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Submission Date:	11/20/2020
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	John H Porter

Accomplishments

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

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

The vast undisturbed landscape of marshes, lagoons and barrier islands provides a unique opportunity to examine linkages among multiple ecosystems, in a way that cannot be done anywhere else in the US because of habitat fragmentation and the

destruction of linkages by human activities. We take advantage of natural 'experiments' of pulse events (e.g., storm disturbance, marine heatwaves) that leverage our decadal-scale observations and experiments, and are conducting new experimental disturbances to investigate the sensitivity and resilience of the foundation species that dominate these ecosystems and their functions.

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

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

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

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

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

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

Major Activities:

Drivers of Long-term Change

Climate Drivers: We collected long-term data from meteorological stations, tide and water temperature stations, an eddy covariance tower, and groundwater wells. A 35-year record was constructed to analyze trends and extremes in water temperature and marine heat waves.

Patterns of Change: Long-term data and experiments detect patterns of change: 1) 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, 2) data compiled for 2013-2018 to evaluate landscape change from storm disturbance, 3) continued experiments on seagrass and oyster reef restoration, marsh transgression, and island grass-shrub transitions, and 4) continued water quality monitoring, now with turbidity measurements via satellite.

Dynamics within Landscape Units

Upland: We continued our long-term experiment to test the mechanisms governing the transition from upland forest to marsh in response to sea-level rise (SLR) and storms, with 24 forested plots along an elevation gradient. Half the plots will be disturbed in yr 4. We monitored tree mortality, shrub growth, non-woody vegetation cover, groundwater level, soil moisture, salinity, light availability and canopy cover, surface elevation, and used drone imagery to look at spatial dynamics. Eight plots were added in the marsh-upland transition to compare with forested plots. We determined invertebrate community structure and diet in the high-marsh and ghost-forest habitats to test their ecological equivalency.

Intertidal: We installed a new instrument on the eddy covariance tower that measures solar-induced chlorophyll fluorescence (SIF) and will be used to scale up gross primary productivity to the landscape scale using remote sensing. We also tracked the rate of upland movement of grazing bands created by the purple marsh crab. For oyster reefs, we used meta-analysis to compare the relative strength of top-down predator effects on recruitment, survival, and growth.

Subtidal: For seagrass, we continued our long-term restoration/resilience experiment (19 yrs) and aquatic eddy covariance measurements of metabolism (13 yrs), and began a new experiment to test seagrass response to disturbance in 2 sites that varied with respect to heat stress. For the lagoon system, we 1) used the Delft3D hydrodynamic and sediment transport model to study how seagrass affects patterns and rates of sediment deposition in meadows and adjacent tidal flats, 2) compared new, high-resolution bathymetric measurements with data from the same locations collected 20 years ago to study bed accumulation, and 3) estimated water column DIC inventory, and created a satellite-based model of water clarity by relating long-term Secchi depth data with Landsat and Sentinel reflectance.

Barrier Island: We studied grasslands-shrub transitions through 1) monitoring long-term plots across the grass/shrub ecotone, 2) a time-series analysis of microclimatic temperature variance and water table changes, and 3) nitrogen fertilization and shrub seeding experiments. To explore the feedbacks between plants and geomorphology, we established transects for long-term monitoring of dune grass species composition and topographic evolution, and continued our annual time series of multispectral and high-resolution optical drone surveys to characterize island vegetation and dune morphological change.

Dynamics Between Landscape Units

Transport of Sediment and Dissolved Constituents: We developed a model to investigate how storm surge affects sediment deposition on marshes, and conducted a meta-analysis of U.S. East Coast bays to determine how marsh area affects sediment availability (Fig. 1). We used the Delft3D model to evaluate exchange (e.g., nutrients) between the shallow bay and ocean and assessed the influence of tidal amplitude, winds and tidal cycle on flushing time.

Oyster Reef – Marsh Coupling: We continued our large-scale experiment with 8 constructed oyster reefs of different designs to determine effects on oyster populations (size, growth, density) and marsh erosion using field data and LiDAR imagery. At the landscape scale, we 1) measured recruitment at 14 sites over 250 km2, 2) related elevation to seasonal oyster recruitment adult density, and 3) began a caging experiment to determine effects of depth and landscape-scale position on predation and oyster survival.

Seagrass - Marsh Coupling: We are determining how seagrass restoration affects carbon (C) accumulation in nearby salt marsh sediments. We sampled transects on 2 islands, one proximal and one distant from the seagrass meadows; sediment cores covered before and after seagrass restoration. Stable isotopes, biomarkers, compound-

specific isotopes, and 210Pb dating will be used to quantify the seagrass contribution to C sequestration in the marsh.

Barrier Island Ecosystem Coupling: For our cross-island transects we measured changes in sediment accretion and monitored species composition and % cover, and characterized vegetation and topography using optical (RGB) and multispectral drone imagery and SfM at scales of 40–50 ha. We developed a new geomorphological-ecological model based on VCR data of barrier island and shrub coevolution that includes sea-level rise and individual storms, shrub expansion and mortality.

Cascading Effects: 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, including the effect of seagrass on marsh width and on barrier island migration. We also developed a coupled transect model, extending from the open lagoon into a coastal upland forest to examine controls of forest retreat and marsh migration using VCR data.

Ecological Consequences of State Changes

Carbon Sequestration: Our work tests how state change affects C storage and sequestration. At the upland-marsh transition, we 1) measured C stored in trees, shrubs, grasses, and soils, and related spatial gradients in C stocks to elevation and salinity. In marshes, we 1) sampled standing stocks of sediment C, 2) completed Pb210 dating to determine rates of C accumulation, and 3) used the eddy covariance system to measure CO2 fluxes. On barrier islands, we analyzed 1) standing stocks of soil C and root biomass in sediment cores along the grass-shrub ecotone, and 2) DOC in groundwater. In seagrass meadows, we 1) continued the time series of C burial and standing stocks in sediment and plant biomass, 2) and used underwater eddy covariance to quantify seagrass metabolism and CO2 dynamics.

Consumer Dynamics: We studied how state change affects consumers. On barrier islands, we 1) tested how invasive algae affects shorebird habitat selection and invertebrates, 2) completed stable isotope analyses of blue mussel prey to assess this as a food source, 3) conducted nest monitoring of American Oystercatchers, colonial seabirds, and Plovers to link with geomorphology and vegetation, and 4) resighted banded bird populations to monitor movements, survival and reproduction. In the intertidal, we 1) assessed if restored oyster reefs can match the population, community, and ecosystem functions of natural reefs, using a 15 yr-time series of 77 restored and natural reefs, and 2) used meta-analysis to synthesize how ecosystem services compare among restored, natural, and degraded oyster reefs. In the subtidal, we 1) continued the time series of seagrass epifauna, infauna, fish, and crabs, 2) analyzed long-term fish data to understand impacts of climate (heatwaves), 3) initiated a study on the density and growth of clams at 50 sites spanning 2–18 yr since seagrass colonization, and 4) analyzed data on catch-per-unit-effort of blue crabs to understand how seascape connectivity and local seagrass variables affect crab density and fecundity.

Specific Objectives:

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

Our specific objectives for this theme are:

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

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

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

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

Our specific objectives for this theme are:

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

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

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

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

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

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

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

Theme 3. Dynamics between Landscape Units: How does connectivity influence ecosystem state change? The VCR is a model system in which to ask how ecosystems are connected through cross-sytem transport of materials and organisms and coupled state change dynamics, and how local and broader-scale patterns and processes are related. Understanding how state change in one part of the landscape can propagate to another is critical to determining the holistic response of coastal barrier systems to present and future climate forcing.

Our specific objectives for this theme are:

Transport:

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

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

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

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

Coupled dynamics:

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

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

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

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

Theme 4. Ecological Consequences of State Change: What are the consequences of ecosystem state

change for ecosystem function? We focus on two important ecosystem functions of coastal barrier

systems: carbon sequestration and habitat provisioning for consumers. Expansions of foundation species (i.e., *Z. marina* seagrass, *M. cerifera* shrub, *C. virginica* oysters) affect carbon cycling and also provide habitat for consumers that may alter predation, pathogens, and trophic dynamics.

Our specific objectives for this theme are:

Carbon cycling and sequestration:

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

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

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

Consumer responses:

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

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

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

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

Significant Results:

Drivers of Long-term Change

The most powerful storm of the 574 in 2013-2018 caused large changes: a 14% loss of barrier island habitat and 61 ha of back-barrier marsh converted to upland (i.e. island rollover). We also observed significant temperature trends in long-term data: 1) an increase in summer water temperature at a rate of 0.021 +- 0.017 °C/y, 2) more days with average temperature >28°C, and 3) more frequent marine heatwaves (19 in the 35-y record), primarily driven by the increase in temperature over the last 3 decades.

