ANNUAL REPORT II

Defense Coastal/Estuarine Research Program 2 (DCERP2)

SERDP Project RC-2245

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14. ABSTRACT
The second cycle of the Defense Coastal Estuarine Research Program (DCERP2) Team designed an integrative research and monitoring program to understand how climate change and local installation and regional activities affect critical ecosystem processes at our primary study site, Marine Corps Base Camp Lejeune (MCBCL), and at secondary installation study sites Fort Bragg and Marine Corps Air Station (MCAS) Cherry Point (both in North Carolina), and Eglin Air Force Base (in Florida). DCERP2 focuses on understanding the ecosystem processes associated with the carbon cycle, nutrient utilization, and sediment transport within the context of climate change impacts. Scientific understanding of ecological processes and the models, tools, and other products being developed at MCBCL are transferrable to other DoD installations in similar ecological settings. In addition, DCERP2 is providing this scientific understanding through publications and presentations and through resulting models, tools, and other products to the scientific community, regional stakeholders, and the general public.

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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, and warming temperatures) 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 with making often complex, ecosystem-based management decisions.

The second cycle of the Defense Coastal Estuarine Research Program (DCERP2) Team designed an integrative research and monitoring program to understand how climate change and local installation and regional activities affect critical ecosystem processes at our primary study site, Marine Corps Base Camp Lejeune (MCBCL), and at secondary installation study sites Fort Bragg and Marine Corps Air Station (MCAS) Cherry Point (both in North Carolina), and Eglin Air Force Base (in Florida). DCERP2 focuses on understanding the ecosystem processes associated with the carbon cycle, nutrient utilization, and sediment transport within the context of climate change impacts. Scientific understanding of ecological processes and the models, tools, and other products being developed at MCBCL are transferrable to other DoD installations in similar ecological settings. In addition, DCERP2 is providing this scientific understanding through publications and presentations and through resulting models, tools, and other products to the scientific community, regional stakeholders, and the general public.

The major objectives of DCERP2 are to

1. Build on the first cycle of DCERP (DCERP1) findings to identify additional thresholds that can serve as indicators of changing ecosystem conditions that could threaten sustainability of the military mission
2. Determine how ecosystem processes (within military land-use environments) respond to climate change to understand the sensitivity and adaptive capacity of these ecosystems
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 the results of scientific studies to natural resource 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

DCERP2 focuses on three thematic priorities of understanding carbon cycling, assessing the future impacts of climate change on the ecosystems under study and translating scientific information into actionable, easy-to-understand information to support management at DoD installations. The DCERP approach is structured to use field measurements, develop process models and tools that inform science-based adaptive management at MCBCL, and use the process models to develop various management and future climate change scenarios, whose results can be transferred to other DoD installations in similar ecological settings.

To better understand the carbon cycle and develop an estuarine/coastal carbon budget, DCERP2 includes systematic, integrated, time-series observations of drivers and indicators that are used in process models by the DCERP2 Aquatic/Estuarine, Coastal Wetlands, and Coastal Barrier Modules. Models are designed to help elucidate the status, trends, and natural variations of environmental parameters, including carbon. The Terrestrial Module uses modeled forecasts of various forestry management strategies common at MCBCL and throughout the southeastern United States to assess carbon storage and flux of MCBCL forest stands and to drive landscape changes in a decision-support tool to aid in the management of the red cockaded-woodpecker, a key endangered species.

To address the climate change theme, the four ecosystem modules are linked to a cross-cutting Climate Change Module that is providing downscaled, climate histories and climate futures for temperature and precipitation at appropriate spatial and temporal scales for use in ecosystem process models. These process models are using these data to assess the impacts of current management practices on the four ecosystems and to run scenarios of the impacts of projected climate change on ecosystem processes.

Data, synthesized outcomes, and scenarios from the DCERP2 research, monitoring, and modeling efforts are managed within a centralized Translating Science into Practice Module. The DCERP Data and Information Management System (DIMS) provides data management and archival capacity for DCERP data, including data querying and visualization tools for assessing management and climate change scenarios via an interactive mapping application. These tools can be used to examine tradeoffs among carbon management strategies amidst other DoD installation priorities such as military mission sustainability, species diversity, and water quality management. Collectively, the DCERP2 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. Transfer of management-focused, decision-support, and modeling tools by the entire DCERP2 Team will form the basis for adaptive management recommendations to sustain coastal habitats and their military missions now and under conditions of climate-changed futures. Publishing significant results in scientific journals will inform the scientific community of DCERP discoveries, and the development of easy-to-understand outreach products will communicate the significance of the discoveries to other stakeholders groups.

Results

DCERP2 is contributing to the understanding of the factors influencing the carbon cycle and the current and future responses of the carbon and nutrient cycles in various coastal ecosystems in the southeastern United States to climate change. To date, the DCERP2 Team has focused on sea level rise as one environmental driver related to climate change. An analysis of data from the upper New River (in North Carolina) revealed that semi-diurnal tidal flow has increased in magnitude since the late 1980s, likely attributable to sea level rise. On Onslow Beach, the DCERP2 Team quantified the rates of change on both the seaward and landward sides of this barrier island. The same sea level changes that brought tidal influence to the upper New River have likely accelerated sediment transport across the barrier island via overwash from storm events. These events are likely to become increasingly more frequent as sea level continues to increase in the future. The DCERP2 Team also continued research on ecological impacts from other climate factors such as increasing temperature, variability in precipitation patterns, and changes in storminess that will result in similar integrated assessments as the program continues.

In 2014, the DCERP2 Team also focused on advancing the carbon cycle from a conceptual model to a quantitative carbon budget for the estuarine/coastal systems of MCBCL. This quantitative carbon accounting requires high spatial- and temporal-resolution sampling to constrain daily, seasonal, and spatial differences in air–water carbon dioxide (CO_2) fluxes and to determine estuarine-scale carbon budget terms. These spatial- and temporal-sampling efforts have constrained inventories of all carbon fractions and yielded preliminary flux magnitudes across several inter-ecosystem boundaries in the estuary, marsh, and coastal barrier island. In addition, these efforts have facilitated initial assessments regarding how spatial and temporal variance in rates may translate into uncertainty in the estimates of scaled fluxes. The preliminary estuarine/coastal carbon budget challenges the conventional view that estuaries are persistent sources of atmospheric CO_2. DCERP2 data suggest that large, episodic events such as storms release significant amounts of CO_2 into the atmosphere. Other studies that have not incorporated the impacts of these major perturbation events have not adequately or realistically assessed the roles and importance of estuaries in mediating CO_2 fluxes. If these preliminary DCERP2 findings are confirmed during our continuing studies, then the results could transform the general understanding of the role of the carbon cycle in estuaries in the southeastern United States.

