RESEARCH PLAN

Defense Coastal/Estuarine Research Program (DCERP)

SERDP Project RC-1413

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Acronyms and Abbreviations

2-D	two-dimensional
3-D	three-dimensional
ADCIRC	Advanced Circulation (model)
ADCP	Acoustic Doppler Current Profiler
ALPHA	Adapted Low-cost Passive High Absorption
ANOVA	analysis of variance
AOC	areas of concern
ASTP	stomatal compensation point
AVIRIS	Sea-viewing Wide Field-of-view Sensor
AVP	automounous vertical profiler
AWAC	Acoustic Wave and Current
BBN	Bayesian Belief Network
BLH	boundary layer height
BMA	benthic microalgae
BMP	best management practice
C	carbon
CAA	Clean Air Act
CAFO	confined animal feeding operation
CFR	Code of Federal Regulations
CMS	Center for Marine Sciences
CO	carbon monoxide
CWA	Clean Water Act
CWSMB	Coupled Water and Salt Mass Balance
DCERP	Defense Coastal/Estuarine Research Program
DEM	digital elevations model
DIC	dissolved inorganic carbon
DIN	dissolved inorganic nitrogen
DIP	dissolved inorganic phosphorus
DO	dissolved oxygen
DOC	dissolved organic carbon
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DON	dissolved organic nitrogen
EF	emission factor
EOS	end of the season
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ESM	Estuarine Simulation Model
FAC	fractional aerosol coefficients
FIB	fecal indicator bacteria
GIS	geographic information systems
GPS	global positioning system
HAB	harmful algal bloom
HPLC	high performance liquid chromatography
HSPF	Hydrologic Simulation Program Fortran
ICW	Intracoastal Waterway
INRMP	*Integrated Natural Resources Management Plan*
IPCC	Intergovernmental Panel on Climate Change

IRMS	isotope ratio mass spectrometry
KBDI	Keetch-Byram drought index
LCAC	landing craft air cushion
LIDAR	Light Detection and Ranging
LTSC	Long-Term Shoreline Change
LVORI	low visibility occurrence risk index
MA	microalgal
MARDIS	Monitoring and Research Data Information System
MARIS	medium-spectral resolution, imaging spectrometer
MCBCL	Marine Corps Base Camp Lejeune
MCE	modified combustion efficiency
MEM2	marsh equilibrium model 2
MHW	mean high water
MODIS	Moderate Resolution Imaging Spectroradiometer
MOU	Memorandum of Understanding
N	nitrogen
NAAQS	National Ambient Air Quality Standards
NADP	National Atmospheric Deposition Program
NCDCM	North Carolina Division of Coastal Management
NCSU	North Carolina State University
NFESC	Naval Facilities Engineering Service Center
NH_3	ammonia
NLM	nutrient load model
NO_2	nitrogen dioxide
NO_x	nitrogen oxide
NOAA	National Oceanic and Atmospheric Administration
NPP	net primary production
NRE	New River Estuary
NRESE	New River Estuary Shoreline Erosion
NWS	National Weather Service
O_2	oxygen
O_3	ozone
OC	organic carbon
OPTMOD	bio-optical model
OSC	On-site Coordinator
P	phosphorus
Pb	lead
PB	prescribed burning
PCR	polymerase chain reaction
PI	Principal Investigator
PM	Program Manager, particulate matter
$PM_{2.5}$, PM_{fine}	(fine) particulate matter with aerodynamic diameter smaller 2.5 microns
PM_{10}	particulate matter with aerodynamic diameter smaller 10 microns
$PM_{10\text{-}2.5}$, PM_c	(coarse) particulate matter aerodynamic diameter with between 2.5 and 10 microns)
POC	phase organic compound
QA	quality assurance
QC	quality control
QPCR	quantitative polymerase chain reaction
RCC	Regional Coordinating Committee
RCW	red-cockaded woodpecker

RDBMS	Relational Database Management System
RFMSS	Range Facility Management Support System
RTI	RTI International
RTK	real-time kinematic
RWE	Representative Wave Energy
SAV	submerged aquatic vegetation
SDI	smoke dispersion index
SeaWIFs	Sea-viewing Wide Field-of-view Sensor
SERDP	Strategic Environmental Research and Development Program
SET	surface elevation table
SMP	Smoke Management Plan
SO_2	sulfur dioxide
SOA	secondary organic aerosol
SOP	standard operating procedure
SPARROW	Spatially Referenced Regressions On Watershed Attributes
SSA	sea salt aerosol
STEBR	Short-Term, Event Beach Response Model
SWAN	Simulating Waves Nearshore (model)
TAC	Technical Advisory Committee
TBD	to be determined
TMDL	total maximum daily load
TSS	total suspended solids
UNC-CH	University of North Carolina at Chapel Hill
UNC-IMS	University of North Carolina Institute of Marine Sciences
UNC-W	University of North Carolina at Wilmington
USACE	U.S. Army Corps of Engineers
USC	University of South Carolina
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VCIS	Ventilation Climate Information System
VI	ventilation index
VIMS	Virginia Institute of Marine Sciences
VOC	volatile organic compounds
VT	Virginia Tech
WEMO	Wave Exposure Model
WSM	watershed simulation model
WWTP	wastewater treatment plant

Research Plan Executive Summary

Introduction

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. The U.S. Department of Defense (DoD) intends to enhance and sustain its training and testing assets and to optimize its stewardship of natural resources through the development and application of an ecosystem-based management approach on DoD facilities.

To accomplish the above goal, the Strategic Environmental Research and Development Program (SERDP) launched the Defense Coastal/Estuarine Research Program (DCERP) at Marine Corps Base Camp Lejeune (MCBCL) in North Carolina. MCBCL provides an ideal platform for DCERP because it integrates coastal barrier, estuarine, coastal wetland, and terrestrial ecosystems, all within the boundaries of DoD properties

DCERP is designed to be implemented in two phases. Phase I of the program represents the planning period and includes the development of an overarching research strategy (*Defense Coastal/Estuarine Research Program Strategic Plan*, henceforth referred to as the DCERP Strategic Plan), design of an ecosystem-based monitoring program (*Defense Coastal/Estuarine Research Program Baseline Monitoring Plan*, henceforth referred to as the DCERP Baseline Monitoring Plan), identification of detailed research projects (*Defense Coastal/Estuarine Research Program Research Plan*, henceforth referred to as the DCERP Research Plan), and development of a data repository design. Phase II of DCERP represents the program's implementation period and includes the execution of the DCERP Research Plan through field research; operation of the long-term ecosystem monitoring system; and collection, management, archiving, and analysis of data from both the research and monitoring components in the DCERP data repository.

The Phase I planning period for DCERP was conducted between November 2006 and June 2007. The Phase II implementation period will start in July 2007 and will last a minimum of 4 years.

Program Organization

DCERP is a collaborative effort between SERDP, the Naval Facilities Engineering Service Center (NFESC), MCBCL, and the RTI International (RTI) DCERP Team. The overarching federal management for DCERP was assigned to NFESC. The DCERP PM is designated by NFESC and identifies the tasks and responsibilities of the RTI DCERP Principal Investigator (PI). The PI facilitates coordination with MCBCL through the DCERP On-site Coordinator (OSC). The DCERP OSC and MCBCL environmental managers will assist the DCERP PM and DCERP PI with the coordination of environmental monitoring and research activities on the Base.

Two committees will provide guidance and input to DCERP. The first, the Technical Advisory Committee (TAC), is a group of discipline experts assembled by the DCERP PM to provide scientific and technical review to ensure the quality and relevance of DCERP. The second committee, the Regional Coordinating Committee (RCC), is a group of local and regional stakeholders that serves as one of the recipients of outreach from MCBCL, the DCERP PI, and SERDP.

The RTI DCERP Team includes the PI, other environmental scientists from RTI, and researchers from the University of North Carolina Institute of Marine Sciences, North Carolina State University, the University of North Carolina at Wilmington, Duke University, the Virginia Institute of Marine Sciences, Virginia Tech, the University of South Carolina, the National Oceanic and Atmospheric Administration (Center for Coastal Fisheries and Habitat Research, Beaufort, NC), the U.S. Geological Survey (Raleigh, NC, office), URS Corporation, and Porter Scientific, Incorporated.

DCERP Overarching Strategy

The RTI DCERP Team has designed an integrative monitoring, modeling, and research strategy for MCBCL that is consistent with guidance on ecosystem-based management from the Ecological Society of America and recent recommendations from the U.S. Commission on Ocean Policy, including principles of adaptive management. This ecosystem-based management strategy will focus on the joint sustainability of military activities and fundamental ecosystem functions and services. The strategy will be designed around specific, quantifiable goals related to the status of resources (training and testing areas) that are central to the military mission of MCBCL.

MCBCL's Natural Resources Management

The mission of MCBCL is to provide military training that promotes the combat readiness of operating forces, and all natural resources management activities on the Base must support this mission. As a military installation, MCBCL has needs or drivers that must be satisfied for the installation's readiness mission to continue without significant disruption. Additionally, MCBCL must comply with related environmental laws and regulations, such as the federal Endangered Species Act (ESA) and the Clean Water Act (CWA), to ensure continuance of the military mission.

Conceptual Model Development

To facilitate the understanding of the ecosystem state and dynamics of the MCBCL region necessary to complete Phase I, the RTI DCERP Team developed an overarching conceptual model for the MCBCL region. This model includes the terrestrial lands of MCBCL, the New River Estuary (NRE), associated coastal wetlands, and the coastal barrier along Onslow Bay, as well as the overarching influence of atmospheric conditions on the region (**Figure ES-1**).

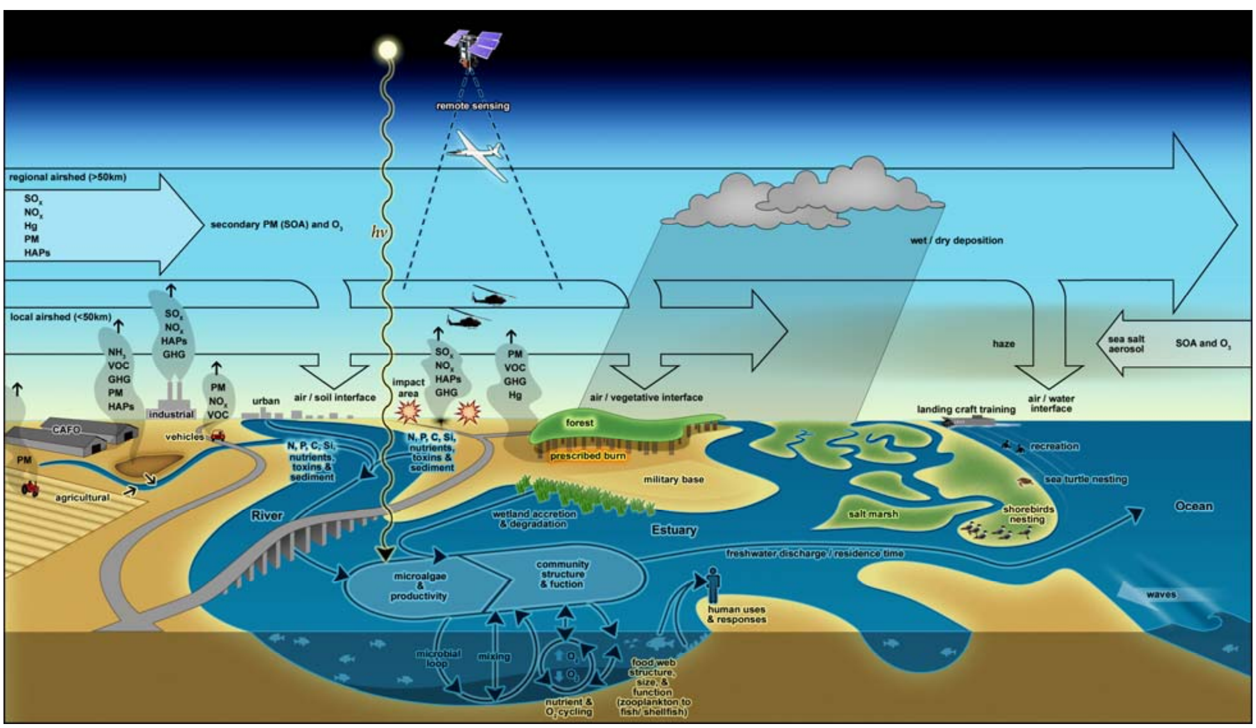


Figure ES-1. Overarching conceptual model for DCERP at MCBCL.

As an initial step in the planning effort, the overarching conceptual model was subdivided into four ecological modules: Aquatic/Estuarine Module, Coastal Wetlands Module (land-estuary margin), Coastal Barrier Module, and Terrestrial Module. These modules are linked to each other and to local and regional disturbances and pollutant sources of anthropogenic origin via atmospheric and aquatic transport mechanisms. Because the atmosphere has an overarching influence on all four ecosystem modules, it is treated as a fifth module (Atmospheric Module). A sixth module (Data Management Module) involves a diverse group of specialists whose expertise will cut across all of the other modules to coordinate data management procedures for the DCERP data and information management system, which consists of three distinct systems: the Monitoring and Research Data Information System (MARDIS) for structured data, a Document Database for unstructured data, and the DCERP Web sites (consisting of a public Web site and a private collaborative Web site). The work conducted for the Data Management Module will include coordination of geospatial data, statistical analysis, and model integration. The RTI DCERP Team will involves the participation of six module teams, one for each module, conducting monitoring and research activities under the direction of a Module Team Leader and Co-leader.

In addition to the overarching conceptual model depicted above, each of the ecosystem teams has developed a detailed conceptual model for their module. These individual conceptual models were developed to identify the key biological, chemical, and physical processes of the ecosystem, as well as the military, non-military, legacy, and natural ecosystem stressors that may affect the ecosystem.

Integrated Ecosystem-Based Management Approach

After developing the individual conceptual models early in Phase I of the program, the DCERP module teams identified knowledge gaps in the conceptual models and determined MCBCL management needs. The module teams then determined potential research questions to fill these knowledge gaps and to address MCBCL management needs. The DCERP Baseline Monitoring Plan is designed to gather environmental data to address management concerns and support the research projects identified in this Research Plan. During Phase II of the program, results from research projects will feed back into the adaptive DCERP Baseline Monitoring Plan so that changes in the frequency of sampling, spatial extent of sampling locations, or parameters to be sampled can be made as necessary. Results from the monitoring and research efforts will be used to identify ecosystem indicators and to develop associated threshold values, tools, or design models that address MCBCL management needs. Once this information is transitioned to MCBCL, the Base's natural resources managers will be able to make decisions as to what types of management actions should be taken and to implement appropriate actions. After implementing these actions, the RTI DCERP Team will continue monitoring (feedback loop) to ensure that the desired management outcomes are achieved. This process is shown in **Figure ES-2**.

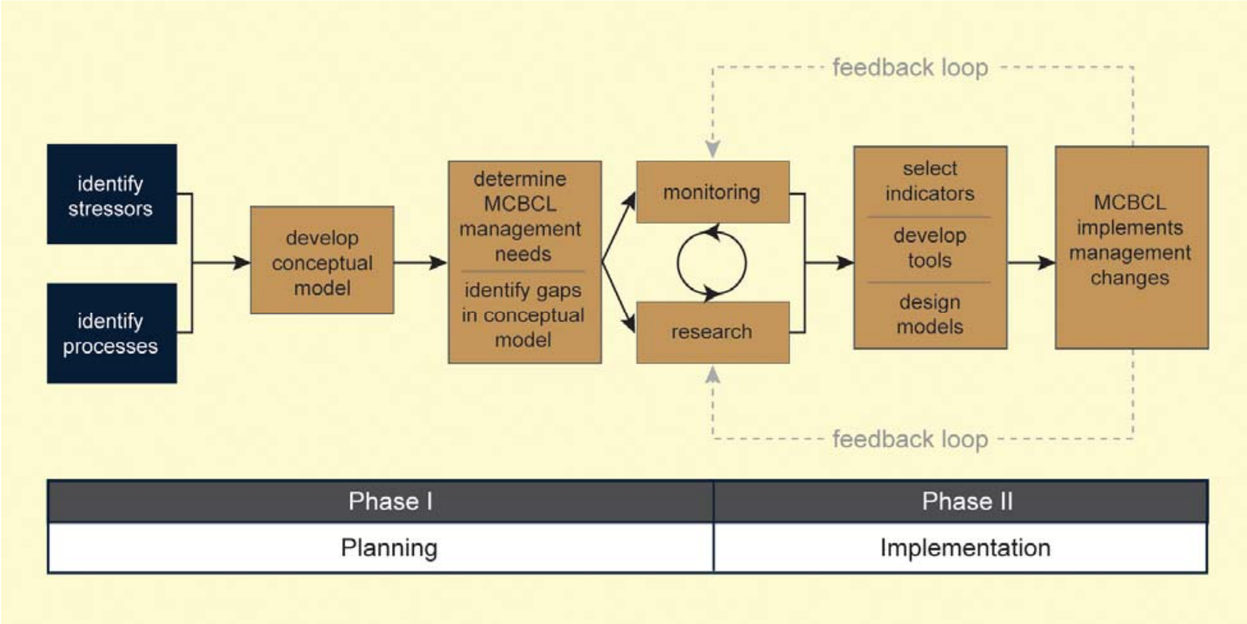


Figure ES-2. DCERP planning and implementation process flow chart.

Purpose of the Research Plan

The main purpose of this DCERP Research Plan is to describe the research program that will be conducted to gain a better understanding of ecosystem processes and reactions to stressors, which is critical for ecosystem-based management. The 13 research projects described in this DCERP Research Plan will focus on what is unknown about each ecosystem module, as outlined in the module's conceptual model, and will include innovative techniques for addressing these knowledge gaps. As indicated in the DCERP Strategic Plan, there are many knowledge gaps in the individual conceptual models. The RTI DCERP Team will use state-of-the-art techniques to test ecosystem response to stressors (e.g., military, non-military, legacy, and natural), to examine potential indicators, and to research and evaluate various management practices. A research program that is driven solely by current MCBCL management needs risks overlooking new insights or future management needs; therefore, it is important that data from DCERP research provide the basic scientific information needed to develop management plans to modulate the impacts of military activities and to sustain the natural resources and use of MCBCL for military training now and in the future.

Objectives of the Research Plan

The main objective of this DCERP Research Plan is to build upon the scientific framework established in the DCERP Strategic Plan by describing the details of our planned research. In addition, this plan is intended to serve as a mechanism for providing clear communication and coordination among DCERP Team scientists, SERDP staff, MCBCL natural resources managers, and local stakeholders (e.g., New River Roundtable, Onslow Bight Conservation Forum, City of Jacksonville, Onslow County Commissioners). Each research project in this document will do the following:

1. Provide clear technical goals and specific objectives to address key knowledge gaps, research needs, and management objectives identified in conceptual models.
2. Incorporate scientifically sound, high-quality research principles that utilize state-of-the-art technologies that are transferable to MCBCL.

3. Translate research results into models, indicators, and tools to predict outcomes of potential management scenarios and allow for adaptive management strategies.

Selection of Research Projects

Initially, the DCERP module teams identified more than 25 research projects to provide information to fill knowledge gaps in the individual conceptual models and to address MCBCL's management needs. This initial project list was prioritized within each module based on each project's ability to address key knowledge gaps in the conceptual model, address key MCBCL management needs, and provide information that was needed by more than one ecosystem module. Other factors were also considered, such as the cost, timing (e.g., seasonal, storm-based, year long), and duration of a research project. This prioritization process was conducted jointly between DCERP researchers, SERDP, NFESC, and MCBCL natural resources managers. Final selection and phasing of the research projects was determined by the RTI PI and was constrained by resource limitations that will be available during each of the 4 years in the Phase II implementation period. **Table ES-1** lists each research project and the project's Senior Researcher and provides a summary of the project's outcomes and benefits to MCBCL; these projects are discussed in detail in Section 5 of this report. This includes specific design information for each of the research projects, hypothesis to be tested, technical goals, technical approach, methods, data analysis, research outcomes, linkages to other modules, military drivers addressed, benefit to MCBCL, schedule and scheduling constraints, budgetary information, and Go/No Go decision points. **Appendix C** summarizes the identified projects that were not included as high priorities for the initial 4-year implementation period, but that may be funded in later years of DCERP.

Table ES-1. DCERP Research Projects and Outcomes

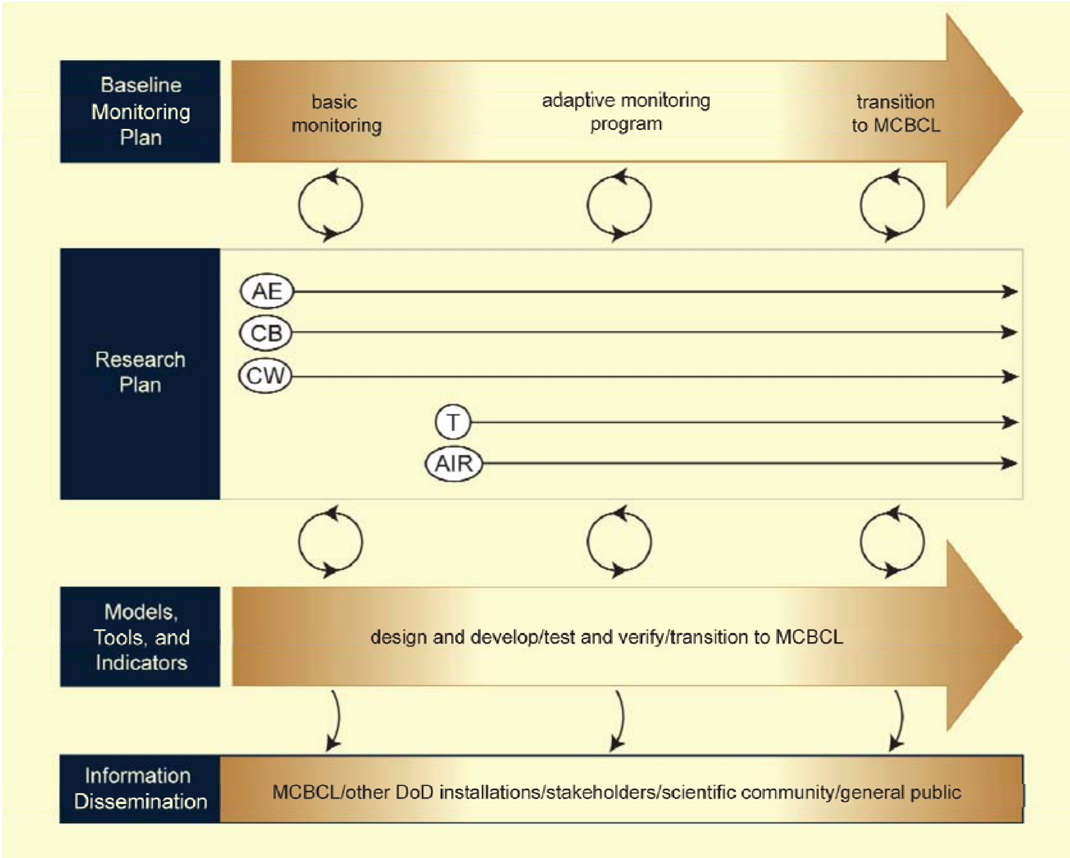
Research Project Title and Outcomes	Senior Researcher/ Duration
AE-1: Develop and Deploy Microalgal Indicators as Measures of Water Quality, Harmful Algal Bloom Dynamics, and Ecosystem Condition **Outcomes and benefit to the Base:** This research project will establish baseline indicators against which to gauge short- and long-term effects of management strategies aimed at protecting water quality and preserving the ecological integrity of the NRE and adjacent wetlands and coastal waters. This project will also produce a decision-support, Bayesian modeling tool for guiding adaptive monitoring and management and provide data needed to link watershed nutrient inputs to estuarine circulation and water quality simulation models.	Hans Paerl/ 7/2007–6/2011
AE-2: Quantifying and Predicting Watershed Inputs of Nutrients, Sediments, and Pathogens **Outcomes and benefit to the Base:** This research project will provide the Base with information on the sources of identified pollutants to help avoid actions under the CWA related to impairment from fecal indicator bacteria (FIB), sediments, or chlorophyll *a* exceedances by identifying emerging problems and using data to inform remedial strategies. This project will also produce a decision-support modeling tool (watershed simulation model [WSM]) for predicting watershed exports as a function of environmental forcing and land-use changes.	Mike Piehler/ 7/2007–6/2011
AE-3: Developing Indicators of Ecosystem Function for Shallow Estuaries: Benthic Functional Responses in the NRE **Outcomes and benefit to the Base:** This research project will provide a cause-and-effect analysis or potential management actions that might be necessary to mitigate long- and short-term impacts of the Base on benthic processes responsible for modulating nutrient enrichment and supporting higher trophic levels in the NRE. This project will also produce a decision-support modeling tool (Estuarine Simulation Model [ESM]) for predicting estuarine responses to natural and anthropogenic disturbance.	Iris Anderson/ 7/2007–6/2011

Research Project Title and Outcomes	Senior Researcher/ Duration
CW-1: Determine Responses of Marsh Vegetation and Surface Elevation to Nutrients **Outcomes and benefit to the Base:** Data derived from this research project will be used to parameterize a model (marsh elevation model 2 [MEM2]) of sediment accretion; forecast the marsh response to environmental changes (e.g., sea-level rise) or management options (e.g., amphibious vehicle maneuvers); quantify the marsh response to fertilization by nitrogen and phosphorus (a potential mitigation strategy); and analyze the current location and condition of marshes to inform the Base where to conduct training activities so as to minimize environmental impacts.	Jim Morris/ 7/2007–6/2011
CW-2: Forecast Influence of Natural and Anthropogenic Factors on Estuarine Shoreline Erosion Rates **Outcomes and benefit to the Base:** This research project will provide information to support shoreline stabilization and wetland restoration efforts (New River Estuary Shoreline Erosion Model [NRESE]); provide input to invasive species management concerns; and assess impacts of the use of tactical vehicles along estuarine shoreline.	Mark Fonseca/ 9/2007–6/2011
CW-3: Hydraulic Exchange and Nutrient Reactivity in the NRE Wetlands **Outcomes and benefit to the Base:** Data derived from this research project will provide information on the value of the marshes as nutrient transformers and the magnitude of subsurface nutrient flux into the NRE, which will inform Base managers about surface and shallow-ground water quality issues.	Craig Tobias/ 7/2008–6/2011
CB-1: Short-term Barrier Evolution Related to Storms and Land Use **Outcomes and benefit to the Base:** This research project will develop a Short-term, Event Beach Response (STEBR) model to provide (1) an understanding of and modeling capability for beach erosion and overwash during storm events, (2) an understanding of the key forces driving beach erosion during storm events and over the short term, and (3) an ability to discern the influence of Base activities versus natural processes affecting beach changes by identifying the underlying causes of beach erosion and forecasting beach erosion under different management scenarios. This project is closely linked to Research Project CB-2.	Jesse McNinch/ 7/2009–6/2011
CB-2: Long-term Barrier Evolution Related to Variations in Underlying Geology, Land Use, and Inlet Dynamics **Outcomes and benefit to the Base:** This research project will develop a Long-term Shoreline Change (LTSC) model to determine (1) the principle drivers of coastal erosion, (2) erosion-rate trends (acceleration or deceleration in coastal retreat rates), (3) erosional “hot spots,” and (4) erosion-mitigation options. Integrated maps of the barrier and adjacent inner shelf that show volume changes through time will help identify sediment transport pathways. These products will also provide a means for calibrating and testing the models produced in Research Project CB-1.	Tony Rodriguez/ 7/2009–6/2011
CB-3: Understanding the Top-down and Bottom-up Drivers of Shorebird Nest Success and Habitat Use in Relation to Beach Management Practices on MCBCL **Outcomes and benefit to the Base:** The results of this project will be used to develop efficient monitoring protocols and conservation management procedures for shorebirds and seabirds and to best design mitigation in the case of beach nourishment or the introduction of new uses to the coastal barrier system. Pilot studies of predator top-down influences will allow MCBCL to design the most efficient use of trapping resources and to minimize the frequency of trapping and the co-occurrence of trapping efforts with human uses of the barrier island.	Sarah Karpanty and Jim Fraser/ 7/2007–6/2009

Research Project Title and Outcomes	Senior Researcher/ Duration
T-1: Varying Prescribed Fire Regimes and Forest Management Effects on Terrestrial Ecosystem Structure and Function **Outcomes and benefit to the Base**: Results from this research project will quantify the effects of military and forestry activities, especially prescribed burning (PB), on plant and animal communities and provide management guidance to the Base on how best to mitigate the adverse effects of such activities.	Norm Christensen/ 1/2008–6/2011
T-2: Effects of Habitat Management for Red-cockaded Woodpeckers (RCW) on Bird Communities **Outcomes and benefit to the Base:** The outcome of this research project will be an efficient method to measure the quality of the RCW habitat over a large spatial extent and to analyze the effects of the current management on not only the endangered RCW but also on other avian species at risk, such as the Bachman's sparrow.	Jeff Walters/ 1/2008–6/2011
Air-1: Optimization of Prescribed Burning (PB) by Minimizing Smoke Emissions and Maximizing Vitality of Fire-adapted Ecosystems **Outcomes and benefit to the Base:** This project is closely linked to Research Project T-1 and will monitor PB emissions from experimental plots with different soil moisture content and fuel loads, and burned at different frequencies. The product resulting from this research project will be an innovative land-management tool with transferable applicability for implementation in the Smoke Management Plan of the NRE region and other populated regions in the southeastern United States.	Karsten Baumann/ 7/2008–6/2011
Air-2: Nitrogen Deposition to Terrestrial and Aquatic Ecosystems **Outcomes and benefit to the Base:** This research project will provide information on the amount and composition of atmospheric deposition (especially for nitrogen) to the terrestrial and aquatic ecosystems, which will be used to model the atmospheric nitrogen contribution to the total nitrogen budget for the NRE. This project will also provide information on the amount and distribution of rainfall across MCBCL.	Wayne Robarge/ 7/2007–6/2011

Integration of Monitoring and Research

Research projects will incorporate appropriate data from the DCERP baseline monitoring program, MCBCL environmental monitoring activities, and other local, state, federal, and private monitoring activities to provide an integrated approach to ecosystem-based management and to alleviate redundancy of data collection. Schedules and site locations for research activities will be coordinated with the baseline monitoring program to ensure that linkages between the baseline monitoring sites and research projects are maintained. Results from research projects will feed back into the adaptive DCERP Baseline Monitoring Plan so that changes in the frequency of sampling, spatial scale of sampling locations, or parameters being sampled can be made as necessary (**Figure ES-2**). The models, tools, and indicators that are designed, developed, tested, and verified as part of the research projects can be transitioned to MCBCL to assist in monitoring and forecasting ecosystem changes. In addition, it is a goal of DCERP to disseminate research results and information from associated models, tools, and indicators to MCBCL, as well as to other user groups, including other DoD installations in similar ecological settings, the scientific community, other stakeholders (e.g. New River Roundtable or Onslow Bight Conservation Forum), and the general public.



Note: AE = Aquatic/Estuarine Module; CB = Coastal Barrier Module; CW = Coastal Wetlands Module; T = Terrestrial Module; AIR = Atmospheric Module

Figure ES-2. Generic roadmap of the integrated monitoring and research plans and the development of model tools and indicators.

Table ES-2 illustrates the overall linkages among the module-specific baseline monitoring activities and the individual research projects. For example, as can be seen from the bullets on the table, monitoring activities for the Aquatic/Estuarine Module will provide important monitoring data for Aquatic/Estuarine Module research projects, as well as for the research efforts of the Coastal Wetlands Module. Because the Atmospheric Module will be conducting the general meteorological monitoring effort, and this data is important to all of the research efforts, it is identified as being linked to all of the research projects.

Table ES-2. Linkages among the Module-Specific Monitoring Activities and the Research Projects

Linkages	Research Projects												
	AE-1	**AE-2**	**AE-3**	**CW-1**	**CW-2**	**CW-3**	**CB-1**	**CB-2**	**CB-3**	**T-1**	**T-2**	**Air-1**	**Air-2**
Aquatic/Estuarine Monitoring	■	■	■		■	■	■	■	■	■	■		
AE-1	■	■	■	■		■							■
AE-2		■	■			■							
AE-3	■		■		■								
Coastal Wetlands Monitoring	■	■	■	■	■	■				■			
CW-1				■	■	■							
CW-2			■	■	■								
CW-3		■		■	■								
Coastal Barrier Monitoring	■	■	■	■	■	■	■	■	■			■	■
CB-1	■						■	■	■				
CB-2							■	■	■				
CB-3									■				
Terrestrial Monitoring	■	■	■	■	■	■	■	■	■	■	■	■	■
T-1										■	■	■	
T-2											■		
Atmospheric Monitoring	■	■	■	■	■	■	■	■	■	■	■	■	■
Air-1										■		■	
Air-2	■	■	■	■					■	■		■	■

■ Module activities in first column provide data for research projects in other columns

Data Management Module

The backbone of the DCERP research, modeling, and management tools will be environmental data collected throughout the duration of the program. The types and volumes of baseline data that currently exist (historical data) and that will be collected during the DCERP monitoring and research program are extensive. It is essential that a comprehensive data management plan be developed and implemented to ensure that these data are accessible to researchers across modules. General categories of data to be collected and managed include the following: structured data (e.g., monitoring and research data), unstructured data (e.g., Web sites, reports, maps, and publications), and spatial data (e.g., vector and raster).

Military Impact Assessment

Determining appropriate management decisions about military activities requires an understanding of all stressors affecting the environment, an assessment of the site-specific impacts of those stressors, and an evaluation of their contribution to site degradation. Although it is understood that many factors can contribute to site-specific military impacts (e.g., intensity and frequency of training, physical characteristics of the site, meteorological conditions, legacy impacts), a consistent, quantitative evaluation methodology appropriate for MCBCL is not currently available. During Year 1 of Phase II, the RTI

DCERP Team will implement a combined research and monitoring effort that will develop a consistent approach for assessing the impact of military training for each of the ecosystems at MCBCL. Assessments will occur at two scales: landscape and plot level.

Transition Plan for Research Results

In order to effectively transition information gained from DCERP research projects to MCBCL natural resources management staff, other DoD facilities, and the scientific community at large, each research project report will contain a plan for transitioning data and tools to other users. To disseminate this information, the RTI DCERP Team will use a variety of venues, including the following: DCERP Web site, peer-review publications, conference and symposium presentations, summary reports for SERDP, and periodic meetings with MCBCL natural resources management staff.

Measures of Success/Outcomes

The successful implementation of DCERP will foster a greater understanding of the biologically diverse coastal barrier, coastal wetland, aquatic/estuarine, and terrestrial ecosystems of MCBCL; the Base's air quality; and the interactions of these systems with military training activities. This understanding will aid in the long-term management and sustainability of MCBCL's ecosystems, which will enhance and maintain MCBCL's military mission. Information and data resulting from the DCERP research effort will increase the ability of natural resources managers to perform assessments and implement appropriate management responses to potential environmental impacts arising from military activities or natural disturbance events.

Measurements of DCERP's success will come from assessing whether the outcomes were achieved in a timely manner. The outcomes that have been defined for DCERP can be grouped into two main categories:

- Programmatic—Includes administrative requirements, such as delivering required documents on schedule and on budget, ensuring that the project Web site is developed and functioning, meeting SERDP quarterly and annual reporting requirements, and providing timely and effective feedback to MCBCL and outreach to stakeholders.
- Project specific—In some cases, these outcomes provide information to address environmental issues that are currently impacting Base operations. Other research efforts were designed to provide outcomes relevant to issues that are currently known and that are anticipated to impact Base operations in the next 3–5 years. In addition, the majority of DCERP research activities will provide information necessary to gain a complete understanding of ecosystem functions, which will better prepare the Base to address future environmental issues.

Specific programmatic and overarching strategic outcomes are included in the Strategic Plan. Project-specific outcomes associated with the individual research projects are listed in Table ES-1.

1.0 Introduction

The U.S. Department of Defense (DoD) intends to enhance and sustain its training and testing assets and to optimize its stewardship of natural resources through the development and application of an ecosystem-based management approach on DoD facilities. DoD policy has established ecosystem-based management as the preferred approach for military lands (Goodman, 1996). This management approach will focus on sustaining and enhancing military operations by monitoring and managing the interdependent natural resource assets on which the future of those operations depend. To expand its commitment to improving military readiness while demonstrating the science behind this approach, the Strategic Environmental Research and Development Program (SERDP) has made a long-term commitment of at least 10 years to fund research and monitoring projects that support the sustainability of military training and testing in ecologically and economically important ecosystems.

To accomplish the above goal, SERDP has launched the Defense Coastal/Estuarine Research Program (DCERP) at Marine Corps Base Camp Lejeune (MCBCL) in North Carolina. (Note: DCERP is the second such program to use an ecosystem-based management approach; the first being the Strategic Ecosystem Management Project, which has been ongoing at Fort Benning, GA, since December 1997.) MCBCL provides an ideal platform for DCERP because it integrates coastal barrier, estuarine, coastal wetland, and terrestrial ecosystems, all within the boundaries of DoD properties.

MCBCL was chosen as the DCERP site for a variety of reasons, including the following:

- The New River Estuary (NRE) watershed, which borders the site, is relatively small and, therefore, manageable
- MCBCL occupies a substantial portion (~80%) of the NRE shoreline
- A barrier island/coastal dune system occurs within MCBCL's boundary that provides a unique amphibious assault training environment
- The variety of ongoing military operations at MCBCL enables researchers to examine training impacts on a broad range of ecosystems, from upland pine savannas to aquatic/estuarine waters to coastal barriers.

Figure 1-1 provides a map of MCBCL in Onslow County, NC, and the surrounding watershed area.

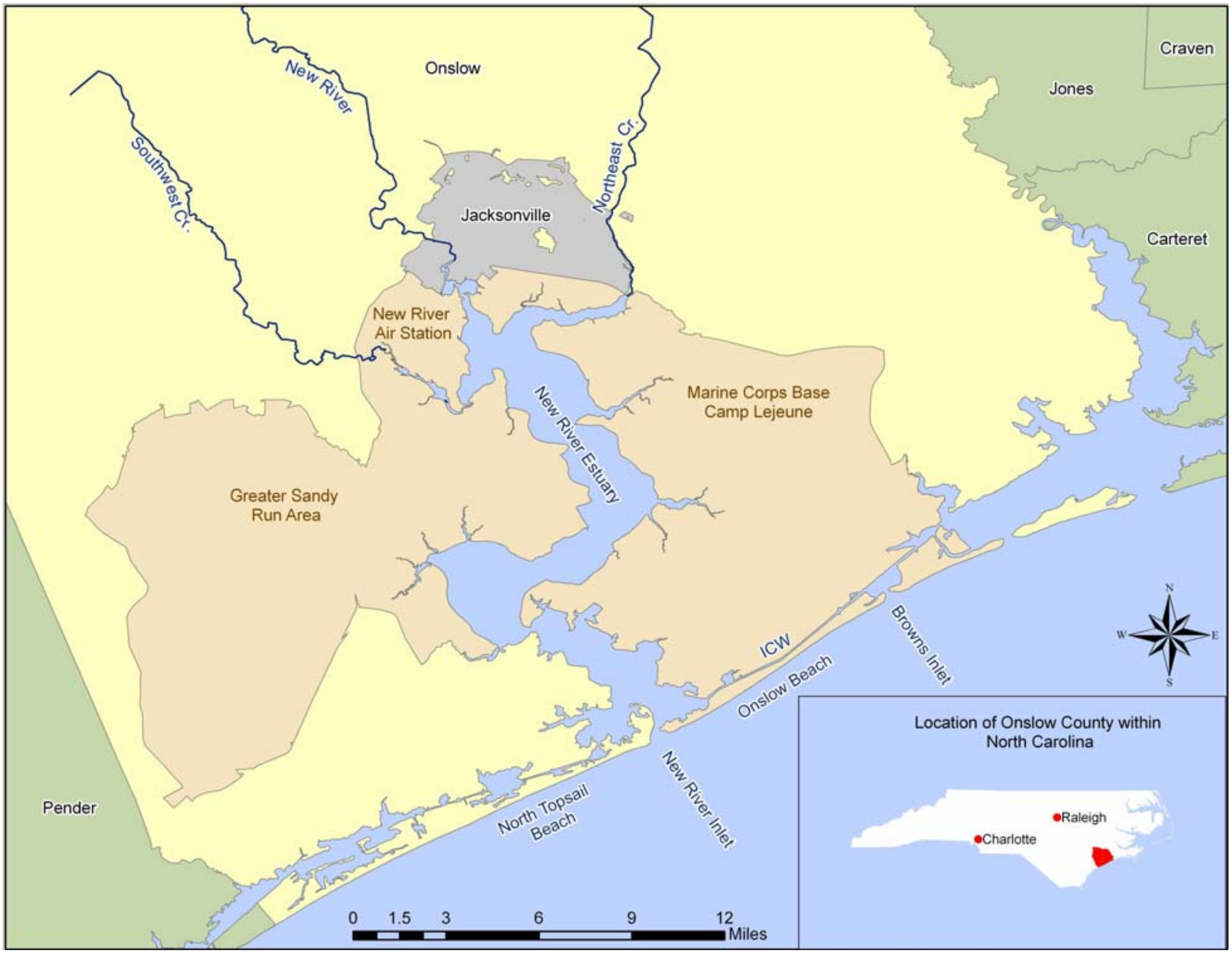


Figure 1-1. Site map of MCBCL.

As stated in the initial DCERP Strategy, *"The overall intent of the DCERP is to develop the knowledge required to assess the interaction between military activities and ecological resources in a coastal/estuarine setting, monitor those interactions, and identify adaptive, ecosystem management approaches for sustainment of military lands and adjacent waters"* (SERDP, 2005). DCERP is designed to conduct relevant research and monitoring, develop and apply indicators, and provide MCBCL resource managers with assessment tools and criteria in support of ecosystem management.

RTI International (RTI), headquartered in Research Triangle Park, NC, is leading the DCERP research and monitoring effort. RTI has assembled a diverse team of experts in relevant disciplines of environmental science with many years of experience working together on interdisciplinary coastal, estuarine, and terrestrial ecosystem projects. The RTI DCERP Team will address the initial DCERP Strategy by developing monitoring approaches and identifying key ecological processes through research and modeling studies, all with the goal of supporting the practice of ecosystem management at other coastal DoD installations in similar ecological settings.

DCERP is designed to be implemented in two phases. Phase I of the program represents the planning period and includes the development of an overarching research strategy (*Defense Coastal/Estuarine Research Program Strategic Plan,* henceforth referred to as theDCERP Strategic Plan), design of an ecosystem-based monitoring program (*Defense Coastal/Estuarine Research Program Baseline Monitoring Plan,* henceforth referred to as the DCERP Baseline Monitoring Plan), identification of detailed research projects (*Defense Coastal/Estuarine Research Program Research Plan*, henceforth referred to as the DCERP Research Plan), and development of a data repository design. The DCERP Strategic Plan (RTI, 2007) provides the key foundation for development of the DCERP Baseline Monitoring Plan and Research Plan. As discussed in the DCERP Strategic Plan, the Baseline Monitoring Plan and Research Plan are based on detailed information presented in conceptual models of DCERP's five ecosystem modules (Aquatic/Estuarine, Coastal Wetlands, Coastal Barrier, Terrestrial, and Atmospheric).

Phase II of DCERP represents the program's implementation period and includes the execution of this DCERP Research Plan through field research; operation of the long-term ecosystem monitoring system; and collection, management, archiving, and analysis of data from both the research and monitoring components into the DCERP Monitoring and Research Data Information System (MARDIS).

The Phase I planning period for DCERP was conducted between November 2006 and June 2007. The Phase II implementation period will start in July 2007 and will last for a minimum of 4 years.

2.0 Program Organization

DCERP is a collaborative effort between SERDP, the Naval Facilities Engineering Service Center (NFESC), MCBCL, and the RTI DCERP Team selected to execute the objectives of SERDP's Ecosystem Management Project. **Figure 2-1** illustrates the overall organization and lines of communication of DCERP.

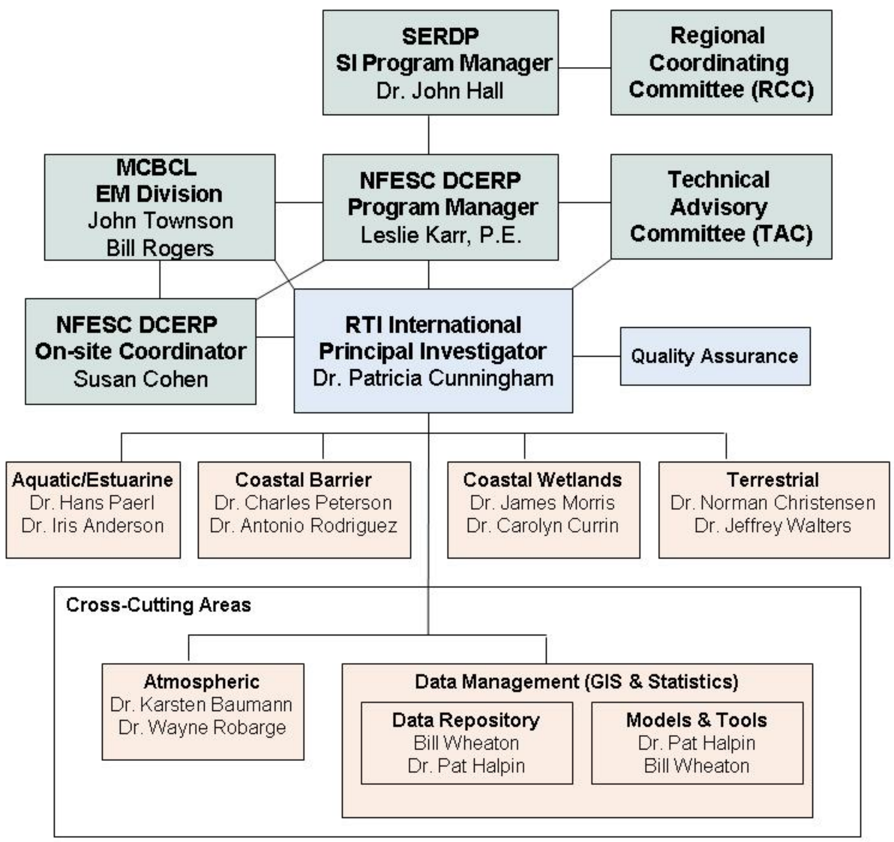


Figure 2-1. Organization of DCERP.

SERDP is an environmental research and development program, planned and executed by the DoD in full partnership with the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA). The SERDP Sustainable Infrastructure (SI) Program Manager (PM), Dr. John Hall, ensures that DCERP activities provide for the enhanced knowledge of ecosystem and military interactions within approved scopes of work and budgets. The overarching federal management for DCERP was assigned to NFESC. The DCERP PM, Ms. Leslie Karr, is designated by NFESC and identifies the tasks and responsibilities of the RTI DCERP Principal Investigator (PI), Dr. Patricia Cunningham. As PI, Dr. Cunningham facilitates coordination of the RTI DCERP Team with MCBCL through the DCERP On-site Coordinator (OSC), Ms. Susan Cohen. At MCBCL, the DCERP OSC, the Director of the Environmental Management Division, Mr. John Townson, and the Head of the Environmental Conservation Branch, Mr. Bill Rogers, assist the DCERP PM and DCERP PI with the coordination of environmental monitoring and research activities on the Base. The DCERP OSC is the primary point of contact between MCBCL and the RTI DCERP Team.

Two committees will provide guidance and input to the RTI DCERP Team. The first, the Technical Advisory Committee (TAC), is a group of discipline experts assembled by the DCERP PM to provide scientific and technical review to ensure the quality and relevance of DCERP. The TAC directs all questions and comments to the DCERP PM. The second committee, the Regional Coordinating Committee (RCC), is a group of local and regional stakeholders that serves as one of the recipients of outreach from MCBCL, the DCERP PI, and the SERDP PM.

The DCERP PI is responsible for the overall scientific quality, cohesiveness, and relevance of the DCERP Baseline Monitoring and Research plans. In addition, the DCERP PI is the primary point of contact for SERDP and MCBCL and coordinates all DCERP activities conducted at MCBCL through the DCERP OSC, Ms. Cohen. The RTI DCERP Team has been organized into six module teams based on the ecosystem-based management objective of the program. Each module team falls under the direction of a Module Team Leader and Co-leader. These module teams conduct research and monitoring activities for DCERP’s five ecosystem modules (Aquatic/Estuarine Module, Coastal Barrier Module, Coastal Wetlands Module, Terrestrial Module, and Atmospheric Module) and the Data Management Module. These six modules are addressed in the DCERP Strategic Plan (RTI, 2007) and will be discussed in more detail in Section 5 of this document, *Module Research Projects*.

3.0 DCERP Overarching Strategy

The RTI DCERP Team has designed an integrative monitoring, modeling, and research strategy for MCBCL that is consistent with guidance on ecosystem-based management from the Ecological Society of America (Christensen et al., 1996) and recent recommendations of the United States Commission on Ocean Policy (2004), including principles of adaptive management (Walters, 2001*)*. This strategy transcends air-land-water boundaries to better understand the causes and nature of ecological and environmental change across the region, as well as locally at MCBCL. Based on interconnectivity, this strategy helps separate the underlying natural (e.g., climatic or biogenic) and anthropogenic-regional processes from locally driven process; identifies stressor-specific indicators of ecosystem status that provide early warning of ecosystem degradation; and specifies critical thresholds for indicators of potential state shifts that could threaten sustainability. A threshold is a point at which further degradation in ecosystem condition will result in the system’s inability to return to its initial state without significant intervention (SERDP, 2005) The biological, chemical, geological, and physical processes that are associated with each ecosystem are summarized in scientifically rigorous conceptual models; these models incorporate an understanding of the dynamic processes that interconnect ecosystem components in often complex ways. **Figure 3-1** presents the overarching conceptual model for the MCBCL region, which includes the terrestrial lands of MCBCL, the NRE, associated coastal wetlands, and the coastal barriers along Onslow Bay, as well as the overarching influence of atmospheric conditions.

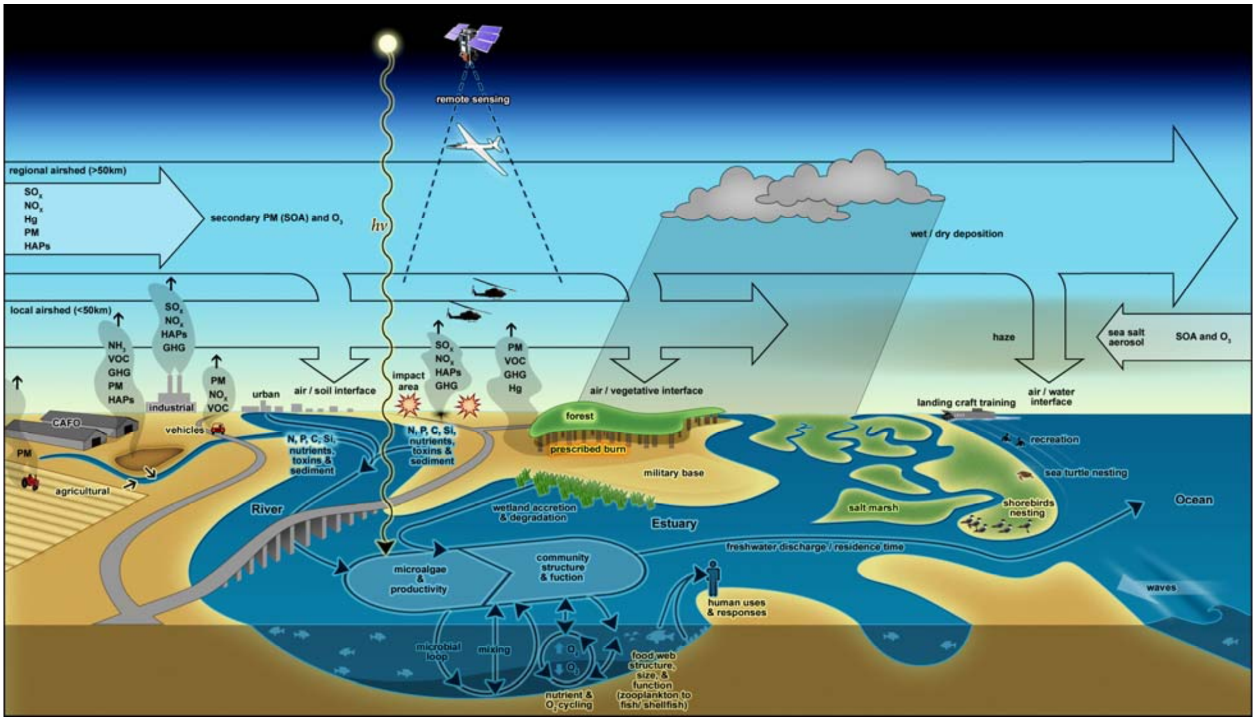


Figure 3-1. Overarching conceptual model for DCERP at MCBCL.

To facilitate an understanding of the ecosystem state and dynamics of the MCBCL region, the RTI DCERP Team subdivided the ecosystem into four ecological modules for monitoring, modeling, and research: the Aquatic/Estuarine Module, Coastal Wetlands Module (land-estuary margin), Coastal Barrier Module, and Terrestrial Module. These modules are linked to each other and to local and regional disturbances and pollutant sources of anthropogenic origin via atmospheric and aquatic transport mechanisms. Because the atmosphere has an overarching influence on all four ecosystem modules, it is treated as a fifth ecosystem module (Atmospheric Module). Individual conceptual models for each of the ecological modules are presented in Section 5 (*Module Research Projects*).

The ecosystem-based management strategy will focus on the joint sustainability of military activities and fundamental ecosystem functions and services. The strategy will be designed around specific, quantifiable goals related to the status of resources (training and testing areas) that are central to the military mission of MCBCL. Assessments of how to manage military activities in ways that sustain the value of natural ecosystem assets will be regularly delivered to MCBCL natural resources managers. In addition, these assessments will be integrated into the ecological conceptual models, biogeochemical syntheses, and environmental and geographic information systems (GIS) databases that will be perpetuated as a legacy of MCBCL's commitment to environmental sustainability.

A sixth module, the Data Management Module, involves a diverse group of specialists whose expertise will cut across all of the other modules to coordinate data management procedures for the DCERP data repository, including coordination of geospatial data, statistical analysis, and model integration. The Data Management Module involves both a data and information management systems component, which includes the data repository (MARDIS) and a models and tools component. SERDP conceived MARDIS as being developed to facilitate the collection and storage of environmental data collected by the RTI DCERP Team, as well as to be the permanent repository for research and monitoring data collected during the DCERP implementation. The models and tools component provides the ultimate cross-cutting function of integrating the simple models, developed in the individual research projects, into integrated management models.

During the first few years of the program, the RTI DCERP Team will develop models and management tools that reflect advances in GIS and spatial and time-series modeling and biological, chemical, and physical processes. This development will be supported by resources allocated to the individual modules. In later years, however, development of calibrated, tested, and operational management models will be proposed for funding as part of the Data Management Module. Management models need to be usable by natural resource and watershed managers and fully tested so they are of known reliability; therefore, these models will be archived in the data repository for development and final calibration and testing before they are made available to MCBCL.

3.1 MCBCL's Natural Resources Management

The mission of MCBCL is to provide military training that promotes the combat readiness of operating forces, and all natural resources management activities on the Base must support this mission. An introduction to the military operations of MCBCL is provided in **Appendix A**. As a military installation, MCBCL has needs or drivers that must be satisfied for the installation's readiness mission to continue without significant disruption. Additionally, MCBCL must comply with related environmental laws and regulations, such as the federal Endangered Species Act (ESA) and Clean Water Act (CWA), to ensure continuance of the military mission. To ensure such compliance, MCBCL has adopted an *Integrated Natural Resources Management Plan* (INRMP) (MCBCL, 2006a), which outlines the Base's conservation efforts and establishes procedures for fiscal years 2007 through 2011. One goal of the INRMP is to minimize future training restrictions (no net loss in the ability to train) by increasing integration between natural resources management planning, training, and operations. It is the goal of DCERP to assist MCBCL in achieving this goal.

Unique to MCBCL are installation-specific drivers that are defined by the Base's mission and geographic location, land uses to support the mission, and natural resources affected by the mission. Identification of the primary military drivers at the Base provided the basis for establishing six natural resource management objectives for MCBCL's INRMP (MCBCL, 2006a). These objectives are the following:

1. Preserve the integrity of the amphibious maneuver areas, including Onslow Bay, the NRE, and the adjoining training areas and airspace of MCBCL.
2. Preserve the integrity of MCBCL as a combined-arms training base by ensuring the continued viability of its impact areas and associated training ranges.
3. Enhance future training uses of MCBCL ranges, training areas, and airspace by fully integrating the *Land Use Master Plan* (MCBCL, 2005) and *Range Transformation Plan* (MCBCL, 2006b).
4. Ensure that MCBCL supports all required military training activities while complying with the ESA and other wildlife requirements.
5. Ensure that MCBCL supports continued military training use of the New River, the NRE, and Onslow Bay by complying with the CWA.
6. Ensure the viability of the New River Air Station as an aviation facility through the elimination of bird and wildlife strike hazards to aircraft while complying with the ESA and other wildlife regulatory requirements.

In addition to these military drivers, MCBCL natural resources managers have identified a prioritized list of conservation and water quality needs that will support implementation of the INRMP. **Appendix B** illustrates the Base's needs and identifies the DCERP approach for addressing these needs. As part of

DCERP, every effort will be made to address areas of concern (AOCs) that are not currently being investigated or to improve upon existing programs that are attempting to address these AOCs.

3.2 Conceptual Model Development

A conceptual model has been developed for each of the five ecosystem modules. As described in the DCERP Strategic Plan, these conceptual models were developed to include the key biological, chemical, and physical processes of the ecosystem, as well as the military, non-military, legacy, and natural ecosystem stressors that may affect the model (**Figure 3-2**).

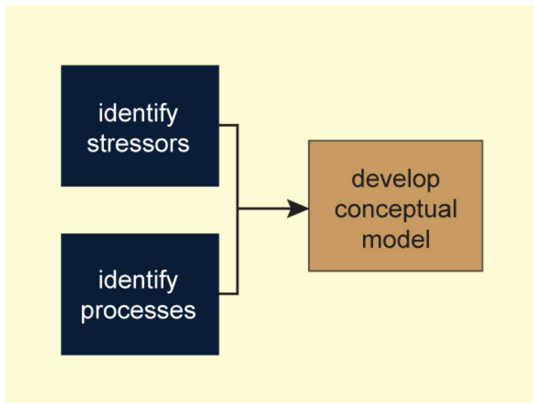


Figure 3-2. Development of the conceptual model.

The focus of the DCERP monitoring and research effort includes biological processes (e.g., primary production and respiration), chemical processes (e.g., water column and sediment nutrient processing/cycling and atmospheric transformations), and physical processes (e.g., hydrodynamics of the NRE and sediment transport along Onslow Beach), which are described in the individual module narratives**.** These key biological, chemical, and physical processes are the driving forces of the function of the ecosystem in the absence of stressors. Although the main processes are generally understood, the biological, chemical, and physical ecosystem processes at MCBCL have not been researched extensively, especially within the context of outside stressors. For DCERP, stressors are defined as activities or events that alter natural ecological processes. The RTI DCERP Team has grouped stressors into four major categories: military, non-military, legacy, and natural. **Table 3-1** provides a definition for each category, as well as specific examples relevant to DCERP. The conceptual models developed for each module were designed to integrate the ecological processes and stressors with the Base's military drivers and conservation and water quality needs, as determined by MCBCL for the management of natural resources. The key military drivers and natural resources management needs are listed in Section 3.1 of this report. For more information on these drivers, please refer to MCBCL's INRMP (MCBCL, 2006a).

Table 3-1. Examples of Military, Non-Military, Legacy, and Natural Ecosystem Stressors

Stressor	Examples
Military	Military stressors are unique activities or events associated with military training and testing at MCBCL, including the use of military tracked vehicles and amphibious watercraft or boats, troop movements on the Base, and the use of firing ranges and impact areas. For example, direct effects of military activities on the NRE include the resuspension of bottom sediments in shallow water areas or physical damage to benthic communities when training boats are launched. In addition, indirect effects of military activities may include erosional runoff from training areas where vehicles and troops have compacted or otherwise disturbed the soil surfaces and bank erosion due to the movement of amphibious watercraft near splash points.

Stressor	Examples
Non-military	Non-military stressors include any anthropogenic activities that can occur on Base or off Base, including runoff of nutrients from confined animal feeding operations (CAFOs), agricultural practices, or urban lands; discharges from industrial facilities and municipal wastewater treatment plants (WWTPs); runoff of land-applied sewage sludge; atmospheric deposition of nutrients and contaminants; groundwater withdrawals; local residential or commercial development; emissions from non-military vehicles; prescribed burning (PB) activities; and commercial and recreational fishing pressures.
Legacy	Legacy stressors are anthropogenic activities that have occurred in the past whose effects are continuing today. Examples include the construction of the Intracoastal Waterway (ICW), early ditching activities to drain land, the historic use of fire, agricultural activities, timber harvesting, and dischargers of nutrients by the City of Jacksonville WWTP (this discharge was eliminated in 2000).
Natural	Natural stressors include natural forces (e.g., hurricanes and sea-level rise) whose effects are enhanced by anthropogenic activity (e.g., global warming). The increased frequency and intensity of natural events, in combination with anthropogenic contributions, could cause ecosystem perturbations outside the range of natural variation.

3.3 Integrated Ecosystem-based Management Approach

Figure 3-3 illustrates the overall process that will be used to meet the DCERP objectives. After developing individual conceptual models in Phase I, the DCERP module teams identified knowledge gaps in the models and determined the needs of MCBCL management. The module teams then determined potential research questions to fill these basic knowledge gaps and to address MCBCL management needs. DCERP is a research-initiated process that is distinct from other ecosystem-based programs that are driven by specific regulatory or management objectives. The DCERP Baseline Monitoring Plan is designed to gather environmental data to address MCBCL management concerns and to support the research projects identified here in the DCERP Research Plan. During Phase II, results from research projects will feed back into the adaptive Baseline Monitoring Plan so that changes in the frequency of sampling, spatial scale of sampling locations, or parameters to be sampled can be adapted as necessary. Results from the monitoring and research efforts will be used to identify ecosystem indicators and to develop associated threshold values, tools, or design models that address MCBCL management needs. This information will be communicated to MCBCL to assist in the decision-making process. This information transfer may occur rapidly for some management needs or may require longer periods for the collection of research and monitoring data to provide appropriate indicators, models, or other tools. Once this information is transitioned to MCBCL, the Base's natural resources managers will be able to make decisions as to what type of management action should be taken and to implement appropriate physical or military operational changes. After the implementation of these changes, the RTI DCERP Team will continue monitoring (feedback loop) to ensure that the desired management outcomes are achieved.