Dynamics within Landscape Units

Upland – Marsh: An extreme event in 2019 during Tropical Storm Melissa where the tide rose >99.7% of all recorded tides resulted in high tree mortality in the following growing season and we are tracking recruitment. Our transect model also shows the role of extreme events in triggering state change: long-term forest retreat rates are controlled by slope and SLR, short-term dynamics are controlled by water level deviations from storm events and forest recovery rates. Based on comparisons of vegetation, elevation, and local SLR, we estimated it will take ~50 yr for forests to be dominated by marsh vegetation, although this approach neglects potential eco-hydro-geomorphic feedbacks that are being tested.

Intertidal Marsh - Tidal Flat: Regional coverage of the dominant (invasive) macroalgae can be predicted by microtopographic variation, water residence time and fetch. Oyster survival is structured by predators, and contrary to the prevailing theory on top-down control in the intertidal, oyster predators were more lethal in the intertidal than the subtidal zone. Oyster reefs decrease the mean and maximum slopes of marsh edges, and reduce erosion rate of the toe but do not impact erosion rates near the vegetation line, causing an elongation of the marsh edge.

Subtidal: Seagrass were resilient to a marine heatwave, with recovery within 2-4 yr (Fig. 2); landscape position modulates heat stress. Annual sediment deposition rates in the seagrass meadow are impacted by winter shoot densities, with a threshold of ~150 shoots/m2. Water depth measurements compared to the late 1990s show that sediment deposition rates in the seagrass meadow are comparable to SLR rates. Long-term in situ aquatic eddy covariance measurements of seagrass metabolism show: 1) temperature stress threshold for *Zostera marina* 28-29 oC, and 2) no stimulation of photosynthesis at high CO2. These results do not support seagrasses being winners in future oceans with high CO2 and temperature.

Barrier Island : Encroachment of the dominant shrub *Morella cerifera* into grasslands is driven by lower exposure to cold temperatures and positive feedbacks on microclimate. The freezing threshold for <1yr seedlings was -6°C and -11°C, and the ~1.3°C

insulation of shrub seedlings by grasses during winter protected seedlings from extreme cold. Once shrubs surpass the grass canopy, they exclude grasses and create a self-reinforcing microclimate by reducing temperature variability. Exposure to salinity >10 ppt limits germination. Dunes grow lower and wider when marsh wrack containing propagules is present, and the high-marsh grass speeds up the dune-building process by enhancing deposition so dune grasses can become established sooner.

Dynamics between Landscape Units

Sediment Transport: Sediment deposition on marshes is affected by storm surge that increases the mass of sediment in flooding water and the duration/extent of flooding. Ponded areas close to the marsh edge are a sediment source for deposition. Marsh deterioration reduces the sediment stock in back-barrier basins and compromises marsh resilience: 1) sediment deposition on the marsh platform decreases exponentially with marsh erosion, and 2) variations in marsh extent affect sediment storage capacity.

Exchange of Dissolved Constituents: Wind-driven fluxes control transport and concentrations within the bays (Fig. 3). Variations in tidal phase and amplitude promote the flushing of the bays. The average flushing time is 24–27 days, decreasing to 21 days with favorable winds.

Oyster Larval Transport and Population Dynamics: Oyster life stage, landscape position, and depth structure survival. At the landscape scale, within-bay oyster recruitment was as variable as among bays, suggesting the importance of local-scale factors. Larval supply is not limiting, and oysters recruited equally to natural shell and artificial reefs. Predation on juvenile oysters was greatest in the intertidal, regardless of location, but predation was strongest on adult oysters in the intertidal back-bay site and subtidal front-bay site.

Coupled State Change Dynamics: Oyster reefs occurr in a narrow elevation range (-0.68 to -0.05 m MSL), with a mean vertical relief of 0.14 m, and occupy 12% of suitable intertidal area. Simulations using the GEOMBEST++Seagrass model showed that seagrass meadows affect sediment transport and impact the evolution of adjacent marshes, and that their presence can reduce island migration rates by taking up accommodation space in the bay. The coupled barrier island-shrub model showed that shrubs cause narrower but taller islands and restrict barrier island rollover. Dune formation (hummock vs. ridge) affects plant community composition of adjacent swales.

Ecological Consequences of State Changes

Carbon Sequestration

Total carbon stocks decrease by ½ along a gradient from healthy forest to marsh, following changes in salinity and elevation, and represent the temporal migration of ecosystems with SLR (Fig. 6). We estimated that it will take ~200 years for marsh soil C accumulation to offset losses due to forest mortality, a timescale that is greater than or equal to the expected survival time of the marshes. Variation in C stocks follow gradients in salinity more closely than gradients in elevation, suggesting salt stress rather than inundation stress is the driver of change. On the islands, standing stocks of soil C were highest in in the top 5 cm of soil under shrub thickets. For seagrass meadows, despite the increase in greenhouse gas emissions, seagrass meadows were a net sink of C, burying 2x more C than bare areas.

Consumer Dynamics

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

habitats. O18 isotopes indicate that blue mussel prey originate from colder, more saline waters outside the VCR and have declined over time. American Oystercatcher and Piping Plover population abundance and distribution is driven by the presence of vegetation-free overwash created by storm events.

Intertidal: Generalist shorebirds select patches of macroalgae and specialist shorebirds select bare sediments; where abundant, invasive macroalgae reduce foraging by specialist birds. Restored oyster reefs can match natural reefs and improve ecological function: 1) oyster abundance and their consumers are equivalent within 6 yr, 2) temporal stability of populations increases with oyster biomass and reef maturity, 3) juvenile and adult oysters, fishes, crabs and shrimp are similar and more abundant on restored and natural reefs relative to degraded ones, and 4) restored and natural reefs increase denitrification, nutrient retention, organic matter, and shoreline protection relative to degraded reefs.

Subtidal: Seagrass restoration enhances fish abundance and biodiversity; two species of forage fish (Atlantic silverside and silver perch) were negatively impacted by marine heatwaves. Adult blue crabs were more abundant in areas of sparse seagrass compared to dense areas, and farther from salt marshes possibly due to foraging or avian predators. Female crabs with mature eggs were more abundant closer to oceanic inlets, where they release eggs.

Key outcomes or Other achievements:

VCR scientists have published 41 journal articles and 2 book chapters in the second year of this funding cycle. A complete list of publications can be found at https://www.vcrlter.virginia.edu/home2/?page_id=215.

Theme 1: Drivers of Long-term Change

Climate Drivers of Change

Summertime water temperatures in the VCR bays have increased 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. There have been 19 marine heatwaves over the last 35 years, an increase driven primarily by increases in water temperature.

Patterns of Change

There has been a 19% net loss of barrier islands over the last ~30 years (1984-2016); highest loss and greatest variance in marsh to upland conversion (indicating island migration) was between 2011-2016. A single storm event in 2015, accounted for 14% of upland loss. Increasing rates of landward barrier island migration are influenced by dune elevation and interior island vegetative cover. Winter warming has resulted in 41% increase in woody vegetation in protected, low elevation areas. Analysis of bathymetric change in seagrass meadows over the last 20 years suggest that sediment deposition rates have generally been comparable to rates of sea-level rise.

Theme 2: Dynamics within Landscape Units

Forest - Marsh - Tidal Flats

Recent modeling suggested forest retreat and marsh migration rates are controlled by slope and SLR. Upland boundary migration rates are controlled by both stochastic water levels and forest recovery rates especially for low to moderate rates of SLR. As SLR rates increase, migration rates revert back to a slope-SLR dependent process. Empirical observations support the model, as vegetation change occurs rapidly after an extreme high water event (with moderate SLR rates). Changes in vegetation and carbon stocks associated with the forest to marsh transition correlate more significantly with salinity than elevation, suggesting salinity is the primary driver of forest retreat rather than flooding.

Subtidal

Our landscape-level restoration seagrass experiment, now in its 19th year, shows that key ecosystem services, including primary productivity, carbon sequestration, nitrogen removal, sediment stabilization and habitat provisioning are reinstated within a decade (Fig. 4). We also found that the seagrass meadows are resilient to marine heatwaves, with plant biomass recovering within 2-4 yr, although lost sediment carbon lags behind. However, the in situ metabolism data do not support the notion that seagrasses may be winners in future oceans with elevated CO2 concentrations and more frequent temperature extremes.

Barrier Island

Cold temperatures limited shrub survival of both seedlings (<-11oC) and adults (<-16oC) and grasses provide insulation to shrub seedlings. Self-reinforcing microclimatic temperature modification by shrubs is evident at multiple life stages, even before coalescence into full shrub thickets, especially during summer months. Shrubs reduce grassland diversity and alter soil characteristics.

