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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
Project Title:	LTER: Climate drivers, dynamics, and consequences of ecosystem state change in coastal barrier systems
PD/PI Name:	Karen J 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
Recipient Organization:	University of Virginia Main Campus
Project/Grant Period:	12/01/2018 - 05/31/2025
Reporting Period:	12/01/2023 - 11/30/2024
Submitting Official (if other than PD\PI):	N/A
Submission Date:	N/A
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	N/A

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:

1) Drivers of Long-term Change

1a) Climate Drivers

We continued long-term data collection at meteorological stations, tide and water temperature stations, and groundwater wells. We completed simulations of VCR storm surge during 9 historic hurricanes and nor’easters varying in return time.

1b) Patterns of Change

We continued long-term collection of water quality data; satellite, plane, and drone imagery to characterize landscape change on islands, marshes, seagrass meadows, and oyster reefs. We conducted bathymetric surveys to quantify the influence of seagrass meadows on deposition/erosion. We continued long-term experiments on seagrass and oyster reef restoration, marsh transgression, and island grass-shrub transitions.

2) Dynamics within Landscape Units

2a) Forest-Marsh

We continued the long-term experiment to test mechanisms underlying forest-marsh responses to sea-level rise (SLR) and storms. We monitored tree water use and mortality, shrub growth, vegetation cover, litterfall, decomposition, groundwater, soil moisture, nutrients, salinity, light, canopy cover, and fauna (see section 4) across an elevation gradient. We added 4 reference plots in the forest upslope and synthesized ecological, hydrological, and geomorphological baselines to determine control-treatment plot pairings for the new girdling experiment. Using slingshots, we collected canopy leaves and measured functional traits for 5 taxa across the salinity gradient to investigate tree acclimation. We paired 15 new high-frequency soil-thickness sensors with our Surface Elevation Tables (SETs) and quantified accretion/subsidence rates across the marsh-forest boundary using elevation data. We collected field data to calibrate a hydrological model aimed at understanding how storm surge affects soil salinity.

2b) Intertidal

We continued long-term measurements of solar-induced chlorophyll fluorescence and canopy reflectance at our marsh eddy-covariance tower. We measured cross-season carbon (C) flows in and out of the marsh along tidal creeks using high-resolution autonomous sensors. We instrumented an intertidal marsh to measure hydrodynamic controls on sediment movement and deposition to a marsh platform, and how marsh-grass attenuates waves. We determined how ventilation of worm burrows affect oxygen dynamics in intertidal mudflats. We upgraded root-zone pipes of our SETs measuring long-term marsh accretion (1997–present).

We added oyster-reef elevation measurements to a hydrodynamic model linking flow and biogeochemistry. Drone-based topography of 4 marshes were coupled with bathymetry to quantify volumetric change at the marsh-mudflat boundary. We measured wave attenuation over oyster reefs and effects on marsh-edge erosion.

2c) Subtidal

We continued 23 years of measuring the seagrass state-change restoration experiment, including seagrass C soil stocks, density and biomass, benthic microalgae, and fauna (see section 4). We sampled leaves for disease analysis related to temperature. We continued 17 years of measuring seagrass metabolism by aquatic eddy covariance. At the lagoon scale, we measured seasonal DIC and alkalinity, and quantified seagrass effects on hydrodynamics, sediment transport, and bivalve larval settlement using flow, optical backscatter sensors, and sediment traps.

2d) Barrier Island

We continued long-term island grassland-shrub surveys by measuring vegetation, microclimate, and soil characteristics in 3 swales differing in dune elevation. We also continued study of microclimate, water table, and vegetation at the grass-shrub ecotone, and testing drivers of shrub productivity. We analyzed LiDAR-based geomorphology, dune height, and back-barrier marsh width using artificial intelligence (machine learning) to identify thresholds for shrub growth.

We investigated plant-geomorphology feedbacks by continuing the dune-grass planting experiment, long-term surveys of species composition and topography, and annual drone surveys of island vegetation and dune morphology (via structure-from-motion) on two islands. We added new measurements of foredune species composition and elevation, and seasonal drone flights and satellite imagery of the most rapidly changing VCR barrier island.

3) Dynamics Between Landscape Units

3a) Sediment Transport

To supplement observed decadal-scale erosion/deposition measurements, we used Delft3D modeling to quantify how seasonal variations in seagrass density and storm winds affect sediment exchange between lagoons and marshes.

3b) Coupled State-Change Dynamics

We continued our long-term experiment with 8 constructed oyster reefs of different materials and designs to test effects on oyster size, growth, and density. We measured wave attenuation, sediment deposition, and marsh erosion. We used aerial and LiDAR imagery, GPS mapping, and GIS to quantify edge erosion at protected vs. unprotected marshes.

We continued our long-term oyster recruitment time series at 12 sites. We tested how elevation, rugosity, wave exposure, water flushing, and adult density affect recruitment and growth. We compared a 20-year Nature Conservancy record of oyster recruitment with our data, and developed oyster habitat suitability models for adults and juvenile recruits. We finished a caging experiment to test how depth and predators affect oyster growth and survival.

We determined how seagrass restoration affects C accumulation in adjacent salt marshes using stable isotopes, biomarkers, and lead-210 (210Pb) dating.

On cross-island transects we measured plant cover, productivity, soil characteristics, and elevation. We ran path-cost analysis on dunes to determine resistance to seawater flow to the island interior for various storm-surge scenarios. We added a shrub planting experiment to test how dune height affects shrub establishment, and used LiDAR to relate changes in dune height and shrub distribution.

3c) Coupling Between Non-Adjacent Systems

We analyzed satellite and drone imagery to determine how rapid barrier-island change cascades to affect island vegetation, marshes, and seagrass meadows.

4) Ecological Consequences of State Changes

4a) Carbon Sequestration

We continued measuring C stocks in uplands, lagoons, and barrier islands. We added a measurements of C stocks in young and old marshes across the landscape, and a 2-year study of forest litter decomposition across microhabitats. We calculated C-export and ecosystem migration rates for storm and sea level rise scenarios, and generated annual, average, and cumulative C release from subsurface stratigraphic units for each scenario. We measured how dune vegetation, age, and position affect dune C.