To facilitate the translation of scientific findings into practice, the DCERP2 Team is developing 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 have been translated through many peer-reviewed scientific publications, presentations at scientific conferences, and at local and regional stakeholder meetings. Although many scientific community outreach efforts have been completed to date, one key activity was the presentation of DCERP findings to the U.S. Global Change Research Program Carbon Cycle Interagency Working Group. Scientific data and information are also being conveyed through DCERP's DIMS, which includes the public Web site, data archive, and access to various tools and models develop by the DCERP2 Team. In 2014, the interactive mapping application (iMAP) was developed and released within DIMS, which allows data, tools, and models to be made available online for the various stakeholders to access. The scientific findings and products from DCERP2 will be a lasting legacy for decades to come.

Benefits

The DCERP Team's research and monitoring efforts will

- 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 future climate change and climate variability (i.e., warming temperatures, wet and dry periods, and episodic storm events) and sea level rise. The analysis and knowledge conveyed will also focus on the ecosystems' resiliency to these environmental stressors and to opportunities for adaptive management of these estuarine coastal systems.
- Quantify and model ecosystem processes regarding carbon cycling, nutrient utilization, sediment transport, and MCBCL land-use change impacts to the New River Estuary under current conditions, as well as a variety of model scenario under future climate conditions.
- Develop models and decision-support tools for use by MCBCL managers and transfer appropriate tools to MCAS Cherry Point and Fort Bragg, both in North Carolina, and Eglin Air Force Base in Florida. The outcomes findings from these models and tools may be applicable to other DoD installations in the southeastern and Gulf Coast Regions of the United States.
- Translate 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; one-on-one interaction with DoD installation managers; the development of technical reports, maps, online tools, and models; and in-person training workshops.

List of Acronyms

AE	Aquatic/Estuarine (Module)
CB	Coastal Barrier (Module)
CC	Climate Change (Module)
CDOM	chromophoric dissolved organic matter
CH_4	methane
cm	centimeter
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
ESM	Estuarine Simulation Model
$g\ C\ m^{-2}$	grams of carbon per square meter
iMAP	interactive mapping application
$kg\ TN\ yr^{-1}$	kilograms of total nitrogen per year
m	meter
m^{-2}	meter squared
MARDIS	Monitoring and Research Data and Information System
MCBCL	Marine Corps Base Camp Lejeune
MEM	Marsh Equilibrium Model
$mm\ y^{-1}$	millimeters per year
NRE	New River Estuary
pCO_2	partial pressure of CO_2
PI	Principal Investigator
RC	Resource Conservation and Climate Change (a SERDP program area)
RCC	Regional Coordinating Committee
RCW	red-cockaded woodpecker
SAB	Scientific Advisory Board
SDSS	Spatial Decision-Support System
SERDP	Strategic Environmental Research and Development Program
SSC	suspended sediment concentration
T	Terrestrial (Module)
TAC	Technical Advisory Committee
TN	total nitrogen
TSP	Translating Science into Practice (Module)

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 focuses on understanding how coastal and estuarine ecosystems respond to climate change and the processes associated with the carbon cycle in these ecosystems. DCERP2 also focuses 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 U.S. Department of Defense (DoD) installations and provide guidance to other stakeholders, including the general public.

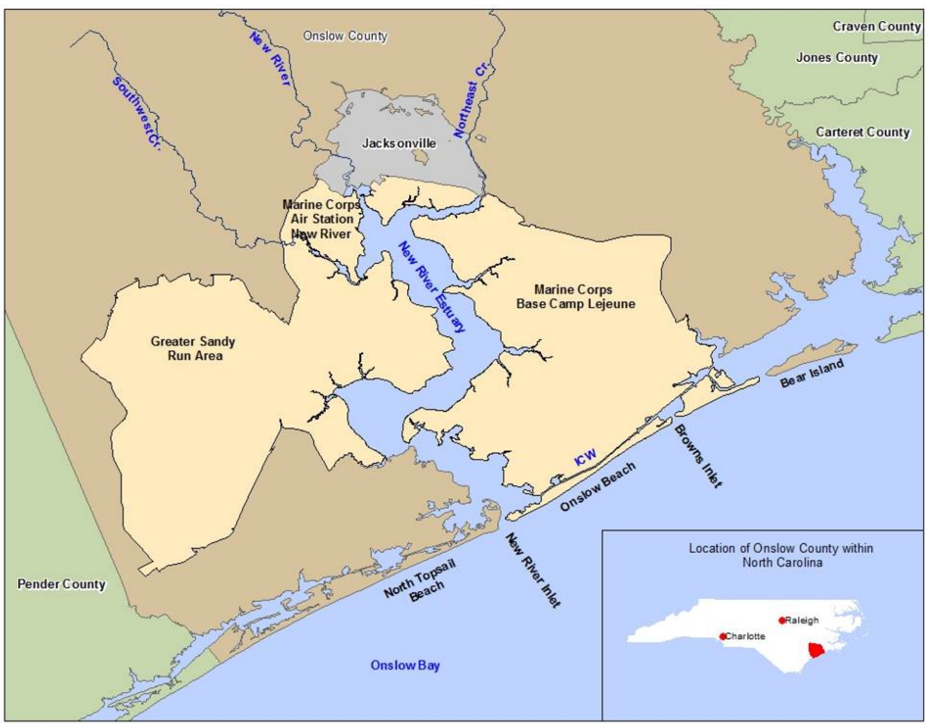

Figure 1-1. Site map of MCBCL.

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, to carry out program activities. 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 that conduct 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 the following four ecosystem modules: 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 DoD installations (Translating Science into Practice [TSP] Module).

As the DCERP Principal Investigator (PI), Dr. Patricia Cunningham of RTI 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 reviews 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, which consists 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 recommends 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, 2013a) and associated monitoring activities described in the *DCERP2 Monitoring Plan* (RTI, 2013b) 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**).

