ANNUAL REPORT

Defense Coastal/Estuarine Research Program 2 (DCERP2)

SERDP Project RC-2245

MAY 2014

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Abstract

Objective

The potential impacts of climate change on military training and associated infrastructure are a growing challenge to our nation's military readiness and U.S. Department of Defense (DoD) stewardship of its natural resources. DoD installations in estuarine/coastal areas are at particular risk from climate change associated with changes in extreme weather (i.e., severe droughts, heavy rainfall events, warming temperatures, and increased storms) and rising sea level compounded by storm surge. In addition, installations will be faced with managing the trade-offs between mission sustainability, ecosystem resilience, carbon management, and other ecosystem service dependencies to achieve installation management goals in a changed climate. To balance military training and testing needs and sustainable natural resources management, installation managers need easy-to-use decision-support tools, models, and other products to assist them in making often complex, ecosystem-based management decisions.

The DCERP2 Team designed an integrative research and monitoring program to understand the impacts of climate change together with local installation and regional activities on critical ecosystem processes at our primary study site, Marine Corps Base Camp Lejeune (MCBCL) and secondary installation study sites throughout the southeastern United States (Fort Bragg and Marine Corps Air Station [MCAS] Cherry Point, both in North Carolina; and Eglin Air Force Base in Florida). This program will focus on the ecosystem processes associated with the carbon cycle, nutrient utilization, and sediment transport within the context of climate change impacts. Models, tools, and other products developed at MCBCL will be transitioned via the DCERP Web site to other DoD installations.

The objectives of the DCERP2 include the following:

1. Determine how ecosystem processes (within military land-use environments) respond to climate change to understand the sensitivity and adaptive capacity of these ecosystems.
2. Build on previous DCERP1 findings to identify additional thresholds that can serve as indicators of tipping point conditions that could threaten sustainability of the military mission.
3. Assess opportunities for adaptive management of estuarine, coastal, and terrestrial ecosystems to enhance carbon storage at MCBCL and other DoD installations in similar coastal settings.
4. Convey results of scientific studies to managers and decision makers by developing clearly written products and easy-to-use decision-support tools and models hosted on a readily accessible Web-based platform.

Technical Approach

The DCERP2 Team builds on the previous 5 years of research at MCBCL and adapts the program to the new priorities of climate change, carbon cycling, and translating scientific information into practice. Our approach is structured to use measurements and develop models and tools that inform science-based adaptive management at MCBCL and that can be easily

transferred to other DoD installations. The technical approach remains organized around the four interconnected ecosystem modules used during DCERP1: Aquatic/Estuarine, Coastal Barrier, Coastal Wetlands, and Terrestrial. These ecosystem modules are linked by a cross-cutting Climate Change Module that will determine climate parameters focused on warming temperatures and perturbations of a changing hydrologic cycle (i.e., wet and dry periods) at appropriate scales for use in ecosystem process models to drive current and future climate scenarios. The program includes systematic, time-series observations of drivers and indicators to determine the status, trends, and natural variations of measured parameters in these ecosystems. Data and outcomes from research and monitoring efforts are managed within a new centralized Translating Science into Practice Module. This module provides the ability to identify synergies and conflicts among carbon management strategies amidst other priorities such as military mission sustainability, natural resource conservation, and water quality management. Collectively, the research and monitoring efforts encompass an integrated continuum of ecosystem response to changing climate with respect to carbon storage, ecosystem services, and managed habitat sustainability. Research results and transfer of management-focused, decision-support, and modeling tools will form the basis for adaptive management recommendations to sustain coastal habitats and their military missions.

Results

Our results from 2013 monitoring and research efforts have started to inform our work on developing a carbon budget for the estuarine/coastal region and improve our understanding of the role of climate change in ecosystem processes. Among new findings on the carbon budget, we discovered that tributary creek data are providing a basis for predicting the impacts of land disturbance on the transport of particulate and dissolved organic matter. We have characterized variations in different forms of carbon with time and along the length of the New River Estuary (NRE) in both the shallow benthic zone and the main channel. This characterization allows us to estimate carbon storage in different portions of this ecosystem, as well as total carbon storage. Results to date indicate that the flux of carbon dioxide from estuaries into the atmosphere may be lower than previously predicted. Information such as this could transform our general understanding of the role of semi-lagoonal estuaries in the carbon cycle . Our work in 2013 continues to support our DCERP1 findings that the sediment accumulation in coastal marshes is largely keeping pace with sea level rise, and our future work will illuminate the mechanisms underlying marsh sediment dynamics and marsh accretion. The amount of organic carbon stored in the higher marsh elevations at MCBCL is estimated to be on par with the highest reported estimates of standing stock of marsh sediment carbon. Data from the coastal barrier island studies indicate that stores of relict marsh carbon laid down as peat deposits underlying Onslow Island are extensive and that this carbon is surprisingly young (less than 1,000 years).

DCERP2 is focused on studying the effects of the four climate drivers and their current impacts on various ecosystem processes to understand potential implications of future climate change on these processes. Therefore, it is important that we capture the widest spectrum of current responses to extremes in these climate drivers that are projected to be even more extreme in the future. During 2013 however, there were no significant storms or precipitation events to provide data on these extremes; therefore, our climate change research focused on the effects of elevated water temperature and water level on ecosystem processes. Results have shown that as development in a watershed increased, the temperature of tributary streams also increased, which

will likely affect the function of both the streams and the estuarine receiving waters. This links directly to our finding that temperature controls the rate of metabolic processes in the estuary, which will affect whether the estuary functions as a source or sink for carbon. Water level was also found to be an important driver of system function in coastal wetlands and on the barrier island. At Onslow Beach, sea level anomalies resulted in elevated water levels, which resulted in significant beach erosion. Elevated water level also decreased the production of below-ground biomass of salt marsh plants, which is a critical contributor to the ability of the salt marshes to maintain their elevation as sea level rises.

The development of several models and tools was initiated in 2013. These models and tools will be accessed through DCERP's Data and Information Management System (DIMS). Significant progress was made on the development of the needed framework and applications to incorporate models and tools into the DIMS. Preliminary calibration of the Estuarine Simulation Model for another estuary, the Neuse River Estuary, adjacent to MCAS Cherry Point, confirms the wider applicability of this estuarine model. Similarly, preliminary development of a forest management model (LANDIS-II) and a red-cockaded woodpecker population model also commenced in 2013 with promising results. These models and tools will continue to be developed as more field data become available.

Benefits

The DCERP Team's research and monitoring effort will

1. Provide integrated analysis and transfer of basic knowledge of aquatic/estuarine, coastal barrier, coastal wetlands, and terrestrial ecosystems with respect to how they may respond to climate change and climate variability (i.e., warming temperatures, wet and dry periods, and episodic storm events) and sea level rise, including their resiliency to these environmental stressors and to opportunities for adaptive management of these estuarine coastal systems
2. Quantify and model processes related to carbon cycling, nutrient utilization, sediment transport, and MCBCL land-use change impacts to the NRE
3. Develop models and decision-support tools at MCBCL and transfer these tools to other DoD installations in similar ecological settings, including MCAS Cherry Point and Fort Bragg, both in North Carolina; Eglin Air Force Base in Florida; and other DoD installations, as appropriate
4. Transition relevant scientific findings into actionable, easy-to-understand information for the broader DoD natural resource managers and other end users through the development of a one-stop-shop Web-based framework housed within the DCERP DIMS.

List of Acronyms

°C	degrees Celsius
ΔpCO_2	air–water pCO_2 gradient
AE	Aquatic/Estuarine (Module)
AFDW	ash-free dry weight
AVP	autonomous vertical profiler
C	carbon, control
CB	Coastal Barrier (Module)
CC	Climate Change (Module)
CDOM	chromophoric dissolved organic matter
CH_4	methane
cm y^{-1}	centimeters per year
CO_2	carbon dioxide
CO_2	carbon dioxide
CW	Coastal Wetlands (Module)
DCERP	Defense Coastal/Estuarine Research Program
DCERP1	first cycle of DCERP
DCERP2	second cycle of DCERP
DIMS	Data and Information Management System
DoD	U.S. Department of Defense
EC	Executive Committee
MARDIS	Monitoring and Research Data and Information System
F	fertilized
ft^3 s^{-1}	cubic feet per second
g C s^{-1}	grams of carbon per second
$g*m^{-2}$	grams per square meter
ICW	Intracoastal Waterway
km	kilometer
m	meter
m^{-2}	meter squared
m^3 s^{-1}	cubic meters per second
MCAS	Marine Corps Air Station
MCBCL	Marine Corps Base Camp Lejeune
MEM	Marsh Equilibrium Model
NAVD 88	North American Vertical Datum of 1988
NAVFAC EXWC	Naval Facilities Engineering and Expeditionary Warfare Center
NRE	New River Estuary
OSC	On-site Coordinator
pCO_2	partial pressure of CO_2
PI	Principal Investigator
RC	Resource Conservation and Climate Change (a SERDP program area)
RCC	Regional Coordinating Committee
SAB	Scientific Advisory Board
SDSS	Spatial Decision Support System
SERDP	Strategic Environmental Research and Development Program

SMS	shallow-water monitoring stations
SSC	suspended sediment concentration
T	Terrestrial (Module)
TAC	Technical Advisory Committee
TSP	Translating Science into Practice (Module)
TSS	total suspended solids

Chapter 1
Programmatic Overview

1.1 Overview of the Program

Critical military training and testing on lands along the nation's coastal and estuarine shorelines are increasingly placed at risk because of development pressures in surrounding areas, impairments due to other anthropogenic disturbances, and increasing requirements for compliance with environmental regulations. To expand its commitment to improving military readiness while demonstrating the science behind this approach, the Strategic Environmental Research and Development Program (SERDP) funds research and monitoring projects that support the sustainability of military training and testing in ecologically and economically important ecosystems.

To accomplish this goal, SERDP launched the Defense Coastal/Estuarine Research Program (DCERP) at Marine Corps Base Camp Lejeune (MCBCL) in North Carolina (**Figure 1-1**). The first cycle of DCERP (DCERP1) was conducted from July 2006–January 2013. DCERP1 focused on understanding coastal and estuarine ecosystem composition, structure, and function within the context of a military training environment. The second cycle of DCERP (DCERP2) is being conducted from February 2013 through October 2017. DCERP2 is focused on understanding how coastal and estuarine ecosystems respond to climate change and the processes associated with the carbon cycle in these ecosystems. DCERP2 is also focused on the development of decision-support tools and models that can translate complex scientific findings to the scientific community and into information that management can use to make decisions on DoD installations and provide guidance to other stakeholders, including the general public.