Theme 3: Dynamics between Landscape Units

Sediment Transport

Model results indicate that annual sediment deposition rates in the seagrass meadow are strongly impacted by winter seagrass densities, with net annual deposition for winter densities above ~150 shoots/m2 and net annual erosion for winter densities below this threshold that can supply sediments to nearby marshes. Our meta-analysis study of coastal bays highlights that restoration interventions should target coastal erosion before the vegetated surface becomes too small compared to the basin area, and that ecosystem responses to changes in habitat size are non-linear.

Subtidal - Intertidal Coupling

Oysters currently occupy 12% of the suitable intertidal area in the VCR, suggesting that there is ample intertidal area for future restoration that will impact both biodiversity and marsh erosion. Oyster patches in the VCR are small, with the 50th percentiles for area and perimeter being 11.6 m2 and 14.5 m, respectively. Reef crests occur in a narrow range of elevation (-0.68 to -0.05 m MSL), with a mean vertical relief of 0.14 m.

Barrier Island Ecosystem Coupling

Dune elevation and shape are critical in structuring adjacent, plant species composition, functional trait composition, and annual net primary productivity in adjacent low-elevation swales. Dune and vegetation dynamics are important predictors of barrier island response to sea-level rise (i.e. landward migration vs. shoreface erosion). First results from the new barrier island-shrub model suggest that barrier island interior vegetation cover is an important control on the long-term behavior and geometry of transgressive barrier islands, and may affect the likelihood of island drowning.

Cascading Effects and Coupling Between Non-adjacent and Adjacent Systems

Blue crabs are dominant mesopredators within mid-Atlantic and Gulf estuaries, where they act as a critical link in moving productivity from the benthos to pelagic fishes. Our results from sampling blue crabs across the restored seagrass meadows indicates that seascape habitat connectivity is as important as local seagrass conditions for blue crab distributions. Seagrass meadows operate as dynamic sources and sinks of back-barrier sediment that can influence the evolution of coupled marsh and barrier island landforms. While they generally reduce marsh erosion and barrier island migration rates, seagrass meadows can also cause unanticipated accelerated marsh loss under certain conditions.

Theme 4: Ecological Consequences of State Changes

Carbon Sequestration

Total carbon stocks decreased by about half along a gradient from healthy forest to marsh, representing the temporal migration of ecosystems with sea-level rise. We estimated that it will take ~200 years for soil carbon accumulation in marshes to offset the losses associated with forest mortality. This replacement timescale is greater than or equal to the expected survival time of these newly formed marshes, suggesting carbon lost from forests may never be replaced. 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 heatwaves which cause die-off of seagrass plants that stabilize sediments.

Consumer Dynamics

Over large spatial scales, effects of the invasive macroalga *A. vermiculophylum* on consumers (invertebrates and birds) were either neutral or negative. Long-term monitoring of migrant and nesting shorebirds reveals responses to climate drivers (including temperature and storms). Piping plovers (ground-nesting shorebird) respond with dramatic population irruptions following storm-driven habitat creation. Colonial waterbirds populations did not show the same response, but instead declined in recent decades, perhaps due to changing fish and predator populations. Migrant shorebirds rely on two types of bivalve prey with differing responses to ocean temperature. Coquina clam prey on sandy intertidal beaches are expected to grow larger sooner under warming ocean temperatures; blue mussel prey abundances have declined over 14 years of data likely due to warming.

Intertidal: Fifteen years of data show that oyster reef restoration can recover ecological functions across multiple levels of organization. We also find evidence that restoration can stabilize ecosystem processes, highlighting a novel metric of restoration success. Our meta-analysis shows that habitat provisioning, biodiversity, biogeochemical functions, and shoreline protection are greater on restored reefs relative to degraded reefs, suggesting that restoration can help recover ecosystem services.

Subtidal: The positive effect of seagrass on fish communities may be dampened by climate change. Seagrass meadows improve fish biodiversity, but some forage fishes are susceptible to marine heatwaves that are on the rise globally.

*** 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 50 graduate students and 6 post-docs conducted research through the program. The inter- and multi-disciplinary nature of the research teaches the students how to operate in a collaborative environment.

Our annual REU, RET and REHS activities provide graduate students experience as mentors. To further support their mentorship experience, in Spring 2020 we developed and launched a workshop on Fundamentals of Learning for Science Mentors for graduates who serve as REU and RET mentors at VCR. The short course introduced concepts and practices in teaching and learning science. Six participants, ranging from masters students to post-docs, from two universities completed the course. They developed an adaptable mentorship plan as their final product. This course will be offered annually and will become a prerequisite for program mentors.

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 2020 we continued to attract involvement by students from the local community, including two selected for our REU program. Though our REU program was ultimately deferred due to COVID-19 restrictions, we made strides in inclusive recruiting and selection through partnerships with the NC-VA Alliance for Minority Participation and PathwaystoScience.org, resulting in 35 applicants from 17 institutions, of which 57% were female, 17% Asian, 11% African American, 7% Latinx, 2% Native, and 2% from community colleges. From ⅓ to ½ of priority applicants selected for each project were members of underrepresented groups in STEM.

Despite our deferred REU program, VCR personnel interacted with undergraduate courses through guest lectures (e.g., Estuarine Ecology, UVA) and career panel participation (Introduction to Ecology, UCSB). As examples, student Spencer Tessone introduced writing students to the process of developing a research question; PI Kirwan led a field trip for community college students; PI Gedan contributed to an open online course on Foundation Species through the University of Houston. We also explored broader collaborations with Eastern Shore Community College (ESCC), especially the biology program. Student Alex Smith recorded two virtual mini lectures on regional ecology for ESCC when classes moved online. While most plans have been temporarily deferred, we have promising agreements with ESCC on 1) developing research experiences and place-based labs for biology students and 2) shifting our summer final presentations (featuring REU students) to a multi-institutional student research showcase and networking event on the ESCC campus.

After schools closed unexpectedly in March, VCR worked with the guidance office to redevelop Northampton High School's career day as a virtual event. Two VCR researchers and others in STEM careers working within the region were featured in the event, which was distributed to every middle and high school student in the county and featured on the county website and Facebook pages. VCR graduate students and staff also collaborated with regional partners to develop and distribute elementary-level at-home learning activities for students and lessons for teachers that focused on building STEM skills in whatever space students had access to.

Based on a need identified by VCR graduate students in an ASM strategic session, VCR staff initiated and helped coordinate, with LNO and the Graduate Student Committee, a Virtual Career Panel series for LTER graduate students. In spring 2020, the three sessions focused on academic-adjacent and non-tenure careers were attended by an average of 150 students per session (¼ of the graduate community of LTER).

Prior post-doc Natasha Woods secured an ROA to continue research at the VCR while engaging an REU from Moravian College, helping to retain Dr. Woods as a member of our research community, where she is the only black woman investigator - and therefore a key role model to our research and local communities.

VCR also supported and led multiple teacher professional development efforts. We received a supplement and recruited two teacher and mentor pairs for RETs. Graduate student Kinsey Tedford presented her research on oyster reef ecology to teachers during a multi-day training on coastal bay ecology. Cora Johnston Baird developed a continuing PD program for elementary teachers on outdoor instruction for safe and place-based inquiry and learning during COVID restrictions. All 40 teachers of Kegotank Elementary participated in the introductory training session, and VCR staff have since revitalized the Kegotank outdoor classroom in preparation for continuing sessions on lesson development.

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

COVID restrictions suspended many of our programs, including twice yearly Art and Ecology workshops for teachers, annual watershed PD with teachers of Clarke County, RETs, REUs, Nature Camp, and the newly developed 'science pub' outreach series (a collaboration with the Cape Charles Brewing Company and a VA Sea Grant fellow) and coastal writing workshop (a collaboration with Coastal Conservatory and UVA Environmental Humanities program).

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

The VCR disseminates research findings and data through the VCR LTER website (https://www.vcrlter.virginia.edu) with 8,252 page views in 4,300 sessions by 2,800 distinct users. During that same period, VCR/LTER data files were downloaded 5,079 times from the Environmental Data Initiative Portal from Nov. 1, 2019 to Oct. 31, 2020.

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

COVID-19 restrictions limited many of our in-person outreach activties. However we were successful in having our research highlighted in a number of media venues. Our researchers' work on "ghost forests," caused by sea level rise, figured prominently in stories in the New York Times (https://www.nytimes.com/interactive/2019/10/08/climate/ghost-forests.html?fbclid=IwAR1rRbsKuF6BCP1MkPkY2A9yKPkgEIJqhTy60epqJYdSiMffORIxKwWc8fw) and Time magazine (https://time.com/5694648/ghost-forests-climate-change/). On November 1, 2020 a special "Ghosts of the Coasts" (https://www.coastaleducation.virginia.edu/wp/?page_id=1389) combination in-person and virtual event which links science and art opened with broad press coverage (e.g., https://www.easternshorepost.com/2020/10/30/artists-and-scientists-

collaborate-to-produce-artful-depictions-of-the-eastern-shores-ghost-forests/, https://news.virginia.edu/content/ghostly-forests-eastern-shore-have-story-tell, https://columbian.gwu.edu/ghosts-coast-artists-and-scientists-bring-ghost-forests-life, https://www.wvtf.org/post/artists-scientists-capture-ghosts-coast#stream/0).

