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Preview of Award 1832221 - Annual Project Report

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Federal Agency and Organization Element to Which Report is Submitted:	4900
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Submitting Official (if other than PD\PI):	John H Porter Co-Principal Investigator
Submission Date:	12/02/2019
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 (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 3 meteorological stations (hourly), 3 tide and water temperature stations (every 6 minutes), a carbon-flux tower (10Hz), and numerous groundwater wells (6 minute - hourly). We monitored water chemistry (temperature, salinity, conductivity, turbidity, nutrients and chlorophyll at 15 sites (quarterly). Turbidity was also measured with satellite imagery. We host a NOAA Climate Reference Network station. A 35-year record of daily average water temperature was constructed to analyze trends and extremes in VCR bays.

Patterns of Change: The barrier islands are highly dynamic, with some shorelines changing by 10s of m per year. We use satellite imagery, aerial photos, LiDAR, drone imagery, published GIS layers, and structure-from-motion (SfM) technology to determine landscape change on islands (geomorphology, vegetation), wetlands and oyster reefs. For islands, we use LiDAR to examine change in upland volume and Sentinel satellite imagery to monitor rapid erosion. We compiled data on storms in 2013-2018. We continued long-term experiments on seagrass and oyster reef

restoration, tree removal on marsh transgression, and grass-shrub transitions on islands.

Dynamics within Landscape Units

Upland - Marsh: We established a new long-term experiment to test mechanisms that govern the transition from forest to marsh. This involved: 1 setting up 24 plots (20x20m) with ghost forests and healthy forests in 3 zones of sea-level rise (SLR) and storm impact; 2) gathering baseline data by tagging all trees and shrubs, measuring tree DBH, and monitoring non-woody vegetation including the invasive common reed; 3) installing wells (groundwater level and salinity), soil moisture sensors and weather stations along transects at the marsh-forest boundary; 4) installing 12 SETs and marker horizons to measure soil elevation and sediment deposition; 5) using drone imagery to monitor tree mortality; and 6) collecting benthic invertebrates. Half the plots will be disturbed in the future.

Intertidal: In a mesocosm study, we studied the effect of density vs. body-size of the fiddler crab on salt marsh characteristics (plant biomass, soil carbon). We did feeding trials (in tall *Spartina alterniflora* vs. short *S. alterniflora*) and predator-risk studies, and measured plant traits to link to purple marsh crab distribution and grazing.

Subtidal: We monitored the landscape-scale, long-term experiment on seagrass restoration and resilience, now in its 18th year. We expanded the spatial scale with 24 sites in 3 new coastal bays, and tested methods for a new long-term experiment that will launch in 2020 on seagrass resilience to marine heatwaves. We completed a 1-yr field experiment with artificial seagrass to isolate the effects of plant structure on sediment grain size, organic matter, and epiphyte biomass that influence seagrass state change.

Barrier Island: To address mechanisms of state change between grasslands and shrubs, we: 1) monitored long-term 5x5 m plots, including clear-cut shrubs across the grass/shrub ecotone; 2) used a novel time-series analysis to interpret microclimatic temperature variance in grass, transition, and shrub plots; 3) initiated a new experiment with shrub seedlings in clipped vs. unclipped grass plots; 4) measured shrub growth, seasonal physiology, and soil N; and 5) conducted lab freezing experiments on shrub seedlings. To explore the feedbacks between plants and geomorphology, we: 1) modified the coastal dune model to include vegetation dynamics (mortality due to overwash) and colonization from wrack containing plant propagules; 2) conducted experiments on wrack effects on dune morphology; and 3) parameterized the model to represent growth and behavior of the grass *Spartina patens*.

Dynamics Between Landscape Units

Sediment Transport: To evaluate how sediment transport affects state transitions across the landscape, we: 1) quantified how turbulent exchange of water flow along the channel-marsh boundary varies over time and how this controls sediment transport to the marsh; 2) developed and extensively tested a large-scale, spatially resolved model of flow and sediment dynamics that includes vegetation to examine spatial and seasonal dynamics of flow and sediment between tidal flats and adjacent seagrass meadows; and 3) extended the flow and sediment dynamic model to investigate coupling between seagrass meadows and marshes.

Oyster Larval Transport and Population Dynamics: We quantified oyster growth and density along 8 constructed oyster reefs and measured oyster recruitment at 14 sites over 250 km2. We initiated a caging experiment at 2 restored reefs to determine effects of depth and landscape-scale position on predation and survival of tethered oysters.

Subtidal - Intertidal Coupling: We monitored 8 restored oyster reefs of varying elevation and spatial extent to determine optimal designs for population stabilization, biodiversity,

organic matter/carbon accumulation and wave attenuation. Wave propagation and height dissipation were measured across each reef and adjacent to the marsh. A VCR-wide survey of mudflats was done to determine geomorphic and hydrodynamic factors affecting the abundance of the invasive macroalga *Agarophyton vermiculophyllum*.

Barrier Island Ecosystem Coupling: We monitored cross-island transects on 2 islands for species composition, % cover, productivity, and plant functional traits, and we characterized vegetation and topography using optical (RGB) and multispectral (5-band) drone imagery and SfM at scales of 40–50 ha.

Coupling Between Non-adjacent and Adjacent Systems: We incorporated seagrass dynamics into the marsh-barrier island model GEOMBEST++ to examine coupled interactions of coastal bays with adjacent (marsh) and non-adjacent (barrier island) systems. We developed a barrier island model that incorporates the relationship between dunes and shrubs.

Ecological Consequences of State Changes

Carbon (C) Sequestration: Our work tests how state change affects C storage and sequestration. At the upland-marsh transition, we: 1) used allometric equations to quantify C in trees and shrubs, destructive harvests for C in herbaceous plants, and sediment coring for soils; and 2) related spatial gradients in C stocks to measurements of elevation, species, and soil characteristics. On barrier islands, we: 1) measured standing stocks of soil C in sediment cores along the grass-shrub ecotone and the shrub chronosequence; and 2) measured DOC in groundwater. In seagrass meadows, we: 1) monitored C burial and standing stocks in sediment and sequestered in plant biomass; and 2) used the underwater eddy covariance technique to quantify seagrass metabolism and CO2 dynamics. In marshes, we sampled standing stocks of sediment C to determine if C produced in seagrass meadows is stored in adjacent marshes; and 2) used the long-term eddy covariance system to measure CO2 fluxes.

Consumer Dynamics: We studied ecosystem state change effects on consumer populations. For shorebirds, we: 1) tested how the invasive algae affected habitat selection and invertebrate prey using visual surveys and structural equation modeling; 2) collected our 14th year of data on migrant shorebirds and their prey, and modeled the factors driving abundance and distribution; 3) completed stable isotope analyses of blue mussel prey to assess source populations; 4) synthesized storm impacts on Piping Plover nesting populations; 5) initiated nest monitoring of American Oystercatchers and Plovers on 3 islands to link with geomorphology and vegetation; and 6) banded Plovers to monitor movements, survival and reproduction. In the subtidal, we started a new long-term time series of seagrass epifauna (throw traps), infauna (cores), fish (seines), and crabs (baited traps) at 24–50 sites across 5 bays. In the intertidal, we measured infauna (abundance, diversity, and biomass) at the 8 restored oyster reefs.

Specific Objectives:

Drivers of Long-term Change

Significant Results:

We identified 574 storms from 2013 to 2018. The storm event in Fall 2015 (Hurricane Joaquin followed by a nor'easter) was the most powerful during this period and will be used for subsequent barrier island landscape modeling. Summertime water temperature is increasing significantly at a rate of 0.021 +- 0.017 °C/y. Days with average temperature >28°C have increased over time, mostly in July (Fig. 1). Marine heat waves are occurring more frequently (19 in the 35-y record). Landsat-8 imagery predicted 31% of the variation in Secchi depth in long-term water quality data (Fig. 2), and described seasonal and interannual trends. Bays had highest clarity in winter and lowest in summer, coinciding with seasonal patterns in phytoplankton and turbidity.

Dynamics within Landscape Units

Upland – Marsh: Chronologies (2000 year) of forest retreat show that marsh migration rates are accelerating in parallel with SLR over decades to centuries. However, modern patterns of vegetation and mortality do not follow current topography, and gradients in forest health occur despite a narrow range of elevations. Model results indicate that for low to moderate upland slopes the landward marsh edge is controlled by the interaction of flooding and forest recovery resulting in punctuated transgressive events. There is a persistent zone of coastal pine forest where young trees cannot establish because they are sensitive to flooding or salinity stresses, but less-sensitive older trees can survive (Fig. 3). This zone, representing up to 1/5 of VCR forested area, is vulnerable to extreme events because the forest is unable to regenerate when mature trees are killed by storms. Lower forest resilience in this zone is reflected in remote sensing imagery. Our findings corroborate the ecological ratchet model of coastal forest disturbance (Fig. 4).