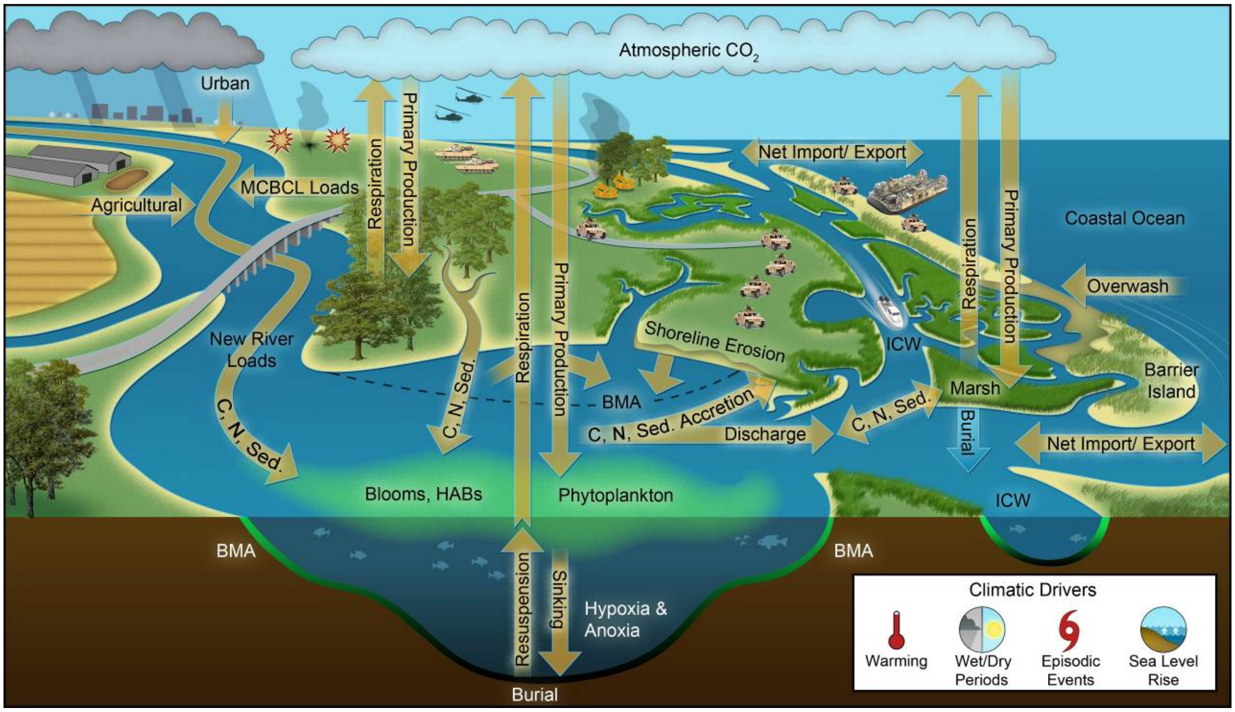

Figure 1-3. The overarching conceptual model for DCERP2.

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's research and modeling activities and to the development of decision-support management tools. During 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). During DCERP2, DIMS was expanded to incorporate the Spatial Decision-Support System (SDSS), which includes the Interactive Mapping Application (iMAP) and visualization of models and tools through common management and climate scenarios. The DIMS consists of several distinct systems as shown in **Figure 1-4**.

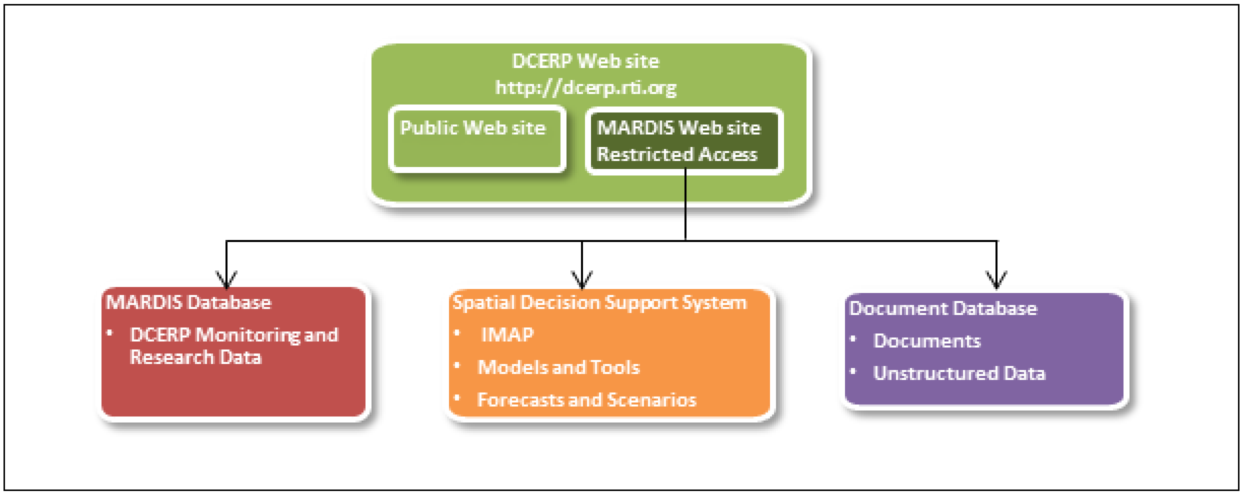

Figure 1-4. Components of the DCERP DIMS.

1.2 Introduction to DCERP2 Themes

The three major themes addressed during 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 during 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 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 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 II* summarizes the major activities and significant findings for the period from January to December 2014. 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 components 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 and 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) employing 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 was convened in November 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. In addition, the team discussed various methods for turning science into practice related to their individual research projects.

1.5 Literature Cited

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

RTI. 2013b. *DCERP2 Monitoring 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

The significant findings and implications of DCERP2 conducted at Marine Corps Base Camp Lejeune (MCBCL) from January through December 2014 are presented in this chapter. The findings are first presented at the programmatic level, then at the thematic level (i.e., carbon, climate change, and translating science into practice [TSP]; **Figure 2-1**) and finally at the module level (i.e., Aquatic/ Estuarine, Coastal Wetlands, Coastal Barrier, Terrestrial, and TSP modules).

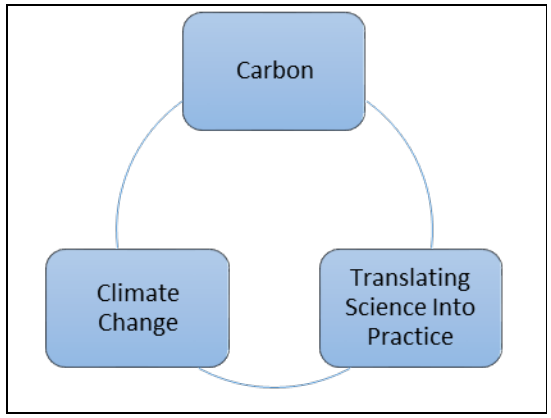

Figure 2-1. DCERP 2 themes.

2.2 Overall DCERP2 Synthesis

DCERP2 is contributing to the understanding of the factors influencing the carbon and nutrient cycles and the current and future responses of these cycles in various southeastern coastal ecosystems to climate change. In addition, we continue to study the movement of sediment from the watershed, within the estuary and marshes and across the barrier island. 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 management and climate scenarios of a variety of ecosystem conditions. This knowledge of how the ecosystems may react to plausible future scenarios has important implications for operations, training, and ecosystem management at the U.S. Department of Defense's (DoD's) numerous installations across the southeastern region of the United States. Additionally, this knowledge is important to the human communities (both small and large) and to the wide variety of public and private-sector activities along the coast.

