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Submitting Official (if other than PD\PI):	John H Porter Co-Principal Investigator
Submission Date:	11/19/2021
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	John H Porter

Accomplishments

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

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: We collected long-term data from meteorological stations, tide and water temperature stations, an eddy covariance tower, and groundwater wells. A 40-yr record has been constructed to analyze trends and extremes in water temperature and marine heat waves.

Patterns of Change: Long-term data and experiments include: 1) satellite imagery, aerial photos, LiDAR, drone imagery, GIS layers, and structure-from-motion (SfM) technology; 2) decadal experiments on seagrass and oyster reef restoration, marsh transgression, and island grass-shrub transitions, 3) water quality monitoring, 4) salt marsh productivity, and 5) monitoring of migrant and nesting shorebird and prey.

Dynamics within Landscape Units

Upland: We continued our long-term forest-marsh transition experiment in response to sea-level rise (SLR) and storms. Continuous measurements include: 1) tree mortality, shrub growth, vegetation cover, litterfall, light availability, soil moisture, elevation, drone imagery, groundwater levels and salinity, and flowering of *Spartina patens*. Measurements added this year: 1) tiles and marker horizons to measure sediment and organic matter deposition from storms; 2) invertebrates to test ecological equivalency; 3) sap flux sensors to measure tree water use in response to saltwater inundation; and 4) “mousecams” to assess occupancy by 4 rodent species.

Intertidal: On the marsh, we conducted an experiment to track the rate of upland movement of purple marsh crab grazing bands. For the oyster reefs, we 1) measured recruitment at 17 sites and related to GPS measurements of relief and elevation; 2) tagged adults and juveniles to measure growth and survival at 10 sites; 3) used meta-analysis to compare effects of predators on recruitment, survival, and growth; 4) and validated our habitat suitability model using 14 yrs of data from 12 reefs.

Subtidal: For seagrass, we continued our long-term restoration/resilience experiment (19 yrs) and aquatic eddy covariance (AEC) measurements of metabolism (14 yrs), and a new experiment to test seagrass response to disturbance at 2 sites that vary in heat stress. We added measurements of temperature, seagrass biomass, and sediment organic/carbon across 5 bays. Ebullition of oxygen was measured summer using bubble traps, and measurements by ‘upside down’ AEC of air-water exchange of oxygen and greenhouse gases were initiated.

For the lagoons, we 1) used the Delft3D hydrodynamic and sediment transport model to study seasonal and annual impacts of seagrass on sediment deposition; 2) compared new bathymetric measurements with data collected 20 yrs ago to study depth change; 3) and determined how seagrass impact flow, sediment transport, and infaunal communities.

Barrier Island: We continued our long-term grass planting project to follow species effects on dune growth. We studied grassland-shrub transitions through 1) monitoring plots across the grass/shrub ecotone; 2) analysis of drivers of shrub ANPP; 3) modeling changes in shrub patch size with encroachment; and 4) nitrogen fertilization and shrub seeding experiments. To explore feedbacks between plants and geomorphology, we 1) resurveyed transects for dune grass species composition and topographic evolution; and 2) continued time series of drone surveys to characterize island vegetation and dune morphological change. We developed the barrier island evolution model, Barrier 3D, and did simulations to study how dune dynamics affect island evolution over long time scales.

Dynamics Between Landscape Units

Transport of Sediment and Dissolved Constituents: We used a the Delft3D model to explore feedbacks between SLR and sediment dynamics, and to quantify the importance of storm surge on marsh deposition. We developed a new metric of storm surge intensity that scales the mass of sediment delivered to marshes during storm surge events.

Oyster Reef – Marsh Coupling: We continued our long-term experiment with 8 constructed oyster reefs to quantify how reef height, width and oyster biomass affect wave attenuation and marsh edge erosion. We quantified marsh edge characteristics using the LiDAR imagery and related the shape and rate of erosion to the presence/absence of fringing reefs.

Seagrass - Marsh Coupling: We sampled transects on 2 islands for stable isotopes, biomarkers, compound-specific isotopes, and 210Pb dating are being used to quantify the seagrass contribution to C sequestration in nearby salt marshes.

Barrier Island Ecosystem Coupling: On cross-island transects we measured changes in sediment accretion and monitored species composition and % cover, and characterized vegetation and topography using drone imagery and SfM at scales of 40–50 ha. We began field experiments to test how dune size affects shrub growth and survival and used our new Barrier 3D model to investigate the role of shrub dynamics in island evolution.

Cascading Effects: We developed a new coupled transect model that extends from the barrier islands, across marsh and bay, and across mainland marsh into a coastal upland forest to examine how one part of the system (e.g., island) can influence other parts (e.g., mainland forest). We are doing this by coupling our bay-marsh-forest model with the Barrier 3d model, both parameterized with VCR data.

Ecological Consequences of State Changes

Carbon Sequestration: This year we 1) Synthesized C stocks and soil C accumulation rates for each ecosystem type, estimated the total C stored across the coastal landscape, and calculated the amount of time it takes for one ecosystem to replace the C lost from another (e.g., forest-marsh transition). 2) Used remote sensing to quantify historical trends in C stored in aboveground biomass in forests and marshes. 3) Surveyed the C stored in trees, shrubs, grasses, and soils at the forest-marsh transition, related those to elevation and salinity, and used the dataset to calibrate the numerical modeling and satellite based metrics of aboveground biomass change. 4) Used the EC system to measure CO_2 fluxes in the marsh. 4) Analyzed soil C standing stocks in the island grass-shrub ecotone and groundwater DOC. 5) In the seagrass meadows, continued the time series of C burial and soil/plant standing stocks, used AEC to quantify seagrass metabolism and CO_2 dynamics, and measured alkalinity and DIC to characterize water column chemistry, carbon storage, air-sea CO_2 flux, and biological signals of CO_2 uptake and release.

Consumer Dynamics: On barrier islands, we collected data on shorebirds and related them to changes in island geomorphology and vegetation. These included 1) the 15th year of spring shorebird abundances, distributions and prey, and modeling factors affecting abundances and distributions of long- versus short-distance migrants; 2) spatial and temporal variation in two key shorebird prey from 2010-2020 and mussel and clam larvae in 2021; 3) distribution, nest abundance and chick survival of American Oystercatchers, colonial seabirds, and Piping Plovers; and 4) resighted banded bird populations to monitor movements, survival and reproduction.

In the intertidal, we assessed if restored oyster reefs reach equivalence with natural reefs, using a 15-yr time series of 77 restored and natural reefs. We synthesized data from 245 restored-degraded reef pairs and 136 restored-reference reef pairs across 3500 km of U.S. Gulf and Atlantic coastline to quantify how restoration affects community structure and ecosystem function.