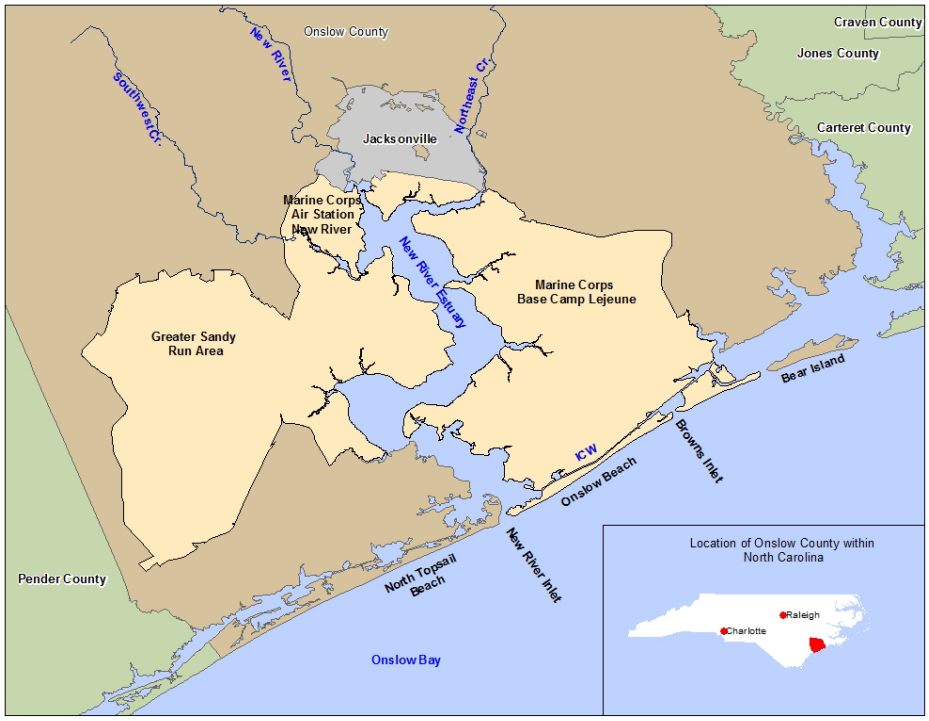

Figure 1-1. Site map of MCBCL.

1.1.1 Program Organization

RTI International is leading the DCERP2 research and monitoring effort and has assembled a diverse team of experts, henceforth referred to as the DCERP2 Team. DCERP is a collaborative effort between SERDP, the Naval Facilities Engineering and Expeditionary Warfare Center, MCBCL, and the DCERP2 Team. The DCERP2 Team consists of six module teams conducting research and modeling activities and, in some cases, monitoring activities. To facilitate a better understanding of the ecological systems, processes, and the dynamics of the MCBCL coastal region, DCERP2 was divided into four ecosystem modules. These ecosystems include the Aquatic/Estuarine (AE), Coastal Wetlands (CW), Coastal Barrier (CB), and the Terrestrial (T) Modules. Two additional cross-cutting modules coordinate with the four ecosystem modules to provide integrated climate change information needed for climate change forecast models (Climate Change [CC] Module) and decision-support tools and models that inform science-based adaptive management at MCBCL and that can be easily transferred to other U.S. Department of Defense (DoD) installations (Translating Science into Practice [TSP] Module).

As the DCERP Principal Investigator (PI), Dr. Patricia Cunningham manages DCERP2 with support from an Executive Committee (EC). The EC consists of three team members who provide their specific professional expertise and represent the different ecosystem modules. The EC meets regularly with the DCERP PI to discuss ongoing activities and ensure that DCERP2 is meeting the goal of providing ecosystem-based management recommendations to DoD. Two additional committees provide guidance and input to DCERP: the Technical Advisory Committee (TAC) and the Regional Coordinating Committee (RCC). The TAC is a group of discipline experts from academia, industry, government, and the military that provides scientific and technical review and guidance to ensure the quality and relevance of DCERP. The RCC is a group of local and regional stakeholders that serves as one of the recipients of outreach activities. During annual meetings, the DCERP2 Team provides a summary of research findings to both the TAC and RCC.

In addition, DCERP2's progress is reviewed annually by SERDP's In-Progress Review Committee, consisting of representatives from the various military service branches, the U.S. Environmental Protection Agency, and the U.S. Department of Energy. The SERDP Scientific Advisory Board (SAB), consisting of various discipline experts, also assesses progress and makes recommendations for program improvements annually throughout the implementation period.

1.1.2 Overarching Strategy

DCERP2 is built on the previous 6 years of research at MCBCL (i.e., DCERP1), and the DCERP2 Team adapted the program to focus on the new priorities of climate change, carbon cycling, and translating science into practice. DCERP2 is based on integrated research and monitoring activities that flow directly from those successfully used in DCERP1. The program is structured to use measurements and develop conceptual and mechanistic models and tools that inform science-based adaptive management at MCBCL and that can be easily transferred to other DoD installations. The monitoring program is designed to document trends, but to be sufficiently adaptive to capture extremes and ecosystem threshold events and to support the research program by satisfying fundamental data needs. Together, these research and monitoring

activities represent an integrated continuum of ecosystem response to changing climate, with respect to carbon cycling, nutrient utilization, sediment loading, and ecosystem services and sustainability. The 13 research projects described in the *DCERP2 Research Plan* (RTI, 2013b) and associated monitoring activities described in the *DCERP2 Monitoring Plan* (RTI, 2013a) are presented in **Tables 1-1 and 1-2**.

Conceptual models are used to illustrate the key biological processes (e.g., primary production), chemical processes (e.g., nutrient cycling), and physical processes (e.g., hydrodynamics, sedimentation) of the ecosystem, as well as the key anthropogenic and natural stressors that alter ecological processes. DCERP2's overarching conceptual model highlights the interconnections among the various ecosystems in examining the estuarine and coastal processes that are affected by climate change and that drive carbon cycling (**Figure 1-3**).

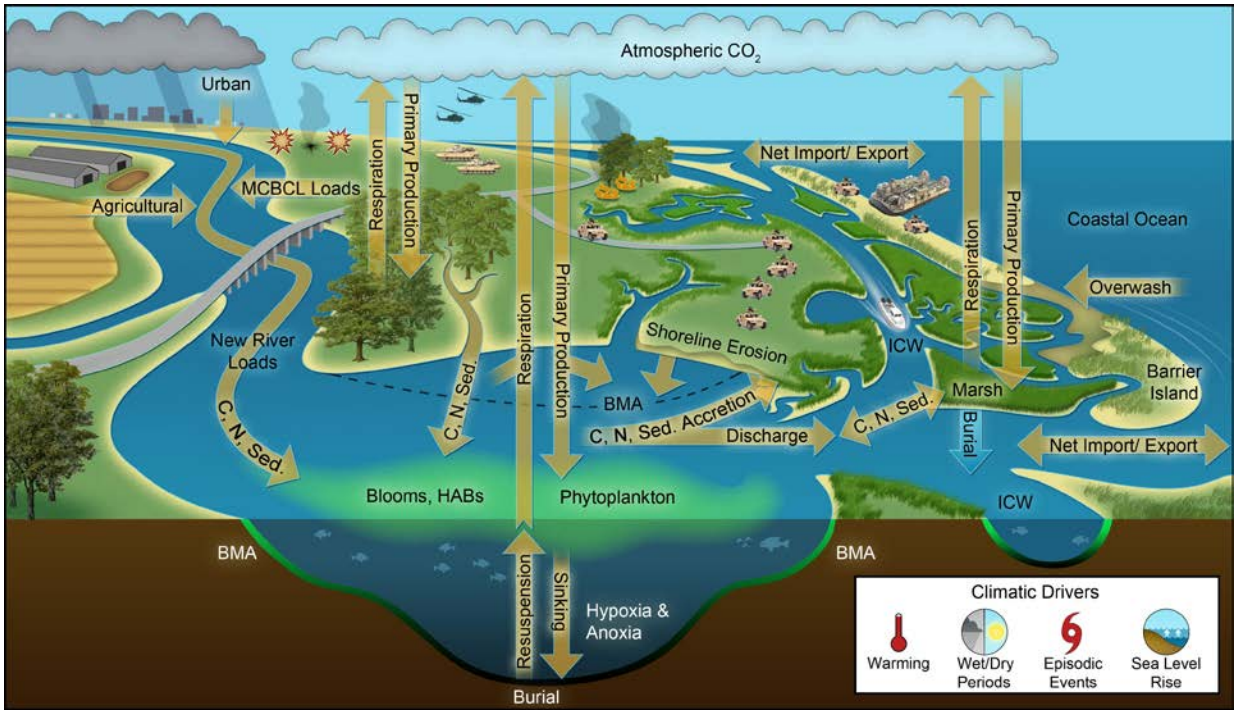

Figure 1-3. The overarching conceptual model for DCERP2.