Intertidal: Fiddler crabs enhanced cordgrass growth in some marshes, but not enough to increase sedimentation. Purple marsh crabs decreased cordgrass growth and in some bare areas sedimentation was greater than ungrazed areas possibly due to bioturbation by fiddler crabs attracted to areas denuded of plants. Macroalgal coverage is dominated by the invasive *A. vemiculophylum;* regional coverage is predicted by microtopographic variation in concert with water residence time and fetch.

Subtidal: The landscape-scale seagrass experiment shows that seagrass biomass, primary productivity and C burial rates are restored to levels of natural meadows within a decade. Restoration resulted in enhanced C stocks (2x), nitrogen stocks (4x), N fixation rates (2x), denitrification rates (4x), N burial (10x), methane emissions (7x), and N2O emissions (3x). Loss of N by burial and denitrification in seagrass meadows exceeds N input from external sources. The seagrass meadow was resilient to a marine heat wave that reduced biomass by 90% in some areas; biomass recovered within 2-4 years (Fig. 5). Metabolism during 2007-2018 was enhanced (10-25x) and balanced overall (P:R=1.01) but variable, with net heterotrophy immediately during the die-off followed by net autotrophy as the meadows recovered. Proximity of meadows to inlets that bring cool ocean water during high tides modulates heat stress. Seagrass meadows doubled benthic microalgal activity, reflected in sediment carbohydrate concentrations. This increased the critical shear stress for sediment erosion, especially during summer, which helped reduce sediment suspension.

Barrier Island: Encroachment of the dominant shrub *Morella cerifera* into grasslands is driven by reduced local exposure to cold temperatures and enhanced by positive feedback on microclimate. Grasses provided ~1.3°C insulation to shrub seedlings during winter. Shrub seedlings reduced summer extremes even before full thickets coalesce. Grasses improve germination and survival of young seedlings (<1 yr) even though seedlings compete for light with grasses during warm months. The coastal dune model shows that dunes grow lower and wider when marsh wrack containing propagules is present, and that the high-marsh grass *Spartina patens* speeds up the dune-building process by enhancing deposition so that dune grasses can become established sooner. This finding is supported by field experiments.

Dynamics between Landscape Units

Hydrologic Connectivity: Oyster life stage, landscape position, and depth, interact to control survival. Recruitment was highly variable across spatial scales; within-bay recruitment was as variable as among-bay recruitment, suggesting the importance of local-scale factors. Larval supply was not limiting, and oysters recruited equally to natural shell reefs and artificial reefs. Juvenile and adult oysters had similar mortality (5–20%) in tethering experiments. Predation on juvenile oysters was greatest in the intertidal, and on adult oysters in both the intertidal and subtidal. Modeling of seasonal hydro-, sediment and vegetation dynamics indicate that meadows are effective sediment traps in summer. In winter meadows with lower biomass near a threshold

between trapping and releasing sediment, making winter sediment fluxes sensitive to specific storm conditions, vegetation state, and sediment depositional patterns from the previous summer.

Coupled State Change Dynamics: LiDAR-derived remote sensing data identified oyster reefs with an accuracy of 81%. Reef crests occurred in a narrow range of elevation (-0.68 to -0.05 m MSL), with a mean vertical relief of 0.14 m. Habitat suitability analysis showed oysters occupy 12% of intertidal area, suggesting that there is ample intertidal area for future restoration. On barrier islands, the GEOMBEST+ model showed that seagrass are a dynamic source or sink of sediment that impacts the evolution of adjacent marshes, and that their presence reduces island migration rates by taking up accommodation space in the bay.

Ecological Consequences of State Changes

Carbon Sequestration: Carbon stocks decrease by about half along a gradient from healthy forest to marsh, representing the temporal migration of ecosystems with SLR (Fig. 6). Soil C and herbaceous vegetation stocks increase from forest to marsh, but this is offset by larger declines in woody biomass. We estimated 200 years for soil C accumulation in marshes to offset losses associated with forest mortality. On the islands, standing stocks of soil C were highest in in the top 5 cm of soil under shrub thickets, but there was no difference in soil carbon down to 60 cm between grasses and shrubs. For seagrass meadows, despite the increase in greenhouse gas emissions, seagrass meadows are a net sink of C, burying 2x more C than bare sediments. Following the marine heat wave, sediment C stocks were reduced by 50% and have lagged behind seagrass biomass recovery.

Consumer Dynamics: Generalist shorebirds select patches of macroalgae and specialist shorebirds select bare sediments; where abundant, invasive macroalgae reduce foraging by specialist birds. Storms caused population irruptions of the federally threatened Piping Plover at the VCR and throughout its range. Over a 13-year period the distribution and number of migrant shorebirds were 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 stable isotopes indicate that blue mussel prey originate from colder, more saline waters than exist in the VCR. In seagrass meadows, blue crabs were more abundant in areas with lower shoot density regardless of sex or size. Egg-bearing females were more abundant outside or near the edge of meadows, and other small crabs were less abundant in meadows. Clams were more abundant within seagrass meadows. Fish abundance increased with distance inwards from meadow edge, suggesting that larger meadows may support greater densities of resident and small, transitory fishes.

Key outcomes or Other achievements:

VCR scientists have published 22 journal articles, 1 book chapter and 3 theses or dissertations in the first year of this funding cycle. A complete list of publications can be found at https://www.vcrlter.virginia.edu/home2/?page_id=215.

Drivers of Long-term Change

Climate Drivers of Change

Summertime water temperatures in the bays of the VCR have increased significantly over the last 35 years at a rate of 0.021 +- 0.017 °C/y as have the number of days with daily average temperature in excess of 28 °C. The system has experienced 19 marine heatwaves over the last 35 years. These have not varied in intensity through time but are becoming more frequent.

Patterns of Change

In our landscape analysis of the Virginia barrier islands (1984, 1998, 2011, 2016), we found both gains and losses in back-barrier marsh and upland, with 19% net loss from the system and increased variance in marsh to upland conversion. This is consistent with recent work indicating a shift towards increasing rates of landward barrier island migration. Despite net loss of upland area, macroclimatic winter warming resulted in 41% increase in woody vegetation in protected, low elevation areas, introducing new ecological scenarios that increase resistance to sediment movement from upland to marsh. Our analysis demonstrated how the interplay between dune elevation and interior island vegetative cover influences landward migration of the boundary between upland and marsh.

Dynamics within Landscape Units

Forest - Marsh - Tidal Flats

Inspired by observations from the VCR, we synthesized studies from around the world that document sea-level driven land conversion and its effect on coastal economies. Migration of wetlands into uplands disproportionately affects rural coasts, and is accelerating through time. Rates of land-conversion depend on topographic slope and rates of sea level rise, suggesting that the rural, subsiding, and gently sloping VCR is a bell-weather for change that will be observed elsewhere in the future.

We determined that coastal forests close to salt marshes contains a persistent but non-regenerating zone of mature trees, the size of which is related to the sea level rise experienced since forest establishment. The transgression of coastal forest and shrub or marsh ecosystems is an ecological ratchet: sea-level rise pushes the regeneration boundary further into the forest while extreme events move the persistence boundary up to the regeneration boundary.

Subtidal

Our landscape-level restoration seagrass experiment, now in its 18th year, shows that key ecosystem services, including primary productivity, carbon sequestration, nitrogen removal, sediment stabilization and habitat provisioning are reinstated within a decade. We also found that the seragrass meadows are resilient in some areas to marine heat waves, with plant biomass recovering within 2-4 yr, although lost sediment carbon lag behind.

Seagrasses reduce mean currents and waves, thus lowering suspended sediment concentrations within the meadow. In addition, seagrass create favorable conditions for benthic microalgal growth, with annual mean sediment carbohydrate concentrations, a proxy for benthic microalgal activity, to be double within the seagrass compared to the unvegetated site. This enhanced the critical shear stress necessary to erode sediments.

Our modeling results indicate that the common conception that seagrass meadows trap sediment in summer and then release much of that in winter should be reconsidered. Depending on the residual density and characteristics of the meadow and the nature of the particular storms in any given winter, the meadow can sequester sediment throughout the year. This has implications for sediment deposition rates on adjacent marshes.

Barrier Island

We have determined that cold temperatures limited shrub survival in both seedlings (<-11 C) and adults (<-16 C) and grasses provide insulation to shrub seedlings. Microclimatic temperature modification by shrubs is evident at multiple life stages, even before coalescence into full shrub thickets, especially during summer months.

Dynamics between Landscape Units

Sediment Transport

The sediment budget among bare tidal flats, seagrass meadows, and adjacent marsh depends sensitively on the wintertime seagrass density and characteristics. In summer, any sediment reaching a seagrass meadow is sequestered. In winter, this sediment may be redistributed within the meadow and the meadow may be a net sink or source of sediment depending on the particulars of the winter storms and the condition and extent of the meadow.