In the subtidal, we 1) continued the time series of seagrass epifauna, infauna, and fish; 2) analyzed long-term fish data to understand impacts of seagrass restoration and depth on abundance and diversity; 3) initiated a study on the density and growth of clams at 50 sites spanning 2–18 yrs since seagrass colonization, and 4) began an experiment to test how seagrass affects water column algae and how this influences 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, high-temperature events) as well as mean climate state values.

Our specific objectives for this theme are:

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

(2) Describe trends and variation in ecosystem distribution, biogeochemical processes, organic matter, primary and secondary production, and community composition within the VCR domain. We do this through measurements of ecosystem state change 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 long-term experiments.

Theme 2. Dynamics within Landscape Units: How do ecological and physical processes interact to maintain ecosystem states or facilitate transitions to new ones? We identify and test mechanisms that can lead to state change (linear, threshold, regime shift). Long- and short-term data are used to parameterize, test, and evaluate mechanistic models. Natural 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-from-motion techniques to determine storm-driven change in the morphology of the marsh-tidal flat boundary, and relate to measured wave and tide guage monitoring of hydrodynamic conditions.

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

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

(6) Quantify plant feedbacks on dune morphology and development on the barrier islands, and the effects on island vulnerability to changes in storm frequency and 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 non-adjacent 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 seagrass- and macroalgal-dominated ecosystems affects diversity and abundance of fauna, including invertebrates, bivalves, fish and shorebirds, and coastal foodwebs.

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

(3) Determine how the abundance, distribution, and community structure of ground-nesting 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 significant temperature trends: 1) an increase in daily average water temperature of 0.24±0.04°C /decade; 2) more days with temperature >28°C, and 3) more frequent marine heatwaves (81 MHWs in 40 years; 49 overlapped with MHWs in adjacent coastal ocean) over the last 4 decades.

Dynamics within Landscape Units

Upland – Marsh

- In inundated forests, trees have low water use from reduced transpiration - a physiological response that predates canopy death - and show a sudden drop in transpiration and a brief period of reverse sap flow during a high-tide saltwater inundation event.

- Groundwater levels and salinity correlate to the hydraulic gradients toward the marsh and uphill (proxies of outgoing and incoming water fluxes), and temperature (proxy for evapotranspiration). A high water table favors the flux of surficial, freshwater to the marsh, and loss of freshwater by evapotranspiration, with losses replenished by saltier water.

- The high-marsh grass, *Spartina patens*, has reduced flowering at the forest edge, limited by light.

- The diversity and abundance of ground-dwelling invertebrates are highest in high-forest plots. Species patterns show that marsh species are entering the forest.

Intertidal

- Infaunal abundance decreased near oyster reefs, likely tied to an increased predatory crabs using the reef as habitat. Oyster reefs at higher elevations on mudflats are larger

and have higher oyster densities. Adult oyster biomass is ~1.5× greater on reefs in predicted 'suitable' habitat over 14-yr.

- Predation has strong effects on reducing oyster survival. Predation is equally strong in intertidal and subtidal, and similar across latitude, temperature, and salinity.

Subtidal

- Seagrass were resilient to a marine heatwave, with recovery within 3 yr; landscape position modulates heat stress. Heat stress did not influence recovery of seagrass after experimental removal, which was 40-50% with in 2 yr.

- Sediment deposition rates in the seagrass meadow are comparable to SLR rates. Repeated bathymetric measurements and model results indicate shallow depressions in seagrass meadows are sites of net deposition.

- Multi-variable non-linear fitting of long-term aquatic eddy covariance data on seagrass metabolism showed a temperature stress threshold for *Zostera marina* 28.5oC.

- Ebullition measurements over seagrass showed that the oxygen bubble flux only amounts to ~3% of GPP in summer.

- Seagrass reduced mean flow rates by >60%, contributing to a ~2X increase in bivalve larval settlement, and reducing reduced bedload transport of sediment.

Barrier Island

- Shrub patch size distribution follows a power law, indicating a critical transition, sustained by local positive feedbacks. Shrub encroachment is also occurring in formerly forested areas.

- Barrier 3D simulations show that dune dynamics can lead to punctuated, or discontinuous retreat of the island. Simulations suggest there are major morphological and behavioral differences between barriers with and without shrubs; islands with shrubs tend to be narrower and migrate landward more slowly, are more likely to migrate landward in a discontinuous (i.e., stop-and-go) manner, and are more vulnerable to drowning.

Dynamics between Landscape Units

Sediment Transport

- Delft3D model runs under different storm surge conditions show that most VCR events are associated with northeasterly winds and can double suspended sediment flux to marshes. Storm surge promotes marsh accretion and increases the inundation area, allowing more sediment deposition. Total marsh deposition increases linearly with the magnitude of storm surge.

- Sea-level rise (SLR) increases the tidal prism and inundation depth, facilitating sediment deposition on marshes. At the same time, SLR enhances ebb-dominated currents and increases sediment resuspension, reducing the sediment-trapping capacity of tidal flats and bays. Combined this increases the elevation difference between marshes and tidal flats.

- Oyster reefs that fringe marshes are effective at trapping sediments along the marsh edge and reducing erosion along the toe of the marsh, decreasing the marsh edge slope.

Seagrass - Marsh Coupling

- Organic content in marsh sediments increases linearly with distance into the marsh, and has a stronger relationship in the marsh adjacent to the oldest restored seagrass meadow compared to marsh adjacent to the younger and smaller meadow.

Oyster Larval Transport and Population Dynamics

- Oyster larval recruitment is variable at the landscape scale, but showed a unimodal (hump-shaped) relationship with reef elevation and vertical relief.

- Based on long-term data, oysters on restored reefs match the density, size, and biomass of reference reefs in ~6 yrs.

- Oyster reef restoration on U.S. Gulf and Atlantic coasts are effective in boosting the density of larval and adult Eastern oysters to match natural reference reefs.

Coupled State Change Dynamics

- Restored reefs at higher elevations near mean sea level recruited more oyster larvae, had greater oyster growth, and greater wave attenuation than similar reef designs at lower elevations.

- The coupled barrier island-shrub model showed that shrubs cause narrower but taller islands and restrict barrier island rollover. Dune formation (hummock vs. ridge) affects plant community composition and biomass of adjacent swales with taller dunes having more biomass. Low (<1.5 m) fronting dunes reduces shrub survival.

Ecological Consequences of State Changes

Carbon Sequestration

- Across the coastal landscape, forests dominated biomass C stocks and salt marsh dominated soil C stocks. Replacement timescales varied between years to millennia, where it took a short amount of time for soil C released from eroding barrier islands and seagrass to be replaced by adjacent marshland, but a long time for replacement in the opposite direction.

