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Accomplishments

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

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

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

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

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

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

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

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

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

Major Activities: **Drivers of Long-term Change**

Climate Drivers: Long-term data and analyses include 1) meteorological stations, tide and water temperature stations, groundwater wells; 2) a 40-yr record on trends and extremes in water temperature and marine heat waves; and 3) a 12-yr record of storm surge events, which we are extending to 40 yr.

Patterns of Change: Long-term data and experiments detect patterns of change include 1) satellite imagery, aerial photos, LiDAR, drone imagery, GIS layers, and structure-from-motion (SfM) technology to determine landscape change on islands, wetlands and oyster reefs; 2) classified 2020 Landsat imagery data for barrier islands; 3) continued experiments on seagrass and oyster reef restoration, marsh transgression, and island grass-shrub transitions; 4) continued water quality monitoring, with water clarity measurements via satellite; 5) continued monitoring of shorebird and prey distributions and abundances on barrier islands; 6) surveys of plant distributions; and 7) bathymetric measurements to quantify 20-yr patterns of change in lagoon depth.

Dynamics within Landscape Units

Upland: The long-term experiment to test the mechanisms underlying the forest-marsh in response to sea-level rise (SLR) and storms includes monitoring tree water use and mortality, shrub growth, non-woody vegetation cover, litterfall, groundwater, soil moisture, nutrients, salinity, light availability, canopy cover and invertebrate community structure/diet across an elevation gradient. Half the plots will be disturbed in yr 5.

Intertidal: Measurements of solar-induced chlorophyll fluorescence and canopy reflectance at our marsh eddy covariance tower estimate the primary productivity and scale up to the landscape scale with remote sensing. For oyster reefs, we added elevation measurements to a hydrodynamic model linking flow and biogeochemical processes, and validated a physical model of oyster habitat suitability previously developed at VCR. Drone-based topographic measurements of 4 marshes are being coupled with bathymetric measurements to map the marsh-flat transition and its change in time.

Subtidal: For seagrass, we continued our long-term restoration/resilience experiment (20 yr) and aquatic eddy covariance measurements of metabolism (14 yr), continued a new experiment to test seagrass response to disturbance in 2 sites that varied in heat stress, and added measurements of CO_2, CH_4, N_2O fluxes. For the lagoon system, we 1) used new, high-resolution bathymetric measurements to quantify changes over a 20-yr time period and seasonal/inter-annual changes in depth in seagrass meadows; 2) estimated water column DIC inventory and measured seasonal cycle of DIC and alkalinity; and 3) quantified effects of seagrass on hydrodynamics, sediment transport, and bivalve larval settlement using flow, optical backscatter sensors and sediment traps.

Barrier Island: We studied grasslands-shrub transitions through 1) new monitoring of vegetation, microclimate, and soil characteristics in three swales that differ in dune elevation; and 2) continued monitoring grass-shrub ecotone for microclimate, water table, and vegetation composition; and examining drivers of shrub productivity. To explore the feedbacks between plants and geomorphology, we established a dune grass planting experiment and transects for long-term monitoring of dune grass species composition and topographic evolution, and continued our annual time series of multispectral and high-resolution optical drone surveys to characterize island vegetation and dune morphological change.

Dynamics Between Landscape Units

Transport of Sediment and Dissolved Constituents: We used the Delft3D model to evaluate exchange (e.g., nutrients) between the lagoon and ocean and assessed the influence of tidal amplitude, winds and tidal cycle on flushing time.

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

attenuation, sediment deposition and marsh erosion for oyster reefs of two different substrate types.

Oyster Larval Transport and Population Dynamics: We measured recruitment and elevation at 14 sites over 250 km2, related elevation and other physical factors to seasonal oyster recruitment and adult density, and used a caging experiment to determine how depth and predators affect oyster recruitment, growth and survival.

Seagrass–Marsh Coupling: We are determining how seagrass restoration affects carbon (C) accumulation in adjacent salt marshes using stable isotopes, biomarkers, and 210Pb dating. With the Delft3D model, we are investigating coupling between sediment dynamics in seagrass meadows and marshes and their impact on erosion and deposition rates.

Barrier Island Ecosystem Coupling: On cross-island transects we measured plant cover, productivity, soil characteristics, and elevation, and characterized vegetation and topography using optical and multispectral drone imagery and SfM at 40–50 ha scales. We added a new shrub planting experiment to test if dune height affects shrub establishment, and used LiDAR to relate changes in dune height and shrub distribution. We used our new geomorphological-ecological model based on VCR data of barrier island and shrub coevolution (including SLR, storms, shrub changes) to understand how shrubs influence long-term island dynamics.

Cascading Effects: Building on the existing forest-marsh-bay model from the previous funding cycle and Barrier 3D developed recently we developed a new model framework —Barrier BMFT—that connects the entire coastal landscape from the shoreface to the mainland forest. To explore the potential for cascading state changes, we ran model experiments in which state changes occur and tracked impacts on the morphology of adjacent and non-adjacent ecosystems.

Ecological Consequences of State Changes

Carbon Sequestration:

We continue to monitor C stocks in the mainland uplands, lagoons and barrier islands. We synthesized C stocks and accumulation rates across each of these ecosystems to establish a landscape-scale C budget, and are using our barrier island model to estimate C released by island migration under different SLR scenarios.

Consumer Dynamics:

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

In the intertidal, we 1) continued tracking upland movement of grazing bands created by purple marsh crabs and conducted experiments to test potential drivers; 2) assessed if restored oyster reefs match population, community, and ecosystem functions of natural reefs, using a 15-yr time series of 77 restored and natural reefs; and 3) used meta-analyses to synthesize restoration success and how ecosystem services (oyster production, habitat provisioning, and biodiversity) compare among restored, natural, and degraded oyster reefs, and to quantify how they are mediated by predators and physical conditions.

In the subtidal, we 1) continued the time series of seagrass epifauna, infauna, and fish; 2) assessed how seagrass restoration affects fish abundance and diversity; and 3) determined experimentally how food availability and predators control hard clam growth and survival.

Specific Objectives:

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

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

Our specific objectives for this theme are:

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

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

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

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

We identify and test mechanisms that can lead to state change (linear, threshold, regime shift). Long- and short-term data are used to parameterize, test, and evaluate mechanistic models. Natural disburbance events (high temperatures and storms) provide valuable opportunities to test conceptual and theoretical models of state change and resilience in the context of climate-related forcing.

Our specific objectives for this theme are:

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

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

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

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

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

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

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

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

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

Our specific objectives for this theme are:

Transport:

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

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

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

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

Coupled dynamics:

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

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

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

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

nonadjacent ecosystems.

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

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

Our specific objectives for this theme are:

Carbon cycling and sequestration:

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

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

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

Consumer responses:

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

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

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

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

Significant Results:

Drivers of Long-term Change

- Long-term data show a significant increase in daily water temperature and frequency of marine heatwaves, and forecast changes to 2100 show an increase in days with average temperature >28°C.

Dynamics within Landscape Units

Upland–Marsh

- Hydrological variables responsible for the forest-marsh vegetation gradient and seasonal patterns are soil water content and groundwater electrical conductivity.
- Shrub basal area doubled in 3 yr, but not in direct response to changes in salinity or light availability or to invasive reed grass distribution.

- Modeling of future marsh migration into coastal forests under sea level rise (SLR) scenarios showed that state change is limited more by slope than by anthropogenic barriers.