Table 1-1. Summary of DCERP2 Module-Specific Monitoring Activities

Module	Activities
Aquatic/ Estuarine	Physical/hydrodynamics: Temperature, light, and stream flow and discharge Chemistry: Carbon, chromophoric dissolved organic matter (CDOM), nutrients, salinity, pH, and oxygen Sedimentology: Suspended sediment concentration (New River), total suspended solids (New River Estuary [NRE]), and turbidity (NRE) Biology: Primary productivity, phytoplankton biomass and community composition, and benthic microalgal biomass
Coastal Wetlands	Shoreline delineation: Surface elevation change, topography, morphology, and marsh edge erosion Hydrodynamics: Tide gauges (water level, temperature, and salinity) Marsh vegetation: Distribution, composition, stem height, and grazer density (snails) Sedimentology: Sedimentation rates, organic content, and particle size

Table 1-2. Research Projects to Be Conducted During DCERP2 (2013–2017)

Research Project Title	Senior Researchers/ Duration
AE-4: Nutrient–Driven Eutrophication and Carbon Flux Modulated by Climate Change in the NRE	Hans Paerl; 3/2013–10/2017
AE-5: Climate and Land Use Impacts on Exports of Carbon, Sediments, and Nutrients from Coastal Subwatersheds	Michael Piehler; 3/2013–10/2017
AE-6: Climatic Drivers Regulating Benthic-Pelagic Carbon and Associated Nutrient Exchanges in the NRE	Iris Anderson; 3/2013–10/2017
CW-4: Improving Model Predictions for Marsh Response to Sea Level Rise and Implications for Natural Resource Management	Carolyn Currin; 3/2013–10/2017
CW-5: Marsh–Atmosphere and Marsh–Creek Exchanges of Carbon	Iris Anderson; 2/2015–10/2016
CB-4: Predicting Sustainability of Coastal Military Training Environments: Developing and Evaluating a Simplified, Numerical Morphology Model	Jesse McNinch; 5/2013–10/2017
CB-5: Linking Barrier Island Transgression Induced by Storms and Sea Level Rise to the Carbon Cycle	Tony Rodriguez; 3/2013–3/2017
T-1: Effects of Different Understory/Midstory Restoration Management Options on Terrestrial Ecosystem Plant and Arthropod Communities	Norman Christensen; 5/2015–6/2017
T-3: Forest Management, Species Habitat, and Implications for Carbon Flux and Storage	Norman Christensen and Steve Mitchell; 3/2013–6/2017
T-4: Impacts of Climate Change on Management of Red-Cockaded Woodpeckers at MCBCL	Jeffrey Walters; 3/2013–6/2015
CC-1: Development of Uniform Historical and Projected Climate to Support Integrated Coastal Ecosystem Research	Ryan Boyles; 3/2013–10/2017
TSP-1: Development of a Common Spatial Decision Support System (SDSS) Framework	Patrick Halpin; 3/2013–10/2017
TSP-2: Coupled Ecosystem Modeling of the NRE for Research, Synthesis, and Management	Mark Brush; 3/2013–10/2017

Environmental data collected throughout DCERP2 are critical to the program research and modeling activities and to the development of decision-support management tools. In DCERP1, the DCERP Team developed the Data and Information Management System (DIMS). The DIMS includes Web-based access and interfaces that allow the DCERP researchers, MCBCL staff, and other users to access DCERP data from the Monitoring and Research Data and Information System (MARDIS). The DIMS consists of several distinct systems as shown in **Figure 1-4**.

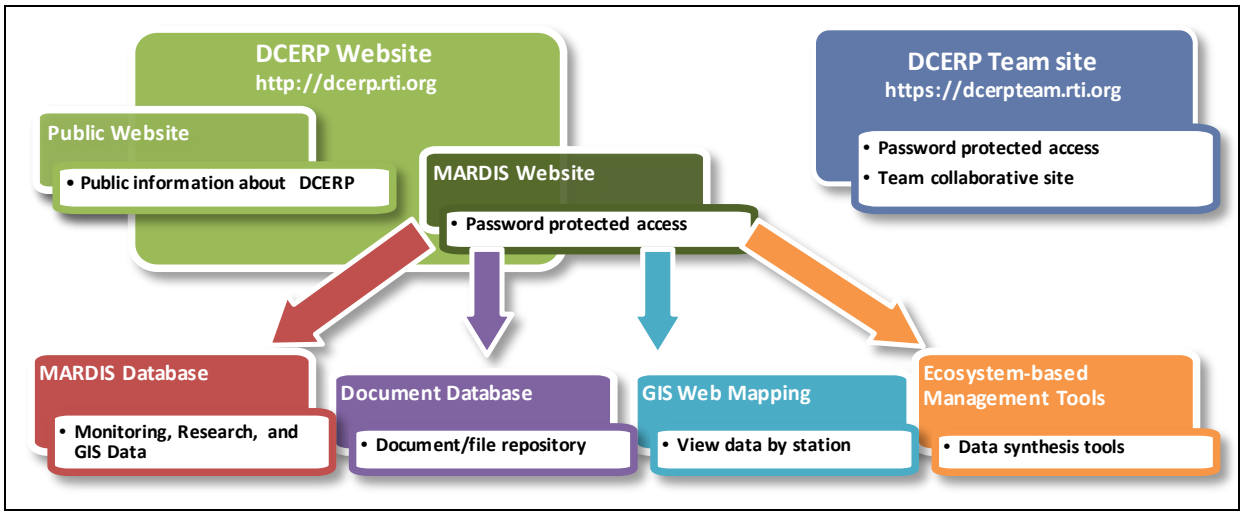

Figure 1-4. DCERP DIMS.

1.2 Introduction to DCERP2 Themes

The three major themes addressed in DCERP2 (i.e., climate change, the carbon cycle, and translating science into practice) span the four ecosystem modules and 13 research projects of DCERP2. DoD lands in the United States and abroad include a large number of installations in coastal settings that are most vulnerable to climatic drivers (e.g., rising sea level, increased temperatures, extended periods of drought or flood conditions, extreme storm events [i.e., hurricanes, cyclones, Nor'easters]). To better manage DoD lands and their infrastructure and natural resource assets, it is imperative that installation managers have accurate research findings to inform their management decisions and prepare for future contingencies necessitated by climate change. In addition, the carbon cycle is inextricably linked to climate change and its association with increasing concentrations of greenhouse gases (e.g., carbon dioxide [CO_2], methane [CH_4]) generated from the use of fossil fuels.

A major focus of DCERP2 is to develop a carbon budget for the estuarine/coastal area and an understanding of carbon cycling and exchanges between the estuary, marshes, coastal barrier, coastal ocean, and the atmosphere. In addition, DCERP2 will develop a carbon accounting tool for forestry management practices. DCERP2 builds on information gained from DCERP1 regarding the importance of freshwater discharge, temperature, light availability, and salinity on both metabolic rates and nitrogen-cycling rates across the estuary. During DCERP2, team members will determine how episodic events affect metabolic and nutrient cycling rates with a new emphasis on carbon cycling. Team members will also improve and expand several tools and models developed during DCERP1. For example, the Marsh Equilibrium Model (MEM) will be refined to include use in both *Spartina*- and *Juncus*-dominated marshes, support the development

of a new point-based model to predict marsh sustainability to sea level rise and carbon sequestration rates, and test adaptive management strategies for sustaining the coastal marshes.

1.3 Organization of the Document

DCERP2 remains organized around four interconnected ecosystem modules established in DCERP1 (i.e., Aquatic/Estuarine, Coastal Barrier, Coastal Wetlands, and Terrestrial). Because climate change has a central role on ecosystem function and services, a fifth cross-cutting Climate Change (CC) Module links the ecosystem modules to a central suite of local- and regional-scale climate forcings. Finally, data and outcomes from our integrated research and monitoring efforts will be managed within the new Translating Science into Practice (TSP) Module, which incorporates many elements of the DCERP1 Data Management Module. This *DCERP2 Annual Report* is organized by these six modules.

The *DCERP2 Annual Report* summarizes the major activities and significant findings for the period from March to December 2013. The entire program is summarized in the abstract, Programmatic Overview (Chapter 1), and Significant Findings and Achievements (Chapter 2). These chapters of the annual report are available to the public and will be used to inform stakeholders. The remaining chapters are organized by monitoring and research activities, with each project summarized in a separate chapter (Chapters 3 through 16).

1.4 Integration of Program Elements

Integration of the component parts of the research and monitoring effort is a hallmark of DCERP. Integration is an ongoing process that occurs both at the thematic level and at the module and project levels. From the beginning of the program, the key steps to ensuring integration involved the following: (1) developing and using conceptual models for each research project, module and at the program level; (2) implementing highly coordinated research and monitoring approaches, including the collection of comparable temporal and spatial information in various environmental matrices simultaneously; (3) using comparable monitoring equipment calibrated to obtain high-quality precision and accuracy for environmental measurements; (4) using comparable units for reporting all environmental measurements; and (5) integrating results through the use of integrative models. For example, the development of a carbon budget is an integrating element that incorporates results from all four ecosystem modules and through the use of models can forecast scenarios of changes in the carbon cycle under both current and future changed climate conditions. Likewise, all research projects will assess climate change as part of their research activities, whether that involves using forecast models or forecast parameters (elevated temperature and salinity conditions) in experimental studies to simulate future climate conditions. In addition, an All-Scientists Meeting will be convened in fall 2014 to assess progress in drafting a carbon budget for the estuarine/coastal area of MCBCL and to ensure that each research project applies uniform standards for forecasting climate change.

Specific roadmaps for each of the four ecosystem modules were developed to illustrate the relationships among DCERP2 monitoring and research activities and to summarize the models, decision-support tools, and indicators that will be developed from these activities, as well as the information that will be disseminated to MCBCL and other stakeholders. The roadmaps for the four ecosystem modules are presented in the *DCERP2 Research Plan* (RTI, 2013b).

1.5 Literature Cited

RTI. 2013a. *DCERP2 Monitoring Plan*. Strategic Environmental Research and Development Program (SERDP) Research Project RC-2245. RTI International, Research Triangle Park, NC.

RTI. 2013b. *DCERP2 Research Plan*. Strategic Environmental Research and Development Program (SERDP) Research Project RC-2245. RTI International, Research Triangle Park, NC.

Chapter 2
Significant Findings and Achievements

2.1 Introduction

This chapter provides a brief summary of the significant findings and implications of DCERP2 conducted at Marine Corps Base Camp Lejeune (MCBCL) from March through December 2013. The most significant findings of DCERP2 are reported in the following sections, first at the ecosystem module level (Sections 2.2 through 2.6), then at a thematic level (Section 2.7), and finally at the programmatic level (Section 2.8). At the *module level*, DCERP research and monitoring activities continued to focus on developing an understanding of ecosystem composition, structure, and function within the context of a military training environment. At the *thematic level*, the significant findings are summarized with regards to our understanding of the carbon cycle and the effects of climate change on ecosystem functions. Finally, at the *programmatic level*, our overall contributions to the advancement of our understanding of coastal/estuarine science and the implications of these finding for managers and decisions makers are discussed.

2.2 Aquatic/Estuarine Ecosystem

During DCERP2, the Aquatic/Estuarine Module examines the tidal reach of the New River Estuary (NRE) from the freshwater head of the New River near Jacksonville, NC, to the tidal inlet at Onslow Bay. The NRE is a relatively small, shallow (3-m mean depth), coastal plain estuary, the majority of which resides within MCBCL. The NRE consists of a series of lagoons and is confined by barrier islands that restrict water exchange with the Atlantic Ocean. The semi-lagoonal nature of the NRE plays a significant role in its sensitivity to nutrient inputs because long flushing times allow more time for algal nutrient assimilations, growth, and internal carbon and nutrient recycling. Principal tributaries discharging into the NRE include the blackwater New River and Southwest and Northeast Creeks. In addition, numerous small creeks, whose catchment areas lie within MCBCL boundaries, discharge into the NRE.