- Ecosystem connectivity defined by sediment and carbon transport tends to enhance the resilience of coastal C pools up to some optimum SLR rate. For example, SLR leads to a gradual shift from a system dominated by aboveground forest C to a system dominated by belowground marsh soil C.

- For the mid-Atlantic coast, remote sensing suggests that climate warming has increased forest biomass and compensated for SLR-driven biomass losses in marshes and retreating forests.

- On the islands, standing stocks of soil C were highest in in the top 5 cm of soil under shrub thickets.

- For seagrass meadows, despite the increase in greenhouse gas emissions, seagrass meadows are a net sink of C, burying 2x more C than bare areas.

- Oyster reef restoration on U.S. Gulf and Atlantic coasts enhances sediment organic C.

Consumer Dynamics

Islands

- Over 14-yr the distribution and number of migrant shorebirds are driven by the abundance of 3 prey items (coquina clams, blue mussel spat, and crustaceans) which vary based on the distribution of sandy ocean intertidal zone and peat bank habitats.

- O18 isotopes indicate that blue mussel prey originate from colder, more saline waters outside the VCR and have declined over time.

- American Oystercatcher and Piping Plover population abundance and distribution is driven by the presence of vegetation-free overwash created by storm events.

Intertidal

- Small generalist shorebirds feed preferentially on smooth tidal flats, and larger more specialized specie are more abundant on hummocky flats.

- Restored oyster reefs rapidly provide habitat to mesopredatory mud crabs, matching the density on reference reefs in ~6 years.

- Oyster reef restoration on U.S. Gulf and Atlantic coasts boost the abundance and diversity of reef invertebrates and fishes by 34–99%, matching reference reefs.

Subtidal

- Seagrass restoration enhances overall fish abundance and biodiversity, but specific effects vary by species.

- Infaunal bivalve recruitment was greater within the seagrass canopy than at adjacent unvegetated sites.

Key outcomes or Other achievements:

VCR scientists have published 31 journal articles, 6 theses or dissertations and 2 book chapters in the past year. 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 yrs (0.24 +- 0.04 °C/decade), as have the number of days with daily average temperature in excess of 28°C. The number of marine heatwaves (MHWs) has increased significantly over the 40-yr period (increase of ~1 MHW/decade;); MHW duration has not significantly changed.

Patterns of Change

There has been a 19% net loss of barrier islands over the last ~30 years (1984-2016). Winter warming has resulted in 41% increase in woody vegetation. Analysis of bathymetric change in seagrass meadows over the last 20 yrs suggest that sediment deposition rates have generally been comparable to rates of sea-level rise (SLR).

Theme 2: Dynamics within Landscape Units

Forest - Marsh - Tidal Flats

Forest retreat and marsh migration rates are controlled by slope and SLR. At the boundary between marsh and forest, salinity at the root depth is high when the water table is high. This counterintuitive result is likely due to depletion of the top freshwater layer caused by surficial fluxes to the marsh and increased evapotranspiration when

water levels are high. The lost freshwater is replaced by more saline water flowing at depth from uphill. By increasing the water table, SLR could increase salinity of the groundwater at the roots depth, triggering forest dieback.

The high marsh foundation species *Spartina patens* is migrating inland, with light limitation of flowering at the forest edge, rarely flowering at <27% ambient light (~50% canopy cover). This has implications for adaptive potential, as reproduction at themigrating boundary is primarily clonal, without the mixing of alleles and associated resilience from sexual reproduction.

Subtidal

Our landscape-level restoration seagrass (*Zostera marina*) experiment, now in its 20th year, shows that key ecosystem services, including production, and removal of carbon and nitrogen are reinstated within 10 yr. Seagrass meadows are resilient to MHW, with plant biomass recovering within 2-4 yr, but recovery of lost sediment carbon lags behind. On a short-term basis (day to hours), seagrass production is significantly reduced when water temperatures exceed 28.5 oC threshold. Organic carbon burial rates are largely determined by sediment accumulation and both change non-linearly as a function of seasonal variation in seagrass density. Seagrass trap sediment at meadow edges during spring-summer growth seasons, but during winter senescence low-density meadows (<160 shoots m−2) are erosional with rates sensitive to density. Small variations in winter densities or meadow-scale (100s meters) summer dieback due to MHW can result in large changes in annual sediment and carbon accumulation.

Barrier Island

Cold temperatures limited shrub survival of both seedlings and adults, and grasses provide insulation to shrub seedlings. Woody patch size distribution follows a power law, indicating a critical transition, sustained by local positive feedbacks. Shrubs enhance grassland cover at the edge, but reduce diversity and alter soil characteristics.

Theme 3: Dynamics between Landscape Units

Sediment Transport

Delft3D model runs under different storm surge conditions show that most storm surge events in the VCR are associated with northeasterly winds and that they can double suspended sediment flux to marshes. Total marsh deposition increases linearly with the magnitude of storm surge. Our meta-analysis study of coastal bays highlights that restoration 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.

Oyster Larval Transport and Population Dynamics

Oysters larvae settle throughout VCR, but recruitment is strongest within a narrow band of both elevation (–0.5 to –0.1 m relative to NAVD88) and vertical relief (0.05–0.2 m).

Subtidal - Intertidal Coupling

Oysters currently occupy 12% of the suitable intertidal area in the VCR and affect marsh edge erosion. Marsh edges lined by oyster reefs have a shallower slope (6 degrees) compared to exposed marshes (11.4 degrees). Retreat of the marsh edge was strongly correlated to elevation, with oyster reefs causing an elongation of the marsh edge by reducing retreat at lower elevations of the marsh edge.

Barrier Island Ecosystem Coupling

Dune elevation and shape influence plant species composition, functional trait composition, shrub expansion, and annual NPP in adjacent low-elevation swales. Dune and vegetation dynamics are important predictors of barrier island response to SLR (i.e. landward migration vs. shoreface erosion). Barrier island interior vegetation cover is an important control on the long-term behavior and geometry of transgressive barrier islands, and may affect the likelihood of island drowning.

Cascading Effects and Coupling Between Non-adjacent and Adjacent Systems

Seagrass meadows operate as dynamic sources and sinks of back-barrier sediment that can influence the evolution of coupled marsh and barrier island landforms. While they generally reduce marsh erosion and barrier island migration rates, seagrass meadows can also cause unanticipated accelerated marsh loss under certain conditions.