Coupled State Change Dynamics

Subtidal - Intertidal Coupling

Using LiDAR based remote sensing, we determined that oyster patches in the VCR are small, with the 50th percentiles for area and perimeter being 11.6 m2 and 14.5 m, respectively. Reef crests occur in a narrow range of elevation (-0.68 to -0.05 m MSL) and patches have an average vertical relief of 0.14 m. Oysters currently occupy 12% of the suitable intertidal area in the VCR, suggesting that there is ample intertidal area for future restoration.

Barrier Island Ecosystem Coupling

Dune elevation is critical in structuring adjacent, low elevation swale species composition, functional trait composition, and annual net primary productivity.

Ecological Consequences of State Changes

Carbon Sequestration

Total carbon stocks decreased by about half along a spatial gradient from healthy forest to marsh, representing the temporal migration of ecosystems with sea level rise. We estimate that it will take on the order of 200 years for soil carbon accumulation in marshes to offset the losses associated with forest mortality.

A state change from bare sediments to seagrass meadows doubled carbon storage in coastal bay sediments within a decade. These carbon stores are vulnerable to marine heat waves which cause die-off of seagrass plants that stabilize sediments.

Consumer Dynamics

Prior studies indicate that invasive macroalga *A. vermiculophylum* provides or enhances some ecosystem services. However over large spatial scales in the VCR, we found effects on consumers (invertebrates and birds) were either neutral or negative. Physical variables provided better resolution of the variability in these consumers.

Long-term monitoring of migrant and nesting shorebirds, demonstrates a variability in short- and long-term responses to climate drivers, including temperature and storms. Piping plovers, an exemplar species of ground-nesting shorebirds in the VCR, respond with dramatic population irruptions following storm-driven habitat creation. However, migrant shorebirds rely on two types of bivalve prey with differing responses to ocean temperature. Important coquina clam prey which are found on sandy intertidal beaches in the VCR are expected to grow larger sooner under warming ocean temperatures, while blue mussel prey may be lost due to warming temperatures. Our long-term monitoring dataset will allow us to continue to relate changes in prey and migrant shorebirds to climate drivers. Ongoing and future work will also assess acidification effects on bivalve prey.

*** 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 15 undergraduates and 38 graduate students and 7 post-docs conducted research through the program. Several students from the local community are becoming 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. In keeping with our goal of building diversity at the VCR, in September we hosted and provided programming for the ESA SEEDS Leadership Meeting for URM science students from across the country.

This year VCR LTER established a new direction for collaborative outreach. In January 2019, 25 VCR researchers and students and over 75 members of the community gathered in At Altitude Gallery for “See What the Scientist Sees” – a research discussion facilitated by aerial photography of the coastal barrier system. In July we held a conversation café with the local arts community to ignite collaborations. Then, in September 2019, we opened a seasonal listening exhibit by the Coastal Conservatory at the Barrier Islands Center cultural heritage museum. The reception was well attended and was covered by the press. The Listening for Coastal Futures: Sounding Science installation includes both coastal sounds and sonified data from VCR LTERs 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.

Our K-12 initiatives remain focused on professional development sessions that impact a minimum of 45 teachers per year, with a goal of increasing environmental literacy and strengthening STEM education on the Eastern Shore and throughout Virginia. We provide two annual Art and Ecology workshops for teachers: plein aire painting and observational drawing. Both focus on observation as the origination for both art and science. In 2019 the program was updated to encourage the enrollment of pairs of science and art teachers, and the final day now focuses on lesson plan development for translation of the experience into the classroom.

In May 2019, we immersed 15 teachers from Clarke County, VA in a meaningful watershed education experience (MWEE) during a 3-day professional development workshop. With guidance from the VCR LTER site director and environmental educators at Blandy Experimental Farm (UVA), teachers explored how their county is connected to the health of coastal waters and formed plans to implement watershed learning into all subject areas. Through this program, our RET (see below), and ongoing partnerships with The Nature Conservancy, VCR SLTER contributes to both teacher professional development and to assisting teachers with issue definition and supporting students to make sense of data. We are using the results of a Needs Assessment (IRB 2907) completed by 80 regional teachers to guide development of continued programming and to provide a baseline against which to gauge their effectiveness.

We also received supplemental RET funding to support research with a 5th grade science teacher for summer 2019. Ms. Stevens’ research piloted a decomposition study under consideration as an LTER cross-site citizen science initiative. We piloted a new model for this RET by partnering with a science education faculty member (UVA), which resulted in modifications to Ms. Stevens instructional model, classroom design, and assessments. We are also examining options for scaling this partnership up in a co-training model. As we build our classroom presence, we continued to provide scholarships for URM students (ages 6-12) to attend week-long sessions of Nature Camp, which focuses on exploring coastal barrier environments while learning about environmental issues. VCR LTER students also partnered with the Eastern Shore Public Library to create science literacy bags and a summer science reading program for early childhood and elementary age students; the program is expected to continue and expand.

*** How have the results been disseminated to communities of interest?**

The VCR disseminates research findings and data through the VCR LTER website (https://www.vcrlter.virginia.edu). Use of the website has increased modestly over the last 12 months, with 9,703 page views in 4,400 sessions by 2,500 distinct users. During that same period, VCR/LTER data files were downloaded 2,297 times from the LTER or Environmental Data Initiative Portals.

As coastal resilience issues and problem-solving gain urgency, especially with the proclamation of Virginia’s new resilience initiatives, VCR LTER researchers and staff spent much of 2019 in a resource capacity for resilience planning. We served on the implementation team for our county’s Resilience Adaptation Feasibility Tool (RAFT) action plan and are now co-leading the revitalization of a climate adaptation working group to guide localities through coastal risks and resilience actions. We coached students on interdisciplinary problem-solving during Sea Grant-led team science workshops, contributed to resilience roundtable discussions in the region, and joined a marsh summit that gathered both researchers and practitioners dealing with coastal issues and resilience.

We also contributed public talks to local civic groups and presented our research and education initiatives as the plenary session for the Mid Atlantic Marine Educators Association.PIs and graduate students are invited speakers for presentations at

venues like the Barrier Islands Center Museum, Eastern Shore Community College, Science and Philosophy seminar series, Garden Club and Rotary club meetings. These presentations are open to the public and attended by local residents and county planners/administrators. VCR PIs and graduate students from UVA and our partner institutions also provide lectures to school and public groups in their areas.

VCR LTER researchers provided plenary talks on SLR and marsh migration at the Marsh Resilience Summit, a two-day science-practitioner dialogue about marsh vulnerability and ways our disciplines and communities respond to changing landscapes. Multiple PIs also contributed regional results and VCR conceptual frameworks to a series of Resilience Roundtables, which brought together researchers and practitioners from coastal Virginia to establish collaborations and identify next steps in coastal research and resilience. In addition to using our new approach of art-based dialogue to engage the public with our research, co-investigators contributed public talks to civic groups in the VCR region and presented our research and education initiatives as the plenary session for the Mid Atlantic Marine Educators Association. Recent research was also presented by over a dozen VCR participants at (bi)annual meetings of the ESA, CERF, ASLO, and AGU. VCR LTER projects, including those on marsh migration and seagrass restoration, received press coverage by UVA Today, the Eastern Shore News (Delmarva Now), Eastern Shore Post, The New York Times, and Time Magazine, among others.

The VCR also remains an active member of the NOAA Sentinel Site Program for the Chesapeake Bay Sentinel Site Cooperative to assess marsh response to sea-level rise. The Cooperative works to maximize the effectiveness of data collection, modeling, and synthesis of marsh responses to a changing climate. VCR is helping to lead a recently funded CBSSC initiative to provide a resilience action workshop for practitioners and planners in the region.

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

Drivers of Long-term Change

Climate Drivers

In our analysis of the historical temperature record and marine heat waves in the VCR we will focus on the attributes of marine heat waves that have been associated with seagrass die-off and how they differ from heatwaves that did not affect seagrass densities.

To improve the accuracy of our predictive modeling of coastal water clarity, we will expand satellite measurements using additional imagery gathered by the Sentinel II system.

We will sample water on peat banks to assess ocean acidification and its impact on bivalve prey of importance to migrant shorebirds.

Patterns of Change

We will develop drone methods to measure macroalgae, oyster reefs and tidal flats. We will determine change in the geomorphology of mudflats and intertidal soft-sediment pools on scales of days to years and relate biodiversity.

We will use drone-based photography and structure-from-motion analysis (SfM) to create high-resolution maps of the morphology of the marsh - tidal flat transition and to monitor its change in response to storms. We will continue annual drone flights and SfM analysis of 2 islands at 40-50 ha scales using optical and multispectral imagery. From the orthomosaics, we will develop models of vegetation (NDVI), elevation. We will use pre- and post-storm satellite imagery to analyze barrier island state change on multi-decadal time scales.