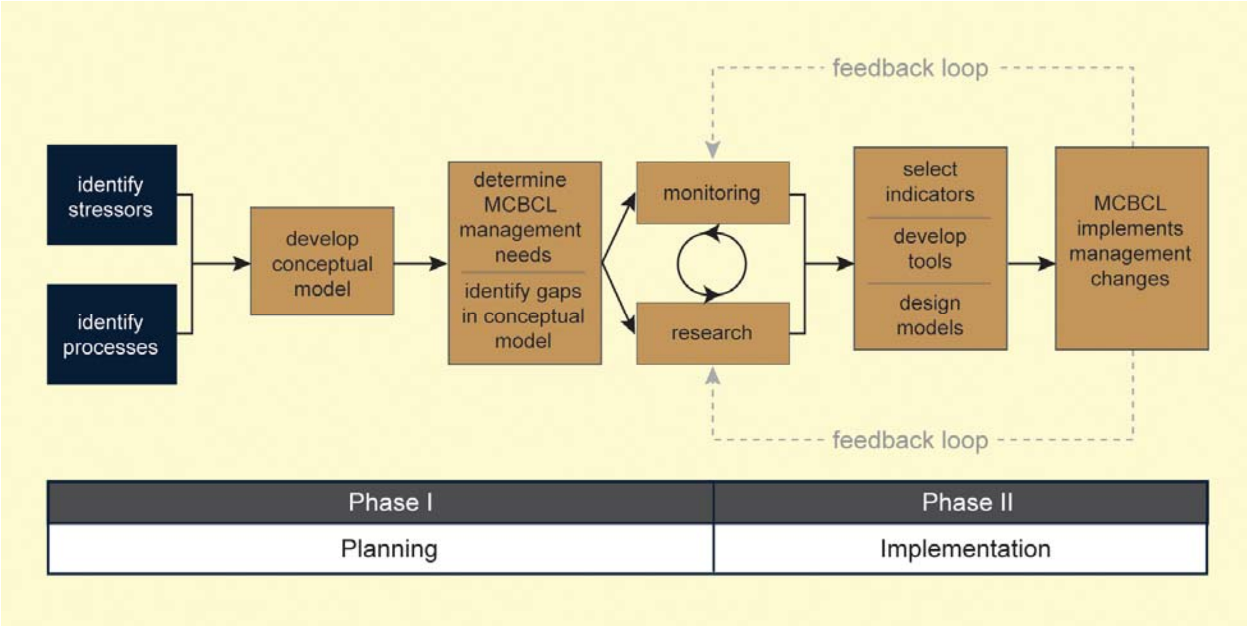


Figure 3-3. DCERP planning and implementation process flow chart.

4.0 Purpose of the Research Plan

The main purpose of this DCERP Research Plan is to describe the research that will be conducted to gain a better understanding of ecosystem processes and reactions to stressors, which is critical for ecosystem-based management. The 13 research projects described in this plan will focus on what is unknown about each ecosystem module, as described in the module's conceptual model, and will include innovative techniques for addressing these knowledge gaps. As indicated in the DCERP Strategic Plan (RTI, 2007), there are many knowledge gaps in the ecosystem conceptual models. The RTI DCERP Team will use state-of-the-art techniques to test ecosystem response to stressors (e.g., military, non-military, legacy, and natural), to examine potential indicators, and to research and evaluate various management practices. A research program driven solely by current MCBCL management needs risks overlooking new insights or future management needs. For example, MCBCL has been intensively managing the longleaf pine habitat for several years with the goal of increasing red-cockaded woodpecker (RCW) populations; however, there has been no monitoring or research to determine how intensive management of this one species is affecting or will affect other plant and animal populations in the future. This is a knowledge gap that can only be filled by conducting more holistic ecosystem assessments of plant and animal communities in the RCW habitat. It is important that data from DCERP research provide the basic scientific information needed to develop management plans to modulate the impacts of military activities and to sustain the natural resources and use of the Base for military training now and in the future.

4.1 Objectives of the Research Plan

The main objective of the DCERP Research Plan is to build upon the scientific framework established in the DCERP Strategic Plan by describing the details of our planned research. In addition, the Research Plan is intended to serve as a mechanism for providing clear communication and coordination among RTI DCERP Team scientists, SERDP staff, MCBCL natural resources managers, and local stakeholders (e.g., New River Roundtable, Onslow Bight Conservation Forum, City of Jacksonville, Onslow County Commissioners). Specifically, each research project description in Section 5 will do the following:

1. Provide clear technical goals and specific objectives to address key knowledge gaps, research needs, and management objectives identified in the conceptual models (RTI, 2007).

2. Incorporate scientifically sound, high-quality research principles that utilize state-of-the-art technologies that are transferable to MCBCL.
3. Translate research results into models, indicators, and tools to predict outcomes of potential management scenarios and allow for adaptive management strategies.

4.2 Selection of Research Projects

Initially, DCERP module teams developed more than 25 research projects to provide information to fill knowledge gaps in the individual conceptual models and address MCBCL management needs. This initial project list was prioritized within each module based on the research project's ability to address key knowledge gaps in the conceptual model, address key management needs of MCBCL, and provide information that was needed by more than one ecosystem module. Other factors were also considered, such as the cost, timing (e.g., seasonal, storm-based, year long), and duration of the research project. This selection process was conducted jointly between DCERP researchers, SERDP, NFESC, and MCBCL natural resources managers. Final selection and phasing of the research projects was determined by the RTI PI and was constrained by resource limitations during each of the 4 years in the Phase II implementation period. **Table 4-1** lists the title of each research project and the project's lead investigator; these projects will be discussed in detail in Section 5 of this report (*Module Research Projects*). **Appendix C** of this report lists the proposed DCERP projects that were not included as high priorities for implementation, but that may be funded in later years of DCERP.

Table 4-1. DCERP Research Projects (2007–2011)

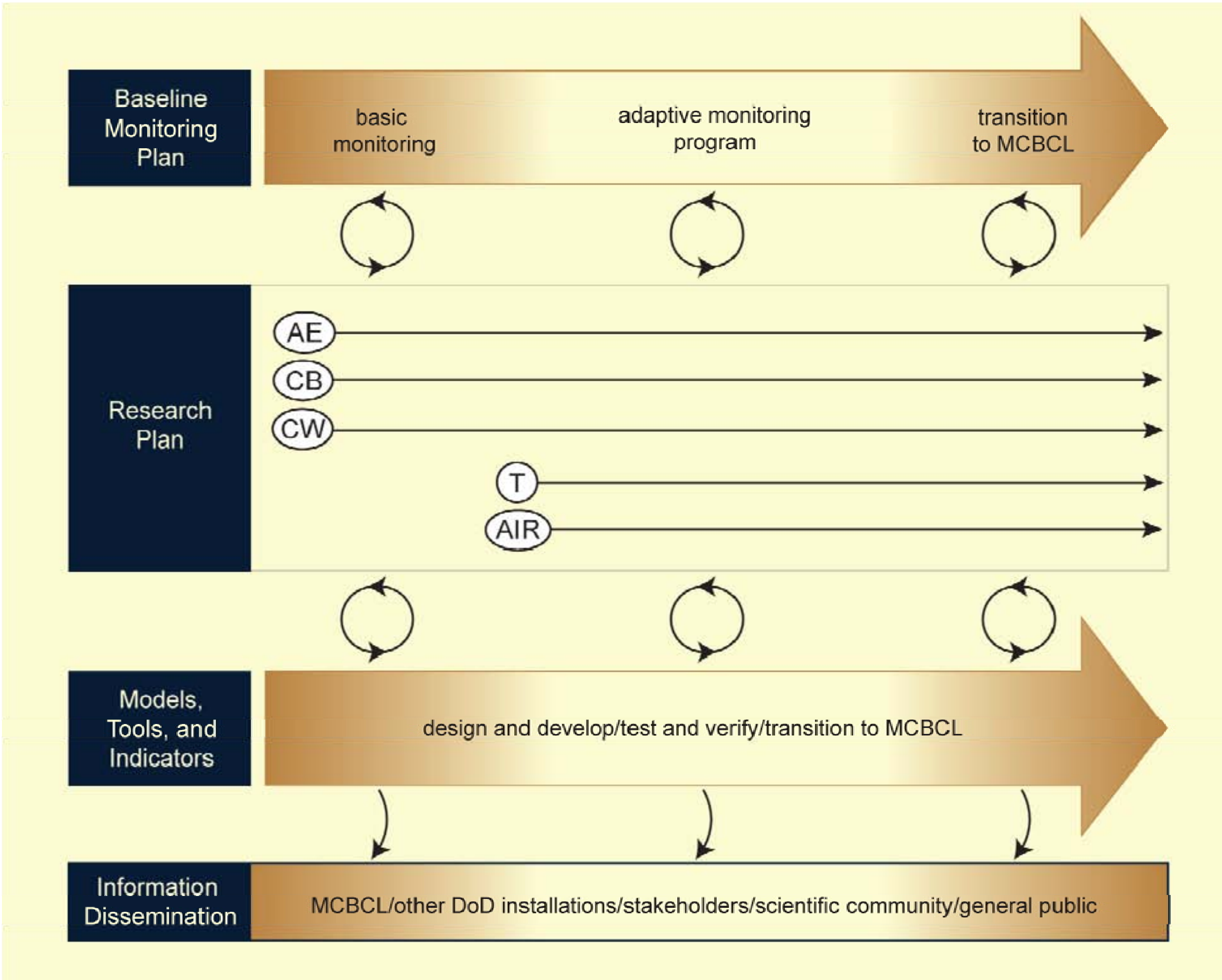
Project	Research Project Title	Senior Researcher(s)
AE-1	Develop and Deploy Microalgal Indicators as Measures of Water Quality, Harmful Algal Bloom (HAB) Dynamics, and Ecosystem Condition	Hans Paerl
AE-2	Quantifying and Predicting Watershed Inputs of Nutrients, Sediments, and Pathogens	Mike Piehler
AE-3	Developing Indicators of Ecosystem Function for Shallow Estuaries: Benthic Functional Responses in the NRE	Iris Anderson
CW-1	Determine Responses of Marsh Vegetation and Surface Elevation to Nutrients	Jim Morris
CW-2	Forecast Influence of Natural and Anthropogenic Factors on Estuarine Shoreline Erosion Rates	Mark Fonseca
CW-3	Hydraulic Exchange and Nutrient Reactivity in the NRE Wetlands	Craig Tobias
CB-1	Short-Term Barrier Evolution Related to Storms and Land Use	Jesse McNinch
CB-2	Long-Term Barrier Evolution Related to Variations in Underlying Geology, Landuse, and Inlet Dynamics	Antonio Rodriguez
CB-3	Understanding the Top-down and Bottom-up Drivers of Shorebird Nest Success and Habitat Use in Relation to Beach Management Practices on MCBCL	Sarah Karpanty and Jim Fraser
T-1	Varying Prescribed Fire Regimes and Forest Management Effects on Terrestrial Ecosystem Structure and Function	Norm Christensen
T-2	Effects of Habitat Management for RCWs on Bird Communities	Jeffrey Walters
Air-1	Optimization of Prescribed Burning (PB) by Minimizing Smoke Emissions and Maximizing Vitality of Fire-Adapted Ecosystems	Karsten Baumann
Air-2	Nitrogen Deposition to Terrestrial and Aquatic Ecosystems	Wayne Robarge

4.3 Integrating DCERP Research and Monitoring

Figure 4-1 provides a graphic representation of DCERP's Phase II (implementation of the DCERP Baseline Monitoring and Research plans), as previously identified in **Figure 3-3**. DCERP's approach closely integrates the DCERP Baseline Monitoring and Research plans (as shown by the feedback loops through the duration of DCERP) so that the outcomes of research projects can be used to modify the adaptive Baseline Monitoring Plan. In turn, the monitoring data can used to develop, refine, and verify the models, tools, and indicators created as part of the research effort. Therefore, the models, tools, and indicators will be continuously modified as additional research and/or monitoring data become available.

The research projects will incorporate data from DCERP's baseline monitoring program, MCBCL environmental monitoring activities, and other local, state, federal, and private monitoring activities to provide an integrated approach to ecosystem-based management and to alleviate redundancy in data collection activities. Research projects will not necessarily start at the same time during DCERP, but will be phased to integrate research linkages among the various modules. Schedules and site locations for all DCERP research activities will be coordinated with the selection of baseline monitoring sites to ensure that linkages between the baseline monitoring and research project sampling sites are maintained whenever possible. Information derived from research projects will aid in adapting elements of the DCERP Baseline Monitoring Plan. For example, initial monitoring activities may need to change (i.e., adding or deleting parameters being sampled; increasing or decreasing sampling frequencies of some parameters; or increasing or decreasing spatial extent of sampling locations) in response to results obtained from research projects. In this way, the baseline monitoring program will be adaptive in nature to respond to new information on environmental parameters being monitored.

Figure 4-1 also shows how the models, tools, and indicators that are designed, developed, tested, and verified can be transitioned to MCBCL to assist in monitoring and forecasting ecosystem changes. The models, tools, and indicators developed from the research projects also should help to streamline the baseline monitoring to a limited set of key parameters that will be easily transitioned to MCBCL at the end of DCERP. It is a goal of DCERP to disseminate monitoring and research results and information from associated models, tools, and indicators to MCBCL, as well as to other users groups, including other DoD installations in similar ecological settings, the scientific community, other stakeholders (e.g., New River Roundtable or Onslow Bight Conservation Forum), and the general public.



Note: AE = Aquatic/Estuarine Module; CB = Coastal Barrier Module; CW = Coastal Wetlands Module; T = Terrestrial Module; AIR = Atmospheric Module

Figure 4-1. Generic roadmap of the integrated DCERP Baseline Monitoring and Research plans and the development of model tools and indicators.

Specific roadmaps for each of the five ecosystem modules illustrate the linkages among monitoring and research activities and summarize the models, tools, and indicators that will be developed from these activities, as well as the information that will be disseminated to MCBCL and other stakeholders. These roadmaps illustrate how information from the research projects and outcomes will be used to refine the monitoring activities before these activities are transitioned to MCBCL at the completion of DCERP. The roadmaps for the five ecosystem module are located in **Appendix E** of this report.

4.4 Other Research and Monitoring Efforts Related to DCERP

The RTI DCERP Team will leverage data from other ongoing research efforts, including data from MCBCL natural resources managers (**Appendix D**), other SERDP-funded research being conducted at MCBCL (**Appendix B**), and other state and local agencies (**Appendix D**).

5.0 Module Research Projects

The following sections contain the proposed research projects for each of the five ecological modules (Aquatic/Estuarine, Coastal Wetlands, Coastal Barrier, Terrestrial, and Atmospheric), including background information on the module, the knowledge gaps in the conceptual model that the research will fill, and the individual research projects that are proposed for implementation. Specific information is provided for each research project, such as the research team, hypothesis to be tested, technical goals, technical approach, methods, data analysis, research outcomes, linkages to other modules, military drivers addressed, benefit to MCBCL, schedule and scheduling constraints, Year 1 go/no go decision points, and budgetary information for each of the four implementation years.

5.1 Aquatic/Estuarine Module

5.1.1 Introduction

Estuaries integrate inputs from terrestrial, freshwater, oceanic, and atmospheric systems (Day and Kemp, 1989; Valiela et al., 1997; Hobbie, 2000), and the accurate assessment and management of estuaries necessitates consideration of their connections to, and interactions with, these other systems. Estuaries also exist in regions of rapidly expanding and diversifying human activity (Nixon, 1995; Boesch et al., 2001; Cloern, 2001). In the context of the MCBCL region, the Aquatic/Estuarine Module will examine the tidal reach of the NRE from the freshwater head of the NRE near Jacksonville, NC, to the tidal inlet at Onslow Bay. **Figure 5-1** presents the conceptual model for the Aquatic/Estuarine Module, illustrating the complementary nature of the critical physical, chemical, and biotic processes and interactions. Understanding and sustaining the function of the NRE cannot occur without quantifying and distinguishing natural processes from human-influenced watershed- and airshed-based impacts, as well as human activities that occur in the estuary (Nixon, 1995; Paerl, 1997; Malone et al., 1999; Boesch et al., 2001).

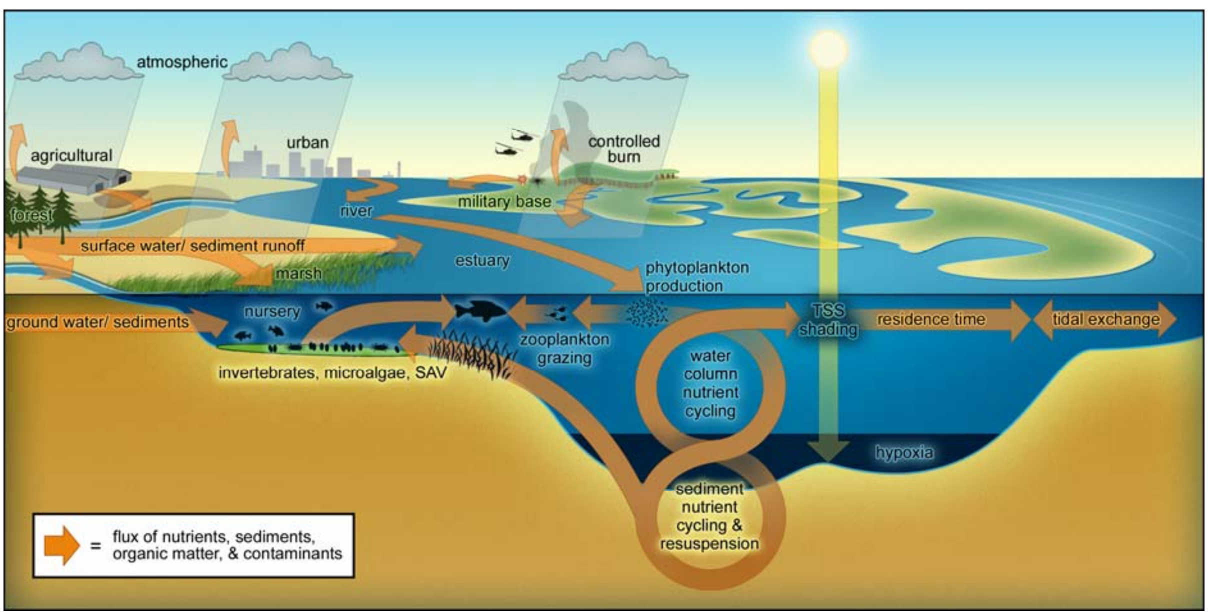


Figure 5-1. Conceptual model for the Aquatic/Estuarine Module.

Estuarine responses to physical, chemical, and biological processes may serve as indicators of ecological change (Cloern, 2001; NRC, 2000; Peierls et al., 2003; Neimi et al., 2004). Inputs of nutrients, sediments, organic matter, and contaminants reach the NRE from multiple sources, including watershed inputs, precipitation and dry deposition from the atmosphere, and tidal exchanges with Onslow Bay. Watershed inputs include sources from the New River at Jacksonville, NC; creeks that drain into the NRE; surface runoff; and groundwater as baseflow. These inputs influence the biological and chemical cycling within the NRE's water column and sediments (e.g., nutrient cycling and sediment transport) (Cloern, 2001; Anderson et al., 2003). Nutrients stimulate both phytoplankton and benthic microalgae (BMA) (primary production), thereby providing food for zooplankton and benthic invertebrates (secondary production), respectively (Hobbie, 2000; Sundbäck et al., 2003). The zooplankton and benthic invertebrates provide food for fish, and phytoplankton is the primary food source for shellfish. An overgrowth of phytoplankton and excessive sediment inputs, however, can reduce light penetration, leading to declines in important nursery area attributes, such as submerged aquatic vegetation (SAV) and BMA abundance (Gallegos et al., 2005), thereby reducing the food supply for benthic-feeding fish and interfering with the role of BMA in modulating water column nutrient enrichment. Additionally, excessive amounts of phytoplankton (e.g., algal blooms) sink from surface to bottom waters within the estuary and, together with watershed inputs of organic matter, lead to depleted oxygen conditions (hypoxia or anoxia) in bottom waters. Such hypoxic and anoxic events can have critical negative impacts on shellfish, other invertebrates, and finfish (Paerl et al., 1998; Rabalais and Turner, 2001). These processes may be influenced by water exchanges with Onslow Bay, which have the potential to remove excess nutrients, organic matter, and phytoplankton. The NRE's response to natural and anthropogenic impacts depends in part on physical and biological interactions, such as wave activity, which lead to the resuspension of bottom sediments, and freshwater discharge and exchange, which affects the estuary's water residence time and degree of stratification (Luettich et al., 2000). These conditions strongly influence the biomass and composition of the autotrophic communities within the NRE, the estuary's susceptibility to hypoxia/anoxia, and the relative importance of microbial processes that may remove nutrients from both the water column and benthos. The following research projects (**Table 5-1**) address challenges that are associated with stresses imposed as a consequence of MCBCL or other direct anthropogenic activities.

Table 5-1. Aquatic/Estuarine Module Research Project Title, Senior Researcher, Benefit to MCBCL, and Duration of Project

Project	Research Project Title	Senior Researcher/ Duration
AE-1	*Develop and Deploy Microalgal Indicators as Measures of Water Quality, Harmful Algal Bloom Dynamics, and Ecosystem Condition*	**Senior Researcher:** Hans Paerl
	Outcomes and benefit to the Base: This research project will establish baseline indicators against which to gauge the short- and long-term effects of management strategies aimed at protecting water quality and preserving the ecological integrity of the NRE and adjacent wetlands and coastal waters. This project will also produce a decision-support, Bayesian modeling tool for guiding adaptive monitoring and management and provide data needed to link watershed nutrient inputs to estuarine circulation and water quality simulation models.	**Duration:** 7/07–06/11
AE-2	*Quantifying and Predicting Watershed Inputs of Nutrients, Sediments and Pathogens*	**Senior Researcher:** Mike Piehler
	Outcomes and benefit to the Base: This research project will provide the Base with information on the sources of identified pollutants to help avoid actions under the CWA related to impairment from fecal indicator bacteria (FIB), sediments, or chlorophyll *a* exceedances by identifying emerging problems and using data to inform remedial strategies. This project will also produce a decision-support modeling tool (watershed simulation model [WSM]) for predicting watershed exports as a function of environmental forcing and land-use changes.	**Duration:** 7/07–6/11

Project	Research Project Title	Senior Researcher/ Duration
AE-3	*Developing Indicators of Ecosystem Function for Shallow Estuaries: Benthic Functional Responses in the New River Estuary.*	**Senior Researcher:** Iris Anderson
	Outcomes and benefit to the Base: This research project will provide a cause-and-effect analysis or potential management actions that might be necessary to mitigate long- and short-term impacts of the Base on benthic processes responsible for modulating nutrient enrichment and supporting higher trophic levels in the NRE. This project will also produce a decision-support modeling tool (Estuarine Simulation Model [ESM]) for predicting estuarine responses to natural and anthropogenic disturbance.	**Duration:** 7/07–6/11

5.1.2 Knowledge Gaps in Conceptual Model and Research Needs

The work of the Aquatic/Estuarine Module Team will begin with efforts to improve the understanding of the NRE's ecosystem processes and to develop diagnostic tools and indicators to assess estuarine function, especially responses to diverse anthropogenic and natural stressors. Key research needs of this module include identifying and distinguishing the effects of local versus regional stressors and their ecological impacts in the NRE. For example, the Aquatic/Estuarine Module Team will assess changes in light quality and quantity within the water column resulting from and during specific MCBCL training events. In addition, determining the impacts resulting from long- and short-term stressors and stressors occurring at different times (e.g., legacy versus current stressors) is a priority for this system. Obtaining quantitative information on the loadings of nutrients, sediment, and pathogens from the watershed and understanding the transformation of nutrients that occurs within the NRE are two research priorities for the Aquatic/Estuarine conceptual model. The identification and development of appropriate indicators of productivity and community structure for the NRE and studies of stressor-specific responses (e.g., algal blooms, hypoxia, and food web perturbations) are also needed.

Studying the factors that modulate the residence time for this estuary and the role of physical processes involved in loading, transformation, exchange and fate of nutrients, sediments, pathogens, and other contaminants are of paramount importance to understanding ecosystem-based management options for the NRE. Water quality within shallow-water estuaries such as the NRE is influenced by coupling between the water column and the benthos, a process that is very sensitive to both the quantity and quality of light reaching the benthos. Water column and sediment interactions and their impacts on nutrient cycling, productivity, water quality, and food-web dynamics (e.g., benthic-pelagic coupling) need to be examined and assessed within this system.

Because of the complexity of estuarine stressors and the need for decision-support tools for the management of the NRE, it is necessary to develop easily applied indicators of ecosystem condition and simulation models to forecast changes in the NRE in response to human (including military) and natural stressors (Paerl et al., 2005). Specifically, there should be a strong emphasis on distinguishing regional from military and non-military stressors and the impacts of these stressors on ecological condition and change in the receiving estuarine ecosystem. The following research questions are designed to address existing knowledge gaps and provide answers to management questions.

5.1.3 Benefit to MCBCL

MCBCL will derive several benefits from the indicators and tools developed by the three research projects for the Aquatic/Estuarine Module. The application of the microalgal (MA) indicators will provide the Base with a set of indicators that are sensitive, rapid, highly specific, easily deployed, readily verifiable, and scalable (from specific habitats to the entire ecosystem) and that will address high-priority concerns about the sources and effects of key stressors impacting water quality. The research effort in the tidal creeks will identify water quality impairments from sediment, chlorophyll *a*, or FIB and will be directly applicable to the development of total maximum daily loads (TMDLs) for impaired waters [CWA Section 303(d)]. FIB and pathogen data will permit identification of fecal indicator signal as opposed to actual human fecal contamination and non-human contamination. Stable isotope and pathogen analyses will allow some degree of source assessment, enhancing the Base's ability to remediate any detected stream-borne pollution. The benthic indicators developed will assess the effects of a variety of stressors on benthic health and determine the susceptibility and resilience of the system to ecosystem impairments, such as increased turbidity, nutrient concentrations, eutrophication, and hypoxia/anoxia. Application of these indicators and tools will help the Base natural resources managers gauge the short- and long-term effects of management strategies aimed at protecting water quality and preserving the ecological integrity of the NRE that are primary goals of the CWA.

5.1.4 Proposed Research Projects – Aquatic Estuarine

5.1.4.1 AE-1: Develop and Deploy Microalgal Indicators as Measures of Water Quality, Harmful Algal Bloom Dynamics, and Ecosystem Condition

Senior Researcher: Hans Paerl (University of North Carolina at Chapel Hill [UNC-CH])
Supporting Researcher: Ken Reckhow (Duke)
Staff: 1 post-doctoral researcher (half time, Years 2–4); 1 research technician (3/4 -time); and 2 graduate students (UNC-CH for 3 years, Duke 2 years)

Hypotheses:

1. Microalgae (MA) dominate primary production in the NRE.
2. Human (e.g., nutrients, sediments, contaminants) and climatic (e.g., hydrologic) environmental factors control MA production and community structure and fate and determine water quality, ecological condition, and sustainability of the NRE.
3. Climatic variability and extremes (e.g., hurricanes) play a central and, at times, dominant role in determining MA production and harmful algal bloom (HAB) potentials.
4. Recently developed diagnostic MA indicators for shallow estuaries, coupled to a Bayesian Belief Network (BBN), will provide a regulatory (e.g., total maximum daily load [TMDL], CWA) tool for researchers and managers to identify, distinguish, and predict local (Base) and regional stressors of ecological condition/change in the NRE.

Technical Goals: Research will identify and quantify ecosystem-scale effects of Base and regional anthropogenic activities and climatic stressors on MA, which are key primary producers and indicators of estuarine water quality and ecological condition. This research will facilitate adaptive management of the NRE, using a BBN, using data from monitoring and experimentation. Results will verify the use of diagnostic photopigment coupled to molecular analyses as broadly applicable, sensitive indicators of water and habitat quality and HAB potentials in estuaries. Results will be "scaled up" to the ecosystem-level by coupling to aircraft- and satellite-based remote sensing [e.g., Moderate Resolution Imaging Spectroradiometer (MODIS), medium-spectral resolution, imaging spectrometer (MERIS), Sea-viewing Wide Field-of-view Sensor (SeaWiFS), and the Sea-viewing Wide Field-of-view Sensor (AVIRIS)], in collaboration with EPA and National Aeronautics and Space Administration. Data will be used to determine compliance with North Carolina and EPA water quality criteria (e.g., nutrient-sensitive waters, TMDL, CWA). Predictive, probabilistic models of MA and HAB dynamics will be developed for long-term adaptive water quality management of the NRE.

Technical Approach:

(a) Background:

Nutrient enrichment is the primary cause of eutrophication, HABs, and habitat degradation (e.g., increased hypoxia, loss of submersed aquatic vegetation, food web changes, loss of fish and shellfish habitats) in North Carolina estuaries (Paerl, 1983, 1987; Christian et al., 1986), including the NRE (Mallin et al., 1997, 2005). There is a need to develop and deploy rapid, quantitative, and broadly applicable indicators of the causes and manifestations of these unwanted conditions as they pertain to amounts and chemical forms of nutrients (nitrogen [N], phosphorus [P]) and other pollutant inputs from local (Base), watershed, and regional (e.g., airshed) activities. The NRE is also impacted by climatic perturbations, including droughts, floods, and tropical storms, the frequencies of which are increasing (Goldenberg et al., 2001; Webster et al., 2005). MA are excellent indicators of ecological change (Paerl et al., 2005) because they are relatively easy to detect, identify, and quantify; conduct a large share of primary production supporting the food web; and are sensitive to diverse environmental stressors in estuaries (Pinckney et al., 2001; Paerl et al., 2003, 2005). MA group-specific (e.g., chlorophytes, cryptomonads, cyanobacteria, dinoflagellates, diatoms) photopigments (chlorophylls and carotenoids) (Jeffrey et al., 1997) will be used to determine community responses to nutrient inputs and environmental perturbations in the NRE watershed. These changes have major implications for trophodynamics and nutrient cycling, they may be used to predict and assess broader-scale biotic conditions (community structure and function) and change. Diagnostic photopigments, in combination with molecular (16s rDNA, *nifH*, *mcy*) identification techniques, will be employed to rapidly detect and characterize (e.g., toxin-producing, food web disruptive, hypoxia generating) HAB species (c.f. Dyble et al., 2002; Litaker et al., 2003). These indicators are being collaboratively tested in North Carolina estuaries and serve as ground truthing data for remote sensing studies and unattended (e.g., profilers) monitoring for estuarine and coastal ecosystems locally and nationally (Paerl et al., 2005).

Increasingly detailed simulation models of aquatic ecosystems have been developed to forecast the impact of nutrient additions and other perturbations on ecosystem condition; however, these models are over-parameterized (Beven, 2001), making it difficult to identify a unique, optimal set of model parameters and to assess the accuracy of forecasts. Instead of a one-time deterministic forecast, an iterative framework of modeling and monitoring integration using a BBN (Reckhow, 1999) will be applied and regularly updated with project data to improve forecasts and support adaptive management.

(b) Experimental Design – The experimental design will take advantage of monthly water quality monitoring and continuous (automounous vertical profiler [AVP]-data flow) sampling in the NRE to best characterize and quantify the relationships between nutrient input, physical features (e.g., light availability, temperature, water column stratification and residence time) MA production, composition, and bloom thresholds (including HABs) on a year-round basis. In addition, seasonal, *in situ* (e.g., natural light and temperature conditions) nutrient addition bioassays will be conducted to identify nutrient limitation and specific nutrient loading/ratio thresholds (reflecting local and regional inputs) for key MA functional groups, including HABs. The experimental design will allow ambient environmental *and* experimental data to be incorporated into process-level (mechanistic) and probabilistic models of nutrient-MA and HAB relationships for the NRE and other shallow estuaries. This information will lend itself to simplification (as to environmental forcing features modulating MA growth, bloom, and HAB dynamics) on useful spatio-temporal scales suitable for adaptive nutrient management of the NRE. These scales will also be optimal for calibrating remote sensing of MA dynamics and causative agents, including changes in land and water use (i.e., upstream withdrawal), nutrient discharge, and optical properties.

(c) Methods: Phytoplankton and benthic MA samples will be obtained monthly from the 8-station monitoring program along the axis of the NRE, and seasonal nutrient addition bioassays conducted in the NRE. Samples will be filtered, sonicated, and extracted in 90% acetone. Extracts will be analyzed by high performance liquid chromatography (HPLC) and photodiode array spectrophotometry (Pinckney et al., 2001). ChemTax, a statistical procedure that partitions chlorophyll *a* into the major algal groups based on diagnostic chlorophylls and carotenoids (Mackey et al., 1998; Paerl et al., 2003) will determine the absolute contributions of each group. Photopigment markers include chlorophyll *b*; lutein (chlorophytes); zeaxanthin; myxoxanthophyll and echinenone (cyanobacteria); fucoxanthin (diatoms); peridinin (dinoflagellates); and alloxanthin (cryptomonads) (**Figure 5-2**).

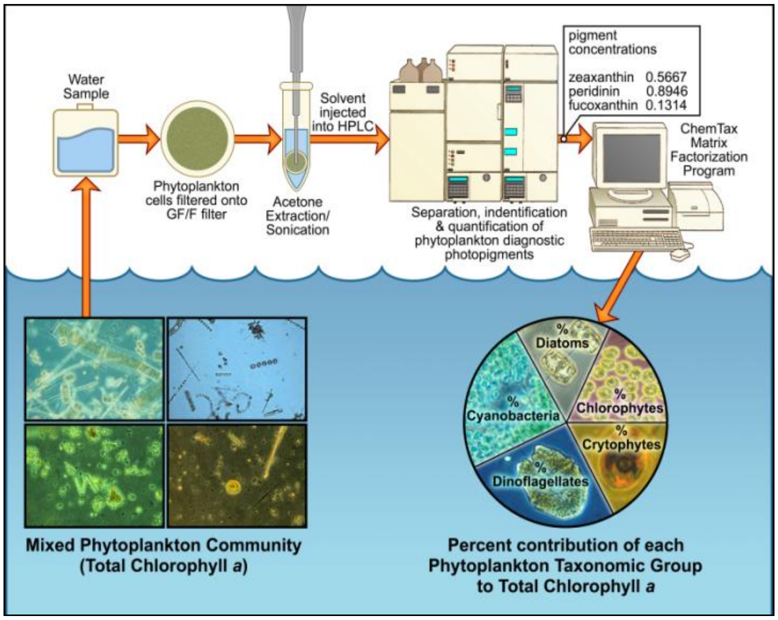


Figure 5-2. Schematic of HPLC-Chemtax based determination of major MA (phytoplankton) groups in a natural water sample (Paerl et al., 2003).

Photopigment composition is generally significantly (linearly) correlated with species cell counts or biovolume estimates (Tester et al., 1995; Pinckney et al., 2001). Periodic microscopic checks will ensure that the appropriate phytoplankton groups are identified and quantified (Lewitus et al., 2005). For molecular identification of MA and HAB community structure and function, selected subsamples will be filtered on Supor™ filters, placed in 2ml tubes, and frozen in Tris EDTA buffer for preserving DNA. Extraction will be by heating and glass bead beating, as described in the lysis protocol with DNAzol ES (the lysis buffer). The DNA is then purified using the DNeasy Plant Kit (Promega) and eluted in water. The 16s rDNA, *nifH* and *mcy* genes will then be polymerase chain reaction (PCR) amplified using standard PCR reaction solutions and specific primers. Gene products will be sequenced at the UNC-CH sequencing facility after standard transforming and cloning of the gene at the University of North Carolina Institute of Marine Sciences (UNC-IMS). Sequence analysis will be used to generate probes for specific HABs of interest. Future NRE research and monitoring will use these probes for rapid HAB screening and quantification. Diagnostic pigment and primary productivity measurements will be used as bioassay response indicators to seasonally evaluate MA responses to nutrient (N, P, Silica) enrichment at levels reflecting tributary inputs. These highly replicated (quadruplicate treatments) *in situ* nutrient addition bioassays are designed to identify growth-limiting nutrients and bloom threshold input levels below which water quality (e.g., North Carolina's chlorophyll *a* standard and nutrient sensitive water designation), EPA-CWA, and HAB criteria can be met for the NRE (Paerl et al., 1995).

(d) Data Analysis and Modeling:

Data Analysis

All field and experimental data will be subjected to statistical analyses, including standard analysis of variance and regression techniques. Multimetric methods such as Principle Components Analysis will be performed on multiple variables indicative of environmental condition and including both historic and current data to determine the variables most responsible for differences observed between sampling sites in the NRE. Errors will be detected by abnormally high coefficients of variation between replicates in bioassays and chemical analyses. If necessary, we will use robust statistical analyses (Maronna et al., 2006) to capture the central tendency of data patterns, thus minimizing the effect of outliers and leverage data points. We will also take advantage of recent developments in statistical pattern recognition (Hastie et al., 2003) to explore the data sets (statistically and visually) for possible relationships that may have eluded us in previous studies. Time series and correlation-based (relative to environmental drivers) data analysis and processing will yield depth-stratified two-dimensional (2-D) maps of MA biomass and community structure in relation to nutrient and hydrologic regimes in the NRE (see Valdes-Weaver et al., [2006] and Paerl et al. [2006] as examples of this approach for the Neuse River Estuary). Similar maps will be generated for nutrient limitation and enrichment effects for each bioassay, and an interactive Web site will be developed where users can obtain a limited number of resultant maps for specific combinations of factors to better identify key nutrient limitation regimes useful for long-term nutrient management of algal blooms and related hypoxia in the NRE and elsewhere. MCBCL will have full access to all data layers and applications. MCBCL will then be able to manipulate and examine the various scenarios to see where and how bloom events might be managed and reduced. This will help MCBCL investigate and prioritize possible nutrient reduction and hydrologic alternatives to modulate the extent of blooms and hypoxia in the NRE. By providing improved information on sources of nutrients fueling blooms and hypoxia, targeted nutrient management in the estuary may be tenable.

Modeling

Modeling will be undertaken using a novel Bayesian approach to support uncertainty analysis and adaptive nutrient/MA bloom management. A BBN (Reckhow, 1999) will be fitted to initial data for development of a model predicting algal biomass response to N inputs and hydrologic drivers; this approach was recently successful in the development of a TMDL for N in the Neuse Estuary (Borsuk et al., 2003, 2004; **Figure 5-3**).

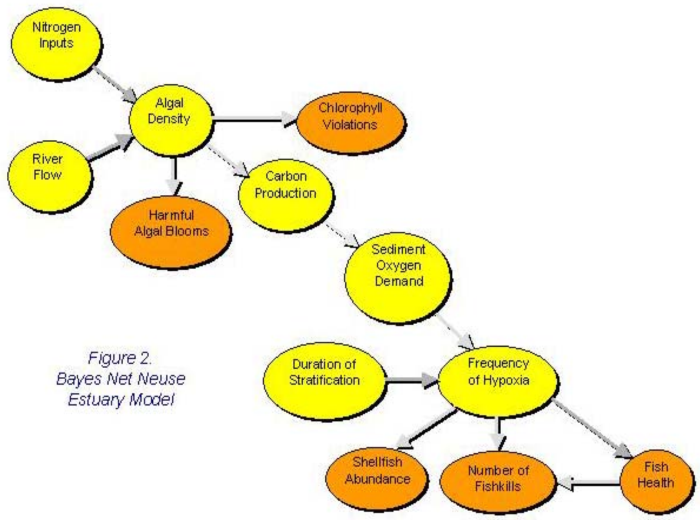


Figure 5-3. Bayes Net Neuse Estuary Model.

A Bayes Network is initially represented as a graphical model with a series of nodes (representing management actions, water quality variables, and important aquatic responses in the system) linked by arrows. The arrows indicate causal linkages among the nodes, and the nodes denote important system processes. Each node is characterized by mathematical expressions that represent knowledge about these system processes. The mathematical expressions may be (1) mechanistic descriptions such as chemical reaction kinetics, (2) empirical relationships such as linear regression models, or (3) relationships derived from expert judgment, depending on how much information we have about the processes underlying a particular node. The possible outcomes at each node are expressed probabilistically; thus a Bayes net is a set of conditional probabilities describing a set of likely system responses with conditionality indicated by the arrows. The ability to incorporate mechanistic, empirical, and judgmental information makes the Bayes net approach extremely flexible and facilitates an extension to non-traditional model endpoints of public concern. As new data are acquired by monitoring, experimentation, and remote sensing, they will be used to update the model and provide revised probabilistic predictions for adaptive management by MCBCL.

(e) Environmental Indicators, Tools and other Outcomes:

Chlorophyll and carotenoid photopigments are diagnostic for major MA functional groups (i.e., diatoms, dinoflagellates, chlorophytes, cyanobacteria, and cryptomonads) and benthic MA forming the base of the NRE food web. Specifically, these indicators will be used to identify and distinguish nutrient from hydrologically driven changes in MA community composition and activity (Pinckney et al., 2001; Paerl et al., 2005), clarify HAB potentials (including use as an early warning tool for HABs), and establish linkages to major biogeochemical perturbations such as hypoxia. Data will be used to develop space-time GIS maps of MA community composition to develop and verify nutrient-eutrophication models that stressors will help predict group-specific MA responses to nutrient and hydrologic stressors, including episodic storm (nor'easters, hurricanes) events and droughts, all of which periodically impact this region and appear to be increasing in frequency and intensity. Deployment of these indicators will allow us to examine impacts of both anthropogenic (nutrient) and natural stressors, including seasonal and/or hurricane induced variations in river discharge, and resulting nutrient and hydrologic changes.

(f) Linkages to other Modules: This research project is integral to all the Aquatic/Estuarine, Coastal Wetlands, Coastal Barrier and Atmospheric modules research and monitoring activities, since it is developing and applying indicators sensitive to and interpretive of nutrient, sediment and contaminant effects (originating from these ecosystem and regional components) on the key biotic communities mediating production, biogechemical cycling, water and habitat quality of the NRE. Because MA are responsible for a bulk of primary production and carbon (C) flux in the system, they are excellent “barometers” of estuarine fertility, productivity, sustainability and overall health. In addition, MA are a key source of biodegradable organic matter or “fuel” for hypoxia and thus provide an important control over benthic processes, including nutrient regeneration, habitability and food supply for fish, shellfish, infauna, fish and flora. The results from this project will be of critical and direct use for the ESM developed by Research Project AE-3 linking terrestrial, wetland and atmospheric biogeochemical processes and inputs to estuarine tropic state and overall ecological condition. These indicators will be used to determine if the estuary is meeting local, State and federal WQ and habitat criteria, as impacted by external (watershed, atmospheric, oceanic) stressors.

(g) Military Drivers: Deployment of these indicators will help MCBCL:

- Improve management capacity for NRE by providing easily deployed, quantitative indicators of MA and HAB response to key stressors (e.g., turbidity, nutrient enrichment, chemical contamination) resulting from military activities (e.g., vehicular impacts, training activities, splash points and Landing Craft Air Cushion (LCAC) operations) and non-military Base activities (e.g., sewage treatment, storm water runoff and future construction and development, and PB).
- Conduct probabilistic predictions of water quality responses to these stressors for adaptive management by MCBCL.
- Determine effects of local and regional impacts of nutrients, sediments and contaminants on NRE water quality to avoid actions under the CWA, TMDLs and state/federal water quality criteria (e.g., acceptable chlorophyll *a* levels, EPA CWA Section 305(b) criteria, HABs, hypoxia).
- Ensure compatibility of key Base activities with acceptable water quality in the NRE.
- Provide tools for assessing water quality (including HABs) and habitat responses to Base versus external activities and stressors for the NRE.
- Assess and predict effects of point and non-point source pollution for the entire estuary (scaling up).
- Determine safety of estuary for military training use, including personnel exposure to HABs.
- Rapidly and quantitatively evaluate the effects of Base and local activities on MA in the face of climatic changes, including a recent rise in frequency and intensity of Atlantic hurricanes.

(h) Benefit to MCBCL: Application of these tools in a long-term monitoring program for the NRE will provide MCBCL with a set of sensitive, rapid, highly specific, easily deployed, readily verifiable, and scalable (from specific habitats to the entire ecosystem) indicators that will address high priority concerns about sources and effects of key stressors impacting water quality. It will also allow MCBCL to establish a baseline of meaningful indicators against which to gauge short and long-term effects of management strategies aimed at protecting water quality and preserving ecological integrity of the NRE and adjacent wetlands and coastal waters. A comprehensive report and publications will address the utility and long-term application of these indicators coupled to BBN and ecosystem-level process modeling (Advanced Circulation model [ADCIRC], ESM, and watershed simulation model [WSM]) and remote sensing as a decision support tool for assessing water quality, habitat condition, causes and effects of environmental stressors resulting from local and regional activities over a wide range of scales.

(i) Schedule:

- Assess impacts of specific nutrient forms and amounts on algal community and HAB dynamics *July 2007–June 2011*
- Assess impacts of hydrologically variable conditions on algal community and HAB dynamics *July 2007–June 2011*
- Couple field pigment-optical measurements to remote sensing *July 2007–June 2011*
- Refine HAB predictions based on above measurements *July 2008– June 2010*
- Develop BBN *July 2009– June 2011*
- Utilize BBN for forecasting HAB potentials *July 2009– June 2011*
- Conduct further data analysis and develop BBN as a monitoring tool *July 2009 –June 2011*
- Prepare and deliver final report on utility/application of these techniques for assessing water quality and habitat condition, and effects of environmental stressors over a range of scales. *June 2011*

Scheduling Constraints: None, except for possible closure of Base areas due to future military exercises on the NRE. We will coordinate sampling with MCBCL if and when these take place.

Year 1 Go/No Go Decision Point: None identified.

Budget (Estimated):

- Year 1 (July 2007– June 2008): $213,000
- Year 2 (July 2008– June 2009): $186, 000
- Year 3 (July 2009 – June 2010): $175, 000
- Year 4 (July 2010 – June 2011): $80, 000
- Total (July 2007 – June 2011): $654,000

5.1.4.2 AE-2: Quantifying and Predicting Watershed Inputs of Nutrients, Sediments, and Pathogens

Senior Researcher: Mike Piehler (UNC-CH)

Supporting Researchers: Rachel Noble (UNC-CH), Craig Tobias (University of North Carolina at Wilmington [UNC-W]) and Mark Brush (Virginia Institute of Marine Science [VIMS])

Hypotheses:

1. Land use and environmental conditions (e.g., precipitation patterns, temperature, sea level) interact to control export of nutrients, sediment and pathogens from coastal watersheds.
2. Predictable patterns of loading of these materials exist for watersheds in different sections of the estuary and with and without military activity.
3. Simulation modeling can be used to predict the effects of changes in land-based activities on watershed exports of nutrients, sediments, and pathogens.

Technical Goals:

1. Identify and quantify tributary and tidal creek sources of nutrients and pathogens to the NRE.
2. Assess the impact of MCBCL land uses on estuarine water quality, including nutrient, suspended solid and FIB loading.
3. Determine the relative amounts of human fecal contamination contributed to the estuarine system, as opposed to animal sources of fecal contamination.
4. Determine dissolved inorganic nitrogen (DIN) source contributions from the watershed, indicate potential processes responsible for N uptake and transformations, and identify zones in the estuary where substantial N processing occurs.
5. Develop and compare a series of WSMs and produce an optimized decision-support tool for predicting watershed inputs of freshwater and pollutants to the NRE.

Technical Approach:

(a) Background:

Understanding the watershed inputs of nutrients, suspended solids and pathogens (or FIB) is critical to assessing system-wide water and habitat quality and to forecasting future changes that may occur. This research will address gaps in the understanding of the role that military lands play in the overall function of a watershed. We will utilize a variety of approaches, including assessing tributary and tidal creek freshwater discharge, determination of concentrations of nutrients, pathogens and FIB, surveys of natural stable isotope abundances and watershed and ecosystem modeling to achieve this goal. Our primary goal is to provide a realistic assessment of changes in estuarine water and habitat quality that are likely to result from representative changes in land use. To do this, we need to qualitatively and quantitatively assess export of nutrients, sediments, and pathogens from sub-watersheds with representative levels of military activity.

New advances in molecular biology have made it possible to quantify specific types of pathogens and indicators. Specifically, a variety of molecular screening and probing techniques are now available to detect the presence and distribution of potentially harmful viral and bacterial pathogens and determine potential sources (human versus non-human) of fecal contamination (Noble et al., 2006). In creeks identified as problematic via FIB measurement, we will conduct further analysis of water samples using the rapid Quantitative Polymerase Chain Reaction method for *Bacteroides thetaiotamicron* (Noble et al., in preparation; Shanks et al., in preparation), which is an exciting candidate for an alternative indicator of fecal contamination. We will incorporate these tools into our sampling program for the NRE and use this information to assist in strategies to mitigate fecal contamination that may be found in stormwater runoff to the NRE.

To further assess sources and transformations of nutrients stable isotope characterization of N, oxygen (O_2), and C will be conducted on components of the tidal creeks. The isotopic composition of N species ($\delta 15N$) will help discern DIN source contributions from the watershed, indicate potential processes responsible for N uptake and transformations, and identify zones in the estuary where substantial N processing occurs. Differences in ^{15}N and ^{18}O composition of nitrate, the dominant form of “new” N in the water column, from different sources can be used to discern source contribution to the total N loading.

The watershed modeling component has the purpose of (1) providing a focal point for the integration of historical, monitoring, and process-level data; (2) developing tools for the study of watershed inputs to the NRE; (3) developing useful management models and decision-support tools; and (4) serving as an adaptive management tool for guiding the monitoring program (e.g., de Jonge and DeGroodt, 1989). Several models currently exist to predict the fluxes of freshwater and pollutants from watersheds to receiving estuaries. These models vary in their temporal resolution and degree of parameterization and uncertainty, and they range from the mechanistic Hydrologic Simulation Program Fortran (HSPF) model (Bicknell et al., 1997), to the semi-empirical SPAtially Referenced Regressions On Watershed Attributes (SPARROW) (Alexander et al., 2001) and BasinSim (Dai et al., 2000) models, to the empirical models of Howarth et al. (1996) and the Nutrient Load Model (NLM) of Valiela et al. (1997). Further, these models vary in their representation of specific land-use types and best management practices (BMPs); e.g., HSPF will allow simulation of varying types of stormwater retention within developed land uses and a variety of BMPs, whereas the simpler models will be based on aggregate measures such as total impervious surface, major landuse classes, and watershed-scale retention and export. Although these models have been compared for large regional watersheds (Alexander et al., 2002), they have yet to be compared for their utility as adaptive management tools in relatively small coastal watersheds.

(b) Experimental Design:

Using an integrated experimental design, including temporally and spatially intensive in situ measurement of creek discharge, assessment of levels and properties of sediment, pathogens, and nutrients and watershed scale modeling will permit the determination of patterns in water movement and the delivery of pollutants in representative sub-watersheds. A focal point of our design will be to incorporate the use of the modern molecular and chemical approaches described below for tracing and assessing loading of pollutants from watershed into receiving waters.

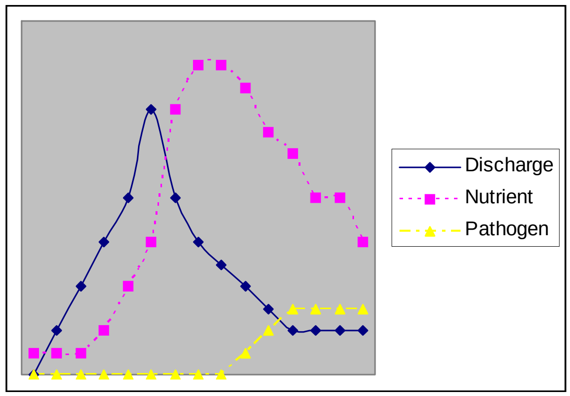


Figure 5-4. Hypothetical hydrograph and concentration curves for a model nutrient and pathogen.

Figure 5-4 depicts a hypothetical hydrograph, pattern of nutrient concentrations through time, and changes in concentration of a pathogen through time. This figure illustrates the type of information we will obtain about the delivery of pollutants from varied land uses. In this case, the concentration of nutrients continues to rise after the peak in discharge, indicating a large source of nutrients some distance up in the watershed. The pattern in pathogen concentration may suggest a groundwater source, with the highest levels occurring in the tail water portion of the hydrograph. Having a better understanding of these relationships will permit better management of MCBCL and will also help predict the impacts of changing land use on the timing and magnitude of nutrient loading from these watersheds.

(c) Methods:

An array of tidal creeks and tributaries spanning both **regional** spatial gradients and disturbance gradients will be instrumented. These creeks will include the following (**Figure 5-5**):

- Back-barrier – Freeman Creek (Site 10), Gilets Creek (Site 9)
- Polyhaline – Traps Creek (Site 7), Chadwick Bay (Site 8)
- Mesohaline – French Creek (Site 6), Town Creek (Site 5)
- Oligohaline – Wilson Bay (Site 3), Southwest Creek (Site 4)

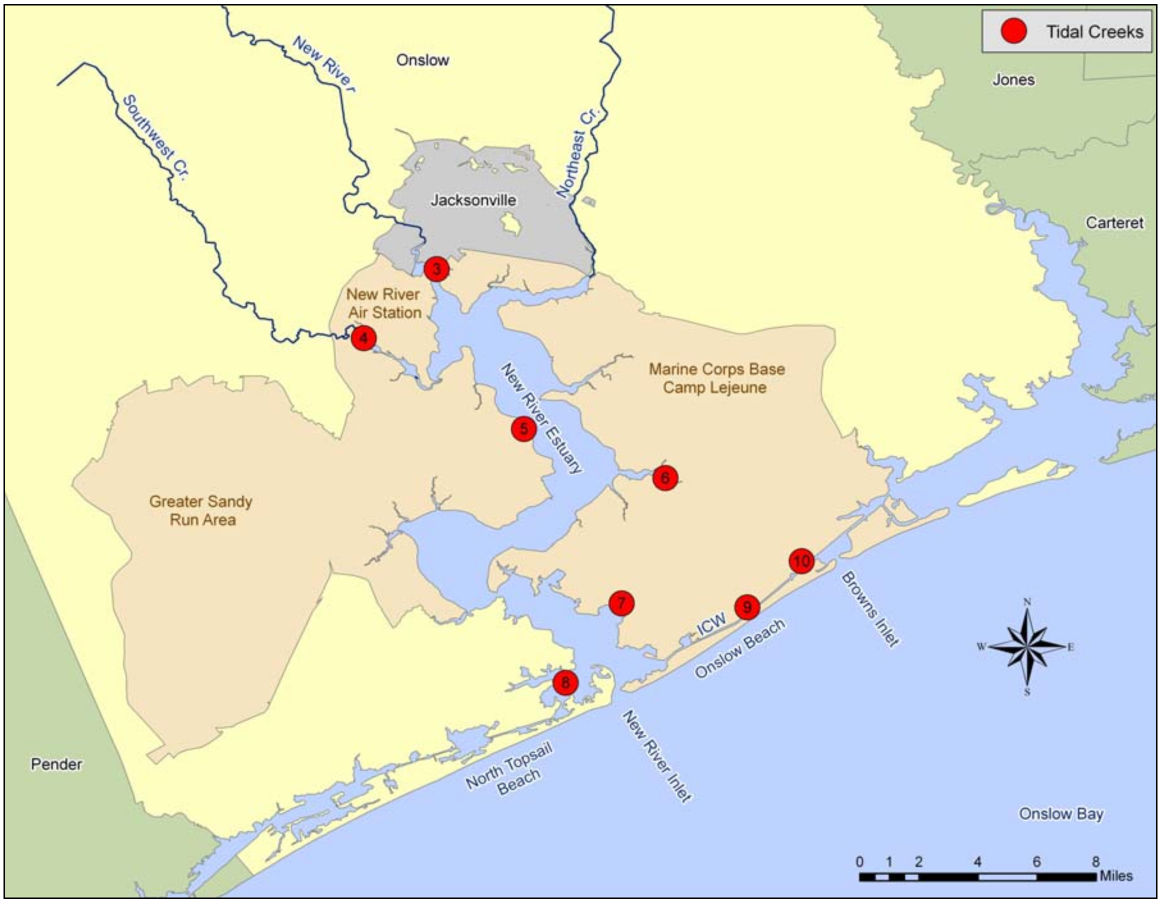


Figure 5-5. Tidal creek monitoring stations.

ISCO automated water samplers equipped with area-velocity modules and levels recorders will be deployed to continuously compute bi-directional flow. Attached YSI data sondes will continuously record temperature, dissolved oxygen (DO), pH, and conductivity. The load of nutrients, sediments, and pathogens will be calculated from the sum of daily water volume based on 0.5-hour records of water velocity and level paired with nutrient, sediment, and pathogen concentrations from monthly baseflow conditions and stormflow periods interpolated (or averaged) to a daily time scale. Daily loads of pollutants will be summed for each month. Nutrient, sediment, and pathogen loading during storms will be partitioned into before-peak, after-peak, and tail of the hydrograph. Nutrients will be quantified on a Lachat nutrient autoanalyzer, and suspended solids will be measured gravimetrically.

For FIB measurements, we will use Enterolert™ and Colilert-18® (IDEXX Laboratories, Inc.) to assess levels of the EPA mandated FIB *Enterococcus* and *E. coli*, respectively. Additionally, we will use the quantitative polymerase chain reaction approach to enumerate specific microbial contaminants in NRE waters. In creeks identified as problematic via FIB measurement, we will conduct further analysis of water samples using the rapid quantitative polymerase chain reaction (QPCR) method for *Bacteroides thetaiotamicron* (Noble et al., in preparation; Shanks et al., in preparation), which is an exciting candidate for an alternative indicator of fecal contamination. *Bacteroides* sp. makes up approximately one-third of the human fecal microflora, considerably outnumbering *Enterococcus* and *E. coli*. The *Bacteroidetes* group belongs to a group of non-spore-forming, gram negative, obligate anaerobes, so there is little concern over regrowth in the environment. More importantly, a range of human and animal-specific *Bacteroides* sp. markers have been developed, increasing the value of this potential indicator (e.g., Bernhard and Field, 2000; Carson et al., 2006). The species *B. thetaiotamicron* is highly abundant in human fecal waste, has been demonstrated to be closely linked to the presence of human fecal contamination, and is found in very low numbers (if at all) in animal feces (Wang et al., 1996). Finally, bacterial markers such as *Bacteroides* sp. have been shown to be potentially useful source-tracking tools. We will use a cost effective, rapid QPCR assay developed by Noble, and currently in use by Rich Haugland at EPA for *B. thetaiotamicron* targeting the 16S rRNA gene. As a target and potential alternate indicator, the utility of *B. thetaiotamicron* has been previously demonstrated (Carson et al., 2006). In eastern North Carolina and in urban stormwater outfalls of southern California, *B. thetaiotamicron* has been shown to be present in high concentrations in human-affected areas and at baseline levels in areas where human fecal contamination was demonstrated not to be present (Noble et al., in preparation).

We will monitor nitrate isotopes ($\delta^{15}N$ and $\delta^{18}O$) in a network of sampling stations dispersed through the subcatchments of the New River watershed. Stations will be selected along the pathway of increasing stream order in subcatchments that are representative of dominant land-use types in the New River watershed. This spatial scheme will permit characterization of N source contribution based on land-use, and allow examination of in-situ mixing and processing (attenuation) of N loads during transport to the head of the estuary (Mayer et al., 2002). Stations will be sampled at regular intervals and, because a large component of the N load exported from the watershed occurs during storms, we will also target select storm events dispersed through the seasons. Ammonium isotopes ($\delta\,^{15}N$) in the stream networks will also be monitored. Due to large isotopic fractionations during ammonia (NH_3) volatilization (Hoefs, 1997), the $\delta\,^{15}N$ should serve as an excellent in situ tracer for ammonium derived specifically from animal husbandry waste lagoons or agricultural applications of anhydrous ammonium fertilizer . Because it is desirable to extend nitrate stable isotope characterization into the estuary, we will use the recently developed ‘denitrifier method’ (Sigman et al., 2001; Casciotti et al., 2002) for this task. It is currently the only method that permits ^{15}N and ^{18}O analysis of nitrate in the brackish-saline waters found in the estuary. All isotopic analysis will be conducted at the UNC-W Center for Marine Science (CMS). The laboratory will be equipped with the capability to analyze all isotopes and sample matrices outlined in the Baseline Monitoring Plan. Isotope measurements are performed via continuous flow on a Thermo Delta V isotopic ratio mass spectrometry (IRMS) equipped with an elemental analyzer, Gas Bench, ‘denitrifier method’, and dissolved inorganic carbon/dissolved organic carbon (DIC/DOC) interfaces.

(d) Data Analysis: To avoid reliance on distributional assumptions, non-parametric techniques will be used whenever appropriate. Standard descriptive statistics will be calculated for variables of interest with principal reliance on sample quantiles, particularly in the case of skewed distributions. Two-sample comparisons of either counts or continuous measures will primarily be made with the Wilcoxon rank-sum test, and the Wilcoxon signed-rank test will be used to test for differences or changes in continuous quantities. Spearman (rank) correlations will be calculated unless there is specific reason to expect a linear association. Statistical modeling will primarily be carried out within the framework of generalized linear models after suitable exploratory analysis suggests appropriate link functions; any needed transformations, and the functional form of the underlying mathematical relationships. Repeated measures or other correlated data will initially be modeled using generalized estimating equations due to their robustness to misspecification of the correlation structure. Every effort will be made to describe data distributions, hypothesis tests, and modeling results in the simplest manner consistent with accuracy and reasonable completeness

Watershed Simulation Models (WSMs): We will take advantage of this unique opportunity of having measured stream fluxes to allow for real-world validation of watershed model output. The models listed above (HSPF, SPARROW, BasinSim, Howarth et al.,1996, and NLM) will be driven with measured atmospheric deposition, meteorological data (air temperature, wind speed, relative humidity, and precipitation at as detailed spatial resolution as possible), and GIS layers (Terrestrial Module), updated to include loss processes in fringing marsh and riparian zones (Coastal Wetlands Module), and validated against measured stream fluxes of freshwater, nutrients, sediments, and pathogens. Models will be compared for their ability to predict fluxes with the correct timing and magnitude, with an emphasis on correct prediction of frequent and large infrequent storm events and on the long-term seasonal cycle in base flow, and for their utility as management tools using indices such as Akaike’s Information Criterion, Håkanson’s (1995) Information Value, and the cost function (e.g., Friedrichs et al., in press) to identify the optimal decision-support modeling tool based on the balance between model complexity, data requirements, and predictability. The models will then be used to project the effects of both natural and anthropogenic stressors and a variety of ecosystem management activities in the watershed (e.g., storms, land use change, PB, clear-cutting, training, traffic, and BMPs). For example, storms will be simulated by depositing appropriate amounts of precipitation over the watershed surface reflective of small, moderate, and severe (e.g., hurricanes) events of varying duration. Impacts of changing land use will be assessed by changing the GIS input data according to projected build-out scenarios (e.g., increasing percent of residential land and/or impervious surface in targeted regions). Impacts of PB, clear-cutting, and training activities will be simulated using results from the Terrestrial Module (e.g., changes in soil organic content and plant productivity), the Atmospheric Module (e.g., effect of PB on atmospheric deposition to the watershed), and best estimates from the extensive literature (particularly on clear-cutting and BMPs) to simulate targeted impacts in specific regions of the watershed. By comparing the predictions of multiple models we gain the advantage of increasing confidence in specific predictions in the case of convergent model output. Conversely, divergent predictions identify areas for future research and model refinement. Modeling results will be used to drive the ESM developed by Research Project AE-3. As new data are acquired through monitoring, experimentation, and remote sensing, they will be used to update the WSM and provide revised predictions for adaptive management.