Theme 4: Ecological Consequences of State Changes

Carbon Sequestration

Carbon stocks are dominated by biomass in forests and organic matter in marsh soils. Total carbon stocks decreased by half on a gradient from healthy forest to marsh, representing the temporal migration of ecosystems with SLR. It will take ~200 years for soil carbon accumulation in marshes to offset the losses from forest mortality. This replacement timescale is greater than or equal to the expected survival time of these newly formed marshes, suggesting carbon lost from forests may never be replaced. We hypothesize that SLR is leading to a shift from a landscape dominated by aboveground forest biomass to belowground marsh biomass. However, remote sensing indicates that warmer temperatures in surviving upland forests may compensate for the loss of aboveground biomass associated with marsh and forest loss.

Seagrass restoration doubled carbon storage in bay sediments within a decade. These carbon stores are vulnerable to MHW which cause die-off of seagrass.

Consumer Dynamics

Shorebirds were positively correlated with the invasive alga *Agraphyton vermiculophylla* on hummocky mudflats, likely due the effect of algae on prey accessibility. Monitoring of shorebirds and their prey reveals responses to climate drivers. Piping plovers (ground-nesting shorebird) have population irruptions following storm-driven habitat creation. Abundance of Red knot, an imperiled long-distance migrant did not change from 2007-2018. Migrant shorebirds select two types of bivalve prey. Blue mussels on exposed peat banks on eroding islands decreased from 2010-2018. Coquina clams on sandy beaches of stable islands did not change. For 2010-2021, condition indices are higher on northern islands for mussels and on southern islands for coquina clams.

Intertidal: Restored reefs match the oyster density and biomass of natural reefs within 6 yrs, and oyster size within 2.5 yrs. Oyster restoration boosts oyster production by 21×, habitat provisioning by 34-99%, and organic matter and nutrient cycling by 36-95%. Predation is a strong driver of oyster survival. The height of the reef plays a role in wave attenuation and marsh edge buffering. The width of the reef, increases area available for oyster growth, but had little effect on wave attenuation.

Subtidal: Seagrass meadows greatly enhance fish abundance and biodiversity. Larval settlement of bivalves increased roughly 2 times within the seagrass compared to an adjacent bare area.

*** 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 53 graduate students and 4 post-docs 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. In 2021, an additional eight VCR grads and early career scientists from five VCR institutions completed the course. Three of those trained in the course became RET project mentors. Many more mentored REUs 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 getting started in outreach (provided by HFR LTER alumni).

In a September 2020 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. REU orientation was expanded to include bystander intervention training and exploration of the Code of Conduct. 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 183 views and sparked many new conversations. We shared the trailer concept with other sites through workshops with UFERN and LTER LNO.

Three elementary teachers – two funded by a supplement and one with matching funds – completed research projects and PD sessions through our RET program. Resulting changes in their teaching will reach all 5th graders in two elementary schools, plus all grades of gifted students at another. Their graduate mentors reported deeper engagement and increased likelihood of continued collaboration with K-12 educators. We are now exploring opportunities to adapt the supports and projects they developed for teachers to enrich curriculum for the Eastern Shore Community College.

In summer 2021, we also revived our REHS program by mentoring a local, rising first-generation college student through seagrass and island bird productivity projects. He returned for our REHS program after showing exceptional skills while previously enrolled in Nature Camp (a TNC x VCR collaboration). Our mentee had the opportunity to work with science mentors from all of the major state institutions where he intends to apply for college. We plan to continue the program in summer 2022 and beyond.

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

he VCR disseminates research findings and data through the VCR LTER website (https://www.vcrlter.virginia.edu) with 8,956 page views in 4,800 sessions by 2,900 distinct users. During that same period, VCR/LTER data files were downloaded 2,179 times from the Environmental Data Initiative or VCR/LTER data portals from Nov. 1, 2020 to Oct. 31, 2021.

#DiscoverEE (Discover Environmental Education) at home learning activities were distributed in English and Spanish through all public library branches and laundromats in both counties – two per month for a year. These materials were designed for equitable outdoor learning at home, using only commonly accessible materials and natural features. Activities connected VA standards of learning with foundational STEM skills including observation and questioning. Given their target on low connectivity audiences, assessment was difficult to gather, though librarians requested continuing development and lauded the appropriateness of the materials for families on the Eastern Shore.

In summer 2021, grads Wittyngham (PI Johnson) and Tedford (PI Castorani) launched VCR’s first citizen science initiative, using Chronolog (https://www.chronolog.io/) repeat photography stations to document coastal landscape change over time (https://www.chronolog.io/project/VCR). Beyond engaging the public, the project is designed to allow remote field observation and data collection by K-12 classes. Tedford introduced it to teachers during professional development in partnership with TNC. We are also partnering with managers of local natural areas to use the resulting landscape timelapses to increase the accessibility of natural area observations for those unable to reach remote coastal access points in our county.

PI McGlathery shared seagrass restoration insights with the National Public Radio station “RadioIQ” (https://www.wvtf.org/news/2020-11-05/seagrass-meadows-restored-off-eastern-shore), following on project coverage on the radio show “The Conversation” (https://theconversation.com/restoring-seagrasses-can-bring-coastal-bays-back-to-life-147798)

Our 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, including through a virtual reception with the artists and scientists, which launched the Climate Ambition Summit hosted by UVA’s Environmental Resilience Institute.

Partners

Much of 2021 was dedicated to fostering a new partnership with the Biology Department of Eastern Shore Community College. An ROA supplement awarded to Dr. Foxworthy funded summer research, getting biology faculty and a rising graduate (transitioning to a 4-year school) involved in ongoing VCR research. Based on that experience, and pilot contributions by grad Smith (PI Kirwan) during 2020 COVID shutdowns, we are now collaboratively revising labs to link VCR research and local ecosystems to student investigations for spring 2022. We are also pursuing a shift from internal end of summer student research presentations to a Regional Research Student Showcase at the Community College. We scoped the idea and identified key partners and outcomes in 2021 with the aim to hold the first event in 2022.

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 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 (MHW) and their effects on seagrass and associated fauna, with an eye toward future changes in MHW frequency and intensity. To improve the accuracy of our predictive modeling of coastal water clarity, we will use imagery gathered by the Sentinel II system.

Patterns of Change: Analysis of landscape change will involve: 1) using drone photography and SfM to create maps of the marsh-tidal flat transition and to monitor its response to storms; 2) updating satellite imagery to analyze barrier island state change on multi-decadal time scales; 3) continuing annual RTK and multispectral drone mapping of barrier island vegetation and bathymetry; and 4) continuing to remap the bathymetry using a high-resolution RTK bathymetric sounder to quantify change over decadal time scales.