The monitoring and research program of the Aquatic/Estuarine Module is designed to gain understanding regarding the complexity of the physical, chemical, and biotic processes regulating the estuarine carbon cycle, as well as the nutrient cycling and sediment transport that determine water and habitat quality. The program was also designed to differentiate natural and anthropogenic ecosystem stressors (past, present, and future) at local and regional scales and to integrate results with the other DCERP modules to identify indicators of estuarine health and develop a carbon budget for the coastal system. Understanding and sustaining the function of the NRE cannot occur without considering these processes in the context of climate change. This integrated approach will permit a rigorous assessment of estuarine ecosystem function and translate that information to aid management decisions in coastal regions.

2.2.1 General Hydrologic and Water Quality Conditions

- The first year of DCERP2 (2013) was marked by the lack of any significant meteorological events (e.g., tropical cyclones, Nor'easters, major droughts). Despite the region having above-average precipitation, the annual mean discharge (2.33 m^3 s^{-1} [82 ft^3

s^{-1}]) for the New River was less than the long-term mean (3.20 m^3 s^{-1} [113 ft^3 s^{-1}]). This discrepancy is most likely a function of variation in regional scale precipitation, but water withdrawals within the upper watershed also could reduce the annual discharge rate.

- Spatial trends of carbon, nutrients, phytoplankton, and sediments along the salinity gradient of the NRE, caused by the mixing of freshwater and seawater, were consistent with patterns determined in DCERP1. Phytoplankton biomass (estimated by chlorophyll *a* concentrations) continued to show a decrease along the salinity gradient. Concentrations of total suspended solids (TSS) continued to be higher at stations closer to the New River Inlet, an area of greater tidal action and sediment resuspension.
- The New River at the long-term Gum Branch monitoring station is tidally influenced, but it is above the limit of saltwater intrusion. The semi-diurnal change in water level due to tidal action is especially notable during periods of low flow. An analysis of the long-term record at this station revealed an increasing trend in the daily minimum and maximum water levels during periods of low discharge from 1987 through 2013. The increase in daily water level over this period is presumably a function of changes in freshwater discharge and sea level.
- Coastal streams remain understudied relative to their upland counterparts. Using data from both DCERP1 and DCERP2, we were able to construct a multi-year time series of stream temperature (**Figure 2-1**). Streams were designated as developed based on the percent imperviousness of their watershed. These data revealed that higher temperatures occurred in streams with more developed watersheds, and larger temperature differences were observed during the summers. Summer mean stream temperatures were as much as 8°C higher in more developed watersheds. There is an apparent upward trend in stream temperature through the 6-year period from 2008 to 2013.

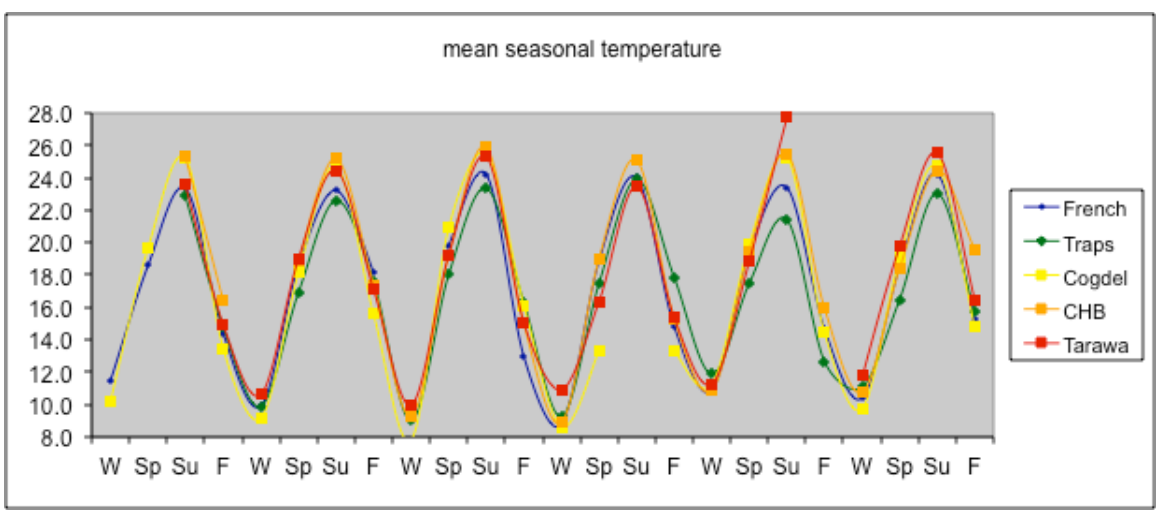

Figure 2-1. Stream temperature in the five study streams (2008 to 2013).

Temperature is in degrees Celsius and is presented for each season (W, Sp, Su, F) from 2008 to 2013. Sites are presented from least developed (blue) to most developed (red).

2.2.2 NRE Carbon Fluxes

- In the New River at Gum Branch, measurements of dissolved carbon fluxes were higher during storm events (47.2 g C s^{-1}) than during base flow periods (5.05 g C s^{-1}). Similarly, suspended sediment flux was two orders of magnitude higher during storm events (mean=410 g s^{-1}) than base flow periods (mean=1.43 g s^{-1}). These contrasts indicate the importance of storms in carbon loading to the NRE, but further research is needed on the frequency of storms relative to base flow to fully evaluate this pattern.
- Quantification of carbon exchanges at pertinent time-space scales is required to determine an estuary-wide carbon budget for the NRE. Accordingly, we integrated the sampling programs of Research Projects AE-4 and AE-6 to: (1) conduct simultaneous spatial surveys of the main channel and peripheral shallows and (2) deploy autonomous monitoring systems to collect parallel diel measurements of surface partial pressure of carbon dioxide (pCO_2) and auxiliary parameters on autonomous vertical profilers (AVPs) and nearby shallow-water stations (**Figure 2-2**).

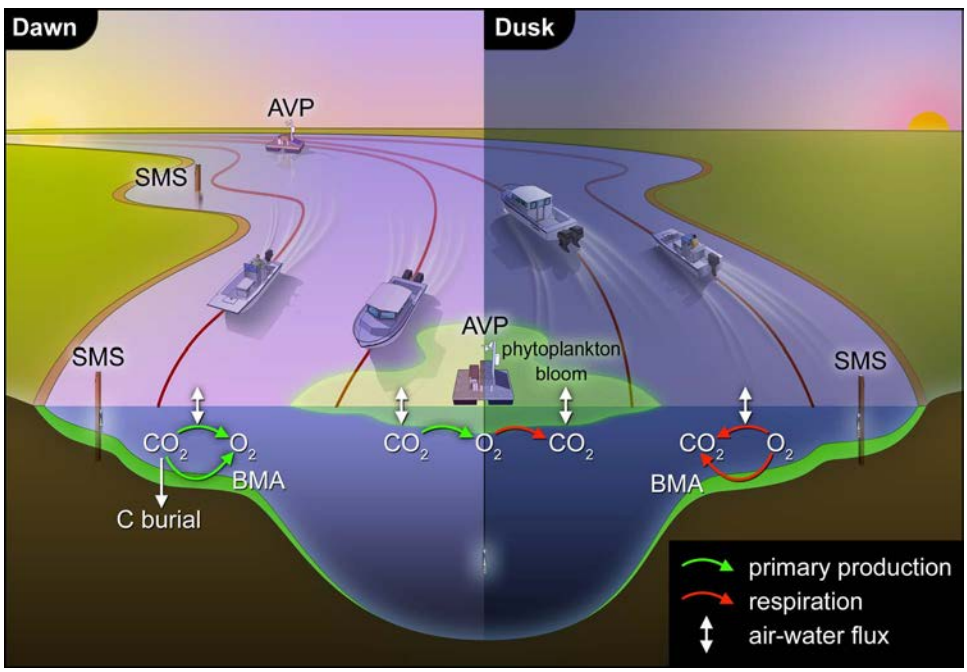

Figure 2-2. Conceptual diagram showing dawn–dusk surveys, and parallel channel- (AVP) and shallow-water monitoring stations (SMS).

- In the NRE, metabolic processing was the dominant factor regulating whether surface waters were a source or sink for atmospheric carbon dioxide (CO_2), and processing rates were highly dependent on the environmental conditions (e.g., nutrient input, water temperature, wind-driven mixing, and light). The magnitude and partitioning of these metabolic controls varied spatially along the axis of the estuary and between the channel and the shoreline. In addition to the high spatial variability in pCO_2 and dissolved oxygen (DO), there was also a large dynamic range on diel scales.

- Samples were collected at dawn, dusk, and the following dawn in September and November 2013 to estimate daily fluxes in carbon, oxygen (O_2), and chlorophyll *a* concentrations. During both months, the NRE varied from being a CO_2 source on the dawn surveys to being a CO_2 sink on the dusk surveys. In September, the largest dawn–dusk change in pCO_2 and dissolved oxygen (DO) occurred in regions of high chlorophyll *a* at the mouth of the New River (**Figure 2-3 top panel**). In November, the highest chlorophyll *a* concentrations were also at the mouth of the New River, but unlike in September, DO remained supersaturated, so both the upper and lower regions of the estuary were CO_2 sinks (**Figure 2-3 bottom panel**).
- The spatial and temporal variability for all survey parameters was lower in November relative to the prior surveys in July and September. Preliminary observations suggest that this lower variability was linked to wind-driven mixing of surface waters and decreased metabolic rates due to the cooler temperatures. This trend is consistent with prior observations of low surface-water variability during colder conditions in the Neuse River Estuary, NC, which is 80 km northeast of the NRE.

