management has included computer scientists. The challenges posed by ecological data provide opportunities for innovation in computer science. Our work on developing wireless sensor networks and processing of the massive data flows they can generate contributes to addressing the cyberinfrastructure challenges now and in the future.

Science-arts/humanities collaborations are a key component of our education and outreach programs. The "Ghost Forest Coastal Change Collective" brings artists into contact with the changing landscape. All along the Eastern Seaboard, the silver trunks of dead trees stand as sentinels at the marsh edge, but signs of coastal change emerge long before the big trees die. Artists explore and envision ghost forests, bringing them into view for the communities who live among them. We are continuing our Humanities Lab focused on “listening to coastal futures”. The Listening for Coastal Futures: Sounding Science installation includes both coastal sounds and sonified data from VCR LTER core data sets; its aim is to catalyze conversations on coastal change. Collaborations are ongoing, with the goal of establishing a robust environmental humanities program at the VCR LTER. These workshops all introduce participants to the place-based science at the VCR-LTER and explore interdisciplinary collaborations.

What is the impact on the development of human resources?

VCR LTER continues our strong tradition of training undergraduate and graduate researchers through a tiered mentoring program; this year 47 graduate students, 3 undergraduate students and 3 post-docs conducted research through the program. Moreover, the inter- and multidisciplinary nature of the research teaches the students how to operate in a collaborative environment. Our REU/HS/T activities provide graduate students mentorship training as they supervise and support the learning experiences of undergraduates, high school students, and K-12 teachers.

Undergraduate training through the VCR was expanded in 2023 when Dr. Natasha Woods (alumni and affiliated researcher) received $500,000 from NSF BRC-BIO to create the Diverse Undergraduate Research Students in Ecology (DURSiE) program, which enhances and diversifies undergraduate participation in barrier island research at the VCR. The program is based at Moravian University, with field research at the VCR LTER.

What was the impact on teaching and educational experiences?

We continued to support student STEM experiences at all education levels. A primary impact is through training of graduate students, many of whom move on to teaching positions at the collegiate level. Additionally, we magnify that expertise by providing additional training for graduate students through our Fundamentals of Learning for Science Mentors workshop for graduates and early career scientists who serve as REU and RET mentors at VCR. The short course introduces concepts and practices in teaching and learning science. The VCR also supports lifelong learning by contributing to certification for the regional Master Naturalists.

VCR researchers frequently provide guest lectures and career panel participation. We continue to build broader collaborations with Eastern Shore Community College (ESCC) science department, with specific focus on 1) developing place-based labs for science classes, 2) supporting research experiences toward newly implemented capstone requirements, and 2) shifting our summer final presentations (featuring REU students) to a multi-institutional student research showcase and networking event on the ESCC campus. Beyond the Eastern Shore, Baird is an active member of the Community College x Field Station interest group that emerged from the Undergraduate Field Experience Research Network (UFERN), which is working to systematically support stronger ties between field-based learning and community colleges.

We also interact with the art community to link science and art. For example, the process of collecting and processing hyperspectral imagery to evaluate an ecosystem (based on research by VCR affiliate Tyler) became the basis for a transdisciplinary middle school unit in art. Every 8th grade art student at Nandua Middle School participated in a presentation about hyperspectral imagery in local research and then completed a multi-step art project applying false color to landscape photographs to create abstract art and mimic a scientific process. The art and an overview of the hyperspectral imagery research that inspired it was viewed by dozens of families during the schools Title I Art Showcase.

What is the impact on physical resources that form infrastructure?

The VCR/LTER is the primary user of the University of Virginia's Coastal Research Center (CRC) and provides, through user fees, resources that allow the center to support a substantial housing, lab and boat infrastructure. The CRC 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. He is now developing new technologies to measure greenhouse gas, methane and nitrous oxide, fluxes from seagrass meadows and gas fluxes across the air-water interface that are needed to determine the net carbon sequestration capacity of seagrass meadows.

What is the impact on institutional resources that form infrastructure?

LTER researchers form the core of a periodic seminar series offered at the Coastal Research Center (CRC) 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 Bay. Researchers from other universities/programs have access to this data, and our network has also been used to support collection of images and data by other user groups. Using this network, our tide and meteorological station data are published in near real-time, allowing their use to support time-critical activities.

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) and affiliated data centers (e.g., EDI, DataOne).

The VCR/LTER shares 329 online datasets with an aggregate volume of approximately 508 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 11/01/2022 to 10/31/2023, VCR/LTER data files have been downloaded 1,745 times via the Environmental Data Initiative Data Portal. An additional 7,685 data entities were downloaded directly from the VCRLTER. 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.

VCR/LTER tide data, updated every 6 minutes, is displayed on the NOAA Advanced Hydrologic Prediction web page (https://water.weather.gov/ahps2/hydrograph.php?wfo=akq&gage=cchv2).

What is the impact on technology transfer?

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 EDI Data Portal. They were used 1,094 times in the past year (excluding robots), with code generated for R (71%), Python (14%), Matlab (9%), SPSS (4%), and SAS (2%).

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. We continue to be active in the management of this resource and in 2019 published a summary of its use (Porter, 2019). At the 2022 LTER All-Scientists' Meeting, a session on data annotation made extensive use of the controlled vocabulary, and in 2022-2023 the Controlled Vocabulary has been the basis for an Environmental Data Initiative working group on faceted search.

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., 2018).

Extensive aquatic eddy covariance measurements of seagrass metabolism have been done at VCR LTER since 2007. In addition to revealing crucial information on temperate (Zostera marina) seagrass health, metabolism, and its control, this effort has been instrumental in further development of this relatively new technique for measuring benthic exchange under naturally varying in situ conditions.

What is the impact on society beyond science and technology?

We all are experiencing anthropogenic changes in the environment, including global warming, sea-level rise and ocean acidification. Understanding of the causes and consequences of these changes, and the processes that drive them are critical to addressing them. It is not sufficient just to have a general sense of what is happening and why it is happening. Details can be important, and research at the Virginia Coast Reserve LTER are helping to develop a sophisticated understanding of how coastal systems can influence and respond to global drivers. Our work on habitat restoration is also showing how practitioners can bring ecosystems back from the brink of local extinction and restore many ecosystem services that benefit society.

What percentage of the award's budget was spent in a foreign country?
Nothing to report.

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.

Change in primary performance site location
Nothing to report.