Additionally, the 20-year Seagrass Restoration was featured on Public Radio (https://www.wvtf.org/post/seagrass-meadows-restored-eastern-shore#stream/0), UVA Arts & Sciences Magazine (http://give.as.virginia.edu/news/story/sea-change-eastern-shore) and the LTER Network News (https://lternet.edu/stories/seagrass-meadows-climate-change).

We used videoconferencing to participate in information manager training in Taiwan in April 2020.

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

Theme 1: Drivers of Long-term Change

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

Patterns of Change: Much of our analysis of landscape change will involve drone imagery, structure-from-motion analysis (SfM), and satellite imagery. This year we will: 1) develop drone methods to measure macroalgae, oyster reefs and tidal flats, and determine geomorphological change geomorphology on days-year scales and relate to biodiversity; 2) use drone photography and SfM to create maps of the morphology of the marsh-tidal flat transition and to monitor its response to storms; 3) use pre- and post-storm satellite imagery to analyze barrier island state change on multi-decadal time scales; and 4) continue to remap the bathymetry of Hog Island Bay using a high-resolution RTK bathymetric sounder to quantify change over the last 20 years, and in South Bay establish new bathymetric transects that will begin a new long-term dataset on bathymetric change.

Theme 2: Dynamics within Landscape Units

Upland - Marsh: We will continue our new long-term experiment on the forest-marsh transition with the following activities: 1) monitor tree and shrub survival and growth in experimental plots spanning a ghost forest to healthy forest transition, and track herbaceous vegetation and tree seedlings; 2) measure transpiration continuously using sap flux sensors; 3) continue to measure SETs located on the marsh-forest gradient; 4) create drone-based image mosaics; 4) sample invertebrates; and 5) analyze high-resolution hydrological data, comparing salinity and groundwater data at 6 wells to soil moisture and meteorological data. We will plan tree girdling activities, the experimental treatment within this large-scale experiment, to be implemented at the end of 2021.

Intertidal: We will complete our oyster predation meta-analysis on tides and water temperature as mediators of oyster predation. We will continue to monitor CO2 exchanges and salt marsh photosynthesis using eddy covariance and solar-induced chlorophyll fluorescence.

Subtidal: We will continue the long-term seagrass restoration/resilience experiment (year 20), including measurements of biomass, diversity, carbon and nitrogen stocks, O2, CO2 and methane fluxes, and sediment and water temperatures. We have developed new techniques that will be tested and used in the field: ‘upside down’ aquatic eddy covariance right below the air-water interface to measure emissions of greenhouse gasses (CO2, CH4, N2O), and underwater sound recording to quantify CH4 bubble release from sediments. The seagrass removal/resilience experiment will continue (year 2), with measurements of population dynamics, sediment and carbon accumulation, and faunal diversity.

Barrier Island: We will use repeat drone imagery to evaluate changes in shrub expansion into grassland, and annual optical and multispectral drone flights and SfM analysis of 2 islands at 40-50 ha scales to develop vegetation models (NDVI). We will continue to monitor species composition change and topographic evolution along newly established transects on 2 islands using vegetation surveys, RTK surveys and repeat drone flights to generate high resolution DEMs and collect multi-spectral data. We will continue our experimental nitrogen additions at the shrub-grass transition and include new measurements of grass/shrub edge interactions.

Theme 3: Dynamics between Landscape Units

Sediment Transport: We will continue to explore the coupled dynamics of tidal flats and marshes using a high-resolution hydrodynamic model, focusing on seagrass effects on marsh deposition and the importance of storm surge events on

transport from tidal flats to marshes. We will study the effects of the patch size and water depth on wave attenuation, bed shear stress and turbulence generated due to vegetation-flow interactions.

Oyster Larval Transport and Population Dynamics: We will finish surveying reef elevation on 13 reefs where we are collecting long-term oyster larval recruitment data, compare NOAA tidal gauge records with reef water-level data to estimate submergence, and assess how local physical conditions influence larval recruitment. We will also survey reef predators via reef excavations and baited trapping, and will do predator-exclusion experiments to understand landscape-scale variation in oyster survival and growth. Using our hydrodynamic model, we will track dispersal pathways of oyster larvae and connectivity among oyster reefs.

Coupled State Change Dynamics*:* Wave heights, bed shear stress and suspended sediment concentrations will continue to be measured adjacent to a marsh edge both behind constructed oyster reefs and at adjacent sites to determine the impact of offshore reefs on marsh edge erosion. LiDAR-based remote sensing will be used to characterize the morphology of marsh edges and drones will be used to quantify the location and rate of change of the marsh edge. Using the new coupled barrier island-shrub model, we will examine feedbacks between shrubs and overwash on long-term island evolution, including how shrubs alter the timescales and geometry of transgressing barriers and the likelihood of the barrier drowning, and how island morphodynamics impact shrub growth and expansion.

Ecological Consequences of State Changes

Carbon Sequestration: 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 are developing a landscape-scale C budget from measurements of soil C burial across VCR ecosystems (forest, marsh, seagrass, barrier islands) and will use it to assess the consequences of historical state changes. We are continuing our of C connectivity between seagrass and 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 that will enable upscaling of GPP using satellite data.

Consumer Dynamics:

Barrier islands: We will collect our 15th year of spring migrant shorebird data including samples of shorebird prey. We will conduct a 3rd year of nesting shorebird and colonial waterbird monitoring and will band an additional 50 Piping Plovers, and will quantify factors affecting the reproduction and survival of American Oystercatcher. We will conduct a full-season of water and blue mussel prey sampling on peat banks to test and develop models linking ocean acidification and bivalve growth.

Intertidal: We will use meta-analysis to examine the drivers of ecosystem services on restored oyster reefs relative to natural and degraded reefs. We will target aspects of restored reefs – construction technique, tidal range, reef height, reef age, water depth, salinity, and harvest pressure – associated with increases in ecosystem services. This analysis will improve the capacity to design restoration projects that can optimize specific ecological functions.

Subtidal: We will continue our time series collection of epifauna, infauna, fish, and crabs at 24–50 seagrass sites across 5 bays to determine patterns of seagrass biodiversity. To understand how seagrass affects clam diet and growth, we will: 1) measure time-specific patterns of growth in clam shells and relate to seagrass meadow age, sediment and hydrodynamic conditions; 2) measure stable isotopes of clam muscle tissue to identify food sources and contributions; and 3) conduct a growth experiment in the field. We will also sample blue crabs to start a long-term dataset and assess if landscape associations are consistent among years.

Supporting Files

Filename	Description	Uploaded By	Uploaded On
VCR LTER Annual Report 2020 figures.pdf	Figures for Accomplishments Section of VCR LTER Annual Report	John Porter	11/03/2020

Products

Books

Book Chapters

Christian, R.R (2020). Reference as a guiding framework: a short biography of Mark M. Brinson. *History of Wetland Science: Perspectives from Wetland Leaders* D.A. Wilcox. Amazon Print-on-Demand. 22. Status = PUBLISHED; Acknowledgement of Federal Support = No ; Peer Reviewed = No ; ISBN: 9798668260232.

Oreska, M. P. J., K. J. McGlathery, R. J. Orth, and D. J. Wilcox (2019). Seagrass mapping: A survey of recent seagrass distribution literature. *A Blue Carbon Primer: The State of Coastal Wetland Carbon Science, Policy, and Practice* L. Windham-Myers, S. Crooks, and T. Troxler. CRC Press. Boca Raton, FL. . Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes ; ISBN: 978-0367893521.

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.