4b) Consumer Dynamics

In the forest, we continued long-term measurement of forest invertebrates, and added small-mammal surveys using live traps and camera traps.

In the intertidal, we examined how burrowing crabs affect worm density and diversity in a cross-LTER study (PIE, VCR, GCE, FCE). We tracked migration of marsh grazing fronts caused by purple marsh crabs and impacts on C storage at VCR and GCE. We also tested how invasive algae affect shorebird habitat selection on mudflats.

In the subtidal, we continued the time series of seagrass epifauna, infauna, and fish. We experimentally tested how food availability and predators control hard clam (*Mercenaria mercenaria*) growth and survival across life stages, and tested how climate and seagrass affect clam growth using a new 120-year sclerochronology record.

On islands, we continued long-term measurement of shorebird and prey distribution/abundance (18 years). We tested how geomorphology, predators, and vegetation affect survival, nesting, reproduction, and movements of banded birds. Lastly, we determine how warming affects densities of ghost crabs, an important shorebird predator.

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 stormfrequency and intensity, sea-level rise, rainfall, and temperature can transform the coastal barrier landscape. Climate change may shift disturbance frequency (e.g.,storms, high temperature 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 usingLiDAR, 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 long-term 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 disturbance 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 structure from motion techniques to determine storm-driven change in the morphology of the marsh tidal 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 influenceecosystem 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 evaluate oyster reef population dynamics, including fecundity, dispersal, settlement and survival.

<u>Coupled dynamics:</u>

(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 adjacentand 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: carbons equestration 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:

<u>Carbon cycling and sequestration:</u>

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

<u>Consumer responses:</u>

(1) Assess how state change from bare subtidal and intertidal flats to seagrass and 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: 1) Drivers of Long-term Change

1a) Climate Drivers

4-5 storm-surge events hit VCR per year (1979-2021). The largest 5% of these, driven by NE winds, create storm surge >1 m above high tides. There are no trends in strength nor duration of storm-surge events, apart from the increase in mean sea level and flooding due to SLR.

1b) Patterns of Change

22% of barrier islands have been lost over the past four decades. Island length has mostly been stable, but peak banks—critical shorebird foraging habitat—decreased by 37% (2004–2021). Moreover, sandy beach needed for shorebird nesting decreased by 39%. Landward migration of barrier islands was tempered by island elevation and vegetation. Winter warming has boosted woody vegetation by 41%.

3 years of lagoon echo-sounding surveys found seasonality in seabed elevation, seagrass height, and meadow extent, and greater deposition than erosion.

2) Dynamics within Landscape Units

2a) Forest-Marsh

Storm surge characteristics, soil type, and initial soil conditions affect salinization. Salinization is worse in fine soils when initially wet; groundwater is primarily impacted in sandy soils; and salinity is stratified along the unsaturated zone in silt-clay soils, causing deeper roots to benefit from lower salinity.

The invasive reed Phragmites australis is common at the marsh-forest boundary but difficult to detect under the forest canopy from aerial surveys. We developed a new method to detect it in the understory using subcanopy LiDAR data.

The marsh-forest boundary in the VCR is found at higher elevations (i.e. more inland) than elsewhere in the Mid-Atlantic due to high salinity, tidal range, and exposure to storms.

Limited subsidence or accretion in the retreating coastal forest suggests that static inundation models can forecast marsh migration. Accretion rates in the transition zone are similar to adjacent marshes, indicating rapid effects of marsh migration on elevation.

2b) Intertidal

Oyster reefs built at higher elevations (near mean-water level) better attenuated waves. Reefs attenuated waves at shallow water depths and <0.5 m above the reef crest, but had minimal impacts at higher water elevations. Oysters on high (vs. low) elevation reefs were twice as dense and 20% larger.

After 5 years, restored oyster reefs did not significantly impact lateral marsh edge retreat, but the slope of the marsh edge decreased, indicating an elongation of the edge with possible sediment deposition along the toe of the marsh. Edge erosion was relatively greater along the upper marsh edge (indicating loss of vegetation) above the elevation of the reef as compared to below reef elevation, suggesting that over longer time-scales oyster reefs can reduce total volumetric sediment erosion from the marsh.

2c) Subtidal

Seagrass meadows recovered from a marine heatwave within 3 yr. Spatial variation in resilience was driven by both temperature (loss) and recovery (hydrodynamics). The seagrass wasting disease that caused complete loss in the 1930s was found on 96% of leaves sampled across all meadows, but there was no apparent impact on seagrass productivity. Short-term temperature stress predicted disease lesion area.

On meadow edges, flow velocities were reduced 30-75% within 1 m, and bivalve recruitment increased. Wave activity and sediment suspension did not differ within 5 m of edges. Repeat echosounding showed seasonal patterns in seabed elevations and seagrass height and extent, and detected a depositional signal over 3 years.

210Pb dating revealed a long-term (1860-2022) average sedimentation rate similar to modern (20-yr) rates for seagrass meadows (0.54 cm/yr). C-14 dating showed large amounts of centuries-old C below modern seagrass meadows. Stable-isotope and DNA analysis of sediment cores showed this old C includes seagrass.

2d) Barrier Island

Dune-grass species differ in cover and lateral expansion rates, affecting sediment accumulation and dune shape and size. Sea oats (Uniola spp.) build taller dunes. High-marsh cordgrass (Spartina patens) establishes following overwash, building elevation until it is outcompeted by other grasses.

Decision-tree and random-forest models predicted shrub presence (90% accuracy). Shrub presence correlates with dune elevations >1.9 m and island interior widths >160 m over a 6-year period. Shrub establishment and removal lag changes in geomorphic conditions, indicating hysteresis. Shrub edge increased 233% over 27 years, boosting grassland biomass and cover by ameliorating microclimate. Grass traits at the shrub edge were altered by more shade, soil nitrogen, and moisture.

Hummock- vs. ridge-form dunes altered storm surge impacts, plant community composition in grass swales, productivity, soil C stocks, and shrub survival.

3) Dynamics between Landscape Units

3a) Sediment Transport

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

Seagrass boosted sediment retention in mudflats-marshes by facilitating a 10x increase in deposition and serving as a sediment source during winter senescence.

Areas behind constructed oyster reefs were net-depositional. Reefs altered marsh-edge erosion at elevations similar to reef height. But, reefs built below the marsh surface did not stabilize the marsh edge.