Intertidal

- Oyster reefs occur in a narrow elevation range (-0.68 to -0.05 m MSL), with a mean vertical relief of 0.14 m, and occupy 12% of suitable area.
- Evaluation of our oyster habitat suitability model with 14 yr of data showed that predicted suitable habitats yielded 1.5x greater oyster biomass.
- Oyster survival and recruitment are structured by predators, with effects stronger on large oysters.
- Oyster restoration increases in oyster abundance, infauna, and organic matter, and restoration is more successful in subtidal polyhaline environments with large tidal ranges.
- Reefs constructed at high elevations (near mean-water level) were more effective at attenuating waves and fostering oyster growth. Oysters atop high elevation reefs were twice as dense and 20% larger than those on low-elevation designs; reef width had a minimal effect on density.
- We discovered blue crabs, *Callinectes sapidus*, ambushing juvenile fiddler crabs and purple-marsh crabs at low tide in marshes. Blue crabs successfully ambushed fiddler crabs 33% of the time.

Subtidal

- Seagrass were resilient to a marine heatwave, with recovery within 2-4 yr; landscape position modulates heat stress.
- Seagrass recovered by 40-50% following experimental removal, but not as expected related to temperature stress, indicating that recovery may also be affected by storms.
- On meadow edges, flow velocities were reduced 30-75% within 1 m, and bivalve recruitment increased. No differences in wave activity and sediment suspension were observed within 5 m of edges.
- 20-yr differences in bathymetry indicate strong spatial patterning that is associated with the deep tidal channel running through the bay.
- 210Pb dating revealed a long-term (1860-present) average sedimentation rate of 0.54 cm/yr similar to modern (20-yr) rates.
- Modeling of long-term in situ aquatic eddy covariance measurements of seagrass metabolism showed a temperature stress threshold for *Zostera marina* ~28.6 oC.
- Summer-long bubble trap measurements over dense seagrass meadows showed that oxygen ebullition (bubbles) represents an insignificant part of photosynthetic production.

Barrier Island

- Dune grasses grow at different rates, vertically and laterally, and affect sediment accumulation.
- Dune formation (hummock vs. ridge) affects plant community composition of adjacent swales, productivity and shrub survival.
- Shrub edge increased 233% in 27 yr resulting in a moderated microclimate that enhances grassland biomass and cover. Shrub age and hydrological variables are important drivers of shrub productivity.
- Dunes grow lower and wider when marsh wrack containing propagules is present, and high-marsh grass speeds up dune-building process by enhancing deposition so dune grasses can become established sooner.

Dynamics between Landscape Units

Sediment Transport

- Delft3D model runs show that typical storm surges can double tidal sediment fluxes to marshes and a large storm surge event can deliver more than the average annual total flux.
- Marsh loss reduces sediment stock and compromises marsh resilience because sediment deposition on the marsh platform decreases exponentially with marsh erosion.
- Seagrass meadows alter the timing of sediment transport to marshes and reduce annual flux by 12%, reflecting the effects of both low fluxes when seagrass densities are high in summer and high fluxes when densities are low in winter.

Exchange of Dissolved Constituents

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

Oyster Larval Transport and Population Dynamics

- Survival is determined by oyster life stage, landscape positionnand depth.
- Recruitment showed unimodal relationships with elevation, fetch, and water residence times, and was greater on high-elevation reefs.
- Predation was highest on juvenile oysters, and on adult oysters in the back-bay site and subtidal front-bay site.

Coupled State Change Dynamics

- Islands with higher dune elevations tend to remain high, while islands with lower initial elevations tend to remain low, resulting in most shrub expansion on higher islands. Islands with shrubs are narrower, migrate landward more slowly, are more likely to migrate landward in a discontinuous manner, and are more vulnerable to drowning. Shrubs expand more slowly on islands experiencing greater dune erosion and overwash disturbance.
- Landward island migration is the main cause of back-barrier marsh loss, and periods of island stability can allow for recovery. Bay extent is largely insensitive to SLR because increased island migration (bay narrowing) offsets increased marsh edge erosion (bay widening).

Ecological Consequences of State Changes

Carbon Sequestration

- A landscape-scale carbon (C) budget for the VCR showed that losses and gains for individual ecosystems largely offset each other, resulting in relatively stable total ecosystem areas, and a 3% (46.1 Gg C) loss in regional C storage since 1996. A metric of C replacement times show it will take only ~2 years of C accumulation in surviving ecosystems to replace this loss, suggesting that compensatory mechanisms act quickly at the landscape scale.

Consumer Dynamics

Islands

- Migrant shorebird distribution and abundance are driven by abundance of 3 prey (coquina clams, blue mussel spat, crustaceans) which vary based on the distribution of sandy ocean intertidal zone, peat bank habitats, and vegetation-free overwash created by storms.
- Predation by Atlantic ghost crabs, Peregrine falcons and owls is impacting survival of pre-fledgling shorebirds.

Intertidal

- Restored oyster reefs can match natural reefs and improve ecological function: 1) oyster abundance and their consumers are equivalent within 6 yr; 2) population stability increases with oyster biomass and reef maturity; 3) juvenile and adult

oysters, fishes, crabs, and shrimp are more abundant; 4) nekton abundance and richness increase as restored reefs age; and 5) reefs increase nitrogen cycling, organic matter, and shoreline protection.
- Salt marsh taxa migrate into the mainland forests with SLR. Invertebrate community structure in the ghost-forest was equivalent to the marsh, with similar species composition, though some had a larger trophic niche in the forest consuming both marsh and terrestrial carbon.
- Grazing fronts of the purple-marsh crab (*Sesarma*) moved at a rate of 1 m/y and lowered the marsh by 10 cm. Predation pressure and plant traits are likely the two main drivers. Predators like blue crabs are likely 'chasing' *Sesarma* to higher ground where grass is more nutritious. As the front moves upland, grass regrows and the marsh to persists.

Subtidal

- Despite high among-year variation in fish abundance and species composition, seine catches in restored seagrass meadows were consistently more numerous (6.4×) and speciose (2.6×) than adjacent unvegetated areas.
- Longer water residence times indirectly reduced fish catches and species richness, but fish community structure was consistent between two meadows that varied by depth and proximity to ocean inlets.
- Food availability to clams is greater inside seagrass meadows enhancing clam growth.

Key outcomes or Other achievements:

VCR scientists have published 137 journal articles and 24 theses or dissertations through the fourth year of this funding cycle. A complete list of publications can be found at https://www.vcrlter.virginia.edu/home2/?page_id=215.

Theme 1: Drivers of Long-term Change

Climate Drivers of Change

Daily average water temperature in the VCR bays has increased over the last 40 years (0.24 +- 0.04 °C/decade), as have the number of marine heatwaves (MHWs; increase ~1 MHW/decade). Forecasts to year 2100 show a dramatic increase in days with average water temperatures >28°C in the coastal ocean (from 0 prior to 2000 to average of 34 in 2100) and a doubling of days > 28°C in the coastal bays (32 prior to 2000 to 70 in 2100).

Patterns of Change

There has been a 19% net loss of barrier islands over the last ~30 yr (1984-2016); highest loss (indicating island migration) was between 2011-2016. Increasing rates of landward barrier island migration are influenced by dune elevation and interior island vegetative cover. Winter warming has resulted in 41% increase in woody vegetation in protected, low elevation areas. Analysis of bathymetric change in seagrass meadows over the last 20 yr suggest that sediment deposition rates have generally been comparable to rates of sea-level rise.

Theme 2: Dynamics within Landscape Units

Forest-Marsh

The dominant high marsh grass, *Spartina patens*, fails to flower in the low-light area of the forest transition; growth in this zone is due to recruitment by seeds dispersed from outside the zone and clonal expansion. Understory shrubs are responding to forest dieback and increasing in number and importance. The saltmarsh amphipod, *Orchestia grillus*, is a key invertebrate indicating marsh migration into the forest, and is found ahead of major loss of the canopy or trees.