We will remap the bathymetry of Hog Island Bay using a new high-resolution bathymetric sounder to quantify change in bathymetry over the last 20 years. We will also establish new bathymetric transects that will form the beginning of a new long-term dataset on bathymetric change in the bays of the VCR.

Dynamics within Landscape Units

Upland - Marsh

We will monitor tree and shrub survival and growth within experimental plots spanning a ghost forest to healthy forest transition. We will track herbaceous vegetation, and tree seedlings. We will install sap flux sensors to measure transpiration continuously, measure SET’s 4 times this year across the marsh-forest gradient and re-sample the experimental plots for benthic invertebrates.

We will collect high resolution hydrological data on two transects at the marsh - forest transition and will develop a hydrological model linking flooding, groundwater levels and salinity to storm surges and rainfall events.

Intertidal

With experimental field studies we will test the effect of fiddler crab body size and density on marsh functions (decomposition, primary production) as part of a cross-LTER experiment with GCE and PIE. We will conduct a caging study to determine the factors that influence crab distributions in the marsh and how they contribute to marsh geomorphology.

We will continue to develop and apply our model of coupled tidal flat and marsh environments to examine the effects of seagrass meadows on marsh deposition rates and patterns, and asses the effects of storm surge on marsh deposition with respect to SLR.

Subtidal

We will continue the long-term seagrass restoration/resilience experiment including measurements O2, CO2 and methane fluxes, and establish replicate large scale plots of seagrass removal at 2 locations that differ in exposure to high temperatures to test seagrass resilience.

We will continue to investigate the coupled dynamics of tidal flats and seagrass meadows using a high-resolution hydrodynamic model that has been tested in the VCR.

Barrier Island

We will continue monitoring our long-term plots shrub thicket, seedling and grass plots. We will begin our experimental nitrogen additions at three distances from shrub thickets.

Dynamics between Landscape Units

Sediment Transport

We will continue to quantify the physical parameters controlling sediment flux between the lagoon and marsh, including near continuous water flow, turbulence, wave, and suspended sediments.

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 and the importance of storm surge events on transport from tidal flats to marshes.

Oyster Larval Transport and Population Dynamics

We will characterize interannual variability in oyster recruitment at 15 sites and expand our caging experiment to 8 sites to examine predation on juveniles and adults in the intertidal and subtidal. We will also quantify the density and identity of stage-specific oyster predators.

Using our hydrodynamic model, we will track the likely dispersal pathways of oyster larvae and connectivity among oyster reefs.

Coupled State Change Dynamics

Wave heights, bed shear stress and suspended sediment concentrations will be measured adjacent to a marsh edge both behind constructed oyster reefs and at adjacent sites to determine the impact that offshore reefs have on marsh edge erosion. LiDAR-based remote sensing and drones will be used to quantify the location and rate of change of the marsh edge.

We will use repeat drone imagery to extract topographic features from cross-island plots and follow dune development over time and changes in species composition and productivity in swales. Using the new 3-dimensional, spatially explicit morphological-ecological model, we will examine feedbacks between shrubs and overwash that can impact long-term island evolution. We will use this model to assess the time scales and conditions under which shrubs are predicted to promote or prevent islands from keeping up with sea-level rise.

Ecological Consequences of State Changes

Carbon Sequestration

We will measure C burial rates in soils near the marsh-forest boundary and develop site-specific curves relating LOI to total organic C. We will compare measurements of soil C accumulation to standing stocks to develop a C budget for the migrating marsh-forest boundary. We will continue to measure soil and groundwater C in grass and shrub habitats on barrier islands, and in the long-term seagrass restoration experiment. We will then compile measurements of soil C burial across multiple ecosystems (forest, marsh, seagrass, barrier islands) to begin developing a landscape-scale C budget. We will assess if C sequestered by seagrass is transported and buried in adjacent marshes.

We will augment the flux tower with a SIF (solar-induced fluorescence) sensor (measuring a proxy for photosynthesis), which we will compare with CO2 eddy-covariance flux measurements to improve our understanding of salt marsh net ecosystem exchange. The measurements here will enable future upscaling of GPP using satellite data.

Consumer Dynamics

We will collect our 15th year of spring migrant shorebird data, including samples of shorebird prey across the VCR. With collaborators we will conduct a 2nd year of nesting shorebird monitoring at the new long-term barrier-island sites and will band an additional 50 Piping Plovers. In partnership with TNC, VDGIF and USFWS, we will quantify factors affecting the reproduction and survival of American Oystercatcher and will conduct a full-season of water and blue mussel sampling on peat banks to test and develop models linking ocean acidificiation and bivalve growth. We will continue to monitor potential movements, or lack thereof, of colonial seabirds from a destroyed Chesapeake Bay nesting colony to the VCR using GPS tags and leg bands.

To determine patterns of seagrass biodiversity and establish a new time series, we will collect epifauna (throw traps), infauna (cores), fish (seines), and crabs (baited traps) at 24–50 sites across 5 bays.

To understand drivers of fish assemblages, we will analyze long-term fish seine data. We will relate response variables (fish abundance, species richness, evenness, composition) to local and landscape-scale ecological and environmental data that include habitat (seagrass characteristics at multiple scales), prey abundance (from infauna and epifauna sampling), and oceanographic conditions (from water quality sampling and remotely-sensed data).

Supporting Files

Filename	Description	Uploaded By	Uploaded On
Figures.pdf	Figures referred to in the text	John Porter	12/02/2019

Products

Books

Book Chapters

C. Reid Nichols, Julie Zinnert, Donald Young (2019). Degredation of Coastal Ecosystems: Causes, Impacts and Mitigation Efforts. *Tomorrow's Coasts: Complex and Impermanent. A collaborative synthesis promoted by the Coastal and Environmental Research Committee of the Southeastern Universities Research Association (SURA)* Linn Donelson Wright and C. Reid Nichols. Springer. . Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes ; ISBN: 978-3319754529.

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.

Mullins, Elsemarie and Moore, Laura J. and Goldstein, Evan B. and Jass, Theo and Bruno, John and Durán Vinent, Orencio. (2019). Investigating dune-building feedback at the plant level: Insights from a multispecies field experiment. *Earth*

Surface Processes and Landforms. . Status = Deposited in NSF-PAR doi:10.1002/esp.4607 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 11/25/2019) Full text Citation details

Zhang, Xiaohe and Leonardi, Nicoletta and Donatelli, Carmine and Fagherazzi, Sergio. (2019). Fate of cohesive sediments in a marsh-dominated estuary. *Advances in Water Resources*. 125 (C) 32 to 40. Status = Deposited in NSF-PAR doi:10.1016/j.advwatres.2019.01.003 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 11/25/2019) Full text Citation details

Fagherazzi, Sergio and Nordio, Giovanna and Munz, Keila and Catucci, Daniele and Kearney, William S.. (2019). Variations in Persistence and Regenerative Zones in Coastal Forests Triggered by Sea Level Rise and Storms. *Remote Sensing*. 11 (17) 2019. Status = Deposited in NSF-PAR doi:10.3390/rs11172019 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 11/25/2019) Full text Citation details

Coleman, Daniel J. and Kirwan, Matthew L.. (2018). The effect of a small vegetation dieback event on salt marsh sediment transport: The effect of vegetation dieback on salt marsh sediment transport. *Earth Surface Processes and Landforms*. . Status = Deposited in NSF-PAR doi:10.1002/esp.4547 ; Federal Government's License = Acknowledged. (Completed by Porter, null on 11/25/2019) Full text Citation details

Cohn, Nicholas and Hoonhout, Bas and Goldstein, Evan and De Vries, Sierd and Moore, Laura and Durán Vinent, Orencio and Ruggiero, Peter. (2019). Exploring Marine and Aeolian Controls on Coastal Foredune Growth Using a Coupled Numerical Model. *Journal of Marine Science and Engineering*. 7 (1) 13. Status = Deposited in NSF-PAR doi:10.3390/jmse7010013 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 11/25/2019) Full text Citation details

Donatelli, Carmine and Ganju, Neil K. and Kalra, Tarandeep Singh and Fagherazzi, Sergio and Leonardi, Nicoletta. (2019). Changes in hydrodynamics and wave energy as a result of seagrass decline along the shoreline of a microtidal back-barrier estuary. *Advances in Water Resources*. 128 (C) 183 to 192. Status = Deposited in NSF-PAR doi:10.1016/j.advwatres.2019.04.017 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 11/25/2019) Full text Citation details