3b) Coupled State-Change Dynamics

Long-term data shows oyster larvae are not majorly limiting, but only 6% of the VCR has conditions for higher-than-average larval recruitment. Recruitment showed unimodal relationships with wind fetch, increased with elevation, and had no relationship with water residence time. Restored oyster reefs have less recruitment than reference reefs, but the cause remains unknown. Predation on juvenile oysters increased in the subtidal (vs. intertidal).

4) Ecological Consequences of State Changes

4a) Carbon Sequestration

Greater shoreface recession on islands has caused proportionally larger amounts of C release. At low SLR rates, a 6% increase in shoreline recession causes a 6% increase in C loss; at high SLR rates, a 100% increase in shoreline recession causes a 130% increase in C loss.

4b) Consumer Dynamics

Migrant shorebirds respond to 3 prey: clams, mussels, crustaceans. Some migrants forage on mudflats and beaches; some specialize on beach prey. Owls, falcons, and ghost crabs reduced pre-fledged oystercatcher survival, dampening population growth. Chicks choose vegetation-free areas near marshes to be near foraging adults. Island length and sandy-beach foraging habitat are stable long-term, but 37% of peat-bank foraging areas were lost recently. Dry sandy beach for nesting shorebirds increased 39% (2004-2021). Island and beach width, and time since storm altered prey use.

Grazing fronts of purple marsh crabs (Sesarma reticulatum) turned marshes into intertidal mudflats, with 40-70% soil C loss. As grazing fronts moved landward ~1 m/y, grasses revegetated the trailing edge. Recovery of soil C may require a century. Regardless of burrow density, crabs did not affect infauna density or diversity. Faunal burrow ventilation influenced sediment metabolism, moving solutes across the sediment–water interface.

Hard clam (Mercenaria mercenaria) food availability was greater inside seagrass meadows, enhancing clam soft-tissue condition but not shell growth. Survival was much greater inside the meadow for small clams. Long-term clam shell growth was unaffected by seagrass, but controlled by climate-driven fluctuations in temperature.

Key outcomes or Other achievements:

This award has resulted in 187 journal articles and 36 theses/dissertations to date (a complete list of publications is at https://www.vcrlter.virginia.edu/home2/?page_id=215).

1) Drivers of Long-term Change

1a) Climate Drivers

Sea-level rise (SLR) and strengthening winds may increase storm surge by 0.7 m in 20 years, accelerating coastal ecosystem state change and threatening mechanisms that maintain resilience.

1b) Patterns of Change

Barrier islands are diminishing in extent and also changing in elevation and ecosystem composition. These and other climate-mediated changes threaten shorebirds that rely on island habitats for reproduction and foraging, and impact bay ecosystems that depend on barrier islands to reduce wave energy.

2) Dynamics within Landscape Units

2a) Forest-Marsh

Over the long term (1984–2020), warmer, wetter years boost upland forest productivity, but SLR diminishes low-lying forest productivity. Moderate storms outweigh the effects of hurricanes in harming forests through salinization because they are more frequent (every 1-2 years) and groundwater recovery is slow. Most at risk are root zones with silt-clay soils and low water content. Soil elevations in retreating coastal forests are remarkably stable, where accretion and subsidence are offset.

Like the rest of the Mid-Atlantic, maritime forest retreat is happening more slowly than SLR, implying forests can resist SLR for decades. Unlike the rest of the Mid-Atlantic, salinization causes VCR marshes to extend more landward and into higher elevations.

Coastal-forest zonation is driven by seasonal hydrology that controls recovery from salinization. Tree species differ in salt tolerance and shifts in composition occur prior to forest dieback. Tree water-use decreases with salinization, and low transpiration increases soil saturation, diluting soil salinity and creating ecosystem water-budget feedbacks that affect forest-to-marsh transition rates.

Canopy loss increases light availability in the retreating forest. As a result, understory shrubs proliferate and the dominant high-marsh cordgrass (Spartina patens) increases flowering and seed production. Salt marsh amphipods migrate into the forest prior to canopy loss.

2b) Intertidal

Oyster reef elevation is important for restoration of both oysters and adjacent marshes. Constructed reefs support more oysters as elevations approach sea-level at the reef crest. High-elevation reefs are more effective at attenuating wave energy than low-elevation reefs; hence, erosion is slower for marshes lined by constructed oyster reefs than unlined marshes. But, protection varies with the difference in marsh and oyster elevation and orientation to waves.

Marsh-crab grazing fronts can quickly denude marshes, transforming the ecosystem and causing long-lasting loss of soil C.

2c) Subtidal

Our seagrass landscape restoration experiment—now in its 23rd year—shows recovery of ecosystem services within a decade. Meadows were resilient to a marine heatwave, with plant biomass recovering in 2-4 years, though lost sediment-C took longer. 90% loss of seagrass biomass caused 20% loss of soil C. Spatial variation in resilience was driven by temperature controlling loss-severity and hydrodynamics controlling recovery rate. Seagrass meadows are a net sink for CO_2 despite enhancing methane release, and seagrass C may be stored in deep sediments for over a century. Meadows control currents and turbulence at small spatial scales (<10 m) and sediment deposition over large spatial scales (>100 m).

2d) Barrier Island

Long-term data (1984-2020) demonstrate that barrier islands are keeping pace with SLR by greater marsh to upland transitions. Over this period, uplands decreased by 22%, but most loss occurred in 1984-1998 and has stabilized since 2016. Woody cover increased and recent upland migration boosted grasslands in 2020.

The type of dune grass species and their lateral growth rates affect dune shape and size. Cordgrass (Spartina spp.) helps grow dunes mainly in early stages and sea oats (Uniola spp.) builds taller, steeper new dunes. In addition to dune height, the width of the island interior has a nonlinear effect in facilitating shrub establishment. Shrubs are also facilitated by grasses, which insulate shrub seedlings from damaging cold. Once established, shrubs modify the microclimate by bringing the water table closer to the surface and enhancing grass cover near shrub patch-edges. In addition to changing edaphic conditions, shrubs reduce plant diversity.