Subtidal

Our landscape-level restoration seagrass experiment, now in its 21st year, shows that key ecosystem services, including primary productivity, carbon sequestration, nitrogen removal, sediment stabilization, habitat provisioning, and enhanced biodiversity are reinstated within a decade. We also found that the seagrass meadows are resilient to marine heatwaves, with plant biomass recovering within 2-4 yr, although lost sediment carbon lags behind. In situ metabolism data do not support the notion that seagrasses will be winners in future oceans with elevated CO2 concentrations and more frequent temperature extremes. Analysis of deep sediment cores revealed large amounts of blue carbon buried in the LTER system that date back to at least the 1700s.

Barrier Island

Cold temperatures limit shrub survival of both seedlings and adults and grasses provide insulation to shrub seedlings. Self-reinforcing microclimatic temperature modification by shrubs is evident at multiple life stages, even before coalescence into full shrub thickets, especially during summer months. Shrubs enhance grassland cover at the edge, but reduce diversity and alter soil characteristics.

Theme 3: Dynamics between Landscape Units

Sediment Transport

Our meta-analysis study of coastal bays highlights that restoration interventions should target coastal erosion before the vegetated surface becomes too small compared to the basin area, and that ecosystem responses to changes in habitat size are non-linear.

Coupled State Change Dynamics

Subtidal - Intertidal Coupling

Oysters currently occupy 12% of the suitable intertidal area in the VCR, suggesting that there is ample intertidal area for future restoration that will impact both biodiversity and marsh erosion. Oyster patches in the VCR are small, with the 50th percentiles for area and perimeter being 11.6 m2 and 14.5 m, respectively. Reef crests occur in a narrow range of elevation (-0.68 to -0.05 m MSL), with a mean vertical relief of 0.14 m. Multi-year oyster recruitment data suggest that larvae are not generally limiting and new restoration by TNC will continue to benefit the metapopulation. Oyster restoration have shown reef elevation to be critical, with oyster densities and reef success increasing as elevations approach sea level at the top of the reef. These reefs are also more effective at attenuating wave energy than lower elevation reefs.

Barrier Island Ecosystem Coupling

The new barrier island model, Barrier 3D, and Barrier 3D with shrubs, has been contributed to the Community Surface Dynamics Modeling System repository and GitHub where other researchers can access and use it, and it is the only barrier island evolution model that currently includes explicit treatment of dune dynamics. Dune elevation and shape are critical in structuring adjacent, plant species composition, functional trait composition, and annual net primary productivity in adjacent low-elevation swales.

Cascading Effects and Coupling Between Non-adjacent and Adjacent Systems

Blue crabs are dominant mesopredators within mid-Atlantic and Gulf estuaries, where they act as a critical link in moving productivity from the benthos to pelagic fishes. Our results from sampling blue crabs across the restored seagrass meadows indicates that seascape habitat connectivity is as important as local seagrass conditions for blue crab

distributions. Oyster reefs create a ‘halo’ of increased infaunal communities to a distance of ~40 m surrounding reef areas. Enhanced infaunal communities occur within 3 years from construction of oyster restoration reefs.

Theme 4: Ecological Consequences of State Changes

Carbon Sequestration

Our landscape carbon analysis indicates that rapid losses and gains within individual ecosystems largely offset each other, resulting in relatively stable total ecosystem areas, and that it will take only ~2 years of carbon accumulation in surviving ecosystems to compensate for this loss, suggesting that compensatory mechanisms act quickly at the scale of landforms. Across the landscape, aboveground biomass has increased since 1984 because enhanced forest growth associated with a warmer and wetter climate has compensated for sea-level driven losses in wetlands and barrier islands.

Consumer Dynamics

Barrier islands: Monitoring of shorebirds and their prey reveals responses to climate drivers. Piping plovers (ground-nesting shorebird) have population irruptions following storm-driven habitat creation. Red knot abundances, an imperiled long-distance migrant, have not changed significantly since 2007. Migrant shorebirds select two types of bivalve prey: blue mussels on exposed peat banks on eroding islands have decreased suggesting temperature-driven northward retreat; coquina clams on sandy beaches of stable islands show no directional change. Predation by Atlantic ghost crabs, Peregrine falcons and owls is now impacting survival of pre-fledgling shorebirds.

Intertidal: Experimental restoration of oyster reefs shows that rebuilding these lost habitats can recover oyster production, habitat provisioning, and ecosystem stability in approximately 6 yr. Our meta-analyses of oyster restoration along US Gulf and Atlantic coasts show that our restoration results extend beyond the VCR. Together these studies support the continued and expanded use of oyster restoration to enhance ecosystem services and match functions provided by natural reefs. Our discovery of blue crab ambushing juvenile fiddler crabs and purple-marsh crabs at low tide has implications for salt marshes as nursery habitats for a commercially important species and for the movement of energy between habitats as blue crabs move among seagrasses, salt marshes and the broader estuary.

Subtidal: Restoration of seagrass meadows increases fish abundance by 6.4x and biodiversity by 2.4x, despite annual variability. These benefits may be dampened by ocean warming and sea level rise. While seagrass restoration yields large and consistent benefits for coastal fishes, consideration of landscape-scale environmental variability in the siting of habitat restoration will improve restoration outcomes and the subsequent provisioning of ecosystem services.

*** 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 48 graduate students, 3 post-docs and 15 undergraduate students conducted research through the program. The inter- and multi-disciplinary nature of the research teaches the students how to operate in a collaborative environment.

In 2020, we piloted a short course in Fundamentals of Learning for Science Mentors to better prepare grads to mentor REUs, RETs, and others. This course was offered again in 2021 and 2022 to VCR grads and early career scientists from five VCR institutions. Those trained in the course became RET project mentors (2021) and REU mentors (2021 and 2022) through our tiered mentorship structure. Mentors reported feeling more prepared and better able to meet their mentees needs using

approaches from the course. Based on needs identified among our scientists, we also provided internal workshops on science communication and career development (networking, CVs/resumes, finding job opportunities).

In a climate and culture assessment of VCR scientists, students, and alumni, we found that few people ever report incidents and that more than half of VCR contributors are unsure how to report. To address this, we developed and implemented a field-focused VCR Code of Conduct, including reporting guidance applicable across institutions. All VCR research staff and most UVA-based PIs, post-docs, and grads completed bystander intervention training with ADVANCEGeo. This training will be offered to all members of the VCR community (new staff, PIs, post-docs, grad students, and research techs) in February 2023, regardless of their home institution. REU orientation was expanded to include bystander intervention training and exploration of the Code of Conduct. To help foster an inclusive field environment for all research teams and to prepare them for the unique challenges posed by conducting research in the field and out of a remote field station, we added a safety planning tool to our Code of Conduct. Based on a template provided by the field station staff — where emergency response information, common environmental hazards, security information, physical/mental demands, and the environmental limits for conducting safe fieldwork are communicated — individual research teams may further complete the document with the challenges most appropriate to their own research. In 2021, to better support incoming scientists, we also worked with ESA SEEDS, the LTER Network, and OBFS to conceptualize and create a 'site trailer' to orient new visitors, especially REUs, and to clarify expectations of the experience of living and working at the Coastal Research Center. Our trailer has received 414 views and sparked many new conversations. REUs in particular have reported feeling better prepared for living at the field station and conducting fieldwork in new environments. We shared the trailer concept with other sites through workshops with UFERN and LTER LNO.