Gaiser, Evelyn E and Bell, David M and Castorani, Max C and Childers, Daniel L and Groffman, Peter M and Jackson, C Rhett and Kominoski, John S and Peters, Debra P and Pickett, Steward T and Ripplinger, Julie and Zinnert, Julie C. (2020). Long-Term Ecological Research and Evolving Frameworks of Disturbance Ecology. *BioScience*. 70 (2) 141 to 156. Status = Deposited in NSF-PAR doi:https://doi.org/10.1093/biosci/biz162 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 05/19/2020) Full text Citation details

Aoki, LR and McGlathery, KJ. (2019). High rates of N fixation in seagrass sediments measured via a direct 30N2 push-pull method. *Marine Ecology Progress Series*. 616 1 to 11. Status = Deposited in NSF-PAR doi:https://doi.org/10.3354/meps12961 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/26/2020) Full text Citation details

Saderne, V. and Geraldi, N. R. and Macreadie, P. I. and Maher, D. T. and Middelburg, J. J. and Serrano, O. and Almahasheer, H. and Arias-Ortiz, A. and Cusack, M. and Eyre, B. D. and Fourqurean, J. W. and Kennedy, H. and Krause-Jensen, D. and Kuwae, T. and Lavery, P. S. and Lovelock, C. E. and Marba, N. and Masqué, P. and Mateo, M. A. and Mazarrasa, I. and McGlathery, K. J. and Oreska, M. P. and Sanders, C. J. and Santos, I. R. and Smoak, J. M. and Tanaya, T. and Watanabe, K. and Duarte, C. M.. (2019). Role of carbonate burial in Blue Carbon budgets. *Nature Communications*. 10 (1) . Status = Deposited in NSF-PAR doi:https://doi.org/10.1038/s41467-019-08842-6 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/26/2020) Full text Citation details

Oreska, Matthew P. and McGlathery, Karen J. and Aoki, Lillian R. and Berger, Amélie C. and Berg, Peter and Mullins, Lindsay. (2020). The greenhouse gas offset potential from seagrass restoration. *Scientific Reports*. 10 (1) . Status = Deposited in NSF-PAR doi:https://doi.org/10.1038/s41598-020-64094-1 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/26/2020) Full text Citation details

Yang, Shi Lun and Luo, Xiangxin and Temmerman, Stijn and Kirwan, Matthew and Bouma, Tjeerd and Xu, Kehui and Zhang, Saisai and Fan, Jiqing and Shi, Benwei and Yang, Haifei and Wang, Ya Ping and Shi, Xuefa and Gao, Shu. (2020). Role of delta-front erosion in sustaining salt marshes under sea-level rise and fluvial sediment decline. *Limnology and Oceanography*. 65 (9) 1990 to 2009. Status = Deposited in NSF-PAR doi:https://doi.org/10.1002/lno.11432 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/07/2020) Full text Citation details

Chen, Zhenshan and Swallow, Stephen K. and Yue, Ian T.. (2020). Non-participation and Heterogeneity in Stated: A Double Hurdle Latent Class Approach for Climate Change Adaptation Plans and Ecosystem Services. *Environmental and Resource Economics*. 77 (1) 35 to 67. Status = Deposited in NSF-PAR doi:https://doi.org/10.1007/s10640-020-00434-z ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/07/2020) Full text Citation details

Langston, Amy K. and Durán Vinent, Orencio and Herbert, Ellen R. and Kirwan, Matthew L.. (2020). Modeling long-term salt marsh response to sea level rise in the sediment-deficient Plum Island Estuary, MA. *Limnology and Oceanography*. 65 (9) 2142 to 2157. Status = Deposited in NSF-PAR doi:https://doi.org/10.1002/lno.11444 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/07/2020) Full text Citation details

Doney, Scott C. and Busch, D. Shallin and Cooley, Sarah R. and Kroeker, Kristy J.. (2020). The Impacts of Ocean Acidification on Marine Ecosystems and Reliant Human Communities. *Annual Review of Environment and Resources*. 45

(1) . Status = Deposited in NSF-PAR doi:https://doi.org/10.1146/annurev-environ-012320-083019 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 06/25/2020) Full text Citation details

Cumbie, Alexandra N. and Espada, Christina D. and Nadolny, Robyn M. and Rose, Robert K. and Dueser, Raymond D. and Hynes, Wayne L. and Gaff, Holly D.. (2020). Survey of Rickettsia parkeri and Amblyomma maculatum associated with small mammals in southeastern Virginia. *Ticks and Tick-borne Diseases*. 11 (6) 101550. Status = Deposited in NSF-PAR doi:https://doi.org/10.1016/j.ttbdis.2020.101550 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/07/2020) Full text Citation details

Goldsmith, Sarah B. and Eon, Rehman S. and Lapszynski, Christopher S. and Badura, Gregory P. and Osgood, David T. and Bachmann, Charles M. and Tyler, Anna Christina. (2020). Assessing Salt Marsh Vulnerability Using High-Resolution Hyperspectral Imagery. *Remote Sensing*. 12 (18) 2938. Status = Deposited in NSF-PAR doi:https://doi.org/10.3390/rs12182938 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/06/2020) Full text Citation details

Schepers, Lennert and Brennand, Patrick and Kirwan, Matthew L. and Guntenspergen, Glenn R. and Temmerman, Stijn. (2020). Coastal Marsh Degradation Into Ponds Induces Irreversible Elevation Loss Relative to Sea Level in a Microtidal System. *Geophysical Research Letters*. 47 (18) . Status = Deposited in NSF-PAR doi:https://doi.org/10.1029/2020GL089121 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/07/2020) Full text Citation details

Wood, Lauren K. and Hays, Spencer and Zinnert, Julie C.. (2020). Decreased temperature variance associated with biotic composition enhances coastal shrub encroachment. *Scientific Reports*. 10 (1) . Status = Deposited in NSF-PAR doi:https://doi.org/10.1038/s41598-020-65161-3 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 05/19/2020) Full text Citation details

Carr, J. and Guntenspergen, G. and Kirwan, M.. (2020). Modeling Marsh-Forest Boundary Transgression in Response to Storms and Sea-Level Rise. *Geophysical Research Letters*. 47 (17) . Status = Deposited in NSF-PAR doi:https://doi.org/10.1029/2020GL088998 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/06/2020) Full text Citation details

Braswell, Anna E. and Heffernan, James B. and Kirwan, Matthew L.. (2020). How Old Are Marshes on the East Coast, USA? Complex Patterns in Wetland Age Within and Among Regions. *Geophysical Research Letters*. 47 (19) . Status = Deposited in NSF-PAR doi:https://doi.org/10.1029/2020GL089415 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/07/2020) Full text Citation details

Failon, Caroline Mackenzie and Wittyngham, Serina Sebilian and Johnson, David Samuel. (2020). Ecological Associations of Littoraria irrorata with Spartina cynosuroides and Spartina alterniflora. *Wetlands*. . Status = Deposited in NSF-PAR doi:10.1007/s13157-020-01306-4 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/12/2020) Full text Citation details

Wittyngham, Serina Sebilian. (2020). Salinity and Simulated Herbivory Influence Spartina alterniflora Traits and Defense Strategy. *Estuaries and Coasts*. . Status = Deposited in NSF-PAR doi:10.1007/s12237-020-00841-x ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/12/2020) Full text Citation details

Palazzoli, I. and Leonardi, N. and Jiménez-Robles, A.M. and Fagherazzi, S.. (2020). Velocity skew controls the flushing of a tracer in a system of shallow bays with multiple inlets. *Continental Shelf Research*. 192 (C) 104008. Status = Deposited in NSF-PAR doi:10.1016/j.csr.2019.104008 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/07/2020) Full text Citation details

Ganju, Neil K. and Defne, Zafer and Fagherazzi, Sergio. (2020). Are Elevation and Open-Water Conversion of Salt Marshes Connected?. *Geophysical Research Letters*. 47 (3) . Status = Deposited in NSF-PAR doi:10.1029/2019GL086703 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/07/2020) Full text Citation details

Zhang, Xiaohe and Fichot, Cédric G. and Baracco, Carly and Guo, Ruizhe and Neugebauer, Sydney and Bengtsson, Zachary and Ganju, Neil and Fagherazzi, Sergio. (2020). Determining the drivers of suspended sediment dynamics in tidal marsh-influenced estuaries using high-resolution ocean color remote sensing. *Remote Sensing of Environment*. 240 (C) 111682. Status = Deposited in NSF-PAR doi:10.1016/j.rse.2020.111682 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/07/2020) Full text Citation details

Volaric, MP and Berg, P and Reidenbach, MA. (2019). An invasive macroalga alters ecosystem metabolism and hydrodynamics on a tidal flat. *Marine Ecology Progress Series*. 628 1 to 16. Status = Deposited in NSF-PAR doi:10.3354/meps13143 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/06/2020) Full text Citation details

Donatelli, Carmine and Zhang, Xiaohe and Ganju, Neil K. and Aretxabaleta, Alfredo L. and Fagherazzi, Sergio and Leonardi, Nicoletta. (2020). A nonlinear relationship between marsh size and sediment trapping capacity compromises salt marshes' stability. *Geology*. . Status = Deposited in NSF-PAR doi:10.1130/G47131.1 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/07/2020) Full text Citation details