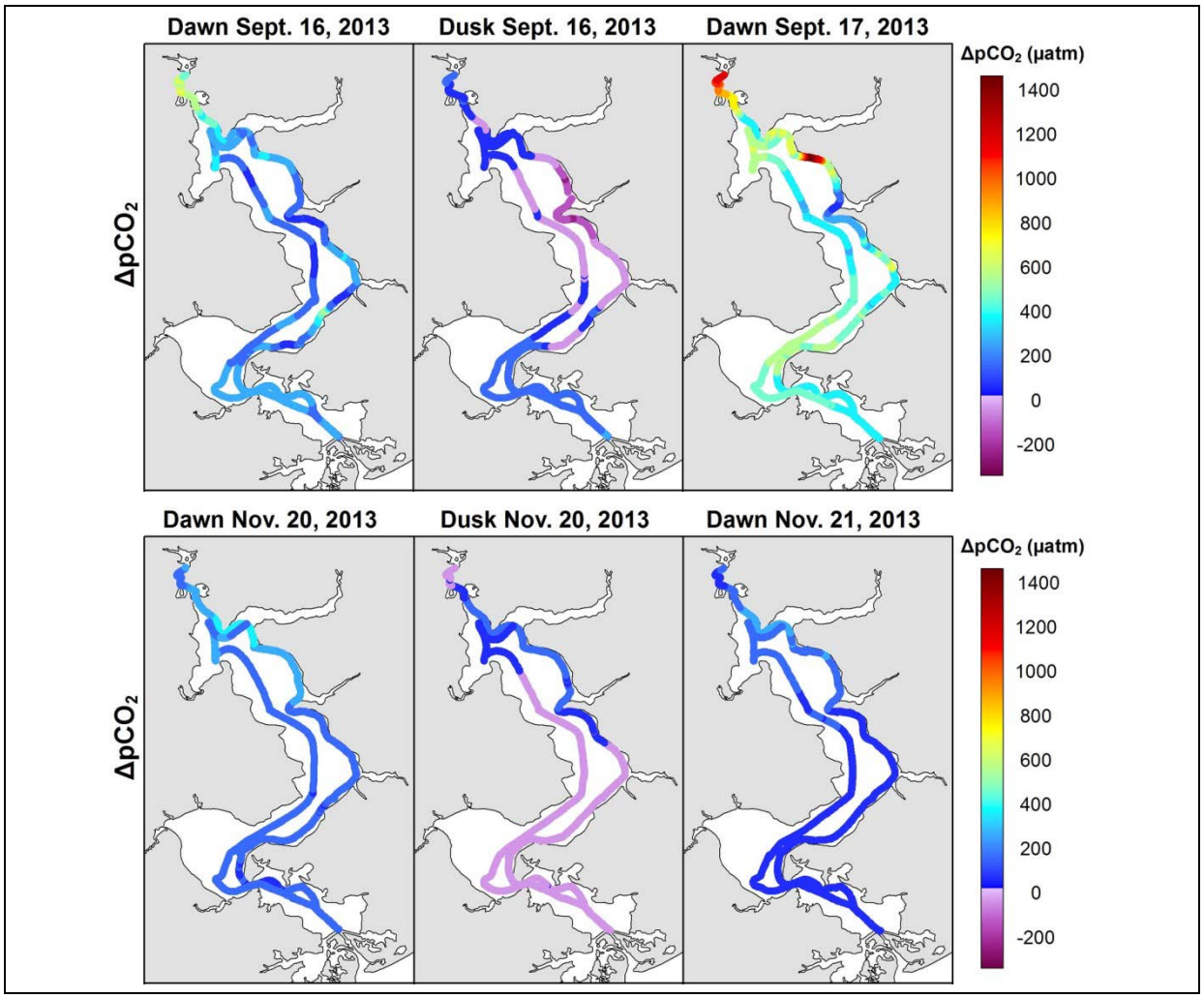

Figure 2-3. Carbon flux (ΔpCO_2) observed during September (top panel) and November (bottom panel) 2013 dawn–dusk surveys.

- Estuaries are traditionally viewed as sources of atmospheric CO_2 due to degradation of allochthonous (external sources) organic matter transported into the estuary. Results thus far indicate that the NRE may be a smaller source of, or even sink for, atmospheric CO_2 on seasonal or longer scales due to high rates of internal primary production.

2.2.3 Estuarine Respiration and Its Partitioning Between the Water Column and Benthic Zone

- We used isotopes to determine how respiration is partitioned between the benthic zone and water column of the NRE. The results indicate approximately a 60:40 split (benthic:water column) for the upper estuary near the City of Jacksonville. The data also indicate that salinity is a reasonable marker by which the system can be partitioned and that metabolism can be assessed by salinity.

2.3 Coastal Wetlands Ecosystem

Coastal marshes are a vital component of the estuarine landscape and link terrestrial and freshwater habitats with the ocean. In the intertidal zone, marshes help to stabilize sediments and minimize erosion. Wetlands improve water quality by acting as nutrient transformers and nutrient sinks, and by trapping sediment. Salt marshes are known to play an important role in the global carbon cycle. Even though marshes account for only a small percentage of the total land area, they sequester CO_2 from the atmosphere and provide carbon storage by acting as a carbon sink, equivalent to other major terrestrial habitats that store carbon, including temperate, tropical, and boreal forests. The coastal wetlands of MCBCL are defined as the vegetated intertidal habitat in salt and brackish waters and encompass the salt marshes along the lower NRE shoreline and Intracoastal Waterway (ICW), as well as the brackish marshes along the upper NRE shoreline and tributaries of the NRE. These areas within the MCBCL region are typically dominated by smooth cordgrass *(Spartina alterniflora*) and black needle rush (*Juncus roemerianus).*

Key objectives of research projects for the Coastal Wetlands Module include the following: (1) measuring processes (delivery of suspended sediments, production of above- and below-ground marsh biomass) that control the marsh's ability to keep pace with sea level rise, (2) improving model predictions on vulnerability of marshes to sea level rise across the MCBCL landscape, (3) assessing the factors affecting flux of carbon from marshes to the estuary and into the atmosphere, (4) determining the role of surface elevation and tidal dynamics on marsh carbon burial rate, and (5) developing strategies for adaptive management of coastal wetlands.

2.3.1 Marsh Surface Elevation Change

- Based on 5 years of data (2008–2013), marsh surface elevation increase at most study sites (**Figure 2-4**) is on pace to keep up with current sea level rise rates. However, marsh sites near Traps Bay and Pollock's Point in the lower NRE are not keeping pace with sea level rise and, therefore, are in the most jeopardy.
- DCERP1 experimental marsh sites that received a fertilizer treatment to evaluate the effects of nutrient addition on sediment accretion were re-measured in 2013. Differences in surface elevation change between fertilized and control sites were highly variable. The

long-term response of these sites will continue to be monitored and may inform utilization of fertilization as a management strategy for marsh restoration and sustainability.

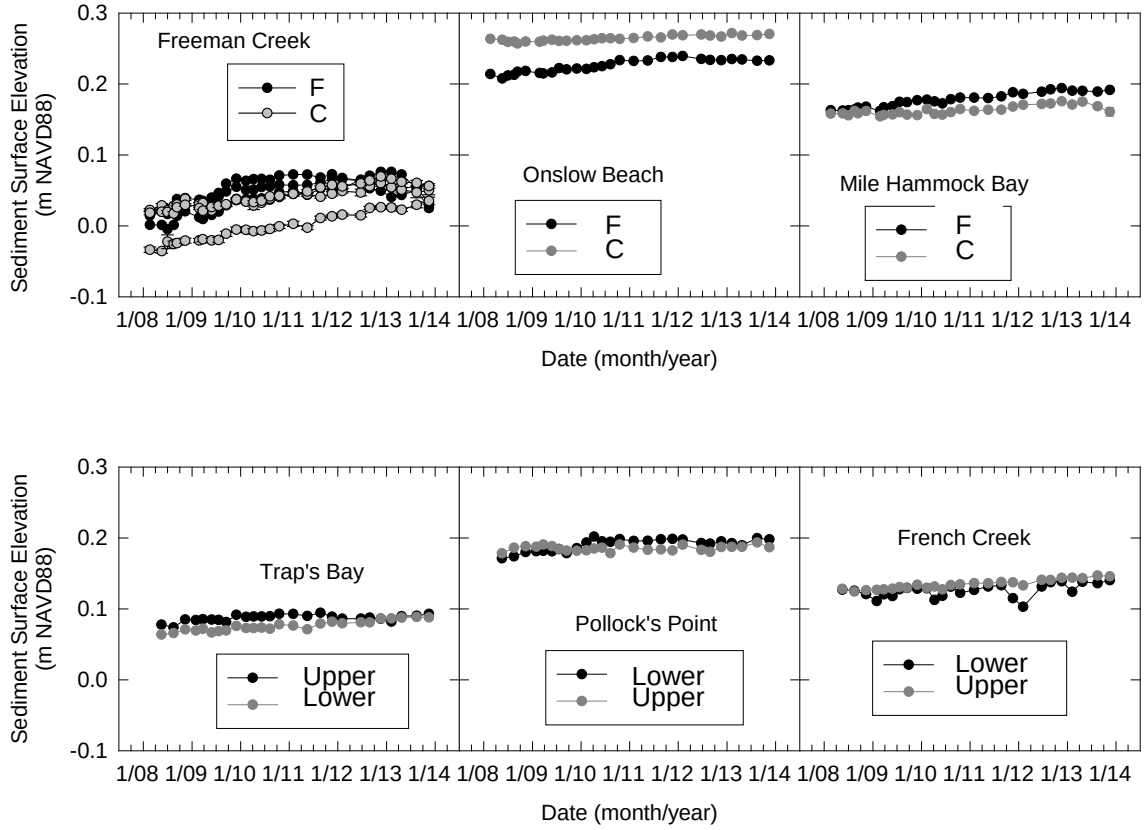

Figure 2-4. Sediment surface elevation at six SET sites in the NRE and ICW. Freeman Creek has six SETS and all other sites have two SETs.

C = control; F = fertilized; Lower = lower elevation sites near open water; NAVD 88 = North American Vertical Datum of 1988, Upper = high elevation sites near shoreline.

2.3.3 Marsh Vegetation and Grazer Community

- In 2013, the long-term trend continued with the decline in smooth cordgrass biomass and stem density at Mile Hammock Bay marshes in the lower NRE. In contrast, other marsh sites (Onslow Beach, Traps Bay, and Pollock's Point) exhibited recovery from the reduced biomass and stem density observed in 2012.
- Snail density on marsh periwinkle (*Littorina irrorata*) more than doubled at Mile Hammock Bay from 2012 to 2013, to an average of more than 250 snails m^{-2}, which is twice as high as previously recorded (during DCERP1). However, this density is on the lower end of that reported from other southeastern U.S. marsh die-off events.

2.3.4 Factors Affecting Marsh Biomass Production

- In smooth cordgrass salt marshes adjacent to the ICW and the lower NRE estuarine shoreline, in situ below-ground biomass of *Spartina* exhibited a clear parabolic

relationship with marsh surface elevation (**Figure 2-5**), similar to the above-ground biomass–elevation relationship reported in DCERP1. Maximum below-ground biomass occurs at a tidal elevation of 0.25 m North American Vertical Datum of 1988 (NAVD 88).