*** 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 10,480 page views in 6,600 sessions by 4,400 distinct users. During that same period, VCR/LTER data files were downloaded 3,402 times from the Environmental Data Initiative portal and 7,717 times from the VCR/LTER data portal from Oct. 1, 2021 to Sep. 30, 2022.

Media and Public Presentations

PI Johnson shards the discovery of blue crabs ambushing fiddler crabs in VCR salt marshes with *Chesapeake Bay Magazine*. *https://chesapeakebaymagazine.com/video-va-blue-crabs-attack-from-land-first-time-recorded-by-scientists/*

In March 2022, a staged reading of Rollover, a play by PI Moore was produced by the UNC Process Series. Although developed coastlines are the focus of this science-art endeavor, VCR science has informed its development and the scientific content that comes through.

PI McGlathery shared insights on blue carbon sequestration in seagrass meadows in Roundtable on "Elevating the Science of Blue Carbon in Federal Decision Making" in Washington, D.C. organized by COMPASS and Restore America's Estuaries. The roundtable was attended by Congressional staffers.

The VCR seagrass restoration work was highlighted in French media outlet "Made in Perpignan."

In March 2022 PI Fagherazzi presented some of the VCR results to a BOEM/ Argonne Webinar titled "Effects of Sea Level Rise on Shoreline Degradation and Erosion"

Virtual and Distributed Platforms

Our virtual Ghosts of the Coast (https://www.coastaleducation.virginia.edu/wp/?page_id=1389) collaboration between artists and scientists continued to share the process of ghost forest formation with new audiences.

Two VCR graduate students (Wittingham and Tedford) developed repeat-photography camera stations for the public to use to contribute to ongoing visual time series of coastal change. This passive outreach tool has received dozens of contributions. Using Chronolog (https://www.chronolog.io/) repeat photography stations, the project documents coastal landscape change over time (https://www.chronolog.io/project/VCR). To date, 436 photos have been collected across the five different stations. One REU student (mentored by Tedford) created a workflow for downloading, storing, and extracting data from the time lapse photos. These photos were also made available on the VCR website to be used for future research or outreach projects. Beyond engaging the public, the project is designed to allow remote field observation and data collection by K-12 classes. We

are also partnering with managers of local natural areas to use the landscape timelapses to increase the accessibility of natural area observations for those unable to reach remote coastal access points in our county.

Partnerships

We continue to build a new partnership with the Biology Department of Eastern Shore Community College b labs to link VCR research and local ecosystems to student investigations.

Informal education partnerships with S&WCD, Eastern Shore Land Trust, and TNC have continued via #DiscoverEE, timelapse citizen science, and others. We also launched new collaborations with UVA's Equity Center to begin co-produced climate equity maps informed by Eastern Shore community needs. We also participated in a public outreach program with TNC to highlight our ongoing oyster restoration projects near Wachapreague, VA.

We continue to contribute to the local Climate Adaptation Working Group, which advises and supports the community on resilience issues, and to work with The Nature Conservancy to provide a scientific basis for some of their land management decisions.

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

Theme 1: Drivers of Long-term Change

Climate Drivers: We will continue our analysis of historical temperature records, marine heatwaves and their effects on seagrass and associated fauna, with a focus on spatial patterns of heating. To improve the accuracy of our predictive modeling of coastal water clarity, we will use imagery gathered by the Sentinel II system. We are working to extend our 12-y record of storm surge events to 40 years and to quantify spatial variations in storm-surge-driven flooding.

Patterns of Change: Much of our analysis of landscape change will involve drone imagery, structure-from-motion analysis (SfM), and satellite imagery. This year we will: 1) develop drone methods to measure macroalgae, oyster reefs and tidal flats, and determine geomorphological change geomorphology on days-year scales and relate to biodiversity; 2) use drone photography and SfM to map interannual and storm-driven changes in the morphology of the marsh-tidal flat transition at 4 locations in Hog Island Bay; 3) analyze state change in 2020 imagery and relate to previous years imagery; 4) interpret LiDAR data to map distribution of *Phragmites australis* on the mainland forest edge; and 5) analyze bathymetric change in Hog Island Bay over the last 20 yr, and continue to monitor bathymetric transects to quantify seasonal and interannual changes in depth.

Theme 2: Dynamics within Landscape Units

Upland - Marsh: We will continue our new long-term experiment on the forest-marsh transition with the following activities: 1) monitor tree and shrub survival and growth in experimental plots spanning a ghost forest to healthy forest transition, and track herbaceous vegetation and tree seedlings; 2) measure transpiration continuously using sap flux sensors; 3) continue to measure SETs located on the marsh-forest gradient; 4) create drone-based image mosaics; 5) sample invertebrates; 6) analyze high-resolution salinity and groundwater data at 8 stations with 16 wells, compare hydrological data to ecological data; and 7) assess occupancy of small mammals. We will plan tree girdling activities, the experimental treatment within this large-scale experiment, to be implemented at the end of 2023.

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

Subtidal: We will continue the long-term seagrass restoration/resilience experiment (yr 21), including measurements of biomass, sediment organic matter, carbon and nitrogen stocks, O2, CO2 and methane fluxes, and sediment and water temperatures. We will continue to apply new techniques and sensors to measure emissions of greenhouse gasses (CO2, CH4, N2O), and underwater sound recording to quantify CH4 bubble release from seagrass. The seagrass removal/resilience experiment will continue (yr 4), with measurements of population dynamics as well as sediment and carbon accumulation. A review of recovery time studies is near completion and to date we have reviewed over 70 publications and collated observations of recovery times for both experimental and natural disturbances.

Barrier Island: We will use repeat drone imagery to evaluate changes in shrub expansion into grassland, and annual optical and multispectral drone flights and SfM analysis of 2 islands to develop vegetation models (NDVI). We will continue to monitor species composition change and topographic evolution along newly established transects on 2 islands using vegetation surveys, RTK surveys and repeat drone flights to generate high resolution DEMs and collect multi-spectral data. We will continue our measurements along the shrub-grass ecotone, in the swales spanning different dune heights, and the dune planting experiment.

Theme 3: Dynamics between Landscape Units

Sediment Transport: We will continue to explore coupled dynamics of tidal flats and marshes using a high-resolution hydrodynamic model, focusing on storm surge flooding and impacts of changing bathymetry and sea level on sediment transport. We will study the effects of the seagrass patch size and water depth on wave attenuation, bed shear stress and turbulence generated due to vegetation-flow interactions.

Oyster Larval Transport and Population Dynamics: We will analyze data on oyster recruitment and growth, and relate these variables to elevation, fetch, water residence time.

Coupled State Change Dynamics: Wave heights, bed shear stress and suspended sediment concentrations will continue to be measured adjacent to a marsh edge behind constructed oyster reefs and at adjacent sites to determine impacts on marsh erosion. Repeat drone-based topographic surveys are being used to characterize change in the morphology of marsh edges.

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

Ecological Consequences of State Changes

Carbon (C) Sequestration: We will continue to measure soil and groundwater C in island grass and shrub habitats, in the long-term seagrass restoration experiment, and across the marsh-forest boundary. We are continuing our work on C connectivity between seagrass and adjacent marshes. We will complete our numerical modeling of C accumulation across the marsh-forest-bay boundary, and run model experiments in which biofilms on mudflats contribute C and alter erodibility. We will run simulations in our barrier island model to estimate the likely impact of future barrier island migration on the VCR C budget.