Coleman, Daniel J. and Ganju, Neil K. and Kirwan, Matthew L.. (2020). Sediment Delivery to a Tidal Marsh Platform Is Minimized by Source Decoupling and Flux Convergence. *Journal of Geophysical Research: Earth Surface*. 125 (8) . Status = Deposited in NSF-PAR doi:10.1029/2020JF005558 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/07/2020) Full text Citation details

Besterman, Alice F. and McGlathery, Karen J. and Reidenbach, Matthew A. and Wiberg, Patricia L. and Pace, Michael L.. (2020). Predicting benthic macroalgal abundance in shallow coastal lagoons from geomorphology and hydrologic flow patterns. *Limnology and Oceanography*. . Status = Deposited in NSF-PAR doi:10.1002/lno.11592 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/07/2020) Full text Citation details

Liu, Wenwen and Chen, Xincong and Strong, Donald R. and Pennings, Steven C. and Kirwan, Matthew L. and Chen, Xiaolin and Zhang, Yihui. (2020). Climate and geographic adaptation drive latitudinal clines in biomass of a widespread saltmarsh plant in its native and introduced ranges. *Limnology and Oceanography*. 65 (6) 1399 to 1409. Status = Deposited in NSF-PAR doi:10.1002/lno.11395 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/07/2020) Full text Citation details

Kirwan, Matthew L. and Gedan, Keryn B.. (2019). Sea-level driven land conversion and the formation of ghost forests. *Nature Climate Change*. 9 (6) 450 to 457. Status = Deposited in NSF-PAR doi:10.1038/s41558-019-0488-7 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/06/2020) Full text Citation details

Wiberg, Patricia L. and Fagherazzi, Sergio and Kirwan, Matthew L.. (2019). Improving Predictions of Salt Marsh Evolution Through Better Integration of Data and Models. *Annual Review of Marine Science*. 12 (1) . Status = Deposited in NSF-PAR doi:10.1146/annurev-marine-010419-010610 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/06/2020) Full text Citation details

Volaric, Martin P. and Berg, Peter and Reidenbach, Matthew A.. (2020). Drivers of Oyster Reef Ecosystem Metabolism Measured Across Multiple Timescales. *Estuaries and Coasts*. . Status = Deposited in NSF-PAR doi:10.1007/s12237-020-00745-w ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/06/2020) Full text Citation details

Thuma, Jessie and Roulston, T'ai and Blum, Linda. (2019). Implications of Sea Level Rise for Bee Communities in Rural Eastern Virginia Coastal Habitats. *Journal of the Kansas Entomological Society*. 92 (4) . Status = Deposited in NSF-PAR doi:10.2317/0022-8567-92.4.602 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/06/2020) Full text Citation details

Berger, Amelie C. and Berg, Peter and McGlathery, Karen J. and Delgard, Marie Lise. (2020). Long-term trends and resilience of seagrass metabolism: A decadal aquatic eddy covariance study. *Limnology and Oceanography*. . Status = Deposited in NSF-PAR doi:10.1002/lno.11397 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/06/2020) Full text Citation details

Schepers, Lennert and Kirwan, Matthew L. and Guntenspergen, Glenn R. and Temmerman, Stijn. (2020). Evaluating indicators of marsh vulnerability to sea level rise along a historical marsh loss gradient. *Earth Surface Processes and Landforms*. 45 (9) 2107 to 2117. Status = Deposited in NSF-PAR doi:10.1002/esp.4869 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 10/06/2020) Full text Citation details

Yeates, Alice G. and Grace, James B. and Olker, Jennifer H. and Guntenspergen, Glenn R. and Cahoon, Donald R. and Adamowicz, Susan and Anisfeld, Shimon C. and Barrett, Nels and Benzecry, Alice and Blum, Linda and Christian, Robert R. and Grzyb, Joseph and Hartig, Ellen Kracauer and Leo, Kelly Hines and Lerberg, Scott and Lynch, James C. and Maher, Nicole and Megonigal, J. Patrick and Reay, William and Siok, Drexel and Starke, Adam and Turner, Vincent and Warren, Scott. (2020). Hurricane Sandy Effects on Coastal Marsh Elevation Change. *Estuaries and Coasts*. . Status = Deposited in

NSF-PAR doi:10.1007/s12237-020-00758-5 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 06/22/2020) Full text Citation details

Mariotti, Giulio and Kearney, William S. and Fagherazzi, Sergio. (2019). Soil creep in a mesotidal salt marsh channel bank: Fast, seasonal, and water table mediated. *Geomorphology*. 334 (C) 126 to 137. Status = Deposited in NSF-PAR doi:10.1016/j.geomorph.2019.03.001 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 09/15/2020) Full text Citation details

Aoki, Lillian R. and McGlathery, Karen J. and Wiberg, Patricia L. and Al-Haj, Alia. (2020). Depth Affects Seagrass Restoration Success and Resilience to Marine Heat Wave Disturbance. *Estuaries and Coasts*. . Status = Deposited in NSF-PAR doi:10.1007/s12237-019-00685-0 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 01/10/2020) 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

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

Blum, Linda K. and Christian, Robert R. and Cahoon, Donald R. and Wiberg, Patricia L.. (2020). Processes Influencing Marsh Elevation Change in Low- and High-Elevation Zones of a Temperate Salt Marsh. *Estuaries and Coasts*. . Status = Deposited in NSF-PAR doi:10.1007/s12237-020-00796-z ; Federal Government's License = Acknowledged. (Completed by Porter, John on 08/10/2020) Full text Citation details

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

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

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

Hogan, S and Reidenbach, MA. (2019). Quantifying and mapping intertidal oyster reefs utilizing LiDAR-based remote sensing. *Marine Ecology Progress Series*. 630 83 to 99. Status = Deposited in NSF-PAR doi:10.3354/meps13118 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 06/02/2020) Full text Citation details

Brown, Joseph K. and Zinnert, Julie C.. (2020). Topography and disturbance influence trait-based composition and productivity of adjacent habitats in a coastal system. *Ecosphere*. 11 (5) . Status = Deposited in NSF-PAR doi:10.1002/ecs2.3139 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 05/19/2020) Full text Citation details

Kirschner, Audrey S. and Zinnert, Julie C.. (2020). Two low-lying coastal grassland species differ in mechanistic response to saline flooding stress. *Plant Ecology*. 221 (6) 475 to 485. Status = Deposited in NSF-PAR doi:10.1007/s11258-020-01026-z ; Federal Government's License = Acknowledged. (Completed by Porter, John on 05/19/2020) Full text Citation details

Besterman, Alice F. and Karpanty, Sarah M. and Pace, Michael L. and Hoskins, Andrew J.. (2020). Impact of exotic macroalga on shorebirds varies with foraging specialization and spatial scale. *PLOS ONE*. 15 (4) e0231337. Status =

Deposited in NSF-PAR doi:10.1371/journal.pone.0231337 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 04/13/2020) 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

Sinclair, Michael N. and Woods, Natasha N. and Zinnert, Julie C.. (2020). Seasonal facilitative and competitive trade-offs between shrub seedlings and coastal grasses. *Ecosphere*. 11 (1) . Status = Deposited in NSF-PAR doi:10.1002/ecs2.2995 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 05/19/2020) 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

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

Reeves, I. R. and Moore, L. J. and Goldstein, E. B. and Murray, A. B. and Carr, J. A. and Kirwan, M. L.. (2020). Impacts of Seagrass Dynamics on the Coupled Long-Term Evolution of Barrier-Marsh-Bay Systems. *Journal of Geophysical Research: Biogeosciences*. 125 (2) . Status = Deposited in NSF-PAR doi:10.1029/2019JG005416 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 02/03/2020) Full text Citation details

Eon, Rehman S. and Bachmann, Charles M. and Lapszynski, Christopher S. and Tyler, Anna Christina and Goldsmith, Sarah. (2020). Retrieval of Sediment Filling Factor in a Salt Panne from Multi-View Hyperspectral Imagery. *Remote Sensing*. 12 (3) 422. Status = Deposited in NSF-PAR doi:10.3390/rs12030422 ; Federal Government's License = Acknowledged. (Completed by Porter, John on 02/28/2020) 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

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

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

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

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

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

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

Licenses

Other Conference Presentations / Papers

Other Products

Other Publications

Patent Applications

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

Tuley, Philip A. *Comparing coastal storm impact to decadal change in barrier island ecosystems*. (2020). Virginia Commonwealth University. Acknowledgement of Federal Support = Yes

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

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

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

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

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

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

Websites or Other Internet Sites

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

Central web site for the VCR/LTER. It includes information about the research, data, documents (including full-text of student theses), photographs and videos. Data include over 250 datasets that are also published on the Environmental Data Initiative and DataONE.org.