Macreadie, Peter I. and Anton, Andrea and Raven, John A. and Beaumont, Nicola and Connolly, Rod M. and Friess, Daniel A. and Kelleway, Jeffrey J. and Kennedy, Hilary and Kuwae, Tomohiro and Lavery, Paul S. and Lovelock, Catherine E. and Smale, Dan A. and Apostolaki, Eugenia T. and Atwood, Trisha B. and Baldock, Jeff and Bianchi, Thomas S. and Chmura, Gail L. and Eyre, Bradley D. and Fourqurean, James W. and Hall-Spencer, Jason M. and Huxham, Mark and Hendriks, Iris E. and Krause-Jensen, Dorte and Laffoley, Dan and Luisetti, Tiziana and Marbà, Núria and Masque, Pere and McGlathery, Karen J. and Megonigal, J. Patrick and Murdiyarso, Daniel and Russell, Bayden D. and Santos, Rui and Serrano, Oscar and Silliman, Brian R. and Watanabe, Kenta and Duarte, Carlos M.. (2019). The future of Blue Carbon science. *Nature Communications*. 10 (1) . Status = Deposited in NSF-PAR doi:10.1038/s41467-019-11693-w ; Federal Government's License = Acknowledged. (Completed by Porter, John on 11/25/2019) Full text Citation details

Robinson, Samantha and Fraser, James and Catlin, Daniel and Karpanty, Sarah and Altman, Jon and Boettcher, Ruth and Holcomb, Kevin and Huber, Coral and Hunt, Kelsi and Wilke, Alexandra. (2019). Irruptions: evidence for breeding season habitat limitation in Piping Plover (Charadrius melodus). *Avian Conservation and Ecology*. 14 (1) . Status = Deposited in NSF-PAR doi:10.5751/ACE-01373-140119 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 11/25/2019) Full text Citation details

Fagherazzi, Sergio and Anisfeld, Shimon C. and Blum, Linda K. and Long, Emily V. and Feagin, Rusty A. and Fernandes, Arnold and Kearney, William S. and Williams, Kimberlyn. (2019). Sea Level Rise and the Dynamics of the Marsh-Upland Boundary. *Frontiers in Environmental Science*. 7 . Status = Deposited in NSF-PAR doi:10.3389/fenvs.2019.00025 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 11/25/2019) Full text Citation details

Duvall, Melissa S. and Wiberg, Patricia L. and Kirwan, Matthew L.. (2019). Controls on Sediment Suspension, Flux, and Marsh Deposition near a Bay-Marsh Boundary. *Estuaries and Coasts*. 42 (2) 403 to 424. Status = Deposited in NSF-PAR doi:10.1007/s12237-018-0478-4 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 11/25/2019) Full text Citation details

Schieder, Nathalie W. and Kirwan, Matthew L.. (2019). Sea-level driven acceleration in coastal forest retreat. *Geology*. 47 (12) 1151 to 1155. Status = Deposited in NSF-PAR doi:10.1130/G46607.1 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 11/25/2019) Full text Citation details

Vinent, Orencio Duran and Johnston, Robert J. and Kirwan, Matthew L. and Leroux, Anke D. and Martin, Vance L.. (2019). Coastal dynamics and adaptation to uncertain sea level rise: Optimal portfolios for salt marsh migration. *Journal of Environmental Economics and Management*. 98 (C) 102262. Status = Deposited in NSF-PAR doi:10.1016/j.jeem.2019.102262 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 11/25/2019) Full text Citation details

Woods, Natasha N. and Dows, Benjamin L. and Goldstein, Evan B. and Moore, Laura J. and Young, Donald R. and Zinnert, Julie C.. (2019). Interaction of seed dispersal and environmental filtering affects woody encroachment patterns in coastal grassland. *Ecosphere*. 10 (7) . Status = Deposited in NSF-PAR doi:10.1002/ecs2.2818 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 09/12/2019) Full text Citation details

Reidenbach, Matthew A. and Timmerman, Ross. (2019). Interactive Effects of Seagrass and the Microphytobenthos on Sediment Suspension Within Shallow Coastal Bays. *Estuaries and Coasts*. . Status = Deposited in NSF-PAR doi:10.1007/s12237-019-00627-w ; Federal Government's License = Acknowledged. (Completed by Porter, John on 09/12/2019) Full text Citation details

Berg, Peter and Delgard, Marie Lise and Polsenaere, Pierre and McGlathery, Karen J. and Doney, Scott C. and Berger, Amelie C.. (2019). Dynamics of benthic metabolism, O 2 , and pCO 2 in a temperate seagrass meadow: Seagrass metabolism, O 2 , and pCO 2 dynamics. *Limnology and Oceanography*. . Status = Deposited in NSF-PAR doi:10.1002/lno.11236 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 08/28/2019) Full text Citation details

Aoki, Lillian R. and McGlathery, Karen J. and Oreska, Matthew P.. (2019). Seagrass restoration reestablishes the coastal nitrogen filter through enhanced burial. *Limnology and Oceanography*. . Status = Deposited in NSF-PAR doi:10.1002/lno.11241 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 07/26/2019) Full text Citation details

Zinnert, Julie C. and Via, Stephen M. and Nettleton, Benjamin P. and Tuley, Philip A. and Moore, Laura J. and Stallins, Jon Anthony. (2019). Connectivity in coastal systems: Barrier island vegetation influences upland migration in a changing climate. *Global Change Biology*. . Status = Deposited in NSF-PAR doi:10.1111/gcb.14635 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 06/28/2019) Full text Citation details

Eon, Rehman S. and Goldsmith, Sarah and Bachmann, Charles M. and Tyler, Anna Christina and Lapszynski, Christopher S. and Badura, Gregory P. and Osgood, David T. and Brett, Ryan. (2019). Retrieval of Salt Marsh Above-Ground Biomass from High-Spatial Resolution Hyperspectral Imagery Using PROSAIL. *Remote Sensing*. 11 (11) 1385. Status = Deposited in NSF-PAR doi:10.3390/rs11111385 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 06/19/2019) Full text Citation details

Geraldi, Nathan R. and Ortega, Alejandra and Serrano, Oscar and Macreadie, Peter I. and Lovelock, Catherine E. and Krause-Jensen, Dorte and Kennedy, Hilary and Lavery, Paul S. and Pace, Michael L. and Kaal, Joeri and Duarte, Carlos M.. (2019). Fingerprinting Blue Carbon: Rationale and Tools to Determine the Source of Organic Carbon in Marine Depositional Environments. *Frontiers in Marine Science*. 6 . Status = Deposited in NSF-PAR doi:10.3389/fmars.2019.00263 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 06/07/2019) Full text Citation details

Kearney, William S. and Fernandes, Arnold and Fagherazzi, Sergio and Magar, Vanesa. (2019). Sea-level rise and storm surges structure coastal forests into persistence and regeneration niches. *PLOS ONE*. 14 (5) e0215977. Status = Deposited in NSF-PAR doi:10.1371/journal.pone.0215977 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 05/23/2019) Full text Citation details

Porter, John H.. (2019). Evaluating a thesaurus for discovery of ecological data. *Ecological Informatics*. 51 (C) 151 to 156. Status = Deposited in NSF-PAR doi:10.1016/j.ecoinf.2019.03.002 ; Federal Government's License = Acknowledged. (Completed by Porter, null on 03/26/2019) Full text Citation details

Badura, Greg and Bachmann, Charles M.. (2019). Assessing Effects of Azimuthally Oriented Roughness on Directional Reflectance of Sand. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. 1 to 14. Status = Deposited in NSF-PAR doi:10.1109/JSTARS.2019.2896592 ; Federal Government's License = Acknowledged. (Completed by Porter, null on 03/06/2019) Full text Citation details

Licenses

Other Conference Presentations / Papers

Other Products

Other Publications

Patents

Technologies or Techniques

Thesis/Dissertations

Raub, Kristin B.. *Coastal Adaptation to Sea Level Rise: Effects of Residential Proximity to the Coast, Climate Change Perceptions, and Attitudes Toward Government for Valuing Ecosystem Outcomes*. (2019). University of Connecticut. Acknowledgement of Federal Support = Yes

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

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

Websites

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 241 datasets that are also published on the Environmental Data Initiative and LTER Data Portals and DataONE.org.

Participants/Organizations

What individuals have worked on the project?