Consumer Dynamics:

Barrier islands: We will collect our 17th year of spring migrant shorebird data including samples of prey, and complete analyses of dietary and habitat selection of long- vs. short-distance migrants related to island geomorphology and sandy beach, peat bank habitats, and intertidal mudflats. In the next year, we will: 1) conduct a 5th year of nesting shorebird and colonial waterbird monitoring and relate distribution and abundance and movements of marked piping plovers, to island geomorphology and vegetation characteristics; 2) conduct a 3rd season assessing the factors affecting reproduction and survival of American Oystercatcher, addressing the influences of predation and flooding; 3) collect a 2nd year of data on drivers of a shorebird predator, the Atlantic Ghost Crab, and place VCR data in the context of coast-wide monitoring of this predator that is hypothesized to be increasing in abundance and expanding northward with warming; and 4) link condition indices of key shorebird prey (coquina clams, blue mussels) and ocean acidification to migrant shorebird abundances.

Subtidal: We will continue our time series collection of epifauna, infauna, and fish at 24–50 seagrass sites across 5 bays. We will collect new measurements of sediment conditions at faunal survey sites to understand the effects of sediments on infaunal communities. To understand how seagrass affects clam growth and survival, we will: 1) continue to measure patterns of growth in clam shells and relate to seagrass meadow age, sediment conditions, and hydrodynamic conditions; 2) use stable isotopes to identify food sources and contributions; and 3) complete field experiments assessing the size-specific growth and survival of clams.

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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Licenses

Other Conference Presentations / Papers

Other Products

Other Publications

Patent Applications

Technologies or Techniques

Thesis/Dissertations

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Jessica A. Flester. *Mainland Seaside Salt Marsh Response and Resilience to Sea-Level Rise on The Eastern Shore of Virginia, USA*. (2020). University of Virginia. Acknowledgement of Federal Support = Yes

Martin Volaric. *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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Audrey Kirschner. *Planting Density Effects on the Growth of Dune Grasses*. (2019). Virginia Commonwealth University. Acknowledgement of Federal Support = Yes

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https://www.coastaleducation.virginia.edu

Coastal Education: Supporting, engaging, and informing a resilient coastal community.

Provides materials for educators, students and the general public.

Virginia Coast Reserve Long-Term Ecological Research
https://www.vcrlter.virginia.edu

The VCR/LTER web site provides access to a wide variety of data (311 formal datasets), images, maps, documents and interactive data displays.

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
McGlathery, Karen	PD/PI	2
Pace, Michael	Co PD/PI	1
Porter, John	Co PD/PI	9
Reidenbach, Matthew	Co PD/PI	1
Wiberg, Patricia	Co PD/PI	1
Bachmann, Charles	Co-Investigator	1
Baird, Cora	Co-Investigator	10
Berg, Peter	Co-Investigator	1
Berger, Amelie	Co-Investigator	6
Carr, Joel	Co-Investigator	1
Castorani, Max	Co-Investigator	1
Doney, Scott	Co-Investigator	1
Dueser, Raymond	Co-Investigator	1
Fagherazzi, Sergio	Co-Investigator	1

Name	Most Senior Project Role	Nearest Person Month Worked
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
Yang, Xi	Co-Investigator	1
Young, Donald	Co-Investigator	1
Zinnert, Julie	Co-Investigator	1
Donatelli, Carmine	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Ewers Lewis, Carolyn	Postdoctoral (scholar, fellow or other postdoctoral position)	12
Smith, Rachel	Postdoctoral (scholar, fellow or other postdoctoral position)	12
Burkett, Thomas	Technician	5
Cronin-Golomb, Olivia	Technician	12
Doughty, Albert	Technician	12
Gustafson, Gunnar	Technician	3
Hoffman, Sophia	Technician	6
Khan, Aliya	Technician	12

Name	Most Senior Project Role	Nearest Person Month Worked
Lee, David	Technician	6
Martinez-Soto, Kayla	Technician	12
Miller, Margot	Technician	10
Morreale, Jonah	Technician	9
Noyes, Sarah	Technician	12
Barnes, Tyler	Graduate Student (research assistant)	4
Bieri, Elizabeth	Graduate Student (research assistant)	4
Bramehy, Emma	Graduate Student (research assistant)	4
Brideau, Lauren	Graduate Student (research assistant)	4
Call, Mikayla	Graduate Student (research assistant)	4
Cornish, Michael	Graduate Student (research assistant)	4
Cortese, Luca	Graduate Student (research assistant)	4
Eisemann, Eve	Graduate Student (research assistant)	4
Flester, Jessica	Graduate Student (research assistant)	4
Franklin, Benton	Graduate Student (research assistant)	4
Giovanna, Nordio	Graduate Student (research assistant)	4
Goetz, Emily	Graduate Student (research assistant)	4
Goldsmith, Sarah	Graduate Student (research assistant)	4
Granados, Paola	Graduate Student (research assistant)	4
Granville, Kayleigh	Graduate Student (research assistant)	4
Groff, Luke	Graduate Student (research assistant)	4
Hardison, Sean	Graduate Student (research assistant)	4
Ingram, Brianna	Graduate Student (research assistant)	4
Jobe, Justus	Graduate Student (research assistant)	4

Name	Most Senior Project Role	Nearest Person Month Worked
Juska, Ieva	Graduate Student (research assistant)	2
Kerns, Kylor	Graduate Student (research assistant)	4
Kottler, Ezra	Graduate Student (research assistant)	4
Lang, Sarah	Graduate Student (research assistant)	4
Lapenta, Kristy	Graduate Student (research assistant)	4
Lapszynski, Chris	Graduate Student (research assistant)	4
LaRoche, Carly	Graduate Student (research assistant)	4
Leff, Riley	Graduate Student (research assistant)	4
Long, E.	Graduate Student (research assistant)	4
Mast, Hannah	Graduate Student (research assistant)	4
Messershmidt, Tyler	Graduate Student (research assistant)	4
Miller, Avery	Graduate Student (research assistant)	4
Molino, Grace	Graduate Student (research assistant)	4
Pant, Manisha	Graduate Student (research assistant)	4
Reeves, Ian	Graduate Student (research assistant)	4
Riffe, Emily	Graduate Student (research assistant)	4
Sabo, Alex	Graduate Student (research assistant)	4
Smith, Alex	Graduate Student (research assistant)	4
Tabor, Charles	Graduate Student (research assistant)	4
Tassone, Spencer	Graduate Student (research assistant)	4
Tedford, Kinsey	Graduate Student (research assistant)	4
Tuley, Philip	Graduate Student (research assistant)	4
Turrietta, Elise	Graduate Student (research assistant)	4
White, Drew	Graduate Student (research assistant)	4

Name	Most Senior Project Role	Nearest Person Month Worked
Wittyngham, Serina	Graduate Student (research assistant)	4
Yates, Griffin	Graduate Student (research assistant)	4
Yiyang, Xu	Graduate Student (research assistant)	4
Zhang, Xiaohe	Graduate Student (research assistant)	1
Zhu, Quingguang	Graduate Student (research assistant)	4
Contanzo, Natalie	Undergraduate Student	2
Dooren, Connor	Undergraduate Student	3
Gundermann, Daria	Undergraduate Student	1
Keese, James	Undergraduate Student	1
McNichols, Austin	Undergraduate Student	2
Mexquititla, Ayleen	Undergraduate Student	3
Nemeth, Andrew	Undergraduate Student	1
Rubin, Sydney	Undergraduate Student	1
Webber, Katherine	Undergraduate Student	2
Davis, James	Research Experience for Undergraduates (REU) Participant	3
Hebert, Renee	Research Experience for Undergraduates (REU) Participant	3
Marin, Laura	Research Experience for Undergraduates (REU) Participant	3
Pongnon, Rasheed	Research Experience for Undergraduates (REU) Participant	3
Salgado, Jackson	Research Experience for Undergraduates (REU) Participant	3
Solomon, Samuel	Research Experience for Undergraduates (REU) Participant	3
Fauber, Donna	Other	12
Woods, Natasha	Other	3