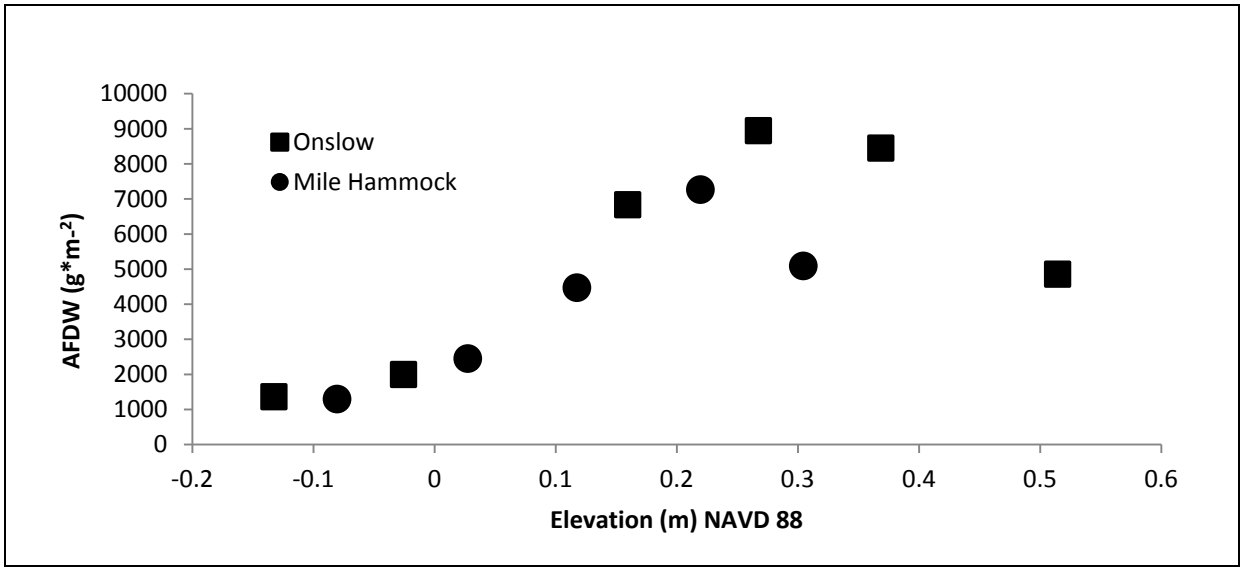

Figure 2-5. Standing below-ground *Spartina alterniflora* biomass across an elevation gradient at two sites.

- The amount of organic carbon at the higher marsh elevations is estimated to be at least 3,000 g C m^{-2}, which is more than one to two orders of magnitude higher than the estimated annual marsh carbon sequestration rate of 20–200 g C m^{-2} reported for salt marshes in the southeastern United States. We will continue sampling at these sites in 2014 and determine below-ground biomass and decomposition experiments to quantify carbon flux within coastal marshes.

2.3.5 Marsh Sediment Dynamics

- There was surprisingly little difference in suspended sediment concentration (SSC) in the marsh creek channel itself and in over-marsh samples collected in the adjoining marsh. We expected that our SSC measurements would show a decline in SSC between the channel and interior of the salt marsh based on the widely held theory that SSC decreases with distance from the channel as hydraulic roughness of the marsh vegetation slows water flow and allows sediment to settle from suspension. Further study is needed to determine the processes controlling SSC as water crosses the channel–marsh boundary, including the role of inundation on suspending and floating material from the marsh surface.
- A preliminary estimate for sedimentation rate for the backbarrier marshes of Onslow Beach was between 0.15 and 0.30 cm y^{-1}. This estimate is useful only to constrain the sedimentation rate to help determine where to focus further analyses to determine the peak of ^{137}Cs activities, which should correspond to a date of 1963, when atmospheric nuclear testing occurred.

2.4 Coastal Barrier

The coastal barrier ecosystem at MCBCL encompasses the shoreface, tidal inlet, backshore beach, dune, shrub zone, maritime forest, and washover sand flat habitats. Onslow Beach is a northeast trending transgressive barrier island. Washover fans in the central and southwestern portions of Onslow Beach indicate that storms are an important driver of geomorphologic change. In contrast, the continuous high-elevation dune ridge in the northeastern portion of the island indicates that the backbarrier is disconnected from beach processes, even during storms. Frequent overwash during storms form new washover fans in the southwestern portion of the island and sediment transport across the island via wind-driven processes is more efficient due to the reduction in vegetation density. Backbarrier salt marshes provide important ecosystem services, which include carbon sequestration as CO_2 from the atmosphere and below-ground storage in the form of peat and organic-rich sediment. As the barrier island moves landward and over the backbarrier marshes in the southwestern portion of the island, this carbon is buried for an unknown period of time before it becomes exposed to the ocean's hydrodynamic processes and is eroded on the beach. In contrast, the northeastern portion of the island has a stable shoreline and the old backbarrier marsh is not being eroded on the beach, making this portion of the island more of a carbon sink than the southwestern end of the island.

An improved understanding of how the morphology of the coastal barrier responds to changes in sea level rise and storminess is critical to improving shoreline management at MCBCL and other coastal U.S. Department of Defense (DoD) installations, as well as other coastal communities. During DCERP2, we address the following three fundamental research questions:

1. How will the morphology of Onslow Beach change in the future under different sea level rise and storminess scenarios?
2. How will this future island morphology impact nesting shorebirds and endangered sea turtles?
3. How does the barrier function as a carbon sink and source?

2.4.1 Barrier Morphology

- On Onslow Beach, the dune line was re-established after a washover fan was formed by the passage of Hurricane Irene in 2011. As Hurricane Sandy moved up the Atlantic Coast in October 2012, the area overwashed again, and the fan expanded approximately an additional 200 m landward. As of early 2014, the dune line has not re-established; however, waves wash across that portion of barrier island during spring tides. These frequent overwash events continue to modify the morphology of the fan, including its landward extent (**Figure 2-6**).

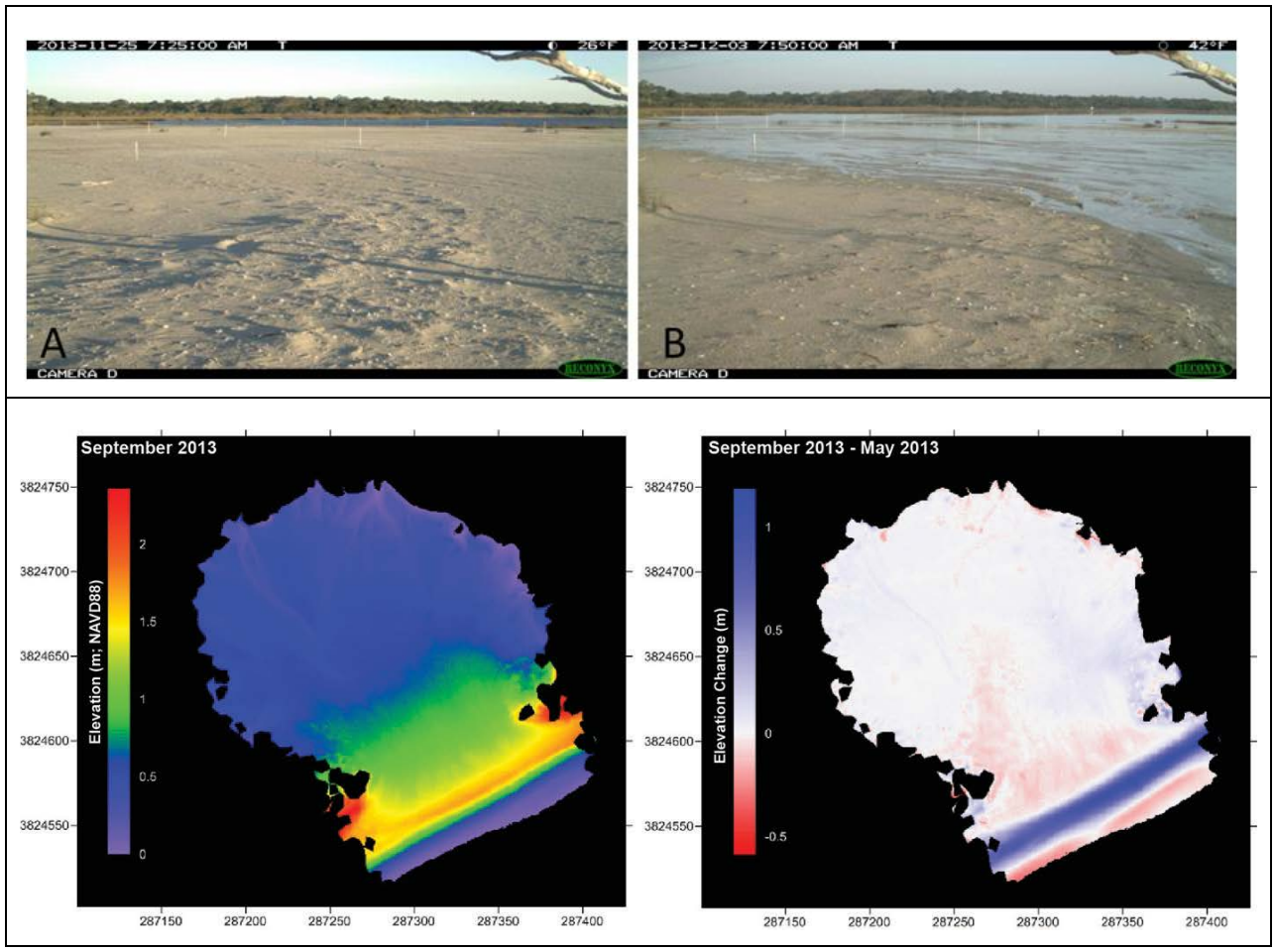

Figure 2-6. A washover fan during low tide (A) and during an overwash event (B) as recorded by a continuously deployed Reconyx camera (top panel). Changes in elevation that occurred at the washover fan site over a 4-month period (lower panel).

- Our results demonstrate that a washover fan does not necessarily represent deposition during one overwash event, but is an integration of different processes that operate over time. For example, the washover fan created by Hurricane Irene in 2011 frequently floods with each successive spring tide. Therefore, we need to be cautious when interpreting storm power from the landward extent of ancient washover fans. Such interpretation is common in the study of past tropical cyclone activity by means of geological evidence and historical records.