3) Dynamics between Landscape Units

3a) Sediment Transport

Seagrass meadows and oyster reefs aid in sediment deposition and may help marshes keep pace with SLR. Restoration should target controlling coastal erosion before the area of intertidal vegetation becomes too small compared with the area of the deeper bay.

3b) Coupled State-Change Dynamics

Oysters occupy 12% of the suitable intertidal area for adult oysters, suggesting ample area for future restoration. Our habitat-suitability models reveal areas best for adult and newly recruited oysters, areas best for adults but not recruits, and areas suitable for recruits but not adults that guide practitioners in future restoration. Geographic variation in habitat suitability across demographic stages indicates different restoration planning scenarios are needed for success. Only 2% (8.7 km2) of the VCR is highly suitable across oyster life-stages, offering more refined locations to target for restoration.

On barrier islands, shrubs slow island landward migration and drowning. Shrubs expand more slowly on islands with more dune erosion and overwash (when storm surge pushes waves over the island interior). Island migration causes back-barrier marsh loss, while periods of island stability allow marsh recovery. The extent of the coastal bays is insensitive to SLR because increased island migration (bay narrowing) offsets increased marsh erosion (bay widening).

4) Ecological Consequences of State Changes

4a) Carbon Sequestration

Landscape connectivity, C accumulation, and landscape C stocks peak at intermediate SLR. Forest loss from SLR shifts the C landscape from dominance by tree-biomass C to marsh-soil C, maintained by marsh-bay sediment transport. Thus, climate change strengthens connectivity between adjacent coastal ecosystems and shifts landscape dynamics towards more labile C, smaller marsh and forest extents, and C accumulation in parts of the landscape more vulnerable to SLR and erosion.

Barrier island transgression causes C release. Recent (1994-2017) beach C loss exceed accumulation in adjacent back-barrier ecosystems by ~30%. Erosion of bay sediments (up to 8 m) accounts for >80% of total C losses. Models indicate nonlinear effects of SLR on shoreface recession and C loss. Thus, landscape C budgets assuming only erosion of C from shallow sediments overstate the coastal C sink. However, deep sediment cores reveal large amounts of “legacy” seagrass C buried in sediments since at least the 1700s.

Bubble-trap measurements showed that emissions of CO_2 and methane must be accounted for when evaluating seagrass meadows as C sinks.

4b) Consumer Dynamics

Climate mediates shorebirds via storms and food-web dynamics. Piping plovers irrupt (migrate to the south) after storm events. Densities of crustaceans and clams preyed on by migratory shorebirds are influenced by island and beach width, and time since storms. Many avian and invertebrate predators prey on pre-fledged birds and represent a major constraint on survival.

Blue crabs ambush juvenile fiddler crabs and purple marsh crabs. Because these two species affect marsh erosion, predation by blue crabs may affect ecosystem resilience.

Hard clams (Mercenaria mercenaria) live many decades; the oldest we found is >120 years. Thus, they are living recorders of climate, leaving growth signatures in their shells that reveal the impacts of ocean warming on productivity.

*** 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 44 graduate students, 2 post-docs and 4 undergraduate REUs at the VCR site conducted research through the program. Many dozens of other undergraduates were mentored in VCR research under PI supervision at their home institutions. The inter- and multi-disciplinary nature of the research teaches the students how to operate in a collaborative environment.

Graduate mentors trained in the fundamentals of learning for mentors course continue to contribute to REU programs; they report feeling more prepared and better able to meet their mentees needs using approaches from the course. Mentors have also expanded from our core REUs to support local community college students. Course instructor Baird (also VCR LTER Site Director) worked with LNO network committees and other LTER sites to adapt the course for broader mentorship training across institutions and career stages. An associated mentorship training and community of practice emerged in spring 2024; Baird served as a co-designer and facilitator.

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

We continued supporting excellent undergraduate education by hosting REUs, continuing our partnership with Eastern Shore Community College (ESCC) by matching two capstone students with research projects, 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. We are deepening our collaboration with ESCC by contributing to career events and partnering on an IUSE proposal to support more capstone research opportunities. The Coastal Conservatory Soundscape Symposium led to the partnerships between PI (Karpanty) and ESCC faculty Foxworthy on migrant shorebirds.

We maintained connections with the 6teachers who completed our RET program throughout VCR VII by supporting water quality investigations in the classroom (all Northampton County 6th grade), co-developing curriculum associated with an NSF CAREER award to PI Castorani, and engaging teachers in ongoing long-term research. We also spent a day with all new teacher hires in Accomack and Northampton Counties, introducing them to the coastal barrier system, VCR studies of coastal change, and opportunities to use the Chronolog coastal timelapse stations for classroom learning. Working across grade levels reinforces associations with scientists and encourages science identity among students.

For the second year, we held field safety calls for all research groups to address concerns and share resources. These calls, added in 2023, have improved our field safety planning and procedures. At the start of the research season, all new project members joined a field station orientation, including a review of the code of conduct and participated in bystander intervention training (based on the IRIS curriculum). A midsummer climate survey revealed a continuing positive trend that these training sessions improve field readiness, knowledge of reporting structures, and a positive workplace climate. For the first time, we also held a new project member virtual orientation in September to introduce matriculating students to resources and opportunities within VCR and the national network as they start their graduate study.

The VCR is part of the Advancing Public Engagement Across LTERs (APEAL) program. The APEAL project seeks to advance the development of evidence-based, community-informed public engagement strategies. Scientists and staff from the LTER site are working with the APEAL team to build on current engagement activities to develop new strategic plans that incorporate both site priorities and research on effective practices. We have been studying our community assets and interests and are integrating these with our engagement goals.

One of our PhD students worked with a local school teacher in our underserved area to develop lesson plans for K-12 education. This work was published in Limnology and Oceanography Bulletin (Granville et al. 2024).

*** 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 8,100 page views in 5,100 sessions by 3,400 distinct users from Nov. 1, 2023 to Oct. 31, 2024, also VCR LTER data files were downloaded 11,531 times from the Environmental Data Initiative portal and 6,365 times from the VCR LTER data portal.

MEDIA AND PUBLIC PRESENTATIONS

In spring 2024, our first Sip of Science evening engagement at a local restaurant was well attended (25+ attendees) and received enthusiastic response.

Recent VCR findings were published by grad students in the ShoreLines Newsletter, which reaches a broad audience on the Eastern Shore through a civic engagement organization.