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

Name	Most Senior Project Role	Nearest Person Month Worked
Carr, Joel	Co-Investigator	1
Castorani, Max	Co-Investigator	1
Christian, Robert	Co-Investigator	1
D'Odorico, Paolo	Co-Investigator	1
Dueser, Raymond	Co-Investigator	1
Fagherazzi, Sergio	Co-Investigator	1
Fenster, Michael	Co-Investigator	1
Gedan, Keryn	Co-Investigator	1
Johnson, David	Co-Investigator	1
Johnston, Cora	Co-Investigator	12
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
Pace, Michael	Co-Investigator	1
Pusede, Sally	Co-Investigator	1
Smith, David	Co-Investigator	1
Sojka, Sarah	Co-Investigator	1
Tyler, Christy	Co-Investigator	1
Yang, Xi	Co-Investigator	1
Young, Donald	Co-Investigator	1
Zinnert, Julie	Co-Investigator	1

Name	Most Senior Project Role	Nearest Person Month Worked
Stevens, Cindy	K-12 Teacher	2
Aoki, Lillian	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Biel, Reuben	Postdoctoral (scholar, fellow or other postdoctoral position)	3
Ewers Lewis, Carolyn	Postdoctoral (scholar, fellow or other postdoctoral position)	5
Goldstein, Evan	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Kearney, William	Postdoctoral (scholar, fellow or other postdoctoral position)	10
Smith, Rachel	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Woods, Natasha	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Lee, David	Technician	12
MacGregor, Jessica	Technician	2
Morreale, Jonah	Technician	8
Parker, Steve	Technician	3
Barnes, Tyler	Graduate Student (research assistant)	1
Berger, Amelie	Graduate Student (research assistant)	4
Besterman, Alice	Graduate Student (research assistant)	4
Brown, Joseph	Graduate Student (research assistant)	4
Coleman, Daniel	Graduate Student (research assistant)	4
Cornish, Michael	Graduate Student (research assistant)	4
Eon, Rehman	Graduate Student (research assistant)	4
Fernandes, Arnold	Graduate Student (research assistant)	4
Flester, Jessica	Graduate Student (research assistant)	4
Goldsmith, Sarah	Graduate Student (research assistant)	4
Granville, Kayleigh	Graduate Student (research assistant)	2
Hardison, Sean	Graduate Student (research assistant)	2

Name	Most Senior Project Role	Nearest Person Month Worked
Heller, Erin	Graduate Student (research assistant)	4
Hogan, Sara	Graduate Student (research assistant)	4
Holstein, Dawn	Graduate Student (research assistant)	4
Jiménez Robles, Alfonso	Graduate Student (research assistant)	4
Juska, Ieva	Graduate Student (research assistant)	2
Kirschner, Audrey	Graduate Student (research assistant)	4
Lapszynski, Chris	Graduate Student (research assistant)	4
Leonardi, Nicoletta	Graduate Student (research assistant)	4
Long, E.	Graduate Student (research assistant)	4
Lunstrum, Abby	Graduate Student (research assistant)	4
Mast, Hannah	Graduate Student (research assistant)	1
Nettleton, Benjamin	Graduate Student (research assistant)	4
Palazzoli, Irene	Graduate Student (research assistant)	4
Reeves, Ian	Graduate Student (research assistant)	4
Sebillian, Serina	Graduate Student (research assistant)	4
Sinclair, Michael	Graduate Student (research assistant)	4
Smith, Alex	Graduate Student (research assistant)	4
Sun, Chao	Graduate Student (research assistant)	4
Tassone, Spencer	Graduate Student (research assistant)	1
Tedford, Kinsey	Graduate Student (research assistant)	4
Tuley, Philip	Graduate Student (research assistant)	4
Volaric, Martin	Graduate Student (research assistant)	4
Williams, Bethany	Graduate Student (research assistant)	4

Name	Most Senior Project Role	Nearest Person Month Worked
Wood, Lauren	Graduate Student (research assistant)	4
Zhang, Xiaohe	Graduate Student (research assistant)	4
Zhu, Quingguang	Graduate Student (research assistant)	4
Kerns, Kylor	Undergraduate Student	2
Longmire, Katherine	Undergraduate Student	4
Bushey, Jacob	Research Experience for Undergraduates (REU) Participant	2
Cheng, Selina	Research Experience for Undergraduates (REU) Participant	4
Cox, Sarah	Research Experience for Undergraduates (REU) Participant	4
Doughty, Morgan	Research Experience for Undergraduates (REU) Participant	4
Edwards, Paige	Research Experience for Undergraduates (REU) Participant	4
Johnson, Lauren	Research Experience for Undergraduates (REU) Participant	4
Philbrick, Abigail	Research Experience for Undergraduates (REU) Participant	4
Cook, Allice	Other	4
Fauber, Donna	Other	4

Full details of individuals who have worked on the project:

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

Contribution to the Project: Project Leadership, Research on Seagrass

Funding Support: NSF

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

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, GIS-based research on coastal change and population and community ecology of small mammals

Funding Support: NSF

International Collaboration: Yes, Taiwan
International Travel: Yes, Germany - 0 years, 0 months, 7 days

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

Contribution to the Project: Environmental Fluid Mechanics research

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Contribution to the Project: Studies of sediment dynamics and water movements

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: SeaGrant, VIMS

International Collaboration: No
International Travel: No

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

Contribution to the Project: Use of hyperspectral remote sensing

Funding Support: Office of Naval Research

International Collaboration: No
International Travel: No

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

Contribution to the Project: Aquatic flux measurements

Funding Support: NSF, UVA Dean's office

International Collaboration: No
International Travel: No

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

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

Funding Support: UVA

International Collaboration: No
International Travel: No

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

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

Funding Support: USGS

International Collaboration: No
International Travel: No

Max 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

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

Cora Johnston
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

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

Michael L Pace
Email: mlp5fy@virginia.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Studied Role of clam aquaculture in VCR

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Cindy Stevens
Email: cindy.stevens@accomack.k12.va.us
Most Senior Project Role: K-12 Teacher
Nearest Person Month Worked: 2

Contribution to the Project: Working with Johnston and McGlathery

Funding Support: NSF RET

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: 6

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Reuben Biel
Email: reuben.biel@unc.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 3

Contribution to the Project: working with L. Moore contributing to development of empirically based parameterizations for the coastal dune model and testing of the maintainer hypothesis.

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: 5

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Evan Goldstein
Email: ebgold@live.unc.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 1

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

Funding Support: NSF

International Collaboration: No
International Travel: No

William Kearney
Email: wk8ud@virginia.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 10

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

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: 1

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

Funding Support: UVA, TNC

International Collaboration: No
International Travel: No

Natasha Woods
Email: nnwoods@vcu.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 6

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

Funding Support: NSF, Ford Foundation

International Collaboration: No
International Travel: No

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

Contribution to the Project: Drives boats, collects data

Funding Support: NSF

International Collaboration: No
International Travel: No

Jessica MacGregor
Email: jmacgreg@gwu.edu

Most Senior Project Role: Technician
Nearest Person Month Worked: 2

Contribution to the Project: Field work with PI Gedan on marsh upland ecotone

Funding Support: NSF

International Collaboration: No
International Travel: No

Jonah Morreale
Email: jm7ux@virginia.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 8

Contribution to the Project: Technical staff of field station

Funding Support: NSF

International Collaboration: No
International Travel: No

Steve C Parker
Email: scp3t@virginia.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 3

Contribution to the Project: Boat driving, equipment maintenance

Funding Support: UVA, NSF

International Collaboration: No
International Travel: No

Tyler Barnes
Email: teb5g@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

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

Alice F Besterman
Email: afb5kg@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Daniel J Coleman
Email: djcoleman@vims.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

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

Rehman Eon
Email: rse4949@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

Arnold Fernandes
Email: arnold26@bu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Worked with PI Fagherazzi on forest response to hurricanes

Funding Support: Volunteer

International Collaboration: No
International Travel: No

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

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: 2

Contribution to the Project: Working with Berg on flux measurements

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: 2

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Erin Heller
Email: elheller@vt.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF GRFP

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: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Alfonso M Jiménez Robles
Email: mjralfonso@gmail.com
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Worked with PI Fagherazzi on hydrodynamic and morphodynamic modeling

Funding Support: Spanish Government

International Collaboration: Yes, Spain
International Travel: No

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

Contribution to the Project: Working with Berg on flux measurements

Funding Support: NSF

International Collaboration: No
International Travel: No

Audrey Kirschner
Email: kirschneras@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

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

Nicoletta Leonardi
Email: N.Leonardi@liverpool.ac.uk
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Worked with PI Fagherazzi on hydrodynamic and morphodynamic modeling

Funding Support: NSF/USGS

International Collaboration: No
International Travel: No

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

Abby M Lunstrum
Email: aml3ra@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with K. McGlathery on nitrogen cycling in seagrass beds

Funding Support: NSF, UVA

International Collaboration: No
International Travel: No

Hannah Mast
Email: hm4vd@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Benjamin Nettleton
Email: nettletonbp@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Contribution to the Project: Worked with PI Fagherazzi on hydrodynamic and morphodynamic modeling

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Serina Sebillian
Email: sseblia@mail.sfsu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with D. Johnson on environmental control of isotopic niche width

Funding Support: NSF

International Collaboration: No
International Travel: No

Michael Sinclair
Email: sinclairmn@vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Chao Sun
Email: sunchaonju@yeah.net
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

Spencer Tassone
Email: sjt7jc@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

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

Martin Volaric
Email: mpv3a@virginia.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Working with Reidenbach and Berg on oyster metabolism

Funding Support: NSF

International Collaboration: No
International Travel: No

Bethany Williams
Email: bwilliams@vims.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Kylor Kerns
Email: kk2kq@virginia.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: Worked with PI McGlathery and her graduate students on seagrass studies

Funding Support: NSF

International Collaboration: No
International Travel: No

Katherine Longmire
Email: klongmire@vims.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 4