Full details of individuals who have worked on the project:

Karen McGlathery
Email: kjm4k@virginia.edu

Most Senior Project Role: PD/PI
Nearest Person Month Worked: 2

Contribution to the Project: Project leadership, seagrass research

Funding Support: NSF, UVA

Change in active other support: No

International Collaboration: No
International Travel: No

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

Contribution to the Project: Studies role of clam aquaculture in VCR

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: 9

Contribution to the Project: Information management, Small mammal research, monitoring stations

Funding Support: NSF

Change in active other support: No

International Collaboration: No
International Travel: No

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

Contribution to the Project: Works on studies of oyster reefs

Funding Support: NSF

Change in active other support: Yes

International Collaboration: No
International Travel: No

Patricia L Wiberg
Email: pw3c@virginia.edu

Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Works on studies of sediment dynamics

Funding Support: NSF

Change in active other support: No

International Collaboration: No
International Travel: No

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

Contribution to the Project: Use of hyperspectral remote sensing

Funding Support: Office of Naval Research

International Collaboration: No
International Travel: No

Cora Johnston Baird
Email: caj2dr@Virginia.EDU
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 10

Contribution to the Project: Site Manager, Education Specialist

Funding Support: NSF, UVA

International Collaboration: No
International Travel: No

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

Contribution to the Project: Aquatic flux measurements

Funding Support: NSF, UVA Dean's office

International Collaboration: No
International Travel: No

Amelie C Berger
Email: acb4rk@virginia.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 6

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: USGS

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Scott Doney
Email: scd5c@virginia.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

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

Funding Support: UVA

International Collaboration: No
International Travel: No

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

Contribution to the Project: Mammalian population and community studies

Funding Support: NSF, USU

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF, USGS

International Collaboration: Yes, China
International Travel: No

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

Contribution to the Project: Monitoring of shoreline change

Funding Support: Randolph-Macon College

International Collaboration: No
International Travel: No

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

Contribution to the Project: Studies marsh/upland interface

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Contribution to the Project: Ecological control of geomorphology

Funding Support: NSF

International Collaboration: No
International Travel: No

Sarah M. Karpanty
Email: karpanty@vt.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

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

Funding Support: Virginia Tech

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Contribution to the Project: Research using stable isotopes

Funding Support: UVA

International Collaboration: No
International Travel: No

Nancy Moncrief
Email: nancy.moncrief@vmnh.virginia.gov
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Mammalian population ecology and genetics studies

Funding Support: Virginia Museum of Natural History

International Collaboration: No
International Travel: No

Laura Moore
Email: moorelj@email.unc.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Contribution to the Project: Atmsopheric fluxes

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Contribution to the Project: Aquatic vertebrates and education

Funding Support: UVA

International Collaboration: No
International Travel: No

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

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

Funding Support: Randolph College

International Collaboration: No
International Travel: No

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

Contribution to the Project: Biogeochemistry of wetlands

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Contribution to the Project: Remote sensing, atmospheric fluxes

Funding Support: NSF

International Collaboration: No
International Travel: No

Donald 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: 6

Contribution to the Project: Working with PI Fagherazzi

Funding Support: NASA

International Collaboration: No
International Travel: No

Carolyn Ewers Lewis
Email: ce8dp@virginia.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 12

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Rachel S Smith
Email: rss2jj@virginia.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 12

Contribution to the Project: Works with PI Castorani on oyster reef ecology and restoration

Funding Support: UVA, TNC

International Collaboration: No
International Travel: No

Thomas Burkett
Email: pnj9ud@virginia.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 5

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Olivia Cronin-Golomb
Email: emb8xg@virginia.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 12

Contribution to the Project: Working with PI Doney. Assisted with analysis of satellite remote sensing of water quality

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

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: 6

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Aliya Khan
Email: akhan65@email.gwu.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 12

Contribution to the Project: Working with PI Gedan on marsh upland ecotone, started Oct 2021

Funding Support: NSF LTER, NSF CZN

International Collaboration: No
International Travel: No

David Lee
Email: ddl5e@virginia.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 6

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: 12

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

Funding Support: NSF, VIMS

International Collaboration: No
International Travel: No

Margot Tabb Miller

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

Contribution to the Project: Chemical analyses

Funding Support: UVA, NSF

International Collaboration: No
International Travel: No

Jonah Morreale
Email: jm7ux@virginia.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 9

Contribution to the Project: Technical staff of field station

Funding Support: NSF

International Collaboration: No
International Travel: No

Sarah Noyes
Email: snoyes@gwmail.gwu.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 12

Contribution to the Project: Worked with Gedan on outreach, Ghost Forest Citizen Science project

Funding Support: GWU

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Elizabeth Bieri
Email: erb2be@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Reidenbach/Wiberg on oyster restoration

Funding Support: NFWF

International Collaboration: No
International Travel: No

Emma Bramehy
Email: eb2vw@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: UVA

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF (VCR LTER), UVA

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF and Virginia Tech

International Collaboration: No
International Travel: No

Michael R Cornish
Email: mcornish@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Luca Cortese
Email: lucacort@bu.edu

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

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

Funding Support: NASA

International Collaboration: No
International Travel: No

Eve Eisemann
Email: eeisemann@unc.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Jessica A. Flester
Email: jaf3bc@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF, UVA

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Emily Goetz
Email: emgoetz@vims.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF, VIMS

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF LTER

International Collaboration: No
International Travel: No

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

Contribution to the Project: Working with Berg on flux measurements

Funding Support: NSF

International Collaboration: No
International Travel: No

Luke Groff

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Sean Hardison
Email: sh5rs@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF, GRF

International Collaboration: No
International Travel: No

Ieva Juska
Email: ij7tt@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 2

Contribution to the Project: Working with Berg on flux measurements. Graduated 1/2022

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Ezra Kottler
Email: ekottler@gwu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with Gedan on dissertation research on Spartina patens response on the marsh-forest ecotone

Funding Support: GW

International Collaboration: No
International Travel: No

Sarah Lang
Email: sel4nd@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Scott Doney on water transparency (Secchi depth) from in situ and remote sensing

Funding Support: VA Spacegrant

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Chris Lapszynski
Email: csl3172@rit.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF CZN

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF, VIMS

International Collaboration: No
International Travel: No

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

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

Funding Support: Nat. Geog., RIT

International Collaboration: No
International Travel: No

Grace Molino
Email: gdmolino@vims.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: USGS, VIMS

International Collaboration: No
International Travel: No

Manisha Pant
Email: mpant@vims.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF, VIMS

International Collaboration: No
International Travel: No

Ian Reeves

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: VCU

International Collaboration: No
International Travel: No

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

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

Funding Support: VCU, NOAA

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Charles Tabor
Email: cat6660@rit.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: RIT

International Collaboration: No
International Travel: No

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

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

Funding Support: UVA, NSF

International Collaboration: No
International Travel: No

Kinsey N Tedford
Email: ktedford@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Philip Tuley
Email: tuleypa@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Drew White
Email: aewhite@vcu.edu

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

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

Funding Support: NSF, Army Corps of Engineers

International Collaboration: No
International Travel: No

Serina Wittyngham
Email: sswittyngham@vims.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with DS Johnson on saltmarsh plant-herbivore interactions

Funding Support: NSF, VA SeaGrant

International Collaboration: No
International Travel: No

Griffin Yates
Email: gby3jr@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF LTER