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.

VCR LTER staff contributed to a public media documentary about changing water and life on the Eastern Shore of VA, and served on discussion panels at premiers that reached hundreds in the region.

Max Castorani spoke with local Charlottesville 29 News about the importance of science for informing oyster reef restoration.

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, Ocean Sciences, and WSN.

PI Fagherazzi and his group gave four presentations at the American Geophysical Union Fall Meeting in 2023 and one at the EGU General Assembly Conference in 2024

PI Reidenbach presented oyster and marsh research at the Coastal Conservatory annual event located at the Eastern Shore Community College in December 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 Zinnert’s island studies were profiled in a radio story by WHRO public media.

Graduate student Benton Franklin presented his VCR LTER research to the business team at Exxon Mobil.

PI Berg and co-workers’ findings on legacy blue carbon found below modern seagrass beds were featured in UVA Today.

VCR researchers also presented research 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 (Chronolog) continue to accumulate public engagement. 609 photos have been submitted by 257 unique visitors; 58 people have submitted more than one photo; 3 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 the Soil and Water Conservation District, Virginia Eastern Shore Land Trust, and The Nature Conservancy have continued through informal education, resilience planning, and other efforts. We sustained for a second year 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. VCR staff served on the Community Advisory Council for a neighborhood resilience plan shepherded by TNC (with NFWF funding); we also continue to provide a scientific basis for TNC's coastal Virginia land management and restoration efforts of oysters and seagrass.

VCR's partnership with the Barrier Islands Center has deepened as a result of the APEAL (Network-wide AISL grant) engagement planning process. Their cultural history of the islands and ties in the community merge with our long-term studies to create collaborations and community engagements around the changing coasts and people of the Eastern Shore. We expect to complete the APEAL strategic engagement planning process in early 2025, which will help shape partnership priorities for the VCR.

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

1) Drivers of Long-term Change

1a) 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 and coastal flooding, we will use imagery gathered by the Sentinel II system.

1b) 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) 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; and 2) increase our temporal imagery classifications and synthesize changes over time.

2) Dynamics within Landscape Units

2a) Forest-Marsh

We will implement our new long-term experiment on the forest-marsh transition by girdling trees in November 2024 in seven selected forest plots, which each have an unmanipulated paired control. We will continue the following activities, which were conducted in past years as baseline datasets: 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) measure changes in elevation and soil thickness with 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, and compare hydrological data to ecological data; 7) assess occupancy of small mammals both inside the plots and in the surrounding landscape; and 8) rank the salinity tolerance of mature trees of predominant species of the Virginia maritime forest.

2b) Intertidal

We will continue an analysis of the seasonal cycle of water column dissolved inorganic carbon (DIC) and alkalinity, and will continue to monitor CO_2 exchanges and salt marsh photosynthesis using eddy covariance and solar-induced chlorophyll fluorescence. These data will be supplemented with high-resolution measurements of tidal-driven carbon flows in selected tidal creeks. 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. In the salt marsh, we will continue to measure accretion and root zone processes using SETs. This will be conducted using a suite of hydrodynamic, suspended sediment, and novel sediment deposition instrumentation.

We will continue to develop a hydrodynamic model to quantify wave attenuation over constructed oyster reefs, both under early development and mature oyster growth. The goal is to quantify flow, bed shear stress, and hydrodynamic drag that will impact sediment transport and erosion adjacent to marsh edges. We will also continue to monitor the impacts of constructed oyster reefs on marsh edge erosion rates.

We will continue quantifying the impacts of marsh grass on wave attenuation and sediment deposition along a marsh platform. These data will be used as input to a localized Delft3D model to quantify sediment transport dynamics and link it to carbon burial on the marsh platform. We will deploy wave and flow sensors within the bay adjacent to a marsh edge and quantify turbulence and sediment movement and deposition on the platform using optical backscatter sensors and sediment settlement plates.

2c) Subtidal

We will continue the long-term seagrass restoration experiment (year 24) with analyses of: 1) time-series measurements of seagrass biomass, benthic microalgae, epiphytes, sediment organic matter, carbon and nitrogen stocks, and sediment and water temperatures; 2) temperature relationships with seagrass biomass, carbon stocks, and disease prevalence; and 3) aquatic eddy covariance measurements of seagrass metabolism and its dynamics.

2d) Barrier Island

We will use drone imagery as follows: 1) repeat drone imagery to evaluate changes in shrub expansion into the grassland swale, 2) annual optical and multispectral drone flights and SfM analysis of 2 islands (Hog, Metompkin) to develop vegetation models (NDVI), and 3) complete drone flights at Cobb Island. We will relate our findings to the role of the marsh grass Spartina patens in dune building. 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 digital elevation models 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.

3) Dynamics between Landscape Units

3b) Coupled State-Change Dynamics

We will continue long-term measurements of annual oyster recruitment and size at 12 sites. We will also continue to measure wave height, bed shear stress, and suspended sediment concentrations adjacent to a marsh edge behind constructed oyster reefs and at adjacent sites without reefs to determine impacts on marsh erosion.

3c) Coupling Between Non-Adjacent Systems

We will analyze topographic changes in dune shape and size from drone data over the last 4 years and relate to changes in vegetation along cross-island transects. We will quantify the temporal lag between shrub expansion and dune elevation.

4) Ecological Consequences of State Changes

4a) Carbon Sequestration

We will continue to measure carbon in soil and groundwater in island grass- and shrub-dominated areas, in biomass and soils in the long-term seagrass restoration experiment, and across the marsh-forest boundary. We are continuing our work on carbon 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 carbon budget. We will model the effect of management activities (shoreline stabilization and thin-layer deposition) on carbon sequestration in the coupled marsh-lagoon system.

4b) Consumer Dynamics

In the subtidal, we will collect our 7th year of data on seagrass epifauna, infauna, and fish at 27–50 seagrass sites across the VCR. We will complete analyses of these time series data to understand how seagrass density, hydrodynamics, and sediment conditions influence seagrass biodiversity.

On barrier islands, we will collect our 19th year of spring migrant shorebird data including samples of prey, and complete and publish 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. We will publish analyses of the factors affecting reproduction and survival of American oystercatcher, addressing the influences of predation and flooding and changing island geomorphology and vegetation.