2.4.2 Characterization of Carbon on the Barrier Island

- The thickness of the Onslow Island backbarrier marsh peat layer is consistent (approximately 75-cm thick) over large distances across the backbarrier marsh system. This result suggests that the sandflat upon which the salt marsh platform formed was colonized very rapidly. Preliminary radiocarbon dating that shows similar ages for peat samples at similar depths obtained more than 100 m apart from each other support this conclusion.

- Preliminary radiocarbon dating of organic material cores sampled from below the barrier are all less than 500 years old. This dating shows that Onslow Island is very young and approximately 2,000 years younger than the Outer Banks barrier island chain to the north. Due to rapid rates of transgression of the southwestern portion of Onslow Island toward the mainland, the duration of carbon storage as peat on this part of the barrier island is no longer than 500 years.

2.4.3 Fauna and Flora on the Coastal Barrier

- Shorebird nesting studies on Onslow Beach revealed that younger washover fans (2–3 years) were used for nesting less frequently than an older fan (17 years old) on a per unit area basis. Except for one Wilson's plover (*Charadrius wilsonia*) nest laid in one of the younger washover fan areas, none of the nests observed in the younger washover fans showed evidence of successful hatching.
- The vegetation plots established during DCERP1 that were located closest to the beach showed that ecological succession has occurred at one of two younger washover fan areas. The predominant mode of regrowth at the one site is vegetative growth from plants bordering the washover fan and not from recruitment from seeds.
- Preliminary analyses of the beach landscape data revealed a tendency for false crawls (sea turtles come ashore, but are unsuccessful in finding beach nesting sites) to occur more frequently on flat (low-slope) beaches that terminate in steeply eroded, scarped dunes. With increased rates of sea level rise, scarped dunes and low-slope beaches will become more extensive, which may result in a higher occurrence of false crawls that could have detrimental effects on reproduction. Increased numbers of false crawls could delay a sea turtle's search for a suitable nesting location and could lead to eggs being laid later in the season, when they may not have enough time to develop before the onset of colder weather.

2.5 Terrestrial

The terrestrial ecosystem at MCBCL encompasses the gradient of vegetation from the salt marsh at the estuary margin, through the brackish and freshwater marsh, to the longleaf pine (*Pinus palustris*), savannas, and pocosins (shrub bog) that dominate MCBCL's terrestrial environments. Variation in the biota and ecosystem processes along these gradients is driven by variation in hydrology, soils, and fire behavior. The main objective of the Terrestrial Module is to provide a greater understanding of how natural and human disturbances, including wildfire, prescribed burning, and other forestry management practices, affect plant and animal habitat quality and management of carbon in the context of likely future climate change. Restoration of populations of red-cockaded woodpecker (RCW, *Picoides borealis*; listed as endangered under the Endangered Species Act) is a priority management objective for MCBCL forests and is, therefore, also a prominent theme in this research. Products from these research activities will produce decision-support tools aimed at improving flexibility for forest management directed at carbon sequestration and ecosystem biodiversity goals in the context of uncertain future climates.

During DCERP2, we address the following three fundamental research questions:

1. What are the effects of different understory restoration options in loblolly pine (*Pinus taeda*) forests being transitioned to longleaf pine on plant communities?
2. What effects do variations in MCBCL forest management, including harvest, thinning, and prescribed burning, have on stand and landscape scale carbon flux and storage in the context of likely future climate change scenarios?
3. What are the likely implications of climate change for management of RCWs at MCBCL?

2.5.1 LANDIS-II Forest Management Model Development

- LANDIS-II (forest management) model simulations using DCERP1 data have produced preliminary maps of carbon storage throughout MCBCL (**Figure 2-7**). Our preliminary findings suggest that above-ground live carbon storage is higher in longleaf pine stands compared to loblolly pine stands, and lowest in pond pine (*Pinus serotina)* stands. However, we will refine our estimates when additional fuel, fire, and carbon data become available.

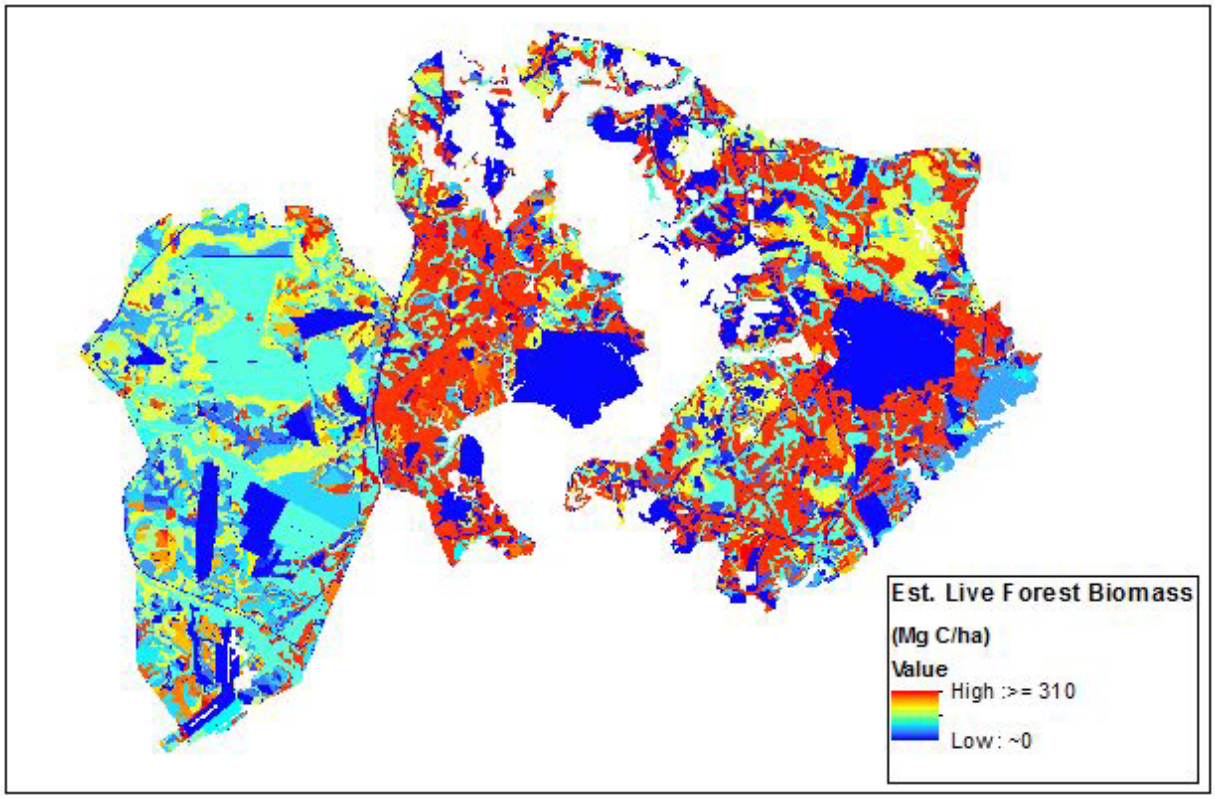

Figure 2-7. Preliminary estimates of above-ground live forest carbon storage throughout MCBCL.

2.5.2 Red-Cockaded Woodpecker Demography

- We investigated long-term changes in RCW life history traits that could be related to climate change. Results from two RCW study sites (i.e., at MCBCL and Fort Bragg, both

in North Carolina) from 1980 through 2011 show that the RCW are lay laying eggs earlier in the year and have increased clutch size and annual fecundity (number fledglings per group; **Figure 2-8**).

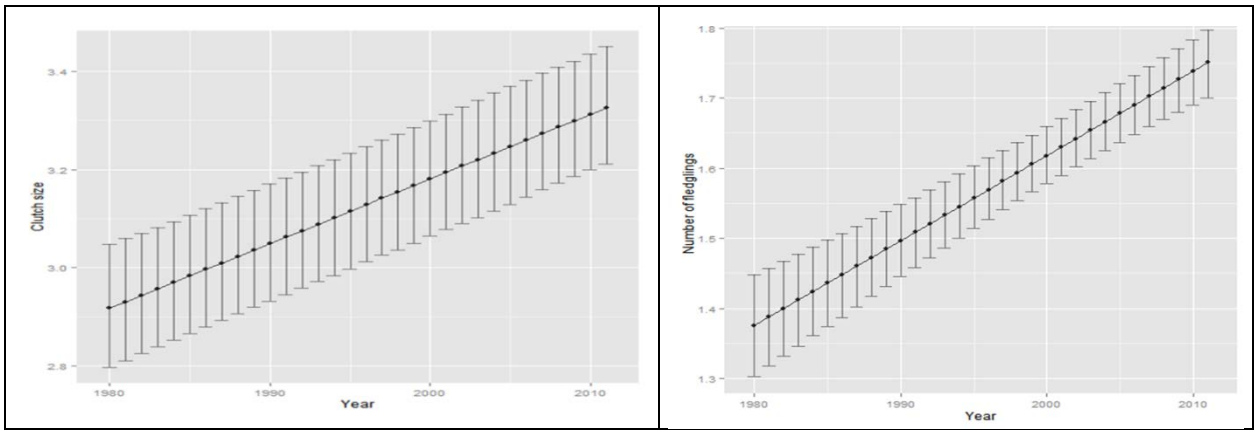

Figure 2-8. Change in RCW clutch sizes (left panel) and annual fecundity (right panel) from 1980–2011.

- We are currently analyzing the relationships between RCW life history traits and weather (e.g., average precipitation, temperature). We are using these parameters to develop a simulation model to assess how the RCW population on MCBCL and Fort Bragg may be altered by future climate conditions. Land managers will be able to assess how management activities might impact the RCW population on current and future landscapes.

2.6 Translating Science into Practice

The goal of the TSP Module is to ensure that the scientific knowledge generated in each of the four DCERP2 ecosystem modules is translated into practical models and tools that are easy to understand and easily accessible so they can be broadly applied for making informed ecosystem-based management decisions. This module provides a Spatial Decision Support System (SDSS) framework to support a one-stop-shop portal for the various tools and models developed by DCERP2 researchers. The TSP Module will allow accessibility to these products by MCBCL and other DoD installation staff. The TSP Module provides overarching support for the entire program in making data, decision-support tools, and models available to a variety of user groups. The TSP Module is a part of the larger thematic area of DCERP2 involved in translating the scientific findings into practice for the scientific community; DoD installation managers; local, regional, state, and federal natural resources managers; and other interested stakeholders.