During the year, the DCERP2 Team transformed their work on the estuarine/coastal carbon budget from a conceptual model to a preliminary quantitative accounting of carbon in the estuarine/coastal ecosystem. This quantitative accounting requires high spatial- and temporal-resolution data to constrain daily, seasonal, and spatial differences in air–water carbon fluxes and to determine system-scale carbon terms in the New River Estuary (NRE). These efforts have resulted in carbon inventories in the estuary, marshes, and barrier island and yielded estimates of carbon flux between these ecosystems. These efforts have also facilitated initial assessments of how spatial and temporal variance in rates may translate into uncertainty in the estimates of scaled fluxes. This quantitative accounting has identified gaps in the understanding of long-term (decadal-century scale) carbon burial in estuarine and marsh sediments. Additional research will be conducted over the remainder of DCERP2 to further refine and quantify the carbon fluxes and boundary conditions.

The DCERP2 Team continues to gather information on the four climate drivers, including increasing temperature, variability in the hydrological cycle, rising sea level, and extreme events. Just as information on these climate drivers cannot be gleaned from a single year of monitoring, process-based models to predict ecosystem change must be developed and validated by using a range of historic and predicted data. For example, a review of the historic water level data in the upper New River revealed an increase in tidal influence at this site over the past 30 years, most likely due to an historic rise in sea level. Similarly, the DCERP2 Team measured the historic and current impact of sea level on the evolution of washover fans on Onslow Beach, erosion of estuarine shorelines, and accretion of sediments in coastal marshes. The knowledge of historic and current ecosystem responses to these climate drivers provides information on anticipated impacts for consideration in future climate scenarios.

Throughout DCERP2, the Team has focused on translation of scientific results into information that can be used by different target audiences, including the scientific community, DoD installations and other land managers, and the general public. Over the past year, significant progress was made on the development of the interactive mapping application (iMAP), which allows data, tools, and models being developed by DCERP2 to be accessed online through the Data and Information Management System (DIMS). The DCERP Team also continued to provide assistance to DoD installation managers and worked on the development of key management-based tools and models. For example, the Estuarine Simulation Model (ESM) was expanded to the Neuse River Estuary, and management scenarios were developed for Marine Corps Air Station Cherry Point. Finally, research results have been published through numerous peer-reviewed scientific publications and presented at scientific conferences and local stakeholder meetings. In 2014, DCERP2 researchers published 14 articles, bringing the total DCERP–related publications to more than 50. During 2015, the DCERP2 Team will continue to engage the target audiences to ensure that results have management-relevant implications.

2.3 Synthesis of DCERP2 Themes

2.3.1 Climate Change

Nearly all DCERP2 research and monitoring efforts incorporate components of climate. The strong interdisciplinary team and the comprehensive assessment of virtually all ecosystems surrounding the NRE have resulted in breakthrough assessments related to climate change. To exemplify the interdisciplinary nature of the climate change focus of DCERP2, we highlight a few recent discoveries made by the DCERP2 Team regarding sea level rise.

Sea level changes are a central forcing feature in estuaries and coastal areas because changes in sea level affect exchange of material to and from the estuary at the upstream and downstream endpoints, estuarine hydrodynamics, and physiology of important organisms such as marsh plants. Analysis of data at the upper New River revealed striking changes in the historical water level record. The New River stream gauge at Gum Branch is broadly considered to be the head of the estuary; however, we discovered that the tidal influence currently prominent at the site is a relatively recent phenomenon (**Figure 2-2**). Historical records revealed that semi-diurnal tidal flow (first evident during low flow periods) has increased in magnitude since the late 1980s. There are other plausible factors that could contribute to increased tidal influence; however, sea level rise is the most likely explanation.

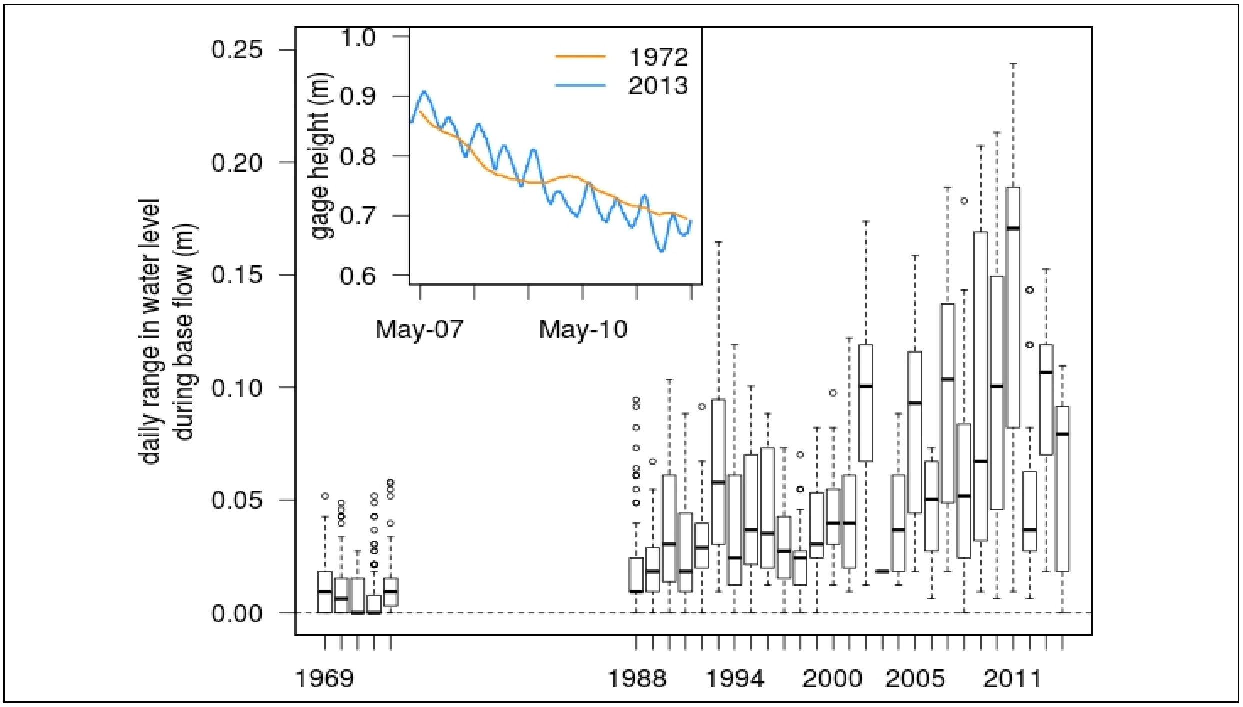

Figure 2-2. Trend in tidal amplitude at Gum Branch from 1988 through 2014; no tidal signal was evident in 1972 (inset).

On Onslow Beach, sea level also modulates the processes that cause both barrier stabilization and erosion. DCERP2 researchers quantified the rates of change on both the seaward and landward sides of the coastal barrier island. We monitor active and historic washover fans and have shown that these fans can facilitate barrier migration and increase the stability of the island. The same sea level changes that brought tidal influence to the New River have likely accelerated sediment transport across the barrier island via overwash. These events are likely to become increasingly more frequent as sea level rise continues to increase in the future.