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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Federal Government's License = Acknowledged. (Completed by Porter, John on 05/19/2020) Full text Citation details

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Eon, Rehman S. and Bachmann, Charles M. and Lapszynski, Christopher S. and Tyler, Anna Christina and Goldsmith, Sarah. (2020). Retrieval of Sediment Filling Factor in a Salt Panne from Multi-View Hyperspectral Imagery. *Remote Sensing*. 12 (3) 422. Status = Added in NSF-PAR

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Licenses

Other Conference Presentations / Papers

Other Products

Other Publications

Patent Applications

Technologies or Techniques

Thesis/Dissertations

Walker, Shannon. *Belowground characteristics of dominant coastal dune grasses and potential community-level effects on coastal erosion*. (2020). Virginia Commonwealth University. Acknowledgement of Federal Support = Yes

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Sean Hardison. *Coastal fish dynamics across scales: roles of warming and restoration, and interactions with fisheries*. (2024). University of Virginia. Acknowledgement of Federal Support = Yes

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Sarah Goldsmith. *Decadal Changes in Salt Marsh Succession and Assessing Salt Marsh Vulnerability using High-Resolution Hyperspectral Imagery*. (2019). Rochester Institute of Technology. Acknowledgement of Federal Support = Yes

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Ieva Juska. *Examining Metabolism in Seagrass Meadows: Trends in Respiration and Non-Dissolved Gas Ebullition*. (2022). University of Virginia. Acknowledgement of Federal Support = Yes

Brahmey, E.. *Exploring Spatial and Temporal Differences Between High and Low Frequency Water Quality Data in Coastal Virginia*. (2023). University of Virginia,. Acknowledgement of Federal Support = Yes

Zhang, Xiaohe. *Exploring sediment dynamics in coastal bays by numerical modeling and remote sensing*. (2020). Boston University. Acknowledgement of Federal Support = Yes

Sinclair, Michael N.. *Facilitative and competitive tradeoffs between Morella cerifera seedlings and coastal grasses*. (2019). Virginia Commonwealth University. Acknowledgement of Federal Support = Yes

Heller, E.L.. *Factors affecting Western Atlantic red knots (Calidris canutus rufa) and their prey during spring migration on Virginia's barrier islands*. (2020). Virginia Tech. Acknowledgement of Federal Support = Yes

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Volaric, Martin. *Oxygen Exchange and Hydrodynamics of Tidal Flat Ecosystems Along the Virginia, USA Coast*. (2019). University of Virginia. Acknowledgement of Federal Support = Yes

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Kinsey Tedford. *Restoring and sustaining oyster reefs: drivers of spatial dynamics in oyster populations*. (2023). University of Virginia. Acknowledgement of Federal Support = Yes

Rubin, Emily Victoria. *Salt Marsh Migration into Abandoned Agricultural Fields and the Role of Kosteletzkya pentacarpos in Ecosystem Transition*. (2024). University of Virginia. Acknowledgement of Federal Support = Yes

Qingguang Zhu. *Sediment Connectivity in the Coupled Tidal Flat-Seagrass-Marsh System*. (2022). University of Virginia. Acknowledgement of Federal Support = Yes

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LaRoche, Carly. *Understanding variability and drivers of seawater inorganic carbonate chemistry across temperate nearshore marine systems in the U.S. Mid-Atlantic*. (2024). University of Virginia. Acknowledgement of Federal Support = Yes

Websites or Other Internet Sites
Coastal Education
https://www.coastaleducation.virginia.edu/

Supporting teachers in authentic science education and data literacy Engaging students in scientific thinking and environmental exploration. Informing A resilient community

Virginia Coast Reserve LTER
https://www.vcrlter.virginia.edu

We provide access to data, maps, photographs, documents, publication lists and research descriptions.

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	12
Reidenbach, Matthew	Co PD/PI	1
Wiberg, Patricia	Co PD/PI	1
Bachmann, Charles	Co-Investigator	1
Baird, Cora	Co-Investigator	9
Berg, Peter	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
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

Name	Most Senior Project Role	Nearest Person Month Worked
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
Zhu, Quingguang	Postdoctoral (scholar, fellow or other postdoctoral position)	4
Burkett, Thomas	Technician	12
Doughty, Albert	Technician	12
Goetz, Emily	Technician	6
Gustafson, Gunnar	Technician	3
Hoffman, Sophia	Technician	12
Lee, David	Technician	1
Martinez-Soto, Kayla	Technician	6
Miller, Margot	Technician	1
Atchley, Savannah	Graduate Student (research assistant)	3
Barksdale, Mary	Graduate Student (research assistant)	3
Barnes, Tyler	Graduate Student (research assistant)	3
Brideau, Lauren	Graduate Student (research assistant)	3
Call, Mikayla	Graduate Student (research assistant)	3
Cornish, Michael	Graduate Student (research assistant)	3
Cortese, Luca	Graduate Student (research assistant)	3
Franklin, Benton	Graduate Student (research assistant)	3
Giovanna, Nordio	Graduate Student (research assistant)	3

Name	Most Senior Project Role	Nearest Person Month Worked
Granados, Paola	Graduate Student (research assistant)	3
Granville, Kayleigh	Graduate Student (research assistant)	3
Groff, Luke	Graduate Student (research assistant)	3
Gurevich, Sofia	Graduate Student (research assistant)	3
Harless, Kaitlyn	Graduate Student (research assistant)	3
Hearl, Ryan	Graduate Student (research assistant)	3
Ingram, Brianna	Graduate Student (research assistant)	3
Jobe, Justus	Graduate Student (research assistant)	3
Kadiyala, Ethan	Graduate Student (research assistant)	3
Kerns, Kylor	Graduate Student (research assistant)	3
Lapenta, Kristy	Graduate Student (research assistant)	3
Lapszynski, Chris	Graduate Student (research assistant)	1
LaRoche, Carly	Graduate Student (research assistant)	3
Leff, Riley	Graduate Student (research assistant)	3
Long, Edward	Graduate Student (research assistant)	3
Martinez, Juan	Graduate Student (research assistant)	3
Mast, Hannah	Graduate Student (research assistant)	3
Messershmidt, Tyler	Graduate Student (research assistant)	3
Molino, Grace	Graduate Student (research assistant)	3
Noori, Amirhossein	Graduate Student (research assistant)	3
Nur, Nayma	Graduate Student (research assistant)	3
O'Donnell, Kelsey	Graduate Student (research assistant)	2
Ortiz-Miller, Isabellla	Graduate Student (research assistant)	3
Oxley, Chris	Graduate Student (research assistant)	3