International Collaboration: No
International Travel: No

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

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

Funding Support: USGS, Chinese Scholarship

International Collaboration: Yes, China
International Travel: No

Xiaohe Zhang
Email: zhangbu@bu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

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

Funding Support: NASA

International Collaboration: No
International Travel: No

Quingguang Zhu
Email: qz3cp@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Natalie Contanzo
Email: nrc8at@virginia.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: Worked with tech. Miller on lab processing of samples

Funding Support: UVA, NSF

International Collaboration: No
International Travel: No

Connor Dooren
Email: cjd8gcq@virginia.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 3

Contribution to the Project: Berg CH4 bubble detection

Funding Support: NSF LTER

International Collaboration: No
International Travel: No

Daria Gundermann
Email: dg4bda@virginia.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Working with tech. Miller on sample processing

Funding Support: UVA, NSF

International Collaboration: No
International Travel: No

James Keese
Email: jrk2nr@virginia.edu

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

Contribution to the Project: Worked with post-doc Lewis on water quality

Funding Support: NSF, UVA

International Collaboration: No
International Travel: No

Austin June McNichols
Email: ajm9tcb@virginia.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: Worked with post-doc Lewis on water quality data

Funding Support: NSF, UVA

International Collaboration: No
International Travel: No

Ayleen Mexquititla
Email: mexquititlaa@moravian.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 3

Contribution to the Project: Working with Natasha Woods on dune plants on barrier islands

Funding Support: NSF ROA Moravian

International Collaboration: No
International Travel: No

Andrew Nemeth
Email: anemeth@vims.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Forest disturbance experiment - Inverts w/Johnson

Funding Support: NSF LTER

International Collaboration: No
International Travel: No

Sydney Anne Rubin
Email: mzw9da@virginia.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Worked with tech. Miller on lab processing of samples

Funding Support: UVA, NSF

International Collaboration: No
International Travel: No

Katherine Hunt Webber
Email: khw4av@virginia.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: Working with post-doc Lewis on water quality data

Funding Support: NSF, UVA

International Collaboration: No
International Travel: No

James Davis
Email: ztq7me@virginia.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Worked with grad students Tedford and Wittyngham on data extraction.

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: 2022

Renee Hebert
Email: rmh5pgw@virginia.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Working with PI McGlathery and Berg on Legacy blue carbon

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: 2022

Laura Marin
Email: lauracarolinamarin0@Gmail.com
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Worked with PI Gedan on coastal forest retreat

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: 2022

Rasheed Pongnon
Email: rasheedp@vt.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Working with PI Karpanty on shorebird and ghost crab 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: 2022

Jackson Salgado
Email: salgadoj2@vcu.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 3

Contribution to the Project: Working on Zinnert island plant project

Funding Support: NSF

International Collaboration: No
International Travel: No
Year of schooling completed: Freshman
Home Institution: Virginia Commonweath University
Government fiscal year(s) was this REU participant supported: 2022

Samuel Solomon
Email: sws4bm@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 coastal forest retreat

Funding Support: NSF

International Collaboration: No
International Travel: No
Year of schooling completed: Sophomore
Home Institution: University of Virginia
Government fiscal year(s) was this REU participant supported: 2022

Donna Fauber
Email: dhf4k@Virginia.EDU

Most Senior Project Role: Other
Nearest Person Month Worked: 12

Contribution to the Project: Educational coordination

Funding Support: NSF

International Collaboration: No
International Travel: No

Natasha Woods
Email: nnwoods@vcu.edu
Most Senior Project Role: Other
Nearest Person Month Worked: 3

Contribution to the Project: Worked with Zinnert on landscape dynamics of barrier islands (via ROA supplement)

Funding Support: NSF

International Collaboration: No
International Travel: No

What other organizations have been involved as partners?

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

Full details of organizations that have been involved as partners:

Accomack Co. Public Schools

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

Partner's Contribution to the Project:
Personnel Exchanges

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

Agricultural Research and Extension Centers - Virginia Tech

Organization Type: Academic Institution
Organization Location: Blacksburg, VA

Partner's Contribution to the Project:
Collaborative Research

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

Barrier Islands Center

Organization Type: Other Nonprofits
Organization Location: Eastville, VA

Partner's Contribution to the Project:
Financial support
Facilities

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

Environmental Education Council of the Eastern Shore

Organization Type: Other Nonprofits
Organization Location: Virginia

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

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

Northampton County Public Schools

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

Partner's Contribution to the Project:
Personnel Exchanges

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

SouthWings

Organization Type: Other Nonprofits
Organization Location: Norfolk, VA

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

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

The Nature Conservancy

Organization Type: Other Nonprofits
Organization Location: USA/Virginia

Partner's Contribution to the Project:
Facilities
Collaborative Research

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

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

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

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

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

COASTAL BAYS

The eelgrass (*Zostera marina*) that once carpeted large areas of the seafloor of the VCR and supported a thriving economy became locally extinct in the early 1930s as a result of disease and storm disturbance, causing a catastrophic shift to an unvegetated state. Now due to restoration, over 35 km2 have been restored to seagrass habitat, and is considered the largest seagrass restoration in the world. This 20-yr landscape-level experiment has shown that within a decade ecosystem services – primary productivity, carbon and nitrogen sequestration, increased water column clarity, sediment stabilization, and

biodiversity – biodiversity are reinstated. VCR scientists were the first to show the role of seagrass restoration in reinstating ‘blue’ carbon storage capacity and our work has both informed VA state policy and set global standards for issuing carbon credits in the voluntary carbon market for seagrass restoration.

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

Our study of oyster reef restoration addresses a key gap in restoration ecology by identifying the recovery timelines for restored oyster reefs and their associated ecosystem services, as well as the physical factors that mediate restoration success. This body of work provides evidence to support the value of continuing oyster restoration efforts by illustrating functional equivalence of restored and natural reefs over time. VCR scientists wrote a policy brief to NOAA about necessity of long-term monitoring for oyster restoration based on our research highlighting the need for managers and conservation practitioners to increase monitoring time frames and include appropriate reference sites in monitoring programs to clarify recovery timelines and assess functional equivalence of restored and natural ecosystems.

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

WETLANDS AND MARITIME FOREST

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

BARRIER ISLANDS

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

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

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

What is the impact on other disciplines?

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

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

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

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

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

What is the impact on the development of human resources?

As illustrated by the number of graduate and undergraduate students listed on our participant list, the VCR LTER project provides abundant opportunities for training. Moreover, the inter- and multidisciplinary nature of the research teaches the students how to operate in a collaborative environment. Our REU, REHS activities provide graduate students mentorship training as they supervise and support the work of undergraduate and high school student interns. Several students from the local community have become involved in our research.

VCR LTER continues our strong tradition of training undergraduate and graduate researchers through a tiered mentoring program; this year 48 graduate students, 12 undergraduate students and 3 post-docs conducted research through the program. We continued to attract involvement by students from the local community, including two selected for our REU program. Our REU program was restarted this year (post-COVID-19), we built on strides in inclusive recruiting and selection resulting in 39 applicants from 22 institutions, of which 74% were female, 8% Asian, 5% African American, 8% Latinx and 2% from community colleges. From ⅓ to ½ of priority applicants selected for each project were members of underrepresented groups in STEM.

What was the impact on teaching and educational experiences?

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

We have impacts on teaching experiences at multiple levels through our participation in REHS for high-school students, REU for undergraduate college students. Additional levels are affected by our RET participation that helps train teachers in STEM enrichment. For example, Cora Johnston Baird developed a professional development program for elementary teachers on outdoor instruction for safe and place-based inquiry and learning during COVID restrictions. In 2020, all 40 teachers of Kegotank Elementary participated in the introductory training session, and VCR staff have since revitalized the Kegotank outdoor classroom in preparation for continuing sessions on lesson development.