The DCERP2 Team continues work on the system-wide impacts from other climate factors such as increasing temperature, changes in precipitation patterns, and changes in storminess that will result in similar integrated assessments as the program continues. An analysis of historical weather conditions and their impacts on life history traits of federally protected red-cockaded woodpeckers (RCWs; *Picoides borealis*) suggests that climate over the past 30 years has already resulted in changes in life history traits. Because North Carolina is the northernmost extent of this species' range, increasing temperatures will likely help local populations at Fort Bragg and MCBCL (both in North Carolina). However, variability in the pattern of precipitation at MCBCL could also have detrimental effects on this coastal RCWs population. The RCW Decision-Support System model will help quantify population dynamics associated with landscape changes resulting from future climate change and will assist managers in understanding the future challenges of managing this endangered species.

2.3.2 Carbon Cycle

Quantifying carbon cycling in the coastal landscape within the MCBCL hinges upon measuring intra-ecosystem inventories and inter-ecosystem fluxes at the appropriate spatial and temporal scales. These results provide data for generating empirical carbon budgets and the mechanistic framework underlying the dynamic ESM and marsh models used to gauge sensitivity of the carbon cycling network to changing climate drivers.

New River Estuary

Carbon is delivered to the NRE through a combination of storm pulse events (soil-derived organic carbon) from the New River watershed and baseflow from terrestrial (organic carbon) and freshwater (inorganic carbon) inputs. Estuarine-wide mapping of the air–water carbon dioxide (CO_2) exchange indicates that the NRE is a source of CO_2 to the atmosphere, but at a rate 10 times lower than previous estimates for similar temperate estuaries. These estimates have been further constrained by time series oxygen budgeting that showed periods of strong photosynthesis that help offset total system respiration.

The 100-year average burial flux of carbon to the sediments of the upper NRE equates with an average sedimentation rate that is twice that of local sea level rise. Since 1900, the carbon burial rate in the upper NRE has ranged over a factor of four and reflects both trends in sediment deposition and pulsed storm delivery. The disproportionally high rates of organic carbon burial associated with hurricanes in the late 1990s resulted in peak carbon burial showing that event scale processes may be a major controlling factor for carbon sequestration in the NRE. Biomarkers indicated a strong terrestrial origin for carbon preserved in the upper NRE sediments.

The tributaries are not passive conduits for carbon. In fact, we found that streams draining all but the most developed watersheds (with the highest nutrients) removed carbon via net respiration. Carbon fluxes from the tributaries draining the MCBCL during base-flow and storm-flow conditions were land-use dependent, indicating that more land development equated with less dissolved organic carbon loading, but more particulate organic carbon loading. Because loads of dissolved organic carbon are much larger than particulate carbon, the net effect of watershed development is a reduction in carbon load into the estuary. Areas where tributaries discharged into the estuary were hot spots for metabolic activity, leading to the increased export of CO_2 from the estuary into the atmosphere. The increased metabolic activity may be because of watershed export of labile organic matter, respired in or near the mouths of the tributaries.

Coastal Marshes

The amount of carbon by marsh type was combined with information about habitat size to estimate a total MCBCL marsh carbon inventory split 2:1 between *Spartina* and *Juncus* marshes. Carbon content of low-elevation *Spartina* marsh sediment cores exhibited relatively low variability because all cores were similar in carbon depth profiles. On average, the carbon content per square meter in the low-elevation *Spartina* marsh is greater than the mid-elevation *Spartina* marsh, which is unexpected because trends of below-ground biomass and production were greater in the mid-elevation marsh. The high-elevation *Juncus* marsh contained more carbon per square meter than either the low- or mid-elevation *Spartina* marshes. Sediment history of marsh cores is pending and, when combined with carbon density profiles, will yield long-term marsh carbon burial rates for comparison to short-term burial rates.

Quantification of carbon exchanges between MCBCL marshes and adjacent surface waters will take place in 2015–2016, but we have found some evidence that *Spartina* marshes may be a source of organic carbon in the sediments of the lower NRE. The magnitude of this carbon source will be further refined and may either represent modern marsh inputs and/or contributions of weathered marsh peats eroded from the shoreface of the barrier islands and tidally imported into the lower NRE.

Onslow Beach

Backbarrier island salt marshes (**Figure 2-3**) provide important ecosystem functions, which include sequestration of atmospheric CO_2 and below-ground carbon storage in the form of peat and organic-rich sediment. As the coastal barrier island moves landward and over the backbarrier marshes in the southwestern portion of the island, this carbon is buried beneath the island for an unknown period of time before it becomes exposed by the ocean's hydrodynamic processes and is eroded on the beach front. In contrast, the northeastern portion of the island has a stable shoreline, and the old backbarrier marsh is not being eroded on the beach front, making this portion of the island more of a carbon sink than the southwestern end of the island.

Figure 2-3. Backbarrier marsh.

Mapping the thickness, distribution, and carbon content of the peat layer under the backbarrier marsh and beneath the coastal barrier island was completed in 2014. The thickness of the backbarrier marsh peat layer is consistent (approximately 75-cm thick) over large distances (approximately 200 m), suggesting that the backbarrier marsh platform formed very rapidly. In contrast, the layer of marsh peat buried below the island is more variable in thickness because of erosional processes associated with island overwash and landward movement of the coastal barrier island. Radiocarbon dating of this peat shows it is 200–300 years older than peat in the backbarrier marsh. The sediment profiles also show that the older peat has an average of 33% less carbon than the younger peat. These data, combined with the ^{14}C age distribution, indicate island migration is on the order of a few hundred years, can now provide estimates of carbon release rates resulting from the shoreface erosion during island transgression. This "resurrected" carbon is comparable to the age of the older carbon fractions stored in other MCBCL marsh habitats and/or potentially delivered from the watershed. Further characterization of the breakdown of this peat may still indicate some bearing on current carbon dynamics in the broader NRE and/or coastal ocean.

Terrestrial Carbon

In contrast to the empirical studies of the estuarine/coastal carbon cycle, terrestrial carbon forecasts for the forested lands of MCBCL are being modeled based on the forest stand age and species composition. The results from this terrestrial carbon modeling suggest that above-ground live carbon storage is highest in longleaf pine (*Pinus palustris*) forests compared to loblolly pine (*Pinus taeda*) forests, and lowest in pond pine (*Pinus serotina*) forests. The amount of above-ground live carbon stores depends on stand development age. Upcoming measurement of soil carbon storage will determine whether longleaf or loblolly pine forests store more carbon overall. Total terrestrial carbon estimates for the installation will be determined based on fire and fuel behavior simulations, stand dynamics, and measurement of soil carbon within managed forest lands at MCBCL.