Name	Most Senior Project Role	Nearest Person Month Worked
Pant, Manisha	Graduate Student (research assistant)	3
Rafael Palacios Gonzalez, Jordi	Graduate Student (research assistant)	3
Riffe, Emily	Graduate Student (research assistant)	3
Sabo, Alex	Graduate Student (research assistant)	3
Say, Caitlin	Graduate Student (research assistant)	3
Sciolino, Anne	Graduate Student (research assistant)	3
Smith, Alex	Graduate Student (research assistant)	3
Tedford, Kinsey	Graduate Student (research assistant)	3
White, Drew	Graduate Student (research assistant)	3
Yates, Griffin	Graduate Student (research assistant)	3
Yiyang, Xu	Graduate Student (research assistant)	3
Hoffman, Leo	Research Experience for Undergraduates (REU) Participant	3
Hunsinger, Jennifer	Research Experience for Undergraduates (REU) Participant	3
Pline, Katherine	Research Experience for Undergraduates (REU) Participant	3
Rippon, Kaedon	Research Experience for Undergraduates (REU) Participant	3
Fauber, Donna	Other	3

Full details of individuals who have worked on the project:

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

Contribution to the Project: Lead Investigator, 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: Wetland research

Funding Support: NSF

Change in active other support: No

International Collaboration: No
International Travel: No

John H Porter
Email: jhp7e@virginia.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 12

Contribution to the Project: Information manager, sensor systems, small-mammal populations

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: Studies of oyster dynamics

Funding Support: NSF

Change in active other support: No

International Collaboration: No
International Travel: No

Patricia L Wiberg
Email: pw3c@virginia.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Studies of sediment dynamics in the coastal environment

Funding Support: NSF UVA

Change in active other support: Yes

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: 9

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

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

Quingguang Zhu
Email: qz3cp@virginia.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 4

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: 12

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: 6

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: 1

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: 3

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: 3

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: 3

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Lauren Brideau
Email: ysd4wx@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

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: 3

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: 3

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: 3

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: 3

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: 3

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

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: 3

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: 3

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: 3

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: 3

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

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: 3

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Ryan Hearl
Email: hearlrm@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

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

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: 3

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: 3

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

Funding Support: NSF, GRF

International Collaboration: No
International Travel: No

Ethan Kadiyala
Email: qkz8dd@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Working with PI Castorani on ecological synchrony

Funding Support: UVA

International Collaboration: No
International Travel: No

Kylor Kerns
Email: kk2kq@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

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: 3

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: 1

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: 3

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: 3

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: 3

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: 3

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: 3

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: 3

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

Funding Support: NSF, VIMS

International Collaboration: No
International Travel: No

Grace Molino
Email: gdmolino@vims.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

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: 3

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: 3

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

Funding Support: RIT

International Collaboration: No
International Travel: No

Kelsey O'Donnell
Email: qnp5rg@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 2

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

Funding Support: NSF, UVA

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: 3

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Chris Oxley
Email: ewc5gu@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Working with PI Castorani on ecological synchrony

Funding Support: UVA

International Collaboration: No
International Travel: No

Manisha Pant
Email: mpant@vims.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

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: 3

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: 3

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: 3

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: 3

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: 3

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: 3

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

Funding Support: 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: 3

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

Drew White
Email: aewhite@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

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: 3

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: 3

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

Funding Support: USGS, Chinese Scholarship

International Collaboration: Yes, China
International Travel: No

Leo Hoffman
Email: leoh25@vt.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Worked with PI Karpanty on shorebird 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: 2024

Jennifer Hunsinger
Email: kjn5cz@virginia.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Worked with PI Gedan on forest transition study

Funding Support: NSF

International Collaboration: No
International Travel: No
Year of schooling completed: Junior
Home Institution: University of Virginia
Government fiscal year(s) was this REU participant supported: 2024

Katherine Pline
Email: plinek@vcu.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

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

Funding Support: NSF

International Collaboration: No
International Travel: No
Year of schooling completed: Junior

Home Institution: Virginia Commonwealth University
Government fiscal year(s) was this REU participant supported: 2024

Kaedon Rippon
Email: npz6cj@virginia.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Worked with PI Gedan on forest transition study

Funding Support: NSF

International Collaboration: No
International Travel: No
Year of schooling completed: Junior
Home Institution: University of Virginia
Government fiscal year(s) was this REU participant supported: 2024

Donna Fauber
Email: dhf4k@Virginia.EDU
Most Senior Project Role: Other
Nearest Person Month Worked: 3

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

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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

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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

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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

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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

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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 advanced theory in understanding complex state-change dynamics in ecosystems dominated by foundation species. The VCR is the most extensive stretch of undisturbed coastal barriers along the U.S. East Coast, and an ideal model for assessing climate impacts and ecosystem state change in shallow coastal regions.

Our research focuses on barrier islands, maritime forests, salt marshes, and shallow coastal bays (supporting seagrass meadows and oyster reefs) 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 allow 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.

Our work contributes substantially to understanding ecological and physical processes and feedbacks that either maintain ecosystem states or facilitate transitions among states, and has identified early 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 influences general knowledge in restoration ecology.

The VCR provides a unique opportunity to address how connectivity among ecological systems on the landscape affects state change. Our work has shown that state change dynamics among adjacent systems are coupled, where state in one system can propagate to the other. Cross-scale interactions involving sediment and organism transport affect the rate and pattern of state change and its ecological consequences (e.g., carbon sequestration). 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.