(e) Environmental Indicators, Tools and other Outcomes:

The application of this research lies in the utility of the data for planning Base activities ranging from training to large capital improvements. Tools will include a series of WSMs (see above) that will connect land activities to exports of nutrients, sediments and pathogens. Using the optimal WSM, MCBCL will be able to assess the likely water quality impacts of Base activities. Creek nutrient, pathogen and sediment loads can be highly variable and are not generally comparable across broad spatial scales. We will rely on internal indicators of desired condition by calculating loads in relatively un-disturbed creeks and comparing them to more disturbed creeks. Because we are also interested in sediment load as a positive feedback to marshes, we will assess thresholds for minimum sediment loading required to support marsh accretion. These site-specific internal indicators will be of significant value to MCBCL for assessing ecosystem condition in the future. The microbiological contaminant analysis portion of this work will use alternative indicators to partition sources of fecal contamination in the NRE. The proposed work is on the forefront of microbiological water quality monitoring technology and has the potential to yield suites of indicators that can be utilized in TMDL development and implementation along many coastal areas of North Carolina.

(f) Linkages to other Modules:

These activities will be directly linked to the creek and estuarine monitoring in this module. This research is co-located with the monitoring sites for the tidal creeks; however it is in no way redundant. The data from this research project will be much more temporally intensive and will permit conclusions about when (e.g., storm versus base flow) pollution is delivered from streams and not simply how much. Delivery of nutrients, suspended material, and FIB from creeks to the estuary is an important materials transport mechanism and is often affected by changes in land activities. This monitoring activity will also be linked to the Coastal Wetlands Module. For marshes, suspended solids are beneficial rather than detrimental. The ability of many marshes to maintain their elevation is dependent upon a supply of suspended sediments. Our creek sites include several areas where the Coastal Wetlands Module will be measuring elevation changes in marshes. Linking their elevation measurements to creek-specific sediment supply will be an important step forward toward mechanistic links between watershed activities and marsh sustainability. The research in this module will also be linked to the Terrestrial Module. The stream sampling sites represent an integration of the effects of watershed processes on the load of nutrients, sediments, and pathogens transported from the landscape. Finally, this research will be integrated with the Atmospheric Module in that precipitation will drive stream discharge and deposition of N may be an important contributor to stream N loading.

(g) Military Drivers:

1. Facilitate complete utilization of MCBCL lands by identifying potential sources of nutrients, suspended material, and fecal contamination and by forecasting water quality impacts of varied land uses
2. Ensure safety of Base personnel and visitors to primary contact with NRE waters through improved understanding of pathogen exposure risks
3. Determine the relative levels of fecal contamination found in estuarine waters, and relate these contamination levels to risk to MCBCL personnel
4. Determine areas that are contributing to microbiological contaminant loading and assess the potential for application of management actions to mitigate contamination.
5. Improve Base management of sediment, nutrient, and pathogens loadings through simulation modeling

(h) Benefit to MCBCL:

Tools, including an optimal WSM and map series, and site-specific sediment, pathogen and nutrient loading data will allow MCBCL to assess its impacts on current and future NRE water quality. This research will be a proactive approach to avoid actions under the CWA related to impairment from either FIB or chlorophyll *a* exceedances. Data and models will be directly applicable to the development of TMDLs in 303(d) listed waters identified as impaired by either elevated chlorophyll a or FIB, including the successful implementation of appropriate mitigation strategies. FIB and pathogen data will permit identification of fecal indicator signal as opposed to actual human fecal contamination and non-human contamination. Both stable isotope and pathogen analyses will allow some degree of source assessment, enhancing MCBCL's ability to remediate any detected stream-borne pollution.

(i) Schedule:

- Instrument tidal creek field sites *Summer–Fall 2007*
- Assess loading of pathogens, suspended solids, and nutrients from tidal creeks and tributaries, conduct stable isotope surveys *2007–2011*
- Relate loading data to atmospheric, terrestrial and marsh data and to land use patterns *2007–2011*
- Develop HSPF, SPARROW, BasinSim, Howarth, and NLM models *2008–2011*
- Determine relative contributions of nutrient, suspended solid, and pathogen loading from tidal creeks and

tributaries to the NRE System *2010*

- Conduct land use change simulations to assess impacts of Base development on water quality *2011*
- Prepare and deliver final report on nutrient, suspended sediment, and pathogen loading from tidal creeks and the optimized, decision-support models to predict water quality implications of land use changes *2011*

Scheduling Constraints: None

Year 1 Go/No Go Decision Point: None identified.

Budget (Estimated):

- Year 1 (July 2007– June 2008): $180,000
- Year 2 (July 2008– June 2009): $177,000
- Year 3 (July 2009 – June 2010): $150,000
- Year 4 (July 2010 – June 2011): $ 17,000
- Total (July 2007 – June 2011): $524,000

5.1.4.3 AE-3: Developing Indicators of Ecosystem Function for Shallow Estuaries: Benthic Functional Responses in the New River Estuary.

Senior Researcher: Iris Anderson (VIMS)

Supporting Researchers: Mark Brush (VIMS), Mike Piehler (UNC-CH), Carolyn Currin (National Oceanic and Atmospheric Administration [NOAA])

Staff: 3 graduate students (2 VIMS, 1 UNC/NOAA); 2 technicians (33 months VIMS; 18 months NOAA)

Hypotheses:

1. In shallow estuaries like the NRE, benthic primary production exceeds pelagic primary production.
2. Water quality and nutrient cycling in the NRE are regulated by the activity of benthic primary producers.
3. The ratio of benthic/pelagic primary production and total system metabolism will decrease in areas with elevated sediment or nutrient input (storm water runoff from increased impervious surfaces, erosion from military training, shoreline erosion from vessel traffic, confined animal feeding operations, and wastewater effluent).
4. With increasing eutrophication and turbidity, phytoplankton will become increasingly important, decreasing the capacity of the system to buffer pollutant loading, thereby increasing the likelihood of CWA violations and degradation of habitat and living resources.

Technical Goals: Elucidate the role of BMA and microbial N cycling processes in modulating the effects of disturbance along gradients of turbidity and nutrient enrichment in the NRE.

We will develop indicators of benthic and ecosystem function that respond to a variety of stressors and that are quantifiable and easily measured. This research will test indicators across gradients of stress and allow us to distinguish benthic and ecosystem responses to local (MCBCL) versus regional (Jacksonville) stressors in the NRE. Local impacts will be assessed by closely located, paired sites (one impacted, one relatively pristine). Regional impacts will be assessed through paired sites near Jacksonville and by comparing sites along the estuarine salinity gradient. Results of these studies and other projects will be integrated into a predictive ESM to understand system response to stressors and to serve as a decision support tool for adaptive management and scenario testing of potential restoration strategies.

Technical Approach:

(a) Background: Human activities along the land margin of the NRE affect delivery of nutrients and sediments to the shallow littoral zone ecosystems that make up most of the surface area of the lower estuary (**Figure 5-6**). These ecosystems serve a critical role in modulating ecosystem responses to stressors such as turbidity and nutrient over-enrichment and serve to retain or transform N during its transport to the coastal ocean (Nixon, 1997; Valiela et al., 1992). The benthic microbial community, including both autotrophic and heterotrophic components, plays a critical role in ecosystem function by regulating organic matter production, decomposition, and nutrient transformations within sediments and exchanges of oxygen and nutrients with the overlying water column with significant implications for eutrophication, nutrient removal, hypoxia, contaminant transport, and degradation, as well as food web support of higher trophic levels (Anderson et al., 2003; Middelburg et al., 2000; Nixon et al., 1995; Reay et al., 1995; Sundbäck et al., 2000). Studies have shown that in response to changes in light and nutrient availability, shallow littoral zone systems may respond with alterations in autotrophic species composition that reduce light penetration to the benthos, cause shifts in food web structure, and accelerate nutrient cycling and hypoxia (Cloern, 2001; NRC, 2003; Boynton et al., 1996; Bartoli et al., 1996; Nixon et al., 2001; Sundbäck et al, 2003; McGlathery et al, 2001). Nutrient flux studies in shallow coastal systems have demonstrated that benthic primary producers, BMA and seagrasses, as well as sediment microorganisms, play a key role in removing, retaining, and transforming nutrients from the water column and, thereby, reduce the potential for water column eutrophication (Anderson et al., 2003). In addition, results of an ongoing SERDP-funded project in Chesapeake Bay have demonstrated that BMA play a key role in supporting and buffering benthic meio- and macrofaunal populations from stressors, including low oxygen, toxic contaminants, and nutrient over-enrichment. Metrics related to benthic, pelagic, and whole-system metabolism are robust and easily measurable indicators of ecosystem health. We hypothesize that turbidity and nutrient enrichment will be key stressors regulating BMA and seagrass function in the NRE. We will relate benthic, pelagic, and system metabolism and nutrient fluxes to inherent optical properties, watershed loadings of nutrients, sediments and organics, and adjacent land uses, including military training, wastewater discharge, nutrient enrichment, development, and stormwater runoff. We hypothesize that increases in land-based nutrient and sediment loading will reduce light penetration and cause a shift in the dominant primary producers from BMA and seagrasses to phytoplankton. This will lead to increased occurrence of hypoxia and reduced food resources for fish and shellfish. Sampling sites will be chosen to distinguish local from regional responses and to determine the role that wetlands play in modulating benthic responses to disturbance in the adjacent uplands.

Results of experimental studies, Research Projects AE-1 and AE-2, and all other DCERP modules will be integrated and scaled to the entire estuary using a mechanistic, spatially explict ESM to predict biogeochemical cycling of carbon, nitrogen, phosphorus, and dissolved oxygen, and food web dynamics from nutrient and sediment inputs through secondary production available to fish and shellfish. The ESM has the purpose of (1) providing a focal point for the integration of historical, monitoring, and process-level data ***for all DCERP modules***; (2) studying NRE structure, function, and response to natural and anthropogenic stressors; (3) serving as a tool for guiding the monitoring program (e.g., de Jonge and DeGroodt, 1989); and (4) developing a useful management model and decision-support tool for MCBCL and the surrounding communities.

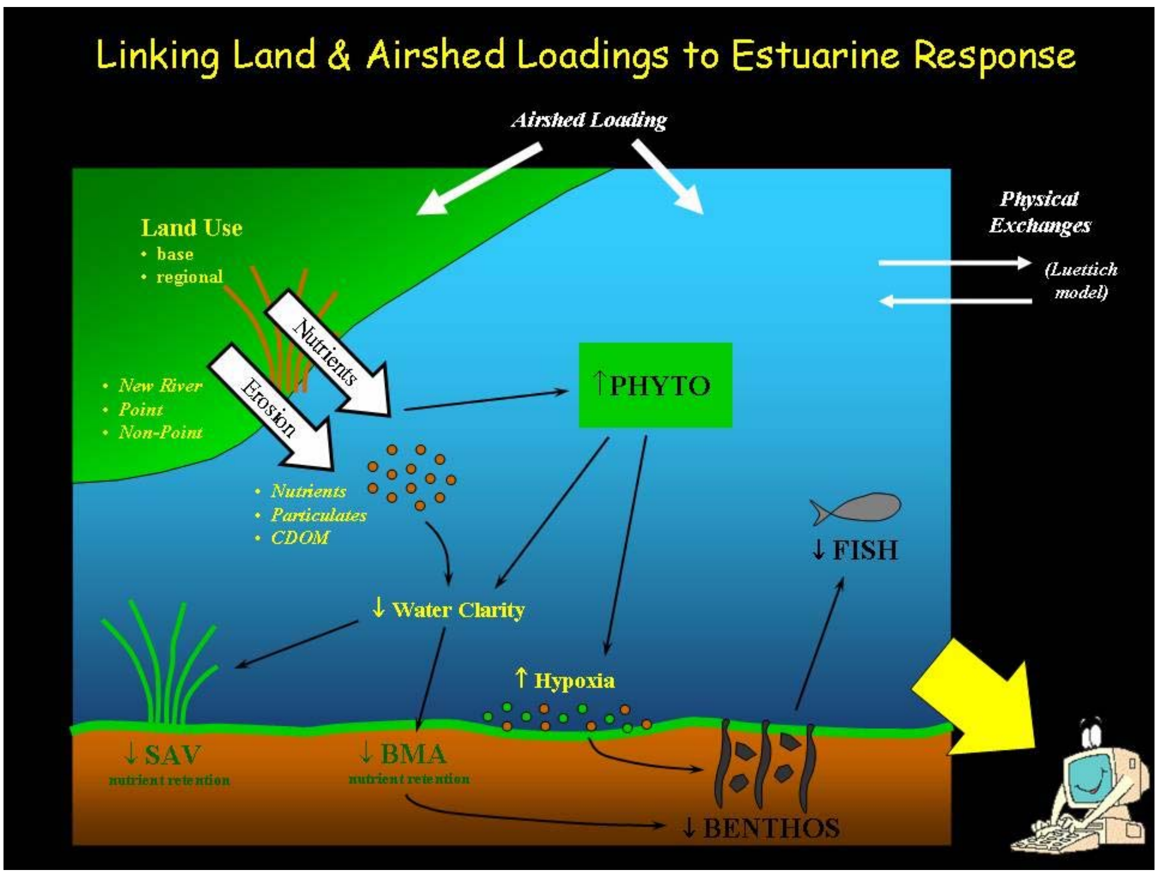


Figure 5-6. Conceptual diagram for Project AE-3.

(b) Experimental Design

Objective 1: Determine the effects of specific military training exercises at splash zones on water column light quality and quantity; compare light quality and quantity and sediment characteristics at impacted and non-impacted sites across the estuary

1. Assess light quality and quantity across the estuarine system at both low impact sites and at sites affected by both non-military and military activities. Measure:
   a. PAR (continuous measurements during military exercises)
   b. turbidity (continuous measurements during military exercises)
   c. light attenuation
   d. benthic chlorophyll
   e. sediment properties including grain size, organic content, pore water nutrients

Objective 2: Assess role of BMA in modulating the effects of disturbance along gradients of turbidity and nutrient enrichment. Paired sites (impacted versus non-impacted) will be chosen to distinguish the effects of specific disturbances on BMA function. At these paired sites, we will do the following:

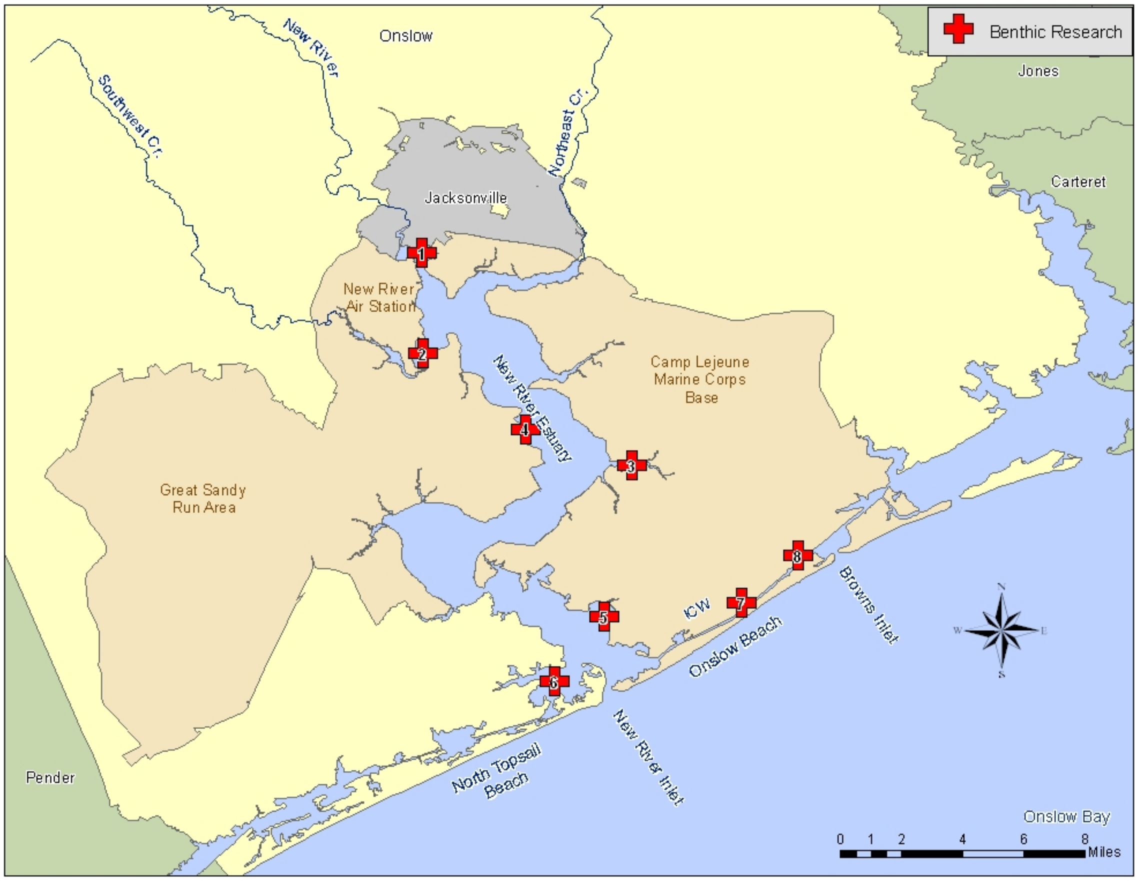
1. Develop a bio-optical model (OPTMOD) to relate light quality and quantity to benthic and pelagic metabolism, including
   a. benthic and pelagic gross and net primary production
   b. benthic and pelagic respiration
   c. total ecosystem metabolism
   d. ratio of benthic/pelagic primary production
   e. sediment/water dissolved inorganic and organic carbon, nitrogen, and phosphorus fluxes.
2. Relate nutrient enrichment in the water column to benthic and pelagic metabolism, including
   a. benthic and pelagic gross and net primary production
   b. benthic and pelagic respiration
   c. total ecosystem metabolism
   d. ratio of benthic/pelagic primary production
   e. sediment/water dissolved inorganic and organic carbon, nitrogen, and phosphorus fluxes
   f. sediment organic nitrogen mineralization
3. Measure the capacity for microbial processes in sediments to remove N by denitrification in sediments exposed to various levels of nutrient enrichment
4. Assess the ability of wetlands to mitigate disturbances due to land use and military activities. At sites with and without fringing wetlands and with various levels of disturbance, use OPTMOD to determine light quality and quantity and resulting impacts on benthic primary production and respiration.

Objective 3: Develop robust, but easily measured indicators of ecosystem function that are sensitive to a variety of stressors.

1. Proposed indicators that we will relate to specific disturbances include:
   a. The ratio of benthic to pelagic primary production
   b. The ratio of production to respiration (shown to be an indicator of disturbance in an ongoing SERDP project)
   c. The sediment/water DIN flux
   d. Denitrification efficiency (N_2-N)/(N_2-N + DIN flux)
   e. Benthic community composition and abundance (BMA, SAV)
2. Indicators will be related to specific land uses, both regional and local (MCBCL), including wastewater discharge, nutrient enrichment, sediment erosion due to specific military activities, stormwater runoff, and increased development.

Objective 4: Integrate above data and other DCERP data into a predictive ESM to understand system response to stressors and to serve as a decision support tool for adaptive management and scenario testing of potential restoration strategies.

(c) Methods: This project will leverage a National Science Foundation–funded controlled mesocosm study of BMA uptake and turnover of N performed in Virginia shallow coastal embayments and will build on a current SERDP-funded study of benthic function along disturbance and salinity gradients in the Chesapeake Bay. During Year 1, an intensive survey of benthic habitats, including determinations of the biological, physical, and chemical characteristics of sediments, optical quality, and quantity throughout the NRE will occur. Intensive monitoring of water optical quality and quantity as well as chemical parameters such as chlorophyll, nutrients, and total suspended solids (TSS) will be performed during MCBCL training maneuvers at specific splash zones within the estuary. During these intensive studies, continuous data will be collected by deployment of logging data sondes and light sensors. Based upon the benthic survey, mapping, historic data, and in consultation with MCBCL Natural Resource managers, regionally distributed stations will be selected throughout the NRE (**Figure 5-7**). Stations will be stratified based on level of disturbance (impacted versus non-impacted), sediment type (if possible), and physical energy regime (wave energy, resuspension). Paired impacted and non-impacted sites will include areas affected by impervious surface on the Base, downstream of impacts area, adjacent to splash zones, and affected by wastewater discharge. The numbers of stations required to provide statistically significant results will be determined by power analyses of existing data from the SERDP-funded study of the Chesapeake Bay.



Legend: (1) Wilson Bay; (2) Southwest Creek; (3) French Creek; (4) Town Creek; (5) Traps Creek; (6) Chadwick Bay; (7) Gillets Creek; (8) Freeman Creek.

Figure 5-7. New River Estuary – benthic research stations.

During Year 2, study sites in the low- to mid-mesohaline zone will be chosen in conjunction with the Coastal Wetlands Module. Sites will be stratified to assess impacts of local and regional land use, including the role that wetlands play in mitigating the impacts of land use and improving light quality and quantity. During Year 3, study sites will be chosen in the high mesohaline and polyhaline zones, including back barrier sites. Development of the ESM will take place during all years of the study. During Year 4, we will complete analyses of samples taken during the previous years, use data to validate the ESM developed during Years 1–3, and test various scenarios using the ESM. We will endeavor to choose stations within individual salinity regimes that reflect the range of disturbance within that regime. Studies will be performed during each of four seasons.

Concurrent with each seasonal study, we will determine the inherent optical properties of the water column at each site using a Wetlabs AC-Spectra instrument (Gallegos et al., 2005), and measure the three optically active constituents (turbidity, chlorophyll and colored dissolved organic matter) in the water column. Radiative transfer modeling (Mobley, 1994) can then be used to predict apparent optical properties, specifically the diffuse attenuation coefficient K_d (Gallegos, 2001), which determines the amount and quality of light reaching the bottom, which in turn controls the rate of benthic microalgal production (Pinckney and Zingmark, 1993; MacIntyre and

Cullen, 1996). We will measure the metabolism of benthic microalgae, the water column, eelgrass, and any dominant macroalgae by developing series of photosynthesis-irradiance curves in a light-gradient box (Goebel et al., 2006). Metabolic rates will be quantified from changes in dissolved oxygen concentrations over time as measured with an YSI-5100 or microelectrode system. Sediments and their pore water will be characterized for sediment grain size, nutrients, organic content, and BMA biomass. Sediment chlorophyll *a*, corrected for phaeophytin, will serve as a surrogate for BMA biomass. The number of cores required for benthic measurements of metabolism and nutrient cycling rates will be determined by power analysis of results of nutrient cycling and metabolism studies done for the SERDP-funded study in the Chesapeake Bay. Sets of cores taken randomly at paired sites (impacted versus non-impacted) within the same salinity regime will be stratified to take into account sediment type and physical regime (if possible) and incubated for measurements of metabolic and nutrient cycling rates, mineralization, and denitrification.

For determinations of primary production, respiration and nutrient fluxes, cores will be incubated under ambient conditions in a temperature and light-controlled environmental chamber over a 24-h light/dark cycle and samples taken at 6-h intervals as described by Anderson et al. (2003). Nitrogen mineralization will be measured using a $^{15}NH_4^+$ isotope dilution technique (Anderson et al., 2003). Denitrification and N fixation will be measured following addition of $^{15}NO_3^-$ and using a combination of isotope pairing and membrane inlet mass spectrometry techniques (An and Joye, 2001). All isotopic analyses will be performed at UNC-W CMS via continuous flow on a Thermo Scientific Delta V IRMS. To synthesize results from benthic and water column metabolic measurements, and to provide a useful indicator of disturbance, we will use high frequency time series oxygen data from deployed sensors and the AVPs (Research Project AE-1) to quantify total ecosystem metabolism.

All metabolic and nutrient cycling rates and OPTMOD from this research project, along with watershed loadings (Research Project AE-2), and data from all other DCERP modules will be used to parameterize the ESM for the NRE, which will include components from nutrients through fish. The integrative nature of the ESM for the DCERP project is highlighted in **Figure 5-8**, which illustrates data sources for model construction and validation.

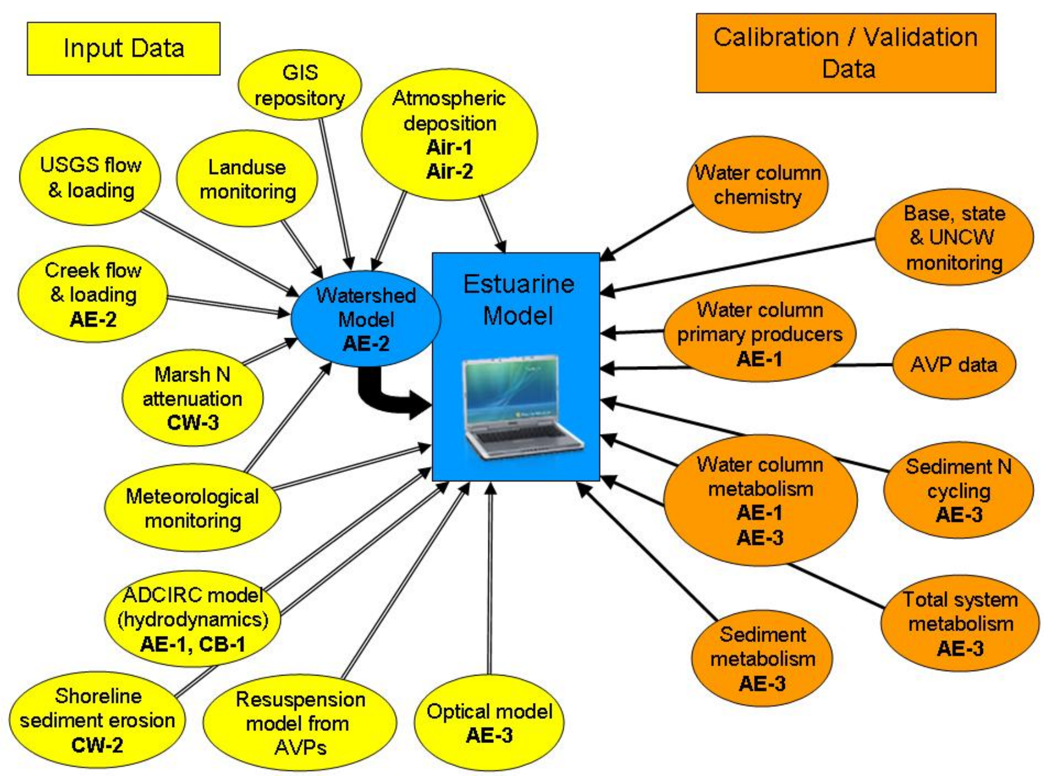


Figure 5-8. Linkages between DCERP project data and the linked WSM-ESM developed in research projectsAE-1, AE-2, and AE-3.

The ESM will begin as a high complexity, mechanistic model of the NRE with a high degree of parameterization and low degree of aggregation typical of the models currently being employed in TMDL development in estuaries around the country (Park et al., 1995). The model will be coupled to the ADCIRC hydrodynamic model (Research Project AE-1) and used to understand NRE function, response to anthropogenic and natural stressors, and the role of the littoral zone in mitigating nutrient and sediment loading, in controlling water quality, and as a food source to higher trophic levels. Although these highly detailed models are ideal for heuristic study of ecosystem structure and function, the large amount of parameterization and uncertainty in these models weakens their utility for making robust predictions for management (e.g., Reckhow, 1994, 1999). Once the full scale model is completed, we will use simulation results and a series of innovations (see below) to simplify the ESM to an “intermediate complexity” version with reduced parameterization and increased predictability, of the type being called for by multiple investigators over the last decade (e.g., Duarte et al., 2003). The intermediate complexity version of the ESM will be more suitable for use in management applications and as a decision-support tool as it will contain fewer parameters and thus be susceptible to reduced error propagation.

(d) Data Analysis: Site differences in metabolism or N cycling process rates and physical/chemical properties will be determined using standard analysis of variance and regression techniques. Multimetric methods such as Principle Components Analysis will be performed on multiple variables indicative of environmental condition and including both historic and current data to determine the variables most responsible for differences observed between sampling sites in the NRE.

The ESM will be constructed using the Neuse Estuary Eutrophication Model and 2 models developed for the nearby York River Estuary, Virginia, as a template (Buzzelli et al., 1999; Sin and Wetzel, 2002). The model will simulate concentrations and dynamics of inorganic, organic, and particulate nutrients (N,P, and Si), phase organic compounds (POC), DOC, phytoplankton (5 groups), BMA, eelgrass and its epiphytes, macroalgae if significant biomass exists in the NRE, meso- and microzooplankton, benthic macro- and meiofauna, DO, metabolism, and energy available to support fish and shellfish. A series of innovative formulations developed to increase model predictive ability and utility in guiding management will be used from Brush (2002); Brush et al. (2002); Brawley et al. (2003); and Brush and Nixon (in prep) to convert the model to an intermediate complexity version suitable as a decision support tool for MCBCL. The models will operate with daily resolution at first (although with a time step of a few hours), and will be adapted to hourly resolution if necessary. Exchanges between relatively coarse spatial elements within the NRE will be obtained from the ADCIRC model for development of the ecosystem model, with complete coupling at the full three-dimensional (3-D) resolution of the ADCIRC model by Year 4. The initial coarse resolution facilitates the need for multiple, fast executing model runs and sensitivity tests always required during development of biological models. A full sensitivity analysis of model parameters will be conducted along with simulations with stochastically varying parameters to propagate error and quantify uncertainty (e.g., Kremer, 1983).

(e) Environmental Indicators, Tools and other Outcomes: Based upon our previous SERDP program (Anderson and Schaffner, unpublished), promising indicators of benthic ecosystem health in subtidal littoral zone systems include:

1. The ratio of production to respiration
2. Net ecosystem metabolism
3. The sediment/water DIN flux
4. Denitrification efficiency (N_2-N)/(N_2-N + DIN flux)
5. Benthic community composition and abundance (BMA, SAV)

Many of these parameters are related to metrics of both BMA community composition and abundance and have been shown to vary across disturbance gradients, including turbidity and nutrient enrichment. Results will be used to determine if the same (or different) indicators apply at the local (MCBCL) and regional scale. A full-scale ESM and intermediate complexity ESM will be produced, with the latter being provided to MCBCL as a decision-support tool to guide NRE management and CWA compliance.

(f) Linkages to other Modules: Our research will be informed by, and closely coordinated with Research Projects AE-1 and AE-2, as well as the Coastal Wetlands Module research projects. This project is highly complimentary to Research Project AE-1 whose focus is on changes in MA community structure as an indicator of ecosystem state. Here we focus on changes in MA and microbial community function, and the role the microbial-mediated processes play in shaping water quality in shallow water estuaries. In our consideration of shoreline erosion and its effects on optical quality, we are collaborating with the Coastal Wetlands Module (Research Project CW-2) and in our assessment of sediment and nutrient loading we are linked to Research Project AE-2 and tidal creek monitoring. Results from all other projects and modules will be synthesized in the ESM.

(g) Military Drivers:

- Need for easily measured indicators of estuarine ecosystem response to stressors (turbidity, nutrient over-enrichment, chemical contamination) resulting from various military activities (vehicular impacts, training activities such as splash points and LCAC operations, and non-military activities (storm water control and sewage treatment).

- Need for a predictive ecosystem model, parameterized with data collected in the NRE, that will serve as a decision-support tool for guiding management and allowing scenario testing of various remediation activities for restoration of the NRE, maintenance of water quality, protection of habitat and living resources, selection of sites for marsh restoration and shoreline stabilization.
- Need for a modeling tool for development of TMDLs to comply with the CWA, EPA, and State requirements.

(h) Benefit to MCBCL: The benthic indicators developed in this research project will assess the effects of a variety of stressors on benthic health and determine susceptibility and resilience of the system to ecosystem impairments such as increased turbidity, nutrient concentrations, eutrophication and hypoxia/anoxia. This project will yield sensitive indicators of trophic status and materials cycling that can distinguish responses to changing eutrophication in the NRE and other temperate estuaries (Mallin et al., 2005). The sampling strategy employed will distinguish benthic responses to local (MCBCL) versus regional stressors. The intermediate complexity ESM will serve as a decision-support tool for Base managers, allowing personnel to test various management scenarios (including TMDL development) for effectiveness in maintaining ecosystem health and guiding management strategies aimed at improving ecosystem integrity within the NRE and meeting the requirements of the CWA.

(i) Schedule:

Year 1 – July 1 2007 – June 30 2008: Benthic system characterization and mapping.

1. Identification of various land use effects on optical quality and quantity throughout the NRE
2. Biological, chemical, and physical characterization of sediments over 4 seasons throughout the NRE.
3. Intensive measurements of optical and water quality responses during MCBCL maneuvers at splash points.
4. Final choice of sampling sites.
5. Development and calibration of the ESM.

Year 2 – July 1, 2008 – June 30, 2009: Determinations of relationships between optical properties and water quality on benthic function and system metabolism at paired stations representing high vs low impacts in the low to mid mesohaline zone. Seasonal measurements of:

1. Optical properties
2. Nutrient fluxes
3. Benthic and pelagic metabolism
4. Nitrogen cycling process rates
5. Continued development and calibration of the ESM

Year 3 – July 1, 2009 – June 30, 2010: Determination of relationships between optical properties, water quality, and wetland mitigation on benthic function, and system metabolism at paired stations representing high versus low impacts in the high mesohaline and polyhaline zones. Seasonal measurements of:

1. Optical properties
2. Nutrient fluxes
3. Benthic and pelagic metabolism
4. Nitrogen cycling process rates
5. Link the ESM to WSMs and ADCIRC model

Year 4 – July 1, 2010 – June 30, 2011

1. Complete all laboratory and statistical analyses of data
2. Validate linked ESM and run various ecosystem simulations; finalize intermediate complexity ESM

Scheduling Constraints: None

Year 1 Go/No Go Decision Point: None identified.

Budget (Estimated):

- Year 1 (July 2007 – June 2008): $200,000
- Year 2 (July 2008 – June 2009): $268,000
- Year 3 (July 2009 – June 2010): $270,000
- Year 4 (July 2010 – June 2011): $ 148,000
- Total (July 2007 – June 2011): $886,000

5.2 Coastal Wetlands Module

5.2.1 Introduction

Coastal marshes are a vital component of the estuarine landscape (**Figure 5-9**) and link terrestrial and freshwater habitats with the sea (Levin et al., 2001). These interactions include the exchange of solutes (including nutrients) (Jordan et al., 1983), fauna, and sediment between marsh, estuary and adjacent landforms. In the intertidal zone, marshes, oyster reefs, and tidal flats help to stabilize sediments and minimize erosion from wind waves and boat wakes (Knutson et al., 1982; Moller et al., 1999; Cooper 2005). Wetlands improve water quality by acting as nutrient transformers and by trapping sediment (Harrison and Bloom, 1977; Valiela and Teal, 1979; Morris, 1991). Generally speaking marshes consume (denitrify) nitrate dissolved in flood water and, thus, have a beneficial effect on estuarine water quality. In addition, coastal wetlands provide critical habitat area for a diverse group of estuarine organisms, serve as nursery habitat for commercially important fishery species (Kneib, 1997), and provide recreational opportunities for people.

The coastal wetlands of this module are defined as the vegetated and non-vegetated intertidal habitat in salt and brackish waters and include the salt marshes along the lower NRE shoreline and ICW to 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)*.

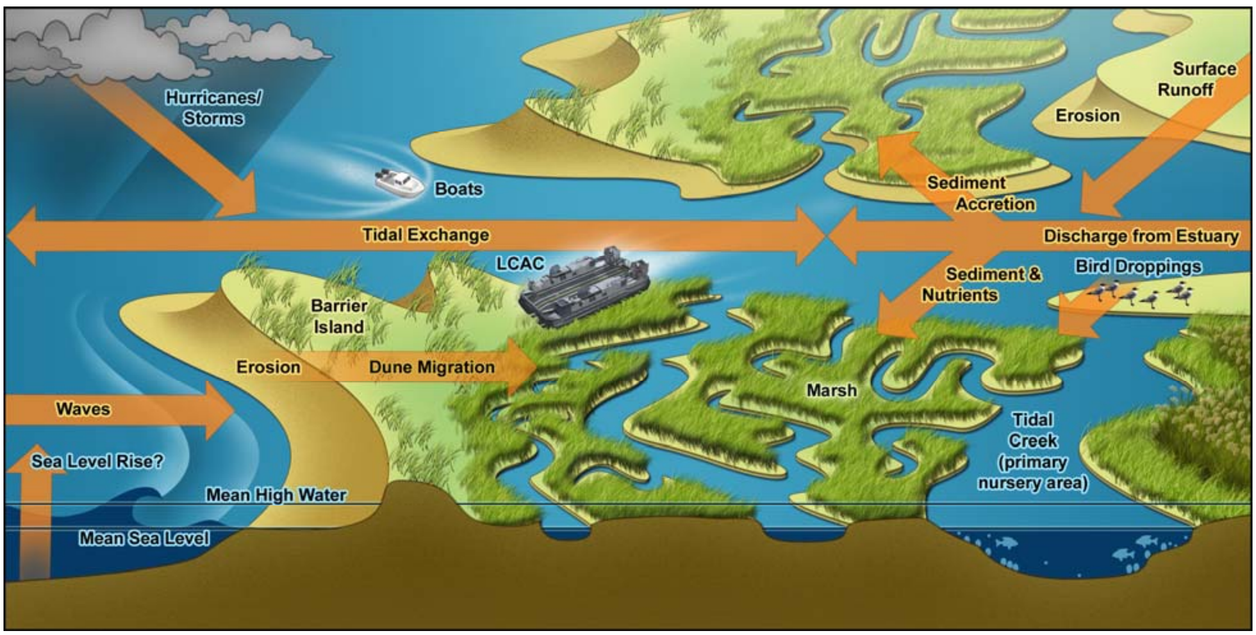


Figure 5-9. Conceptual model for the Coastal Wetlands Module.

Figure 5-9 presents the conceptual model for the Coastal Wetlands Module, illustrating the complementary nature of these critical estuarine physical, chemical, and biotic processes and interactions. The area of marsh in the New River Basin represents about 10% of the surface area of open water and, thus, is likely to have an impact on water quality. Marshes also provide a platform over which the barrier dune system can migrate, and the dunes protect the marshes from erosive wave energy that would otherwise degrade them. Likewise, the marsh can migrate over the terrestrial landscape in response to rising sea level.

The following three research projects (**Table 5-2**) address challenges that are associated with stresses imposed as a consequence of MCBCL and other direct anthropogenic activities and of global climate change, particularly sea-level rise.

Table 5-2. Coastal Wetlands Module Research Project Title, Senior Researcher, Benefit to MCBCL, and Duration of Project

Project	Research Project Title	Senior Researcher/ Duration
CW-1	*Determine Responses of Marsh Vegetation and Surface Elevation to Nutrients*	**Senior Researcher:** Jim Morris
	Outcomes and benefit to the Base: Data derived from these research activities will be used to parameterize a model of sediment accretion, forecast the marsh response to stressors (amphibious maneuvers and sea-level rise), and will quantify the marsh response to fertilization by N and P (a potential mitigation strategy).	**Duration:** 7/07–6/11
CW-2	*Forecast influence of natural and anthropogenic factors on estuarine shoreline erosion rates*	**Senior Research:** Mark Fonseca
	Outcomes and benefit to the Base: This work will inform shoreline stabilization and wetland restoration efforts, provide input to invasive species management concerns, and will assess impacts of tactical vehicles.	**Duration:** 7/07–6/11
CW-3	*Hydraulic exchange and nutrient reactivity in the NRE wetlands*	**Senior Researcher:** Craig Tobias
	Outcomes and benefit to the Base: Data derived from these research activities will provide information on the value of the marshes as nutrient transformers and the magnitude of subsurface nutrient flux to the estuary.	**Duration:** 7/08–6/11

5.2.2 Knowledge Gaps in Conceptual Model and Research Needs

Given the importance of the estuarine shoreline for military training activities, as well as its role in protecting building structures, it is crucial that research be conducted to address estuarine shoreline erosion within the NRE. A previous study by the U.S. Army Corps of Engineers (USACE, 2001) estimated recession rates in the NRE ranging from 0.1 to 1.7 feet per year, though these estimates do not include effects of the hurricanes that impacted MCBCL post-1988. The study also noted that many of the shoreline stabilization efforts, including revetments, were unstable and had failed (USACE, 2001). The study recommended that a shoreline management plan be developed in order to protect upland areas (which are being lost at a rate of 0.81 hectares/year), man-made structures and training areas, and fishery and wetland habitat (USACE, 2001).

Shoreline stabilization of the land-water interface on the high wave energy oceanfront has been studied extensively (USACE, 1977), but shoreline erosion on estuarine coasts is less well understood (NRC, 2006). Wave energy is the primary force driving estuarine shoreline erosion, and models have been developed to predict marsh vegetation and community composition based on wave energy (Keddy, 1982; Roland and Douglass, 2005). Our ability to predict and mitigate estuarine shoreline erosion is complicated by the fact that the wave environment in estuarine waters is changing as a result of more and larger-sized boats and their wakes (Crawford et al., 1998; Kennish, 2002). This is particularly an issue in the NRE, which is traversed by the ICW and supports a variety of military vessels and landing craft, as well as commercial and recreational watercraft.

Marshes trap sediment, but whether or not they can keep pace with sea-level rise depends on sediment availability, the rate of sea-level rise, the density of marsh vegetation, the intensity and frequency of storms, and variables such as nutrient enrichment that affect the density of marsh vegetation and, potentially, the species of vegetation. This latter variable is potentially important because of differences in the drag forces their canopies exert on flowing water (Leonard and Reed, 2002). Regarding the importance of plant community composition, the invasive species *Phragmites australis* is now common in the MCBCL region, but its history and current rate of spread are uncertain. The vulnerability of coastal wetlands to sea-level rise is a function of the local tidal amplitude and marsh surface elevation relative to local mean and high water (Morris et al., 2002). As the rate of sea-level rise increases, the equilibrium elevation of the marsh will decrease. As this elevation approaches the lower limit of a wetland's range of tolerance, the marsh will convert to open water upon any further increase in the rate of sea-level rise.

Key objectives of research projects for the coastal wetlands of MCBCL include: (1) measuring rates and mapping the spatial distribution of shoreline erosion; (2) developing strategies for wetland restoration and mitigation of effects of training activities; (3) assessing the current stability and maximum rate of sediment accretion in intertidal salt marshes; (4) measuring the flux of shallow ground water through marshes; and (5) assessing the fate of nutrients transported into the marshes.

5.2.3 Benefit to MCBCL

This section outlines examples of specific benefits to MCBCL that will be derived from research done by the Coastal Wetlands Module. The list is certainly not exhaustive, but it does reflect the input from Base personnel during several meetings.

- Establish the optimal elevation and location for successful marsh restoration projects.

  One or more major marsh restoration projects have been located on MCBCL and more are contemplated. One benefit of the work proposed here is an understanding of habitat distribution of the salt marsh within the vertical confines of the tidal frame and its optimal elevation. In other words, what is the best elevation relative to mean high water (MHW) to locate a restored marsh to maximize its probability of survival?

- Identify the location of areas of shoreline erosion and recommend mitigation.

  Marsh habitat is subject to erosion around aquatic boundaries as a consequence of wave attack. This can be attributed to wind waves, boat wakes, or mechanical destruction by amphibious exercises. Our project will map the rate of shoreline erosion and attribute the erosion to a cause. This is likely to vary spatially with the geometry of the landscape, vegetation and sediment characteristics of the shoreline, the intensity of boat traffic, and training. From a detailed knowledge of the causes and effects, it will be possible to design strategies for mitigation (e.g., harden shorelines, establish no wake zones, or plan an orderly retreat).

- Establish the benefit to estuarine water quality of the coastal wetlands.

  MCBCL is subject to the same water quality regulations that govern the behavior of other private and government entities. Coastal wetlands are known to degrade a number of toxic substances and to consume various forms of nutrients that degrade water quality. Research done by the Coastal Wetlands Module will quantify the flux of shallow ground water through the tidal wetlands and the fate of nutrients transiting the wetlands in ground water. This will inform managers who may face problems with ground water quality issues.

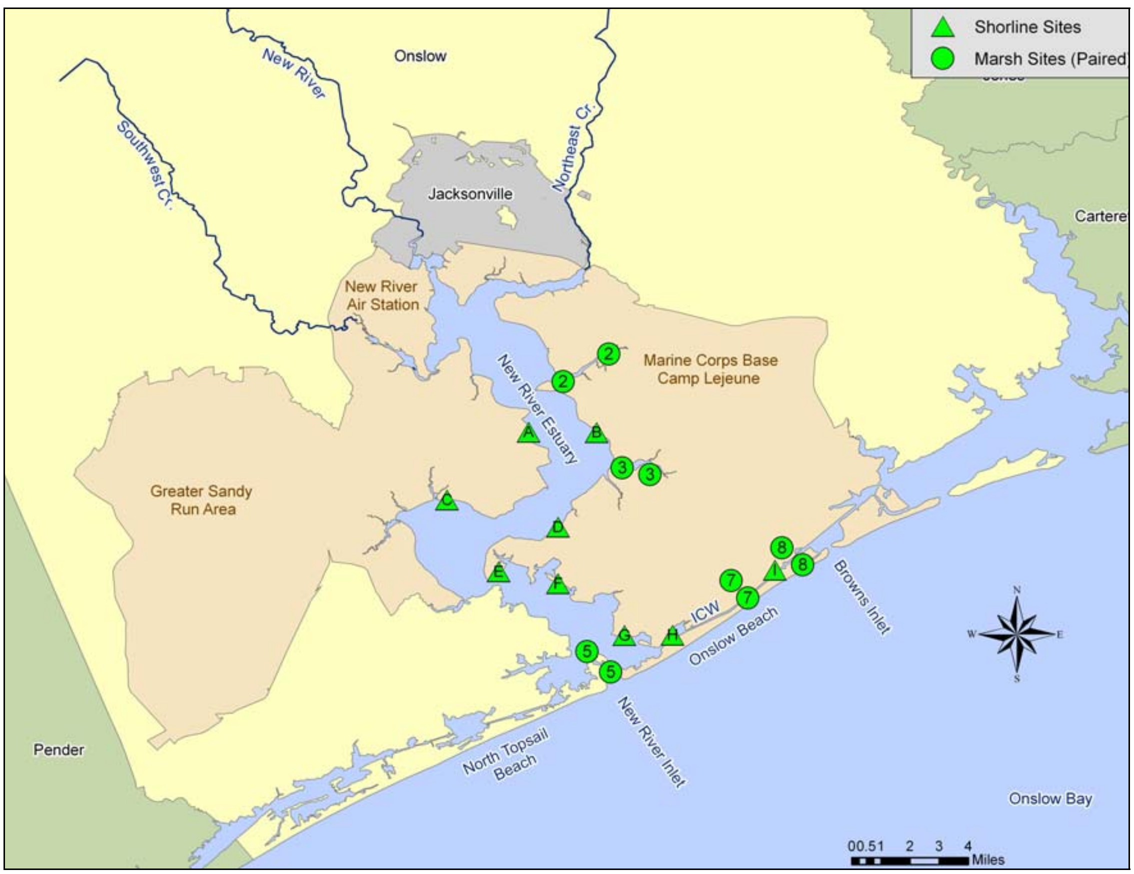
- Identify areas where sediment accretion is not keeping pace with sea level.

  The vulnerability of coastal wetlands and property to storms and sea-level rise are serious long-term threats. The Intergovernmental Panel on Climate Change (IPCC) has estimated that thermal expansion of the oceans could add 0.11 to 0.43 m during the 21st century, with an additional glacial contribution of 0.01 to 0.23 m. We will estimate whether the local area marshes will be able to keep pace with sea level, and we will establish whether amphibious operations are compromising the sustainability of wetlands. We will provide a map of the relative elevation of wetlands, which will show the location of areas that are vulnerable to deterioration and, thus, should be managed differently so as to reverse the trend.

Marsh sites at Freeman's and Gillet's Creeks (Sites 7 and 8) will be located on both sides of the ICW. The sites inland of the ICW and French Creek (Site 3) are considered primary nursery areas for nekton. Piezometer arrays will be deployed at Marsh Sites 2, 3, and 7 as part of Research Project CW-3.

5.2.4 Proposed Research Projects – Coastal Wetlands

Research projects proposed by the Coastal Wetlands Module addresses three major themes. Two of these (Research Projects CW-1 and CW-2) address changes is geomorphology driven by sea-level change, stress from amphibious maneuvers, and wave erosion. Research Project CW-3 addresses the flux of shallow ground water from upland areas through the marshes and the transformation of nutrients in ground water that transits the marsh. Research sites are strategically chosen to take advantage of significant activity (e.g., amphibious operations, splash points), proximity to upland land uses (groundwater and nutrient flux), research and monitoring by other projects (barrier island migration), or other significant attributes (shoreline stabilization structures). Marsh research areas (**Figure 5-10**, Sites 7 and 8) on the seaward side of the ICW are behind the barrier island and will provide information on how these landforms interact. For example, does the dune complex provide a sediment subsidy to the wetlands? How fast are the dunes migrating? Sites at TMZ Bluebird (Site 5 in **Figure 5-10**) are located within current and former LCAC amphibious training zones. Operations at one LCAC training zone have been discontinued and will provide information on the recovery rates of marshes. Results on marsh accretion and erosion obtained at the active LCAC training site will be contrasted with measurements made in the relatively undisturbed Gillet's and Freeman's Creeks (Sites 7 and 8).



Map Legend: Site 2 (Wallace Creek), Site 3 (French Creek), Site 5 (TMZ Bluebird), Site 7 (Gilletts Creek), and Site 8 (Freeman Creek).

Figure 5-10. Site map with the approximate locations of research stations.

5.2.4.1 CW-1: Determine Responses of Marsh Vegetation and Surface Elevation to Nutrients

Senior Researcher: Jim Morris (University of South Carolina [USC])
Supporting Researcher: Carolyn Currin (NOAA)

Hypotheses:

1. Intertidal salt marshes will equilibrate at an elevation within the tidal frame that is inversely proportional to the rate of sea-level rise.
2. The equilibrium elevation of salt marshes will decrease relative to undisturbed controls in sites where amphibious training reduces standing biomass density.
3. The equilibrium elevation of salt marshes can be increased by raising biomass density either by fertilization or by modifying the training schedule.
4. The skewness of the frequency distribution of relative marsh elevation is a diagnostic of its vulnerability to sea-level rise or disturbance (storms, amphibious maneuvers).

Technical Goals:

1. Map the current elevations of intertidal salt marshes relative to mean sea level.
2. Identify areas of salt marsh that are low in the tidal frame and, therefore, vulnerable to sea-level rise.
3. Assess the stability of salt marsh habitat used for amphibious training exercises (LCAC operations).
4. Identify the primary nutrient (N or P) that limits primary production in local salt marshes and the response of primary production to N and P fertilization.
5. Measure the current rate of sediment accretion in salt marshes in control sites, in sites treated with N and P nutrients, and in sites subjected to amphibious maneuvers.
6. Measure the responses of above-ground and below-ground primary production to changes in the relative elevation of the marsh surface.
7. Calibrate the marsh equilibrium model 2 (MEM2) for marsh sediment accretion using empirical data collected in technical goals 1, 5, and 6.

Technical Approach

(a) Background: Marshes occupy a broad, flat expanse of landscape referred to as the marsh platform at an elevation that approximates that of MHW. They typically support high rates of primary production; yet they exist in one of the most stressful physical and physiological zones in nature. Threats to these shoreline habitats include erosion from tidal forces and wave energy, rising sea level, and amphibious training exercises.

The elevation of the platform relative to sea level determines total wetland area, inundation frequency and duration, wetland productivity (Morris, 2000; Morris et al., 2002), and the character of nutrient and contaminant transformation and exchange with adjacent aquatic systems. Coastal wetlands adapt to changes in sea level and land use by accreting or losing sediment (Morris et al., 2002; Kearney et al., 2002) and transgressing across the land margin (Gardner and Porter, 2001). Marshes equilibrate at a relative elevation that depends on the rate of sea-level rise and local sediment supply. It has been suggested that the frequency distribution of marsh elevations relative to mean sea level, determined by analysis of Light Detection and Ranging (LIDAR) data, is diagnostic of marsh stability and resilience to changes in sea level and human impacts (Morris et al., 2005; **Figure 5-11**).

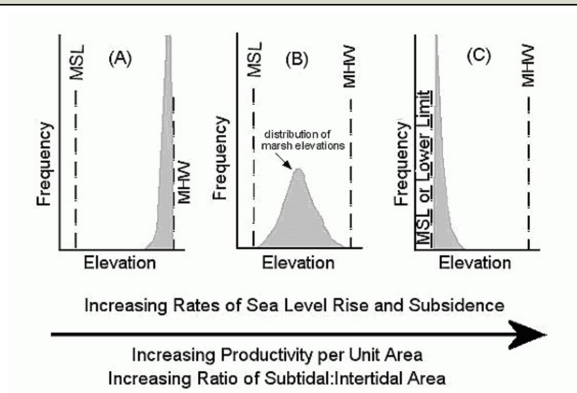


Figure 5-11. The frequency distributions of marsh elevation vary as a function of the rate of sea-level rise (Morris et al., 2005).

The vegetation in a marsh is confined to a vertical range within the upper tidal frame, and its distribution within that range is a function of the rates of sea-level rise, sediment accretion, and land subsidence. A distribution with right-skew (as in figure C) is characteristic of a marsh that is near the lower limit for its vegetation and signifies a lack of tolerance for disturbance or further increases in rate of sea-level rise.

MEM2 that can forecast changes in the relative elevation of the marsh surface and marsh response to sea-level rise has been developed (Morris et al., 2002), but must be locally calibrated by measuring the response of vegetation to relative elevation, the change in elevation of the marsh surface as a consequence of changes in the biomass density of the vegetation and sea level. An improved description of the model, which includes the contribution of below-ground organic matter production and sediment bulk density is shown here:

1. $dS/dt = (q + K_sB_s)D + k_rB_r$ = sediment accretion rate; B_s, B_r and D are above-ground biomass, root production and depth, respectively.
2. $BD = \alpha - \beta k_rB_r/\{(q + K_sB_s)D + k_rB_r\}$ = bulk density
3. $dZ/dt = (dS/dt)/BD$ = rate of change of surface elevation
4. $B_s = m_sD$ = standing above-ground biomass
5. $B_r/B_s = (m_rD + d_r)$ or $B_r = m_sD(m_rD + d_r)$ = root:shoot ratio

Substitute into Eq. 3 and solve for dZ/dt = r gives:

6. $$D^4\{k_s^2m_s^2+2k_rk_sm_rm_s^2 + kr^2m_s^2m_r^2\} + D^3\{2qk_sm_s+2qk_rm_sm_r+2k_rk_sm_s^2d_r+4k_rk_sm_sm_rd_s+2m_s^2m_rd_rk_r^2+2k_r^2m_sm_r^2d_s\} + D^2\{q^2+2qk_sd_s+2k_sm_sd_s+k_s^2d_s^2+2qk_rm_sd_r+2qk_rm_rd_s+4k_rk_sm_sd_sd_r+2k_rk_sd_s^2m_r +k_r^2m_s^2d_r^2+k_r^2m_r^2d_s^2+4k_r^2m_sm_rd_sdr-r[\alpha\ k_sm_s+k_r(\alpha-\beta)m_sm_r]\} + D\{2qk_rd_sd_r+2k_rk_sd_s^2d_r+k_r^2m_sd_sd_r^2+2d_r^2m_rd_rd_s^2-r\alpha(q+k_sd_s)-rk_r(\alpha-\beta)(m_sm_r+m_rd_s)\}= 0$$

   when the surface is in equilibrium with sea level (dZ/dt = r), where r is the rate of sea-level rise.

Eq. 6 has one dependent variable, D or depth below MHW. The remaining constants (q, m_s, m_r, dr, k_s, k_r, α and β) define sedimentation rates, the responses of above- and below-ground production to depth, the refractory fraction of organic matter, and the change in bulk density as a function of sediment organic matter content. All will be measured except the refractory fraction of below-ground organic matter production (k_r), which will be obtained from the literature.

Output from MEM2 (**Figure 5-12**) demonstrates that the depth of the marsh surface below MHW increases with rate of sea-level rise, and shoot production increases, but root production is maximized at intermediate rates of sea-level rise. Conversely, sediment organic matter concentration increases as depth and sea-level rise decrease. At high elevations (shallow depth), flooding is less frequent, mineral input is reduced, and salt stress on the plant community increases. Productivity will generally increase with increasing depth up to a threshold where hypoxia prevents marsh development at greater depths.

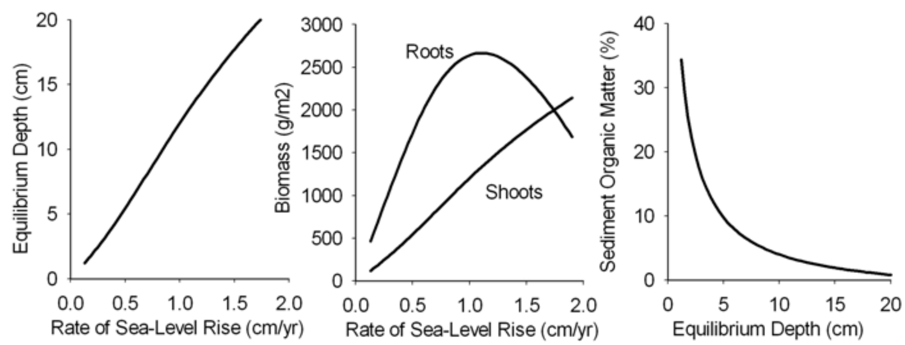


Figure 5-12. MEM2 output for a microtidal estuary (tidal amplitude=20 cm) showing the equilibrium depth (left) and biomass (middle) as function of rate of sea-level rise, and the sediment organic matter concentration (right) as a function of depth.

(b) Experimental Design: Hypothesis 1) Intertidal salt marshes will equilibrate at an elevation within the tidal frame that is inversely proportional to the rate of sea-level rise. This hypothesis will be tested empirically and by model simulations (as described above). Experimentally, the hypothesis will be rejected if observations do not show an increase in accretion rate with an increase in sea-level rise, or do not show a decrease in accretion rate with a decline in sea level. Stations for this experiment will be established at Sites 5, 7, and 8 (see **Figure 5-10**). The parameter values in the model will be derived by repeated measurements of marsh surface elevation in plots that vary in treatment (see Hypothesis 3, below), as well as through the use of experiments designed specifically to define various response variables. One of these is a type of planter known as a 'marsh organ' that raises or lowers the marsh surface experimentally (**Figure 5-13)**. The device is planted with recruits taken from the neighboring marsh and after a season of growth the harvest of roots and shoots gives the biomass response to relative elevation, which is a critical relationship in the MEM2.

Figure 5-13. Results of a marsh organ experiment in a microtidal estuary in Louisiana.

Hypothesis 2) The equilibrium elevation of salt marshes in sites where amphibious training reduces standing biomass density will decrease relative to undisturbed controls. Replicate (3) Surface Elevation Table (SET) plots will be established at TMZ Bluebird (Site 5, see **Figure 5-10)** and the results contrasted with results obtained in control areas (Sites 7 and 8, see **Figure 5-10**). The hypothesis will be rejected if the biomass of Site 5 is lower than Sites 7 and 8 *and* the elevation of Site 5 rises at a lower rate than at Sites 7 and 8. A SET experiment will also be established at an adjacent site where amphibious landings have been discontinued. At that site, we expect to find that the marsh is recovering (biomass and elevation increasing). SETs will be used opportunistically as well to take advantage of episodic events such as storms or training exercises.

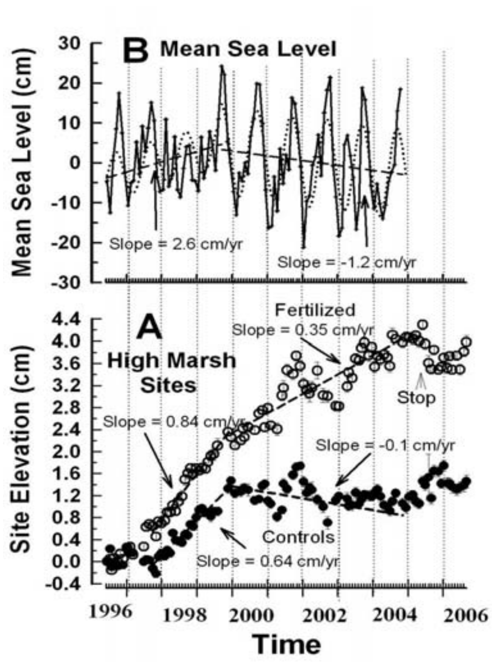


Figure 5-14. Monthly mean sea level (NOAA Charleston Harbor gauge) with trends indicated (top figure) and trends in marsh surface elevation of marsh sites in North Inlet, SC that were fertilized or not (bottom).

Hypothesis 3) The equilibrium elevation of salt marshes can be increased by raising biomass density either by fertilization or by modifying the training schedule. This hypothesis will be tested by measuring accretion rates in marsh plots that are fertilized with nutrients to stimulate biomass production (**Figure 5-14**). Note that where biomass was increased by fertilization that the increase in elevation is greater than controls. Also note that the accretion rates responded to a change in the rate of sea-level rise. A fertilization experiment with N plus P nutrients added to 1.5 x 1.5 m^2 plots of salt marsh will be replicated (3) and instrumented with SETs. The experiment will be conducted over 5 years to allow time for equilibration and interannual variability in mean sea level. During this time, the marsh elevation in the fertilized plots and controls will be monitored with a SET every 2 months. The hypothesis will be rejected if the elevation of these experimental plots does not increase relative to controls.

Hypothesis 4) The skewness of the frequency distribution of relative marsh elevation is a diagnostic of its vulnerability to sea-level rise or disturbance (storms, amphibious maneuvers). LIDAR data taken from the marsh surface will be analyzed. Its frequency distributions will be plotted and a skewness statistic computed for spatially distributed subsets of data. These skewness distributions will be mapped and regressed against absolute normalized elevations. Hypothesis 4 can be rejected if no correlation is found between absolute elevation and skewness.