2.3.3 Translating Science into Practice

The goal of the TSP theme is to ensure that the scientific knowledge generated in each of the four DCERP2 ecosystem modules and the downscaled climate information developed by the Climate Change Module 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. The team's effort to bring findings and information to a broader audience is also reflected in the number of presentations, publications, and engagements with stakeholders at the national, state, and local levels. In 2014, the estuarine/coastal carbon research was briefed to the U.S. Global Change Research Program, which provides a coordinated and focused scientific strategy for conducting federal carbon cycle research. Workshops for MCBCL and Marine Corps Air Station Cherry Point staff demonstrated the ESM for the New and Neuse Rivers, respectively. The DCERP2 Team also worked with MCBCL's Environmental Management Division on three living shoreline pilot projects. Several researchers were interviewed by National Public Radio for *The State of Things* and *Science Friday* programs; others provided interviews to several coastal and regional newspapers and gave presentations to local and regional stakeholder groups.

The TSP Module is assisting the DCERP2 Team in bringing information and tools in different formats to end users, whether the end user is the scientific community, DoD installation managers, or other interested stakeholders, including the general public. Specifically, the Spatial Decision-Support System (SDSS) component of the DCERP DIMS was developed this year to provide a one-stop-shop portal for the various DCERP1 and DCERP2 data, tools, and models.

<u>Spatial Decision-Support System</u>

The iMAP component of the SDSS is now available to MCBCL and other end users and displays DCERP1 and DCERP2 data and results. iMAP provides a means for users to easily visualize the DCERP monitoring and research data. To compare results from different models and tools, iMAP was developed to display outputs of common land management and climate scenarios from the process models, including the Geospatial Marsh Model, CSHORE-C15 (for coastal barrier morphology), LANDIS-II (for forest management), and the RCW Decision-Support System. This application will enable managers to consider the tradeoffs from disparate decisions.

<u>Estuarine Simulation Model</u>

The online version of the ESM for the NRE was expanded to include data through 2014. In addition, the ESM for the Neuse River Estuary was completed by using data from 2007–2010 and made accessible online to Marine Corps Air Station Cherry Point managers. The online ESM tool allows users to conduct scenario analysis associated with nutrient loading, displays a suite of model output and metrics for water quality criteria attainment, and allows users to export results to their computers. Calibration of the Neuse River ESM data confirms the wider applicability of this model to more than one estuarine system. As it did in the NRE, this ESM is accurately reproducing observed chlorophyll *a* and nutrient concentrations in surface waters of the Neuse River and is producing reasonable predictions of both benthic microalgal biomass and dissolved oxygen concentrations.

2.4 Ecosystem Module Level Findings

The ecosystem-level findings are representative of the advancements made by each of the DCERP2 modules during 2014 and are more focused on ecosystem structure, function, and response to stressors, such as various management decisions and/or climate change drivers. These findings help support our understanding of current conditions within each ecosystem and across the various ecosystems under study and our understanding of plausible conditions that may influence these ecosystems in the future.

2.4.1 Aquatic/Estuarine Ecosystem

Research and monitoring activities of the Aquatic/Estuarine Module examine the tidal reach of the NRE from the freshwater head of the New River to the tidal inlet at Onslow Bay. The NRE is a relatively small, shallow (2-m mean depth), Coastal Plain estuary, the majority of which resides within MCBCL's boundaries. The NRE is confined by coastal 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.

- In shallow estuaries such as the NRE, the benthic filter plays a critical role in reducing release of nitrogen into the water column and thereby provides a buffer against eutrophication (e.g., phytoplankton blooms). Seasonally and for individual estuarine regions, benthic processes were able to remove up to 100% of the total nitrogen (TN) produced by internally driven processes, measured as benthic mineralization. A greater percentage of this nitrogen was removed in the lower estuary when compared to the middle and upper regions of the estuary, likely due to greater light availability near the New River Inlet. When scaled up across the entire estuary, benthic processes were capable of removing 100% of the estimated annual average external nitrogen load that entered the NRE between 1998 and 2011 (794,000 kg TN yr^{-1}).
- Measurements of partial pressure of CO_2 (pCO_2) in the surface waters of the NRE showed up to a four-fold difference over the diel or day–night cycle. The highest values were observed at dawn after respiration during the previous night, and the lowest values were observed at dusk as a result of daytime CO_2 uptake via photosynthesis (**Figure 2-4**). These data indicate that metabolic processes are an important factor in controlling CO_2 flux, thereby supporting the need for high-resolution spatial surveys to account for diel variations in CO_2 and providing a realistic estimate of system-scale CO_2 fluxes. DCERP2 is one of the few studies in which diel changes in the CO_2 flux have been monitored. Temperature is another important driver of CO_2 fluxes, which affect both physical and biological process rates.

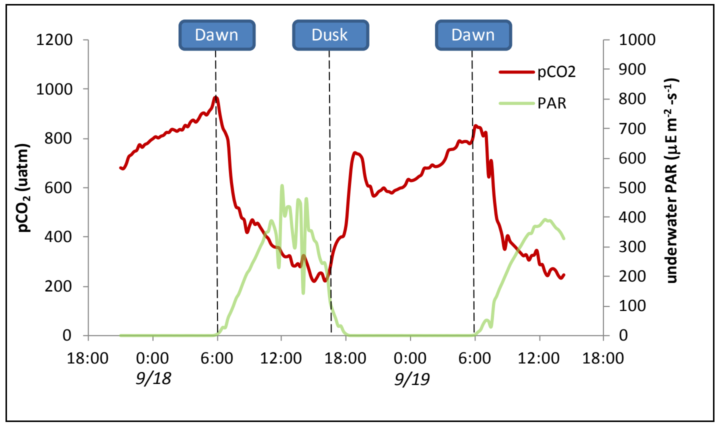

Figure 2-4. Daily flux of atmospheric CO_2 and solar radiation in the shallow estuary.

- The pattern of CO_2 exchanges in the upper region of the NRE deviated strongly from those observed in both the middle and lower estuary. This pattern was particularly true during the spring when the upper estuary was a strong sink for CO_2 due to phytoplankton blooms caused by elevated nitrate levels from the New River watershed, whereas the middle and lower estuary were moderate sources of CO_2. The phytoplankton blooms can subsequently sink, and the materials are remineralized to release ammonium, which can fuel additional blooms, and CO_2. In contrast, during the fall (September), the upper estuary was a strong source of CO_2 into the atmosphere, whereas in the middle and lower estuary, the net flux of CO_2 was near zero. The high CO_2 emissions in the upper estuary below Jacksonville, NC, can be partly explained by inputs of organic carbon from the surrounding watershed that are subsequently decomposed and release CO_2 at the head of the estuary, as well as from the decomposition of legacy organic sediments in Wilson Bay, which received effluent from a wastewater treatment facility until 1998.

2.4.2 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 large amounts of CO2 from the atmosphere and provide carbon storage by acting as a carbon sink, equivalent to other major terrestrial habitats, 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 estuarine shoreline and Intracoastal Waterway, as well as the brackish marshes along the middle estuarine 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*), respectively.