Theme 2: Dynamics within Landscape Units

Upland - Marsh: We will continue our new long-term experiment on the forest-marsh transition with these activities: 1) monitor tree and shrub survival, and track herbaceous vegetation and tree seedlings; 2) measure transpiration continuously using sap flux sensors in hardwood and softwood trees; 3) continue to measure SETs located on the marsh-forest gradient; 4) install shallow SET pipes and an automated SET device; 4) create drone image mosaics; 4) sample invertebrates; and 5) analyze hydrological data, comparing salinity and groundwater data to soil moisture and meteorological data. We will develop a coupled hydrological-forest dynamics model to explore the connection between flooding, salinity, and forest structure.

Intertidal: We will continue these activities: 1) quantify the effects of constructed oyster reefs on wave attenuation and marsh edge erosion; and 2) measure oyster reef elevation and relief for comparisons with oyster recruitment, growth, and survival. We will complete a tagging study to estimate survival of adult and juvenile oysters.

Subtidal: We will continue the long-term seagrass restoration/resilience experiment (yr 20), including measurements of biomass, diversity, carbon and nitrogen stocks, O2, CO2 and methane fluxes, and sediment and water temperatures. The seagrass removal/resilience experiment will continue (yr 3), with measurements of population dynamics, sediment and

carbon accumulation, faunal diversity, hydrodynamics, sediment transport, and larval settlement. A review of over 70 published recovery time studies will be completed for both experimental and natural disturbances.

Barrier Island: We will use repeat drone imagery to evaluate species effects on dune shape/size and shrub expansion into grassland, and annual optical and multispectral drone flights and SfM analysis to develop vegetation models (NDVI). We will continue to monitor transects on 2 islands using vegetation surveys, RTK surveys and drone flights to generate DEMs and collect multi-spectral data. We will monitor grass/shrub edge interactions and follow growth of experimentally planted shrubs in different grass densities. We will initiate an experiment to assess the role of *Spartina patens* grass in dune building. We will evaluate earlier surveyed overwash areas on 2 islands to assess vegetative and topographic recovery patterns over the last decade.

Theme 3: Dynamics between Landscape Units

Sediment Transport: We will continue to explore the coupled dynamics of tidal flats and marshes using a high-resolution hydrodynamic model, focusing on seagrass effects on marsh deposition, the importance of storm surge events on transport from tidal flats to marshes, and impacts of changing bathymetry on patterns of sediment transport. We will study the effects of the seagrass patch size and water depth on wave attenuation, bed shear stress and turbulence.

Oyster Larval Transport and Population Dynamics: We will complete a 4th year measuring oyster larval recruitment at 17 sites. We will characterize oyster larval transport using new Delft3D simulations of larval movement that incorporate winds, tides, waves, and bathymetry. Dispersal estimates will be used to estimate demographic connectivity at the landscape scale, identify population sources and sinks, and locate areas ideal for future restoration.

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

Cascading Effects: We will use the newly-developed transect model spanning the entire coastal landscape (from barrier to mainland forest) to run model experiments designed to examine coupled interactions of adjacent and non-adjacent subsystems and the potential for cascading state changes across the landscape. We plan to evaluate previous observations of marsh loss in the VCR via rapid barrier migration, and we will explore how barrier island state change from immobility to rapid migration (and vice versa) can potentially cause state changes across the coastal transect.

Ecological Consequences of State Changes

Carbon Sequestration: We will continue to measure soil, biomass and groundwater C across the landscape in island, marsh and seagrass habitats. For seagrass, new measurements will be expanded including ‘upside down’ aquatic eddy covariance below the air-water interface to determine oxygen and greenhouse gasses (CO_2, CH_4) emissions, and underwater sound recording to quantify CH_4 bubble release from sediments. On the marsh, we will use the CO_2 eddy covariance flux and SIF (solar-induced fluorescence) measurements to scale up GPP using satellite imagery. We are continuing our study of C connectivity between seagrass and adjacent marshes to identify C source composition in the marsh based on stable isotope analysis and Bayesian mixing models to quantify the contribution of restored seagrass. For the forest-marsh-mudflat boundary, we will complete numerical modeling of C cycling to define optimum rates of SLR for each component of the landscape and the entire landscape. Also at the landscape scale, we will refine a C budget from measurements of soil C burial for forest, marsh, seagrass, barrier island ecosystems, and will use it to assess the consequences of historical state changes.

Consumer Dynamics:

Barrier islands: For shorebirds, we will 1) collect our 16th year of spring migrant data including samples of prey; 2) complete analyses of dietary and habitat selection of long- versus short-distance migrants related to island geomorphology and sandy beach versus peat bank habitats; 3) conduct a 4th year of nesting shorebird and colonial waterbird monitoring and relate distribution, abundance, and movements to island geomorphology and vegetation; 4) conduct a 2nd season assessing the factors affecting the reproduction and survival of American Oystercatcher; 5) analyze 2010-2021 samples to detect spatial and temporal changes in clam and mussel condition related to ocean acidification.

Intertidal: Building on prior meta-analysis, we will determine the ecological and oceanographic drivers underlying among-study variation in how restored oyster reefs enhance biodiversity and ecosystem function.

Subtidal: For seagrass habitats, we will 1) continue our time series collection of epifauna, infauna, and fishes at 24–50 seagrass sites across 5 bays to determine patterns of biodiversity; 2) conduct new analyses of 2019–2021 fish data to understand how prey availability, habitat structure, and oceanography affect fish abundance and diversity; 3) evaluation growth rings of hard clams to understand long-term patterns of clam growth across the seagrass chronosequence; and 4) carry out stable isotope analysis of clam tissues to resolve clam diet and its spatial variation.

Products

Books

Book Chapters

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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

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

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Berger. Amelie C.. *Long-term aquatic eddy covariance measurements of seagrass metabolism and ecosystem response to warming oceans*. (2021). University of Virginia. Acknowledgement of Federal Support = Yes

Besterman, Alice. *Macroalgal Distribution and Impacts on Intertida\ l Flats, With Emphasis on the Exotic Species Agarophyton Vermiculophyllum*. (2019). University of Virginia. Acknowledgement of Federal Support = Yes

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

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

Nicole Keller. *Stimulated growth response to sand burial of a coastal shrub*. (2020). Virginia Commonwealth University. Acknowledgement of Federal Support = Yes

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Brown, Joseph. *lant communities in dynamic systems: how disturbance influences coastal plant community structure and function*. (2021). Virginia Commonwealth University. Acknowledgement of Federal Support = Yes

Websites or Other Internet Sites
Virginia Coast Reserve Long-Term Ecological Research
https://www.vcrlter.virginia.edu

Central web site for the VCR/LTER. It includes information about the research, data, documents (including full-text of student theses), photographs and videos. Data include over 270 datasets that are also published on the Environmental Data Initiative and DataONE.org.