(c) Methods: The area around each SET site (3 replicates at each) will be subdivided into 2 halves. Fertilizer will be added to one half of each plot seasonally during the growing season for 5 years. Biomass will be measured nondestructively in the plots and marsh surface elevations will be measured every 2 months. At the conclusion of

the 5 year experiment, the vegetation will be harvested and the model calibrated. Separate plots fertilized with only N or P will be used to determine the identity of the primary and secondary limiting nutrients, and plants will be harvested at the end of the season (EOS) for measurement of EOS biomass, and these measurements will be contrasted with EOS biomass measurements taken from nearby control plots. Net primary production (NPP) must be measured nondestructively in plots where SET measurements are made. One nondestructive method requires a census and measurements of stem heights (Morris and Haskin, 1990). We have found that salt marsh NPP is highly correlated with end-of-season biomass (Morris, in press), as measured by summing stem heights, and we will employ this technique, which will allow a much greater spatial coverage than the labor intensive method of making monthly measurements. High spatial resolution (ca. 1 m) multispectral data taken from satellite or aircraft will be classified to the level of major plant communities using a trained artificial neural network (Morris et al., 2005). Period imagery will be examined to identify changes in area, geometry and position. LIDAR data will be used to map marsh elevations and to derive diagnostic frequency distribution.
(d) Data Analysis: (1) Marsh Sediment Accretion: Monthly change in marsh surface elevation derived from the SET devices will be summaried by treatment (fertilized marsh vs controls) and site. Trends in marsh sediment accretion will be summarized by linear regression analysis and contrasted with the rate of sea-level rise, also obtained by linear regression (**Figure 5-14**). There are long-period cycles of sea-level rise (Morris et al., 2002) that likely will necessitate subsetting the analysis of data according to sea-level trend. (2) Model synthesis: The empirical results of our study will be synthesized into the MEM2 that predicts sediment accretion and change in relative marsh surface elevation described above and in Morris et al. (2002). Parameter values for the model are derived from measurements of marsh accretion rate, sea level, and biomass. The biomass response to change in elevation is derived by taking advantage of annual sea-level anomalies and from linear regressions of above-ground biomass and root: shoot ratio against depth from the 'marsh organ' experiments. (3) Marsh elevations: The frequency distribution of marsh elevations will be computed for the estuary as a whole and for spatially distributed subsets. From these distributions a skewness statistic will be computed and mapped. A map of absolute normalized elevations will also be plotted, and the absolute elevations regressed against the skewness statistic. A high correlation will support Hypothesis 4.
(e) Environmental Indicators, Tools and other Outcomes: ▪ A major outcome of this work will be a user-friendly model (MEM2) this is parameterized and that can be run to test the consequences of various environmental changes (e.g., rate of sea-level rise) or management options (e.g., increase in primary production) to the productivity and sustainability of area marshes. ▪ A second product will be a map of wetland elevations and an analysis of their present condition. This will inform managers about how and where to schedule training activities, or where to plan for an orderly retreat from the coastline (e.g., increase set backs for building construction). ▪ A related product, if the analysis of the skewness statistic proves to be useful, will be a GIS tool that will allow for a rapid assessment of the vulnerability of marshes to disturbance and stress ▪ There will be an assessment of how the present amphibious training exercises are affecting sediment accretion and primary productivity of salt marshes.
(f) Linkages to other Modules: Within the Coastal Wetlands Module, Research Project CW-1, will rely on Research Projects CW-2 and CW-3 to provide a forecast of effects of marsh loss (or expansion) on water quality. The project will utilize baseline monitoring data on the change and distribution of vegetation community types (e.g., movement of the marsh-terrestrial boundary), shoreline delineation, marsh elevation and marsh sediment accretion rates from the broader baseline monitoring project program. Research on wetland stability and nutrient flux will be used by the Aquatic/Estuarine Module to forecast changes in the water quality of the estuary. The Terrestrial Module will provide remote sensing technologies used to quantify the community composition, geometry and extent of shoreline marsh and riparian landscapes. The Coastal Barrier Module will provide information on the rate of migration of the dune complex (transformation of marsh to dune), and water quality data provided by the Aquatic/Estuarine Module will be used in conjunction with nutrient drivers of marsh primary production to determine the direction of the impacts.
(g) Military Drivers: Preserve integrity of amphibious maneuver areas; Ensure that MCBCL wetlands support continued military training use of the New River and NRE by complying with CWA (with Research Projects CW-2 and CW-3, will forecast change in marsh area and its contribution to water quality). These research objectives will ensure that the coastal wetlands function in a manner that supports the continued military training use of the New River and Onslow Bay by maintaining the integrity of the amphibious maneuver areas. This work will inform shoreline stabilization and wetland restoration efforts, assess impacts of tactical vehicles, and will result in recommendations for forestalling loss of valuable marsh habitat.

(h) Benefit to MCBCL: The health of the coastal wetlands dictates their ability to serve as a trap for nutrients and sediments, which improves water quality. The marshes protect infrastructure by serving as buffers against coastal storms. They compensate for rising sea level and increased storm activity. The salt marshes support the barrier island and are essential for its survival. Data derived from these research activities will be used to parameterize MEM2 that will forecast the relative elevation of area marshes and their survival in response to stresses from rising sea level and amphibious training activities. This research will identify the primary and secondary nutrients that limit primary production and recommend strategies for mitigating the stresses.

(i) Schedule: The experiments will begin during the summer of 2007 and will run for 4 years. The project will require tidal data (from the monitoring effort) to analyze changes in mean sea level and LIDAR and global positioning system (GPS) data to provide data on the current relative elevation of the marsh. The first year of the project will be devoted to setting up field experiments. The subsequent 3 years are essential to establish annual trends, which are required for model parameterization.

Scheduling Constraints: Field work needs to be performed at low tide.

Year 1 Go/No Go Decision Point: None identified.

Budget (Estimated):

- Year 1 (July 2007 – June 2008): $120,000
- Year 2 (July 2008 – June 2009): $121,000
- Year 3 (July 2009 – June 2010): $115,000
- Year 4 (July 2010 – June 2011): $ 80,000
- Total (July 2007 – June 2011): $436,000

5.2.4.2 CW-2: Forecast Influence of Natural and Anthropogenic Factors on Estuarine Shoreline Erosion Rates

Senior Researcher: Mark Fonseca (NOAA)
Supporting Researcher: Carolyn Currin (NOAA)
Staff: Amit Malhotra (NOAA), 1 technician (NOAA)

Hypotheses:

1. Exposure to wind wave energy is not a significant factor in shoreline erosion on MCBCL.
2. Military activities and recreational boating do not contribute significantly to shoreline erosion in MCBCL
3. Shoreline vegetation and sediment characteristics (species composition, stem density, particle-size) do not effect shoreline erosion rates on MCBCL
4. Storm events do not alter shoreline sediment accretion or erosion rates

Technical Objectives/Goals Classify shorelines by wind wave energy using NOAA Wave Exposure Model (WEMO); identify shorelines where boat wake energy significantly increases total wave energy; Quantify effect of military training on shoreline erosion; evaluate vegetation and ecosystem services of shoreline habitats along estuarine physico-chemical gradients; provide data to estimate contribution of sediment loading to estuary via shoreline erosion; develop a spatially registered predictive model of estuarine shoreline erosion; evaluate effectiveness of current shoreline stabilization structures; and develop a Base-wide shoreline erosion protection plan.

Technical Approach

(a) Background: Natural wind-wave events, tidal currents and weathering processes all contribute to estuarine shoreline erosion. An additional source of wave energy is boat wakes, which can make a significant addition to wind wave energy (Kennish, 2002; NRC, 2006). The effects of sea-level rise will compound the problem, as small increases in sea level translate into much larger changes in horizontal position of the high water line in low relief shorelines characteristic of the lower NRE. A previous study by the U.S. Army Corps of Engineers (USACE) (USACE, 2001) for MCBCL evaluated shoreline erosion in a portion of the NRE (upriver of the ICW). This report provides a strong foundation for additional work as it started to identify high-priority segments of the shoreline in terms of erosion. However, this report utilized the Edelman model, which is a model developed primarily for dune erosion in the early 1970’s and its efficacy for vegetated estuarine shorelines remains largely untested. In this Module, we will apply a much more robust model of wave energy (NOAA’S WEMO), empirical measures of shoreline wave energy that evaluate wave energy climates in an explicit geographic context by combining wind data with local bathymetric effects (Cooper, 2005; Roland and Douglass, 2005). With WEMO and the field calibration component, we will significantly reduce statistical uncertainty and produce a spatially registered predictive model of estuarine shoreline erosion (New River Estuary Shoreline Erosion [NRESE]).

Shoreline vegetation community structure and composition can strongly influence shoreline erosion rates (Keddy, 1982; Kautsky, 1987; Coops et al., 1991) as measured by the geographic position of the vegetated shoreline. In addition to horizontal shifts in shoreline habitats, vertical changes in sediment elevation may occur which are influenced by vegetation density (Gleason et al.,1979; Cahoon et al.,1999; Leonard et al., 2002), and subtle elevation changes in turn alter the distribution and composition of shoreline habitats. The incorporation of vegetation into shoreline stabilization efforts (e.g., 'living shorelines') is a recent approach which seeks to stabilize shorelines, preserve intertidal vegetated habitats, and avoid some of the problems of hardened shorelines, which may exacerbate erosion in adjacent habitats (NRC, 2006; Seitz et al., 2006). The selection of an appropriate shoreline stabilization method is dependent in large part upon the wave energy of the eroding shoreline. New River Estuary provides a valuable training ground for military operations utilizing boats in nearshore, shallow-water, and riverine environments. We propose to assess shoreline habitats in the NRE, and characterize their sediment accretion rate and horizontal erosion rate in conjunction with measures of vegetation type, tidal elevation, slope, and sediment type. However, in order to develop the NRESE model, as well as inform a shoreline management plan, it will be necessary to evaluate both the natural wave exposure setting as well as that generated by vessels, particularly in areas with short fetches and proximity to navigation channels and/or splash points.

(c) Methods: We will utilize NOAA's WEMO to create sampling strata of wind wave energy. Shoreline sites have been selected a priori that include military splash points, sites identified as High Priority shoreline stabilization sites (USACE, 2001), and control sites (see **Figure 5-10**). Additional sites for more limited measures may be selected based on WEMO results (see below). WEMO produces a spatially registered GIS grid of wave energy (joules m^{-1}) based on NOAA shoreline shapefiles, local NOAA bathymetry and historical NOAA wind data. Although innumerable combinations of wind data may be used, convention calls for use of exceedance events (top 5% of wind speed events; Keddy, 1982; Fonseca et al., 2001) as these are the most likely to produce changes in habitat distribution. Because WEMO uses input data that have undergone independent quality control and assurance, WEMO forecasts are not affected by boat wakes and typically predict 90% of the variation in wave energy at a site (unpublished data). For additional quality assurance, we will collect additional wave energy data using RBR TWR-2050 submersible tide and wave recorders at shoreline stations at least 2000 feet from the nearest channel to minimize vessel wake influence (*sensu* Peratrovich et al., 2002) and locally calibrate WEMO. Additionally, data will be examined for Kelvin wave excursions (Kelvin, 1904) characteristic of vessel wakes; those data would then be deleted from the calibration. However, given that data for these calibrations are recorded for 120 s at 4 Hz every 30 minutes for a month at a time, it is our experience that in open areas where wind waves develop, boat wake signatures from distant channels are embedded within the natural wave signal. However, areas where boat wakes <u>are</u> a management problem tend to be in comparatively quiescent areas where such waves are easily discerned from natural waves. Such areas are typically in restricted navigational areas where shorelines are in close proximity to channels. Besides running WEMO for these areas (as we will for the entire NRE), we will conduct both long and short-term surveys of boat wakes. Several short-term surveys will be conducted by placing an observer who records (and photographs) vessel size, estimated speed and time of passage in synchrony with the pressure sensor. These surveys would target the restricted navigation areas where wind waves are minimal, as well as at the end of no-wake zones where vessel acceleration produces exceptionally large waves, and in unregulated speed portions of the ICW through MCBCL and during times when boating activity may be expected to be high (seasonal migration periods and weekends). These data will be used not only to provide an assessment of peak boat activity and potential exceedance effects, it will provide a catalog of wave events useful for discrimination from natural background in other parts of the study. For long-term wake studies, wave recorders will be placed continuously at the aforementioned zones for a year (sensors would record at 4 Hz and be rotated out every 3 weeks due to data storage and potential fouling). This continual record in these low natural wave environments will provide an unprecedented evaluation of boat wake effects from the ICW. When possible, we will measure wave energy from scheduled military activities (LCAC and other) in consultation with MCBCL. If possible our Nortek Acoustic Wave and Current (AWAC) Profiler would be deployed to make much more detailed, directional wave measurements of those activities to provide much more specific information on effects of wakes and other water motion effects of military vehicles in shallow, estuarine habitats where both shoreline and benthic erosion is possible.

Changes in shoreline location and surface elevation, as well as vegetation and sediment properties, will be obtained through Coastal Wetlands Module monitoring (Marsh Surface Elevation and Land cover/Shoreline Erosion) efforts, at several temporal and spatial scales. Short-term, fine-scale (sub-cm measures will be obtained with SETs, larger-scale (500 m^2), fine to medium-scale (sub-cm to 2 cm vertical resolution) will be obtained with digital elevations models (DEMs) obtained by real-time kinetic (RTK) DGPS (see DCERP Monitoring Plan for details). As part of this research, we will compare results obtained with RTK DGPS technology with results obtained from a ground-based laser system (Riegl LMSZ210ii 3D terrestrial laser scanner) obtained by the Coastal Barrier Module, and based on that comparison, will optimize protocols for obtaining DEMs in vegetated intertidal habitats. As part of this analysis, we will develop Change Analysis routines within ArcGIS utilizing DEM data collected with both methodologies. Although annual changes in marsh surface elevation will be obtained in the Coastal Wetlands Module monitoring, we will examine the potential for event-driven changes (either storms or military training exercises) in this research module.

Several of the shoreline sites (A-I, see **Figure 5-10**) include hardened or stabilized shorelines, and we will evaluate the effectiveness of these efforts using the methods described above. We are currently evaluating the effectiveness of alternative shoreline stabilization structures, including offshore stone sills and oyster reefs, at six sites in nearby Carteret County, NC (Meyer et al., 1997; Currin et al., in press; Currin, unpublished data). We will combine the results of these efforts to develop a site-specific shoreline management plan for MCBCL. This effort will identify areas most vulnerable to erosion, recommend site-specific stabilization options, and inform land-based management efforts to minimize effects of shoreline erosion on MCBCL operations and infrastructure by recommending setbacks and/or other best management practices.

Temporal aspects of sampling fall into two categories: (1) chronic conditions and (2) acute or extreme events. The work with WEMO typically is composed of hourly observations of wind speed and direction; we frequently use the previous 3 years of these data from the time of model computation as this covers the life history of many wetland plants. Even so, we use the top 5% of wind speed events (exceedance events) to create wave exposure values as opposed to average values as these exceedance events are considered to be the “clock-setting” events for habitat disturbance. Acute event temporal scales are adjusted to the duration of events.

(d) Data Analysis: WEMO is essential to our ability to interpret historical erosion rates, and forecast future estuarine shoreline erosion rates. WEMO 3.0 calculates wave height and derived wave energy called Representative Wave Energy (RWE). Model runs will be performed for a wide variety of water elevations that would arise from different storm scenarios along with varying scenarios of wind approach due to storm tracks. The historical wind record will provide a hindcast of conditions leading up to the present relationship of shoreline erosion to wind events; the scenario evaluations will provide forecasts of shoreline vulnerability and thus form the basis for a shoreline protection plan.

RWE Mode. Coastal managers are often required to estimate wave energy in coastal regions or in inland waters from local wind information. This entails the computation of wave propagation in coastal regions with shallow waters taking into account the effects of wind and local bathymetry. WEMO is modified to essentially carry out such computations as a numerical one-dimensional model. RWE computed by WEMO is based on linear wave theory and ray tracing technique. It represents the wave energy flux per unit wave crest width transmitted across a plane perpendicular to wave advance. RWE units are Watts/m or kg-m/s^3.

WEMO computes the wave height for RWE in a monochromatic approach, i.e., along each ray generated by the winds in same direction. Waves generated are propagated along the fetch rays. Propagation of water waves over irregular bottom bathymetry involves processes like shoaling, refraction, diffraction and energy dissipation. In order to decrease complexity and computation time, refraction and diffraction of the waves are neglected and propagation is carried out by shoaling, wind generation and dissipation over downwind distance over water (fetch). The final output is the combined effect of wind generation, shoaling and dissipation due to wave breaking and a fetch-weighting process to account for shoreline irregularities. Fetch is defined as the distance from the site to land along a given compass heading. Fetch longer than 10 km were clipped at 10 km as this was considered to be a sufficient distance to generate a maximum wave height effect following empirical experimentation with the USACE Automated Coastal Engineering System software (version 1.07). Although the fetch may be adjusted in WEMO, 10 km is recommended. Effective fetch was computed by measuring along a user-selected set of rays radiating out from either side of the i^{th} compass heading at equal degree increments (total number of rays ranges between 16 and 56, depending on the judgment of the User in the need to capture shoreline shape; uncomplicated, linear shorelines can probably be accurately assessed using the lowest number of rays, while highly crenulated shorelines with complicated intervening bathymetry should use the maximum number of rays). Effective fetch is then calculated by summing the product of fetch x cosine of the angle of departure from the i^{th} heading over each of *n* number of lines and dividing by the sum of the cosine of all angles. This weighting of multiple fetch measures for each ray heading helps account for irregularities in shoreline geometry. The user manual accompanying WEMO can be made available upon request.

The reference grid used as an input in the propagation module is, in general terms, a depth matrix constructed using add-ins from ArcGIS bathymetry grids. Values of wave height and wave energy are provided as outputs at the grid nodes in the form of a text file, and either a contour map or colorized maps (georeferenced).

Once the initial WEMO output is created, we will then begin to relate current shoreline structure and composition to the wave climate. In addition to the focal sites A-I defined in the Baseline Monitoring Plan, randomly selected shoreline topographic profile stations will be selected using wave climate as a stratification process. At these

stations, particle size and presence of upland erosion will be measured at a statistically valid subset of conditions across wave energy classes and classified following the USACE 2001 report (ER-01-117). This relationship will provide the empirical predictive basis for erosion potential to be applied throughout MCBCL. We will combine these results with the assessment of shoreline type generated in the monitoring plan to forecast vulnerability under a wide variety of water level (storm surge) and wind onset conditions both as a full matrix of conditions, as well as those predicted under the NOAA SLOSH model (5.11). Moreover, at the permanent shoreline stations, we will conduct annual surveys of vegetation and elevation to better validate the model relationships and forecasts. We will also mobilize to conduct topographic surveys following any exceedance events (top 5% wind event on an annual average basis) as safety permits, and to improve model prediction for other storm scenarios. We will also utilize the data to make an estimate of shoreline erosion using the Conservation of Sediment Volume approach (NRC, 2006). This approach utilizes data on currents and wave energy in conjunction with sediment particle-size to calculate site-specific net deposition or erosion. However, it does not include consideration of processes potentially important on vegetated estuarine shoreline, including below-ground root production, decomposition, subsurface compaction and sediment accretion processes. We will use data collected in the Coastal Wetlands Module Marsh Surface Elevation monitoring program to make site-specific measures of these parameters. We will use multivariate statistics, including principal component analysis, multidimensional scaling, and cluster analysis, to determine the parameters most useful in predicting estuarine shoreline accretion or erosion rates in the NRE. These results will be utilized to develop the NRESE model, and to develop a shoreline management plan.
(e) Environmental Indicators, Tools and other Outcomes: Results from this work will be used to forecast shoreline erosion in the NRE, and also to aid in the development of a shoreline stabilization and protection plan. Specific products include: predictive model of NRESE; GIS map indicating degree of erosion vulnerability for the entire NRE shoreline; identification of site-specific factors influencing erosion in vulnerable areas; Shoreline management plan for MCBCL. Should MCBCL staff identify other vulnerable and strategic sites, we will develop shoreline stabilization approaches for these sites as well.
(f) Linkages to other Modules: The project will utilize baseline monitoring data on vegetation, sediment properties, shoreline delineation, marsh elevation and marsh sediment accretion rates. Project models and management recommendations will utilize data on the influence of elevation, nutrients, and vegetation on accretion rates from Research Project CW-1, as well as the Coastal Barrier and Aquatic/Estuarine Modules's monitoring data (TSS, nutrients and dune migration). This research will also provide information on suspended sediments to Research Projects AE-2 and AE-3. In addition, remote sensing technologies applied under Coastal Wetlands monitoring will be used to quantify the community composition, geometry and extent of shoreline marsh and riparian landscapes in context of their exposure to wave energy. We will quantify the extent of hardened shoreline (seawalls, bulkheads, riprap), using digitized aerial photography and ground-truthing with GPS to identify areas that differentially affect ecosystem processes. This will also aid in identifying MCBCL facilities that may become susceptible to shoreline erosion processes.
(g) Military Drivers: Preserve integrity of amphibious maneuver areas; Ensure that MCBCL supports continued military training use of the New River and NRE by complying with CWA (estimate contribution of estuarine shoreline erosion to suspended sediments in the NRE). This will result from collaboration with Aquatic/Estuarine Module Research Project AE-1, *Develop and Deploy Microalgal Indicators as Measures of Local and Regional Impacts on Water Quality, Harmful Algal Bloom Dynamics, and Ecosystem Condition of the New River Estuary*.
(h) Benefit to MCBCL: This research will aid in efforts to forecast and forestall erosion of the barrier island complex and estuarine shorelines. Assessment of estuarine shoreline erosion will provide information to improve water quality. This work will inform shoreline stabilization and wetland restoration efforts, and will assess impacts of tactical vehicles.
(i) Schedule: This project will begin in September 2007, and will run through June 2011.
Scheduling Constraints: Data will be collected seasonally, and will also need to include peaks in recreational boating activity, storm events, and military training exercises.
Year 1 Go/No Go Decision Point: If we cannot successfully calibrate the WEMO model for the NRE shoreline, development of the NRESE model will be a No Go as we will not be able to obtain a spatially explicit estimate of wave energy to accompany measures of shoreline erosion, vegetation, and sediment accretion for use in the NRESE model.

Budget (Estimated):

- Year 1 (July 2007 – June 2008): $40,000
- Year 2 (July 2008 – June 2009): $100,000
- Year 3 (July 2009 – June 2010): $75,000
- Year 4 (July 2010 – June 2011): $ 84,000
- Total (July 2007 – June 2011): $296,000

5.2.4.3 CW-3: Hydraulic Exchange and Nutrient Reactivity in the NRE Wetlands

Senior Researcher: Craig Tobias (UNC-W)
Supporting Researcher: Jim Morris (USC)

Hypotheses:

1. The marshes of the NRE attenuate watershed inputs of nutrients by intercepting and processing a fraction (currently undetermined) of the shallow groundwater and sheet flow arriving from adjacent watersheds.
2. These marshes also modify the water quality of the NRE directly by processing organic and inorganic nutrients delivered to the marsh surface/subsurface from inundating tidal water.
3. The importance of marshes in mediating nutrient exchange between the watershed and estuary can be quantified by combining marsh water budgets with marsh nutrient budgets, and accounting for nutrient reactivity of the marsh subsurface.

Technical Objectives/Goals: (1) Determine water exchange of groundwater and tidal water through the coastal marshes along the NRE. (2) Couple water fluxes with nutrient chemistry to estimate nutrient exchange between marsh-estuary and marsh-upland boundaries. (3) Quantify marsh reactivity with respect to nutrients (e.g., denitrification) at the flow-path and marsh scale. (4) Couple reactivity measurements with solute fluxes to determine the contribution of marshes to buffering watershed nutrient load, and the role of marshes in the overall water quality budget of the NRE.

Technical Approach

(a) Background: Marshes receive delivery of nutrients and contaminants from groundwater and tidal water. Groundwater discharge at the coast is focused in the intertidal zone; areas commonly inhabited by emergent tidal marshes (Bokuniewicz, 1992; Reilly and Goodman, 1985). Tidal flooding of the marsh typically comprises the annually dominant input to the marsh water budget (Tobias et al., 2001a). Although both of these water sources tend to contain solutes in their chemically oxidized forms (e.g., nitrate), organic rich marsh sediments tend to be highly reducing. Consequently, during the advection of groundwater and tidal infiltration into the marsh subsurface, flow paths cross a sharp redox transition zone which is highly reactive with respect to nutrients and/or contaminants (Tobias et al., 2001b; Harvey and Odum, 1990). The coastal wetland piezometer networks established as part of the monitoring program will be instrumental in determining water flow path direction, velocity, flux rates and water residence times. The monitoring scheme is limited in its capacity to quantify rates of nutrient/contaminant processing or attenuation. Additional process-based experimentation is required. The piezometer network will therefore also serve as the platform for a series of conservative and stable isotope tracer experiments designed to fill this knowledge gap.

(b) Experimental Design: Linear arrays of piezometers (**Figure 5-15**) will be established along transects through different Marsh Sites 2, 3 and 7 (see **Figure 5-10**) parallel to the flow path. Measurements of groundwater surface elevation and conductivity will be used to compute flow velocities (Gardner and Reeves, 2002). Experiments will be conducted at the 1–10 meter spatial scale as appropriately determined by velocity. Using a subset of the piezometer arrays established for the wetland monitoring, a series of in situ experiments will be conducted at the flow path scale in the marsh subsurface. These experiments will combine

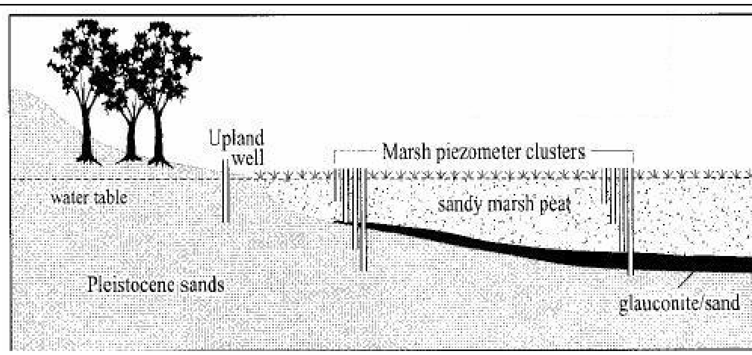


Figure 5-15. Schematic of a typical piezometer transect (Tobias et al., 2001a).

natural gradient tracer measurements and vertically resolved push-pull tracer measurements. Both techniques have proven useful in tracking the fate of groundwater derived nitrate inputs to marshes under in situ hydraulic and chemical conditions. (Tobias et al., 2001c; Addy et al., 2005).

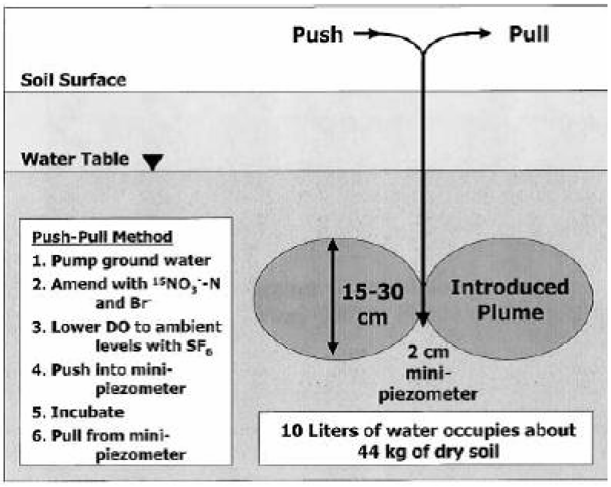


Figure 5-16. Schematic of the in situ push-pull mini-piezometer method.

(c) Methods: Measurements of gradients in natural tracers and vertically resolved push-pull tracers will be used to track the fate of groundwater derived nitrate inputs to marshes under in situ hydraulic and chemical conditions. (Tobias et al., 2001c; Addy et al., 2005). The push-pull approach (**Figure 5-16**) offers an additional advantage in zones of slow water movement, high reaction rates, and rate heterogeneity on small spatial scales. The principle behind each technique is similar: (1) isotopically label the nutrient or contaminant of interest and introduce it with a conservative tracer (e.g., bromide or sulfur hexafluoride) into the flow path through an 'injection' piezometer; (2) sample the 'labeled' plume as it transits the marsh subsurface using an array or target piezometers, or for the push-pull, pump the injection piezometer after some requisite time period; (3) consumption of labeled substrate relative to the conservative tracer, as well as changes in the isotopic composition of the substrate and potential product pools are used to identify relevant reaction pathways and the in situ rates at which they occur. DIN processing will be primarily targeted. The work can be extended to include processing of carbon-containing contaminants of concern for specific sites and contaminants as determined in conjunction with other DCERP Team researchers.

(d) Data Analysis: The data analysis is divided into 2 components: water / nutrient flux; and nutrient reactivity of the subsurface. The water/nutrient fluxes will be estimated first by using a 2D ground water flow model calibrated with hydraulic head, hydraulic conductivity, and salinity. Secondly, the use of a Coupled Water and Salt Mass Balance (CWSMB) Model will be constructed to independently quantify all components of the marsh water budget. Error estimates of the CWSMB model will be achieved through a series of Monte Carlo simulations where all input parameters are varied simultaneous according to normally distributed random values that reflect their measured variance in the field. Sensitivity of the model output will also be determined through manipulation of each input parameter individually across 2 standard deviations of their observed means. Estimates of subsurface nutrient reactivity (the tracer tests) will be determined by breakthrough curve separation analysis between conservative and non-conservative tracers, and by stable isotope tracer modeling of isotopically tagged reactive nutrients and their reaction end-products. Error estimates are assigned to the measured reaction rates as standard errors derived from replicate tracer additions to a specific marsh subsurface horizon.

(e) Environmental Indicators, Tools and other Outcomes: Based on previous experience, the magnitude of hydraulic connection between upland, marsh, and estuary is a function of tidal and shallow groundwater forcing functions. The extent of nutrient reactivity is a function of temperature and nutrient concentration. Therefore, the overall contribution of the marsh to mediation NRE water quality can be correlated to the following easily measured seasonal environmental variables: (1) tidal amplitude; (2) water table elevation; (3) temperature; and (4) nutrient concentration (tidal water and shallow groundwater). These four parameters will thus serve as environmental indicators (i.e., proxies) of marsh contribution to NRE water quality at any given time.

(f) Linkages to other Modules: The project leverages the Coastal Wetlands Module monitoring in terms of infrastructure, chemical monitoring, and hydraulic characterization efforts. Reactivity measurements can be integrated into the Research Project CW-1 to identify feedbacks between marsh productivity/accretion and the nutrient retention role of the marshes in the NRE landscape. Because water is the currency of exchange between ecosystem components (marsh, watershed, and estuary), the project links closely with Aquatic/Estuarine Module's monitoring and research components to generally determine marsh contribution to the New River water quality, and specifically identify the coincidence of nutrient hotspots with marsh position in the NRE. The work will further benefit from and contribute to ongoing U.S. Geological Survey (USGS) efforts to develop regional water budget and groundwater flow models in the vicinity of MCBCL.

(g) Military Drivers: The results from this work will provide an estimate of the extent of nutrient uptake and hydraulic connectivity of the marshes to uplands and to the NRE. Consequently, the work assesses the relative importance of the marshes in maintaining the water quality of the NRE. The specific military drivers that benefit

from this result are: (1) Ensure that MCBCL supports continued military training activities while complying with the CWA; (2) Preserve the integrity of the amphibious maneuver areas in the NRE and adjoining training areas. Water is the currency of exchange between adjacent ecosystems. Quantifying that exchange of water and fluxes of nutrients is necessary to assess linkages between terrestrial, wetland, and aquatic estuarine systems to determine how much the impacts on one component cascades to the other components.
(h) Benefit to MCBCL: Data derived from these research activities will provide information on the value of the marshes as nutrient transformers and the magnitude of subsurface nutrient flux to the estuary. Subsurface nutrient flux could be substantial and may affect water quality in the estuary.
(i) Schedule: This project can be completed in 3 years. Year 2-install additional piezometers, refine delineation of flowpaths and velocity, and conduct preliminary conservative tracer tests. Year 3- perform natural gradient and/or push-pull reactive tracer experiments. Year 4- repeat tracer experiments at select sites, complete data synthesis, and prepare manuscript for peer-review.
Scheduling Constraints: None
Year 1 Go/No Go Decision Point: None identified.
Budget (Estimated): ▪ Year 1 (July 2007 – June 2008): $0 ▪ Year 2 (July 2008 – June 2009): $46,000 ▪ Year 3 (July 2009 – June 2010): $48,000 ▪ Year 4 (July 2010 – June 2011): $ 49,000 ▪ Total (July 2007 – June 2011): $143,000

5.3 Coastal Barrier Module

5.3.1 Introduction

The coastal barrier ecosystem at MCBCL extends from the shoreface toe at -10 meter water depth to the estuarine or ICW shoreline. This ecosystem encompasses the shoreface, tidal inlet, backshore beach, aeolian dune, shrub zone, incipient maritime forest, and washover sand flat habitats. These habitats are defined by intrinsic ecological processes, but are linked together by sediment transport, nutrient exchange, and biological uses, each of which undergoes substantial change over multiple time scales.

The entire ecology of coastal barriers is organized directly and indirectly by the physical dynamics of meteorologically driven ocean forcing and the resulting sediment transport and morphologic changes (Godfrey and Godfrey, 1976; Wells and Peterson, 1986) (**Figure 5-17**). Variations in the underlying geology and bathymetry of coastal areas influence how shorelines will respond (i.e., accrete, erode, change in sediment type) to different physical forcings (McNinch, 2004; Rodriguez et al., 2004). Low-lying coastal barriers, such as those of MCBCL, experience frequent overwash during storms. This process reinitiates the succession of dune and shrub-zone plant communities, provides new habitat for bird nesting and foraging, and extends and revitalizes salt marshes when overwash progresses across the island to the sound shoreline. The inlets of coastal barriers are especially dynamic, and storm overwash at inlets plays an important role in maintaining flat and sparsely vegetated areas suitable for nesting and foraging by piping plovers, and other shorebirds such as, terns, and gulls (Fraser et al., 2005).

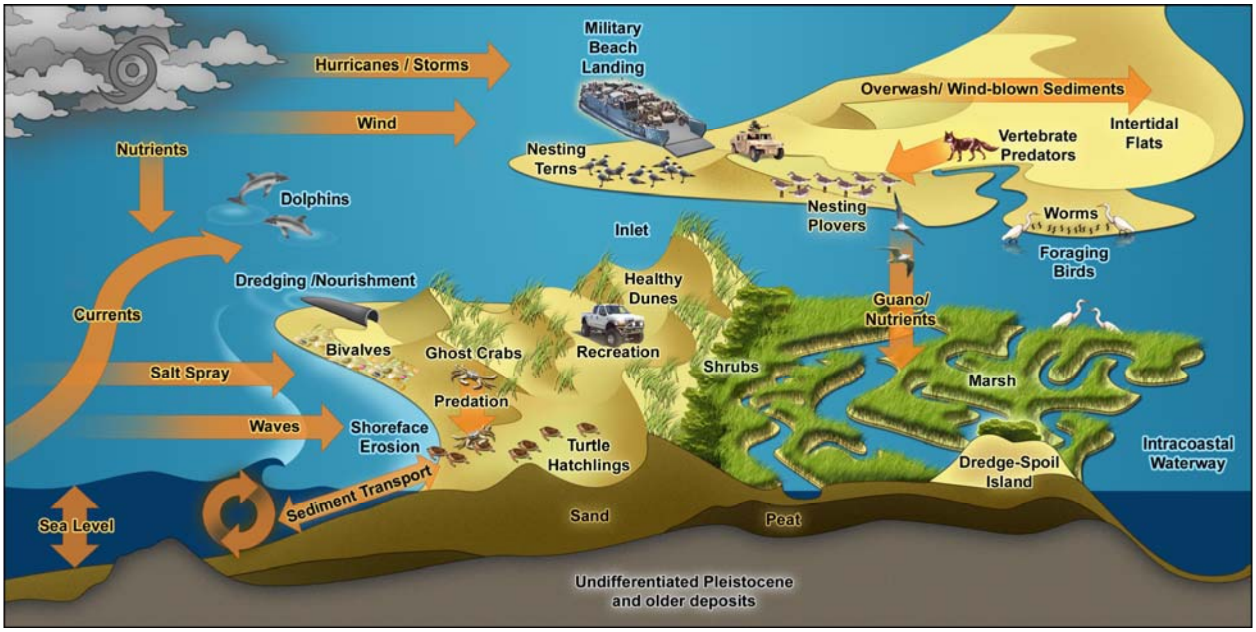


Figure 5-17. Conceptual model for the Coastal Barrier Module.

The intertidal portion of the shoreface enjoys high production of characteristic invertebrates, such as coquina clams and mole crabs, which qualifies the area as a key habitat, one that supplies food for abundant and valuable surf fishes, crabs, and shorebirds, including the piping plover (Federally Threatened), red knot (Candidate Species for Listing), and many other state and federal at-risk bird species (Brown and McLachlan, 1990; Fraser et al., 2005; Karpanty et al., in press). This area is also the most morphologically dynamic portion of the barrier and is constantly changing shape with changing tides and sea state. Predators influence the distribution, abundance, and breeding success of nesting sea turtles and nesting and migratory shorebirds and terns. Depredation of sea turtles and birds may alter rates of guano deposition on the barrier island and impact nutrient cycling.

The proposed research projects of the Coastal Barrier Module build upon the monitoring data, are linked within the module and between modules, and address the most pressing military drivers and goals (**Table 5-3**). The research projects will use the monitoring data to develop maps of shoreline change and the underlying cause for spatial variations in coastal retreat rates. Conceptual models that predict the morphology and location of the shoreline will be developed. Barrier response to extreme storm events and the rate of recovery will be derived. Efficient monitoring protocols and conservation management procedures for shorebirds and seabirds will be developed to best design mitigation in the case of beach nourishment or the introduction of new uses to the coastal barrier system. Results from examining predator top-down influences will allow MCBCL to design the most efficient use of trapping resources and minimize the frequency of trapping and the co-occurrence of trapping efforts with human uses of the barrier islands.

Table 5-3. Coastal Barrier Module Research Project Title, Senior Researcher, Benefit to MCBCL, and Duration of Project

Project	Research Project Title	Senior Researcher/ Duration
CB-1	*Short-term Barrier Evolution Related to Storms and Land Use*	**Senior Researcher:** Jesse McNinch
	Outcomes and benefit to the Base: This project will help mitigate Onslow Beach erosion resulting from natural impacts (storms, climate, sea-level), training activities, and management practices.	**Duration:** 7/09–6/11
CB-2	*Long-term Barrier Evolution Related to Variations in Underlying Geology, Land Use, and Inlet Dynamics*	**Senior Researcher:** Tony Rodriguez
	Outcomes and benefit to the Base: This project will assess the principle drivers of Onslow Beach erosion, including natural (storms, climate, sea-level, underlying geology) and anthropogenic (training activities and management practices)	**Duration:** 7/09-6/11
CB-3	*Understanding the Top-down and Bottom-up Drivers of Shorebird Nest Success and, Habitat Use in Relation to Beach Management Practices on MCBCL.*	**Senior Researchers:** Sarah Karpanty and Jim Fraser
	Outcomes and benefit to the Base: Results will be used to develop efficient monitoring protocols and conservation management procedures for shorebirds and seabirds and to best design mitigation in the case of beach nourishment or the introduction of new uses to the coastal barrier system. Pilot studies of predator top-down influences will allow MCBCL to design the most efficient use of trapping resources and minimize the frequency of trapping and the co-occurrence of trapping efforts with human uses of the barrier islands.	**Duration:** 7/07–7/10

5.3.2 Knowledge Gaps in Conceptual Model and Research Needs

An improved understanding of the morphological response of the coastal barrier ecosystem to changes in natural physical processes and anthropogenic stressors is critical for better shoreline management at MCBCL and elsewhere (Pilkey et al., 1993). Variations in the underlying geology and principle sediment-transport pathways play a large role in modulating shoreline-erosion rates, but this has not been fully studied for MCBCL. Variations in the underlying geology will be constrained from seismic data and cores. Isopach and structure maps produced from these data will be compared with spatial variations in barrier volume, derived from merged bathymetric and topographic maps through time, to determine linkages. The biological responses to and sustainability for thresholds to physical, sedimentological, and morphological change are poorly understood (Peterson and Bishop, 2005). However, before we can fully understand these thresholds, it is necessary to fill in multiple knowledge gaps regarding the biotic community. For example, we do not know the factors that determine shorebird distribution, abundance, and reproductive success; or the distribution, abundance, and colonization of the coastal barrier by predators.

5.3.3 Benefit to MCBCL

Research projects will address MCBCL's most pressing management needs, including beach erosion and habitat conservation on the coastal barrier. Existing barrier management will be enhanced by (1) Identifying the underlying causes accelerating beach erosion on Onslow Beach, (2) Forecasting beach erosion if current management does not change, (3) Developing a beach-erosion plan that provides management alternatives to counter beach erosion, (4) Developing efficient monitoring protocols and conservation management procedures for shorebirds and seabirds, and (5) Designing the most efficient use of predator trapping resources to minimize the frequency of trapping and the co-occurrence of trapping efforts with human uses of the barrier.

5.3.4 Proposed Research Projects – Coastal Barrier

The following three research projects address the barrier as a whole, which will facilitate integration of diverse data sets. The barrier ecology will be placed in context with the hydrodynamics, sediment transport and associated morphologic change, anthropogenic activities, and impacts from extreme storm events. These are the main stressors of habitat change. The study site overlaps with three areas where the Coastal Wetlands Module is proposing research and monitoring activities, and encompasses the New River Inlet and Brown's Inlet, which are important for defining the circulation dynamics in the estuary and the sediment budget of Onslow Beach.

5.3.4.1 CB-1: Short-Term Barrier Evolution Related to Storms and Land Use

Senior Researcher: Jesse McNinch (VIMS)
Supporting Researcher(s): Richard Luettich (UNC-IMS) and Tony Rodriguez (UNC-IMS)

Hypotheses:

1. Post-storm beach recovery, in part, compensates for the total loss of southern Onslow Beach, which is predicted by modeling the impact of a hypothetical 100-hundred year storm.
2. The volume of beach and nearshore sand is controlled by framework geology and small-scale variations in sand volume dictate the extent of erosion during storms and seasonal time scales.
3. Land-use practices can influence the amount of washover during storm events.

Technical Objectives/Goals:

Model short-term beach response (erosion/accretion) to storms, variable bathymetry and bottom type, and Base-related land use. Develop observational and modeling tools that will discern key variables forcing beach erosion such as waves, currents, geology, and bar morphodynamics. Results from the Short-Term, Event Beach Response (STEBR) Model will be integrated within the Long-Term Shoreline Change (LTSC) Model (see Research Project CB-2) to provide a basis for beach management strategies.

Technical Approach

(a) Background:

The coastal barrier ecosystem is organized directly and indirectly by the physical dynamics of ocean forcing and sediment transport. Physical processes operating in the nearshore vary in magnitude on time scales ranging from hours (coastal storms) and months (seasonal weather patterns) to decades (climate and associated sea-level change). The morphological response of the coastal barrier ecosystem to these perturbations is poorly understood, but is critically needed for better shoreline management. Variations in the underlying geology of coastal areas control how shorelines will respond (e.g., accrete, erode, alter sediment type) to different physical forcings and the underlying geology contains a long-term history of coastal evolution. Anthropogenic stress such as dredging, construction, landing craft deployment, amphibious training, and munitions practice further impact the morphology of the coastal barrier and play a large roll in regulating rates of change. It is necessary to place directly measured short-term morphologic changes, in context with the long-term evolution, as derived from the geologic record in order to differentiate between background and anthropogenic stressors. Additionally, it has been demonstrated that shorelines can exhibit non-linear rates of retreat in response to variations in underlying geology at century and decadal time scales. Sustaining the value of environmental and mission-related assets, while conducting shoreline management requires a better understanding of the short- and long-term rates of coastal change, which will help differentiate between geologic, hydrodynamic, and anthropogenic forcing mechanisms.

Results shown in **Figure 5-18** exemplify the objectives and goals for the Base barrier beaches. Using variables collected in the monitoring effort (e.g., constraints of geological framework, 3-dimensional bedforms) combined with fine-tuned inputs (e.g., sediment transport pathways during storms) observed during the research projects, we will develop an analytical model (STEBR) that predicts changes in the beach in response to short-term, storm response and/or changes in the geological parameters (e.g., beach slope, removal of dunes) from Base use. Although the results from the northern Outer Banks, shown above, are very encouraging, model skill can be greatly improved. The monitoring and research plans proposed for the Base will provide critical baseline data that will greatly improve our ability to predict beach erosion across the field site and will couple with the long-term efforts (Research Project CB-2).

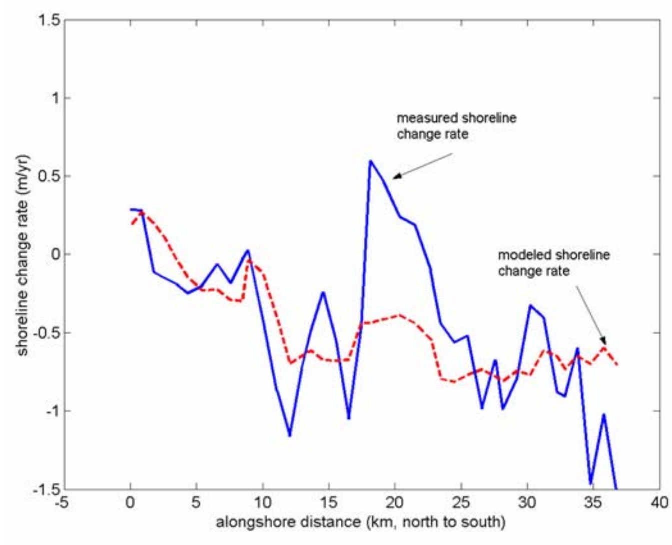


Figure 5-18. Modeled shoreline change based solely on framework geology compared to measured changes along a 40 km stretch of the Northern Outer Banks, NC.

(b) Experimental Design:

Critical variables for modeling short-term beach response will be identified from observations collected during the monitoring phase. These include characterization of the underlying geology across the coastal barrier and nearshore, sediment volume, sediment transport pathways, nearshore bathymetry, and wave climate. The research component will focus on problem regions (e.g., areas with higher erosion) identified during the monitoring phase to fine-tune our observations of relevant processes followed by development of a predicting model. Initially, the model will be largely empirical based on the observations from the field site. We anticipate upgrading the model to a more physics-based analytical type so that it may be more easily used at other similar field settings. This overall design of field observations incorporated into an empirical-analytical model will provide each of the previously stated technical goals.

(c) Methods:

Seismic and sedimentological data collected as part of the coastal barrier monitoring program will provide critical baseline information that will only need to be supplemented to accomplish the stated goals. Supplemental exercises will include the following: (1) nearshore bathymetry and sediment characteristics will be mapped at smaller field sites semi-annually using a combination of swath sonar and radar; (2) mapping will also be conducted before and after select events such as large amphibious exercises and significant storms; (3) numeric models (ADCIRC and Simulating Waves Nearshore [SWAN] model), constrained by collected bathymetry, offshore wave/wind measurements and nearshore waves/currents (Acoustic Doppler Current Profiler [ADCP]), will simulate the velocity flow field and pathways of sediment transport; and (4) shoreline changes will be measured semi-annually and around select events using RTK-GPS, a dual-channel positioning system with 5–10 cm accuracy, and radar. We anticipate these data will allow us to discern key variables forcing shoreline change, which will both simplify the monitoring program undertaken by Base personnel and will help calibrate and verify the LTSC.

(d) Data Analysis:

Geophysical data, swath bathymetry and seismic reflection profiles, will be processed using conventional, proprietary software. All spatial data will be referenced to established horizontal and vertical data and made available to Base personnel and collaborating scientists in a variety of user-friendly formats (e.g., segy, Fledermaus, Arc). Radar data will be similarly processed using proprietary software and provided to users in a spatially referenced format that shows shoreline and sand bar information. Radar-derived wave data will be analyzed using conventional harmonic analyses (e.g., FFTs,) to calculate wave period, wave direction, and inferred wave height. Radar-measured wave information will be verified with measurements collected by the ADCP (see Coastal Barriers hydrodynamic monitoring section in the DCERP Monitoring Plan).

(e) Environmental Indicators, Tools and other Outcomes:

The research design, from the hypothesis to methodology and data analysis, is oriented towards achieving the

technical goals and objectives described above. These technical goals will provide the Base with relevant outcomes that can be instrumental in sustaining the coastal barrier environments. Specifically, this research module will provide: (1) an understanding of and modeling capability for beach erosion and overwash during storm events, (2) an understanding of the key forces driving beach erosion during storm events and over the short term, and (3) an ability to discern the influence of Base activities versus natural processes affecting beach changes.
(f) Linkages to other Modules: This research project is intimately linked with the long-term coastal change Research Project CB-2. Both research plans were designed together and we anticipate sharing all monitoring and research data, as well as model results so that there is a seamless understanding from short-term, storm events to long-term (decadel to century) time periods. Furthermore, the coastal barrier objectives are key in predicting habitat changes for shore birds and turtles.
(g) Military Drivers: This research will directly address the need to preserve the integrity of the amphibious maneuver area along Onslow Beach and ensuring its continued viability. Seismic and sedimentalogical data collected as part of the coastal barrier monitoring program coupled with modeling results from STEBR will be used to quantify both natural and anthropogenic effects on beach erosion. By directly integrating these results into the LTSC model, management strategies will be developed that will focus on the maintenance and preservation of Onslow Beach as a key training locale in the face of continued day-to-day natural erosion forces, as well as future climate change.
(h) Benefit to MCBCL: The current erosion of Onslow Beach is resulting from the combined impact of natural events (storms, climate, sea-level), training activities and management practices. In order to minimize future loss of essential training area on the beach, the various impacts of all of these forces must be constrained. Results derived from STEBR and LTSC models will be applied directly towards mitigating Onslow Beach erosion. In addition, this project will help with the interpretation of morphologic monitoring data
(i) Schedule: This is a 2-year project. The start date is June 1, 2009 and the end date is May 31, 2011. The project will make use of the monitoring data collected each year, the Cleary and Riggs (1999) report, and any other newly acquired data.
Scheduling Constraints: None
Year 1 Go/No Go Decision Point: None identified. (Project does not start until Year 3.)
Budget (Estimated): ▪ Year 1 (July 2007 – June 2008): $0 ▪ Year 2 (July 2008 – June 2009): $0 ▪ Year 3 (July 2009 – June 2010): $73,000 ▪ Year 4 (July 2010 – June 2011): $ 75,000 ▪ Total (July 2007 – June 2011): $148,000

5.3.4.2 CB-2: Long-Term Barrier Evolution Related to Variations in Underlying Geology, Land Use, and Inlet Dynamics

Senior Researcher: Tony Rodriguez (UNC-IMS) **Supporting Researchers:** Jesse McNinch (VIMS) and Richard Luettich (UNC-IMS) **Staff:** 1 graduate student and 1 technician
Hypotheses: 1. Erosional "hot spots", identified as localized areas with higher than average coastal retreat rates, are not a result of anthropogenic activities or variable hydrodynamic processes. 2. Onslow Beach is sediment starved due to a lack of unconsolidated material located seaward of the shoreface, an insufficient amount of sediment transported to the area by longshore drift, and a low rate of production of new sediment through bioerosion of limestone outcrops.
Technical Objectives/Goals: Place the short-term geomorphic evolution of the area derived from the monitoring data in context with the historical (100 years) and geological (thousands of years) geomorphic evolution. Correlate the historical rates of shoreline erosion with anthropogenic activities (e.g., waterway dredging, dredge spoil disposal, and Base activities), storms, inlet dynamics, and the underlying geology to identify the principle forcing mechanisms and direction of morphologic change. Compare the historical average rates of shoreline erosion along

the barrier with the long-term evolution of the area derived from paleogeographic maps constructed from cores, seismic data, and radiocarbon dates obtained from new and previously collected data (Crowson, 1980; Robertson, 1994; Riggs et al., 1995; Johnston, 1998; Riggs and Cleary, 1998; Cleary and Riggs, 1999; Filardi, 1999; Sault, 1999; Sproat, 1999; Wise, 1999). Provide predictions of both long-term (century) and short term (seasonal to decadal) morphologic changes (shoreline migration, island topography) to the coastal barrier island by integrating results with the short-term (event) beach-response model (see accompanying short-term Research Project CB-1).

Technical Approach

(a) Background:

Sustaining the value of environmental and mission-related assets while conducting shoreline management requires a better understanding of the short- and long-term rates of coastal change, which will help differentiate between geologic, hydrodynamic, and anthropogenic forcing mechanisms. The coastal barrier ecosystem is organized directly and indirectly by the physical dynamics of ocean forcing and sediment transport. Physical processes operating in the nearshore vary in magnitude on time scales ranging from hours (coastal storms) and months (seasonal weather patterns) to decades (climate and associated sea-level change). The morphological response of the coastal barrier ecosystem to these perturbations is poorly understood, but is critically needed for better shoreline management. Variations in the underlying geology of coastal areas control how shorelines will respond (e.g., accrete, erode, alter sediment type) to different physical forcing mechanisms and the underlying geology contains a long-term history of coastal evolution (Kraft, 1971; Belknap and Kraft, 1985; Pilkey and Davis, 1987; Riggs et al., 1995; Thieler et al., 1995; Riggs et al., 1996). Anthropogenic stressors such as dredging, construction, landing craft deployment, amphibious training, and munitions practice further impact the morphology of the coastal barrier and play a large roll in regulating rates of change. It is necessary to place short-term morphologic changes, measured directly, in context with the long-term evolution, derived from the geologic record, to differentiate between background and anthropogenic stressors. Additionally, it has been demonstrated that shorelines can exhibit non-linear rates of retreat in response to variations in underlying geology at century and decadal time scales (Rodriguez et al., 2004; Browder and McNinch, 2006).

Onslow Beach encompasses 2 different military use areas, including; highest-use training and moderate-use training (**Figure 5-19**). The North Carolina Division of Coastal Management's (NCDCM) long-term average erosion rates for Onslow Beach (1938–1992) show that the highest rate of erosion is near the New River Inlet and erosion rates decrease towards the northeast (**Figure 5-19**). The highest-use training area does not correspond with the area where the beach is eroding most rapidly and the two moderate-use training areas are located either where the beach is eroding at the slowest or most rapid rate (**Figure 5-19**). This suggests that Base activities are not the principal cause of coastal erosion. Cleary and Riggs (1999) and Sault (1999) hypothesized that differential erosion rates are largely a product of historic inlet modifications. USACE estimated that the average annual erosion rate for the southern 7 km section of Onslow Beach between 1857 and 1933 was less than 0.35 m/yr and the NCDCM showed that this rate increased to 2 m/yr between 1938 and 1980. The timing of this increase in beach erosion corresponds with the establishment of MCBCL in 1941. It is not surprising that the part of the coastal barrier that experiences the highest erosion rate has virtually no dunes, but extensive overwash fans (**Figure 5-19**, Area 1), and the part of the coastal barrier that experiences the lowest erosion rate has high-elevation and continuous dunes. The morphologic variations that exist throughout the study area likely reflect variations in the underlying geology, especially the Belgrade formation headland, which is located at the New River Inlet, and the contact between the Belgrade Formation limestone and the Silverdale Formation sand, which trends south from Brown's Inlet (Johnston, 1998; Cleary and Riggs, 1999; Filardi, 1999). Determining the factors that contribute to the along-strike variability in coastal retreat rates and their relative importance will lead to: (1) more accurate predictions of shoreline change if no mitigation options are employed, (2) appropriate evaluation of erosion-mitigation options, and (3) better understanding of the impacts future Base activities will have on the coastal barrier.

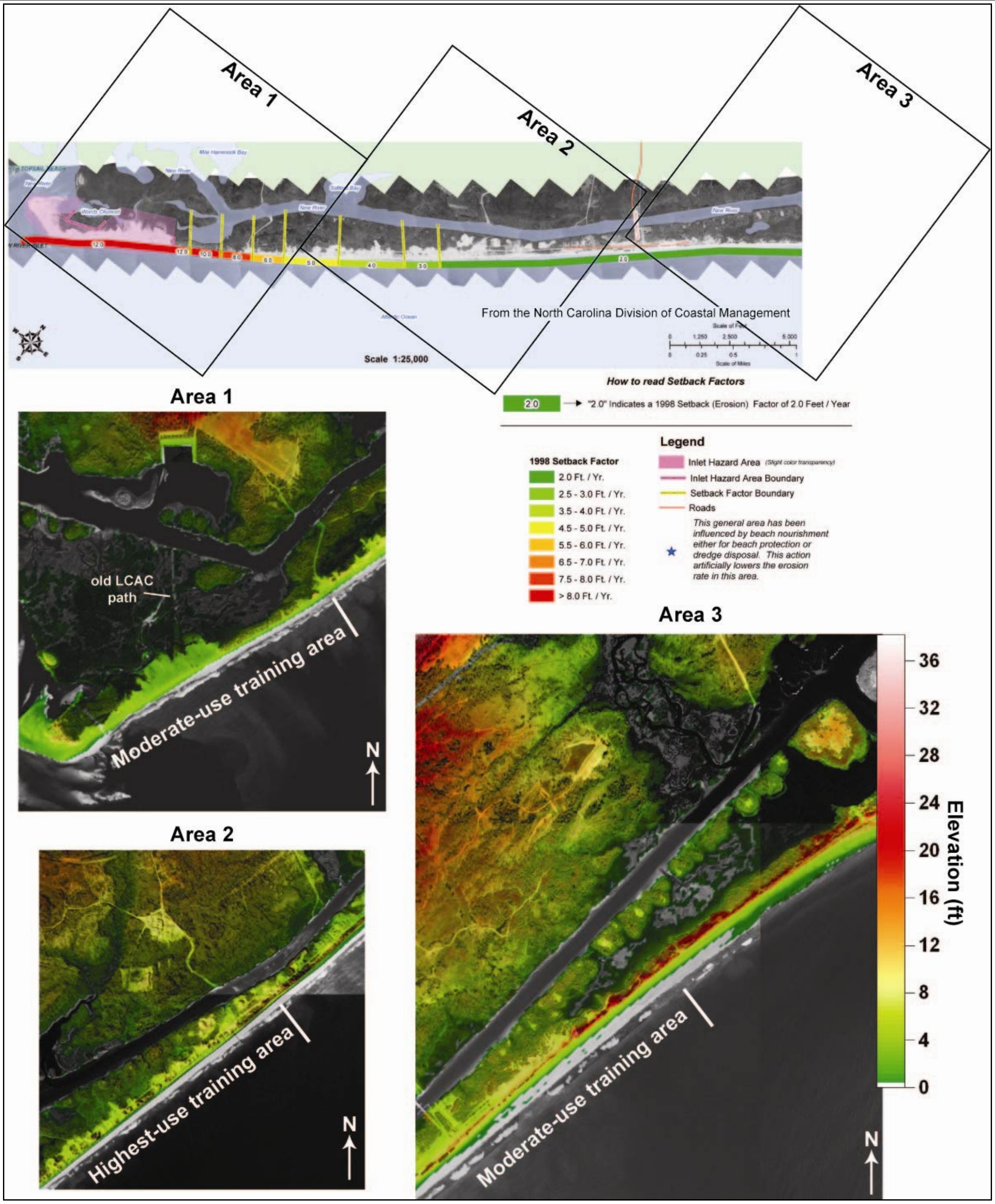


Figure 5-19. Average erosion rates for the study area, determined by the North Carolina Division of Coastal Management from 1938 to 1992, and LIDAR data suggests that there is not a strong relationship between Base activities and shoreline erosion rates.

The lithology and bathymetry of the sea floor, just seaward of the shoreface toe, is highly variable (Cleary and Riggs, 1999; **Figure 5-20**) and likely plays an important roll in shoreline evolution by modifying the wave field and regulating sediment supply. Paleochannels filled with unconsolidated sand and gravel (**Figure 5-19**) extend through the shoreface and onto the inner shelf (Cleary and Riggs, 1999). Browder and McNinch (2006) recognized an association between erosional "hot spots" and paleochannels along the North Carolina and Virginia coast, but this has not previously been recognized along Onslow Beach. Sandy limestone of the Upper Oligocene Belgrade Formation is the most widespread unit exposed at the sea floor and in places, high-relief hard-bottoms extend

>2 m above the surrounding sea floor (Johnston, 1998; Cleary and Riggs, 1999; Filardi, 1999). Although most of the sea floor is lithified, the rock scarps may represent a major source of sediment to the beaches through bioerosion and sediment transport during storms (Crowson, 1980; Riggs et al., 1995); however, this has not been quantified.

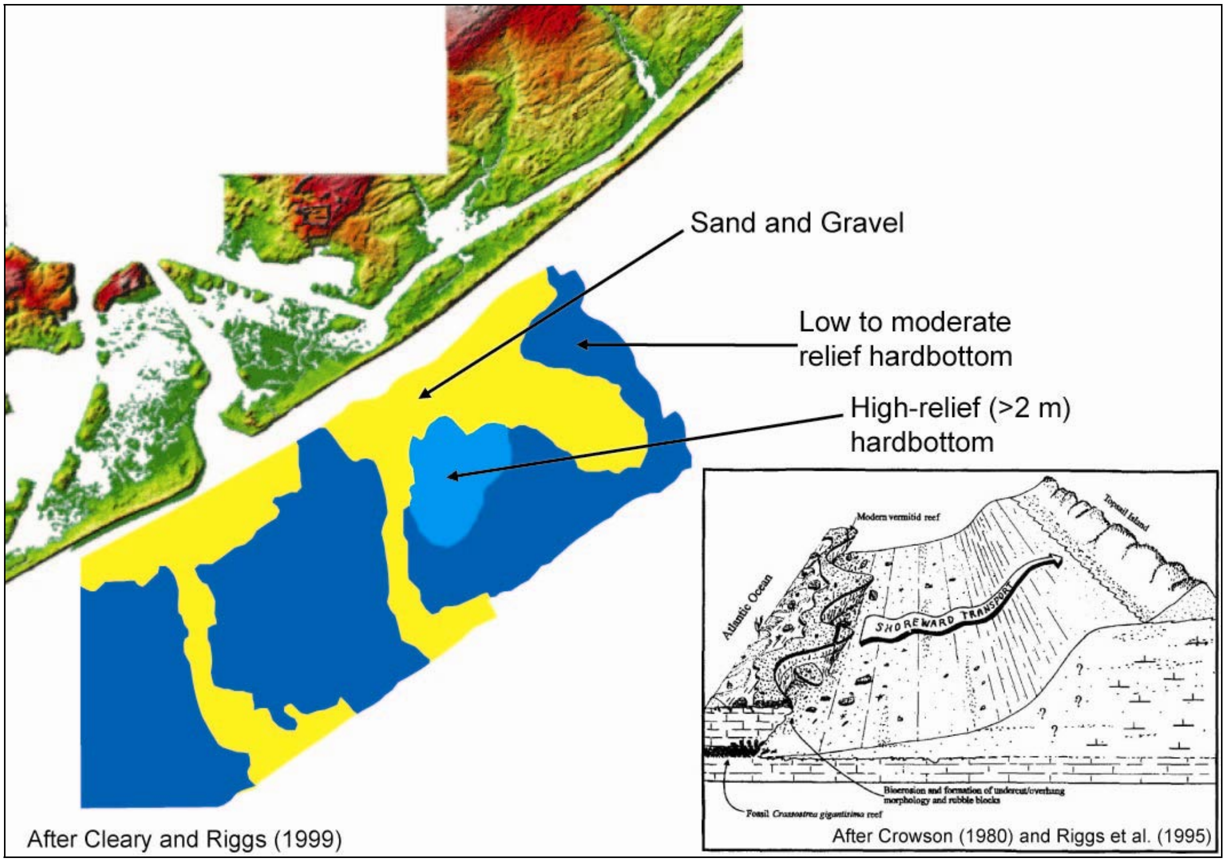


Figure 5-20. Map showing the lithologies exposed at the sea floor and large bathymetric features (Cleary and Riggs, 1999).