VCR researchers frequently provide guest lectures (e.g., Estuarine Ecology, UVA; Lessons in Conservation Success, UVA, Conservation Biology, ECU) and career panel participation (e.g., Introduction to Ecology, UCSB). For example, student Spencer Tessone introduced writing students to the process of developing a research question; PI Kirwan led a field trip for community college students; PI Gedan contributed to an open online course on Foundation Species through the University of Houston. We also explored broader collaborations with Eastern Shore Community College (ESCC), especially the biology program. Student Alex Smith recorded two virtual minilectures on regional ecology for ESCC when classes moved online. While most plans have been temporarily deferred, we have promising agreements with ESCC on 1) developing research experiences and place-based labs for biology students and 2) shifting our summer final presentations (featuring REU students) to a multi-institutional student research showcase and networking event on the ESCC campus. After schools closed unexpectedly in March 2020, VCR worked with the guidance office to redevelop Northampton High School's career day as a virtual event. Two VCR researchers and others in STEM careers working within the region were featured in the event, which was distributed to every middle and high school student in the county and featured on the county website and Facebook pages. VCR graduate students and staff also collaborated with regional partners to develop and distribute elementary-level at-home learning activities for students and lessons for teachers that focused on building STEM skills in whatever space students had access to.

We also interact with the art community to link science and art. For example, the process of collecting and processing hyperspectral imagery to evaluate an ecosystem (based on research by VCR affiliate Tyler) became the basis for a transdisciplinary middle school unit in art. Every 7th and 8th grade art student (n=35) at Nandua Middle School participated in a presentation about hyperspectral imagery in local research and then completed a multi-step art project applying false color to landscape photographs to create abstract art and mimic a scientific process. The art and an overview of the hyperspectral imagery research that inspired it was viewed by 100 families during the annual Student Showcase. Copies of the art are being prepared for display at the participating universities. Similarly, in November 2020, researchers' efforts on studying "Ghost Forests" killed by sea level rise were linked to art focusing on these landscapes to create an in-person and virtual experience that brings together art and the underlying science.

Cora Johnston Baird completed ADVANCEGeo leadership training on behalf of the LTER Network and has subsequently helped plan and facilitate trainings on harassment prevention and reporting. She also co-chaired a session on gender inclusion at field stations during the Organization for Biological Field Stations' annual meeting.

For groups visiting our laboratory in Oyster Virginia, we have implemented an "augmented reality sandbox" which projects contour lines and water features onto a sand substrate. As the sand is moved around, contour lines and water features change automatically, allowing users to get a viceral sense of how changes to the landscape interact with water. Understanding this relationship is critical to understanding the coastal landscape.

In 2022, we installed a boardwalk at the Brownsville forest site, where researchers and visitors can walk the sea level-rise driven transition from forest to marsh. The boardwalk will help us to scale up outreach activities. In the past, PI Gedan has taken field courses, RETs, and artists to visit the site.

What is the impact on physical resources that form infrastructure?

The VCR/LTER is the primary user of the University of Virginia's Coastal Research Center (CRC) and provides, through user fees, resources that allow the center to support a substantial housing, lab and boat infrastructure. The CRC provides facilities for a number of smaller, more limited projects and educational programs.

Reidenbach has developed an underwater laser-based velocity measuring system. Particle image velocimetry (PIV) has been used for a number of years in laboratories to measure velocity and turbulence over an area ranging from square millimeters to square meters. This system uses a laser and optics to create a laser light sheet. This light illuminates suspended particles in the flow and, using a digital camera, particle motion is recorded. With the recent development of laser diodes, powerful yet energy efficient lasers can be placed in water tight housings and submersed underwater. The system developed uses a 250 mW laser with a wavelength of 532 nm (green light). A waterproof housing has been designed to hold both the laser and optics used to spread the beam into a narrow, yet wide sheet. Imaging of the illuminated particles is done using a high definition camera to obtain images up to 60 frames per second. The system is attached to a rigid frame and can be deployed in the coastal ocean where suspended sediment particles are tracked. This PIV system has recently been coupled with a planar-optode system that utilizes thin oxygen sensitive foils to quantify oxygen fluxes at the sediment water interface. This coupled system enables researchers to quantify the interactive effects of hydrodynamics and biological activity (such as burrowing) on oxygen exchange across the seafloor.

Berg has pioneered the approach of underwater eddy correlation to measure oxygen fluxes in benthic systems. This technique has the advantage over conventional techniques of measuring dynamic fluxes with a high temporal resolution (64 hz), and over a large spatial scale (10-100 km2), which captures natural heterogeneity in these systems. Novel results obtained from the application of this technique are the identification of multiple time-scale processes that drive seagrass, oyster, and algal metabolism, and a hysteresis in seagrass metabolism that occurs over the day. He is now developing new technologies to measure greenhouse gas, methane and nitrous oxide, fluxes from seagrass meadows and gas fluxes across the air-water interface that are needed to determine the net carbon sequestration capacity of seagrass meadows.

What is the impact on institutional resources that form infrastructure?

LTER researchers form the core of a periodic seminar series offered at the Coastal Research Center (CRC) of the University of Virginia. Additionally, ecological science programs in the Northampton County High School are highly dependent on resources and facilities provided through our SLTER program.

Our wireless network provides real-time access to remote monitoring locations in and around Hog Island Bay. Researchers from other universities/programs have access to this data, and our network has also been used to support collection of images and data by other user groups. Using this network, our tide and meteorological station data are published in near real-time, allowing their use to support time-critical activities.

What is the impact on information resources that form infrastructure?

This project provides a wide array of information resources to the larger scientific community through our formal datasets, which are available via our site data catalog (http://www.vcrlter.virginia.edu/cgi-bin/browseData.cgi) and affiliated data centers (e.g., EDI, DataOne).

The VCR/LTER shares 311 online datasets with an aggregate volume of approximately 508 GB. These are published via the VCR/LTER web site, the Environmental Data Initiative Data Portal and DataOne Search. The datasets are frequently downloaded for use by researchers and students. During the period from 10/01/2021 to 09/30/2022, VCR/LTER data files have been downloaded 3,402 times via the Environmental Data Initiative Data Portal. An additional 7,717 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 2,881 times in the past year (excluding robots), with code generated for R (34%), Matlab (26%), SPSS (17%), SAS (16%), and Python (7%).

The VCR/LTER organized and hosted a workshop in 2013 that enhanced the LTER Controlled Vocabulary, a tool that is used to improve data discoverability. The LTER Controlled Vocabulary has been integrated into other systems, such as the European LTER ENVTHES project. We continue to be active in the management of this resource and in 2019 published a summary of its use (Porter, 2019). At the 2022 LTER All-Scientists' Meeting, a session on data annotation made extensive use of the controlled vocabulary.

Many of the models developed in the course of LTER-VCR efforts are readily available to the scientific community via the Community Surface Modeling Dynamics System, including the coastal dune model (Duran and Moore 2013;2015), GEOMBEST (Brenner et al., 2015) and GEOMBEST+ (Walters et al., 2014; Lauzon et al., 2018).

Extensive aquatic eddy covariance measurements of seagrass metabolism have been done at VCR LTER since 2007. In addition to revealing crucial information on temperate (Zostera marina) seagrass health, metabolism, and its control, this

effort has been instrumental in further development of this relatively new technique for measuring benthic exchange under naturally varying in situ conditions.

What is the impact on society beyond science and technology?

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

What percentage of the award's budget was spent in a foreign country?

All funds were spent in the US.

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.