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
McGlathery, Karen	PD/PI	3
Pace, Michael	Co PD/PI	1
Porter, John	Co PD/PI	8
Reidenbach, Matthew	Co PD/PI	2
Wiberg, Patricia	Co PD/PI	1
Anderson, Iris	Co-Investigator	1
Bachmann, Charles	Co-Investigator	1

Name	Most Senior Project Role	Nearest Person Month Worked
Baird, Cora	Co-Investigator	12
Berg, Peter	Co-Investigator	1
Blum, Linda	Co-Investigator	1
Carr, Joel	Co-Investigator	1
Castorani, Max	Co-Investigator	1
Christian, Robert	Co-Investigator	1
D'Odorico, Paolo	Co-Investigator	1
Doney, Scott	Co-Investigator	1
Dueser, Raymond	Co-Investigator	1
Fagherazzi, Sergio	Co-Investigator	1
Fenster, Michael	Co-Investigator	1
Gedan, Keryn	Co-Investigator	1
Johnson, David	Co-Investigator	1
Karpanty, Sarah	Co-Investigator	1
Kirwan, Matthew	Co-Investigator	1
Macko, Stephen	Co-Investigator	1
Mills, Aaron	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

Name	Most Senior Project Role	Nearest Person Month Worked
Young, Donald	Co-Investigator	1
Zinnert, Julie	Co-Investigator	1
Foxworthy, Alex	Community College Faculty	1
Holland, Miranda	K-12 Teacher	2
Marshall, Margaret	K-12 Teacher	2
Sadler, Krista	K-12 Teacher	2
Anarde, Katherine	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Aoki, Lillian	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Ewers Lewis, Carolyn	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Smith, Rachel	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Doughty, Albert	Technician	12
Hinson, Ivy	Technician	4
Khan, Aliya	Technician	1
Lee, David	Technician	12
Martinez-Soto, Kayla	Technician	12
Mohammadi, Rose	Technician	10
Morreale, Jonah	Technician	12
Noyes, Sarah	Technician	2
Walker, Shannon	Technician	7
Barnes, Tyler	Graduate Student (research assistant)	4
Berger, Amelie	Graduate Student (research assistant)	4
Bieri, Elizabeth	Graduate Student (research assistant)	4
Brideau, Lauren	Graduate Student (research assistant)	4
Brown, Joseph	Graduate Student (research assistant)	4

Name	Most Senior Project Role	Nearest Person Month Worked
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
Granville, Kayleigh	Graduate Student (research assistant)	4
Groff, Luke	Graduate Student (research assistant)	4
Hardison, Sean	Graduate Student (research assistant)	4
Hogan, Sara	Graduate Student (research assistant)	4
Holstein, Dawn	Graduate Student (research assistant)	1
Ingram, Brianna	Graduate Student (research assistant)	4
Jobe, Justus	Graduate Student (research assistant)	4
Juska, Ieva	Graduate Student (research assistant)	4
Kadiyala, Ethan	Graduate Student (research assistant)	4
Kerns, Kylor	Graduate Student (research assistant)	4
Kottler, Ezra	Graduate Student (research assistant)	4
Lang, Sarah	Graduate Student (research assistant)	4
Lapszynski, Chris	Graduate Student (research assistant)	4
LaRoche, Carly	Graduate Student (research assistant)	4
Leff, Riley	Graduate Student (research assistant)	4

Name	Most Senior Project Role	Nearest Person Month Worked
Long, 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
Olivier, Gourgue	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
Wittyngham, Serina	Graduate Student (research assistant)	4
Wood, Lauren	Graduate Student (research assistant)	4
Yiyang, Xu	Graduate Student (research assistant)	4
Zezheng, Liu	Graduate Student (research assistant)	4
Zhang, Xiaohe	Graduate Student (research assistant)	4
Zhu, Quingguang	Graduate Student (research assistant)	4
Jean, Carlens	Undergraduate Student	3

Name	Most Senior Project Role	Nearest Person Month Worked
Melendez-Vera, Oscar	High School Student	1
Bollinger, Abby	Research Experience for Undergraduates (REU) Participant	4
Coffey, Davis	Research Experience for Undergraduates (REU) Participant	4
Marshall, Alex	Research Experience for Undergraduates (REU) Participant	4
Marshall, Hayley	Research Experience for Undergraduates (REU) Participant	4
Nicholson, Megan	Research Experience for Undergraduates (REU) Participant	4
Rebello, Luana	Research Experience for Undergraduates (REU) Participant	4
Schlachter, Kay	Research Experience for Undergraduates (REU) Participant	4
Sward, Rheya	Research Experience for Undergraduates (REU) Participant	4
Fauber, Donna	Other	4
Woods, Natasha	Other	1

Full details of individuals who have worked on the project:

Karen McGlathery
Email: kjm4k@virginia.edu
Most Senior Project Role: PD/PI
Nearest Person Month Worked: 3

Contribution to the Project: Lead Principal Investigator, Seagrass

Funding Support: NSF

Change in active other support: No

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

Change in active other support: Yes

International Collaboration: No
International Travel: No

John H Porter
Email: jhp7e@virginia.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 8

Contribution to the Project: Information management, sensor support, population ecology

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: 2

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: Yes

International Collaboration: No
International Travel: No

Iris Anderson
Email: iris@vims.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Studies of nitrogen and phosphorus cycling and clam aquaculture

Funding Support: SeaGrant, VIMS

International Collaboration: No
International Travel: No

Charles Bachmann

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

Contribution to the Project: Use of hyperspectral remote sensing

Funding Support: Office of Naval Research

International Collaboration: No
International Travel: No

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

Contribution to the Project: Site Manager, Education Specialist

Funding Support: NSF, UVA

International Collaboration: No
International Travel: No

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

Contribution to the Project: Aquatic flux measurements

Funding Support: NSF, UVA Dean's office

International Collaboration: No
International Travel: No

Linda K. Blum
Email: lkb2e@virginia.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Study of linkages between ecological and geomorphological process in salt marshes focused primarily on soil organic matter accumulation and thus plant belowground production and decomposition

Funding Support: UVA

International Collaboration: No
International Travel: No

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

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

Funding Support: USGS

International Collaboration: No
International Travel: No

Max 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

Robert R Christian
Email: CHRISTIANR@ecu.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Network analysis, studies of marsh macrophytes

Funding Support: Personal

International Collaboration: No
International Travel: No

Paolo D'Odorico
Email: pd6v@virginia.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Modeling of coastal lagoons

Funding Support: UVA

International Collaboration: No
International Travel: No

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, Italy
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

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

Contribution to the Project: Worked on streambed biogeochemistry

Funding Support: NSF

International Collaboration: No
International Travel: No

Nancy Moncrief

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

Contribution to the Project: Mammalian population ecology and genetics studies

Funding Support: Virginia Museum of Natural History

International Collaboration: No
International Travel: No

Laura 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

Alex Foxworthy
Email: wfoxworthy@es.vccs.edu
Most Senior Project Role: Community College Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Seagrass research collaboration via ROA supplement