Inset is a schematic diagram illustrating bioerosion of the limestone scarp and storm-transport of the resulting sediment to the beach (after Crowson, 1980; Riggs et al., 1995).

(b) Experimental Design

Objectives will be addressed by comparing the evolution of the study area and the principle drivers of change at three different time-scales: millennial, decadal, and yearly. The evolution of the coastal area (millennial time scale) will be reconstructed by examining the sedimentary record preserved in the paleochannels and behind the barrier (Sproat, 1999; Wise, 1999). Historical (decadal) changes in shoreline position, inlet morphology, and vegetation cover will be compared with maps of the underlying geology and records of Base activities and anthropogenic stressors (Johnston, 1998; Filardi, 1999; Cleary and Riggs, 1999). Present-day sediment dynamics (erosion, accretion, and transport) will be obtained through analysis of the monitoring data. The information will be used to test and calibrate the modeling efforts of Research Project CB-1.

(c) Methods:

Previously collected data and interpretations from Riggs et al. (1995); Johnston (1998); Riggs and Cleary (1998); Cleary and Riggs (1999); Filardi (1999); Sproat (1999); and Wise (1999) will be used as a guide for additional data collection and incorporated into this study. Historical aerial photos from North Topsail to Browns Island will be analyzed using ArcGIS to quantify changes in shoreline position, vegetation cover, and inlet architecture. Aerial photos from the 1930's to present are part of the Base's GIS database and are rectified. Calculations will be placed in context with records of Base activities, and storms (some of these data should be available from previous efforts. Data collected for the monitoring program, including 3-D bathymetry, 3-D topography, and sediment texture, will be interpreted as part of this research project (see DCERP Baseline Monitoring Plan). High-resolution seismic and side-scan sonar data will be collected to map paleovalleys and constrain sea-floor lithology. Approximately 300 line-km of seismic data from the study area, including an axial (dip-oriented) seismic line up each of the paleovalleys, will be collected with an Edgetech SB512i chirp system. Coring locations will be chosen based on the seismic data and resulting paleogeographic maps. Cores will be collected offshore from the R/V Pelican operated by VIMS. Cores from subaerial and intertidal areas will be collected using the Geoprobe Macro-Core ™ sampling tool. The sampling tool will be driven to depth using a gas-powered portable jackhammer.

Seismic-data interpretations will be verified from the lithologic and paleontologic (macrofauna) data obtained from the cores. Cores will also provide material for radiocarbon dating. Cores will be described, emphasizing sediment texture, composition, color, and sedimentary structures, including bedding surfaces, stratification, and trace fossils. Compressive and shear strength will be measured using a torvane and a pocket penetrometer to estimate sediment compaction (Paul and Barras, 1998; Massey et al., 2006). Grain-size data will be collected by using a Cilas laser particle-size analyzer (for clay, silt, and sand sized particles) and sieves (for particle sizes >2 mm). Samples for paleontological and radiocarbon analysis will also be collected (mainly wood and shell material). It is important for material age dated to be preserved in situ. Whole plant fragments and wood are preferred over bulk peat material and carbonate. Whole pieces of plants provide accurate ages because they are fragile and the possibility of redeposition is small (Gehrels et al., 1996; Törnqvist et al., 1998). Shell material can easily be displaced, for example, fine-grained sediment can be removed creating shell lags. Articulated bivalves indicate that preservation was in-situ and if DIC is necessary to date, this will be the primary type. Samples will be analyzed using the NSF National Ocean Sciences Accelerator Mass Spectrometer Facility at the Woods Hole Oceanographic Institution.

(d) Data Analysis:

Seismic and side-scan sonar data will be processed by applying time varying gain and a band-pass filter prior to interpretation. These data will be uploaded into Chesapeake Technology Inc. SonarWiz map plus SBP software for interpretation. Seismic facies and bounding surfaces will be identified and mapped through the area. Isopach maps of seismic facies and structure maps of regional seismic surfaces will be produced using the contouring software package Surfer™. Core descriptions will be integrated with the seismic data interpretations and radiocarbon dates to develop the geological evolution of the area. Vegetation and shoreline positions will be digitized on the aerial photographs using ArcGIS and rates of change calculated. The spatial variation in rates of change for the historical data set will be correlated with maps of the underlying geology, land use, and timing of periodic anthropogenic stressors such as dredging and disposal of sediment using ArcGIS. Using Surfer™, seamless bathymetric and topographic maps will be created from each monitoring effort, and these maps subtracted from one another to determine areas of erosion and accretion and quantify volume changes.

(e) Environmental Indicators, Tools and other Outcomes:

By producing maps of the area that show its evolution at three different time scales, including: 6 ka to 1930 AD (geological), 1930 AD to 2003 AD (historical), and 2007 AD to 2011 AD (monitoring) and by correlating the location, magnitude, and timing of natural (storms) and anthropogenic (Base activities) stressors with these maps, (1) The principle drivers of coastal erosion will be identified, (2) Erosion-rate trends will be quantified (acceleration or deceleration in coastal retreat rates), (3) Erosional "hot spots" will be identified and their spatial variability through time constrained, and (4) Erosion-mitigation options will be evaluated. Integrated maps of the barrier and adjacent inner shelf that show volume changes through time will help identify sediment transport pathways. These products will also provide a means for calibrating and testing the models produced in Research Project CB-1.

(f) Linkages to other Modules:

Extensive coastal wetlands exist on the landward side of the barrier and movement of the shoreline directly affects the function of this environment. For example, wind-transported sand from the barrier and sand washed over the barrier during storms are important sediment sources for coastal wetlands that help this environment "keep up" with sea-level rise. Inlet dynamics, in part, control the hydrodynamics (including salinity gradient) and sediment cycling in the NRE. Changes in the orientation and dimensions of the inlet will influence estuarine flushing and the tidal regime.

(g) Military Drivers: This research will directly address the need to preserve the integrity of the amphibious maneuver area along Onslow Beach thereby insuring its continued viability by quantifying erosion-rate trends (acceleration or deceleration in coastal retreat rates), identifying erosional hot spots, constraining the spatial variability of erosional hot spots through time, and by evaluating erosion-mitigation options.
(h) Benefit to MCBCL: Loss of training area along Onslow Bay is one of the most important issues facing MCBCL. This project will assess the principle process driving Onslow Beach erosion, including natural (storms, climate, sea-level, underlying geology) and anthropogenic (training activities and management practices). From quantitative measures of shoreline movement and sediment sequestration in the past, predictive models of shoreline position will be derived. Additionally, the research will provide important geomorphic information, including long- and short-term reconstructions of coastal evolution vital for insuring the continued viability of the training range.
(i) Schedule: This is a 2-year project. The start date is June 1, 2009 and the end date is June 30, 2011. The project will make use of the monitoring data collected each year, previous work in the area by Riggs et al. (1995); Johnston (1998); Riggs and Cleary (1998); Cleary and Riggs (1999); Filardi (1999); Sproat (1999); and Wise (1999) and other newly acquired data.
Scheduling Constraints: Seismic data and offshore cores need to be collected when wave height is low.
Year 1 Go/No Go Decision Point: None identified. (Project does not start until Year 3.)
Budget (Estimated): ▪ Year 1 (July 2007 – June 2008): $0 ▪ Year 2 (July 2008 – June 2009): $0 ▪ Year 3 (July 2009 – June 2010): $81,000 ▪ Year 4 (July 2010 – June 2011): $85,000 ▪ Total (July 2007 – June 2011): $166,000

5.3.4.3 CB-3: Understanding the Top-down and Bottom-up Drivers of Shorebird Nest Success and Habitat Use in Relation to Beach Management Practices on MCBCL

Senior Researchers: Sarah Karpanty (Virginia Tech [VT] and Jim Fraser (VT) **Supporting Researcher:** Pete Peterson (UNC) **Staff:** 2 graduate students (1-VT, 1-UNC-IMS), 1 technician (6 months); 1 post-doctoral researcher (Years 3 and 4, UNC-IMS)
Hypotheses: **1:** Shorebird breeding season distribution, abundance, and nest success are driven by bottom-up processes such as physical sedimentary structure, prey abundance, prey diversity, and prey distribution, which vary in relation to beach management practices. ▪ 1A: Sediment composition does not impact shorebird foraging and nesting distributions, abundance, survival, or reproductive output. ▪ 1B: Prey community composition, physical processes, sediment composition do not vary across land uses or in relation to beach management practices. ▪ 1C: Prey community composition, physical processes, and sediment composition, independent of beach management practice, do not influence shorebird foraging and nesting distributions, abundance, survival, or reproductive output. ▪ 1D: Legacy sedimentology (e.g., overwash and erosion) does not influence shorebird distribution, abundance, survivial, or reproductive output.
2: Shorebird breeding season distribution, abundance, nest success and reproductive output are driven by top-down processes such predation, by natural or feral predators, which vary in relation to beach management practices. ▪ 2A: Predator abundance, diversity, and distribution do not vary across land uses or beach management practices.

- 2B: Predation by natural and feral predators on barrier island avian species is incidental, and there is no evidence of regular patterns of predation or visits to nests by predators (e.g., trap-lining).
- 2C: Terrestrial predator foraging, habitat use, and colonization of MCBCL barrier islands are not influenced by human uses of the barrier island; predator occupancy is not greater in areas of human use on the islands than in “natural” areas.
- 2D: The probability of natural or feral predator occupancy/abundance on the barrier island is not explained by a logistic regression of season, predator species, habitat availability, prey availability, or abiotic factors such as weather.
- 2E: Natural and feral predators on the barrier islands at MCBCL are not depredating of nesting and hatchling birds.

Technical Objectives/Goals:

1. To understand the biotic and abiotic variables that drive shorebird reproductive output and breeding season distribution on MCBCL.
2. To relate trends in shorebird foraging and nesting distributions, abundance and reproductive output to variation in land use (e.g., military training versus recreation versus no present human activities with attention to frequency and duration of specific activities in each category) and management practices (e.g., beach closures, ORV regulations, restricted military or recreation activities, potential beach replenishment, vegetation control, dune rebuilding) so that (1) shorebird indices may be used as indicators of ecosystem function, and (2) the best and most efficient management and monitoring can be applied.
3. To understand those elements of predator ecology on barrier islands needed to enhance shorebird conservation and most efficiently control predators as needed.

Technical Approach

(a) Background:

Barrier islands provide key habitats for nesting, migrating, and wintering shorebirds. Many shorebird species are declining worldwide due to a variety of factors stemming from habitat degradation and loss. A number of shorebird species use MCBCL (see below), including the threatened piping plover (*Charadrius melodus*) and the ESA candidate species, the red knot (*Calidris canutus rufa*). Under the ESA, MCBCL is required to use its authorities to further the conservation of the piping plover and may soon be required to do the same for the red knot. Moreover, under a recently signed Memorandum of Understanding (MOU) (71 Federal Register 51580-51585), DoD agreed to work with the FWS to step up its protection of migratory birds, including taking actions to minimize take, to identify and protect key habitats, and to prevent damage to such habitats.

A key to successful conservation and management of shorebirds and other migratory birds at MCBCL is a detailed understanding of whether shorebird populations that use the barrier island system are more greatly limited by top-down (e.g., predation) or bottom-up processes (e.g., food availability and sedimentary habitat) (**Table 5-4**). On coastal barrier islands with heavy human use, predation by meso-predators (e.g., foxes, raccoons, feral cats) has been demonstrated to often be the most important factor affecting shorebird productivity, survival, and distribution (e.g., Patterson et al., 1991). Prey community structure (e.g., abundance by species, size class distribution) and availability is also frequently identified as an important factor limiting avian use of an area on migratory stopover, nesting success, and over-winter survival (Newton, 2005), and experimental studies have demonstrated that foraging shorebirds can alter the composition of invertebrate prey communities (Quammen, 1981, 1984). Finally, in addition to the biologically mediated top-down and bottom-up processes of predation and food limitation, physical forces can structure coastal shorebird communities. The morphology of coastal barrier islands is extremely dynamic and at any given moment reflects a temporary balance between geology and physical forces. Washover fans, for example, typify barrier islands in a wave-dominated setting that are undergoing long-term transgression or possibly the recent impact of a severe storm. Understanding the historical trends and predicting future washovers is important for management strategies of biota using this habitat and long-term sediment budgets. Bay side intertidal flats formed and maintained by these washovers are key habitats for migrating and resident shorebirds and seabirds. Piping plover nesting density and nesting success often are greatest on beaches adjacent to such flats. Wintering piping plovers forage on bayside intertidal areas in preference to the ocean swash zone whenever bay flats are available (Fraser et al., 2005; Loegering and Fraser, 1995). Other species, such as ruddy turnstones, willets, sanderlings and red knots also forage extensively in these habitats (Karpanty et al., 2006).

Once the relative importance of top-down and bottom-up processes on the abundance, survival and productivity of key shorebirds is known, then the Base’s INRMP can be revised to use resources most efficiently to manage limiting factors to best meet the intent of the ESA and this new MOU (e.g., control predators versus supplement food availability versus create washover habitats).

Table 5-4. Selected Shorebirds/Seabirds that Use MCBCL and Their Status

Species	Nester	Migrant	Status
Piping plover	X (potential)	X	Federally threatened
Red knot		X	Federal candidate species
Wilson's plover	X	X	High concern (North American Shorebird Plan)
American Oystercatcher	X	X	High concern (North American Shorebird Plan)
Sanderling		X	Possibly declining
Black-bellied plover		X	Common
Semipalmated sandpiper		X	Common
Semipalmated plover		X	Common
Least tern	X	X	Possibly declining

(b) Experimental Design

In this section, we have connected the hypotheses with project technical objectives to illustrate how the evaluation of each hypothesis (1A through 1D and 2A through 2E) will address a specific objective. Methods and relationships to MCBCL priorities are described in subsequent sections. Other members of the Coastal Barrier Module Team will conduct simultaneous studies of sedimentology and benthic invertebrate communities, along with our studies of shorebirds and predators on the accessible portions of Onslow Beach Island. Concurrent studies of these biotic and abiotic processes and impacts on shorebird population parameters will allow us to understand how the physical and biological processes (both non-human and human factors) interact in this coastal barrier ecosystem and will allow MCBCL to best manage for species of concern while also managing for the sustainability of the physical island structure. These hypotheses can only be fully addressed given the simultaneous completion of all the research and monitoring activities of the Coastal Barrier Module, especially the synthesis of these data as proposed in the DCERP Baseline Monitoring Plan.

Objective 1. To understand the biotic and abiotic variables that drive shorebird nest success and bredding season distribution on MCBCL.

- 1**:** Shorebird distribution, abundance, and nest success are driven by bottom-up processes such as physical sedimentary structure, prey abundance, prey diversity, and prey distribution, which vary in relation to beach management practices.
- 1A: Sediment composition does not impact shorebird distribution, abundance, survival, or reproductive output.
- 1C: Prey community composition, physical processes, and sediment composition, independent of beach management practice, do not influence shorebird distribution, abundance, survival, or reproductive output.
- 1D: Legacy sedimentology (e.g., overwash and erosion) does not influence shorebird distribution, abundance, survival, or reproductive output.
- 2**:** Shorebird distribution, abundance, survival, and nest success are driven by top-down processes such as predation, by natural or feral predators, which vary in relation to beach management practices.

Objective 2. To relate trends in shorebird foraging and nesting distributions, abundance, and nest success to variations in land use (e.g., military training of varying intensity versus recreation versus no present human activities) and management practices (e.g., beach closures, off-road vehicle regulations, restricted military or recreation activities, potential beach renourishment, vegetation control, dune rebuilding) so that (1) shorebird indices may be used as indicators of ecosystem function, and (2) the best and most efficient management and monitoring can be applied.

- 1B: Prey community composition, physical processes, sediment composition do not vary in relation to land use or beach management practices.
- 2A: Predator abundance, diversity, and distribution do not vary across land uses or beach management practices.

Objective 3. To understand those elements of predator ecology on barrier islands needed to enhance shorebird conservation and most efficiently control predators as needed.

- 2B: Predation by natural and feral predators on barrier island birds is incidental, and there is no evidence of regular patterns of predation or visits to nests by predators (e.g., trap-lining).
- 2C: Terrestrial predator foraging, habitat use, and colonization of MCBCL barrier islands are not influenced by human uses of the barrier island; predator occupancy is not greater in areas of human use on the islands than “natural” areas.
- 2D: The probability of natural or feral predator occupancy/abundance on the barrier island is not explained by a logistic regression of season, predator species, habitat availability, or abiotic factors such as weather.
- 2E: Natural and feral predators on the barrier islands at MCBCL are not depredating nesting birds.

(c) Methods: Description of basic methods are provided here for the overall project and each hypothesis.

Field Crew and Logistics

Our primary team, as covered by the budget outline here, will be composed of Sarah Karpanty (VT), Jim Fraser (VT), 1 graduate student (VT), and 1 seasonal research technician. Accomplishment of all objectives and exploration of all hypotheses above requires synthesis of the data collected in this research project with data collected for Coastal Barrier Module monitoring activites and will require synthesis by Dr. Peterson. The field team will be based in Jacksonville, NC and will commute daily to/from MCBCL barrier islands using a 4-wheel-drive truck that can also be used to access remote beach locations efficiently. When necessary, we will use a 22-ft Southern Skimmer to access intertidal areas in and around inlets and behind the barrier island systems and to access more remote sections of the islands with minimal disturbance.

1A-D: *Shorebird distribution, abundance, and nest success are driven by bottom-up processes, such as physical habitat structure, prey abundance, prey diversity, and prey distribution, which vary in relation to beach management practices.*

We will study the factors affecting nesting success of breeding shorebirds in accessible areas of MCBCL (**Figure 5-21**). We will conduct transect and point count surveys, search for nests, and monitor productivity, survival, and fledgling success in available and accessible habitats for nesting shorebirds, including but not limited to Wilson’s plover and Least terns. We will study habitat selection and use by species of interest by comparing behavior and ecology of focal individuals between used and unused random points. We will compare apparent foraging success of focal shorebirds in different habitats using foraging rate as an index of foraging success. We will sub-sample the benthic prey base and general habitat features of shorebird focal species with respect to used and un-used available habitats. We will capture and individually mark with color-bands a statistically valid sample of each breeding focal shorebird species (adults and chicks) to estimate nest success across years. Capture methods may involve noose carpets, fall traps, funnel traps, whoosh nets, cannon netting, mist netting, spot-lighting or walk-in traps on beaches or other open areas used by the shorebirds and seabirds of interest. We are committed to coordinating all aspects of these trapping efforts with MCBCL staff.

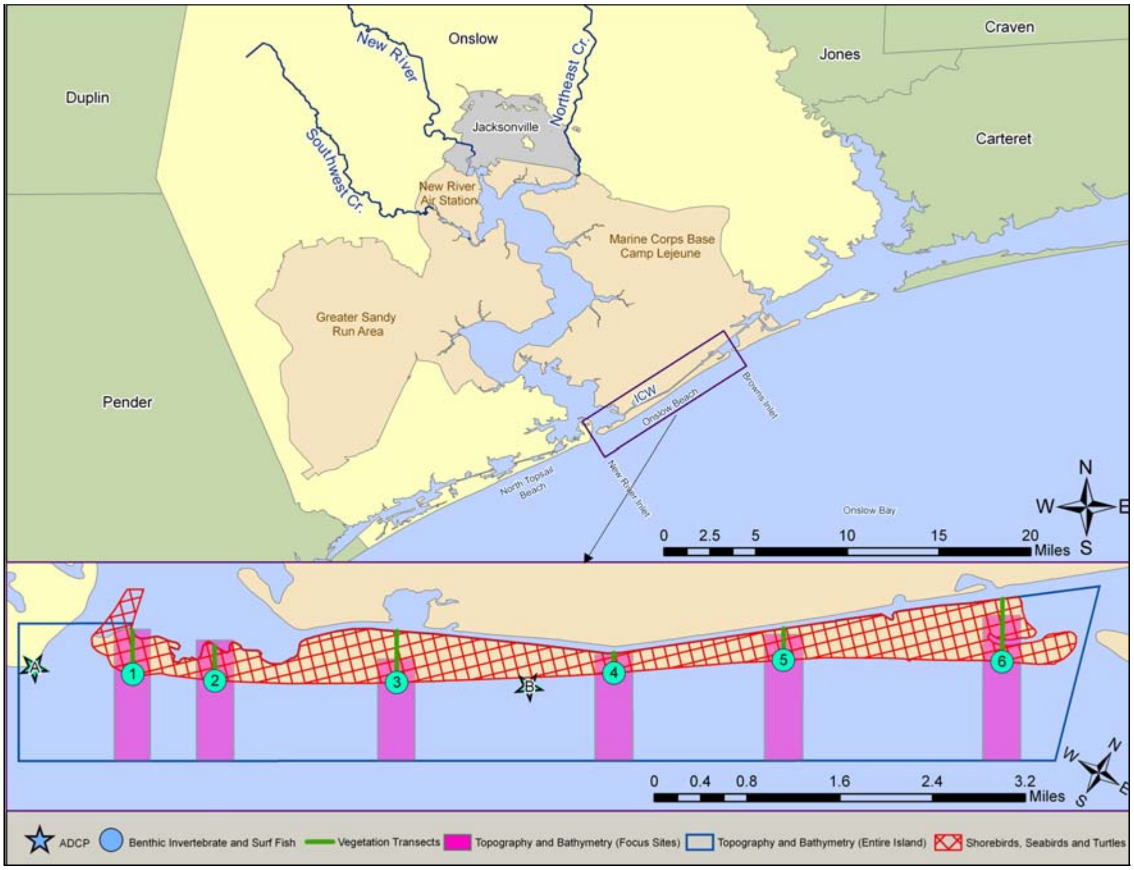


Figure 5-21. Coastal Barrier Module monitoring sites.

To determine what abiotic or biotic, bottom-up, factors are driving shorebird distribution and nest success at MCBCL, we will use the following procedures for focal bird sampling and random point selection. We will sample individuals of each species according to a stratified random scheme, without replacement, until all color-tagged individuals have been sampled at least once per season (breeding, migratory, wintering seasons). The stratifying variables will be determined based on regions of MCBCL beaches with varying land use and/or management practices. Once all individuals have been sampled each season, we will attempt multiple sampling events again using a stratified random sampling procedure.

Upon location of the focal bird, the observers will remain at a distance from the bird and any flock-mates that does not disturb their behavior and with the use of spotting scopes will immediately record the number of birds, flock species composition, and area encompassed by the flock. Data also will immediately be recorded on distance to the tide line, tidal state, distance to known roosts (calculated later from GPS points), ground aspect and slope, wind conditions, temperature, wave height, potential disturbance (e.g., dogs, people, gulls), potential predators and predator refuges, vegetation cover and distance, and any observable prey within 50 m. The observers will then collect behavioral data for up to 5 minutes on the focal bird to include foraging (and instantaneous intake rate), searching, roosting, preening, aggression, and flying of the tagged bird. Behavioral data will be recorded in scan samples each 10 seconds.

After collection of 5 minutes of behavioral data, or upon departure of the individual, the observers will note the location of the tagged or focal individual, as well as the spread of the flock perpendicular to the tide line. The observers will then immediately move to the location of the focal bird and collect three sediment core samples that are placed at the location of the tagged, focal bird and spread evenly across the estimated width of the flock perpendicular to the tide line. Thus, if the flock spread was 10 meters, samples would be centered at the location of the tagged bird and separated from each other by 5 meters in a straight line perpendicular to the tide line. Three cores, 10.5 cm in diameter and pushed 3.5 cm (average length of shorebird bill) into the sediment, will be analyzed for invertebrate composition and densities given available monetary resources. All samples may not be analyed given financial limitations. If possible, core samples are flushed through a series of screens to separate invertebrates from most of the beach sediments (6.4 mm, 3.2 mm, and 1.5 mm). Invertebrates can be preserved in buffered formalin with Rose Bengal vital stain at this point for later identification and quantification in the lab.

In order to determine if sites in which focal bird individuals are located are different than would be expected if habitat choice were random, ecological samples as described above will be conducted daily on a series of random points throughout MCBCL's barrier islands. Points will be paired by habitat type (e.g., ocean beach versus intertidal flat) and stratified by elevation within habitat, and taken along with the focal bird samples. Samples will be systematically spaced over time of day and tidal cycles. If birds of the same focal species are present at the randomly selected locations, observers will collect the behavioral and ecological data just described before continuing on to another random site where there are no individuals of the focal species. Once a random site without individuals of the focal species is located, observers will collect habitat variables and core samples as described in the previous section. Core samples spaced 5 m apart in a line perpendicular to the tide line and centered at the random point will be collected.

2A-F: *Shorebird distribution, abundance, survival, and reproductive output are driven by top-down processes, such as predation, by natural or feral predators, which vary in relation to beach management practices.*

We will determine the causes of nest failure for focal shorebird species by examining field signs such as tracks near the nests, and by monitoring nests with remote continuous recording video and automatically triggered film cameras. Video and film analyses will take place in a laboratory setting. We will set up automatically triggered heat and motion-sensing cameras in barrier island habitats to determine the species of meso-predators that use the islands, their densities (if individuals can be identified by pelage) or occupancy patterns (if individuals are not distinguishable, MacKenzie et al., 2006), rates at which the islands are re-colonized after trapping efforts by MCBCL staff, and seasonal patterns of predator use of the island habitats in general, and of distinct areas varying in land use and management practices. We will place track stations in addition to camera-traps, search systematically for scat, and determine patterns of predation on shorebirds using continuous recording cameras at nests of a sample of key species of concern. Systematic camera-trapping of predators in MCBCL habitats will take place for 2-weeks each in January, April, July, and October for a 2-year period to determine predator densities (or occupancy) patterns during shorebird wintering, migratory, and breeding seasons. Camera stations will be hidden in vegetation when possible and established according to a random stratified sampling scheme with MCBCL land use/management practices as the stratifying variables. Results of camera trapping studies will allow focused searching for predator scats and subsequent diet analyses.

(d) Data Analysis:

We will conduct standard use-availability analyses to quantify selected habitat of shorebirds of interest. We will conduct multiple regression analyses to explore how abundance, survival, and reproductive indices are related to other measured variables (see methods for variables collected). Multiple linear regression procedures will be utilized to determine the effects of independent variables on the behavior time budgets and foraging rates of shorebirds. Multi-way analysis of variance (ANOVA) will be used to test whether independent variables found to be significant in the regression procedures vary significantly among habitats, zones of different management practices or land use or with any interactions of the explanatory variables. Multiple logistic regressions with AIC model-selection techniques will be used to determine what explanatory variables (e.g., density of invertebrates, habitat type, tide state. etc.) distinguish sites in which focal birds are located from random sites without focal birds. Predator occupancy and density patterns will be calculated using standardized logistic regression modeling procedures (MacKenzie et al., 2006). We will analyze scat samples and camera records to quantify the proportion of shorebirds and sea turtles that are taken by season and year. We will use standard parametric ANOVA methods to compare productivity indices between Year 1 and 2 of the habitat manipulation experiment.

(e) Environmental Indicators, Tools and other Outcomes:

- Avian reproductive success, nest success, avian abundance by species, habitat, and season will be indicators for the efficacy of MCBCL barrier island management practices.
- Annual and seasonal variation in predator abundances and colonization rates may be indicators for the efficacy of predator control procedures and other management practices.

(f) Linkages to other Modules:

Results of this project will be integrated with the coastal barrier hydrodynamics, meteorology, geomorphology, sedimentology, and benthic invertebrate monitoring activities to best understand the top-down and bottom-up influences on the avian community. Once the factors limiting certain avian populations at MCBCL are identified in this research project, baseline monitoring activities can be refined to focus on those parameters only.

(g) Military Drivers: 4. Ensure that MCBCL supports all required military training activities while complying with the ESA and other wildlife requirements. We will identify what specific top-down and bottom-up processes are limiting shorebird species of concern and that will allow MCBCL to focus specifically on those variables for management.

(h) Benefit to MCBCL: Information obtained during this research will be incorporated into the Base's INRMP to best meet the intent of the ESA and MOU with the FWS. Results will be used to develop efficient monitoring protocols and conservation management procedures and to best design mitigation in the case of beach nourishment or the introduction of new uses to the coastal barrier system. Pilot studies of predator top-down influences will allow MCBCL to design the most efficient use of trapping resources and minimize the frequency of trapping and the co-occurrence of trapping efforts with human uses of the barrier islands. Results may open the door to non-lethal predator control tactics. It also will quantify predator impacts on shorebirds and seabirds and allow for the best design of management for these species that does not involve predator control.
(i) Schedule: ▪ Year-round periodic sampling, August 1, 2008–June 30, 2009 ▪ Benthic and sediment sampling as part of the Coastal Barrier Module monitoting: Year-round ▪ Shorebird sampling: every 10 days year-round by MCBCL staff; DCERP research activities described in this Plan will be focused between March and August 2008 and 2009 ▪ Predator sampling: We will conduct camera-based surveys 4 times annually for 2 weeks per sampling event for a total of 8 weeks/year (January, April, July, October).
Scheduling Constraints: Must sample at least 2 consecutive years to observe trends. First shorebird-seabird nesting season starts in March 2008. We will begin predator sampling in Jan. 2008 and shorebirds in March, graduate students must start classes in August 2007 and 2 consecutive years of data are needed.
Year 1 Go/No Go Decision Point: None identified.
Budget (Estimated): ▪ Year 1 (July 2007 – June 2008): $85,000 ▪ Year 2 (July 2008 – June 2009): $75,000 ▪ Year 3 (July 2009 – June 2010): $0 ▪ Year 4 (July 2010 – June 2011): $0 ▪ Total (July 2007 – June 2011): $ 160,000

5.4 Terrestrial Module

5.4.1 Introduction

The terrestrial ecosystem refers to the gradient of vegetation from salt marsh at the estuary margin, through brackish/freshwater marsh, to the longleaf pine savannas and pocosins (shrub bog) that dominate the terrestrial environments on MCBCL (Wells, 1942; Christensen, 2000). The gradients between these habitat types differentiate the terrestrial ecosystem of the coastal zone from that of inland sites, such as Fort Benning, where dry longleaf pine savannas and bottomland hardwoods dominate. Most of the rare species characteristic of coastal terrestrial ecosystems, including species of concern on MCBCL, are found in the transitional zones along these gradients. The research proposed for this module will be carried out at a variety of MCBCL locales, including the Great Sandy Run Area.

Variation in the biota and ecosystem processes along these gradients is driven by variation in hydrology, soils, and fire behavior. **Figure 5-22** presents the conceptual model for the Terrestrial Module, illustrating the complementary nature of these critical physical, chemical, and biotic processes and interactions. Salt marsh ecosystems are inundated daily with saline waters, and freshwater/brackish marsh ecosystem soils are frequently saturated with waters of lower salinity. Pocosin vegetation occurs on poorly drained organic soils and experiences infrequent (> 40 years), high-intensity fires. Longleaf pine savannas generally occur on shallow organic and mineral soils; the depth of the water table in these ecosystems varies from a few centimeters to more than a meter, depending on topography, creating a gradient between dry upland savannas and wet flatwoods. These variations have significant effects on plant composition and diversity (Walker and Peet, 1984). The locations of transitions from one ecosystem to another along this gradient are often influenced by disturbance (fire) history (Garren, 1943; Christensen, 1981). Specific conservation challenges associated with different parts of these gradients include recovering the endangered RCW in longleaf pine savannas, promoting herb diversity (e.g., Venus flytrap, *Dionea muscipula*) in wet savanna-pocosin transitions, and combating invasive species in freshwater marshes. Fire is a natural part of this landscape, and natural fire regimes (frequency and intensity) change across this soil-hydrology-vegetation gradient, from frequent surface fires in longleaf pine savannas to relatively infrequent and intense crown fires in pocosins.

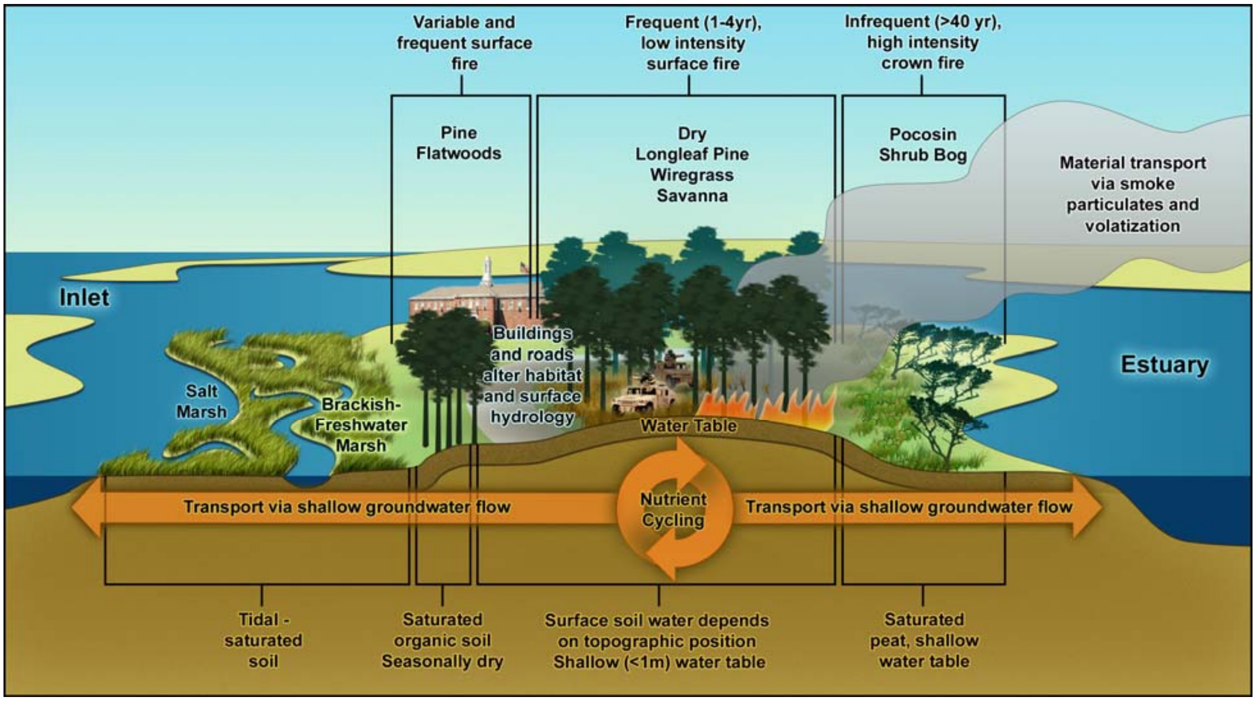


Figure 5-22. Conceptual model for the Terrestrial Module.

The research program in the Terrestrial Module focuses primarily on critical knowledge gaps related to 3 major issues in the Base's management of terrestrial habitats, use of prescribed fire, forest management activities (specifically cutting and fuel management), and improvement of habitat for RCWs. Although the general relationship between fire and vegetation change is understood in longleaf pine forests, and the utility of PB in managing such forests is well established, little is known about variations in natural fire regimes (i.e., frequency, season, and intensity of fire) along fuel and moisture gradients, and thus what changes in PB regimes might be appropriate across the soil-moisture gradient. This is particularly the case for pocosin and flatwood vegetation, and ecotones. The influence of such variations on total nutrient capital and patterns of nutrient cycling are unknown. Equally unknown is the influence of these variations on flowering and seed production of target plant species along the moisture gradient. The finer details of ecosystem variability and the characteristics and endemic species associated with unique habitats such as lime sinks are poorly understood. The needs of RCWs are well known, but virtually nothing is known of community dynamics between the plants at the base of the food chain and the RCW at the top, or within the consumer community at the top beyond the RCW (U.S. FWS, 2003). New regulations from the FWS require MCBCL to convert most of the pine acreage on the Base into high quality foraging habitat for RCWs, and to be able to quantify habitat quality. Therefore a greater understanding is needed of how intensive management for RCW may affect other species.

The three research projects proposed for the Terrestrial Module (**Table 5-5**) constitute an integrated program designed to provide a greater understanding of how forest management and especially PB affect plant and animal communities across the soil-moisture gradient. The relationship between RCW foraging habitat quality and community composition will be an outcome of this understanding. The research projects build upon the vegetation monitoring proposed for the Terrestrial Module, which will provide much of the data to be used in assessing relationships between management and community composition. The research projects include additional components that add to that foundation, specifically experimental plots (Research Projects T-1 and T-2), and sampling of more components of the community (Research Project T-2). Research Projects T-1 also examines the effects of military training activities on habitat quality and community composition.

Table 5-5. Terrestrial Module Research Project Title, Senior Researcher, Benefit to MCBCL, and Duration of Project

Project	Research Project Title	Senior Researcher/ Duration
T-1	*Varying Prescribed Fire Regimes and Forest Management Effects on Terrestrial Ecosystem Structure and Function.*	**Senior Researcher:** Norm Christensen
	Outcomes and benefit to the Base: Provide measures of the effects of military and forestry activities on plant and animal communities and guidance on how best to mitigate any adverse effects of such activities.	**Duration:** 1/08–6/11
T-2	*Effects of habitat management for red-cockaded woodpeckers on bird communities*	**Senior Researcher:** Jeff Walters
	Outcomes and benefit to the Base: Provide an efficient method to measure quality of RCW habitat over a large spatial extent and analysis of effects of management on not only the endangered RCW, but also another species at risk, the Bachman’s sparrow	**Duration:** 1/08–6/11

5.4.2 Knowledge Gaps in Conceptual Model and Research Needs

Much of MCBCL’s management activity is focused on the terrestrial environment (see MCBCL, 2006a) and as a result many management priorities and knowledge gaps are being addressed by other current research, and therefore need not be included in the DCERP Research Plan. We will coordinate our efforts with these other projects, several of which involve our module research team members. Conversion of the dominant tree species in upland pine savanna and pine flatwood loblolly habitat from loblolly to longleaf pine while retaining wildlife value, especially for RCWs, is an important management need in many parts of the Base. Aspects of this issue is being addressed by other SERDP projects (CS-1303, SI-1474) led by Joan Walker. Another management need is to be better able to use habitat off Base in recovery of RCWs, so that the birds on Base are better connected to other populations in the region, and so that the responsibility of RCW recovery in the region does not fall solely to MCBCL. Other SERDP projects in which the Terrestrial Module co-lead (Walters) is involved are assessing the value of habitat patches off Base for RCWs (SI-1471, SI-1472, SI-1469) and providing tools that Base managers can use to promote regional RCW recovery through the Onslow Bight Conservation Partnership. One of these projects (SI-1471) will quantify the value of pocosins as dispersal habitat for RCWs, and thus partially address an additional management need, determining importance to RCWs and other natural resource values of pocosins. Finally, as detailed in the Monitoring Plan, an additional management need, RCW monitoring, is being addressed in a project headed by the Terrestrial Module co-leader (Walters) funded directly by MCBCL. This project is also providing information on effects of military training activity on RCWs.

Our research projects focus on the most critical management priorities, knowledge gaps and research needs that are not addressed by these other ongoing projects. We focus on how PB and forest management programs designed chiefly for two species, the RCW and longleaf pine, affect the dynamics and composition of the greater terrestrial communities in which these species reside, and how those impacts vary along the soil-moisture gradient characteristic of terrestrial ecosystems at MCBCL and other coastal environments. This research program will also evaluate the values and impacts of mechanical fuel management in meeting forest restoration goals.

5.4.3 Benefit to MCBCL

The research proposed relates broadly to one of MCBCL's military drivers, to ensure that MCBCL supports all required military training activities while complying with the ESA and other wildlife requirements. The research will provide an improved understanding of the functioning of terrestrial communities that will better enable managers at MCBCL and other facilities in coastal environments to integrate training with forest sustainability, habitat restoration and endangered species management. Fire management is particularly critical in the Base's terrestrial environments, and an objective of the proposed work is to find optimal frequencies and PB seasons for the maintenance of species diversity, improvement of RCW habitat and minimization of wildfire risk, across the variety of terrestrial communities found on the Base. At the same time, the research, in combination with that proposed for the Atmospheric Module (Research Project Air-1), will provide an understanding of fire dynamics that will enable Base managers to reduce issues associated with air quality while retaining the ability to burn to achieve management objectives, including the management of fuel loads. This research will provide a direct evaluation of the possible effects of changes in fire management and military maneuvers (those of particular interest to MCBCL) on the establishment and spread of non-native invasive plant species. Management of species at risk, especially RCWs, remains a very high management priority at MCBCL. The proposed research will result in practical benefits in terms of meeting obligations under the ESA, specifically improved means to measure habitat quality for RCWs. It will also provide information about other at-risk species found on the Base, including several plant species and Bachman's sparrow, and most importantly, will facilitate the ability of Base managers to practice ecosystem management by revealing how entire terrestrial communities (as opposed to single species) respond to management activities and military training uses.

5.4.4 Proposed Research Projects – Terrestrial

5.4.4.1 T-1: Varying Prescribed Fire Regimes and Forest Management Effects on Terrestrial Ecosystem Structure and Function

Senior Researcher: Norm Christensen (Duke)
Supporting Researcher: Karsten Baumann (ARA)
Staff: 1 post-doctoral researcher, 1 technician, 1 graduate student, and 2 seasonal undergraduate field assistants (Duke)

Hypotheses:

1. Species diversity will increase with increasing fire frequency (e.g., annual fires), and this effect will increase with increasing moisture.
2. Herbaceous productivity will be highest at intermediate fire frequencies and with increasing moisture.
3. Herbaceous diversity and productivity will decline and growth of invasive alien herb species will increase with increasing vehicle traffic. Moist areas will be more sensitive to these impacts.
4. Herbaceous composition will vary depending on fire season.
5. Changes in the composition, productivity and diversity of the herbaceous community will be highly correlated with variations in the composition of insect and bird communities.
6. The abundance and spread of invasive non-native species will increase with increased disturbance of the forest canopy associated with forest management and restoration, especially where fires are frequent or especially intense.
7. Forest management activities will have their greatest impacts on species richness and composition at the diverse moist end of the environmental gradient.

Technical Objectives/Goals: Measure impacts of (1) different forest cutting regimes and fuel management, and (2) different fire frequencies and seasons on fuels, fire behavior (including fuel consumption and ash fall), forest stand (tree and herb layer) production, composition, and diversity, and the abundance of key insect and bird species. Project will provide a more detailed basis than currently exists for matching fire management protocols to specific goals. This research will focus on numerous data gaps, including the following:

1. Effects of variations in fire regimes (frequency, season and intensity of fire) along fuel and moisture gradients.

2. Impacts of forest management (partial and clear cutting) on herbaceous communities and the interaction of those activities with fire management.
3. Connections between fire regimes, human activities, herbaceous communities and habitat for insect and bird communities.
4. Improved understanding of these effects at the moist, e.g., pocosin transition, end of the moisture gradient.

These results will bear directly on management objectives, including the following:

1. Restoration of longleaf pine habitat
2. Recovery of RCW populations
3. Conservation of native biological diversity
4. Support for military maneuvers
5. Sustainable forest management
6. Fire and fuel management

Conditions for the Project: Identify an array of stands encompassing the gradient of soil/site moisture conditions from dry longleaf pine to the longleaf-pocosin ecotone and the range of conditions over which military activities occur. This array corresponds to many of the areas typically burned at MCBCL each year.

Technical Approach

(a) Background: Goals of PB include fuel management, wildfire control, biodiversity and compositional maintenance, and endangered species management. On sites where species composition has been altered by invasive non-native species or by past land use, prescribed fire may be an important tool for the restoration of natural plant communities.[1] Fire frequency and season of burn are both known to greatly impact ecosystem composition, especially in longleaf pine dominated systems (e.g., Schneider, 1988 and Glitzenstein et al 2003). Many areas on MCBCL have had a history of fire suppression and associated loss of biodiversity, whereas a few areas (such as some impact areas) have been burned more frequently than would have occurred naturally. Although fires are typically prescribed in the late winter when burns are most easily set and managed, and air quality concerns are minimal, the specific season within which burns occur significantly influences not only fire behavior, but the relative success of different species. Growing season burns are currently prescribed on MCBCL to achieve specific objectives such as hardwood control or restoration of particular species populations. The specific nature of responses to varying fire frequency and seasonality likely vary along moisture-driven compositional gradients on MCBCL. The focus here will be on focal areas for MCBCL PB programs, that is, longleaf and some loblolly pine communities that are typically maintained by high-frequency (1–5 year return time), low-severity fire regimes. The optimal fire frequencies and seasons for achieving the restoration targets need to be identified. The interaction of fire regime effects with the effects of vehicle traffic (associated with military maneuvers) and forest management (associated with timber harvest and restoration) has not been studied. Furthermore, little is known regarding the variation in effects along terrestrial ecosystem moisture gradients over which management takes place.

(b) Experimental Design:

Independent variables will include:

- Soil/site moisture—this will be treated as a continuous variable and characterized by soil organic matter and depth to water table.
- Fire regime—this is a combination of discrete variables, namely growing season versus non-growing season fire. Co-variates include measures of local fire intensity (flame heights and fire temperatures).
- Forest management regime—this will include evaluation of uncut, thinned or partial cuts, and clear cut areas.
- Wherever possible, the effects of military activities (foot and vehicle traffic) will be examined as a co-variate in this project.

Dependent variables will include:

- Herbaceous layer species composition and relative abundance (annually sampled)
- Herbaceous biomass and fuels (continuous)
- Insect and bird species composition and abundance (sampled annually)

This research will be carried out in 50-60 year old loblolly pine stands that are slated for eventual restoration to longleaf pine. Working with MCBCL forest management staff, a minimum of 4 stands of 50-60 year old loblolly pine will be selected for each management treatment. Treatments will include 1) no cutting; 2) Canopy thinning without mechanical fuel treatment; 3) Canopy thinning with mechanical fuel treatment. Treatment areas will be subjected to either growing season or non-growing season prescribed fire on a triennial basis. All experimental plots will be sampled for herb layer, insect and bird composition and abundance each year (this will require several samples through the growing/breeding season). In addition, fuel amounts will be measured after Andrews and Bradshaw (1997).

Differences among treatments will be tested using a combination of ANVOVA, ANCOVA and multiple regressions analyses.

(c) Methods:

(1) Stands slated for forest management restoration will be identified on MCBCL. This will mostly involve areas now dominated loblolly pine, although some areas now supporting loblolly pine or pond pine may also be included. Past fire and land-use history will be determined and herb/shrub layer compositional variation will be sampled in identified stands for which such information is currently unavailable. (2) A series of experimental treatment areas spanning the range of species composition and management activities will be monitored for vegetation change, structure, and species richness. Burn treatments will be done in conjunction with MCBCL's on-going fire management program. Individual burn units will be sufficiently large to accommodate simultaneous studies of emissions to the atmosphere from burn units that will be undertaken by Research Project Air-1.

(2) Experimental plots will be monitored during fires for flame height and soil surface temperature (using ceramic paints), total fuel consumed, and ash deposition. Effects of treatments on soil water quality will be monitored in shallow (1–3 m) wells. Treatment plots will be subsequently monitored for species abundance, diversity, cover of herbs, and biomass of woody plants using the same general methodology as in the terrestrial vegetation monitoring program. Bird composition and abundance will be assessed from point vocal samples located across the treatment at several times through the breeding season. Sweep net samples of insects will be taken twice during each growing season at each experimental plot. Insects will be euthanized and identified in the laboratory to the lowest taxon possible.

(d) Data Analysis:

Data will be analyzed using standard parametric approaches such as analysis of variance and regression. Novel multivariate analyses will include non-metric multidimensional scaling (McCune and Grace, 2002), CART® analysis and Mantel's comparisons (Mantel, 1967). Changes in fuel conditions will be measured and used to estimate fire risk in the context of USFS fire danger rating models (Andrews and Bradshaw, 1997).

(e) Environmental Indicators, Tools and other Outcomes:

Potential environmental indicators to come from this project include the following:

- Species indicators (including alien species) of environment, fire and management regime. This will address Base needs to understand consequences of variation in burn regimes and forest restoration activities on plant abundance and diversity and provide the basis for optimizing management activities with respect to location and timing.
- Indicators of habitat quality for RCW and other species. This will include a mechanistic understanding of the connection between fire, management and the RCW by providing information on trophic connections.
- Fuel indices. These results will provide detailed information on the effects of variations in site conditions and prescribed fire regime on fuels and fire risk. It is therefore directly relevant to MCBCL's fire management program.

(f) Linkages to other Modules:

This research project will provide direct linkages to the following:

- Directly support Research Project T-2 related to RCW recovery and management.
- This design and experimental plot sampling will support Research Project Air-1
- Groundwater quality measurements will provide information to the Coastal Wetlands and Aquatic/Estuarine modules on possible impacts of terrestrial management activities on water quality.
- Results will improve design and interpretation of terrestrial vegetation baseline monitoring program.

(g) Military Drivers: This project directly addresses one of the six military drivers, to ensure that MCBCL supports all required military training activities while complying with the ESA, and other wildlife requirements.

(h) Benefit to MCBCL: Results for this research will be directly applicable to MCBCL's fire management and forest restoration program, as well as efforts to restore and manage at risk (e.g., RCW) and invasive species. It will provide measures of the effects of important military activities on plant and animal communities in the context of fire management, and guidance on how best to mitigate any adverse effects of such activities.

(i) Schedule:

1. Identify focal vegetation types and develop detailed model for MCBCL of variability in species composition and diversity along environmental and land-use gradients and in relation to current variations in fire management (7/2008 –12/2009) 2. Establish experimental plots. Treatment areas and experimental plots will be located and sampled (pre-treatment will be located by 1/2010). 3. Experimental treatments will be implemented winter and late spring of 2010. Additional areas will likely be treated in subsequent years. 4. Monitor experimental plots and monitor results for all subsequent seasons (3/2010–2/2011) 5. Prepare interim report (2/2011). 6. Prepare final report (6/2011).
Scheduling Constraints: Site identification and pre-sampling must begin in early 2008 in order to implement initial treatments in the late winter and spring of 2009.
Year 1 Go/No Go Decision Point: None indentified. (A small amount of this project occurs in Year 1.)
Budget (Estimated): ▪ Year 1 (July 2007 – June 2008): $ 49,000 ▪ Year 2 (July 2008 – June 2009): $ 100,000 ▪ Year 3 (July 2009 – June 2010): $ 110,00 ▪ Year 4 (July 2010 – June 2011): $ 129,000 ▪ Total (July 2007 – June 2011): $ 388,000

5.4.4.2 T-2: Effects of Habitat Management for Red-Cockaded Woodpeckers on Bird Communities

Senior Researcher: Jeffrey R. Walters (VT) **Staff**: 1 Ph.D student, 1 full-time technician, 1 seasonal technician.
Hypotheses: 1. Improving quality of upland savannah and wet flatwood habitats for RCWs also benefits the remainder of the avian community characteristic of these habitats. These benefits will be evident in changes in abundance and diversity as habitat quality improves.
Technical Objectives/Goals: The objectives of this project are to measure foraging habitat quality for RCWs, and changes therein over time, within upland pine savanna and pine flatwood ecosystems; relate these attributes to avian community composition through both empirical and experimental work; and to measure avian community composition in ecosystems other than upland pine savannas and pine flatwoods. Pond pine pocosins will be a particular focus of the last objective: determining the natural resource value of this ecosystem type is a key management objective, a knowledge gap and a research need.
Technical Approach: **(a) Background:** The new Recovery Plan for the RCW (U.S. FWS, 2003) requires that each woodpecker group be provided 49 ha of high quality foraging habitat, defined as open pine stands with moderate densities of large, old pines, a rich herbaceous groundcover, and relatively few mid-story hardwoods or medium-sized pines. Convery (2002) estimated that only 2% of the pine stands on MCBCL meet these criteria currently. Therefore improving foraging habitat for RCWs, through timber management and prescribed fire, is a high management priority at MCBCL. Currently MCBCL is managing 198 foraging areas for RCWs, averaging 81 ha each, to increase the RCW population from its current size of 79 active territories to the recovery goal of 173 active territories (MCBCL, 2006a). The net result is that over 16,000 ha are being managed for RCWs, representing essentially all the upland pine savannah and pine flatwood habitat on Mainside. Base managers are taking an ecosystem management approach to this activity (MCBCL, 2006a) and indeed the features of high quality RCW foraging habitat (open pine stands with diverse groundcover) mimic the characteristics of pristine longleaf ecosystems, and are to be produced by similar processes, that is, through use of prescribed fire to mimic historic fire regimes. Thus, on MCBCL, managing for high quality RCW foraging habitat is viewed as ecosystem restoration. This restoration process poses several challenges. First, documenting changes in habitat quality on a small scale over such a large area is a difficult challenge. Second, although it is widely believed that restoration of historic fire regimes and habitat structure in these ecosystems will benefit species characteristic of these ecosystems other than RCWs, effects of habitat restoration on other vertebrates are poorly documented. We propose to measure RCW foraging habitat quality, and quantify its relationship to the abundance and diversity of other bird species. We expect that avian diversity will increase with habitat quality, and that community composition will change as habitat

quality is improved, specifically that species associated with mid-story hardwoods will decline and that species associated with fire-maintained pine savannas (Engstrom, 1993) such as Bachman's sparrow (another at-risk species found at MCBCL) and RCWs will increase. We will use recent studies by Allen et al. (2006) and Provencher et al. (2002) to specify the expected relationship between community composition and habitat quality. We will test the validity of these relationships experimentally by quantifying changes in bird abundance and diversity following application of prescribed fire and resulting changes in habitat quality on the experimental plots used in Research Project T-1. Our measurements of RCW habitat quality will provide a data set that can be used to ground-truth other methods of measuring habitat quality that are less labor-intensive. In particular, we will use these data to test methods of measuring habitat quality by remote sensing that are being developed through other SERDP projects (SI-1471 and SI-1472) in which the Senior Researcher is involved. Also, we will test for effects of other factors of interest besides habitat quality in our analyses of bird abundance and diversity data. Specifically, we will test for relationships of bird abundance and diversity to intensity of military training activity, and for effects of distance and connectivity to sources of native species on effectiveness of restoration of natural communities.
(b) Experimental Design: The vegetation plots described in the Terrestrial Module section of the DCERP Baseline Monitoring Plan will be used as point count stations. To these will be added other point count stations to increase the density of sampling within pine uplands, pine flatwoods and ecotones involving these habitat types, and extend the sampling into additional habitat types within and beyond the terrestrial zone such as pocosins, marshes, bottomland hardwood forest, and coastal scrub. This set of point count stations will be used to determine correlations of habitat type and condition to abundance and diversity of bird species. Quantitative models will be employed in analysis of data from pine habitats to relate bird data to vegetation and insect data. Results for other habitat types will be primarily descriptive, as plant and insect communities will not be measured in those habitat types. Point counts will also be conducted on the experimental plots described in Research Project T-1 to address experimentally the relationship of the interaction between fire and the soil-moisture gradient to avian community composition, and test specific hypotheses about community interactions derived from the correlative work. Finally, components of vegetation used to define RCW foraging habitat quality will be measured at an additional set of locations within stands used by RCWs to increase sample size for assessment of methods of measuring RCW habitat quality.
(c) Methods: To determine how bird community composition changes with habitat quality, bird censusing will be conducted at the permanent vegetation plots established for Research Project T-1, and additional points established in RCW habitat using standard point count methodology (Hutto et al., 1986) during spring and early summer each year. Vegetation data collected on the permanent plots will be used to quantify RCW habitat quality at those points. At the additional points, specific data on each component of RCW habitat quality as defined by the FWS (2003) will be collected. We will structure the spatial distribution of census points to capture habitat variation along the soil-moisture gradient within the terrestrial zone, as well as variation in habitat quality (i.e., degree of restoration). For the experimental work, both pre-treatment and post-treatment counts will be conducted on the experimental burn plots established for Research Project T-1. For the descriptive work, we will establish census points not only along the full range of the soil-moisture gradient within the terrestrial environment, that is, including pocosin and marsh habitats, but also into other adjoining habitats associated with other modules, specifically bottomland hardwood forests (Coastal Wetlands Module) and coastal scrub (Coastal Barrier Module), to provide a full description of bird communities on MCBCL.
(d) Data Analysis: Species abundance will be estimated from bird census data using current techniques (Nichols et al., 2000; Farnsworth et al., 2002) that include estimation of detection probabilities. For pocosin, marsh, bottomland hardwood forest and coastal scrub habitats, analysis will be limited to description of community composition. Within upland pine savanna and pine flatwood habitats, regression techniques will be used to model bird abundance and diversity as a function of RCW foraging habitat quality, site characteristics (i.e., position in the soil-moisture gradient and vegetative features other than those used to define RCW foraging habitat quality), patch size and patch connectivity. One objective of the analysis will be to identify indicator species reliably associated with high quality habitat. The vegetation data collected at sampling points will enable us to define RCW foraging habitat quality at each point using the metrics developed by the FWS (2003). To assess methods to measure RCW habitat quality we will relate this known habitat quality to estimates of quality from other, less labor-intensive methods, including, but not limited to, remote sensing and stand inventory data.
(e) Environmental Indicators, Tools and other Outcomes: As an outcome of this study, we hope to identify bird species whose presence and/or abundance can serve as indicators of avian communities associated with high quality pine habitat, and thus as indicators of restoration success. Different species may serve as indicators for different community types along the soil-moisture gradients characterizing the terrestrial zone.
(f) Linkages to other Modules: Within the Terrestrial Module, this project is closely integrated with Research

Projects T-1. It will also provide data on avian abundance to the Coastal Barrier Module.
(g) Military Drivers: This project directly addresses one of the six military drivers, to ensure that MCBCL supports all required military training activities while complying with the ESA and other wildlife requirements.
(h) Benefit to MCBCL: This project will provide methods to measure good quality RCW habitat, an important current issue at MCBL. It also provides extensive analysis of effects of management on not only the endangered RCW, but also another species at risk, the Bachman's sparrow. It provides data on abundance and habitat associations of an additional species at risk, the painted bunting.
(i) Schedule: The project will begin July 1, 2008 and end July 30, 2011. Bird censusing will be conducted during April-June 2009, 2010 and 2011.
Scheduling Constraints: Bird censusing must be conducted during the breeding season, April-June, and therefore the study must begin by April 2009.
Year 1 Go/No Go Decision Point: None specified; however, this project depends on the success of research project T-1 to establish appropriate vegetation plots. If T-1 cannot establish an appropriate number of vegetation plots, this project will be a NO GO.
Budget (Estimated): ▪ Year 1 (July 2007 – June 2008): $13,000 ▪ Year 2 (July 2008 – June 2009): $122,000 ▪ Year 3 (July 2009 – June 2010): $115,000 ▪ Year 4 (July 2010 – June 2011): $175,000 ▪ Total (July 2007 – June 2011): $425,000

5.5. Atmospheric Module

5.5.1 Introduction

The atmosphere represents one of the major pathways for the transport of nutrients and potential pollutants into and from terrestrial and aquatic ecosystems (Lawrence et al., 2000; Paerl et al., 2002). It is also one of the primary pathways for the redistribution of nutrients and potential pollutants observed along coastal areas (Melillo et al., 1989). Because the atmosphere is not passive, transformations of various gaseous and particulate species, while undergoing transport, broaden the scope of emissions that need to be quantified. These transformations occur in the presence of other atmospheric constituents derived from local and distant regional sources, further complicating attempts to successfully attribute or predict impacts from emissions associated with MCBCL activities on neighboring communities. The vegetative cover of the terrestrial ecosystem at MCBCL represents a large surface area that promotes atmospheric deposition. Atmospheric deposition, in turn, represents an input into both the terrestrial and aquatic ecosystems. Nutrients and pollutants from atmospheric deposition are incorporated into internal nutrient cycles within the respective ecosystems at the Base, exerting their influence on various time scales, depending on the nature of the ecosystem itself and activities undertaken by MCBCL staff to optimize their primary training mission. The proximity of MCBCL to the near-coastal environment adds another level of complexity because the presence of marine-derived sea salt aerosols (SSA) imposes a natural gradient of deposition across the Base and also exerts an influence on atmospheric transformations not typically encountered further inland (Andreae et al., 1986; O'Dowd et al., 1997).

The input of nutrients and potential pollutants via atmospheric deposition interacts with most key terrestrial and aquatic ecological processes occurring at MCBCL, as illustrated in **Figure 5-23** and as reported for similar ecosystems (Van Der Salem et al., 1999; Lawrence et al., 2000). Atmospheric deposition is the only direct source of inputs to the surface of open waters of the aquatic ecosystem, but the frequency and composition of these inputs are as important in influencing flora diversity. Changes in the dominant forms of a given nutrient (e.g., N) over time will lead to shifts in the dominant flora within the aquatic ecosystem (Paerl et al., 2002). Such changes will impact the entire food chain of the ecosystem, as well as the system's ability to respond to natural disturbances induced by storm events and tides. The aquatic ecosystem also is impacted by atmospheric deposition after it is filtered and altered by passage through the terrestrial ecosystem. Sensitivities of nutrient inputs to the terrestrial ecosystem have been described in Section 5.4, Terrestrial Module. This impact occurs on all time scales, from rapid inputs following large rainfall events (runoff) to slow but critical changes in baseflow from the superficial aquifer (Hunsaker et al., 1994; Osgood and Zaeman, 1998). It may not always be immediately evident which impact is playing the dominant role in forcing change within the aquatic ecosystem.