Contribution to the Project: Working with D. Johnson on ecological control of geomorphology

Funding Support: NSF

International Collaboration: No
International Travel: No

Jacob Bushey
Email: jhb3qb@virginia.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 2

Contribution to the Project: Working with Reidenbach on oyster restoration

Funding Support: NSF

International Collaboration: No
International Travel: No
Year of schooling completed: Junior
Home Institution: University of Virginia
Government fiscal year(s) was this REU participant supported: 2019

Selina Cheng
Email: sc3ay@virginia.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Castorani

Funding Support: NSF

International Collaboration: No
International Travel: No
Year of schooling completed: Junior
Home Institution: University of Virginia
Government fiscal year(s) was this REU participant supported: 2019

Sarah Cox
Email: sc8df@virginia.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Berg

Funding Support: NSF

International Collaboration: No
International Travel: No
Year of schooling completed: Junior
Home Institution: University of Virginia
Government fiscal year(s) was this REU participant supported: 2019

Morgan Doughty
Email: morgandoughty01@gmail.com
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 4

Contribution to the Project: Working with PIs McGlathery and Wiberg

Funding Support: NSF

International Collaboration: No
International Travel: No
Year of schooling completed: Sophomore
Home Institution: Eastern Shore Community College
Government fiscal year(s) was this REU participant supported: 2019

Paige Edwards
Email: poedwards@randolphcollege.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Sojka

Funding Support: NSF

International Collaboration: No
International Travel: No
Year of schooling completed: Junior
Home Institution: Randolf College
Government fiscal year(s) was this REU participant supported: 2019

Lauren Johnson
Email: lnj3cd@virginia.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Wiberg

Funding Support: NSF

International Collaboration: No
International Travel: No
Year of schooling completed: Junior
Home Institution: University of Virginia
Government fiscal year(s) was this REU participant supported: 2019

Abigail Philbrick
Email: aphilbrick@gwmail.gwu.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 4

Contribution to the Project: Working with PI Gedan

Funding Support: NSF

International Collaboration: No
International Travel: No

Year of schooling completed: Junior
Home Institution: George Washington University
Government fiscal year(s) was this REU participant supported: 2019

Allice McEnerney Cook
Email: acook6@verizon.net
Most Senior Project Role: Other
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Contribution to the Project: Educational coordination

Funding Support: NSF

International Collaboration: No
International Travel: No

What other organizations have been involved as partners?

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

Full details of organizations that have been involved as partners:

Accomack Co. Public Schools

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

Partner's Contribution to the Project:
Personnel Exchanges

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

Agricultural Research and Extension Centers - Virginia Tech

Organization Type: Academic Institution
Organization Location: Blacksburg, VA

Partner's Contribution to the Project:
Collaborative Research

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

Barrier Islands Center

Organization Type: Other Nonprofits
Organization Location: Eastville, VA

Partner's Contribution to the Project:
Financial support
Facilities

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

Environmental Education Council of the Eastern Shore

Organization Type: Other Nonprofits
Organization Location: Virginia

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

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

Northampton County Public Schools

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

Partner's Contribution to the Project:
Personnel Exchanges

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

SouthWings

Organization Type: Other Nonprofits
Organization Location: Norfolk, VA

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

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

The Nature Conservancy

Organization Type: Other Nonprofits
Organization Location: USA/Virginia

Partner's Contribution to the Project:
Facilities
Collaborative Research

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

Virginia Institute of Marine Sciences

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

Partner's Contribution to the Project:
Collaborative Research

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

What other collaborators or contacts have been involved?
Nothing to report

Impacts

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

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

Our research focuses on barrier island grasslands and shrub thickets, salt marshes, seagrass meadows and oyster reefs that comprise the VCR and the connections between them. On barrier islands, grasslands are transitioning to shrub thickets and dune grasses affect dune morphology; both influence island vulnerability to storms. In coastal bays, seagrass and oyster restoration is reversing the state change that occurred when these habitats were lost in the last century. For intertidal marshes, sea-level rise and storms cause migration into uplands and erosion at the seaward border. We link ecological and physical (geomorphic, hydrologic) processes that are critical to ecosystem dynamics. For example, sediment transport and deposition allows marshes to keep pace with rising seas, oyster reefs and seagrass affect marsh erosion during storms, and vegetation (shrubs, grass) affects how barrier islands build elevation and migrate inland in response to sea-level rise and storms.

We have made significant contributions to understanding ecological and physical processes, feedbacks that either maintain or facilitate transitions in ecosystem states, and have identified leading indicators of threshold responses. We are leaders in developing and testing mechanistic models with long- and short-term observations and experimental data, and using these to project state change and its ecological consequences at the VCDR and globally.

The VCR domain provides a unique opportunity to address how connectivity among ecological systems on the landscape (coastal bays, intertidal marshes, barrier islands) affects state change. Our work to date has shown that state change

dynamics among adjacent systems is coupled, where state in one system can propagate to the other. This integrated long-term research informs management and conservation of coastal ecosystems at the VCR, and through synthesis and comparative work our research impact extends globally.

WATERSHEDS AND COASTAL BAYS

The eelgrass (*Zostera marina*) that once carpeted the seafloor of the VCR coastal bays and supported a thriving economy became locally extinct in the early 1930s as a result of disease and storm disturbance, causing a catastrophic shift to an unvegetated state. Now due to restoration, over 35 km2 have been restored to seagrass habitat; this is a 2-decade landscape-level experiment has shown that a decade is required for primary productivity, carbon and nitrogen sequestration, increased water column clarity, and sediment stabilization to be reinstated. We were the first to show the role of restoration in reinstating carbon storage capacity.

Our research on the invasive macroalga, *Agarophyton vermiculophylla*, is widely recognized as 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; it supports novel invertebrate communities and enhances nitrogen removal through denitrification., but at the same time is associated with the pathogenic bacteria *Vibrio* spp. that is a public health hazard, and may impede specialist shorebird foraging in intertidal flats.

WETLANDS

The phenomenon of critical slowing down is a leading indicator of ecosystem collapse in the VCR and elsewhere, where recovery to disturbance slows as an ecosystem approaches a critical threshold.

Surface Elevation Tables (SETs) quantify changes in sedimentation and subsidence that ultimately will determine the fate of marshes in the face of sea-level rise. Models, parameterized with VCR data predict marshes respond to sea-level rise and have been applied to the PIE and GCE LTER sites. Short-term experiments and long-term biomass records indicate that productivity and its effect on salt marsh accretion respond non-linearly to changes in flooding duration.

Restoration projects aim to mitigate storm impact using salt marshes and vegetated surfaces (“living shorelines”). Based on a large dataset of marsh erosion and wave measurements collected around the world, erosion rates of marsh boundaries and incident wave energy collapse into a unique linear relationship. Long-term salt marsh loss by erosion is dictated by average wave conditions, and is, therefore, predictable. Moderate storms with a return period of 2.5 months drive erosion; large storms and hurricanes contribute less than 1% to long-term salt-marsh erosion rates.

BARRIER ISLANDS

Barrier island plant 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 (vs. 'dune-builder feedback,' which leads to increases in island elevation). This feedback, working in conjunction with physical processes alone, has the potential to accelerate large-scale shifts from dune-dominated to overwash-dominated barrier island morphologies with climate change-induced increases in storm intensity and sea-level rise. We have shown how vegetation affects dune morphology island vulnerability to overwash during storms. Sand delivered by overwash allows back-barrier marshes to persist under conditions in which they would otherwise disappear, leading to increased island resilience. The importance this coupling is redefining the way barrier island response to changing conditions is assessed.

What is the impact on other disciplines?

The studies conducted by the VCR/LTER are inherently interdisciplinary including ecologists, hydrologists, biologists, geomorphologists and physical oceanographers. Our strength is our integrated approach linking ecological and physical (geomorphology, hydrology) processes that are critical to ecosystem dynamics in coastal systems. For example, biotic feedbacks in seagrass ecosystems on sediment deposition and resuspension by currents and waves measured by physical scientists are critical to understanding growth and population dynamics. Through this collaboration, we have created a novel model coupling hydrodynamics with vegetation growth that describes the non-linear state-change dynamics in seagrass 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 with development of wireless sensor networks, and processing of the massive data flows they can generate, contributes to better defining the cyberinfrastructure challenges that will confront us in coming decades.

Science – arts/humanities collaborations are a key component of our education and outreach programs. As part of our collaboration in the LTER sponsored Ecological Reflections program we hold two Art and Ecology Professional Development workshops for public school Art Teachers annually. We also host a Nature Writing workshop for undergraduate Engineering Students with faculty from the Science Technology and Society program in the UVA School of Engineering. Participants are encouraged to find new ways to incorporate environmental issues/themes in their artwork and classroom projects. Paintings, drawings, essays, poems and short fiction created during the workshops are used to generate public Art and Ecology exhibitions displayed at the local Barrier Islands Center Museum and on the grounds of UVA. More recently, we have initiated an Humanities Lab focused on “listening” in the coastal zone. These workshops all introduce participants to the place-based science being conducted at the VCR-LTER and explore interdisciplinary collaborations. In September 2019, we opened a seasonal listening exhibit by the Coastal Conservatory at the Barrier Islands Center cultural heritage museum. The reception was well attended and was covered by the press. 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.