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
McGlathery, Karen	PD/PI	1
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

Name	Most Senior Project Role	Nearest Person Month Worked
Bachmann, Charles	Co-Investigator	1
Baird, Cora	Co-Investigator	12
Berg, Peter	Co-Investigator	1
Blum, Linda	Co-Investigator	1
Carr, Joel	Co-Investigator	1
Castorani, Max	Co-Investigator	1
Christian, Robert	Co-Investigator	1
D'Odorico, Paolo	Co-Investigator	1
Dueser, Raymond	Co-Investigator	1
Fagherazzi, Sergio	Co-Investigator	1
Fenster, Michael	Co-Investigator	1
Gedan, Keryn	Co-Investigator	1
Johnson, David	Co-Investigator	1
Karpanty, Sarah	Co-Investigator	1
Kirwan, Matthew	Co-Investigator	1
Macko, Stephen	Co-Investigator	1
Mills, Aaron	Co-Investigator	1
Moncrief, Nancy	Co-Investigator	1
Moore, Laura	Co-Investigator	1
Pusede, Sally	Co-Investigator	1
Smith, David	Co-Investigator	1
Sojka, Sarah	Co-Investigator	1
Tyler, Christy	Co-Investigator	1
Yang, Xi	Co-Investigator	1

Name	Most Senior Project Role	Nearest Person Month Worked
Young, Donald	Co-Investigator	1
Zinnert, Julie	Co-Investigator	1
Aoki, Lillian	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Biel, Reuben	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Ewers Lewis, Carolyn	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Goldstein, Evan	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Smith, Rachel	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Woods, Natasha	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Doughty, Albert	Technician	12
Lee, David	Technician	12
MacGregor, Jessica	Technician	2
Martinez-Soto, Kayla	Technician	2
Morreale, Jonah	Technician	12
Barnes, Tyler	Graduate Student (research assistant)	4
Berger, Amelie	Graduate Student (research assistant)	4
Besterman, Alice	Graduate Student (research assistant)	4
Bieri, Elizabeth	Graduate Student (research assistant)	4
Brown, Joseph	Graduate Student (research assistant)	4
Call, Mikayla	Graduate Student (research assistant)	4
Coleman, Daniel	Graduate Student (research assistant)	4
Cornish, Michael	Graduate Student (research assistant)	4

Name	Most Senior Project Role	Nearest Person Month Worked
Eon, Rehman	Graduate Student (research assistant)	4
Flester, Jessica	Graduate Student (research assistant)	4
Giovanna, Nordio	Graduate Student (research assistant)	6
Goetz, Emily	Graduate Student (research assistant)	4
Goldsmith, Sarah	Graduate Student (research assistant)	4
Granville, Kayleigh	Graduate Student (research assistant)	4
Hardison, Sean	Graduate Student (research assistant)	4
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)	4
Kerns, Kylor	Graduate Student (research assistant)	4
Kirschner, Audrey	Graduate Student (research assistant)	4
Lang, Sarah	Graduate Student (research assistant)	4
Lapszynski, Chris	Graduate Student (research assistant)	4
LaRoche, Carly	Graduate Student (research assistant)	4
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)	4
Messershmidt, Tyler	Graduate Student (research assistant)	4
Nettleton, Benjamin	Graduate Student (research assistant)	4

Name	Most Senior Project Role	Nearest Person Month Worked
Olivier, Gourgue	Graduate Student (research assistant)	4
Palazzoli, Irene	Graduate Student (research assistant)	4
Pant, Manisha	Graduate Student (research assistant)	4
Reeves, Ian	Graduate Student (research assistant)	4
Riffe, Emily	Graduate Student (research assistant)	4
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)	4
Tedford, Kinsey	Graduate Student (research assistant)	4
Tuley, Philip	Graduate Student (research assistant)	4
Turrietta, Elise	Graduate Student (research assistant)	4
Walker, Shannon	Graduate Student (research assistant)	4
Wittyngham, Serina	Graduate Student (research assistant)	4
Wood, Lauren	Graduate Student (research assistant)	4
Yiyang, Xu	Graduate Student (research assistant)	4
Zezheng, Liu	Graduate Student (research assistant)	4
Zhang, Xiaohe	Graduate Student (research assistant)	4
Zhu, Quingguang	Graduate Student (research assistant)	4
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: 1

Contribution to the Project: Lead PI, Seagrass research

Funding Support: NSF

Change in active other support: Yes

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

Change in active other support: Yes

International Collaboration: No
International Travel: No

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

Contribution to the Project: Information management, GIS analysis, small mammal ecology

Funding Support: NSF, UVA

Change in active other support: No

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

Change in active other support: Yes

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

Change in active other support: Yes

International Collaboration: No
International Travel: No

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

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

Funding Support: SeaGrant, VIMS

International Collaboration: No
International Travel: No

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

Contribution to the Project: Use of hyperspectral remote sensing

Funding Support: Office of Naval Research

International Collaboration: No
International Travel: No

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

Contribution to the Project: Site Manager, Education Specialist

Funding Support: NSF

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

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

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

Funding Support: Virginia Tech

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Contribution to the Project: Research using stable isotopes

Funding Support: UVA

International Collaboration: No
International Travel: No

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

Contribution to the Project: Worked on streambed biogeochemistry

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Contribution to the Project: Mammalian population ecology and genetics studies

Funding Support: Virginia Museum of Natural History

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Contribution to the Project: Atmsopheric fluxes

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Contribution to the Project: Aquatic vertebrates and education

Funding Support: UVA

International Collaboration: No
International Travel: No

Sarah Sojka
Email: ssojka@randolphcollege.edu

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

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

Funding Support: Randolph College

International Collaboration: No
International Travel: No

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

Contribution to the Project: Biogeochemistry of wetlands

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Contribution to the Project: Remote sensing, atmospheric fluxes

Funding Support: NSF

International Collaboration: No
International Travel: No

Donald Young
Email: dyoung@vcu.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Julie C Zinnert
Email: jczinnert@vcu.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Linking remote sensing to environmental and ecological functioning at the VCR island chain scale and spatial-temporal variability in vegetation hyperspectral indices to characterize terrain state

Funding Support: Army Corps of Engineers

International Collaboration: No
International Travel: No

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: 6

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: 6

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: 6

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

Rachel S Smith
Email: rss2jj@virginia.edu

Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 6

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

Funding Support: UVA, TNC

International Collaboration: No
International Travel: No

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

Albert Doughty
Email: ad7rw@virginia.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 12

Contribution to the Project: Boat driving, equipment maintenance

Funding Support: UVA, NSF

International Collaboration: No
International Travel: No

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

Kayla Martinez-Soto
Email: ksmartin@vims.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 2

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

Funding Support: NSF, VIMS

International Collaboration: No
International Travel: No

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

Contribution to the Project: Technical staff of field station

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

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

Funding Support: NFWF

International Collaboration: No
International Travel: No

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

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

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

Funding Support: NSF and Virginia Tech

International Collaboration: No
International Travel: No

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

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

Nordio Giovanna
Email: nordiog@bu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Emily Goetz
Email: emgoetz@vims.edu

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

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

Funding Support: NSF, VIMS

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Contribution to the Project: Working with Berg on flux measurements

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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: 4

Contribution to the Project: Working with Berg on flux measurements

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Audrey Kirschner
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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

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

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

Funding Support: VA Spacegrant

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF, VIMS

International Collaboration: No
International Travel: No

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

Gourgue Olivier
Email: ogourgue@bu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: EU Scholarship

International Collaboration: Yes, Belgium
International Travel: No

Irene Palazzoli
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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

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

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

Funding Support: NSF, VIMS

International Collaboration: No
International Travel: No

Ian Reeves
Email: irbreeves@gmail.com

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: VCU

International Collaboration: No
International Travel: No

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: 4

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

Funding Support: UVA, NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Shannon Walker
Email: walkers5@mymail.vcu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: VCU, US Army Corps

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF, VA SeaGrant

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: USGS, Chinese Scholarship

International Collaboration: Yes, China
International Travel: No

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

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

Funding Support: Chinese Schoarship

International Collaboration: Yes, China
International Travel: No

Xiaohe Zhang
Email: zhangbu@bu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

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

Funding Support: NSF

International Collaboration: No
International Travel: No

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

Name	Type of Partner Organization	Location
The Nature Conservancy	Other Nonprofits	USA/Virginia
Virginia Institute of Marine Sciences	Academic Institution	Gloucester Point, VA

Full details of organizations that have been involved as partners:

Accomack Co. Public Schools

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

Partner's Contribution to the Project:
Personnel Exchanges

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

Agricultural Research and Extension Centers - Virginia Tech

Organization Type: Academic Institution
Organization Location: Blacksburg, VA

Partner's Contribution to the Project:
Collaborative Research

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

Barrier Islands Center

Organization Type: Other Nonprofits
Organization Location: Eastville, VA

Partner's Contribution to the Project:
Financial support
Facilities

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

Environmental Education Council of the Eastern Shore

Organization Type: Other Nonprofits
Organization Location: Virginia

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

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

Northampton County Public Schools

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

Partner's Contribution to the Project:
Personnel Exchanges

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

SouthWings

Organization Type: Other Nonprofits
Organization Location: Norfolk, VA

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

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

The Nature Conservancy

Organization Type: Other Nonprofits
Organization Location: USA/Virginia

Partner's Contribution to the Project:
Facilities
Collaborative Research

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

Virginia Institute of Marine Sciences

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

Partner's Contribution to the Project:
Collaborative Research

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

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

Impacts

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

VCR research has contributed to theoretical advances in understanding complex dynamics of state change in ecosystems dominated by foundation species. The VCR is 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 islands, salt marshes, and coastal lagoons with seagrass meadows and oyster reefs that comprise the VCR and the connections between them. We link ecological and physical (geomorphic, hydrologic) processes that are critical to ecosystem dynamics. For example, sediment transport and deposition allows marshes to keep pace with rising seas, oyster reefs and seagrass affect marsh erosion during storms, and vegetation (shrubs, grass) affects how barrier islands build elevation and migrate inland in response to sea-level rise and storms.