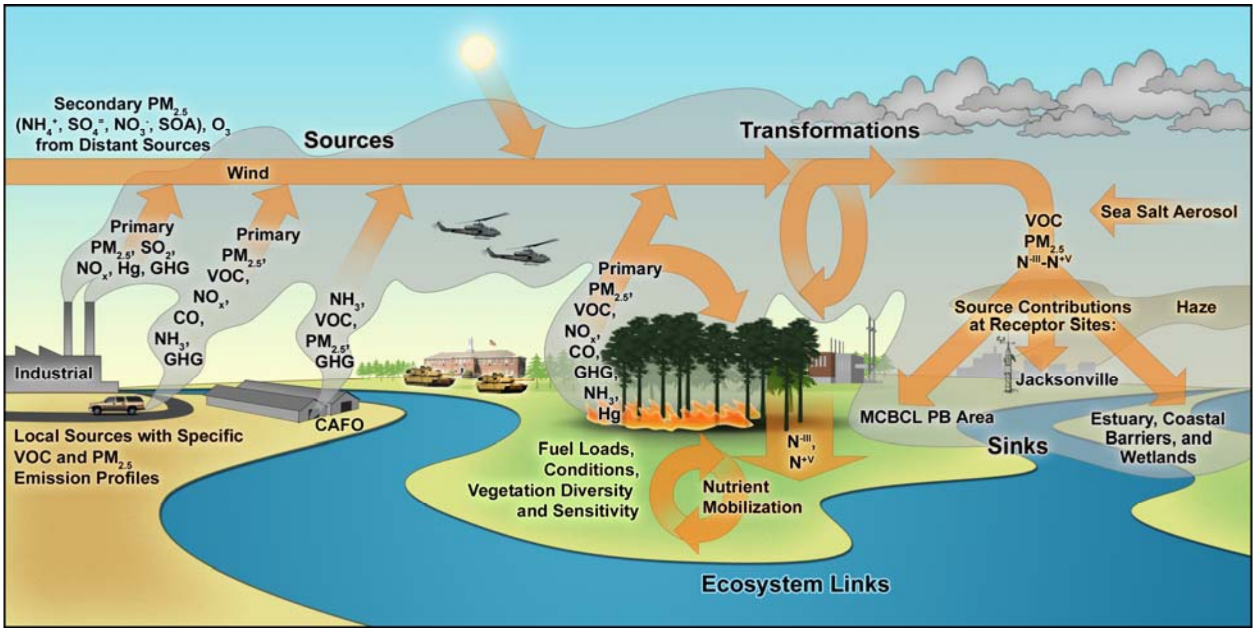


Figure 5-23. Conceptual model for the Atmospheric Module.

Fire is a natural part of this landscape, and natural fire regimes (e.g., frequency, intensity, and season) vary across this soil-hydrology-vegetation gradient, from frequent surface fires in longleaf pine savannas to relatively infrequent and intense crown fires in pocosin (Kodama et al., 1980); however, PB was used by native Americans for improving access, hunting, and farming and was adopted by the early European settlers. By the 1980s, PB had become the dominant land management tool in the southeastern United States, and MCBCL managers have implemented this technique to reduce wildfire risk, manage range and forest ecosystems, and provide and maintain terrain for training and testing. PB is also mandated by the ESA to recreate the natural fire regimes needed to maintain the health of native forest ecosystems and, thus, to protect the habitat of threatened and endangered species. Despite its essential ecosystem benefits, PB is a major source for fine particulate matter ($PM_{2.5}$) and other air pollutants due to its incomplete and largely uncontrolled combustion process, which involves flaming and smoldering phases with different effective fuel consumption, unknown ecological sensitivities toward PB conducted in growing versus dormant seasons (Johnson et al., 1998), and unclear ecological benefits on larger spatial and temporal scales (MacLean et al., 1983; Raison et al., 1985). Certain fuel and fire meteorological parameters influence the emissions from the different combustion phases, which in turn participate in transport processes within the atmospheric boundary layer, causing air quality impacts on local to regional scales (Lee et al., 2005; Friedli et al., 2007).

Dry deposition of atmospheric constituents, either nutrients or pollutants, is directly dependent on their ambient concentration near the ground. These concentrations are influenced by different anthropogenic and biogenic sources; meteorological conditions driving their atmospheric dispersion and transformation; and sinks (see **Figure 5-23**). Among the six criteria air pollutants regulated for the protection of human health under 40 Code of Federal Regulations (CFR) of the Clean Air Act (CAA), ozone (O_3) and $PM_{2.5}$

are the most difficult to control because they are products of complex atmospheric formation processes involving heterogeneous photo-chemical reactions of certain precursors (U.S. EPA, 1996; U.S. EPA, 1997; Seinfeld and Pandis, 1998). Ammonia (NH_3) and volatile organic compounds (VOCs, also regulated under the CAA) are of particular importance because of their precursor role in these processes yielding secondary inorganic aerosol and secondary organic aerosol (NH_4^+, $SO_4^=$, NO_3^-, and SOA), respectively. Other CAA-regulated criteria pollutants are sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and lead (Pb). Increased NO_x and NH_3 emissions and the formation of $PM_{2.5}$ alter patterns in atmospheric deposition through changes in the amount, composition, and distance of transport. Depending on the activity and function of the deposition surface, certain air pollutants potentially act as ecosystem stressors, such as acid rain and ozone for example. In their Criteria Documents for O_3 and PM, the EPA has compiled and evaluated a substantial body of research work from the past 20 to 30 years demonstrating the direct and indirect effects of O_3 and fine/coarse PM on vegetated and aquatic ecosystems (U.S. EPA, 2004b; 2006).

Projects Air-1 and Air-2 represent research in the areas of PB and N deposition, respectively (**Table 5-6**). These areas will enable MCBCL to understand their ecosystem's sensitivity to proper forest management, nutrient loadings to sensitive waters, and impacts from off-site sources, such as CAFOs. The location of Research Project Air-1 studies will be a function of research sites selected for Research Project T-1. A map depicting sampling locations for Research Project Air-2 is contained with the research plan description.

Table 5-6. Atmospheric Module Research Project Title, Senior Researcher, Benefit to MCBCL, and Duration of Project

Project	Research Project Title	Senior Researcher/ Duration
Air-1	*Optimization of Prescribed Burning (PB) by minimizing smoke emissions and maximizing vitality of fire-adapted ecosystems*	**Senior Researcher:** Karsten Baumann
	Outcomes and benefit to the Base: Provide innovative land management tool with transferable applicability for implementation in the Smoke Management Plan (SMP) of the NRE region and other populated regions in the Southeastern US.	**Duration:** 7/08–6/11
Air-2	*Nitrogen Deposition to Terrestrial and Aquatic Ecosystems*	**Senior Researcher:** Wayne Robarge
	Outcomes and benefit to the Base: Provide information on the amount and composition of atmospheric deposition (especially for N) to the terrestrial and aquatic ecosystems that will be used to model the atmospheric N contribution to the total N budget for the NRE. Provide information on the amount and distribution of rainfall across MCBCL.	**Duration:** 7/07–6/11

5.5.2 Knowledge Gaps in Conceptual Model and Research Needs

There are several gaps in our knowledge concerning the Atmospheric Module relating to atmospheric deposition, emissions, PB, and influences from the ocean. The source apportionment of nutrients from atmospheric deposition (especially N) to estuarine waters derived from direct deposition, or indirectly via surface runoff or superficial groundwater, is unknown, as is the percentage of deposited nutrients that is incorporated into terrestrial ecosystems and the micro-environments within these ecosystems every year. The impacts that the current level of wet and dry mercury deposition are having on the flora and fauna and on potential long-term sustainability of the terrestrial and aquatic ecosystems within MCBCL are also unknown. Atmospheric ozone can act as a surrogate air quality indicator of ecosystem stress; however, the spatial and temporal patterns of ozone exposure across the various MCBCL terrestrial ecosystems are unknown. The presence of significant stress due to ozone exposure would compound impacts from atmospheric deposition. Heavy metals of fine PM have been associated with forest decline partly due to their correlated deposition pattern, and *in vitro* studies found particularly Fe, Al, Ni, Zn, Mg, and Pb playing most important roles in tree injury and decline (U.S. EPA, 2004b). The predominantly sandy texture of the majority of soils at MCBCL will promote rapid infiltration of rainwater and subsequent movement of atmospheric deposition to the underlying superficial groundwater. In addition, the relationship between significant rainfall events, evapo-transpiration demand of the terrestrial canopy, and the residence time within the superficial groundwater has not been established for the various surface waters at MCBCL.

Knowledge gaps also exist in the understanding of mobile/stationary emissions and emission profiles for MCBCL. An estimate of the emissions associated with military vehicles (e.g., aircraft, watercraft, and land-based), certain stationary sources, sewage handling and disposal activities, general maintenance activities (e.g., painting), and PB is not available for MCBCL. In addition, projections of continued and future atmospheric deposition across MCBCL's terrestrial and aquatic ecosystems requires an assessment of spatially resolved emission source terms that may be contributing to the overall inputs; however, this assessment is unavailable for MCBCL.

Several aspects of PB require additional study. Relatively low-intensity burns result in ash and particulate transport to nearby unburned terrestrial ecosystems. The qualitative and quantitative aspects (e.g., influence of fuel load, initial fuel conditions, vegetation diversity, composition of emitted ash, particles and gases) of this nutrient redistribution are unknown, especially when PB is restricted to only a few months of the year, which results in intense activity and redistribution over a relatively short period of time. In addition, fuel combustion during PB is highly incomplete, mainly due to the underlying soil; thus, emissions have relatively little thermal buoyancy, allowing significant residence time of the plume within the canopy. The fraction of the emitted nutrients retained (including the fraction deposited to the canopy and subsequently returned to the soil via precipitative through fall/stem-flow) versus the fraction of pollutants released for regional dispersion is unknown. Prescribed burns can result in short-term (days to months) changes at the soil-vegetation interface and lead to conditions that may enhance emissions of gases, such as NH_3 and NO_x. The amount and frequency of soil gaseous emissions following prescribed burns is unknown for MCBCL's terrestrial ecosystems, as is the amount of mercury locked in MCBCL's forests and potentially released during PB. Mercury deposited to the ecosystem via wet and dry pathways is trapped and predominantly locked in the upper organic soil layers of northern latitude forests, making PB an important mechanism for mercury release and atmospheric redistribution (Friedli et al., 2007). Lastly, more comprehensive emissions data are needed on flaming versus smoldering of fire during prescribed burns, as well as on how prescribed burns differ from wildfire events.

Close proximity to the open ocean can markedly alter the air circulation and residence time of atmospheric air masses. This can result in errors in model projections of atmospheric composition and deposition based on meteorology from more inland locations. The understanding of the seasonality of air circulation patterns and meteorology for MCBCL remains incomplete. In addition, the proximity of MCBCL to the open ocean influences aerosol formation. The extent and influence of SSA on atmospheric processes are not well known, including the gradient in SSA deposition moving inland, enhanced dry deposition of gaseous N species due to partitioning onto relatively large SSA, and the potential for secondary organic aerosol (SOA) formation (Spokes et al., 2000; Tanaka et al., 2003; Cai and Griffin, 2006).

5.5.3 Benefit to MCBCL

More than 8 million acres of land are subject to PB every year in the Southeastern U.S. [Wade et al., 2000], with the most intense burnings and highest emissions occurring on military installations. Since PB is heavily utilized in the forested Southeast, this region's ambient $PM_{2.5}$ levels are particularly sensitive to changes in land management procedures and regulations. The U.S. EPA lists PB as the 3rd largest source of primary anthropogenic $PM_{2.5}$ in the U.S., just behind residential wood burning, emitting 12% of the total $PM_{2.5}$ mass (U.S. EPA, 2004a). Source apportionment modeling of $PM_{2.5}$ mass concentrations from 24 Speciation Trend Network sites suggests PB may contribute more than 30% of the annual $PM_{2.5}$ mass in the Southeastern U.S. (Lee et al., 2007). Our 2003/4 Pilot Study at Forts Benning and Gordon, GA showed that PB significantly impacted air quality in neighboring urban communities (Lee et al., 2005). Ambient $PM_{2.5}$ species measured at the urban receptor sites located 20-25 km downwind from these installations revealed that PB contributed on average 38 ±6 % to the total $PM_{2.5}$ mass during and on the day following a burn. These results demonstrate DoD's increasing difficulty in fulfilling its training and testing mission without violating future National Ambient Air Quality Standards (NAAQS). Without distinguishing between PB and residential wood burning, wood combustion was found to contribute 25–66 % of the $PM_{2.5}$ organic carbon (OC) and 15 ±12% of the $PM_{2.5}$ mass measured in urban and suburban/rural locations of the Southeastern U.S., with higher contributions in the colder months (Zheng et al., 2002). Thus, civilian burn activities will potentially contribute to regional background levels and will need to be distinguished from PB emissions to correctly isolate the corresponding ecosystem links.

The currently employed tools to plan and conduct PB at MCBCL bear significant capacity for optimizing this land management tool without sacrificing its ecological benefits. Hence, we will identify the critical points in the fuel model that allow the implementation of a parameterization scheme to better forecast amount and composition of smoke emissions. In related research proposed for funding under SISON-08-03, additional emission monitoring data and source apportionment modeling results will be generated that can support MCBCL's decision making smoke management planning, as well as enhance the fuel loading model. Optimizing PB carries with it the consideration of combustion emissions impacts on air quality downwind. Although the detailed study of these impacts is outside the scope of the DCERP, it is important to understand the drivers behind selecting the best burn scenario for forest growth, habitat, and ecosystem health. Future DCERP research planning may want to consider air quality impacts on ecosystems (as opposed to urban populations). On-site and off-site emissions and deposition of fuel combustion products such as nutrients, organics, PM, ozone, and trace metals from PB and other emission sources vary seasonally and influence vegetation. EPA has performed extensive literature reviews of research that document the impacts of pollutants such as PM and ozone on ecosystems (U.S. EPA 2004b, 2006). In its 2004 "Air Quality Criteria for Particulate Matter" [U.S. EPA, 2004b], EPA discusses documented ecosystem impacts from fine and coarse PM – pollutants either *directly* emitted from many different anthropogenic sources (e.g., industrial, mobile, PB) and biogenic sources such as wild fires, or especially in the case of fine PM, also formed via *secondary* atmospheric processes from gaseous precursors involving gas-to-particle conversion.

PB typically mobilizes nutrients within local environments due to smoke plumes remaining within the canopy structure for significant times and distances. The resulting deposition of ash and smoke represents enhanced inputs into these downwind canopies. Measurements of atmospheric deposition provided by this project will allow an evaluation of the magnitude of the inputs represented by deposition of smoke and ash to downwind canopies during flaming and smoldering phases of PB, in addition to more regional wet and dry deposition trends.

5.5.4 Proposed Research Projects – Atmospheric

Research Projects Air-1 and Air-2 represent research in the areas of PB and N deposition, respectively. These areas will enable MCBCL to understand their ecosystem's sensitivity to proper forest management and nutrient loadings to sensitive waters. The location of Research Project Air-1 studies will be a function of research sites selected for Research Project T-1. Maps depicting sampling locations for Research Project Air-2 are contained with the research plan description (Section 5.5.4.2).

5.5.4.1 Air-1: Optimization of Prescribed Burning (PB) by minimizing smoke emissions and maximizing vitality of fire-adapted ecosystems

Senior Researcher: Karsten Baumann

Hypotheses:

1. Alternative land management tools and procedures can improve PB decision making by enhancing fuel models with information on the relationship of fuel consumed and smoke emitted.
2. PB can be optimized if the role of primary particle emissions and gaseous emissions in generating secondary smoke particles can be predicted.

Technical Objectives/Goals: Improve PB emission inventories; quantify fuel consumption and correlate with specific fuel conditions; improve fuel models currently being developed for the region by quantifying and parameterizing emissions from different combustion stages; establish links between measured emissions and ecosystem parameters; support the Terrestrial Module's identification of ecosystem sensitivities towards burn frequency, time/season and ecological effects on C sequestration, landscape, land use, species habitat, and potential changes in future emissions (once fire-intolerant species have disappeared).

Technical Approach

(a) Background:

PB is an essential tool for maintaining ecological health in natural fire regimes, however, increasing pressure from air quality regulators calls for minimizing impacts from smoke emissions. Most military installations in the United States use PB to maintain property for training. Guided by the ESA, the Department of Interior mandates that most military installations in the Southeast use PB to maintain native forest ecosystems and protect threatened and endangered species habitats. MCBCL's annual PB target is 25,000 acres burned between December and May. The current fuel model aids in the PB planning process by prioritizing certain ecological criteria, including longleaf plantations, threatened and endangered plant species, RCW recruitment sites and clusters, and time since last burn among others. Data availability, redundancy, value in maintaining ecosystem integrity and desired future landscape conditions are additional criteria considered in the decision making process. Once the Training Areas have been identified and scheduled for PB, VSMOKE-GIS, a dispersion model interface (Harms and Lavdas, 1997) is used in conjunction with the Ventilation Climate Information System (VCIS), a nation-wide database of surface wind and ventilation index (VI) that is the product of wind speed and mixing height (Ferguson et al., 2004). MCBCL land managers currently derive the VI from the National Weather Service's daily fire weather forecast from http://fire.boi.noaa.gov/FIREWX/RDUFWFMHX.html, with which they determine the PB category via http://www.dfr.state.nc.us/fire_control/fire_category.htm and ultimately the target amount of PB acres from the smoke management tonnage table at http://www.dfr.state.nc.us/fire_control/smoke _guidelines.htm. This procedure is relatively weak in predicting how fast and in what way fuel will burn and currently does not contain a processor that considers fuel chemistry or fuel characteristics relative to what PB emits from vegetation and soil overall or more specifically during the different combustion stages, i.e., flaming and smoldering. Also, no distinction is currently being made between primary PM emissions and secondary PM formation from gaseous precursors especially organic compounds, whose atmospheric processes are largely unknown (Robinson et al., 2007).

The vegetation gradient at MCBCL is exceptionally steep spanning from salt marsh at the estuary margin, through brackish/freshwater marsh, to the longleaf pine savannas and pocosins (shrub bog). Variation in the biota and hence fuel mix and load along this gradient is driven by variation in hydrology, soils and fire behavior. These differences in vegetation composition, soil composition and soil/fuel moisture will cause significant variations in the combustion process. Combustion can be divided into flaming and smoldering processes. Flaming combustion occurs at temperatures greater than 1500°C for brief periods early in the burn when the most volatile compounds heterogeneously react in the gas phase. Flaming almost completely oxidizes the fuel to the most common gas and particle oxides. Smoldering combustion occurs for hours or days after flaming combustion subsides or in areas with high fuel moisture. Smoldering at the fuel surface produces significant quantities of particles largely by the condensation of volatilized organics from incomplete oxidation. As a result, the amount and composition of gas- and particle-phase species emitted as the combustion process evolves during a PB will depend on the fuel characteristics.

This research provides input to Research Project T-1 by contributing data to help fill gaps, including the following

1. Effects of variations in fire regimes (frequency, season and intensity of fire) along fuel and moisture gradients.
2. Connections between fire regimes, herbaceous communities and habitat for insect and bird communities
3. Improved understanding of these PB effects at the moist, e.g., pocosin, end of the moisture gradient.

The goal of this research is to collaborate with Research Project T-1 to identify the critical points in the fuel model that allow the implementation of a parameterization scheme. This requires that the research field measurements cover a minimum level of fuel variability to enable the team to conduct a statistically robust parameterization of PB emissions towards the development of an accurate emissions forecasting tool. In related research proposed for funding under SERDP SISON-08-03, additional data and/or information may become available that can support MCBCL's decision making smoke management planning, as well as enhance the fuel loading model.

A large fraction of PB generated smoke is primary organic aerosol directly emitted into the atmosphere. The organic portion is the least understood component of $PM_{2.5}$. However, $PM_{2.5}$ is not only made up of such primary emissions; a secondary aerosol fraction resulting from the reaction of VOC in the atmosphere is an important contributor. This SOA fraction is extremely complex as the precursor VOC can originate from many different sources besides PB, and can constitute a significant portion of ambient $PM_{2.5}$ (e.g., Turpin and Huntzicker, 1995). The Fractional Aerosol Coefficients (FAC), developed and first published by Grosjean and Seinfeld (1989) is a very crude first order approximation of potential SOA formation (i.e., the amount of SOA produce during the amount of fuel and time burned), which can be estimated for the VOC emissions from the different fuel-linked test fires. Thus, relationships can be established between certain fuel/vegetation conditions, burning stage, season and the PB's VOC emissions' potential for creating SOA downwind.

(b) Experimental Design

The work described in the different phases below assumes the combined ecological and smoke emissions characterization of three different burns per season (growing versus dormant), each conducted during one week at three different areas within the installation as part of the experimental fires conducted as described under Research Project T-1. Each burn will involve the collection of a detailed inventory of the vegetation before and after the burn. Research Project T-1 will also be responsible for the ecological evaluation, including GIS data recording, mapping and development of fire danger rating and fuel models. The emissions characterization part will be covered by this research project and includes the smoke emissions measurements and evaluation separating flaming-dominated combustion stages from smoldering, the linking of emissions with ecological and meteorological factors, the transition from a diagnostic approach to a prognostic approach by enhancing MCBCL's Prescribed Burning Prioritization Model with combustion emission information, and other comprehensive evaluation and implementation work.

(c) Methods:

In close collaboration with MCBCL land management team and DCERP researchers from the Terrestrial Module, we will conduct field experiments during the growing and dormant seasons that will allow the establishment of the necessary links between fuel loads, conditions and PB emissions. In close coordination with the Research Project T-1 team's inventory plots that are monitored for vegetation change, structure, and species richness, experimental PB will be conducted and emissions measured in replicated treatment plots that are test burned at different intervals (e.g., returning after 2, 3, or 4 years) during both dormant and growing seasons. The methods employed are described according to the different phases involved, distinguishing Planning, Pre-Burn, Burn and Post-Burn phases.

The integrating approach followed by the Atmospheric Module's Baseline Monitoring Plan allows the identification of certain episodes of interest where ecological impacts from on-site PB activities can be studied in greater detail. A possible outcome of this study may be the creation of a new research project with focus on specific sensitivity of ecosystem response to PB relative to other on/off-site military and non-military stressors and activities and/or the identification of a particularly sensitive area within MCBCL where impact studies should be focused.

1. Planning Phase: In coordination and collaboration with MCBCL's staff and Research Project T-1, we will i) identify schedule and locations of training areas planned to be burned in the upcoming growing and dormant seasons; ii) establish a burn notification mechanism for most effective preparation of the field study component; iii) update current burn conduct procedures for least disruptive integration of emission measurement activities. Due to the complex interactions and dependencies on training activities and weather conditions, a progressively more detailed communication plan will be established to maintain the highest possible level of flexibility for the conduct and measurements of the PB and PB emissions, respectively. Flaming and smoldering emissions will be sampled from two different burns (locations) during the growing and dormant season, respectively, and measure ecosystem-specific parameters that specifically describe forest fuel types, condition, and amount of the combusted biomass from before/after fuel loadings analyses. In addition, we will collect, assemble and merge existing data records of the local meteorological, air quality indicators (including $PM_{2.5}$ and PM_{10} concentrations from NCDENR's neighboring monitoring sites), and burn activities on the installation, which will help identify important air quality and meteorological factors that are linked to MCBCL's PB program. Data collected as part of the baseline monitoring activities will further assist and support such a climatological trends analysis.

2. Pre-Burn Phase: Research Project T-1 will monitor experimental treatment plots (ca. 20 x 20 m) for fire and soil temperature, total fuel consumed, and ash deposition. Their inventoried available fuel data includes down deadwood characterized in amount, size, and distribution (horizontal and vertical), and related to the detailed attribute data for other ecosystem components, (i.e., shrub and herbaceous understory, standing dead and live biomass). The T-1 data set will also contain moisture levels of the dead and live fuel, including litter, duff and macro-fauna, additional forest species and coarse woody debris decay classes in the vegetation associations for each of the experimental burn sites. Fuel loading information will be provided to MCBCL staff for incorporation into PB plans. Field equipment will be positioned and tested according to procedures developed by MCBCL. The deployment of the field equipment requires knowledge of the anticipated wind direction so that a reference sampler capturing background conditions can be positioned and operated upwind. Furthermore, the three comprehensive monitoring sites operated across the MCBCL study area as part of the Baseline Monitoring Plan collecting continuous real-time meteorological (O_3, $PM_{2.5}$ and PM_{10} concentration data), will be serviced and checked for proper operation prior to ignition of the test fires.

3. Burn Phase: PB emission measurements will strictly follow quality assured standard operating procedures (SOPs) that have been developed and successfully applied during the 2004 Pilot Study. These procedures and protocols also ensure minimal disruption of the burn crew's activity. Emission monitoring of combustion will be divided into flaming and smoldering phases. Plumes measured in the field are made up of chemical species emissions from both phases, and are technically "mixed phase". Typically, plumes are characterized by their modified combustion efficiency (MCE) $CO_2/(CO+CO_2)$ at greater than or less than 0.9 to determine dominance of flaming or smoldering combustion, respectively. Real-time continuous CO and CO_2 measurements will aid in ad hoc distinctions between smoldering and flaming conditions via the MCE. Although less intense than flaming, smoldering at the fuel surface produces particles largely by the condensation of volatilized organics for hours and days after the flaming. Hence, smoldering emissions significantly contribute to the overall particulate emissions produced during PB and are the largest contributor to particulate emissions that directly impact local air quality.

We will deploy a mobile medium-volume particle composition sampler that allows the sampling of emissions from the moving flaming front, and hence represent the emissions clearly dominated by flaming processes. The same unit also will be used to sample the smoldering emissions, which follow the flaming phase and typically last for several hours up to several days, and have proven to be critically important during nocturnal accumulation periods. As mentioned earlier, another sampler will be deployed upwind providing important background concentrations. Each sample will be taken over an integrated time of 1 to several hours and consist of different portions being analyzed for particle-phase organic compounds (POC) via gas chromatography/mass spectrometry, water-soluble ionic species, C, OC and total $PM_{2.5}$ mass. Numerous PM-bound metallic and mineral elements will be determined via energy dispersive X-ray fluorescence and Inductively Coupled Plasma Mass Spectrometry. More than 100 POC species, including key molecular markers such as levoglucosan, pimaric acid, sandaraco-pimaric acid, abietic acid, and retene will be detected and quantified and roughly 42 VOC species will be measured, including ethyne (acetylene) and 1,3-butadiene (potential carcinogen), aromatics and biogenics (isoprene, mono-terpenes) that are important PM precursors, as well as CO, CO_2 and CH_4. Other reactive gases that play an important role in aerosol chemistry, i.e., NH_3, nitric acid, SO_2, and certain light organic acids will also be measured.

Use of passive and active samplers distributed downwind from the smoke plume and evaluated within the Research Project Air-2 will help characterize the physical dispersion of the plume and quantify enhanced N inputs into downwind canopies resulting from ash and smoke deposition. Additional information will be gained from the data collected by the baseline monitoring network; e.g., the influence of nocturnal boundary layer dynamics on abundance and deposition of important nutrients and pollutants.

4. Post-Burn Phase: Basic tests will be conducted to guarantee the integrity of all instruments and to ensure highest quality of the collected data. Routine flow checks and sensor calibration checks are part of the previously developed SOPs. A sub-set of samples will undergo the same sample analyses to help identify any sampling errors and quantify measurement accuracy. Detailed quality assurance/quality control (QA/QC) protocols for sample analyses have been established and reported elsewhere (Baumann et al., 2003; Solomon et al., 2003; Colman et al., 2001; Sheesley, 2000). Vegetation plots will be re-measured following PB to determine the consumption of fuel biomass by size class, using field protocols based on methods established by the U.S. Department of Agriculture (USDA) Forest Service in field instructions for Southern Forest Inventory. Duff, litter and stump biomass consumed will be determined by direct field measurements of biomass consumption from the PB.

(d) Data Analysis:

One of our main goals is to more accurately determine emission factors (EF) for chemical species and vegetation type, to improve total emission estimates based on land area burned, fuel loading, C fraction of the fuel, and combustion fraction, besides EF.

Assuming that a certain MCBCL training area burn falls into a specific vegetation class, and that all of the C combusted in that fire is emitted into 5 measurable forms of C, CO_2, CO, CH_4, VOC, and particulate carbon, the EF of a species *n*, is then calculated from the ratio of the mass concentration of that species to the total carbon concentration emitted:

$$EF_n = [n] / ([C]_{CO2} + [C]_{CO} + [C]_{CH4} + [C]_{VOC} + [C]_{pC})$$

We have the unique opportunity to verify this value and its uncertainty by comparing it with the value from the series of representative plot surveys within different vegetation classes determined in situ by the T-1 field team before and after burns. Besides the C content of the actually combusted fuel, the plot surveys also provide important parameters that describe the fuel mix and condition, including vegetation classes, woody relative to chlorophyll containing mass fractions, water contents, soil moisture, temperature and organic mass fractions including life organisms (microbes) and dead litter (duff).

Links to meteorological conditions will be established by integrating National Weather Service (NWS) fire weather forecast data of important parameters such as the Keetch-Byram drought index (KBDI), the smoke dispersion index (SDI), boundary layer height (BLH) and transport wind speed determining the VI, wind direction, Turner stability class, probability of precipitation, fog potential, low visibility occurrence risk index (LVORI), relative humidity, etc. We will identify the conditions under which a particular PB conducted on the installation had significant impact on the $PM_{2.5}$ measured at the baseline monitoring sites and NCDENR's regulatory monitoring sites in the surrounding region, which will help us indicate measures of how this impact could have been mitigated most effectively. Possible measures might be different interpretation of the burn forecast and/or fuel condition, change in burn location and/or burn conduct, reduction or avoidance of smoldering phase.

The FAC, developed and first published by Grosjean and Seinfeld (1989) is a very crude first order approximation of P(SOA) formation. It summarizes the complicated oxidation-condensation processes that govern SOA formation into one constant for each precursor VOC species (Grosjean, 1992) and is defined as:

$$\text{FAC} = \text{aerosol from VOC } (\mu g m^{-3}) \, / \, \text{initial VOC } (\mu g m^{-3})$$

With this definition, and knowing unit mass PB emissions E_{VOC} from the fuel-linked test fires and the fraction of VOC that has reacted with OH in the atmosphere (FR), the amount of SOA potentially formed from each VOC can be calculated as:

$$P(SOA) = E_{VOC} * FR * FAC.$$

FR is calculated assuming first order principles from OH-reaction (Atkinson, 1990) for midday (OH) of 10^4 and 10^6 molecules/cm^3, for dormant and growing season, respectively, and a 5 hour reaction period, yielding FR = 1-exp(-kt).

(e) Environmental Indicators, Tools and other Outcomes:

In the future, temporally and spatially resolved $PM_{2.5}$ mass measurements may serve as a surrogate for chemical speciation profiles of PB emissions, indirectly indicating PB performance and ultimate quality of forest management.

This research will result in the incorporation of refined decision making criteria into the current prioritization fuel model based on the multi-linear relationships between detailed emissions composition and character, highly refined fuel conditions and specific fire weather forecast parameters. These relationships may have to be established based on a semi-empirical modeling approach using statistical tools such as ANOVA and PCA in combination with linear regressions of standardized principal components if indicated. The final tool will provide more quantitative information in support of the decision making process based on input parameters such as VI, SDI, and LVORI on the one hand (addressing smoke dispersion criteria), and vegetation class, time and season when last burned, KBDI and fuel moisture on the other hand (addressing smoke generation criteria).

(f) Linkages to other Modules:

This research is closely linked to the Terrestrial Module's Research Project T-1, which provides the framework for the atmospheric component of the fuel model research. The T-1 study of the ecosystem's sensitivities to PB and its response via change, structure, and species richness will indicate potential measures for effectively optimizing the PB conduct. One measure of selecting the optimum conditions in PB is consideration of fuel loading. To improve the fuel model, it is essential to understand how combustion emissions vary with fuel.

The integrated wet and dry N deposition measurements performed within Research Project Air-2 will provide the links to sensitive ecosystem parameters affecting nutrient cycling on local to regional scales.

(g) Military Drivers: Compliance with ESA and other wildlife requirements. Enhance future training opportunities within Range Transformation Plan. Demonstrate stewardship responsibilities. Secure flexibility in future land management alternatives through concerted stakeholder partnerships (e.g., with The Nature Conservancy and Onslow Bight Conservation Forum).

(h) Benefit to MCBCL: By improving the fuel model, MCBCL will be able to forecast emissions from PB based on fuel and ecosystem type (in conjunction with the Terrestrial module). Further, MCBCL will be able to maintain compliance with Clean Air Rules while demonstrating leadership in environmental sustainability. This research will, in tandem with Research Project T-1, provide MCBCL an innovative land management tool with transferable applicability for implementation in the SMP of the NRE region and other populated regions in the Southeastern US.

(i) Schedule:

- Retrieve and compile data from NCDENR DAQ regulatory monitoring sites operated in the region within ca. 100 km around MCBCL. Evaluate the high-resolution data collected from the baseline monitoring activities in conjunction with the NCDENR data, and identify and analyze weekly PM filter samples of interest (7/2008–2/2009)
- Select two PB sites and identify critical measurement parameters (7/2009–11/2009)
- Prepare and conduct Field Intensive I; i.e., dormant season 1, QA/QC and report preliminary data (12/2009–2/2010)
- QA/QC and merge data from different teams, begin comprehensive evaluation, and conduct Field Intensive II; growing season 1 (3/2010–6/2010)
- QA/QC and merge data from different teams, identify focus parameters, plan and conduct concerted field effort for Field Intensive III; dormant season 2 (7/2010–2/2011)
- Evaluate dormant season 2 data; plan and conduct Field Intensive IV; growing season 2, QA/QC and merge data from different teams, begin statistical evaluations towards linear relationships between fuel conditions, fire weather forecast parameters and measured emissions (3/2011–6/2011)
- Apply and evaluate fuel model parameterization, prepare documentation and final report of this project stage, carry out preliminary evaluation and interpretation among the Atmospheric Module's research projects and disciplines, and formulate data information system needs (3/2011–6/2011)
- Deliver final report (6/2011)

Scheduling Constraints: None

Year 1 Go/No Go Decision Point: None specified; however, the project is dependent on the success of Research Project T-1 to establish an appropriate number of vegetation plots. If T-1 cannot establish an appropriate number of plots, then Air-1 will be a NO GO.

Budget (Estimated):

- Year 1 (July 2007 – June 2008): $ 0
- Year 2 (July 2008 – June 2009): $ 11,000
- Year 3 (July 2009 – June 2010): $ 82,000
- Year 4 (July 2010 – June 2011): $ 110,000
- Total (July 2007 – June 2011): $ 203,000

5.5.4.2 Air-2: Nitrogen Deposition to Terrestrial and Aquatic Ecosystems

Senior Researchers: Wayne P. Robarge (North Carolina State University [NCSU])
Staff: research technician (7 months/year); undergraduate student (12 month/year)

Hypothesis: Atmospheric deposition (both wet and dry) represents the dominant source of new N (DIN and dissolved organic nitrogen [DON] species) into the terrestrial and aquatic ecosystems of MCBCL. Local influences, and national trends in N emissions to the atmosphere suggest that N-loading may continue to increase with time at MCBCL, having a direct impact on the sustainability of the terrestrial and aquatic ecosystems.

Technical Objectives/Goals: This research program is designed to (1) assess the magnitude and temporal and spatial trends in N deposition (both wet and dry deposition) to the vegetative canopies and underlying soil-groundwater ecosystem across MCBCL; (2) provide baseline estimates of N deposition to contrast to local remobilization and deposition of N as the result of PB within the confines of MCBCL; (3) estimate the fraction of DON prevalent in wet deposition occurring at MCBCL; and to (4) estimate the magnitude and long-term temporal trends in N-deposition (wet deposition) to surrounding aquatic ecosystems at MCBCL.

Technical Approach

(a) Background: Airborne transport crosses watershed and state boundaries. Any impact observed on the habitats of interest must take into account sources of airborne pollutants transporting into and depositing on the area (via wet and dry deposition), as well as sources within MCBCL and subsequent transport of locally derived airborne pollutants. The NRE, MCBCL, and surrounding coastal waters lie directly east of Sampson and Duplin Counties, which have the highest density of CAFOs in the United States. (McCulloch et al., 1998). Ammonia emissions from these operations have impacted rainfall chemistry in the region (Walker et al., 2000b) and increased N deposition up to 80 km away (Walker et al., 2000a), which is within range of the NRE, MCBCL, and surrounding waters.

The vegetative cover of the terrestrial ecosystem at MCBCL represents a large surface area that promotes atmospheric deposition. Atmospheric deposition, in turn, represents an input into both the terrestrial and aquatic ecosystems. Nutrients and pollutants from atmospheric deposition are incorporated into internal nutrient cycles within the respective ecosystems at the Base, exerting their influence on various time scales, depending on the nature of the ecosystem itself and activities undertaken by MCBCL staff to optimize their primary training mission. The proximity of MCBCL to the near-coastal environment adds another level of complexity because the presence of marine-derived SSA impose a natural gradient of deposition across the Base and also exerts an influence on atmospheric transformations not typically encountered further inland (Andreae et al., 1986; O'Dowd et al., 1997).

Except for N-fixation by native plant species, inputs from migrating wildlife, and nutrient release from soil weathering, atmospheric deposition represents the only source of new nutrients into the terrestrial ecosystems at MCBCL. The amount, composition, and frequency of inputs are necessary to assess the sustainability of current terrestrial ecosystems and to determine long-term sustainability in regards to native flora and fauna, as well as the training mission of MCBCL. Wet deposition can be estimated from rainfall records or measured directly, whereas dry deposition (which will be at least equal to wet deposition) must be estimated from on-site measurements. Changes in forest management (such as thinning and clear cutting) will have direct impacts on atmospheric deposition and nutrient inputs. The short-term capabilities of forest to retain nutrients from atmospheric deposition will be influenced by the frequency and acreage of prescribed burns (~ 20,000 acres per year), which illustrates the linkage between the Atmospheric Module and the Terrestrial and Aquatic/Estuarine modules.

(b) Experimental Design:

Magnitude/Temporal/Spatial Trends in Wet and Dry N Deposition – Measurements of wet deposition are usually expressed in units of mass of a chemical species per unit area per unit time. Determination of mass in wet deposition requires knowledge of both the chemical composition and quantity (volume) or rainfall using collectors of known surface area (mass of chemical species A per unit time = concentration of chemical species A x volume of rainfall collected per unit time). Extrapolation of single point measurements of rainfall amounts and chemical composition to broader areas can be improved upon by deployment of more collectors and/or deployment of devices dedicated solely to measuring rainfall amount. Chemical analysis of collected rainfall, plus the cost of individual rainfall collectors, limits the practicality of deployment of large numbers of standard wet deposition collectors. It is more cost effective to decrease the uncertainty in wet deposition across a broader area by deployment of lower-cost devices dedicated to measuring solely rainfall amounts. The magnitude of wet deposition is thus addressed by selection of point measurements of rainfall composition times the volume of wet deposition over a given area as derived from data from a number of lower-cost devices dedicated to measuring rainfall amounts.

Wet deposition in terms of rainfall occurs as discrete events of varying duration. The temporal resolution of rainfall events will increase in cost with the attempt to determine intra- and inter-variability in rainfall composition and amount. In the United States, the standard duration selected by the National Atmospheric Deposition Program (NADP, 2000) to characterize wet deposition is one week (7 days). This temporal protocol was adopted by this project to generate a dataset consistent with the NADP program, facilitating comparison of data generated by DCERP to NADP collectors located within North Carolina. In addition, the other research modules in DCERP have indicated that a temporal resolution of one week would be adequate for measures of wet deposition into the terrestrial and aquatic ecosystem.

Characterization of the spatial trends in wet deposition at MCBCL requires consideration of the physical size of MCBCL (>100,000+ acres), diversity in terrestrial and aquatic ecosystems and land use, and proximity to the Atlantic Ocean. Priority in placement of rainfall collectors is given to distance from the ocean, plus proximity to the New River, which dissects MCBCL. These point measurements of rainfall composition and amount are supplemented by a network of devices dedicated to measuring solely rainfall amounts positioned along transects across MCBCL at approximately the same distance from the ocean as the corresponding rainfall collector. This design will be used to assess spatial patterns in rainfall amounts across MCBCL at different time scales (minimum one week), as well as variation in rainfall composition moving away from the ocean.

Dry deposition to terrestrial canopies will be estimated using throughfall/stemflow. Vegetative canopies represent large exposed collection surfaces for dry deposition. Throughfall/stemflow represents rainwater (wet deposition) that has interacted with the vegetative canopy. Measurement of the chemical composition of throughfall/stemflow represents the mass (flux) of soluble nutrients entering the underlying soil-groundwater ecosystem (Boehlmann et al., 2005; Thimonier et al., 2005). Correction for the mass of nutrients in wet deposition (Net Throughfall/stemflow) provides an indirect measure of dry deposition of nutrients to the overhead vegetative canopy, which are subsequently washed off during rain or fog events. Measurement of throughfall/stemflow offers a robust means to measure deposition that has been used in long-term forest ecosystem research (e.g., Swiss Long-Term Forest Ecosystem Research Programme; Schmitt et al., 2007) and in urban and rural environments (Balestrini et al., 2007; Bohlmann et al., 2005; Juknys et al., 2007).

The magnitude of dry deposition will be expressed the same as wet deposition (mass of chemical species per unit area per unit time). The temporal resolution selected is one week to be consistent with the measurements of wet deposition. The spatial scale selected for dry deposition measurements, however, will be restricted to single representative sites for select types of vegetative canopies (currently estimated to be 3 sites). Local spatial variability in throughfall under a given vegetative canopy requires an increase in the number of throughfall samplers per site. The cost associated with deployment, sample collection and processing, and maintenance of throughfall/stemflow sites will limit the number of sites used to estimate dry deposition. Results from these three sites will be extrapolated to a broader scale using GIS-based distributions of the vegetative canopies selected for study, plus the rainfall composition and rainfall amount data generated from characterizing wet deposition.

Baseline Estimates of N Deposition – Measures of wet and dry deposition will be expressed in units of mass of chemical species per unit area per unit time, with a minimum resolution of one week. These units allow summation of results for individual chemical species measured across different time scales (monthly, seasonal, yearly) and also facilitate comparisons as a function of location. The inclusion of an estimate of dry deposition provides a measure of total potential inputs of N deposition that can be summed and expressed on various time scales. This information is required to differentiate additional inputs into terrestrial canopies due to local sources of inputs arising form MCBCL activities such as PB.

Organic-N in Wet Deposition – Chemical characterization of the composition of wet deposition will include total DON. As with other chemical constituents, results will be expressed as mass of DON in deposition per unit area per unit time, facilitating comparisons in DON deposition on various temporal and spatial scales.

Wet N Deposition into Aquatic Ecosystems – The combination of rainfall collectors and dedicated devices to measure rainfall amount will be used to extrapolate the amount of wet N deposition occurring to the various aquatic ecosystems at MCBCL (New River, tidal creeks, wetlands and marshes).

(c) Methods: *Wet Deposition* – The primary component of wet deposition anticipated at MCBCL is rainfall. National Atmospheric Deposition Program (NADP) style collectors will be employed to collect and record rainfall events at four locations at MCBCL (**Figure 5-24**). The 4 locations are selected as a function of distance from the ocean and also to provide needed information for potential atmospheric inputs into the New River watershed. Samples will be collected weekly following established NADP protocols (NADP, 1999). Chemical analysis of the samples will include pH, soluble cations (ammonium, magnesium, calcium, sodium potassium), soluble anions (chloride, nitrate, nitrite, sulfate), and total DON and DOC. NADP collector NC29 (Hofmann Forest, Onslow, Co., NC; Lat. 34.825, Long. -77.3228 is located approximately 6 miles to the NE of MCBCL).

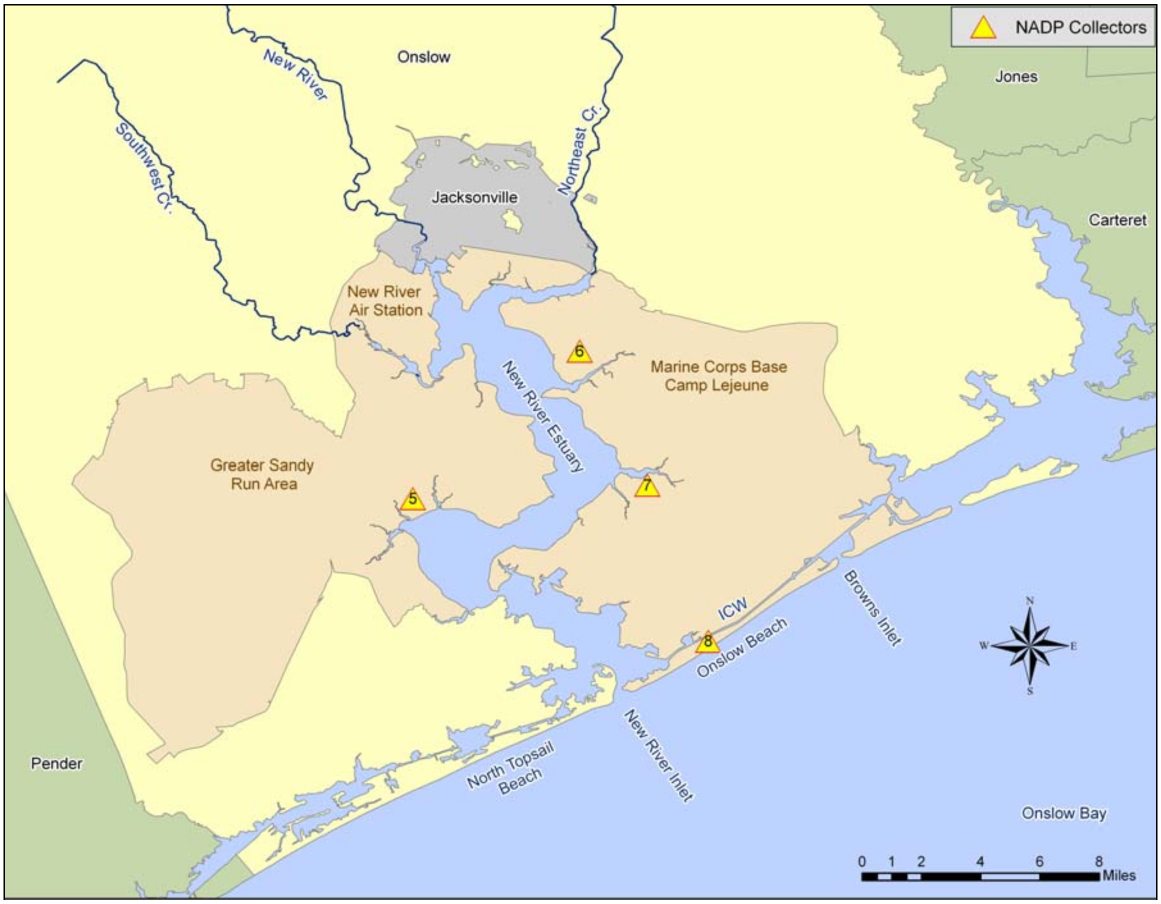


Figure 5-24. Approximate location of planned deployment of NADP collectors at MCBCL.

Additional tipping bucket rain gauges with dedicated data loggers will be deployed across MCBCL to assess spatial variability in rainfall amounts on an event basis (**Figure 5-25**). Using the ocean as a starting point, three transects of tipping bucket gauges will be deployed approximately parallel to Onslow Beach and approximately 5 miles apart. The transects are designed to include the deployed NADP collectors. Deployment of the tipping bucket gauges will address the needs of this project and the need for quantitative information of rainfall amount and duration at several tidal creek locations across the New River for the Aquatic/Estuarine and Coastal Wetlands modules.

The combined information from rainfall chemistry and spatial distribution of rainfall events will be used to calculate the weekly mass (flux) of wet deposition to MCBCL. Measurement of wet deposition should continue for at least a continuous 2-year period to delineate temporal trends in deposition within seasons and across years.

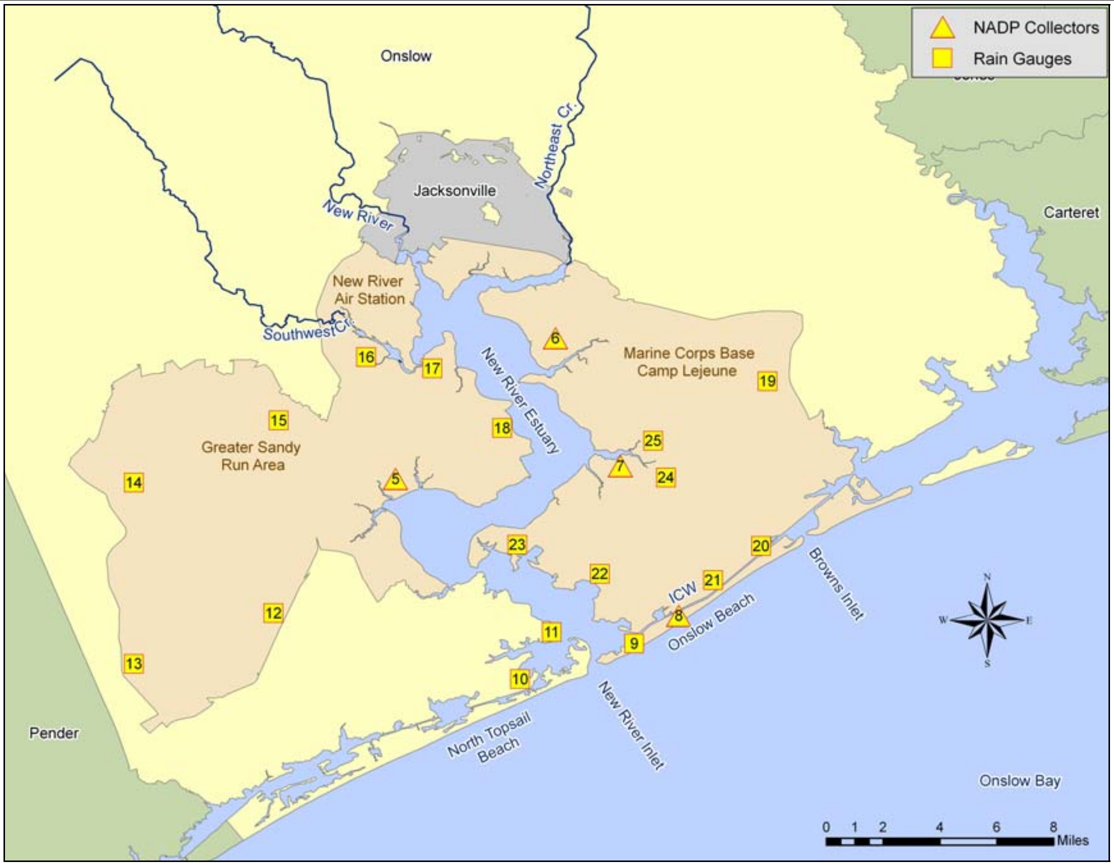


Figure 5-25. Approximate location of planned deployment of tipping bucket collectors with dedicated data loggers at MCBCL. Also shown is planned location of NADP collectors.

Dry Deposition – Throughfall/Stemflow – Throughfall/stemflow collectors will be deployed in at least three locations across MCBCL under representative vegetative canopies for the military reservation (e.g., pine flatwoods, dry longleaf pine – wiregrass savanna, hardwoods). Sufficient samplers will be deployed at each location to account for spatial variability within the canopy. Selection of sites will be done in cooperation with MCBCL staff, and Aquatic/Estuarine and Terrestrial Modules leads to select areas that are considered representative of sub-watersheds draining into extensive Aquatic/Estuarine Module research areas, and consistent with burn schedule for range management.

Samples will be collected weekly following written protocols, which will include cleaning of the collectors with distilled-deionized water. Thymol will be used to preserve samples during sampling events and after sample collection. Chemical analysis of the samples will include pH, soluble cations (ammonium, magnesium, calcium, sodium potassium), soluble anions (chloride, nitrate, nitrite, sulfate), and total DON and DOC. The volume of throughfall/stemflow recorded together with the chemical composition will be used to calculate weekly flux of soluble nutrients to the underlying soil-groundwater ecosystem. Correction of the weekly flux with wet deposition data from the deployed NADP collectors will provide an indirect measure of the weekly flux via dry deposition to the overhead vegetative canopy. Measurement of throughfall/stemflow should continue for at least a continuous 2-year period to delineate temporal trends in deposition within seasons and across years.

Dry Deposition – Gas/Canopy Interactions – Direct gas phase deposition to vegetative canopies will be estimated using a canopy compensation point model (Sutton, et al., 2002). The indirect estimates of dry deposition via throughfall/stemflow measurements do not provide information regarding direct incorporation of atmospheric gases (NH_3 and NO_2) into the vegetative canopy. This information is necessary to complete the yearly nutrient flux to the underlying soil-groundwater ecosystem.

Plants may act as a source or sink for gases (such as NH_3), depending on the ratio of the atmospheric concentration to the gaseous concentration in the leaf substomatal cavity (i.e., stomatal compensation point, Farquhar et al., 1980). Emission occurs if the mole fraction of the gas in the atmosphere is lower than the stomatal compensation point, while uptake (deposition) occurs when the mole fraction of gas in the atmosphere is higher than the stomatal compensation point. Estimation of the stomatal compensation point (ASCP) is therefore necessary for the accurate prediction of bidirectional gas fluxes over vegetation. Previous measurements for NH_3 show that the ASCP varies by vegetation type, growth stage, and N status, and can be predicted at the leaf level as a function temperature and apoplastic NH_4^+ and H^+ concentrations (Farquhar et al., 1980; Morgan and Parton, 1989; Dabney, 1990; Schjoerring, 1991; Husted and Schjoerring, 1995a, 1995b; Harper and Sharpe, 1995; Schjoerring et al., 1998). Nemitz et al. (2000) and Hill et al. (2001) expressed the ASCP as the function of leaf temperature and the ratio of $[NH_4^+]/[H^+]$ in plant apoplast.

Parameters for the compensation point model include measures of wind speed, relative humidity, solar radiation, temperature, and leaf apoplast chemistry (Sutton et al., 2000; Mattsson and Schjoerring 2002), as well as ambient atmospheric concentrations of ambient gases (Duyzer, et al., 1992; Farquhar, et al., 1980). Measures of leaf apoplast chemistry will be made on samples collected from the representative vegetative canopies and will require direct access to the canopy. Mathematical calculations employed for the canopy compensation point model are straightforward and do not require access to specialized computing facilities. Calculations of direct gas phase deposition can be scaled to weekly time frame to compliment direct measurements of wet deposition and throughfall/stemflow.

Integrated measurements of gaseous NH_3 and NO_2 will be made by using passive samplers deployed on transects across MCBCL. Passive samplers offer a relatively low-cost, robust, replicated way to monitor ambient concentration of gases (Tang et al., 2001). Two options are available to this project that will allow measurement of NH_3 and NO_2 across a range of concentrations (Adapted Low-cost Passive High Absorption [ALPHA] samplers; Tang et al., 2001; Radiello™ Passive Diffusion Samplers, Environmental Research Centre, Padova, Italy; *http://www.radiello.it/english/ index_en.html*). Both units are available commercially with the United States. The ALPHA samplers are currently used extensively as part of United Kingdom National Ammonia Monitoring Network (Sutton et al., 1997). The ALPHA samplers are capable of detection limits < 0.1 $\mu g/m^3$ for 2-week exposure periods. The Radiello™ samplers are capable of similar detection limits over shorter periods of time (typically one week) due to their increased diffusion cross-sectional area because of their cylindrical design (Dr. David Gay, Assoc. Research Scientist, Mercury Deposition Network (NADP), Illinois State Water Survey, personnel communication). Plans call for an extensive evaluation of the Radiello™ Samplers in 2007–2008 as potential additions to CASTNET - Clean Air Status and Trends Network (*http://www.epa.gov/castnet/*). (Dr. Gary Lear, U.S. Environmental Protection Agency, Washington, D.C., personnel communication). One of the lead investigators for this project (Wayne P. Robarge) will partake in this evaluation of the Radiello™ Samplers at other research sites across eastern North Carolina. The Radiello™ Samplers have been used to monitor VOCs in urban environments (Bruno et al., 2007) and in work places (Carrieri et al., 2006; Strandberg et al., 2006; see extensive review by Namiesnik et al., 2005). The extensive evaluation to be conducted under the auspices of the EPA CASTNET program should lead to adoption and application of Radiello™ Samplers in environmental programs.

Passive collectors will be collocated with tipping bucket gauges and NADP collectors (**Figure 5-25**), but additional stations may be required to assess a gradient in ambient atmospheric chemistry moving away from the ocean, across MCBCL to the city of Jacksonville, NC.

(d) Data Analysis: ***Descriptive Summary of Wet Deposition –*** The planned placement of the NADP collectors (see **Figure 5-24**) is designed in part to provide information concerning frequency and composition of rainfall across MCBCL. With inclusion of information from NADP collector NC29 (located at Hofmann Forest, ~ 6 miles northwest of Jacksonville, NC), the planned network will encompass a distance of approximately 15–20 miles.

The NADP collectors will provide weekly measurements of the ionic composition and concentration of DON and DOC in rainfall. Additional information that can be calculated includes molar ratios of various ionic fractions, and % composition across fractions for certain elements, especially N. This information can be presented in temporal plots contrasting trends in rainfall composition as a function of season. Further analysis will reveal trends as a function of wind direction, season, and position along sampling network, assuming a sufficient number of events are sampled.

Since the NADP collectors also collect volume, integrated weekly deposition (mass per unit area per unit time; e.g., kg/ha/yr) of ionic composition and concentration of DON and DOC can be calculated. This data can be expressed as a function of time, position, and season. Cumulative plots of deposition per unit time will provide measures of average weekly deposition, and will act to smooth out differences in rainfall amounts between events.

Descriptive Summary of Dry Deposition – Throughfall/Stemflow: Collectors will be deployed under the representative vegetative canopies for MCBCL (e.g., pine flatwoods, dry longleaf pine – wiregrass savanna, hardwoods). Due to cost restrictions, these sites will not be replicated, but sufficient number of collectors will be deployed under each representative canopy to properly characterize throughfall/stemflow.

The collectors will provide weekly measurements of the ionic composition and concentration of DON and DOC of throughfall/stemflow. Additional information that can be calculated includes molar ratios of various ionic fractions, and % composition across fractions for certain elements, especially N. This information can be presented on temporal plots contrasting trends in rainfall composition as a function of season. Further analysis will reveal trends as a function of wind direction and season.

As with the NADP collectors, integrated weekly deposition (mass per unit area per unit time; e.g., kg/ha/yr) of ionic composition and concentration of DON and DOC to the forest floor/soil can be calculated. This data can be expressed as a function of time, position, and season. Cumulative plots of deposition per unit time will provide measures of average weekly deposition, and will act to smooth out differences between events. Local variation within a canopy can be assessed by contrasting deposition amounts per collector, allowing an assessment of the local micro-environment for deposition within each vegetative canopy.

Net throughfall/stemflow (=Throughfall/stemflow deposition – Wet deposition) will be assessed using wet deposition estimates derived from the NADP collectors. These calculations will be done using deposition estimates (e.g., kg/ha/yr) to average out spatial and temporal differences in events sampled by the respective throughfall/stemflow and NADP collectors. Calculated net throughfall will provide an indirect estimate of dry deposition of individual chemical species. Negative differences will indicate retention by the overhead canopy and incorporation within the overstory biomass. Positive differences will reflect both leaching losses from the canopy, as well as dry deposition of atmospheric constituents to the overhead canopy. Typically base cations such as potassium are known to readily leach from vegetative canopies. However, major constituents of atmospheric deposition such as N and S compounds do not leach from canopies, and positive values in net throughfall will be taken as an indirect measure of dry deposition for these elements.

Descriptive Summary of Dry Deposition – Gas/Canopy Interactions: These measurements are designed to provide a direct estimate of NH_3 and nitrogen dioxide (NO_2) dry deposition to the representative vegetative canopies at MCBCL. Typically throughfall/stemflow will underestimate the dry deposition of these 2 N-containing gases due to direct incorporation into the leaves via the stomatal cavity. For example, Schmitt et al. (2006) reported that throughfall measurements underestimated N deposition by as much as 2 kg/ha/yr compared to an inferential method such as the canopy compensation model. Model calculations will be provided on a weekly basis of estimated dry position of NH_3 and NO_2 as mass per unit area. These estimates will be summed over time for comparison to N deposition estimates derived from wet deposition and via net throughfall/stemflow. These results will be compared between the representative canopies and across years.

Use of the passive collectors for NH_3 and NO_2 will also provide integrated estimates of the atmospheric concentrations of these gases across MCBCL, and to the extent possible, as a function of usage class (see **Figure 5-24**).

Statistical Analysis of Wet Deposition (NADP Style-Collectors): Statistical analysis of the data collected from the 4 NADP style-collectors deployed across MCBCL will be conducted using the technique of Repeated Measures. (Note: data from the NADP collector NC29, Hofmann Forest, will be included as well when the data becomes available. There is often a several month delay in the release of data for the NADP collectors.) Repeated Measures refers to when data are generated for two of more measurements of the same type on the same subject. The repeated measures are the levels which constitute the within subject factors in the analysis. In this project, the within subjects factor is time (rainfall events) and the between subjects factor is location. This approach will be used to test differences in rainfall composition and amount across MCBCL. Inclusion of data from the NADP collector NC29, Hofmann Forest, will test whether information from collector NC29 is sufficient to characterize wet deposition at MCBCL, or whether dedicated wet deposition collectors need to be installed at one or more locations across MCBCL.

Statistical Analysis of Spatial Distribution of Wet Deposition: Rainfall amount data collected at sites with the NADP style-collectors, existing meteorological stations, and the network of tipping bucket gauges to be deployed across MCBCL (see **Figure 5-25**) will provide the necessary data to generate a response surface. Use of computer-aided analyses allows generation of response surfaces without a need of a defined grid of samplers. With GPS information, the location of the samplers will be known and will form the basis for developing response surfaces. The shape and character of the fitted response surfaces will provide information on the spatial distribution of rainfall amount at MCBCL. With a sufficient number of observations, the nature of the response surface can be tested across seasons and between years, as well as potentially single large events. Following successful generation of response surfaces for rainfall amount, rainfall composition data will be included to generate response surfaces for nutrient deposition (especially N). Results from Repeated Measures analysis of rainfall data collected using NADP style-collectors will aid in the generation of the nutrient deposition response surfaces.

Statistical Analysis of Net Throughfall/stemflow: Repeated Measures analysis will also be used to assess differences in Net Throughfall/stemflow between the 3 vegetative canopies (pine flatwoods, dry longleaf pine – wiregrass savanna, hardwoods) selected as study sites in this project. The basic outline of the analysis will mimic that described for Wet Deposition (NADP style-collectors).

(e) Environmental Indicators: This project will generate no specific environmental indicators. Information generated by this project will directly support development of environmental indicators via the Terrestrial and Aquatic/Estuarine Modules by providing information on amount and composition of atmospheric deposition (especially for N) to the respective ecosystems. The statistical analysis of the spatial distribution of the wet deposition measurements described above will allow an estimate of the total N loading across the MCBCL.

(f) Linkages to other Modules: *Terrestrial* – Except for N-fixation by native plant species, inputs from migrating wildlife, and nutrient release from soil weathering, atmospheric deposition represents the only source of new nutrients into the terrestrial ecosystems at MCBCL. This project will supply needed information to determine the amount, composition, and frequency of atmospheric inputs in order to assess the importance of atmospheric deposition on the sustainability of current terrestrial ecosystems and to determine long-term sustainability in regards to native flora and fauna, as well as the training mission of MCBCL.

Aquatic/Estuarine and Coastal Barrier – Atmospheric deposition can represent a significant percentage (20% to 50%) of new nutrients introduced into the aquatic/estuarine and coastal barrier ecosystems being investigated at MCBCL (Paerl et al., 2002). Knowledge of the composition of atmospheric inputs is particularly important to assess sustainability. This project will provide estimates of direct wet deposition (composition and amount) to the NRE within the confines of MCBCL. This project will also provide an estimate of the nutrient loading from atmospheric deposition to the forest floor/soil of terrestrial ecosystems that drain into the NRE and associated coastal wetlands. This information is necessary to complete an assessment of whether and to what extent terrestrial ecosystems export nutrients to surrounding aquatic/estuarine ecosystems, especially after implementation of current management practices such as PB, or from current and potential increases in hard surfaces within the confines of MCBCL. Results from this project will also provide a measure of the amount of organic-N present that is present in wet deposition at MCBCL.