What is the impact on the development of human resources?

As can be seen from the number of graduate and undergraduate students listed on our participant list, this project provides abundant opportunities for training. Moreover, the inter- and multi-disciplinary nature of the research teaches the students how to operate in a collaborative environment. Each year, the VCR LTER supports approximately 30 graduate students who conduct their M.S. and Ph.D. projects at the VCR site and approximately 10 undergraduate students work each year as research assistants in the field and laboratory. 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 are becoming 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.

We have programs that help translate our science into educational experiences in K-12 classrooms through our outreach to K-12 teachers. For example, our Meaningful Watershed Education Experience (MWEE) exposes K-12 teachers from around the state so that teachers can explore how their county is connected to the health of coastal waters and formed plans to implement watershed learning into all subject areas. Through this program, our RET participants, and ongoing partnerships with The Nature Conservancy, VCR SLTER contributes to both teacher professional development and to assisting teachers with issue definition and supporting students to make sense of data.

What is the impact on physical resources that form infrastructure?

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

Reidenbach has developed an underwater laser-based velocity measuring system. Particle image velocimetry (PIV) has been used for a number of years in laboratories to measure velocity and turbulence over an area ranging from square millimeters to square meters. This system uses a laser and optics to create a laser light sheet. This light illuminates suspended particles in the flow and, using a digital camera, particle motion is recorded. With the recent development of laser diodes, powerful yet energy efficient lasers can be placed in water tight housings and submersed underwater. The system developed uses a 250 mW laser with a wavelength of 532 nm (green light). A waterproof housing has been designed to hold both the laser and

optics used to spread the beam into a narrow, yet wide sheet. Imaging of the illuminated particles is done using a high definition camera to obtain images up to 60 frames per second. The system is attached to a rigid frame and can be deployed in the coastal ocean where suspended sediment particles are tracked. This PIV system has recently been coupled with a planar-optode system that utilizes thin oxygen sensitive foils to quantify oxygen fluxes at the sediment water interface. This coupled system enables researchers to quantify the interactive effects of hydrodynamics and biological activity (such as burrowing) on oxygen exchange across the seafloor.

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

What is the impact on institutional resources that form infrastructure?

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

Our wireless network provides real-time access to remote monitoring locations in and around Hog Island 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), LTER Network, and affiliated data centers (e.g., KNB, DataOne).

The VCR/LTER shares 241 online datasets with an aggregate volume of approximately 430 GB. These are published via the VCR/LTER web site, the Environmental Data Initiative Data Portal and DataOne Search. The datasets are frequently downloaded for use by researchers and students. During the period from 11/1/2018 to 10/31/2019 VCR/LTER data files have been downloaded at 2,297 times via the Environmental Data Initiative Data Portal. An additional 727 data entities were downloaded directly from the VCRLTER. For most downloads no information regarding by whom or why data was downloaded is available. However, the 33 downloads for which a reason was given were split roughly evenly between research (45%) and education (55%) (e.g., student class projects). 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 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).

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 are typically used 1,100 times per month, with R-based code generated 40% of the time, Matlab 22%, and SAS, SPSS and Python accounting for 12.6% each. 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)

What is the impact on society beyond science and technology?

As coastal resilience issues and problem-solving gain urgency, especially with the proclamation of Virginia's new resilience initiatives, VCR LTER researchers and staff spent much of 2019 in a resource capacity for resilience planning. We served on the implementation team for our county's Resilience Adaptation Feasibility Tool (RAFT) action plan and are now co-leading the revitalization of a climate adaptation working group to guide localities through coastal risks and resilience actions. We coached students on interdisciplinary problem-solving during Sea Grant-led team science workshops, contributed to resilience roundtable discussions in the region, and joined a marsh summit that gathered both researchers and practitioners dealing with coastal issues and resilience. We also contributed public talks to local civic groups and presented our research and education initiatives as the plenary session for the Mid Atlantic Marine Educators Association.

In January 2019, 25 VCR researchers and students and over 75 members of the community gathered in At Altitude Gallery for "See What the Scientist Sees" – a research discussion facilitated by aerial photography of the coastal barrier system. In July we held a conversation café with the local arts community to ignite collaborations.

The high historic rate of sea-level rise (~5mm yr-1) within the Virginia Coast Reserve make it a bell-weather site for assessing the probable impacts of global sea-level changes. Our results concerning the response of salt marshes, upland and lagoon systems can provide insights that extend to other systems that are only now beginning to experience heightened sea level. VCR researchers work with regional planners and decision-makers in the Mid-Atlantic Climate Adaptation Working Group. In addition, VCR researchers have worked with The Nature Conservancy (TNC) to develop a web-based decision tool for coastal resilience that includes natural and social science data to visualize future scenarios of climate change and sea-level rise (http://maps.coastalresilience.org/virginia/).

Our work on the interactions of predators and nesting shorebirds in the VCR, in collaboration with The Nature Conservancy and Virginia Department of Game and Inland Fisheries, was a key component of the new Guidance and Best Practices for Coordinated Predation Management to Benefit Temperate Nesting Shorebirds in the Atlantic Flyway. This document is being used across the Atlantic Flyway to guide science-based management decisions regarding nesting shorebirds and their predators. Our findings from long-term monitoring of spring migratory shorebird population and habitat ecology in the VCR is being used in the U.S. Fish and Wildlife Service's recovery planning for the federally-threatened Red Knot. Our ability to make fine-scale, site-specific predictions of island geomorphology and Piping Plover habitat suitability in response to SLR and shoreline change is novel and will be useful managers coast-wide as application of the models is expanded geographically. Our findings related to SLR and beach management strategies at Assateague Island, where models were developed and first tested, have relevant implications for policy-makers today. For example, we found that a beach management strategy that involved annual sand nourishment along the sections of Assateague Island would result in vegetation encroachment and reduce the area of habitat suitable for Piping Plovers as compared to a scenario of modest SLR (3-4 mm yr-1) and no sand nourishment. While there is no such identical management strategy currently proposed for Assateague Island, targeted sand placement in order to stabilize barrier islands is a commonly discussed management strategy along the U.S. Atlantic Coast.

We work closely with colleagues at the Virginia Institute of Marine Sciences and The Nature Conservancy to address issues relevant to sustainable restoration of seagrass and oysters in the VCR and globally. Our results guide restoration efforts and economic valuation of ecosystem services. VCR research is the first to show the importance of restored seagrass meadows in sequestering carbon and highlighted the role of habitat restoration in mitigating rising atmospheric CO2 levels. Because the scale and success of seagrass restoration, VCR scientists wrote the international protocol for the Verified Carbon Standards program on to assign carbon credits on international trade markets for seagrass restoration.

Our work on how restored oyster reefs affect marsh edge erosion is key to developing living shorelines in Virginia and throughout shallow coastal regions in the U.S. and abroad. Our findings on hydrodynamic influences on oyster feeding and larval settlement is useful to practitioners in understanding how currents and exposure affect oyster growth and the persistence of oyster reefs.

In collaboration with the TNC, we have done a retrospective analysis of long-term trends in erosion and accretion of mainland marshes throughout the VCR from the 1950's to the present. This is coupled with information on the presence of oyster reefs as a potential buffer to marsh erosion. Patterns of erosion were also overlain on maps of TNC-conserved lands to identify potential areas to study climate adaptation and the potential for marshes to transgress onto the mainland with predicted scenarios of climate change and sea-level rise.

Knowledge of the relationship between land use, nutrient contamination of groundwater, groundwater export of nutrients to coastal bays, and the fate of nutrients within bays will be of benefit to state and federal agencies charged with managing coastal resources. This knowledge will be especially important given the ongoing return of seagrasses to large areas of the coastal bays, from which they have been absent for over 70 years. In the decade of seagrass restoration, ecosystem services have been reinstated, including increased water quality and clarity (decreased sediment suspension), and increased biodiversity (foraminfera), and faunal abundance (introduced scallops). The VCR coastal bays are also a model system to understand the important role of plants in mediating nutrient export from coastal watersheds to the open ocean.

Barrier islands are heavily developed landforms that are highly vulnerable to changing climate conditions. Concepts such as green and nature-based solutions are gaining attention within the coastal management and engineering community. Our work contributes to understanding how upland communities contribute to the overall resilience of barrier islands and how they will respond to climate change —including the mechanisms influencing and driving future island response—which is a prerequisite to sustainable coastal management. Upland communities are overlooked and we do not fully understand the ecosystem services they provide. Our work is bringing attention to these vulnerable landscapes.

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.