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

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

COASTAL BAYS

The eelgrass (Zostera marina) that once carpeted 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 2-decade landscape-level experiment has shown that within a decade ecosystem services - primary productivity, carbon and nitrogen sequestration, increased water column clarity, and sediment stabilization – biodiversity are reinstated. We were the first to show the role of seagrass restoration in reinstating ‘blue’ carbon storage capacity.

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

Our research on the invasive macroalga, *Agarophyton vermiculophylla*, is 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.

Our study of oyster reef restoration addresses a key gap in restoration ecology by identifying the recovery timeline for restored oyster reefs. This work provides evidence to support the value of continuing oyster restoration efforts by illustrating functional equivalence of restored and natural reefs over time. The study also highlights the need for managers and conservation practitioners to increase monitoring time frames and include appropriate reference sites in monitoring programs to clarify recovery timelines and assess functional equivalence of restored and natural ecosystems. Likewise, our oyster restoration meta-analysis supports the use of oyster restoration to increase ecosystem services in coastal habitats.

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

WETLANDS AND MARITIME FOREST

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

BARRIER ISLANDS

Barrier island plants and shorebirds and their invertebrate prey communities serve as sentinels to climate change. We quantified how across the breeding range of the Piping Plover storm overwash events cause dramatic population irruptions. Ocean intertidal habitat states, sand and exposed peat substrates, host unique invertebrate communities for migratory shorebird populations, and modeling is showing how these habitats and invertebrate communities will respond to warming ocean temperatures and acidification, and impact higher trophic levels.

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

We have established that long-term and landscape-scale vegetation patterns on the islands reflect non-linear dynamics and threshold responses to environmental drivers. We coined the term 'maintainer feedback' to apply to processes that maintain low elevations (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?

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

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

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

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

What is the impact on the development of human resources?

As can be seen from the number of graduate and undergraduate students listed on our participant list, this project provides abundant opportunities for training. Moreover, the inter- and multi-disciplinary nature of the research teaches the students how to operate in a collaborative environment. Our REU, REHS activities provide graduate students mentorship training as they supervise and support the work of undergraduate and high school student interns. Several students from the local community have become involved in our research, including one REU who studied with us during the summer of his transition from community college to a 4-year science program.

VCR LTER continues our strong tradition of training undergraduate and graduate researchers through a tiered mentoring program; this year 50 graduate students and 6 post-docs conducted research through the program. We continued to attract involvement by students from the local community, including two selected for our REU program. Though our REU program

was ultimately deferred due to COVID-19, we made strides in inclusive recruiting and selection through partnerships with the NC-VA Alliance for Minority Participation and PathwaystoScience.org, resulting in 35 applicants from 17 institutions, of which 57% were female, 17% Asian, 11% African American, 7% Latinx, 2% Native, and 2% from community colleges. From ⅓ to ½ of priority applicants selected for each project were members of underrepresented groups in STEM.

What was the impact on teaching and educational experiences?

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

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

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

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

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

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

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

The VCR/LTER shares 257 online datasets with an aggregate volume of approximately 441 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 11/1/2019 to 10/31/2020 VCR/LTER data files have been downloaded at 5,072 times via the Environmental Data Initiative Data Portal. An additional 486 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 36 downloads for which a reason was given, research made up 75% and education 25% (e.g., student class projects) of the downloads. 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 decisionsupport tool, where it can be queried and analyzed with other geospatial data to visualize risk and evaluate effectiveness of nature-based solutions for coastal protection.

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

What is the impact on technology transfer?

The VCR/LTER developed code-generation tools that transform EML Metadata into usable programs for analysis in the R, SAS and SPSS statistical languages (and in collaboration with the GCE LTER, Matlab). These are provided as a web service and used in our local web data catalog and on the LTER Data Portal. They were used 6,591 times in the past year (excluding robots), with R-based code generated 53% of the time, Matlab 20%, and SAS, SPSS and Python accounting for 9% each.

The VCR/LTER organized and hosted a workshop in 2013 that enhanced the LTER Controlled Vocabulary, a tool that is used to improve data discoverability. The LTER Controlled Vocabulary has been integrated into other systems, such as the European LTER ENVTHES project. We continue to be active in the management of this resource and in 2019 published a summary of its use (Porter, 2019).

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

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

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

What is the impact on society beyond science and technology?

We all are experiencing anthropogenic changes in the environment, including global warming, sea-level rise and ocean acidification. Understanding of the causes and consequences of these changes, and the processes that drive them are critical to addressing them. It is not sufficient just to have a general sense of what is happening and why it is happening. Details can be important, and research at the Virginia Coast Reserve LTER are helping to develop a sophisticated understanding of how coastal systems can influence and respond to global drivers.

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

Changes/Problems

Changes in approach and reason for change
Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them

VCR LTER field work was limited during the 2020 field season due to COVID precautions. Boats could accommodate 2 people at a time (in addition to the staff driver) for field work on the lagoons or barrier islands. Land-based sampling on the mainland marshes and forests was less impacted, especially when researchers could commute to the site and didn't require housing. Despite these limitations, we were able to complete all long-term sampling and experiments, with the exception of fish seining which could not be done following social distance protocols. The UVA Coastal Research Center that hosts the VCR LTER was closed from mid-March to early June, all staff worked from home, and no university researchers were allowed to visit. After early June, we were allowed to partially open, with a capacity of 3-4 people at a time at the Center, rather than the normal 10-20 people. We were not authorized to have undergraduate or high school students at the field station, so our REU and REHS programs were suspended in 2020. Soon after the COVID limitations were put in place, we encouraged graduate students to focus on methods development, data mining, modeling, and limited field campaigns. Graduate student research was the most heavily impacted by COVID restrictions.

The following activities planned for 2020 did not take place due to COVID:

In the interidal: 1) a caging experiment to look at the interaction between the purple marsh crab (*Sesarma* sp.), the salt marsh plant *Spartina* sp., and sediment; 2) a cross-LTER caging experiment to look at fiddler-crab body size and density on salt marsh functioning also was not conducted; and 3) field experiments on oyster larval recruitment.

In the subtidal: 1) the annual long-term fish sampling due to social distancing restrictions; 2) the annual sampling of seagrass infaunal and epifaunal invertebrates, but identification and enumeration of fauna was delayed without undergraduate research assistance; 3) development of new methods to quantify gas fluxes in seagrass meadows were delayed, and in situ measurements were cut back from the entire summer to one week; and 4) field measurements to validate predictions of seagrass habitat niche model were suspended.

On the barrier islands: 1) we delayed establishing our new long-term experiment to quantify dune grass species growth as a function of elevation and time, and we have instead focused on establishing transects for our new long-term monitoring of dune grass species composition and topographic evolution along three transects on each of Hog and Metompkin Island; 2) we did not collect our 15th year of data on migrant shorebirds and their prey due to covid-restrictions during the migration season (May 2020); and 3) we missed the spring (but not fall) session of small mammal monitoring on Hog Island.

As noted above, COVID restrictions suspended many of our educational and outreach programs, including twice yearly Art and Ecology workshops for teachers, annual watershed PD with teachers of Clarke County, RETs, REUs, Nature Camp, and the newly developed ‘science pub’ outreach series (a collaboration with the Cape Charles Brewing Company and a VA Sea Grant fellow) and coastal writing workshop (a collaboration with Coastal Conservatory and UVA Environmental Humanities program).

Most of these delays will be resolved when restrictions related to COVID-19 are relaxed. UVA is moving from Phase 1 to Phase 2 of the UVA research ramp-up plan in November 2020.

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

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

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

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

Change in primary performance site location
Nothing to report.