- Based on data from 2008–2014, the increase in marsh surface elevation at most study sites is keeping pace with the current rate of sea level rise. There has been a significant net average rate of increase of 1.5 to 10.8 mm y^{-1} in marsh surface elevation over the past 6 years at all but one study site. However, in 2014 five sites exhibited a surface elevation increase that was less than the local rate of sea level rise (2.7 mm y^{-1}). If the net rate of marsh elevation increase is less than sea level rise rate, then these marshes would be in jeopardy of being inundated in the future.

- Salt marsh sediment accretion rates are two to five times higher than net marsh surface elevation change. This difference suggests that subsidence, sediment compaction, decomposition of marsh biomass, and perhaps resuspension of accreted sediments are significant processes impacting MCBCL marshes that result in the lower net surface elevations observed than would be expected by accretion rates alone.
- Below-ground biomass production measured in experimental cores ranged from 78 to 930 g C m^{-2} and increased with elevation within each marsh site. These rates and spatial patterns are similar to previously published values from a Virginia *Spartina* marsh. Some fraction of below-ground biomass is preserved for long time periods (decadal to century or greater). Preserved below-ground biomass translates directly into long-term carbon burial and contributes to soil volume, thereby contributing to marsh elevation increases. Rates of below-ground production and storage are not well documented for tidal wetlands, so these data will inform projections of the fate of marshes under future sea level rise scenarios.
- We discovered a correlation between suspended sediment concentration (SSC) and tidal creek morphology. We measured distinct funnel shapes (tapering of the channel width from the creek mouth to the headwaters) of three creeks. Because SSC was correlated with this funnel shape, easily accessible geographical information systems data could provide a prediction of the median SSC for any tidal creeks which is an important source of sediment to the adjacent marshes. SSC is a critical, but poorly constrained parameter for modeling the effect of sea level rise on marshes, and this predictive tool for determining the median SSC of any tidal creek will increase the accuracy of broad-scale, high-resolution shoreline morphodynamic modeling efforts.
- Our research is the first to measure the contribution of the surface microlayer to the sediment flux within a salt marsh. The surface microlayer refers to the material floating at the surface of the water column, which is not captured in standard SSC sampling protocols. However, we found that during the course of tidal inundation, this material sinks from the surface microlayer into the underlying water column, where it is captured by SSC sampling protocols. This source of sediment to a marsh has significant consequences for marsh sediment transport modeling and carbon budgets because it is a transport mechanism that operates independently from water flow velocity, the primary driver of sediment transport in existing mechanistic models. Discovery of this velocity-independent transport mechanism provides an explanation for the higher SSC that we observed in water samples collected in the salt marsh than in the adjacent marsh channel.

2.4.3 Coastal Barrier Ecosystem

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 coastal 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 forms new washover fans in the southwestern portion of the island, and sediment transport across the island via wind-driven processes is more efficient because of the reduction in vegetation density.

- Researchers have been tracking the evolution of the washover fan initially formed after the passage of Hurricane Irene in 2011 and found that the dune line was re-established within 1 year. When Hurricane Sandy moved up the East Coast in October 2012, the area overwashed again, causing the fan to expand an additional 650 feet (200 m) landward. The dune line has not re-established, and frequent overwash events continue to modify fan morphology, but the landward edge of the fan was stable in 2014 (**Figure 2-5**). This result demonstrates that we are capturing the fan's transition from an overwash-dominated fan that is expanding laterally, to a wind-dominated fan that is expanding vertically (raising island elevation) as vegetation densities continue to increase and trap sand. This threshold of transition is an important factor for determining the resilience of a coastal barrier island to storms.

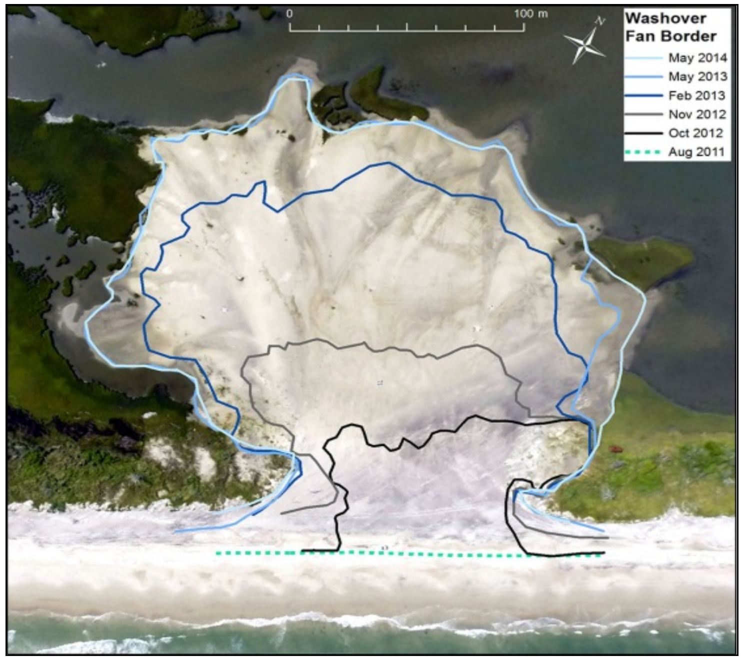

Figure 2-5. Changes in aerial extent of the washover fan formed in 2011.
Notice that areal changes were negligible between May 2013 and May 2014, suggesting the fan is stabilizing.

- One of the oldest washover fans on Onslow Beach is important as nesting habitat for many species of shorebirds. In contrast, two younger washover fans were not important for nesting, but for different reasons. One site had too little vegetation, whereas the other site had too much vegetation. Resting and foraging birds most frequently used the washover fan with less vegetation, indicating the value of open sand with sparse vegetation in providing predator-free habitat. This washover fan should become a more important shorebird nesting area in the future as vegetation on the site develops, especially for plovers, which prefer sparse vegetation, but easy access to feeding areas. DCERP2 researchers recommend that MCBCL managers continue protecting this area and limit access to the fan with less vegetation as the site becomes more useful for nesting shorebird populations in the future.

2.4.4 Terrestrial Ecosystem

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, savannas, and pocosins (shrub bog) that dominate MCBCL's terrestrial environments. Variations in the biota and ecosystem processes along these gradients are driven by variations in hydrology, soils, and fire behavior. The Terrestrial Module continues to build on data collected during DCERP1 and uses this information in process models to inform forestry management decisions, as well as decisions about recovery of RCW populations at MCBCL. LANDIS-II, a forestry management model, can project the effects of different forest management techniques, including harvesting, understory thinning, and prescribed burning, and the impact of each technique on stand and landscape scale carbon flux and storage in the context of future climate change scenarios. The RCW Decision-Support System model outputs allow for a study of the implications of various management and climate change scenarios for determining demographics of RCW populations at MCBCL.