Funding Support: NSF

International Collaboration: No
International Travel: No

Miranda Holland
Email: miranda.holland@accomack.k12.va.us
Most Senior Project Role: K-12 Teacher
Nearest Person Month Worked: 2

Contribution to the Project: RET participant - oyster reefs (Tedford mentored)

Funding Support: NSF RET supplement

International Collaboration: No
International Travel: No

Margaret Marshall
Email: mmarshall@ncpsk12.com
Most Senior Project Role: K-12 Teacher
Nearest Person Month Worked: 2

Contribution to the Project: RET participant - seagrass (Granville mentored)

Funding Support: NSF RET supplement

International Collaboration: No
International Travel: No

Krista Sadler
Email: krista.sadler@accomack.k12.va.us
Most Senior Project Role: K-12 Teacher
Nearest Person Month Worked: 2

Contribution to the Project: RET participant - island birds (Call mentored)

Funding Support: NSF RET supplement

International Collaboration: No
International Travel: No

Katherine Anarde
Email: kanarde@unc.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 6

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Lillian Aoki
Email: lra53@cornell.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 1

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

Funding Support: NSF

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: 6

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: 6

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

Funding Support: UVA, TNC

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

Ivy Hinson

Email: ihinson@email.gwu.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 4

Contribution to the Project: Worked with PI Gedan on marsh upland ecotone (Aug - Nov 2020)

Funding Support: NSF LTER

International Collaboration: No
International Travel: No

Aliya Khan
Email: akhan65@email.gwu.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 1

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: 12

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

Rose Mohammadi
Email: rmohammadi@email.gwu.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 10

Contribution to the Project: Worked with Gedan from Nov 2020 - Aug 2021 on forest disturbance exp; left for grad school at Berkeley in Aug. 2021

Funding Support: NSF LTER 50% / NSF CZN 50%

International Collaboration: No
International Travel: No

Jonah Morreale
Email: jm7ux@virginia.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 12

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: 2

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

Funding Support: GWU

International Collaboration: No
International Travel: No

Shannon Walker
Email: walkers5@mymail.vcu.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 7

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

Funding Support: VCU, US Army Corps, ORISE

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

Amelie C Berger

Email: acb4rk@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with PIs McGlathery and Berg on studies of seagrass metabolism using eddy covariance techniques

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Joseph Brown
Email: brownjk5@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF, VCU

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: NSF

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

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

Sara Hogan
Email: sh8kj@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with Reidenbach on oyster restoration

Funding Support: NSF

International Collaboration: No
International Travel: No

Dawn Holstein
Email: dnholstein@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF, GRF

International Collaboration: No
International Travel: No

Ieva Juska
Email: ij7tt@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

Ethan Kadiyala
Email: qkz8dd@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 (award to Castorani), UVA

International Collaboration: No
International Travel: No

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

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

Gourgue Olivier
Email: ogourgue@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: EU Scholarship

International Collaboration: Yes, Belgium
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

Lauren Wood
Email: woodlk@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Liu Zezheng
Email: zliu1@bu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Fagherazzi on tidal channels

Funding Support: Chinese Schoarship

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: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Carlens Jean
Email: jeanc@vcu.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 3

Contribution to the Project: Student research assistant on seagrass research collaboration via ROA supplement

Funding Support: ROA supplement

International Collaboration: No
International Travel: No

Oscar Melendez-Vera
Email: oscarmelendezvera@gmail.com
Most Senior Project Role: High School Student
Nearest Person Month Worked: 1

Contribution to the Project: REHS with seagrass project and Karpanty island birds

Funding Support: NSF

International Collaboration: No
International Travel: No

Abby Bollinger
Email: abollinger3939@gmail.com
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 4

Contribution to the Project: Gedan forest disturbance work

Funding Support: NSF LTER

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

Davis Coffey
Email: dnc3ex@virginia.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 4

Contribution to the Project: Berg bubble project

Funding Support: NSF LTER

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

Alex Marshall
Email: amm3hp@virginia.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 4

Contribution to the Project: McGlathery seagrass project

Funding Support: NSF LTER

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

Hayley Marshall
Email: hmm9jb@virginia.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 4

Contribution to the Project: Reidenbach seagrass project

Funding Support: NSF LTER

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

Megan Nicholson
Email: nicholsonma@mymail.vcu.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 4

Contribution to the Project: Zinnert island plant project

Funding Support: NSF LTER

International Collaboration: No
International Travel: No

Year of schooling completed: Junior
Home Institution: VCU
Government fiscal year(s) was this REU participant supported:

Luana Rebello
Email: rebellol@moravian.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 4

Contribution to the Project: Woods island shrub supplement project

Funding Support: Funded under Dr N Woods' ROA supplement for island shrub work

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

Kay Schlachter
Email: kcs5xu@virginia.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 4

Contribution to the Project: Castorani clam and seagrass project

Funding Support: NSF LTER

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

Rheya Sward
Email: rheya_sward17@gwu.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 4

Contribution to the Project: Gedan forest disturbance work

Funding Support: NSF LTER

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

Donna Fauber
Email: dhf4k@Virginia.EDU
Most Senior Project Role: Other
Nearest Person Month Worked: 4

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: 1

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

Virginia Institute of Marine Sciences

Organization Type: Academic Institution
Organization Location: Gloucester Point, VA

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution: Collaborate with Robert J. Orth on seagrass restoration

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

Impacts

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

VCR research has contributed to theoretical advances in understanding dynamics of state change in ecosystems dominated by foundation species. The VCR is one of the most expansive undisturbed coastal barrier systems in the world, and is an ideal location to assess climate impacts and ecosystem state change.

Our research focuses on barrier islands, salt marshes, and coastal lagoons with seagrass meadows and oyster reefs, and the connections between them. We link ecological and physical (geomorphic, hydrologic) processes that are critical to ecosystem dynamics. For example, sediment transport and deposition 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 develop and test mechanistic models with long- and short-term observations and experimental data, and using these to project state change and its ecological consequences.

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 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 2-decade landscape level experiment on seagrass (*Zostera marina*) restoration has shown that within a decade ecosystem services - primary productivity, carbon and nitrogen sequestration, increased water column clarity, and sediment stabilization are reinstated. We were the first to show the role of seagrass restoration in increasing ‘blue’ carbon storage. We have shown how marine heatwaves affect seagrass production and health, on scales from short-term (hours) to long-term (years. These results can help to identify optimal restoration sites in a warming ocean. Understanding how seagrass restoration and marine heatwaves affect ecologically and economically important fishes has implications for communities that rely on these species for their livelihoods. Our studies suggests that future climate-driven changes to seagrass, salt marshes, and barrier islands will change the local abundance and distribution of blue crabs.