2.6.1 Development of a Common Spatial Decision Support System Framework

- In 2013, we started building the SDSS framework that facilitates access to and interaction with tools and models developed within DCERP. Greatest efficiency was achieved by designing single-purpose, Web-based mapping applications that are easily incorporated into the SDSS framework. The framework can be easily accessed by different users with

any Web browser and does not require special software. However, access will be secure and role based; therefore, ensuring the security of the data and the system.

- One such single-purpose mapping application that we developed in 2013 is to access information on DCERP1 and DCERP2 stations. Initial functionalities include locating stations by station name, parameters collected, or within a user-defined radius of a point; and reporting station information such as a list of parameters collected at the station, dates of operation, and the name of the lead investigator using that station. The next step is to make DCERP data available for viewing and querying in the mapping application.

2.6.2 Estuarine Simulation Model

- An improved, online version of the ESM for the NRE has been finalized. The online tool displays an expanded suite of model parameters and allows users to export results directly to their desktop computers.
- Preliminary calibration of the ESM–Neuse River Estuary (part of the Albemarle–Pamlico Estuarine System adjacent to Marine Corps Air Station [MCAS] Cherry Point) confirms the wider applicability of this estuarine model. This ESM developed for MCAS Cherry Point is accurately reproducing observed chlorophyll *a* and nutrient concentrations in surface waters of the Neuse River, producing reasonable predictions of both benthic microalgal biomass and DO concentrations within the correct ranges. This model will be finalized in 2014 and made available through the SDSS framework.

2.7 Synthesis of Climate Change and Carbon Cycle

2.7.1 Climate Change

Projections that climate change will affect coastal military installations, operations, and missions in the United States and globally led SERDP to focus DCERP2 on climate change as one of its three central themes. Predicted changes in climate will also affect private-sector and other public interests in coastal regions, broadening the applicability of the research results and tools developed. DCERP2 is investigating four specific climatic drivers: temperature, precipitation patterns, storm frequency and intensity, and sea level. The Climate Change Module is providing uniform historical climate data and future climate scenarios for consistent use across the DCERP2 Team. Effects of changes in storm frequency and intensity and precipitation patterns were studied during 2013, but due to the relatively unremarkable conditions (no large storms or precipitation extremes), the results were not striking. However, results from temperature and water level research were substantial and compelling.

Estuarine metabolism was determined to modulate the exchange of CO_2 between the estuary and the atmosphere, and temperature was a key driver of the metabolic rate. The amount of developed lands within a watershed was found to increase tributary stream temperatures, likely affecting the function of both the streams and the estuarine receiving waters. As development in a watershed increased, the temperature of tributary streams also increased. Additionally, there was an increase in temperatures in all tributary streams during the complete record of DCERP (2007–2013), which is consistent with recent observations in other U.S. rivers. Water level was found to be an important driver of system function in coastal wetlands and on the barrier island.

Sea level anomalies (the difference between the total sea level and the average sea level for a time of year), resulted in elevated water levels at Onslow Beach. These anomalies corresponded with significant periods of erosion and beach loss. Water level also affected the production of below-ground biomass of salt marsh plants, which are a critical contributor to the marshes' ability to maintain their elevation as water level rises. Data collected on marsh elevation, sediment supply, and below-ground biomass will be used to develop predictive models of marsh responses to changing future water levels.

In the terrestrial ecosystem, a review of long-term data clearly showed how local climatic variations may have already affected the reproductive performance of the RCWs, a key endangered species in southeastern longleaf pine ecosystems. Over the past 30 years, RCWs were found to nest earlier and lay more eggs per clutch in 2011 as compared to 1980. These changes in the reproductive performance of RCWs associated with historic climate change will provide data needed to forecast this species's survival under projected changes in climate in the future.

2.7.2 Carbon Cycle

A quantitative budget of the carbon cycle in the MCBCL coastal landscape must be based on careful characterization of amounts of carbon in key elements of each habitat on that landscape (e.g., the estuary, coastal wetlands), as well as the fluxes of carbon among those elements and among the various habitats. Such an accounting will allow us to explore the likely impacts of different climate change scenarios and localized anthropogenic drivers on future carbon stores and fluxes.

In 2013, we made significant progress in the characterization of the carbon cycle. We established baseline and ranges of variation in the delivery of particulate and dissolved carbon in the New River and its tributary creeks. Among new findings, we discovered that the New River supplies significant carbon in the form of algal biomass to and likely supports significant respiration in the NRE. Analysis of tributary creek data has revealed the potential to use land-use as a proxy to predicting organic carbon loading to the NRE. We have characterized variations in carbon fractions temporally and spatially along the axis of the NRE, and this allows us to estimate carbon storage in different portions of this ecosystem, as well as total carbon storage. Estuarine-wide temporal mapping of CO_2 flux has provided a direct measure of carbon exchange between the atmosphere and estuarine waters. Results to date indicate that the flux of CO_2 from estuaries into the atmosphere may be lower than previously predicted. Information such as this could transform our general understanding of the role of estuaries in the overall landscape. Oxygen isotope studies have clarified the importance of fluxes of respired carbon between estuarine waters and bottom sediments, and they suggest important differences in these fluxes between the upper and lower portions of the NRE. Data from the coastal barrier island studies indicate that relict marsh carbon stored as peat deposits underlying Onslow Island are extensive and that this carbon is surprisingly young (less than 1,000 years). This carbon is not that much older than carbon stored in other MCBCL habitats. Further characterization of the size and rate of turnover of the peat deposits may still indicate some bearing on "modern" carbon dynamics in the broader NRE and/or coastal ocean. The results from the early terrestrial carbon modeling suggest that above-ground live carbon storage is highest in longleaf pine stands, compared to loblolly pine stands, and lowest in pond pine stands. Likewise, potential below-ground carbon sequestration is

also likely highest in longleaf pine stands, given the extensive taproot characteristic of longleaf pine. We will revised these estimates based on fire and fuel behavior and simulate the effect of different forest management scenarios on forest carbon storage and cycling at MCBCL.

These first year results leave us optimistic that our integrated process-level approach provides an accounting of present-day carbon storage in the MCBCL, enhances the understanding of how coastal carbon cycling may likely change on the decadal scale, and facilitates application of this knowledge and models to other regions faced with similar climate drivers.

2.8 Overall Synthesis and Significance of Findings to Date

The work now underway in DCERP2 is already significantly contributing to our understanding of the factors influencing the carbon cycle and the current and future responses of the carbon and nutrient cycles in various southeastern coastal ecosystems to climate change. An overall objective of the DCERP2 is to understand the approaches to and the outcomes of applying climate-related information to a suite of environmental process models to be able to forecast plausible future scenarios of a variety of ecosystem conditions. This knowledge has important implications for operations, training, and ecosystem management at DoD's numerous installations across the southeastern region of the United States. Additionally, it is important to the human communities (both small and large) and to the wide variety of public and private-sector activities along the southeastern coastline.

Once developed, the MCBCL carbon budget will provide an understanding of the likely impacts of human activities and climate change on carbon stores and fluxes across coastal landscapes. Work conducted in 2013 has quantified important elements of that budget, including the amounts of carbon in different portions of MCBCL's coastal forests, barrier island, coastal wetlands, streams and the estuary. Results to date suggest that the flux of CO_2 from estuaries into the atmosphere is lower than previously thought. If confirmed during our continuing studies, this result could transform our general understanding of the role of estuaries in the carbon cycle across the landscape. Our results also suggest that the cycling of carbon between sediments and water varies between the upper and lower parts of the estuary. This could have implications for management activities in these different regions.

Coastal wetlands are abundant and important along the entire southeastern coastline as a major sink for carbon in the estuarine/coastal region. In addition, marshes are a breeding habitat for commercially important fish and shellfish species, and they provide critical protection from storm surge for natural and developed inland communities. Sea level rise is an especially important concern in these ecosystems because the marshes must keep pace by accreting sediment to increase their elevation and to keep pace with sea level or they will convert to open water. Our work in 2013 continues to support our DCERP1 findings that sediment accumulation in MCBCL coastal marshes is keeping pace with current sea level. Future work will focus on the mechanisms underpinning such sediment change (accretion or erosion) and understanding possible impacts of storm events, nutrient enrichment, and human activities on the trajectory of change.

From Texas to New England, barrier islands are a prominent feature of U.S. coasts. Coastal recreation is a major contribution to the region's economy. These islands are important habitat

for a unique variety of plant and animal species, and they play a unique and important role in the training mission at MCBCL. Our results verify that barrier island sediments store considerable amounts of carbon as buried peat deposits. One of our most surprising findings is that this carbon is relatively young. This finding suggests that a more direct and active connection than what was previously believed exists between the accumulation of carbon in organic sediments of estuarine and coastal wetland ecosystems and the storage of carbon beneath barrier island sands. Barrier island dynamics are particularly sensitive to changes in sea level and to storm frequency and intensity. Our continuing work will quantify the effects of these hydrodynamic processes on island morphology and species habitat, as well as their connection to carbon dynamics.

Terrestrial ecosystems near the coast harbor a large array of species, and they also store and cycle large quantities of carbon. Forest management activities, including timber harvest, habitat restoration, and prescribed burning have important consequences for both biodiversity and the carbon cycle. Research in this first year has drawn on DCERP1data to quantify carbon stores across the MCBCL landscape in relation to past forest management practices and patterns of disturbance. We have also used historical data to evaluate patterns of change in species of special interest such as the endangered RCW. Our work will continue with the development of models to predict changes in carbon storage and the dynamics of RCW populations under different management and climate change scenarios. Although this work is directed specifically to the management priorities at MCBCL and other coastal military installations, it has important implications for land managers throughout the southeastern region of the United States.

To address the theme of translating science into practice, the DCERP2 Team developed information for three distinct target audiences: the scientific community, DoD installations and other land managers, and other stakeholders, including the general public. Research results from DCERP2 were translated through numerous peer-reviewed scientific publications, presentations at scientific conferences and stakeholder meetings. Research results were also translated through the distribution of quarterly newsletters. DCERP2 provides training opportunities for undergraduate, graduate, and doctoral students contributing to the legacy of the program for decades to come. Upgrades to our integrated Data and Information Management System (DIMS) and development of the new SDSS framework will increase the access and usability of the DCERP data through a suite of models and tools currently under development. The DCERP2 Team will use these models and tools to consider end-user management scenarios (e.g., land use changes) to illustrate the potential effects and trade-offs associated with various management actions on ecosystem processes and biological populations. The results from these management scenarios will be available incrementally throughout the program when the models and tools are validated. Ultimately, end users will be able to access the integrated results of management and climate change scenarios resulting from DCERP2 through DIMS and the SDSS framework.