- Using the LANDIS-II model, we have conducted preliminary simulations on the impacts of different forest management scenarios on long-term carbon storage at MCBCL: unharvested (control) and a 50-year harvest with a mean fire return interval of 3 years for longleaf and loblolly pines and a 40-year fire interval for pond pine pocosins (treatment). Our simulations assume that, with the exception of pond pine pocosins, frequent, low-severity fire dominates the MCBCL landscape because that is the current forest management practice for managing the longleaf pine ecosystem, which subsequently reduces the risk of catastrophic wildfires. The 40-year fire return interval for pond pine forests is characteristic of the natural fire cycle of high-intensity and low-frequency wildfires. Carbon storage appears to be highest when fires and timber harvesting are excluded (i.e., unharvested).
- LANDIS-II simulations of the two management scenarios demonstrate different levels of above-ground carbon storage among the three major pine species at MCBCL: longleaf pine, loblolly pine, and pond pine. When these forest stands are left unharvested, average above-ground forest carbon storage per square meter is highest among longleaf pine stands, approximately 20% lower among loblolly stands, and is far lower in pond pine stands (**Figure 2-6**). There are two reasons for these results. First, longleaf pines live significantly longer than loblolly pines and, therefore, can accumulate more carbon. Second, pond pines live in organic, low-nutrient soils and, as a result, grow very slowly and do not have a high capacity for carbon storage. LANDIS-II simulations show that if the forests are left unharvested with only low-severity prescribed burns (e.g., no high-severity crown fires), rates of carbon sequestration across MCBCL are indicative of a significant carbon sink for approximately 30 years. After that time, sequestration rates appear to plateau or decline slightly as the forest approaches 100 years of age, indicating that little additional carbon will be sequestered on an annual basis. Small negative deviations in sequestration rates, if persistent, can result in significant carbon fluxes over the long term. These scenarios will be further refined with field-based data.
- LANDIS-II simulations further show that if the MCBCL forests are harvested on a 50-year rotation, the longleaf pine stands will have the highest amount of carbon, followed by loblolly pine stands, and the lowest carbon storage by the pocosin-dwelling pond pines (**Figure 2-6**). In addition, the total carbon storage of all three pine species across MCBCL in the 50-year harvest scenario is less than the carbon storage attained in the unharvested scenario.

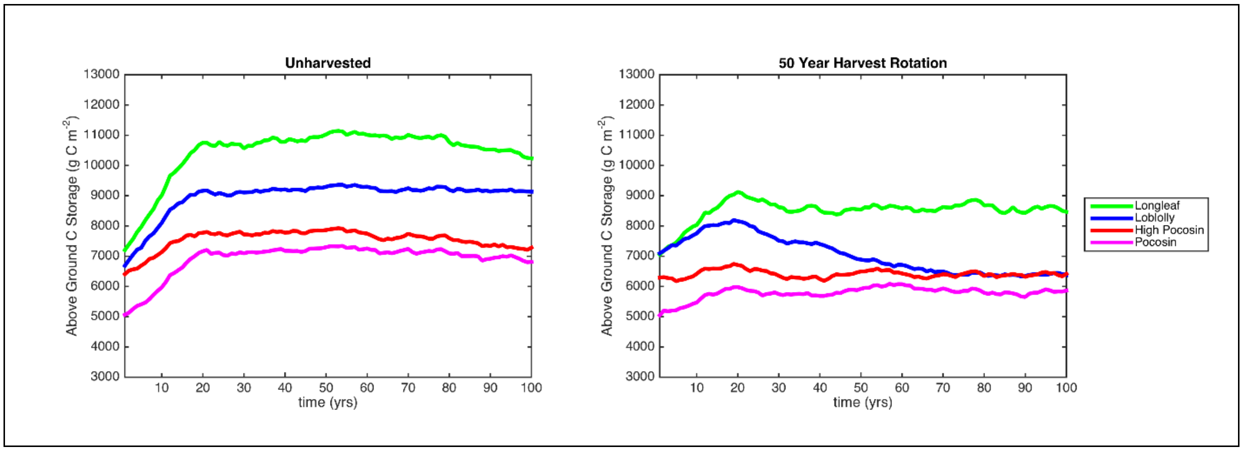

Figure 2-6. Patterns of above-ground biomass accumulation in an unharvested landscape and harvested landscape (50-year harvest rotation).

Note: Longleaf pine (green), loblolly pine (blue), pocosins (pink), and high pocosins (red).

- An analysis of historic weather data (1980 through 2011), shows that a number of RCW life history traits have changed over this 31-year period. The major changes include earlier egg-laying dates, increases in variance in egg-laying dates, and increases in survival rate. These observed changes in life history traits and weather are non-linear, characterized by change through the 1980s into the early 1990s, followed by a period of stability, and then renewed change beginning in the mid-2000s. At MCBCL, there was a correlation between those dates and precipitation, whereas in the Sandhills Region, there was a correlation between those dates and increasingly warmer temperatures. In DCERP2, we hypothesize that the non-linear changes that we observed were likely driven by climate and reflect the complexity of climate change in the southeastern United States. If our hypothesis is correct, the effects of climate change on RCWs in the Sandhills Region of North Carolina (Fort Bragg) will be positive (with rising temperatures), at least in the immediate future because North Carolina represents the northern most range of this species. Rising temperatures may also have positive effects on RCWs at MCBCL, but another possible scenario is that increased precipitation and greater variability in precipitation will have adverse effects on productivity in this coastal RCW population.

2.5 Summary of Upcoming Activities

In 2015, the Aquatic/Estuarine Module will continue monitoring carbon in the various compartments of the NRE and its tributaries to confirm their preliminary findings. The Coastal Wetlands Module will use a specially designed chamber to initiate monitoring of CO_2 and methane changes at the marsh–atmosphere interface and at the marsh–creek interface. Work will also begin on the development of geomorphology models to predict future marsh sustainability. The Coastal Barrier Module will start modeling the shoreline changes associated with various hydrodynamic processes to aid in understanding the rate of turnover of the peat deposits beneath the barrier island. All of these efforts will help to refine the empirical estimate of the overall estuarine/coastal budget. The Climate Change Module will begin development of standard climate histories and future climate projections for use in the process models.

On the terrestrial landscape, carbon estimates will be revised based on LANDIS-II simulations of fire and fuel behavior and soil carbon storage within the context of different forest management scenarios typically used at MCBCL and throughout the southeastern United States. The Terrestrial Module will also finalize the RCW Decision-Support System to predict RCW demographics under various landscape and climate change conditions. Finally, the first set of model results will be incorporated into the iMAP, and the applicability of the ESM will be extended to a third estuarine area adjacent to Eglin Air Force Base in Florida. The DCERP2 Team as a whole will continue to promote DCERP more widely in formats most appropriate in order to its target end users.