Our seagrass and oyster research has made contributed to understanding success and failure in coastal restoration, recovery trajectories and timelines for success, functioning of restored ecosystems relative to natural references, and benefits for ecosystems and society, including carbon sequestration, biodiversity, and coastal protection. This body of work has also resulted in recommendations for the design, monitoring, and evaluation of restoration projects, and the communication of these recommendations to restoration practitioners (e.g., TNC) and policy-makers (e.g., NOAA)

Our research has identified the recovery timeline for restored oyster reefs and how long it takes to reach functional equivalence of restored and natural reefs. It also highlights the need for practitioners to increase monitoring time frames and include appropriate reference sites. Likewise, our oyster restoration meta-analysis supports the use of oyster restoration to increase ecosystem services in coastal habitats. We have shown the importance of predation as a potential constraint on restoration success. Validation of our oyster habitat suitability model shows the value of using physically-driven models to select optimal restoration sites.

Research on the invasive macroalga, *Agarophyton vermiculophylla*, is an example of how species introductions can lead to novel habitats. This macroalgae now dominates intertidal flats and marshes that previously did not support macroalgal populations. It has both positive and negative impacts on the system, supporting novel invertebrate communities and enhancing nitrogen removal through denitrification; at the same time it is associated with the pathogenic bacteria Vibrio spp. that is a public health hazard.

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, Surface Elevation Tables (SETs) and coupled models are used to predict changes in marsh habitat area and carbon sequestration benefits that can translate into carbon accounting efforts and species survival analysis for high marsh habitat specialists. 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, to whom we have presented our findings. 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. We quantified how across the breeding range of the Piping Plover storm overwash events cause dramatic population irruptions. Ocean intertidal habitat states, sand and exposed peat substrates, host unique invertebrate communities for migratory shorebird populations, and modeling is showing how these habitats and invertebrate communities will respond to warming ocean temperatures and acidification, and impact higher trophic levels.

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 non-linear dynamics and threshold responses to environmental drivers. We coined the term 'maintainer feedback' to apply to processes that maintain low elevations. This feedback, in conjunction with physical processes, has the potential to accelerate large-scale shifts from dune-dominated to overwash-dominated barrier islands with 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 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 CZ will study 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. The VCR LTER has also leverage support from the NSF Coasts and People program, for a project focused on climate equity in response to threats of saltwater inundation from sea-level rise and storms on the rural Eastern Shore of Virginia.

Biotic feedbacks in seagrass ecosystems on sediment deposition and resuspension by currents and waves measured by physical scientists are critical to understanding growth and population dynamics. We have created a novel model coupling hydrodynamics with vegetation growth that describes the non-linear state-change dynamics in seagrass and marsh ecosystems.

Research on ecological information management has included computer scientists. The challenges posed by ecological data provide opportunities for innovation in computer science. Our work 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. In collaboration with the LTER Ecological Reflections program we hold two Art and Ecology Professional Development workshops for public school Art Teachers annually. Participants are encouraged to find new ways to incorporate environmental issues/themes in their artwork and classroom projects. 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. We recently hosted the Coastal Futures Conservatory – an interdisciplinary science-art-humanities collaboration at UVA – and partners from several southeastern universities. 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 can be seen from the number of graduate and undergraduate students listed on our participant list, this project provides abundant opportunities for training. Moreover, the inter- and multi-disciplinary nature of the research teaches the students how to operate in a collaborative environment. 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, including one REU who studied with us during the summer of his transition from community college to a 4-year science program.

VCR LTER continues our strong tradition of training undergraduate and graduate researchers through a tiered mentoring program; this year 53 graduate students and 4 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. We have made strides in inclusive recruiting and selection for our REU program through partnerships with the NC-VA Alliance for Minority Participation and PathwaystoScience.org, resulting in 35 applicants from 17 institutions, of which 57% were female, 17% Asian, 11% African American, 7% Latinx, 2% Native, 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. All 40 teachers of Kegotank Elementary have 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) 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. 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.

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, 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 visceral sense of how changes to the landscape interact with water. Understanding this relationship is critical to understanding the coastal landscape.

What is the impact on physical resources that form infrastructure?

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

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

Berg has pioneered the approach of underwater eddy correlation to measure oxygen fluxes in benthic systems. This technique has the advantage over conventional techniques of measuring dynamic fluxes with a high temporal resolution (64 hz), and over a large spatial scale (10-100 km2), which captures natural heterogeneity in these systems. Novel results obtained from the application of this technique are the identification of multiple time-scale processes that drive seagrass, oyster, and algal metabolism, and a hysteresis in seagrass metabolism that occurs over the day.

Porter and Dueser have developed a low-cost “mousecam” system which allows unattended field photography of small mammals. It is a variant of a “Hunt Trap” which uses inverted 5-gallon buckets to exclude non-target species and extraneous changes in lighting, thus leading to low levels of false triggering. It can be used to assess occupancy and activity patterns in small mammals.

What is the impact on institutional resources that form infrastructure?

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

Our wireless network provides real-time access to remote monitoring locations in and around Hog Island 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 274 online datasets with an aggregate volume of approximately 456 GB. These are published via the VCR/LTER web site, the Environmental Data Initiative Data Portal and DataOne Search. The datasets are frequently downloaded for use by researchers and students. During the period from 11/1/2020 to 10/31/21 VCR/LTER data files have been downloaded at 1,726 times via the Environmental Data Initiative Data Portal. An additional 452 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 LTER Data Portal. They were used 1,117 times in the past year (excluding robots), with R-based code generated 55% of the time, Matlab 17%, Python 16%, SPSS 7% and SAS 6%.

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).

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).

PI Reidenbach developed online curriculum for middle school students to meet Commonwealth of Virginia learning standards for Environmental Sciences. Two online modules were developed: Sea-level rise impacts on coastal communities, and Marine biology and coastal ecosystems. (http://www.wiseengineering.org)

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. Citizen science efforts, such as the “Ghosts of the Coast” project, launched this year on Survey123 and SciStarter.com, allow for science communication directly to the public and an exchange of information that can inform new scientific research. 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.

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

Changes/Problems

Changes in approach and reason for change
Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them
Nothing to report.

Changes that have a significant impact on expenditures
Nothing to report.

Significant changes in use or care of human subjects
Nothing to report.

Significant changes in use or care of vertebrate animals
Nothing to report.

Significant changes in use or care of biohazards
Nothing to report.

Change in primary performance site location
Nothing to report.