The degree of atmospheric inputs to coastal barrier and coastal wetland ecosystems may be markedly enhanced by the presence of marine aerosols. The presence of marine aerosols can alter the partitioning between gases and particulates in the atmosphere, favoring the retention of gases (such as NH_3 and nitric acid) on larger particles. Larger particles have higher deposition rates, thus effectively increasing the net dry deposition of a gaseous species. In turn, this may increase overall atmospheric deposition within the coastal barrier and coastal wetland ecosystems. Besides estimates of wet deposition, the use of the integrated measurements of gaseous NH_3 and NO_2 using passive samplers in this project as a function of distance across MCBCL will provide an indirect estimate of whether there is a significant gradient for these gaseous components moving from Jacksonville to Onslow Beach. Presence of a significant gradient would support further research into the potential for enhanced deposition of N-containing species into coastal barrier and coastal wetland ecosystems due to marine aerosols.

Atmospheric – PB is an essential management tool used by staff at MCBCL to meet the training mission of the Base. Prescribed burns typically mobilize nutrients within local canopies due to smoke plumes remaining within the canopy structure for significant distances. The resulting deposition of ash and smoke represents enhanced inputs into these downwind canopies. Measurements of atmospheric deposition provided by this project will allow an evaluation of the magnitude of the additional inputs represented by deposition of smoke and ash to downwind canopies during prescribed burns.

(g) Military Drivers: MCBCL has many unique features (e.g., Onslow Beach) that support its fundamental training mission. Long-term sustainability of MCBCL terrestrial and aquatic ecosystems must be assured. Atmospheric deposition represents a potentially significant input of nutrients to the terrestrial and aquatic ecosystems at MCBCL. Knowledge of wet and dry deposition will compliment military objectives as follows:

- Projection of current and potentially future runoff from hard surfaces, especially with potential troop assignment following Base Realignment and Closure 2005.
- Identification of potential nutrient stressors limiting development of native forest ecosystems while maximizing land-use to meet training obligations.
- Identification of potential enhanced nutrient inputs from surrounding areas in North Carolina due to regional changes in agricultural practices and population changes along the coast.

(h) Benefit to MCBCL: An assessment of current and projected changes in nutrient loading from atmospheric deposition is a vital component to understanding the sensitivities of MCBCL’s ecosystem to different stressors. Information from this project will be of benefit to MCBCL as follows:

- Assist in planning/successful replacement of existing tree species with those common to native forest ecosystems.
- Provide actual baseline data of atmospheric inputs into areas with federally protected species, allowing

assessment in changes in species densities in the future with potential shifts in atmospheric deposition due to influences outside the confines of MCBCL.

- Provide an estimate of the extent to which forested canopies at MCBCL serve as sinks for atmospheric species.
- Provide an estimate of variation (if any) in long term rainfall amounts and composition across the confines of MCBCL, presenting a platform for future monitoring plans or selection of areas for land use activities, such as land application of bio-solids.
- Provide information on the applicability of current, relatively low cost, approaches (NADP-style rainfall collectors, passive samplers) to monitoring atmospheric deposition and ambient atmospheric composition to delineate possible impacts as a function of land usage within the confines of MCBCL.
- Assessment of suitability of "nearby" federal and state atmospheric monitoring stations (e.g., NADP collector NC29 at Hofmann Forest, Onslow Co.) to project atmospheric deposition within the confines of MCBCL and whether expenditure of MCBCL resources to develop within-base monitoring would yield additional information.

(i) Schedule: Year 1(July 2007 – June 2008)

- Order NADP collectors, tipping bucket gauges, passive samplers, and purchase components for throughfall/stemflow collectors.
- Select sites for deployment of NADP collectors, tipping bucket gauges, passive samplers.
- Select sites for deployment of throughfall/stemflow collectors.
- Build stands and other support structures for collectors.
- Compile written protocols for operation of all collectors and for handling collected samples.
- Deploy NADP collectors, tipping bucket gauges, passive samplers – October 2008.
- Deploy throughfall/stemflow collectors – November - December 2008.
- Assess operation of all collectors with target of data collection starting January 2008.
- Establish routine operation of all collectors January – June 2008.

Year 2 (July 2008 – June 2009)

- Operate/maintain all collectors on regular schedule.
- Carry out analyses of collected samples.
- Collect foliage samples for apoplast chemistry analysis – April – October 2008.
- Provide initial summary of wet deposition data generated from NADP collectors, tipping bucket gauges.
- Provide initial summary of throughfall/stemflow deposition to forest floor/soil within representative canopies.
- Model dry deposition of gaseous NH_3 and NO_2 to representative canopies using Compensation Point Model.
- Presents results at scientific meetings and other forums deemed appropriate.

Year 3 (July 2009 – June 2010)

- Operate/maintain all collectors on regular schedule.
- Carry out analyses of collected samples.
- Assess whether there is a need to expand existing collector network, or to development an additional collector transect, especially for tipping bucket gauges and passive samplers.
- Collect foliage samples for apoplast chemistry analysis – April – October 2009.
- Provide 2-year summary of wet deposition data generated from NADP collectors, tipping bucket gauges.
- Provide 2-year summary of throughfall/stemflow deposition to forest floor/soil within representative canopies.
- Provide final summary of modeling dry deposition of gaseous NH_3 and NO_2 to representative canopies using Compensation Point Model.
- Presents results at scientific meetings and other forums deemed appropriate.
- Prepare publications based on results from using Compensation Point Model.

Year 4 (July 2010 – June 2011)

- Operate/maintain all collectors on regular schedule until January 2011.
- Terminate all sample collection January 2011 unless specifically requested by other modules to keep certain collectors functioning (e.g., NADP collectors).
- Complete all analyses of collected samples.
- Remove collectors from sites at MCBCL.
- Prepare section of final report detailing wet deposition data generated from NADP collectors, tipping bucket gauges.

▪ Prepare section of final report detailing data generated by throughfall/stemflow deposition to forest floor/soil within representative canopies. ▪ Prepare final report integrating all measurements. ▪ Presents results at scientific meetings and other forums deemed appropriate. ▪ Prepare publications for scientific journals.
Scheduling Constraints: The primary scheduling constraint on this project will be the identification of suitable locations for throughfall/stemflow samplers in representative canopies at MCBCL. Site location will require cooperation of MCBCL staff and input from the Terrestrial module to ascertain representative canopies are selected for the planned 3-year monitoring project.
Year 1 Go/No Go Decision Point: None identified.
Budget (Estimated): ▪ Year 1(July 2007 – June 2008): $140,000 ▪ Year 2 (July 2008 – June 2009): $127,000 ▪ Year 3 (July 2009 – June 2010): $110,000 ▪ Year 4 (July 2010 – June 2011): $90,000 ▪ Total Projected Costs (minus institutional costs) = $467,000

6.0 Data Management Module

The backbone of the DCERP research, modeling, and management tools will be environmental data collected throughout the duration of the program. The types and volumes of baseline data that currently exist (historic data) and that will be collected during the DCERP baseline monitoring and research program are extensive. It is essential that a comprehensive data management plan be developed and implemented to ensure that these data are accessible to researchers across modules. General categories of data to be collected and managed include the following: structure data (e.g., monitoring and research data), unstructured data (e.g., Web sites, reports, and publications), and spatial data (e.g., vector and raster).

The Data Management Module will develop data and information management systems to support the other DCERP modules. MARDIS will store and manage the data collected by the DCERP module teams. The Document Database and provide for simple retrieval unstructured data, such as documents. General categories of data to be collected and managed include the following:

- *Structured Data*: Tabular environmental monitoring data from each module having defined content and structure that will be managed in a standard Relational Database Management System (RDBMS)
- *Non-spatial* and *unstructured data*: Spreadsheets, SAS files, word processing documents, Web sites, reports, and research publications that provide valuable information for DCERP, but that are not in a structured format suitable for an RDBMS. These files will be managed in a Document Database and will be searchable via explicit metadata that describe the content of each file. Rather than storing and managing raw data (such as monitoring data), this database will manage documents.
- *Spatial data (vector and raster*): Where possible and appropriate, geospatial data will be stored and managed in geospatial databases so that they are accessible via similar mechanisms as structured data. In some cases, however, these data may need to be stored outside a geospatial database and managed at a file system level.

The DCERP Strategic Plan calls for the development of a data repository to provide the tools and structure to manage these data. Based on our understanding of the needs of the project, the concepts implied by the term “data repository” should be expanded to include concepts of overall data and information management systems. The models and tools currently included as outcomes for selected research projects will be housed in the data and information management system. Although the data management plan does not currently include the development of an overall decision-support system, the data systems will be designed to enable the development and use of an overall decision-support system in the future. For example, the technology environments proposed for the data systems should enable future use of technologies, such as Web-based tools, Web services, and other interoperable technologies.

6.1 Data and Information Managment System

6.1.1 MARDIS: Structured Data

The Data Management Module Team will work with the Module Team Leaders to define the database structure of MARDIS using RDBMS technologies. This will involve on-site or teleconference meetings so that staff who are designing the system understand the type, content, volume, and resolution of the research and monitoring data being collected. If possible, Module Team Leaders should provide sample data tables to help in communicating content and format. Standards for specifying the locations of monitoring stations will also be developed to ensure that the locations of each monitoring datum are correctly assigned to an accurate location. Use of GPS devices to record the location of monitoring devices will be encouraged—especially for any ad hoc or event-driven monitoring where new stations are being set up or existing stations are temporarily being moved.

In addition, the Data Management Module Team will work with the other DCERP module teams to define appropriate formats for monitoring and research data to be uploaded into MARDIS. For each type of monitoring data to be collected, a standard data delivery format will be specified that will be used to upload these periodic monitoring datasets to MARDIS. Different upload schedules will be defined for different types of monitoring (i.e., different equipment or collection schedules will determine period intervals between each upload). After performing quality checks on their data, the research groups will convert the data to the agreed-upon upload formats and upload the data to MARDIS. MARDIS will include selected data checks to ensure the basic accuracy and consistency of the upload process and that the data being uploaded conform to the specified data formats. Basic quality checks will also be made to ensure that, where possible, data values that are invalid or out of range are detected prior to loading. MARDIS will include a staging area where data will be uploaded and checked. After the data checks are completed successfully, the data will be appended into the core database. This process will ensure that only the highest quality data are maintained in MARDIS. The uploaded data will be stored in structured relational database tables that will hold these long-term data so that, in the future, researchers from any module can access and download different types of data for any time period.

Research groups will be responsible for processing raw monitoring data results (e.g., laboratory results) into agreed-upon formats for upload. In addition, research groups will be responsible for conducting the QA/QC procedures for data they are collecting. The MARDIS upload mechanism can provide some data checks to ensure that data formats are correct, but the mechanism cannot do a complete QA/QC on raw data. All monitoring and research procedures (including both field and laboratory equipment methods) will be developed by the individual investigators as SOPs, and these procedures will be archived in MARDIS. Researchers will frequently perform data analyses, data synthesis, and data integration on monitoring data, thereby generating derivative data files and products. These analytical products may be held in the form of spreadsheets, documents, tables, or other relatively unstructured formats that are suitable for research purposes. Although these data products are not in structured formats and will not be loadable into standardized database tables, they should still be submitted so that they can be documented and managed. The Document Database design will provide a system to allow researchers to upload the documents and describe their contents using standard ecological metadata definitions (see Section 6.1.2). The Document Database will also provide a mechanism for researchers to search the repository for these unstructured files to find documents that may contain data of interest.

Historical data from non-DCERP sources will be assessed to determine whether or not the data should be translated and uploaded to MARDIS or should remain in their native format and either be stored in the Document Database (most likely if the data is not being changed or updated) or, if pointers to the locations of these external data sources exist, be included in MARDIS.

MARDIS will include the development of Web-based query tools to enable researchers to find and download data of interest and develop selected data summary tools to perform basic statistical analyses of data (i.e., if researchers commonly use mean monthly temperatures in their research rather than daily temperatures, MARDIS could include tools that would automatically calculate mean monthly temperature data and manage these derivative data). In addition, MARDIS will enable the development of Web-based models or other analysis tools that will be driven by data from the repository.

6.1.2 Document Database: Unstructured Data

The data and information management system's Document Database will house and manage non-spatial, unstructured, or derivative data. Rather than present the data in structured database formats, the Document Database will provide easy-to-use formats (e.g., spreadsheets, SAS databases, tables) for use by the module teams. The data and information management system will include a tool for researchers to upload these non-structured data tables and explicit metadata into a Document Database. The Document Database will provide query functions to help researchers understand the content of the documents stored and locate documents or files that contain data of value to their research.

6.1.3 Geospatial Data

The data and information management system will explicitly include the management of geospatial data. The specific structures and formats chosen will be based on requirements and needs analysis carried out with research modules and MCBCL staff. It is presumed, however, that geospatial databases will be developed that will enable the use of geospatial data standards, Web-based mapping, and Web-based geospatial data services to allow the design and development of decision-support systems in the future that will run against geospatial data in the data repository.

6.1.4 Web Sites

The DCERP Collaborative Web site is a place where DCERP Team members can share administrative planning documents, reports of activities, and other information of interest to their group and other DCERP Team members. It also includes a calendar for scheduling and managing field monitoring and research activities. This site is password protected and can only be viewed by the DCERP Team.

The DCERP public Web site (http://dcerp.rti.org/) provides the general public with information about the program, including the mission statement for DCERP, as well as the background, objectives, approach, and benefits to MCBCL. Only documents that have been reviewed and approved by the researchers, MCBCL, and SERDP will be posted on the public Web site. The public Web site also contains contact information for SERDP staff, the DCERP PM, the DCERP OSC, the DCERP PI, and all DCERP Module Team members, as well as links to affiliated organizations.

6.2 Data Reporting

Standard reporting applications will be implemented for the data and information management systems to develop reports to document the system's contents. Reports will include lists of all files in the system, the number of records in files, and perhaps charts and graphs that indicate how records have been added each month or quarter. A final report will be prepared indicating the final structure and content of the data and information management system.

6.3 Models and Management Tools

An ultimate goal of DCERP is to develop tools to enable MCBCL managers to identify adaptive, ecosystem-based management approaches, such as models for forecasting the impacts of military activities and other stressors or indicators for assessing healthy, transitional, or degraded conditions. The scale and complexity of these tools will depend on the needs of MCBCL and the level of funding available to the program. Currently, several of the proposed research projects include tools and models as project outcomes, which will enable MCBCL managers to make informed decisions to support their long-term goals of military training and preparedness.

As the DCERP ecosystem research and monitoring strategy is implemented, the need to develop analytical workflow systems and management tools to automate the processing of raw monitoring data into useful management information will increase. The RTI DCERP Team will work with MCBCL staff to identify and prioritize opportunities for the development of automated workflow processes, integrated models, and new management tools. Because this process will necessarily be driven by emerging end-user needs at MCBCL and the data products and models yet to be developed by DCERP, it is difficult to directly anticipate and prioritize the specific models and tools that will be needed at this time. As DCERP evolves and matures, planning for the future development and implementation of these end-user tools will require a focused planning and evaluation effort to identify and prioritize this work. These efforts will be conducted in close coordination with the development of the DCERP data and information management systems, and outcomes of these efforts will be used to refine the data repository and information management system architecture of DCERP. Full implementation of automated data analysis systems, integrated models, and decision-support tools identified by this process will then be proposed for funding through the DCERP effort or a separate funding arrangement, if appropriate.

7.0 Military Activity Impact

In order to be able to make appropriate management decisions about the effects of military training activities on MCBCL's natural resources, it is important to understand the military stressors impacting the environment, assess the site-specific impact of those stressors, and evaluate their contribution to site degradation in comparison to those impacts resulting from non-military, legacy, and natural perturbations. Although it is understood that many factors can contribute to site-specific military impacts (e.g., intensity and frequency of training, physical characteristics of the site, meteorological conditions, soil type, soil moisture levels, and landscape), a consistent, quantitative evaluation methodology appropriate for MCBCL currently does not exist. During the first year of Phase II, the RTI DCERP Team will implement a combined research and monitoring effort that will develop a consistent approach for assessing the impact of military training at MCBCL in general, as well as the publicly available, study-specific impacts related to each of the individual Base ecosystems.

This approach will include a five-step process. First**,** RTI staff will identify, acquire, and review existing literature on military impacts to the various ecosystem types present at MCBCL (e.g., estuarine, wetlands, coastal barrier, and terrestrial). This literature review will focus on impacts from various military training activities to each ecosystem, as well as recommendations for the remediation of environmental impacts employed at other DoD installations in similar ecological settings and using similar training and testing vehicles and equipment. This information will be summarized for the DCERP module teams and MCBCL.

The second step will involve meetings with the Terrestrial Module Team that will be developing a land cover/land use GIS data layer; MCBCL range control staff; and the DCERP OSC to discuss the nature and extent of the observed impacts of training activities, what training activities or vehicles result in observable ecosystem impacts, and the extent of movements of troops and various training vehicles across MCBCL. In addition, these meetings will allow the RTI DCERP Team to become more familiar with the

Range Facility Management Support System (RFMSS), MCBCL's military training/testing tracking database. Examples of RFMSS data include number of vehicles launched from each splash point into the estuary or the number of foot soldiers training in a specific training zone. From these meetings, the RTI DCERP Team will develop specific questions about the various military activities in each of the ecosystems on Base.

In the third step**,** RTI's contractor (URS Corporation), the designer of the RFMSS database, will develop and conduct queries to extract real-time data from RFMSS on use of the Base's land and estuarine and coastal waters, including the vehicles/watercraft types used and the number of troops involved in individual training maneuvers in various ecosystems. MCBCL uses this database to plan training exercises and, increasingly, to track this information so that commanders provide updates after the exercise to ensure that the RFMSS reflects not only planned training but also actual training activities. The RTI DCERP Team will use this information to evaluate whether there are clear gradients of military activity for specific vehicle types used in each ecosystem.

In the fourth step**,** information from the RFMSS database will be used in conjunction with the land use/ land cover database to help integrate the spectrum of military training impacts to the terrestrial and aquatic ecosystems in various areas of the Base. This GIS-based system will combine analysis of land-use change and military impacts and will calculate changes in the spatial dispersion of different types of military impacts. This system will combine information on (1) surface features (e.g., land cover, soil and topographic characteristics); (2) current climate (e.g., moisture and saturation levels); and (3) military uses (e.g., types and intensities of different military uses). These inputs will be combined to create a continuous value index of military use (**Figure 7-1**).

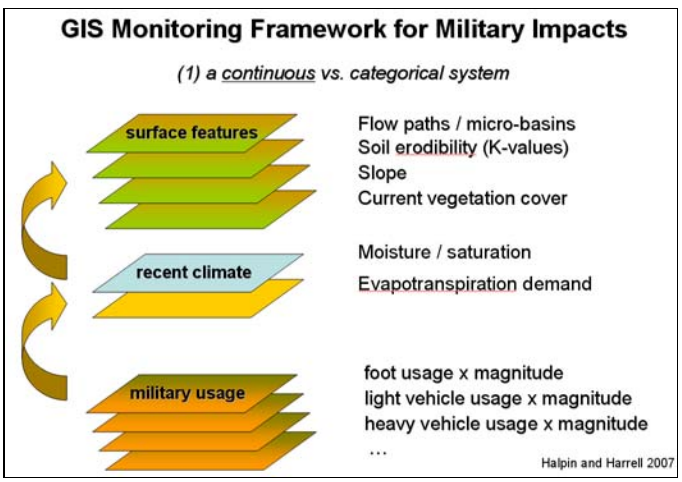


Figure 7-1. Development of a military-impacts GIS model.

Because military uses are not uniformly distributed, the RTI DCERP Team will need to develop a system to more realistically represent patterns of land use. The land cover change and military impacts monitoring system will spatially distribute the likely intensity of military use by developing models based on distances from roads, restricted areas, and usage characteristics that affect the actual military use of the landscape (**Figure 7-2**).

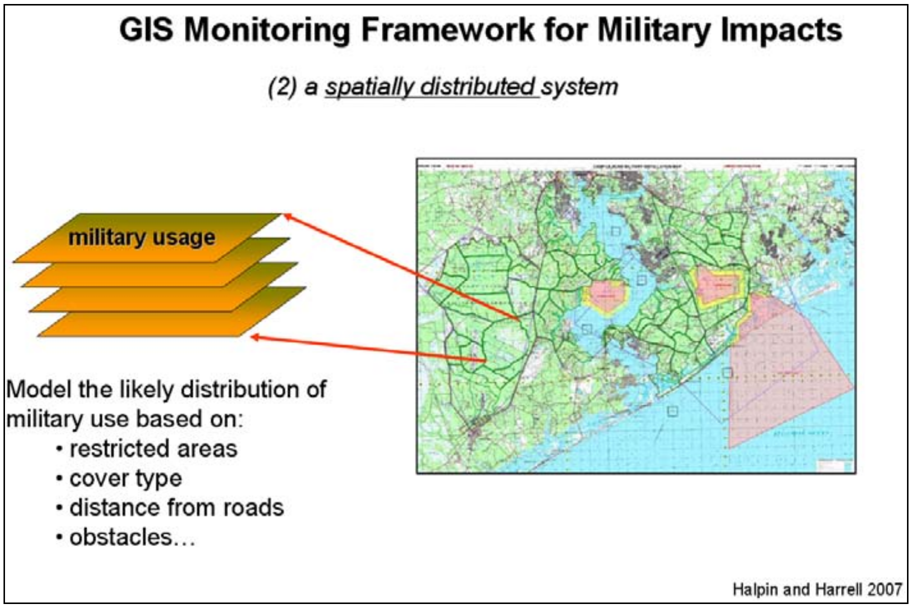


Figure 7-2. Modeling the spatial distribution of military impacts.

The development of a spatially distributed land cover change and military impacts system will help provide a direct tool for Base managers and the research community to use to more realistically characterize differences in the spatial and temporal distribution of accumulation of military impacts. Some of the potential advantages of a continuous and spatially distributed system are the following:

- More precision than frequent/infrequent use categories
- Ability to modify impacts outcomes with dynamic conditions
- Increased ability to more realistically distribute impacts
- More flexible system for isolating and testing impact drivers.

Finally, the DCERP module teams will meet and discuss potential indicators of military impacts for their respective modules to incorporate the military activities analysis associated with their respective modules and to determine whether the Baseline Monitoring and Research plans should be modified to discriminate the military impacts from other impacts (e.g., non-military, legacy or natural perturbations).

8.0 Quality Assurance

RTI and its subcontractors will perform and document QA/QC procedures to ensure the technical accuracy and scientific defensibility of work conducted under this DCERP contract. Quality assurance is a key component of RTI's work processes; therefore, RTI and each subcontractor will prepare (as necessary and appropriate) SOPs, data collection plans, software requirements documents, database design documents, and model verification test plans for their own work. These documents will clearly describe the measures taken to ensure adequate QA and QC. Each subcontractor will also develop SOPs or employ existing SOPs to cover key routine activities, including environmental data collection and analysis, model development, data management, and data validation. RTI will post these SOPs and other QA planning documents to MARDIS where they will be archived with the products and data they support.

RTI and its subcontractors will develop, implement, and document QC checks to ensure the appropriateness and accuracy of the conceptual approach, methodologies, data, algorithms, models, and the documentation of data and methods used in and the results of the analyses. RTI and its subcontractors will use a variety of QC techniques to identify potential sources of error during this work. Each contractor will confirm the reasonableness of environmental data collected under this project and check hand-entered data for accurate transcription (of values and units). Calculation checks will also be performed. Documentation will be written in a clear, transparent manner and will be concise, complete, and editorially correct.

9.0 Transition Plan for Research Results

The RTI DCERP Team members all have extensive experience in disseminating scientific and management information to a wide spectrum of audiences and through diverse communications media. A regular flow of professional basic scientific and management-oriented publications is expected from all team members, beginning within two years of initiation of the monitoring and research phase of this program. These papers will be provided to the RTI PI, the DCERP PM, SERDP, and MCBCL Director of the Environmental Management Division for initial review, then submitted to and ultimately published in high-impact, peer-reviewed scientific journals. From the past productivity of the scientists assembled for this program, this flow of information is likely to be both regular and strong. In addition, chapters contributed to edited and peer-reviewed scientific books will likely be vehicles for the dissemination of printed results of monitoring and research studies.

The research scientists that comprise the RTI DCERP Team also participate in meetings of scientific societies, scientific conferences, and in special *ad hoc* symposia at which verbal presentations of new results are made. We anticipate this process will serve to provide even more rapid dissemination of results from this program than print publications. Presentations will also be made regularly at SERDP meetings.

During Phase II implementation, the RTI DCERP Team will provide quarterly reports and briefing updates (as desired) to MCBCL natural resources management staff. The reports will summarize the progress and results of monitoring and research in each module and facilitate feedback from MCBCL staff, thereby strengthening the link between DCERP researchers and the Base. In addition to these reports, the DCERP Team will provide relevant information to natural resources and environmental managers in special forums, including public information sessions relating to environmental issues in which the Base has a stake. Such presentations will be carefully reviewed by the RTI PI, the DCERP PM, SERDP, and MCBCL staff in advance, following the guidelines included in the DCERP Terms of Reference.

A DCERP Web site also will be established during the first six months of the program. The Web site will be initially populated by links to other sites, documents, and databases of relevance to the coastal barrier, aquatic/estuarine, coastal wetland, terrestrial ecosystems, and air quality of MCBCL, as well as information about the final DCERP Baseline Monitoring Plan and Research Plan established for this project. During the subsequent phase of implementation of monitoring, modeling, and research, the DCERP Web site will be used to disseminate basic scientific and management-related papers produced as part of the program; guidance for ecosystem models developed for MCBCL; PowerPoint presentations created by DCERP Team scientists working on the program; and user-friendly tools for applying and displaying results of application of the ecosystem-based models to management issues, both on the Base and in analogous military lands. We anticipate different layers of access to portions of this Web site so that draft materials intended only for internal DCERP Team members, MCBCL, and SERDP review can be closed to access by the general public until they are approved and finalized.

10.0 Measures of Success

The successful implementation of DCERP will foster a greater understanding of biologically diverse aquatic/estuarine, coastal wetland, coastal barrier, and terrestrial ecosystems of MCBCL; the Base's air quality; and the interactions of these systems with military training activities. This understanding will aid in the long-term management and sustainability of MCBCL ecosystems, which will enhance and maintain MCBCL's military mission. Information and data resulting from the DCERP research and monitoring efforts will increase the ability of resource managers to perform assessments and implement appropriate management responses to potential environmental impacts arising from military activities or natural disturbance events. In addition, DCERP's monitoring metrics and techniques likely will be transferable to other DoD installations in ecologically similar settings.

Measurement of DCERP's success will come from assessing whether the desired outcomes are achieved, and whether the outcomes are produced in a timely manner. The outcomes defined for DCERP can be grouped into two main categories:

- Programmatic—Includes administrative requirements such as delivering required documents on schedule and on budget, ensuring that the project Web site is developed and functioning, meeting SERDP quarterly and annual reporting requirements, and providing timely and effective feedback to MCBCL and outreach to stakeholders. The DCERP Strategic Plan provides a list and delivery schedule for currently anticipated programmatic products/outcomes.
- Project specific—Includes those outcomes resulting from the research efforts. In some cases, these outcomes provide information to address environmental issues that are currently impacting Base operations. Other research efforts were designed to provide outcomes relevant to issues that are currently known and that are anticipated to impact Base operations in the next 3–5 years. In addition, the majority of the DCERP research activities will provide the information necessary to gain a complete understanding of ecosystem functions, which will better prepare the Base to address future environmental issues. **Table 9-1** includes key outcomes that are anticipated to result from each of the 13 research projects described in the plan.

Table 9-1. Timeline for DCERP Research Project Outcomes

Research Project	Outcome	Completion Date
AE-1	Use diagnostic MA indicators to determine the effects of local (MCBCL) and regional nutrient, sediment, and contaminant inputs on NRE water quality (including HABs) as a tool to ensure compliance with the CWA, TMDLs, and State water quality criteria (e.g., acceptable chlorophyll *a* levels, HAB, and hypoxia potentials).	June 2011
	Couple MA indicators to probabilistic and mechanistic ecosystem models capable of distinguishing climatic (e.g., droughts, hurricanes, floods) from anthropogenically driven changes in NRE water quality and habitat condition and HAB potentials. This will help MCBCL evaluate specific effects of wastewater treatment, training, construction, and PB on NRE water quality.	June 2011
	Use indicators to calibrate aircraft and satellite remote sensing to “scale up” to ecosystem responses to local and regional nutrient, sediment, and hydrologic perturbations.	June 2011
	Develop GIS maps of MA community composition and verify nutrient-eutrophication models that will help forecast bloom responses, including HABs to nutrients and hydrodynamics of the NRE.	June 2011
AE-2	Develop a watershed model to link land-based activities to exports of nutrients, sediments, and pathogens to the NRE. MCBCL will be able to assess likely water quality impacts of activities ranging from troop training to large infrastructure development.	June 2011
	Develop a model relating creek sediment loading to marsh accretion across the estuarine landscape. Assess thresholds of minimum sediment loading required to support marsh accretion.	June 2011
	Deploy microbiological indicators to distinguish fecal contamination from FIB loading to the NRE. MCBCL will be able to use these indicators in TMDL development and implementation.	June 2011

Research Project	Outcome	Completion Date
	Provide site-specific data on base flow versus storm flow loading of non-point source pollution for potential MCBCL remedial actions.	June 2011
AE-3	Develop suite of indicators of benthic ecosystem health to assess subtidal littoral zone systems that may include: ratio of production to respiration, net ecosystem metabolism, sediment/water DIN flux, denitrification efficiency (N_2-N)/(N_2-N + DIN flux), sediment DO profile, and benthic community composition and abundance (BMA, SAV).	June 2011
CW-1	Develop a user-friendly model that can be run to test the consequences of various environmental changes (e.g., rate of sea-level rise) or management options (e.g., increase in primary production through fertilization – a potential mitigation strategy) to the productivity and sustainability of area marshes.	June 2011
	Develop map of wetland elevations and an analysis of their present condition that will inform managers about how and where to schedule training activities and where shorelines are most vulnerable to erosion.	June 2010*
	Develop a GIS tool that will allow rapid assessment of the vulnerability of marshes to disturbance and stress.	June 2009*
	Prepare report on how the present amphibious training exercises are affecting sediment accretion and primary productivity of NRE salt marshes.	June 2011
CW-2	Develop shoreline stabilization and protection plan.	June 2010
	Develop predictive model of estuarine shoreline erosion (NRESE).	June 2011
	Provide GIS map indicating relative wave energy for the entire NRE shoreline.	November 2008
	Prepare a report to identify site-specific factors influencing erosion in vulnerable areas of the NRE.	June 2010
	Oversee evaluation of the effectiveness of MCBCL shoreline-stabilization efforts.	June 2011
CW-3	Prepare report on the overall contribution of the marsh to mediation of NRE water quality via regulation of water fluxes, nutrient fluxes, and nutrient transformations.	June 2011
CB-1	Develop model for forecasting beach erosion and overwash during storm events.	June 2011
	Prepare a report summarizing the key forces driving beach erosion during storm events and over the short term, and land uses, including Base activities versus natural processes affecting beach changes.	June 2011
CB-2	Develop maps of the Onslow Beach area that show its evolution at three different time scales, including: 6 ka to 1930 AD (geological), 1930 AD to 2003 AD (historical), and 2007 AD to 2011 AD (current monitoring) and by correlating the location, magnitude, and timing of natural (storms) and anthropogenic (Base activities) stressors with these maps.	June 2011
	Identify the principle stressors affecting coastal erosion.	June 2010
	Quantify erosion-rate trends (acceleration or deceleration in coastal retreat rates).	June 2011
	Identify erosional "hot spots" and their spatial variability through time.	June 2011

* Contingent upon availability of high quality LIDAR multispectral data.

Research Project	Outcome	Completion Date
CB-3	Develop efficient monitoring protocols and conservation management plan for selected indicator shorebirds and seabirds and recommend key features for a mitigation plan in the event of beach nourishment or introduction of new uses to the coastal barrier system.	June 2010
	Develop a simple toolbox of avian indicators (such as avian reproductive success, survival, or abundance by species, habitat, and/or season) that can be more efficiently monitored than weekly surveys and can be effective for present and future ESA consultation events.	June 2010
	Develop indicator for efficacy of predator control procedures and other management practices, using annual and seasonal variation in relative predator abundances.	June 2010
T-1	Develop species indicators (including alien species) of environment, fire regime, and forest management so that the Base can understand consequences of variations in burn regimes and activities on plant abundance and diversity and optimize military activities with respect to location and timing.	June 2011
	Develop indicators of habitat quality for RCW and other species, which will include a mechanistic understanding of the connection between fire, management, and the RCW by providing information on trophic connections.	June 2011
	Develop fuel indices on the effects of variations in site conditions and prescribed fire regimes on fuels and fire risk, which will be valuable to MCBCL's fire management program.	June 2011
T-2	Develop method to measure quality of RCW habitat over a large spatial extent. Determine effects of management for the endangered RCW on another species at risk, such as the Bachman's sparrow.	June 2011
	Identify bird species whose presence and/or abundance can serve as indicators of avian communities associated with high-quality pine habitat, and thus, as indicators of restoration success. Different species may serve as indicators for different community types along the soil-moisture gradients characterizing the terrestrial zone.	December 2009
Air-1	Develop Modified Prioritization Model that is linked to fuel parameters, season, fuel load maximum and minimum, and moisture content. This can be used to help MCBCL determine when to initiate prescribed burns.	June 2011
	Provide temporally and spatially resolved PB emission factors for broad spectrum of gaseous and particulate species, distinguishing ecosystem specific vegetation classes for benefit of emissions inventory reporting and sub-regional SMP development.	June 2010
	Develop MCBCL air quality climatology from baseline monitoring data and evaluate in context of sub-regional conditions and trends.	June 2009
Air-2	Provide information on the amount and composition of atmospheric deposition (especially for N) to the terrestrial and aquatic ecosystems that will be used to model the atmospheric N contribution to the N budget for the NRE.	June 2011
	Assess the equilibrium status between NH_3 and inorganic fraction of $PM_{2.5}$ (NH_3-based aerosols).	July 2010
	Assess the equilibrium status between NO_x and inorganic fraction of $PM_{2.5}$ (NH_3-based aerosols).	July 2010

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Appendix A

Introduction to Military Operations
Marine Corps Base Camp Lejeune

Background

Marine Corps Base Camp Lejeune (MCBCL) is the U. S. Marine Corps' (USMC's) largest amphibious training base and is home to 47,000 Marines and Sailors (U.S. Navy personnel)— the largest single concentration of Marines in the world. MCBCL encompasses approximately 159,000 acres, including the onshore, nearshore, and surf areas in and adjacent to the Atlantic Ocean and the New River. The installation includes the following:

- 11 nautical miles (nm) of ocean coastline, including 1.4 nm of amphibious landing beach, 1.6 nm of recreational beach, and 4 nm of buffer/impact-area beach
- 246 square miles (mi^2) of land area, with more than 101,000 acres of usable training area
- 74 live fire ranges and training facilities
- A Military Operations in Urban Terrain (MOUT) Facility with 31 buildings; an Urban Training Facility with 70 buildings; and a Combat Town with 14 buildings
- Shallow ocean areas (less than 100 fathoms) and the New River
- 200 mi^2 of Special Use Airspace, restricted for military use from sea level to 17,999 feet
- 3 impact areas that support munitions from 5.56 mm to 155 mm, delivered by direct fire, indirect fire, Fixed Wing and Rotary Wing aircraft, and Naval Gunfire
- 48 Tactical Landing Zones; 12 Ground and 5 Water Drop Zones; 34 Gun Positions; 8 Mortar Positions; and 12 Observation Posts
- A landing helicopter assault (LHA) deck for helicopter pilot training and an air field seizure facility with a mock airport and two runways.

To train and maintain combat-ready troops for expeditionary deployment, MCBCL must provide a variety of environmental conditions and ecosystems in which to train Marines. This objective must be met in a way that provides for sustainable, healthy ecosystems; complies with all applicable environmental laws and regulations; and provides for no net loss in the capability of military installation lands to support the military mission of the installation.

MCBCL Military Mission and Operations

The USMC mission is national defense, and the mission of MCBCL is to train and maintain combat-ready units for expeditionary deployment anywhere in the world. The MCBCL's tenants include the 2nd Marine Division, 2nd Marine Logistics Group, II Marine Expeditionary Force, United States Coast Guard (USCG), and U.S. Naval Hospital Camp Lejeune.

To accomplish the national security mission, Marines, Sailors, and USCG personnel must be trained in all requirements for responding to national security threats. Training activities include, but are not limited to, amphibious/expeditionary operations, employment of combined arms, use of tracked vehicles, infantry and vehicle maneuvers, artillery and small-arms firing, aerial weapons delivery, engineer-support operations, logistics support, field combat service support, communications, airlift support for troops and weapons, equipment maintenance and field medical treatment, and harbor/port security. MCBCL units train with some of the most modern and sophisticated weapon systems and equipment available to the U.S. military. This technology is constantly evolving and oftentimes requires large land areas for training.

MCBCL provides support and services that enhance the operational readiness and the quality of life of the operating forces and MCBCL community. MCBCL provides deployment support to warfighting commands, such as the 22nd, 24th, and 26th Marine Expeditionary Units; the 2nd Marine Expeditionary Brigade; the II Marine Expeditionary Force; and the USMC Forces Special Operations Command. MCBCL is also responsible for providing resident formal school training to approximately 39,000 Marines annually through the Marines of School of Infantry East, Sniper School, Marine Corps Combat

Service Support Schools, Marine Corps Engineer School, Field Medical Support School, and the USCG Special Mission Training Center.

Training Environments

MCBCL has more than 101,000 acres and 97 training areas subdivided into the following:

- Training maneuver areas (located near cantonment areas) that are used for ground training, including bivouacking and foot travel
- Tactical maneuver areas that support both mechanized and ground training
- Special training areas, including Combat Town and MOUT facilities
- Amphibious training.

The following sections provide a description of some of the assets at MCBCL.

Training Maneuver Areas

MCBCL has 82 designated training maneuver areas in and around the live fire ranges and impact areas. Each training area is designated alphabetically from “BC” to “SW.” Seventy-seven of the 82 training areas are designated as tactical maneuver areas, and 4 areas are designated for amphibious exercise support and beach training.

Impact Areas

There are three main impact areas in MCBCL: G-10, K-2, and BT-3/N-1. Impact areas are dudded areas, i.e., places where high explosives are used and if they do not explode on impact, they do not dud (things that should, but do not, explode). Unexploded ordnance is present in impact areas, and access is strictly controlled.

G-10 Impact Area and Ranges

G-10, located east of the New River, supports air-to-ground operations, helicopter gunnery exercises, mortar fires, field artillery indirect fires, infantry weapons, and infantry rocket and missile live-fire evolutions. Laser designators can be used within the G-10 Impact Area. Seven ranges encircle the G-10 Impact Area: G-3, G-3A, G-5, G-6 Company Battle Course, G-8, and G-9. Each range can support multiple direct- and indirect-fire weapon systems.

K-2 Impact Area and Ranges

K-2, located on the western banks of the New River, supports infantry weapons training, mortar fires, field artillery indirect fires, and infantry rocket training. The K-2 Impact Area has 23 live-fire ranges oriented around its perimeter. Each range can support multiple direct- and indirect-fire weapon systems. These ranges are oriented to support infantry weapon systems and infantry tactics.

BT-3/N-1 Impact Area

BT-3/N-1 is located on the southeast corner of MCBCL, with a 168-degree direction of fire (seaward). This impact area is a live-fire range that can support air-to-ground weapons, ground-to-air Stinger and Avenger fires, field artillery direct fires, riverine training, helicopter gunnery exercises, and machine gun familiarization training. The H Range (the Riverine Assault and Waterborne Gunnery Range) is located within the boundaries of BT-3/N-1.

Engineer Training Areas (ETAs)

There are eight ETAs on MCBCL, with the primary function to provide operational engineering units and the Marine Corps Engineer School with facilities to conduct engineer demolition training. Alternative uses of the ETAs are as an infiltration course at ETA- 1; as a mechanized assault course and breaching operations range at ETA-2; for execution of live-fire breaching exercises at ETA-4; and as a close-quarters battle area and MOUT breaching house at ETA-5A. ETA-6 is not a live-fire ETA and has been converted to a Combat Vehicle Operators Training Confidence Course.

Military Operations in Urban Terrain (MOUT) Facility and MOUT Assault Courses (MACs)

The MOUT Facility is a 31-building facility focused on training for combat in urban areas. The new Urban Training Facility, located nearby, has 69 buildings (including 5 live-fire houses). The Urban Training Facility is laid out to resemble a Middle Eastern village and includes a market area, tunnels, walls, and courtyards, with a firm base and Vehicle Check Point nearby.

Greater Sandy Run Area (GSRA) Ranges.

The Greater Sandy Run Area (GSRA) ranges are located on the western side of MCBCL. These ranges primarily support tank, Light Armored Vehicle (LAV), Amphibious Assault Vehicle (AAV), and Infantry platoon training.

Stone Bay Ranges

Stone Bay has three 50-target known distance rifle ranges, two pistol ranges, and a 1,000-yard sniper range. The Weapons Training Battalion maintains and operates these pistol and rifle ranges for annual marksmanship qualification training and familiarization firing. There are 8 additional ranges at Stone Bay or within the Special Operations Training Ground compound, including Dodge City; 1-story and 3-story shoot houses; breacher facilities; climbing walls/towers; and a multipurpose range.

Live-Fire Ranges

When shooting explosive materials, all firing is done into impact areas; however, when shooting into live-fire ranges, inert munitions (i.e., all explosive material has been removed) are utilized.

Observation Posts (OPs)

There are 12 Observation Posts (OPs) at MCBCL. These OPs are used for observation of live-fire and laser operations at each of the impact areas, amphibious operations on the beach area, and live-fire and maneuver events at the GSRA and on ranges L-5 and F-5.

Helicopter Landing Zones (HLZ)

MCBCL has two types of HLZs: Tactical Landing Zones (TLZs) and Administrative Landing Zones (ALZs). There are 48 TLZs within MCBCL’s boundaries (named after birds) and 24 numerically identified ALZs. The TLZs are scheduled for heliborne operations, rappelling, fast rope, and Special Purpose Insertion Extraction rig training.

Drop Zones (DZ)

Drop Zones (DZs) are TLZs designated for parachute operations. MCBCL has 12 DZs and 5 additional Water Drop Zones (WDZs).

Gun Positions (GPs)

There are 34 Gun Positions (GPs) used for artillery training, and the majority of GPs on MCBCL double as LZs.

Onslow Beach

MCBCL also maintains 11 nm of Onslow Beach to support amphibious operations. Operations at the beach range from daily exercises by the 2nd Amphibious Assault Battalion and Joint Armed Services training to periodic, large-scale training, such as the quarterly Capability Exercises that include explosives on the beach, inland artillery fire, and 3 Landing Craft Air Cushion (LCAC) and 10 to 12 AAV landings.

New River

The USMC has a mission requirement to conduct combat and combat-support operations in shallow-water and riverine environments. Training on the New River includes activities by two USMC commands and one USCG unit. 2nd MARDIV supports II MEF with 17 Riverine Assault Craft (RAC), 65 Rigid Raider Craft (RRC), and 100 Combat Rubber Raider Craft (CRRC). These boats include jet and propeller-driven boats designed for high-speed military operations in shallow-water and riverine environments.

Day and night training exercises include insertion and extraction of personnel, re-supply and refuel between vessels, waterborne refueling, formation traveling, and live-fire of medium and heavy machine guns. Current exercises occur at a rate of approximately 635 per year and are expected to increase to 830 per year.

The 8th Engineer Support Battalion uses boats to transport and build floating bridges and has 21 Bridge Erection Boats (BEB) in their inventory. BEBs are 27 feet long and are driven by twin hydro-jet propulsion units powered by two diesel engines. These boats have traditionally been used to transport and build expeditionary-type bridging and to ferry equipment across areas too wide to bridge. The recent acquisition of GSRA has also required an increase in military training traffic on the New River. Seventy-ton M1A1 tanks belonging to the 2nd Tank Battalion are now ferried across the river to reach training areas and firing ranges in GSRA.

Types/Groups of Military Training Operations

All Marines on MCBCL can be divided into four major groups: (1) logistics, (2) command, (3) aviation, and (4) ground combat units.

Logistics and Command Troops

Logistics and command troops are generally restricted to well-established, cleared, disturbed areas, such as TLZs, DZs, and GPs. There are 48 TLZs within MCBCL’s boundaries: 12 DZs, and 34 GPs.

Aviation Troops

Aviation troops are obviously restricted in usage

Ground Combat Units

There are 7 types of ground combat units: reconnaissance (recon), combat engineers, and Infantry; Light Armored Vehicles; artillery; tanks; and Amphibious Vehicles. The use of the land by ground combat units can be viewed from the perspective of duration and footprint (i.e., how much time a unit spends on the ground and to what level does a unit’s activity impact the MCBCL ecosystem). Usually, the longer the duration of time units spend on the ground will result in more intense and/or a greater impact on the ecosystem.

Reconnaissance, Combat Engineers, and Infantry

Recon, combat engineer, and Infantry units travel off-road on foot. Occasionally, these units will be accompanied by support/safety vehicles, but the movement of these vehicles is highly regulated (i.e., slow, deliberate movement, can't hit trees or remove vegetation).

Units can be broken into groups of various sizes. Recon engineers usually train as a small-fire team (i.e., group of 4+ troops) or as a squad (i.e., group of <13 troops); combat engineers usually train as a platoon (i.e., group of 41+ troops); and Infantry engineers usually train as a company (i.e., group of 167+ troops), but often will break up into platoons. Occasionally, these three types groups train as part of a complete battalion (i.e., 800 troops)

Fire teams, squads, and platoons can travel on foot over MCBCL training areas that are far from roads. Company- and battalion-sized units go off-road and train in the woods, but these groups tend to stay out of swamps and heavily vegetated areas without first breaking into smaller units. The deeper Marines get into the woods and the smaller the unit size, the less stationary the training activity conducted (i.e., Marines keep moving and do not set up semi-permanent camps). When combat engineers move into the woods, they behave like an Infantry unit, but when they have their heavy equipment with them, they behave more like artillery or tanks, limiting movement to roads, trails, and existing open areas.

Light Armored Vehicles (LAV)

An LAV is an all-terrain, all-weather, 8-wheeled vehicle with night capabilities that provides strategic mobility to reach and engage the threat; tactical mobility for effective use of fire power to defeat soft and armored targets; and battlefield survivability to conduct combat missions. The LAV is fully amphibious, with a maximum of 3 minutes preparation. LAV units travel in groups of a minimum of 4 vehicles. When not participating in amphibious operations (Figure 1), LAVs are restricted to tank trails, road, and open areas (similar to LZs).

Figure 1. LAV participating in an amphibious military task (i.e., crossing a stream).

Artillery and Tanks

Artillery and tanks tend to have long duration activities and big footprints, but are restricted to roads, tank trails, and existing open areas, and fire berms in established areas.

In theory, all vehicle (tracked and wheeled) traffic occurs in landing zones, on tank trails or roads, and on the beach. Occasionally, a High Mobility Multipurpose Wheeled Vehicle (HMMWV or Humvee) or LAV is driven in an open area; however, because off-road traffic in open areas is not authorized, this is an unusual occurrence.

Amphibious Units

An amphibious operation is a military operation launched from the sea and embarked upon using ships or craft by an amphibious force, with the primary purpose of introducing a landing force ashore to accomplish the assigned mission. Types of amphibious operations include assaults, withdrawals, demonstrations, and raids in a permissive, uncertain, or hostile environment. There are five types of AVs that train at MCBCL:

Landing Craft Air Cushion. LCACs transport the weapons systems, equipment, cargo, and personnel of the assault elements of the USMC Air/Ground Task Force, both from ship to shore and across the beach. An LCAC is a high-speed, fully amphibious landing craft that can cover an entire area of beach and is capable of carrying a payload of 60–75 tons (Figure 2).

Figure 2. Landing Craft, Air Cushion (LCAC) coming ashore.

Amphibious Assault Vehicle. The AAV is an armored assault, amphibious, tracked landing vehicle (Figure 3) that can carry troops in amphibious operations from ship to shore, through rough water and the surf zone. The engine compartment of the AAV can be completely water-sealed, making the vehicle seaworthy. Once on shore, an AAV can also carry troops to inland objectives. The AAV provides protected transport of up to 25 combat-loaded Marines through all types of terrain.

Figure 3. Amphibious assault vehicle (AAV) coming ashore.

Landing Craft Utility. The Landing Craft Utility (LCU) vehicle is designed to land/retrieve personnel and equipment (e.g., tanks, artillery, equipment, motor vehicles) after the initial assault waves of an amphibious operation. The LCU has the capability of sustained sea operations for approximately seven days (Figure 4).

Figure 4. Landing Craft Utility (LCU) vehicle transporting equipment.

Expeditionary Fighting Vehicle (EFV). The EFV is an amphibious vehicle that will replace the AAV and that provides the capability to maneuver combat at 20–25 knots in the water while loaded with a Marine rifle squad, as well as to maneuver cross country with agility and mobility equal or greater than that of the M1 Main Battle Tank. The EFV is a capable all-around weapon and, with water speeds of 23 to 29 miles per hour, can be launched from amphibious ships 25 miles or more offshore to reach the shore far more quickly than the current vehicle (Figure 5). The improved mobility of the EFV reduces the risk to U.S. Navy ships from missiles, aircraft, boats, and mines. On land, the EFV can achieve speeds of 45 miles an hour, with cross-country mobility equal to a M1 Abrams tank.

Figure 5. Expeditionary Fighting Vehicle (EFV) in swim mode.

Splash points are used by AVs to enter and exit water environments. Some splash points have been paved to reduce erosion (Figure 6), whereas others have been improved (Figure 7). Accessed from Onslow Beach and the New River, splash points are used by all AVs types (e.g., LCAC, AAV, EFV, LAV) except the LCU, which never leaves the beach for other destinations on Base.

Figure 6. Improved splash point.

Figure 7. Unimproved splash point.

The AAV, EFV, LAV, and LCAC all use the splash points that are along the beach and across the Intracoastal Waterway. The AAV, EFV, and LAV also use eight splash points between LZ Oriole and French Creek to travel across the New River to nine other splash points on the western side of the New River. These vehicles access the splash points by overland routes of tank trails. The LCAC is the only AV that also utilizes marsh areas. LCACs enter the New River inlet (from the ocean) and travel between two tidal creeks, covering a span of approximately 300m between these two entry points. LCACs exit the marsh at one point and then enter Mile Hammock Bay via the water, traveling a distance across the marsh of roughly 1000 meters. There are approximately 6 amphibious training events per year, and a training event can be up to 30 runs.

Natural Resources Management on MCBCL

The mission of MCBCL is to provide military training that promotes the combat readiness of operating forces. MCBCL, like all military installations, has needs or drivers that must be satisfied for the installation's readiness mission to continue without significant disruption. Additionally, legal or regulatory drivers, such as the federal Endangered Species Act (ESA) and Clean Water Act (CWA), must be complied with to ensure continuance of the military mission. Unique to MCBCL are installation-specific drivers that are defined by the Base's mission, land uses to support the mission, and the geographic location and natural resources affected by the mission.

All natural resources management activities on MCBCL support the military mission. Marines depend on sustainable natural resources to provide the proper environment for training and operations. Training restrictions implemented for threatened and endangered species living on MCBCL demonstrate the effect that declining natural resources can have on the military mission.

MCBCL is committed to environmental protection, continual environmental improvement, and pollution prevention. MCBCL's environmental policy is to protect current and future training mission capabilities by respecting and maintaining the natural environment. This policy includes the following components:

- Conserving the air, land, and water resources as vital USMC assets
- Protecting the environment to ensure current and future military readiness through sustained realistic training opportunities
- Maintaining and enhancing the biodiversity of the ecosystem through integrated natural resources management
- Reviewing all proposed activities for potential environmental impacts in accordance with National Environmental Policy Act
- Minimizing the impact on the environment through environmental quality assessment, education, pollution prevention, and use of geographic information systems (GIS) technology
- Complying with all federal environmental requirements and promoting community outreach activities
- Fostering cooperation with surrounding communities by publicizing MCBCL's environmental initiatives and supporting joint environmental protection programs.

As technology improves and science expands, new information is provided for natural resources management. The professionals at MCBCL respond to this information to ensure a natural resources management program that embraces the latest scientific data and continues to provide a sustainable environment in which Marines may train.

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Appendix B

Prioritized List of MCBCL's Conservation and Water Quality Needs

Conservation and Water Quality Needs	Module /Source	Approach for addressing MCBCL's Needs
High Priority Needs		
Primary Nursery Area (PNA) mitigation/delineation	Coastal Wetland	1. Research the determination of French Creek as a freshwater PNA. 2. Evaluate applicability of trading restoration credits. 3. Evaluate mitigation efforts that could lead to PNA boundary alterations.
Onslow Beach erosion	Coastal Barrier	1. Quantify long- and short-term shoreline change. 2. Identify erosion "hot spots" and their causes. 3. Predict shoreline changes based on various weather conditions and management scenarios.
Air quality/smoke management	Atmospheric and Other SERDP-funded project	1. Implement an ambient air monitoring program. 2. Identify ecosystem sensitivities, stressors, and contributors to nitrogen and carbon. 3. Transition information from two other SERDP-funded projects *Characterization of Emissions and Air Quality Modeling for Predicting the Impacts of Prescribed Burns at DoD Lands* (Talat Odman) and *Advanced Chemical Measurements of Smoke from DoD-Prescribed Burns* (Tim Johnson).
Measuring good quality habitat for red cockaded woodpeckers (RCW)	Other SERDP-funded project	Transition information from *A Decision support system for Identifying and ranking critical habitat parcels on and in the vicinity of DoD Installations* (SI-1472; Jeff Walters)
N1/BT3 monitoring for whales/ marine mammals	Other SERDP-funded project	Transition information from *Predictive Spatial Analysis of Marine Mammal Habitat* (CS-1390; Andy Read/Pat Halpin/Larry Crowder/David Hyrenbach)
RCW flexibility for Range Development - Regional RCW credit	Other SERDP-funded project	1. Transition information from *Trading Habitat Patches for the RCW: Incorporating the Role of Landscape Structure and Uncertainty in Decision Making* (SI-1469; Michael Jones). 2. Transition information from *Habitat Connectivity for Multiple Rare, Threatened and Endangered Species On and Around Military Installations* (SI-1471; Aaron Moody)
Stormwater runoff reduction and water quality studies	Aquatic/ Estuarine	1. Employ sampling and analytical techniques to monitor water quality and develop methods for reducing runoff
Near field water quality studies	Aquatic/ Estuarine	1. Sampling and analysis of areas in proximity to wastewater effluent diffuser to characterize water quality.
Distinguish/quantify effects of point & non-point inputs nutrient, sediment and pathogen inputs.	Aquatic/ Estuarine	1. Bioassays of in situ nutrient and other pollutant effects on planktonic and benthic microalgae 2. Determine cause of algal blooms (nutrient and climate driven events).

Conservation and Water Quality Needs	Module /Source	Approach for addressing MCBCL's Needs
Water quality/ primary nursery areas	Aquatic/ Estuarine	1. Employ sampling/analytical techniques used for estuary
Physical-chemical-biological interactions & their control on WQ/habitat	Aquatic/ Estuarine	1. Deploy in stream, real-time physical/chemical profiling/sensing and sampling capabilities. Couple to nutrient-productivity dynamics and modeling
Medium Priority Needs		
Wetland (marsh) restoration opportunities in New River Estuary	Coastal Wetland	1. Evaluate past remediation efforts (shoreline stabilization). 2. Evaluate aerial extent of marshes based on historic aerial photographs. 3. Conduct water quality sampling and modeling to determine the wetland areas at greatest risk and where mitigation may be needed.
Species at Risk - beach amaranth	Coastal Barrier	1. Evaluate MCBCL's existing monitoring data. 2. Research ability to propagate and transplant species (no approach currently identified).
Species at Risk - sea turtles	Coastal Barrier	1. Evaluate MCBCL's existing sea turtle monitoring protocol and data. 2. Conduct research on hatchling predation.
Species at Risk - shorebirds	Coastal Barrier	1. Evaluate MCBCL's existing monitoring data. 2. Research use of overwash area on the south end of Onslow Beach.
Species at Risk - RCW	Terrestrial	1. Research stress hormone as indicator of RCW habitat quality and impacts of military training activity on RCW. 2. Determine habitat potential of pond pine (no approach currently identified).
Fire effects on vegetation, and quantifying/qualifying prescribed burns	Terrestrial	1. Determine ecosystems sensitivities to prescribe burn frequency and season. 2. Determine areas of good quality habitat.
Species at Risk - rough-leaved loosestrife	Terrestrial	1. Evaluate MCBCL's existing rough-leaved loosestrife monitoring protocol and data (no approach currently identified).
Habitat restoration and tactical vehicle off-road impacts	Terrestrial	1. Determine impacts of compaction from off-road vehicles on wiregrass (no approach currently identified). 2. Determine which training areas can best tolerate off-road vehicle use (no approach currently identified).
Northern Pocosin in Great Sandy Run Area (GSRA)	Terrestrial	No approach currently identified.
RCW monitoring	Other SERDP-funded project	Transition information from *Demographic and Population Response of Red-cockaded Woodpeckers on MCBCL to a Basewide Management Plan* (Jeff Walters)

Conservation and Water Quality Needs	Module /Source	Approach for addressing MCBCL's Needs
Additional military effects/RCW study	Other SERDP-funded project	Transition information from *Assessment of Training Noise Impact on the RCW* (CS-1083; Larry Pate)
Longleaf /loblolly decline	Other SERDP-funded project	Transition information from *Regenerating Longleaf Pine on Hydric Soils: Short- and Long-Term Effects on Native Ground-Layer Vegetation* (CS-1303; Joan Walker) and *Managing Declining Pine Stands for the Restoration of RCW Habitat* (SI-1474; Joan Walker)
Benthic organism Index of Biological Integrity (IBI)	Aquatic/ Estuarine	1. Use meiofaunal taxa composition to develop benthic indicators
Benthic-water column exchange and hypoxia research	Other SERDP-funded research	Transition data from *An Integrated Approach to Understand Relationships between Shallow Water Benthic Community Structure and Ecosystem Function* (CS-1335; Linda Schaffner/Iris Anderson)
Blue crab studies	Other	Transfer data from Martin Posey's (UNC-W) MCBCL funded study
Determine nutrient, sediment and pathogens loadings from the watershed; determine transformations of nutrients within the estuary. Determine interactive role of climatic/hydrologic roles	Aquatic/ Estuarine	1. Identify sources and loadings of nutrients, sediments and pathogens 2. Examine new vs. internally-regenerated nutrient sources and inputs 3. Determine inputs, effects and fates of nutrients, sediments and pathogens under hydrologically variable conditions 4. Model sediment-water column inputs and exchange of nutrients, sediments and pathogens
Identify and quantify nutrients controlling primary production, excess production and algal blooms	Aquatic/ Estuarine	1. Identify and quantify limiting nutrients 2. Identify and quantify sources of limiting nutrients 3. Establish thresholds of nutrient limitation and algal bloom 4. Target tributaries and estuarine segments not currently sampled. 5. Dynamic model to predict estuarine responses to nutrient inputs.
Determine causes and effects of harmful algal blooms (HABs). Link nutrient-productivity to hypoxia potentials	Aquatic/ Estuarine	1. Deploy microalgal indicators to examine HAB potentials and thresholds in water column and sediments 2. Develop indicators of productivity and community structure and assess stressor specific responses (algal blooms, hypoxia, food web perturbations)
Low Priority Needs		
Coliform counts - Freemans Creek (and other 303(d) TMDL identified tributaries)	Aquatic/ Estuarine	Pathogen tracking/source identification: 1. Differentiate between pathogen sources. 2. Partition nitrogen sources.

Conservation and Water Quality Needs	Module /Source	Approach for addressing MCBCL's Needs
Invasive species: alligator weed, *Phragmites*	Coastal Wetland	1. Determine aerial extent of *Phragmites*. 2. Determine affects of alligator weed on flood control (no approach currently identified).
Habitat restoration and tactical vehicle off-road impacts - maritime forest	Coastal Barrier	1. Survey biodiversity of maritime forests.

Appendix C

Research Projects Assigned a Lower Priority during the First Four Implementation Years Based on Available Resources and Review by the RTI DCERP Team, SERDP, and the MCBCL Staff

Aquatic/Estuarine Module: Stressor-specific indicators of benthic community integrity.

Senior Researcher: Linda Schaffner (VIMS)
Supporting Researcher: Pete Peterson (UNC-IMS)

Hypothesis:

Differential responses of major macro- and meiobenthic invertebrate taxa to various stressors in the New River Estuary (NRE) environment will allow for relatively rapid, robust and ecologically meaningful identification of impairments in biotic integrity and estuarine habitat quality associated with local and regional activities.

Based on results presented in Diaz and Rosenberg (1995), Peterson (1996), Lenihan et al. (2003), Metcalfe (2005), Schaffner et al. (2006), Bilkovic et al. (2006) and articles cited therein, the following specific responses are expected for the major benthic taxa that we propose to use as ecological indicators for the NRE:

Annelids - positive response for organic enrichment; minimal response for sediment toxicity, hypoxia, shoreline disturbance; negative response for anoxia

Bivalves - positive response for organic enrichment; negative response for shoreline disturbance, high sediment toxicity, hypoxia, anoxia

Crustaceans (infaunal only) - negative response for high sediment toxicity, organic enrichment, shoreline disturbance, hypoxia, anoxia

Nematodes - positive response for organic enrichment; minimal response for hypoxia, physical disturbance; negative response for high sediment toxicity, anoxia

Copepods (interstitial only) – minimal response for physical disturbance; negative response for high sediment toxicity, organic enrichment, hypoxia, anoxia

Foraminiferans – minimal response for physical disturbance; negative response for sediment toxicity, organic enrichment, hypoxia, anoxia

At the community level we predict the following relationships:

Abundance – moderate stimulation of abundance with disturbance due to physical processes or organic enrichment; reduced abundance associated with hypoxia, anoxia and sediment toxicity

Biomass - moderate stimulation of biomass with organic enrichment; reduced biomass associated with physical disturbance, hypoxia, anoxia and sediment toxicity

Species diversity – highest species diversity at intermediate disturbance for all stressors

Technical Goals: Develop rapid, quantifiable benthic community indicators of ecosystem integrity, related to organic enrichment, hypoxia/anoxia, physical disturbance and sediment toxicity using ecologically relevant benthic invertebrate communities. Develop methods to identify local and regional stressor-specific effects within the NRE environment and in the context of natural processes and variability. Develop methods to index the trophic support value of primary nursery areas within the NRE environment. Facilitate adaptive management of the NRE and help set goals for restoration activities or sustainability. Test, verify and refine the indices currently used to conduct long-term benthic monitoring. Provide new methods that serve to reduce the future costs of monitoring while increasing sensitivity.