Subtidal Ecosystems:

Seagrass that once carpeted large areas of the VCR seafloor and supported a thriving economy based on natural resources became locally extinct in the early 1930s due to disease and a hurricane, causing a catastrophic shift to an unvegetated state. Informed by VCR science, >40 km2 of seagrass was restored—the largest seagrass restoration in the world. This 23-yr landscape-scale experiment has shown that within a decade ecosystem services are reinstated: primary productivity, carbon and nitrogen sequestration, water-column clarity, sediment stabilization, and biodiversity. VCR scientists were the first to show how seagrass restoration reinstates ‘blue’ carbon storage 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. New data on 210Pb and 14C dating, sediment organic matter and carbon content, and stable isotopic and DNA analysis of sediments revealed that buried seagrass carbon is preserved for more than a century. Ocean warming and marine heatwaves that are occurring more frequently harm seagrass meadows by decreasing productivity and intensifying disease prevalence. Seagrass decline leads to the loss of some of this ‘legacy’ carbon stock. Understanding how seagrass restoration and marine heatwaves affect ecologically and economically valuable fishes has implications for recreational and commercial fishing communities that directly or indirectly rely on these species for their livelihoods or food security. For instance, we have shown that seagrass restoration greatly boosts the number of juvenile fish that use this habitat as a critical ‘nursery’.

VCR studies of oyster-reef restoration address key gaps in restoration ecology. We have quantified the recovery timelines for restored reefs and their ecosystem services, and the factors mediating restoration success. This evidence supports the value of continued restoration efforts by demonstrating functional equivalence of restored and natural reefs within a decade. Our oyster habitat suitability models guide restoration practitioners in where and how to restore reefs. VCR scientists wrote a policy brief to NOAA about the value of long-term monitoring and appropriate design for oyster restoration based on our research. Additionally, our work has shown how oyster restoration can be used as a nature-based solution to combat marsh erosion. We developed methods to quantify marsh edge morphology using airborne LiDAR data and validated these methods with in-situ observations. Long-term oyster restoration experiments compare the morphology and retreat at paired reef-lined and unprotected marsh edges.

Intertidal Ecosystems:

Tidal wetlands exist in the narrow band of elevation affected by tides; their distribution is fundamentally defined by the limits of the sea and is 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. We use elevation measurements and models 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 Isand Ecosystems:

Barrier island plants and shorebirds and their invertebrate prey communities serve as sentinels to climate change. The VCR is a habitat for both migratory and resident shorebirds. Habitat classification studies and documented changes in island geomorphology explain shifts in nesting and reproductive success. This is critical to understanding of how imperiled shorebirds respond to climate- and storm-driven changes and inform planning and management decisions by Virginia Department of Wildlife Resources, USFWS, and TNC.

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 on island 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 have shown how vegetation affects dune morphology and 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. For example, 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 of sediments and carbon between seagrass meadows and adjacent tidal marshes.

VCR research has leveraged recent support from NSF to establish a Critical Zone Observatory (CZO) 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 NSF Coastlines and People (CoPe) Focused Hubs, one starting in 2021 and one in 2022. Both CoPe Hubs leverage VCR research to address climate equity issues on the coast, building on VCR research on nature-based solutions for shoreline protection, storm surge, sea-level rise and saltwater intrusion.

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 to continue to develop a robust environmental arts-humanities program at the VCR LTER. These collaborations 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 44 graduate students, 4 undergraduate students and 2 post-docs conducted research through the program. 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, affiliated researcher, and PI in the next funding cycle of VCR LTER) 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. The VCR also supports lifelong learning by contributing to certification for the regional Master Naturalists and the Virginia Association of Environmental Educators.

VCR joined four other LTER sites to pilot an Ecosystem Pen Pals program. All 5th grade students at Occohannock Elementary School corresponded with students near LTER sites across the country during a cross-curricular series of lessons that blended language arts and science. The program is now expanding.

A VCR PhD student worked with a local school teacher to develop lesson plans for K-12 education. This work was published in Limnology and Oceanography Bulletin (Granville et al. 2024).

We continue to build collaborations with Eastern Shore Community College (ESCC) science department, with specific focus on: 1) developing place-based labs for science classes, and 2) supporting research experiences toward newly implemented capstone requirements. Two ESCC students completed research projects with VCR in summer 2024, and a VCR grad is collaborating with ESCC science faculty Foxworthy to evaluate and refine student and mentor experiences during capstone research projects.
We also interact with the art community to link science and art. During the local Earth Day Festival, VCR staff helped visitors plot SLR during their lives to create a community graph of rising sea levels, while middle school art students created a mural of water issues on the Shore that they discovered by interviewing family members. The mural became part of a public art show and continues to circulate at local events.

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.

Berg has pioneered the approach of underwater eddy covariance 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.

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 uses 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.

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 these 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 344 online datasets with an aggregate volume of approximately 510 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 11/01/2023 to 10/31/2024, VCR LTER data files have been downloaded 11,531 times via the Environmental Data Initiative Data Portal. An additional 6,365 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 2,364 times in the past year (excluding robots), with code generated for R (49%), Python (9%), Matlab (16%), SPSS (12%), and SAS (14%).

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).

Development of the aquatic eddy covariance technique by PI Berg has led to numerous national and international collaborations, including Portugal, Spain, England and New Zealand. Berg was awarded the American Geophysical Union Reeburgh Lectureship in 2024, presented annually and recognizing a scientist making significant contributions to the fields of global biogeochemistry and marine geochemistry through novel measurements.

What is the impact on society beyond science and technology?

Nearly half the world's population lives on the coast and even more depend on coastal resources. Long-term ecological studies are essential to understanding how and why these ecosystems are changing, how to mitigate such changes, and the likely effects on the well-being of coastal residents and economies. Our research is developing a predictive understanding of coastal change in response to climate drivers, including sea-level rise, warming air and water temperatures, and changes in the frequency and magnitude of storms and rainfall. The vast and undeveloped VCR landscape is ideally suited for long-term research to understand changes in ecosystems and their functions that benefit society (e.g., protecting shorelines, producing seafood, sequestering carbon, promoting biodiversity, providing wildlife habitat). Integrating long-term observations, experiments, and models to predict future conditions, VCR LTER research will transform knowledge on coastal dynamics in a changing climate from local to landscape scales. Our findings advance broad ecological theory while improving coastal management through globally relevant science and lasting partnerships with regional practitioners. Workforce training and community engagement are priorities of the program. Activities integrate research with postdoc and graduate-student mentorship, undergraduate training, professional development for educators at rural K-12 schools, research internships for community college students, and public outreach through science-art collaborations and citizen science.

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.