Technical Approach:

(a) Background: A key issue for management and restoration of estuarine and coastal systems such as the NRE is identifying stressor-specific effects on ecosystem health and the potential for stressor interactions. Among the most widely used biotic indicators of integrity for estuarine and coastal ecosystems are those based on benthic invertebrate communities (e.g., the Benthic Index of Biotic Integrity, or B-IBI; Weisburg et al., 1997, Diaz et al., 2004). Benthic macrofauna are excellent indicators of aquatic ecosystem status and trends because they: (1) respond to local as well as regional environmental impacts; (2) exhibit sensitivity to diverse stressors; (3) respond quickly to disturbances, i.e. over days to months; (4) are important food web components supporting higher trophic levels (Diaz and Schaffner, 1990); (5) significantly affect transport and cycling of nutrients and toxicants through feeding and bioturbation activities (Mayer et al., 1995; Schaffner et al., 1997; Jordan and Smith, 2005); and (6) monitoring benthic macrofauna provides a cost effective *in situ* measure of biotic integrity/habitat quality (Weisberg et al., 1997, Diaz et al., 2004). This assemblage often has the strongest supporting database within and across systems, which facilitates data interpretation and cross-system comparisons. We will also study meiofauna because they show stressor-specific effects, are functionally important and are key components of estuarine food webs, which support the juveniles of numerous fish species (Metcalfe, 2005).

The B-IBI and other related approaches (see Diaz et al., 2004) are based on a general conceptual model of soft-sediment benthic community responses to disturbance (e.g., Pearson and Rosenberg, 1978). Recent studies provide both experimental and observational field evidence that macro- and meiobenthic invertebrate communities

exhibit stressor-specific disturbance responses that can help to guide the development of effective management and restoration goals (Peterson, 1996, Lenihan et al., 2003, Metcalfe, 2003, Schaffner et al., 2006). We propose that differential responses of macro- and meiobenthic invertebrate assemblages to specific stressors in the NRE will allow for relatively rapid, robust and ecologically meaningful identification of the effects of local versus regional impairments in water quality. We will test specific predictions along the estuarine salinity gradient.
(b) Methods: Field surveys will be combined with a manipulative field experiment to identify the effects of multiple stressors and their interactions operating on a suite of biotic indicators at regional and local scales within the NRE. Macrofauna and meiofauna community composition (major phyla, B-IBI metrics such as diversity, abundance, % pollution tolerant species) will be examined for major disturbance types (organic enrichment, hypoxia/anoxia, physical disturbance and sediment toxicity) and along the estuarine gradient using a field-based sampling survey. In addition, we intend to include metrics that will help us to assess the ability of the NRE benthic ecosystem to support higher trophic levels (e.g., clam biomass; clams are the major diet component of blue crabs). We will use designated primary nursery areas and other relatively unimpacted habitat areas as reference (healthy) end-member sampling sites. We will also collect basic environmental data (depth, salinity, temperature, dissolved oxygen, and sediment parameters (grain size, TOC, TN, chla) at each station sampled for biota. Field-sampling conducted during the summer index period of Project Year 2 will provide the samples needed to compute the B-IBI and other indicators of interest (major taxa composition, trophic-support metrics). Station selection within the NRE will be based on results of preliminary benthic invertebrate sampling done as part of the first year of this monitoring program and discussions with base personnel and other project investigators. Our approach will be to select stations for based on disturbance regimes (stressor type and intensity). A small subset of stations will be sampled monthly, except during winter (July, Aug, Sept, Oct, Nov, Jan, March, April, May, June, July, Aug, Sept, Oct, Nov) beginning in July of the second year and continuing through November of the third year. This monthly sampling will allow us to capture stressor effects on annual secondary production and temporal changes in food web structure that are important to juvenile fish. Sampling a subset of stations during two years also allows us to get some insight regarding interannual variation in benthic integrity, as measured by the B-IBI. The potential for interacting effects of stressors on macrofauna and meiofauna indicators will be further examined in manipulative experiments conducted during Project Year 3. Effects of sediment toxicity will be assessed by using field-collected toxic sediment from the NRE, or if suitable sediment cannot be obtained within the estuary, by spiking sediment with individual toxicants, in order to obtain varying levels of toxicity. Defaunated sediment from a relatively pristine site will be organically enriched by adding phytoplankton detritus in order to obtain varying levels of organic enrichment. Replicate plots of sediment for each treatment type will be created within major salinity, turbidity and hypoxia regimes. The sites will be located near stations used for long-tem monitoring by other projects, with consideration of major fisheries activities (e.g., shrimp trawling). Experiments will be established prior to the late winter recruitment of the annual fauna and a subset will be protected from predators using exclusion cages. Subsets of plots will be sampled at intervals spring through fall to assess patterns of community composition over time for major phyla as well as traditional B-IBI metrics. Data will be analyzed following the approaches outlined in Weisberg et al. (1997), Lenihan et al. (2003) and Schaffner et al. (2006).
(c) Data Analysis: Our basic approach to data analysis will be to test the hypotheses above, using both parametric (ANOVA, regression) and multivariate methods to elucidate relationships among stressor types and macro- and meiofauna based metrics (Schaffner et al., 2006). In order to resolve relationships between B-IBI and other parameters, we will perform multivariate data analyses using non-metric multi-dimensional scaling ordination (MDS) or principal components analysis (PCA) using the PRIMER package (Clarke and Warwick, 2001). Finally, we will develop regression models as appropriate based on the results of MDS.
(d) Environmental Indicators: This project will allow us to test, verify and refine the B-IBIs currently used to assess benthic integrity in the North Carolina region. We also intend to compare the performance of major taxon level indicators relative to the B-IBI approach, with the intent of providing a faster, more cost-effective means of measuring benthic integrity. Finally, we plan to develop a set of indicators that will be used to evaluate benthic habitat value in trophic support of nekton.
(e) Linkages to other Modules: The proposed investigations provide information needed for the modeling components of research projects AE-1 and AE-3
(f) Military Drivers: Drivers #1-6 of Base needs. Develop stressor-specific management and restoration goals. Supporting military operations while maximizing sustainability of NRE ecosystem.
(g) Benefits to MCBCL: Provide MCBCL with an assessment of how specific stressors affect the biotic integrity of benthic habitats within the NRE. Provide a baseline against which to gauge short and long-term affects of management strategies. Protect the ecological integrity of the NRE while supporting the necessary base activities. Aid in the development of goals for restoration or sustainability, which will facilitate adaptive management. At the

end of the four years of monitoring and research, a report and technical guidance document, as well as peer-reviewed publications will be prepared that address the utility and long-term application of our findings for assessing ecosystem integrity, habitat condition, and the relative importance of multiple stressors..

(h) Schedule:

- 1st Year. Establish stations for field-based comparisons and monthly sampling. Conduct summer field program (begin/end: July/Aug). Conduct monthly sampling program (begin/end July/Nov). Begin processing samples (Sept.)
- 2nd Year. Conduct summer field program at a subset of stations sampled in 2nd year (begin/end: July/Aug). Conduct monthly sampling program (begin/end Mar/Nov). Process samples from field survey and associated environmental parameters, analyze data, calculate secondary production and metrics. (begin Jan). Conduct and process samples from field experiments (begin Apr).
- 3rd Year. Process samples from field survey and associated environmental parameters, analyze data, calculate secondary production and metrics; process samples from field experiments. (end Dec). Analyze all data; compare B-IBI, other macrofauna metrics and meiofauna metrics relative to available data on water and sediment quality, land use, fisheries and base activities (begin/end Jan/Dec).
- 4th Year. Prepare reports and technical guidance (begin/end Jan/Jun)

Scheduling Constraints:

Must have regular access to sites within the installation, and generally within ± 1 week of intended sampling date.

Budget (Estimated):

- 1st Year: $39,000
- 2nd Year: $171,000
- 3rd Year: $182,000
- 4th Year: $ 19,000

Total: $411,000

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Coastal Barrier Module: Meso-Predator Foraging Ecology, Habitat Use, and Movements at Camp Lejeune and Their Impacts on Coastal Barrier Island Fauna.

Senior Researcher: Sarah Karpanty (VT)
Supporting Researchers: Jim Fraser (VT) and Pete Peterson (UNC-IMS)
Staff:1 graduate student and 3 technicians

Hypotheses:

H1: Predator abundance, diversity, and distribution do not vary across beach management practices.

H2: Foraging ecology of natural and feral predators on barrier island avian and sea turtle species is incidental, confined only to times of food scarcity on the mainland.

H3: Terrestrial predator foraging, habitat use, and colonization of MCBCL barrier islands are not influenced by human uses of the barrier island.

H4: Terrestrial predators do not prefer wild food items in comparison to human trash and debris.

H5: Trapping frequency based on identified colonization rates of natural and feral terrestrial predators on the barrier islands of MCBCL is not an effective means of controlling negative impacts on nesting birds and sea turtles.

H6: The probability of natural or feral predator colonization is not explained by a logistic regression of season, animal age, habitat availability, prey availability, or abiotic factors such as weather.

H7: Natural and feral predators on the barrier islands at MCBCL are not significantly decreasing survival of nesting and hatchling birds and sea turtles.

Technical Objectives/Goals: To understand those elements of predator ecology on barrier islands needed to enhance shorebird and turtle conservation and most efficiently control predators as needed.

Technical Approach

(a) Background:

The Department of Defense recently signed a Memorandum of Understanding with the U.S. Fish and Wildlife Service to improve conservation of migratory birds (71 FR 51580-51585). Moreover, under the Endangered Species Act, MCBCL, like other federal installations, is required to use its authorities for the conservation of threatened and endangered species such as the piping plover, and loggerhead and green turtles. A principal cause of the loss of nests and young of these species is predation by meso-predators, such as foxes and feral cats. The importance of predation on reproductive success of shorebirds and turtles at Camp Lejeune will be quantified in research projects 3 and 8, described in this larger proposal. To date, the management approach on MCBCL, as in many other places, has largely consisted of trapping predators. However, predator trapping is controversial. A more detailed understanding of the ecology of these predator species on barrier islands might allow for an alternative approach to reducing their effects on nesting shorebirds and turtles. An increased understanding of meso-predator diet, ranging ecology, and migration patterns from the mainland and between barrier islands would permit the most efficient use of trapping resources and lead to a methodology that would minimize the frequency of trapping and the co-occurrence of trapping efforts with human uses of the barrier islands.

(b) Methods:

We will capture meso-predators (e.g feral cats, raccoons, foxes) using the barrier islands within MCBCL, fit them with radio transmitters, and tag them with individually-identified markers, year-round. We will radio-track them during day and night to determine habitat use, ranging ecology, and foraging strategies. Tracking will be year-round, but may be most intense during the shorebird and sea turtle nesting period. We will determine food habitats by sampling scats and by direct observation of tagged individuals if possible. We will set up cameras in barrier island habitats to determine the species of meso-predators that use the islands, their densities, and rates at which islands are re-colonized after trapping efforts. If it is determined in Research Project CB-3 that guano deposition by nesting birds is an important source of nutrients in this coastal barrier system, we will monitor how rates of deposition differ in areas with differing predator densities by monitoring bird numbers in areas with differing predator densities.

(c) Data Analysis:

We will estimate population size, density, turnover rates, and colonization rates using standard mark-recapture techniques and Program MARK. We will calculate predator home range sizes using kernel home range estimators and habitat preference using standard use-availability analyses. We will relate movement patterns to measured abiotic and biotic factors. We will analyze diets to quantify the proportion of shorebirds and sea turtles that are taken by season and year, and we will relate this data to Research Project CB-3 to quantify the impact of these predators on the population dynamics of shorebirds and sea turtles at MCBCL.

(d) Environmental Indicators, Tools and other Outcomes:

Annual and seasonal variation in predator abundances and colonization rates may be indicators for the efficacy of predator control procedures and other management practices. Predator diet can be used as an indicator of prey availability and the integrity of the coastal barrier ecosystem.

(e) Linkages to other Modules:

This work should be concurrent with research cb-3 and cb-6 so that the impacts of predators on shorebirds, seabirds, and sea turtles can be quantified and understood in the context of other limiting factors, such as benthic prey availability for these vertebrates. These concurrent projects will allow us to understand the relative influences of top-down and bottom-up processes on shorebirds and seabirds in this coastal barrier system. It also links to the terrestrial module as predator colonization rates of the barrier islands will likely be strongly influenced by terrestrial source populations.

(f) Military Drivers: 4. Ensure Camp Lejeune supports all required military training activities while complying with the Endangered Species Act and other wildlife requirements.

(g) Benefit to MCBCL:

Results from this study will be used to design the most efficient use of trapping resources and lead to a methodology that would minimize the frequency of trapping and the co-occurrence of trapping efforts with human uses of the barrier islands. Results may open the door to non-lethal predator control tactics. It also will quantify predator impacts on shorebirds and seabirds and allow best design of other management for these species that does not involve predator control.

(h) Schedule:

Year-round, Management uses of data will be maximized if coincident with the shorebird and turtle research projects.

Scheduling Constraints:

Data collection should fully commence by December, of the first year so that a winter trapping and marking season can be conducted before the first shorebird-seabird nesting season starts in March, of the first year. For this to take place, graduate student must start in August, of the first year. 2-years consecutive data needed.

Budget (Estimated):

Note: Cost estimates are estimated as if each monitoring or research project was stand-alone. Significant cost-savings possible if projects done simultaneously, in some cases two projects (e.g.,shorebird research and monitoring) can be done nearly for the price of one. In the budget spreadsheet, it is noted where saving may be achieved in final negotiations. In final negotiations, we will work with coastal barrier partners to share resources wherever possible.

- 1st Year: $ 213,000

- 2nd Year: $ 184,000
- 3rd Year: $ 184,000
- 4th Year: $ 105,000

Total: $ 686,000

References: None identified.

Coastal Barrier Module: Turtle Management Ecology: Factors Driving the Nest Site Selection of Adult Turtles and the Survival of Hatchlings during Movement to the Water.

Senior Researcher: Sarah Karpanty (VT)
Supporting Researcher: Jim Fraser (VT)
Staff: 1 graduate student and 1 technician

Hypotheses:

H1: There is no significant impact of natural and feral predators on the survival of hatchling sea turtles at MCBCL, turtles are effectively managed so the impact of top-down processes is negligible on their population dynamics.

H2: There are no significant differences in sites selected and not-selected by sea turtles at MCBCL that can be manipulated, managed, or identified for more successful relocation of nests.

Technical Objectives/Goals:
To determine the habitat features selected by turtles at Camp Lejeune to facilitate planning for beach renourishment as well as nest relocation protocols. To quantify survival of nestlings during movement to the water and the variables influencing survival rates.

Technical Approach

(a) Background:
Loggerhead, and occasionally Green, Turtles nest on the barrier island beaches of Camp Lejeune. Given these turtles' status as federally listed species, Camp Lejeune has a federal responsibility to conduct turtle conservation programs. Under a Biological Opinion of the USFWS, MCBCL is permitted to move turtle nests laid in the amphibious assault training zone. To maximize the potential hatchling success of the moved nests, as well as to plan for potential future beach modification activities (e.g.,including re-nourishment, restoration, new training activities, etc.), it is important to understand the factors that drive nest site selection of adult turtles, and presumably, the hatchling success of turtle eggs at MCBCL. Predation on nests currently is managed by placing predator excluders over turtle nests. This program has been highly successful, resulting in approximately 100% exclusion of predators from nests. However, hatchling turtles are vulnerable to predation during their movement from the nest to the ocean. Currently, the survival of turtle hatchlings during this short, but crucial, period is unknown.

(b) Methods:
We will measure the characteristics of turtle nesting sites on Camp Lejeune accessible sites and compare them with published characteristics in other locations on the coast as well as sites not used by turtles at MCBCL. Some characteristics that we will examine include beach width, slope, sand grain size, beach compaction characteristics, and nest temperature. We will monitor hatchlings as they leave the nest using remote cameras and calculate the percent migration success. This research will take place during the turtle nesting season annually, May-August.

(c) Data Analysis:
Habitat selection will be quantified using standard use-availability analyses. We will use logistic regression to determine variables that drive presence or absence of sea turtles from particular micro-habitats. We plan to combine hatchling migration success data with diet data from the proposed research project, *Meso-Predator Foraging Ecology, Habitat Use, and Movements at Camp Lejeune and Their Impacts on Coastal Barrier Island Fauna*, and MCBCL monitoring data for turtles to quantify the impact of predators on these populations of sea turtles.

(d) Environmental Indicators, Tools and other Outcomes:
Sea turtle hatchling survival will be an indicator of predator community structure and the efficacy of predator control techniques. Reproductive success of relocated nests based on recommended features will be an indicator of success of management efforts in cooperation with the USFWS biological opinion.

(e) Linkages to other Modules:
This data from research project, *Understanding the Top-down and Bottom-up Drivers of Shorebird Productivity, Survival, Habitat Use, Foraging Dynamics, and Demography in Relation to Beach Management Practices on MCBCL,* will be used with this project so that the impacts of predators on sea turtles can be quantified using multiple data sets and understood in the context of other limiting factors, such as benthic prey availability for these vertebrates. These projects will allow us to understand the relative influences of top-down and bottom-up processes on turtles in this coastal barrier system.

(f) Military Drivers: 4. Ensure Camp Lejeune supports all required military training activities while complying with the Endangered Species Act and other wildlife requirements.

(g) Benefit to MCBCL:
Results will help to maximize the potential hatchling success of the moved nests, as well as to plan for potential future beach modification activities (e.g.,including re-nourishment, restoration, new training activities, etc.). Results will provide information for potential future Environmental Impact Statements for beach re-nourishment or other management activities.

(h) Schedule:
Field work during turtle breeding season (May-August annually); Interacts with, but not dependent upon, meso-predator research project.

Scheduling Constraints:
Sample only during the Spring to Summer sea turtle egg laying and hatching periods (May through August); must sample for at least 2 consecutive years to see trends.

Budget (Estimated):
- 1st Year: $67,000
- 2nd Year: $48,000
- 3rd Year: $48,000
- 4th Year: $ 28,000
- Total: $191,000

References: None identified.

Coastal Barrier Module: Barrier Island Vegetation

Senior Researcher: Stephen Broome (NCSU)
Supporting Researcher(s): Antonio Rodriguez, Pete Peterson (UNC-CH IMS), Jesse McNinch (VIMS)
Staff: one graduate student and one-half time for a technician.

Hypotheses:
H1: Structure and function of barrier island vegetation is impacted by anthropogenic activities.

Technical Objectives/Goals:

Determine the extent, condition, and species composition of the existing barrier island plant communities. 2) Assess the importance of sand accumulation by dune vegetation on island geomorphology and mitigation of erosion during storms. 3) Identify and document the effects of training and other activities that impact dune grass and shrub vegetation. 4) Develop management strategies to mitigate those effects, restore and sustain native vegetation communities.

Technical Approach

(a) Background:
Coastal dunes are natural features of sandy seashores that are formed as sand brought on shore by waves is moved inland by wind and accumulated by vegetation. Grasses adapted to the beach environment grow up through the sand stabilizing the surface and promoting further accretion. During storms frontal dunes function as sand reservoirs, dissipate wave energy, and act as barriers to storm waves and swash. Dunes provide a supply of sand to adjust the beach profile during storms thereby dissipating wave energy. The near-shore sediments, the beach, and frontal dunes form a dynamic, integrated unit. Preservation and management of the vegetation that is damaged by traffic and other uses is necessary to maintain the integrity of the beach/dune system, and maintain habitat for birds and other fauna.

(b) Methods: Sampling each plant community along transects across the barrier island will be used to assess vegetation. Randomly placed quadrats will be used to determine species composition and plant cover. Current aerial photography will be compared with photography from the past to determine changes in vegetation that may have occurred. Existing Lidar data and surveys on the ground will be used to determine the relationship of elevation, depth to water table, and soil characteristics to plant species and cover, and to estimate the volume of sand accumulated due to vegetation. Sand accumulation information will complement the short-term geomorphology study. The effect of traffic on vegetation and sand stability will be evaluated to determine the need for active management of vegetation. Protocols will be developed for mitigation and restoration of vegetation. This will include techniques for preserving existing vegetation, replanting when necessary, fertilization, and seasonal timing of activities to minimize impact.
(c) Data Analysis: Plant communities will mapped using GIS information to delineate plant communities. Where appropriate, significant differences in species, composition and cover will be determined using Analysis of Variance.
(d) Environmental Indicators, Tools and other Outcomes: None provided.
(e) Linkages to other Modules: The vegetation study is closely linked to all the other barrier island modules because of the effect of vegetation on habitat for birds and mammals, and physical processes such as sand accumulation to form dunes, which effects island geomorphology and overwash.
(f) Military Drivers: 1, 2, and 3.
(g) Benefit to MCBCL: Information obtained and protocols developed would help to preserve and maintain the natural vegetation and beach environment, by mitigating the effects of training, recreation and other uses.
(h) Schedule: Four- year project. First Year, begin compiling historic aerial photographs to assess changes in vegetation over time and the effects of recreation and training impacts. Second Year vegetation surveys and mapping. Second and third Years. Test plantings of native vegetation in areas that are impacted by training and recreation use. Forth Year monitor test plantings develop protocol and publish a barrier island vegetation management manual to be used by base personnel.
Scheduling Constraints: None.
Budget (Estimated): None identified.
References: None

Terrestrial Module: Stress Hormones as an Integrative Measure of Habitat Quality for Bird Species

Senior Researcher: Jeffrey R. Walters (Virginia Tech) **Supporting Researcher(s) and Staff**: Ignacio Moore (Virginia Tech); 1 post-doctoral researcher
Hypotheses: 1. Stress hormone levels of target bird species will be lower in higher quality upland pine savannah and wet pine flatwood habitats. 2. Stress hormone levels of target bird species will not differ between high military training use and low military training use areas.
Technical Objectives/Goals: Management of species at risk, particularly the RCW, is a high management priority at MCBCL. The Base is required by the FWS to recover the RCW population, and to improve the quality of foraging habitat assigned to each RCW group on the Base to meet specified standards. Because of the large area requirements of the RCW, to meet these requirements the Base must manage nearly every acre of upland pine savannah and pine flatwood habitat for the RCW. How to monitor RCW habitat quality with precision over such a large area is an important technical problem, and how management of habitat for RCWs affects the remainder of the avian community is an important knowledge gap. The objectives of this project are to to compare baseline stress hormone levels and stress response of RCWs and other birds of conservation concern living within high

quality habitat to those of birds living in low quality habitat, and those living within high use training areas to those living outside of such areas. This will enable an assessment of stress hormones as an integrative measure of habitat quality and military training impacts.
Technical Approach: **(a) Background:** The new Recovery Plan for the RCW (U.S. FWS, 2003) requires that each woodpecker group be provided 49 ha of high quality foraging habitat, defined as open pine stands with moderate densities of large, old pines, a rich herbaceous groundcover, and relatively few midstory hardwoods or medium-sized pines. Currently MCBCL is managing 198 foraging areas for RCWs, averaging 81ha each, to increase the RCW population from its current size of 79 active territories to the recovery goal of 173 active territories (MCBCL, 2006a). The net result is that over 16,000 ha are being managed for RCWs, representing essentially all the upland pine savannah and pine flatwood habitat on Mainside MCBCL. Documenting changes in habitat quality on a small scale over such a large area is a difficult challenge. Stress hormones represent a potential integrative measure of habitat quality as perceived by an animal for RCWs and other avian species. Release of stress hormones supports short-term adaptive responses to challenges by elevating the performance of key physiological systems, enabling the animal to flee or fight or do whatever else is most appropriate (Sapolsky et al., 2000). The strength of the stress response (i.e., change in hormone concentrations from baseline levels in response to a stressor) often serves as an indicator of an animal's health or condition. Prolonged stress leading to chronically elevated baseline stress hormone levels, however, can lead to a multitude of problems. Baseline stress hormone levels generally correlate positively with the amount of stress an animal is currently experiencing, and therefore can be used to assess whether daily living conditions are chronically stressful for individuals in a particular habitat (Wingfield et al., 1997; Clinchy et al., 2004). Baseline stress hormone levels and the strength of the stress response in RCWs and other bird species in high quality and low quality pine habitat will provide a measure of the extent to which management of pine habitat is improving living conditions for these species. Measuring stress hormone levels within high use military training areas and outside of such areas can provide an indicator of impacts of training as well as habitat quality on bird species. Although human activities are often stressful to birds (e.g., Wasser et al., 1997), in other cases birds habituate to particular activities so that stress levels are actually lower in areas where these activities are frequent than in areas where they are infrequent (e.g., Fowler, 1999). Either outcome is conceivable in the case of military training activities. Studies of stress response are particularly desirable in this context as they integrate effects on the multitude of behaviors that one might try to examine into a single measure of impact on the animal's well being. Indeed this approach is the focus of an ongoing project funded by SERDP examining impacts of military training activities on endangered bird species at Fort Hood in Texas (SI-1396). This project will augment SI-1396 in addressing the generality of this technique.
(b) Experimental Design: Sampling will follow a 2x2 design, in high quality and low quality RCW foraging habitat, and high use and low use military training areas. Desired sample size is 10 sites per treatment combination, and multiple individuals of each target species will be sampled at each site in 2 seasons. Bachman's sparrow and RCW will be 2 target species, and a third will be selected based on capture success.
(c) Methods: Birds will be captured both within high use training areas and within low use traing areas, and within both habitat that is considered restored to high quality conditions, and in areas that remain in poor condition due to past fire suppression. Areas of high quality and low quality RCW foraging habitat will be identified based on results from Research Project T-2, and high use and low use military training areas will be identified based on information provided by MCBCL. The methodology for measuring stress hormones will follow well established techniques (Romero, 2004): birds will be captured, and blood samples will be taken within three minutes of capture, the birds will be kept in a cloth bag for 30 minutes, and then a second blood sample will be taken prior to releasing the bird. Corticosterone levels within the samples will be measured using standard assays. The initial sample measures baseline stress hormone level and the difference between the second sample and the first measures the strength of the stress response. Two species of interest, the RCW and Bachman's sparrow, will be specifically targeted for sampling. RCWs will be captured from their roost cavities just prior to their normal emergence time. Bachman's sparrows will be captured using mist nets. An additional resident species captured in mist nets as a byproduct of sampling for Bachman's sparrows will serve as an additional target species, depending on capture success. In all cases, both breeding season (May-June) and winter (January-February) samples will be collected.
(d) Data Analysis: Hormone data will be analyzed using a 2-factor ANOVA, with 2 levels for each factor (high or low habitat quality; high or low training use), by species. Sampling sites will be selected to enable a balanced design for this analysis.
(e) Environmental Indicators, Tools and other Outcomes: The outcome of this study could provide a tool, measurement of stress hormone levels, for assessing cumulative impacts of management and training activities on at-risk species.

(f) Linkages to other Modules: This study is closely integrated with the other research projects in the Terrestrial Module (Research Projects T-1 and T-2), but is not substantially linked to other modules.

(g) Military Drivers: This project directly addresses one of the 6 military drivers, to ensure that MCBCL supports all required military training activities while complying with the ESA and other wildlife requirements.

(h) Benefit to MCBCL: This project may provide a method to assess impacts of management and training activities on species at-risk, specifically RCWs and Bachman's sparrows. It may provide an integrative measure of quality of RCW habitat, an important current issue at MCBCL.

(i) Schedule: Hormone sampling will be conducted in 2 periods, January-February (winter) and May-June (breeding season). Analysis of hormone samples will be completed by the beginning of the forth year and the remaining time of the project will be devoted to report writing and manuscript preparation.

Scheduling Constraints: The breeding season hormone sampling must be conducted during April-June.

Budget (Estimated):

- 1st Year: $0
- 2nd Year: $49,263
- 3rd Year: $90,349
- 4th Year: $45,113
- Total: $184,725

References:

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Atmospheric Module: Source Apportionment Analysis for Three Pollutants in the MCBCL Ambient Air

Senior Researcher: Marion Deerhake (RTI International)

Supporting Research(s) and Staff: 1 Principal Scientist, 1 air quality modeler, 1 air quality engineer, 1 GIS analyst.

Hypotheses:

Emission sources of ozone precursors, $PM_{2.5}$, and NH_3 in the vicinity of MCBCL may deteriorate the Base's ambient air quality, threaten Base compliance with air standards, threaten nutrient sensitive waters, and in turn, impact sustainability of MCBCL's operations and ecosystems.

Technical Objectives/Goals: To gauge the contribution of local (less than 50 km) off-site emission sources to MCBCL's ambient air quality and surface waters (via atmospheric deposition).

Technical Approach

(a) Background: Three air pollutants play a prominent role in eastern North Carolina air quality – ozone, $PM_{2.5}$, and NH_3. Ozone can be formed in warm months from precursor anthropogenic and biogenic VOC and NO_x emissions. Fine particulates ($PM_{2.5}$) are either emitted directly as black carbon or inorganic dust or are formed as ammonium salts of NH_3 and nitrates, sulfates, or chlorides (Ansari and Pandis, 1998). Nitrogen-based pollutants are commonly emitted as NO_x or NH_3 from traditional stationary sources (e.g., coal-fired boilers), CAFOs, and mobile sources. The distance these pollutants travel depends not only on their physical/chemical character, but also on atmospheric and meteorological conditions. Ammonia nitrogen's deposition velocity makes it more likely to deposit nearer its source (e.g., within 50 km) while ammonium $PM_{2.5}$ and ozone can potentially transport longer distances. Nitrogen species loadings in coastal waters from atmospheric deposition and nonpoint source discharges can cause eutrophication in nutrient sensitive waters, harming fish or shellfish, aquatic vegetation, and coral reefs. The impacts of NH_3 emissions from CAFOs in eastern North Carolina have been researched and modeled as part of a 2003 Smithfield Agreement study (RTI, 2003). Inhalation of ozone and $PM_{2.5}$ has adverse effects on human health such as respiratory disease and can cause ecosystem damage (U.S. EPA, 2004). Both ozone and $PM_{2.5}$ have National Ambient Air Quality Standards (U.S. EPA, 2006). Ozone and $PM_{2.5}$ attainment are at risk as standards become more stringent and development in eastern North Carolina grows. Ammonia is regulated as a hazardous substance under the Superfund Amendments and Reauthorization Act's Toxic Release Inventory program, and aqueous N is regulated via nutrient reduction standards for water quality. Nutrient sensitive ecosystems in eastern North Carolina may become more challenging to protect as nutrient reduction strategies for water quality are exhausted and atmospheric deposition plays a larger role. Knowledge of the role that off-site sources play compared to MCBCL in ambient ozone, $PM_{2.5}$, and N pollutants will enable MCBCL to develop an air quality strategy that optimizes Base operations, protects the MCBCL ecosystem, and ensures regulatory compliance.

(b) Experimental Design (new section requested by Brad Smith) – The proposed research is designed to identify and assess the potential air quality impacts of regional emission sources of ozone precursors, PM_{fine}, and NH_3 over MCBCL's airshed. This will be accomplished through the use of emission inventories, dispersion/deposition modeling, and GIS.

(c) Methods:

- This study will not require field sampling.
- RTI will prepare an inventory of major emitters of ozone precursors (NO_x and VOC), $PM_{2.5}$ (and/or precursors), and NH_3 up to 50 km beyond the New River watershed boundary or MCBCL property boundary. (This area will be deemed the study area.) The most recent year of emissions containing sufficient data for modeling will be selected for analysis. Emitters studied will include stationary sources (e.g., coal-fired boilers, CAFOs) and mobile sources. RTI will select the top 10 emission sources other than MCBCL in the study area for each of the following pollutants: VOCs, NOx, $PM_{2.5}$, and NH_3. If the source is mobile, RTI will designate a location representative of that mobile source.
- RTI will perform AERMOD modeling (http://www.epa.gov/scram001/ dispersion_prefrec.htm#aermod) for each of the top 10 sources, predicting the ambient concentration of that source's pollutant(s) over a designated receptor area of MCBCL. We will use 5 years of meteorological data from the nearest, most representative National Weather Service station.
- RTI will apply NOAA's HYSPLIT model (http://www.arl.noaa.gov/ready/hysplit4.html) to the study area, identifying the back trajectories starting from the MCBCL boundary. Plots of the results will indicate potential emisson sources in the upwind direction. Any sources located on a trajectory may contribute to the air quality over MCBCL.
- RTI will apply GIS to depict the AERMOD results for local sources of each pollutant.
- RTI will prepare a report of findings.

(d) Data Analysis: The AERMOD dispersion model includes AERMET (meterological preprocessor), AERMAP (mapping preprocessor), and AERMOD (dispersion processor). Analysis of outputs from AERMOD will be supplemented with NOAA HYSPLIT runs to determine meteorological patterns for each season. RTI will identify input data sources for the three AERMOD modeling components, using EPA guidance on quality assured data. For example, 5 years of meteorological data from the nearest National Weather Service station will be used. Emissions inventories from NCDENR (http://daq.state.nc.us/monitor/eminv) will be used for stationary sources; emission factors will be used for CAFOs; mobile emissions will require additional research. Dispersion modeling will predict transport to the MCBCL atmosphere. Where deposition velocities are available for pollutants (e.g., NH_3), deposition will be predicted. For ozone, only NO_x and VOC emissions in summer months will be modeled. Emission sources modeled will be ranked based on level of contribution to the ambient air over MCBCL.

(e) Environmental Indicators, Tools and other Outcomes: Ammonia can be used as an indicator of eutrophication potential and $PM_{2.5}$. NO_x can also be used as an indicator of $PM_{2.5}$. NO_x and/or VOC can be used as an indicator of ozone formation potential in summer months. Tools and outcomes generated from this effort will include (1) a customized emission inventory of off-site emission sources in the region of MCBCL; (2) GIS mapping of modeled predictions of off-site sources' pollution contributions to ambient air quality over MCBCL and deposition loading to the MCBCL watershed; (3) HYSPLIT mapping of back trajectory analyses from MCBCL to off-site emission sources deemed of particular concern to MCBCL air quality.

(f) Linkages to other Modules: Ozone is linked to the Terrestrial Module in multiple ways. First ozone can damage vegetation. Second ozone formation can be influenced by biogenic emissions from vegetation (e.g., isoprene) and from prescribed burn emissions (Research Project Air-1). Therefore, studying the contribution of the ozone precursors VOCs and NO_x from local off-site sources can promote a better understanding of ozone formation in the MCBCL area. $PM_{2.5}$ is linked to the Terrestrial Module because it can be generated by PB as well as land-based and amphibious operations that combust fuels. (Diesel fuel and coal combustion emit $PM_{2.5}$ as well as $NO_{x,,\ which}$ is a $PM_{2.5}$ precursor.) Nitrogen deposition as NH_3, NO_x, or ammonium nitrate $PM_{2.5}$ are linked to the Aquatic/Estuarine Module because MCBCL is located in nutrient sensitive waters susceptible to eutrophication from N loading increases (Research Project AE-2). Ammonia is also linked to the Terrestrial Module because both dry and wet deposition of NH_3 can promote vegetative growth (Research Project Air-2).

(g) Military Drivers: *Air Quality* - Compliance with emission standards associated with ozone and $PM_{2.5}$ National Ambient Air Quality Standards (NAAQS) and area attainment status. *Water quality* – compliance with nutrient-related water quality standards, particularly standards to minimize aquatic life impacts from eutrophication. Standards may include stormwater management, nonpoint source discharge, effluent discharge, and sedimentation and erosion control. Understanding the role of atmospheric deposition from off-site sources can enable MCBCL to develop water quality management strategies. *Endangered species* – protecting the terrestrial habitats that could be sensitive to ozone (vegetation damage) and N (fertilization); wildlife that could be sensitive to ozone and $PM_{2.5}$; and aquatic life that could be sensitive to N from atmospheric deposition.

(h) Benefit to MCBCL: Understanding the role of off-site emission sources helps MCBCL (1) understand its role in regional ozone and $PM_{2.5}$ attainment and, if necessary, negotiate emission reduction strategies to assure compliance with area NAAQS attainment requirements; and (2) understand its role in water quality protection and compliance; and (3) identify any potential off-site threats to endangered species/ecosystems and seek mitigation of those threats.

(i) Schedule:

▪ Definition of study area and emissions inventorying	Jan-Mar, First Year
▪ AERMOD preparation and modeling	Feb-May, First Year
▪ GIS analysis	June-Aug, First Year
▪ HYSPLIT analysis	August, First Year
▪ Results analysis	Sept-Nov, Second Year
▪ Prepare report	Dec-Feb, Second Year
▪ Deliver final report	March, Second Year

Scheduling Constraints:

None. This research project does not depend on field work. Data will be retrieved from EPA and DENR records and guidance.

Budget (Estimated):

- 1st Year : $ 26,000
- 2nd Year: $ 26,000
- Total: $ 52,000

References:

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Coastal Wetlands Module: Fishery Utilization of Marsh Habitat in Primary Nursery Areas

Senior Researcher: Dave Meyer (NOAA)
Supporting Staff: 1.5 technicians

Hypotheses:

1. Military related training does not have a significant affect on habitat support functions, including PNA functions, for nekton.
2. Habitat support functions, including PNA functions, for nekton do not differ within creeks based on proximity to head waters**.**
3. Resident nekton fitness condition does not differ within creeks based on proximity to head waters.
4. Land and water based military activities do not affect nekton fitness condition.

Technical Objectives/Goals:

To identify the extent and function of PNAs in strategic areas of the MCBCL, and assess impacts of Base activities on nekton utilization of marsh habitats.

Technical Approach

(a) Background: Intertidal marshes provide critical nursery habitat and food resources to fish and shellfish, and for this reason marshes are a vital component of designated PNAs. Estuarine waters designated as Primary Nursery Areas by the North Carolina Division of Marine Fisheries and North Carolina Wildlife Resources Commission are protected from a variety of activities, including dredging and trawling. Some of these limitations have adverse impacts on the MCBCL training mission. In addition, land-based activities can alter upland drainage patterns and estuarine water quality, potentially creating freshets, increased sedimentation, and other alterations with the net effect of creating an unpredictable and/or adverse environment for nekton. It has been shown that species show preference to some marsh habitats over others (Meyer, 2006); thus, not all marsh habitat is equal in terms of its value for aquatic organisms. The areas designated as PNA need to be evaluated in terms of nekton abundance, community structure, breeding potential for resident marsh nekton and resident nekton health condition. The PNA sampling done by the State is limited in time and space, and the State relies on limited data in determining the extent and type of activities allowed in designated PNA. In order to obtain better data on the habitat value of PNAs, as well as quantify the response of fish communities to human disturbances (such as dredging), the State may be willing to permit limited exceptions to prohibited activities in PNAs.

(b) Experimental Design: This work is designed to examine the plot (sub-site) individual creek watershed (site) and installation level (all sites combined) scales. As set up in this fashion, we will have the ability to track initial baseline nekton usage differences and monitor utilization trends over time at all of these scales. A stratified sampling design will be used with individual sub-sites within each creek. This will encompass a range from the creek headwater to the creek mouth. By using this design, we will be able to examine utilization trend differences within creeks based on proximity to the creek mouth, and assist with PNA delineation and habitat uniqueness. Also, individual creek sites will have sufficient independent replication (n=3) so that among site comparisons can be performed to examine affects of military use. Installation wide trends can be assessed by the combination of all sites with sub- site levels serving as pseudo-replicates.

(c) Methods: The late winter, late spring, and early fall time periods correspond to critical time periods for target nekton life histories, including spawning and recruitment (late winter through late spring) and estimated young of year population contribution (early fall). Designated PNA sites of particular interest to the MCBCL will be selected for study. Marsh nekton will be collected using a combination of gear types, including fyke nets to examine community structure, eel pot collections to specifically examine relative abundance of resident marsh nekton, and gill nets to examine predator nekton usage.

Fyke nets will be used to quantify the community composition, abundance and biomass of larval and juvenile fish occupying intertidal marsh habitats (Meyer et al., 2001), and provide individuals for nekton health condition (length versus weight) (Oliva-Paterna et al., 2003). Because fyke net collections utilize tidal inundation and evacuation to collect comparative samples, this collections method will be used at all site pairs with sufficient tidal regimes within the installation. Fyke nets, constructed of black 3.2 mm stretch mesh net, with a mouth measuring 1 m^2 with 3 m will be used. Three sub-sites, within each sampling site (creek head waters, mid creek and creek mouth), 5 contiguous linear meters of marsh fringe will be demarcated and sampled. Collection methods will follow Meyer (2004) and Meyer et al. (2001). Fyke nets will be set in place during a high tide and nekton collected once the tide has evacuated from the fyke nets during the subsequent low tide.

Because resident nekton are important components of estuarine ecosystems and site selection across the installation contains areas with variable degrees of tidal inundation baited eel pots (Meyer 2006) will be used to assess usage across all study sites within sub-sites. Eel pots used will measure 80 cm in length, 22.5 cm in diameter, be constructed of 0.5 cm bar mesh and have conical capture ends that position inward with 6 cm long by 3 cm wide capture openings (Halpin 1997, 2000; Kneib and Craig 2001; Meyer 2006). At each sub-site selected for fyke net collections, eel pots will be set in the upper and lower marsh area. Within each eel pot, 210 g of dry dog food will added and the eel pot allowed to fish for a short duration (approximately 1 h) (Kneib and Craig 2001) within a 3 hour time window, 1.5 hours before to 1.5 hours after high tide. Relative abundance will be examined based on catch per hour (CPH) fished for each eel pot (Meyer 2006). Water depths, as measured during set and collection (Meyer 1994; 2006) will be measured for each eel pot as well as set and collection times.

Predator fish usage for each wetland site will be measured via multimesh gill net sampling (Roundtree and Able, 1997; Meyer 2004). Each gill net will consist of three 10 m long x 1.8 m high panels. Each panel will consist of a different stretch mesh size (3.8, 6.4, and 8.9 cm), and will be separated from one another by 3 m open spaces (Meyer 2004). Gill nets will be anchored parallel to prevailing tidal current. All nets will be set during the late afternoon to early evening hours and allowed to fish overnight, uninterrupted for ~12 - 14 hours. Upon retrieval each net panel and its catch will be placed in a separate container for determination of catch based on mesh size and location. All fish will be identified to species and measured (total length).

(d) Data Analysis: For each collection date, data on faunal composition and abundance at each area site comparison will be examined according to collection method. For each collection date the Shapiro-Wilk Test will be used to test the normality of the data (residuals) (Shapiro and Wilk, 1965; Sen et al., 2003) for each area and gear type. If data are found not to be normally distributed, they will be nlog (x + 1) transformed and again residuals tested for normality using the Shapiro-Wilk Test. If data are observed to be normally distributed either before or after transformation, then the Student-Newman Keuls (SNK) procedure will be used to detect significant differences between the means for a given area or date comparison (Sokal and Rohlf, 1981). When conditions of data normality can not be met after transformation, data will be ranked and analyzed using SNK to detect significant differences between the means. Population size class frequency similarity for common forage species collected using fyke nets and eel pots will be assessed between marsh types at each area using the non-parametric Kolmogorov-Smirnov 2 sample test (Sokal and Rohlf 1981; Kneib and Craig 2001). In addition, Wilcoxon Two Sample Tests will be used to assess whether mean size of the area comparisons differed significantly from one another (Sokal and Rohlf 1981; Kneib and Craig 2001). For all results, any significant differences in results will have a p value $\leq$ 0.05. Nekton condition assessments will follow Oliva-Paterna et al. (2003) and use analysis of covariance (ANCOVA) to assess difference among habitat types.

Effects of human activities (dredging, land-use changes) could be determined for affected creeks using a BACI design, when sufficient lead time allows. Before and after collections within locations affected by future anthropogenic activities, along with reference site evaluation for interannual variability assessment, can delineate the extent of habitat modification impacts within particular creeks. Overall quality and habitat value of designated PNA sites will be evaluated in conjunction with additional measures of the ecosystem (benthos, primary production, water quality etc.) collected from the different projects among the various modules.

(e) Environmental Indicators, Tools and other Outcomes: Instead of biotic and abiotic threshold indicators to determine habitat condition, this research will use reference 'un-impacted' habitats to assess environmental degradation of those considered impacted by military and upland land use. Because of this, the threshold for assessment of degradation will be set at the alpha (p) = 0.05 level. Statistical tests used to compare sites based on these treatment types will consider $p \leq 0.05$ the threshold for significant effects.

(f) Linkages to other Modules: Linkage with corresponding site locations will occur between nekton sampling and other research projects within the CW module (CW-1, CW-2 and CW-3). This specific overlap of site use will allow additional data layering and improve our ability to assign causality to observed trends and linkages among module components. Additional linkages to the other modules will also occur through site commonality, overlap, or contiguous relation to those within other monitoring modules, including: the Aquatic/Estuarine, Coastal Barrier, Terrestrial and Atmospheric modules.

(f) Mission Drivers: This project will ensure that the MCBCL supports all required military training activities while complying with the ESA and other wildlife requirements. The project will investigate currently designated PNAs that restrict MCBCL training operations**.**

(h) Benefit to MCBCL: This research will investigate the extent of designated PNA within the Base, evaluate their relative habitat value, and determine whether limited exceptions to prohibited activities within the PNA may occur without harming the nursery function of the habitat. Information obtained could be used to assist with better delineation of PNA boundaries by state regulatory agencies. Further, exemptions for habitat modifications within PNA's by the Base might be mitigated through provision of gathered information on existing PNA functions to state regulatory agencies by NOAA, in kind habitat mitigation, or habitat enhancement.

(i) Schedule: Nekton, including fyke, gill and eel pot collections and relative environmental parameters will be collected tri-annually during late winter, late spring and early fall time periods. Parameters measured include: salinity, water temperature, water transparency, water dissolved oxygen, water depth, collection time, nekton abundance, biomass and size, and nekton condition.

Scheduling Constraints: This work must occur during the late winter, late spring and early fall time periods, which correspond to critical time periods for target nekton life histories. This includes spawning and recruitment (late winter through late spring) and estimated young of year population contribution (early fall).

Budget (Estimated):

- 1st Year: $22,000
- 2nd Year: $70,000
- 3rd Year: $72,000
- 4th Year: $54,000
- Total: $218,000

References:

Halpin, P. M. 1997. Habitat use patterns of mummichog, *Fundulus heteroclitus*, in New England. I. Intramarsh variation. *Estuaries 20*:616–625.

Kneib, R. T. and A. H. Craig. 2001. Efficacy of Minnow traps for sampling mummichogs in tidal marshes. Estuaries 24:884–893.

Meyer, D. L. 2006. A comparison of nekton utilization of smooth cordgrass (*Spartina alterniflora*) marsh based on marsh size and degree of isolation from like habitat: Do size and site location matter? Ph.D. Dissertation. University of North Carolina Wilmington.

Meyer, D.L., Johnson, J.M., Gill, J. 2001. A comparison of fisheries use of *Phragmites australis* and *Spartina alterniflora* marsh in Chesapeake Bay, USA. *Marine Ecology Progress Series 209*:71–84.

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Oliva-Paterna, F.J., Minano, P.A., Torralva, M. 2003. Habitat quality affects the condition of *Barbus sclateri* in Mediterranean semi-arid streams. *Environmental Biology of Fishes 67*:13–22.

Rountree, R. A. and K. W. Able. 1997. Nocturnal fish use of New Jersey marsh creek and adjacent bay shoal habitats. *Estuarine and Coastal Shelf Science 44*:703–711.

Shapiro, S. S. and M. B. Wilk. 1965. An analysis of variance test for normality (complete samples). *Biometrika 52*:591–611.

Sen, P. K, J. Jureckova and J. Picek. 2003. Goodness-of -fit test for Shapiro-Wilk type with nuisance regression and scale. *Australian Journal of Statistics*. 32:163–177

Sokal, R. R. and F. J. Rohlf. 1981. Biometry. 2nd edition. W. H. Freeman and Company, San Francisco, California.

Appendix D

Sources of Monitoring Data Occurring Within or Near the MCBCL

EMD Branch	Monitoring Activity	Status	Data[1]
Forestry	Timber/stand inventories (Ecosystem Management Model)	Ongoing	GIS layers
	Vegetation photo-points (to follow long-term veg changes)	Annual	Photographic
	Gypsy moth trapping	Annual	Spreadsheet/log book
	Southern pine beetle	As-needed basis	Spreadsheet/log-book
	Fuels research (seasonal dryness of fuels)	Ongoing	J. Reardon (Missoula Sciences Fire Lab, USFS)
	Air smoke monitoring data	Completed	D. Wade et. al
Threatened and Endangered Species	RCW - monitor 100 population	Annual	Jeff Walters/GIS layers
	RCW -inspect high traffic clusters to assess impacts	Weekly	Jay Carter (private consultant)
	Rough leaf loosestrife surveys	Annual	Spreadsheet/GIS layers
	Bald eagle surveys	Annual	Log book/database
	Mid-tide level GPS	1-2 measurements/ year	Under development
	Coastal golden rod survey	Annual	Spreadsheet/GIS layers
	Sea turtle surveys	Seasonal with nesting season	Log book/spread sheet/database
	Shorebirds surveys	Weekly presence-absence survey	Spreadsheet/database
	Turtle and shorebird predation/trapping program	Seasonal with turtle nesting season	Log book
	Sea beach amaranth surveys	Annual	Log book/GIS layer
Land and Wildlife	Wetlands (training areas monitored for impacts)	Ongoing	Log book/spreadsheet
	Training effects on soils and dunes	Annual, qualitative visual inspection	Log book/spreadsheet
	Soil erosion, in training areas, recently initiated	Categorical data from visual inspection	Log book/spreadsheet
	Non-native exotic flora and fauna monitoring	Annual, qualitative visual inspection	Log book/spreadsheet
	Deer monitoring, harvest/game management	Ongoing	Log book/spreadsheet
	Wood duck box monitoring	Annual	Log book/spreadsheet
	Quail surveys	Annual	Log book/spreadsheet
	Turkey surveys	Annual	Log book/spreadsheet
	Amphibians (frog calls) surveys	Seasonal	Log book/spreadsheet
	Alligator surveys	Annual	Log book/spreadsheet
	Shellfish sampling	Annual	Logbook/GIS layer
	Fish pond population surveys	Annual	Log book/spreadsheet
	Cactus moth surveys	Annual	Log book/spreadsheet
	Creel surveys	Annual	Log book/spreadsheet
	Christmas bird counts	Annual	National database

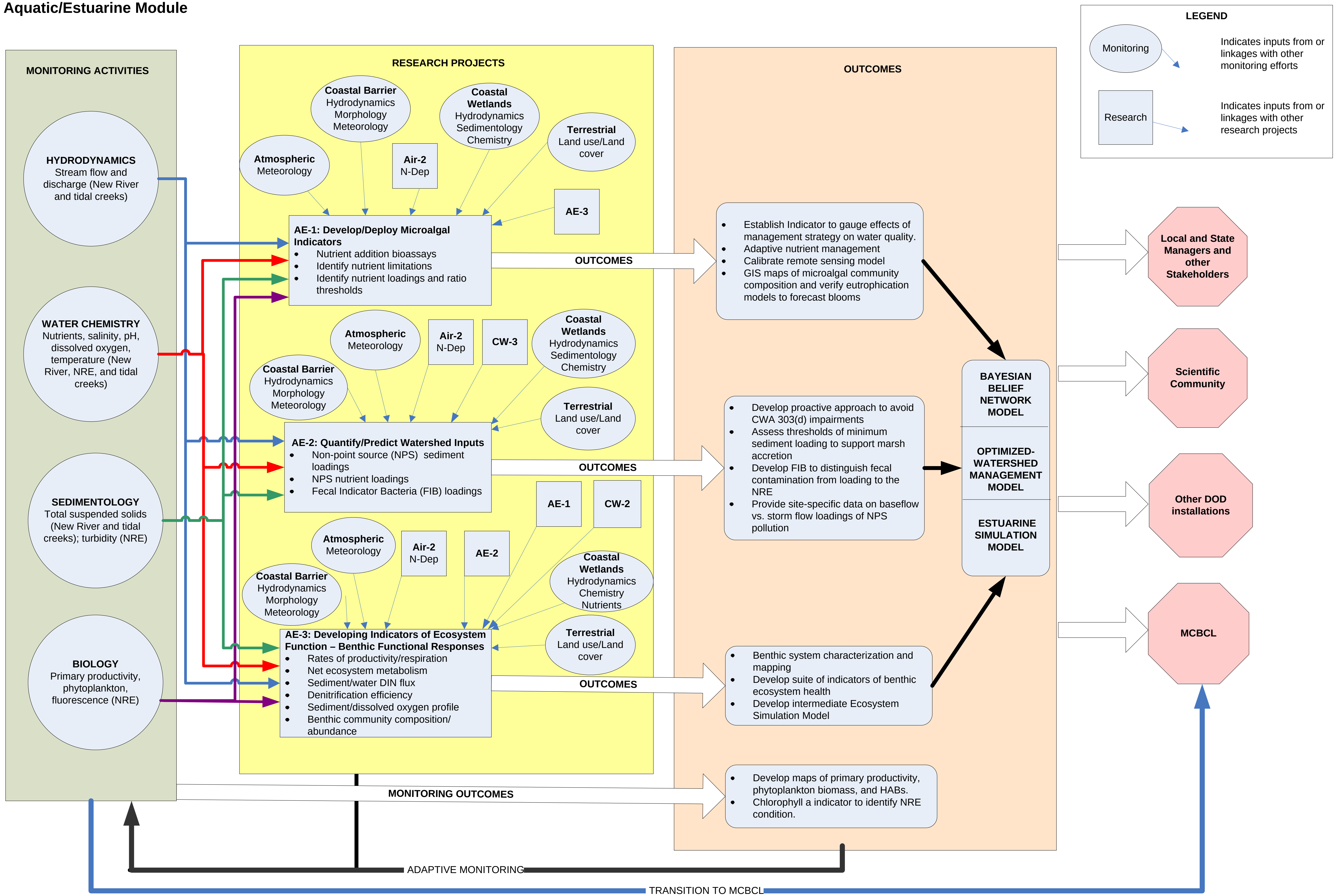
EMD Branch	Monitoring Activity	Status	Data[1]
	Shorebird & waterfowl counts (part of Atlantic Mig. Bird Initiative)	Annual	National database
	Migratory bird count (Int. Migratory Bird Day)	Annual	National database
	Rusty black birds, Smithsonian	Ongoing	Held by researchers
	Pocosin hydrology and vegetation monitoring (wetland mitigation site)	Ongoing	Spreadsheet/database
Water Quality	Storm-water monitoring	Annual	Spreadsheet
	Wastewater NPDES monitoring	Monthly	Spreadsheet
	Shellfish surveys	Annual	NC Division of Marine Fisheries
	Shellfish sanitation/bacteriological (shellfish sanitation program)	Annual	NCDENR
	Ambient water quality monitoring	Annual	NCDENR
	Water quality (water chemistry) monitoring	Annual	UNCW (Mike Mallin)
	Blue crab distribution of juveniles	Monthly	NSF-CRUI program at UNCW
Air Quality	Stationary emission points	Continuous	Spreadsheet/report
CLEO	Off-road recreational vehicle order compliance	Measured by # of violations	Log book/spreadsheet
Other: Range Control	Noise pollution (single-event noise monitoring)	Ongoing, in-house	Database

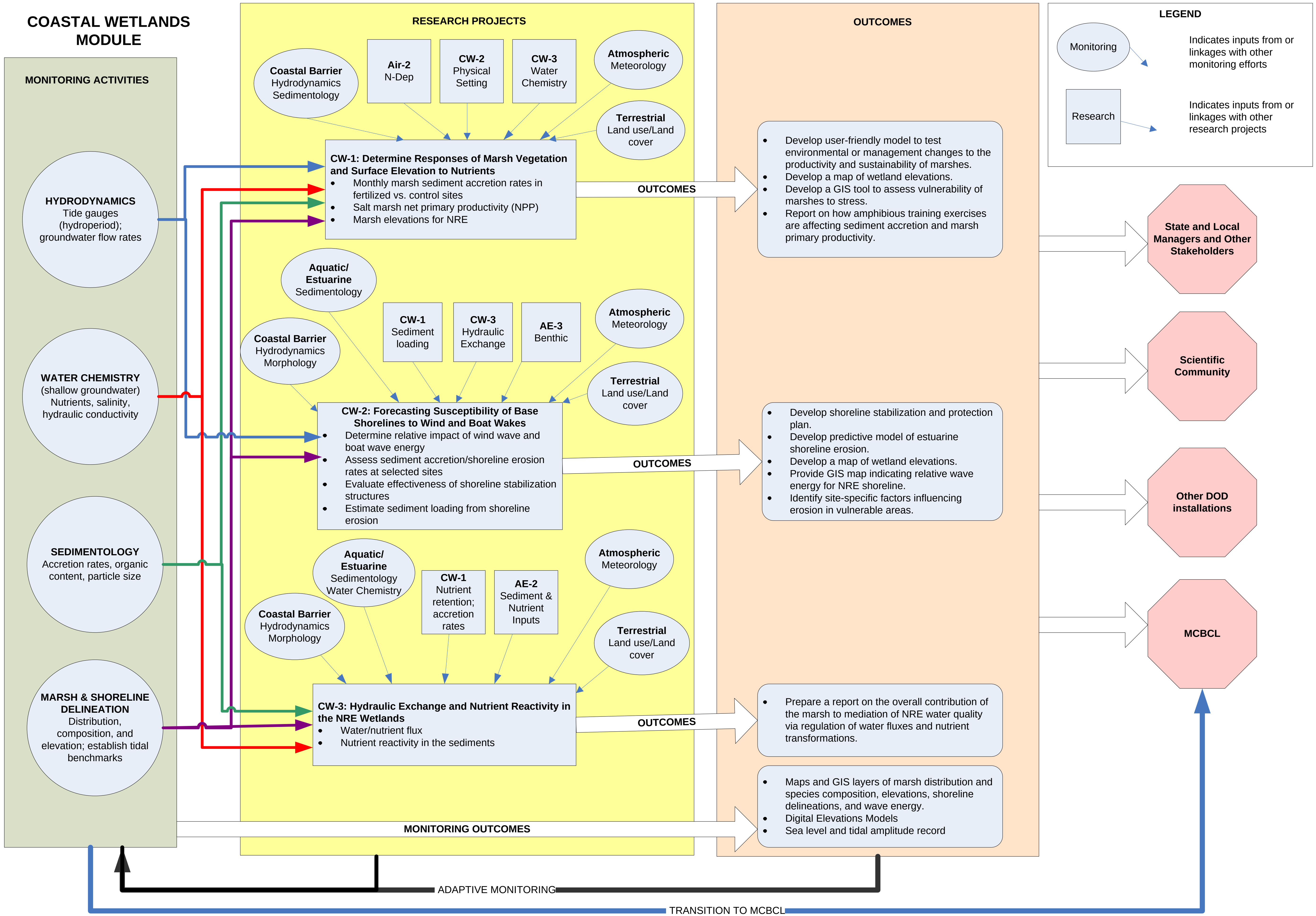
[1] Unless otherwise noted, the monitoring activity is conducted by the Environmental Management Division, Installations and Environment Department, Marine Corps Base Camp Lejeune.

Appendix E

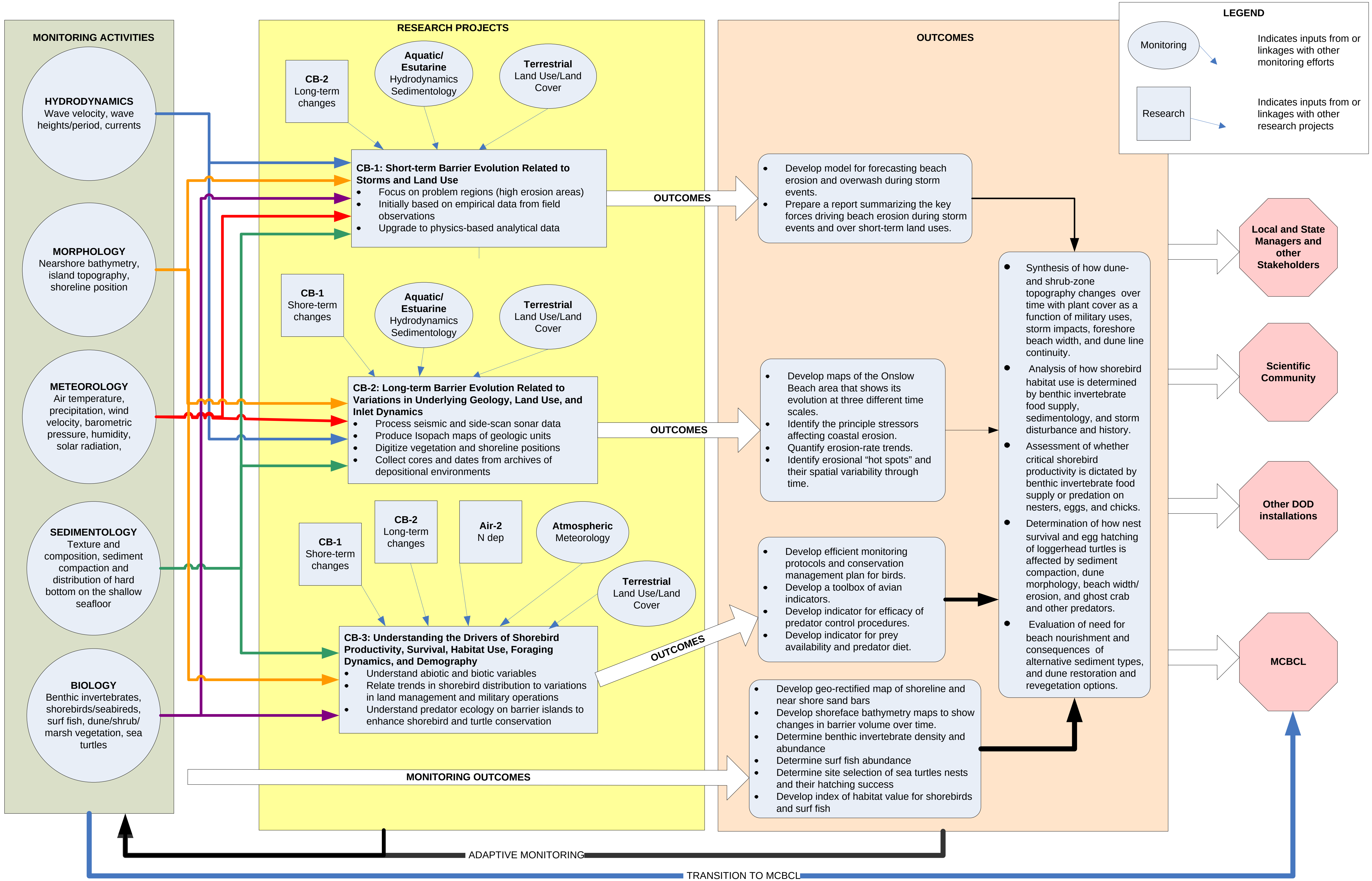
Ecosystem Module Roadmaps

Aquatic/Estuarine Module

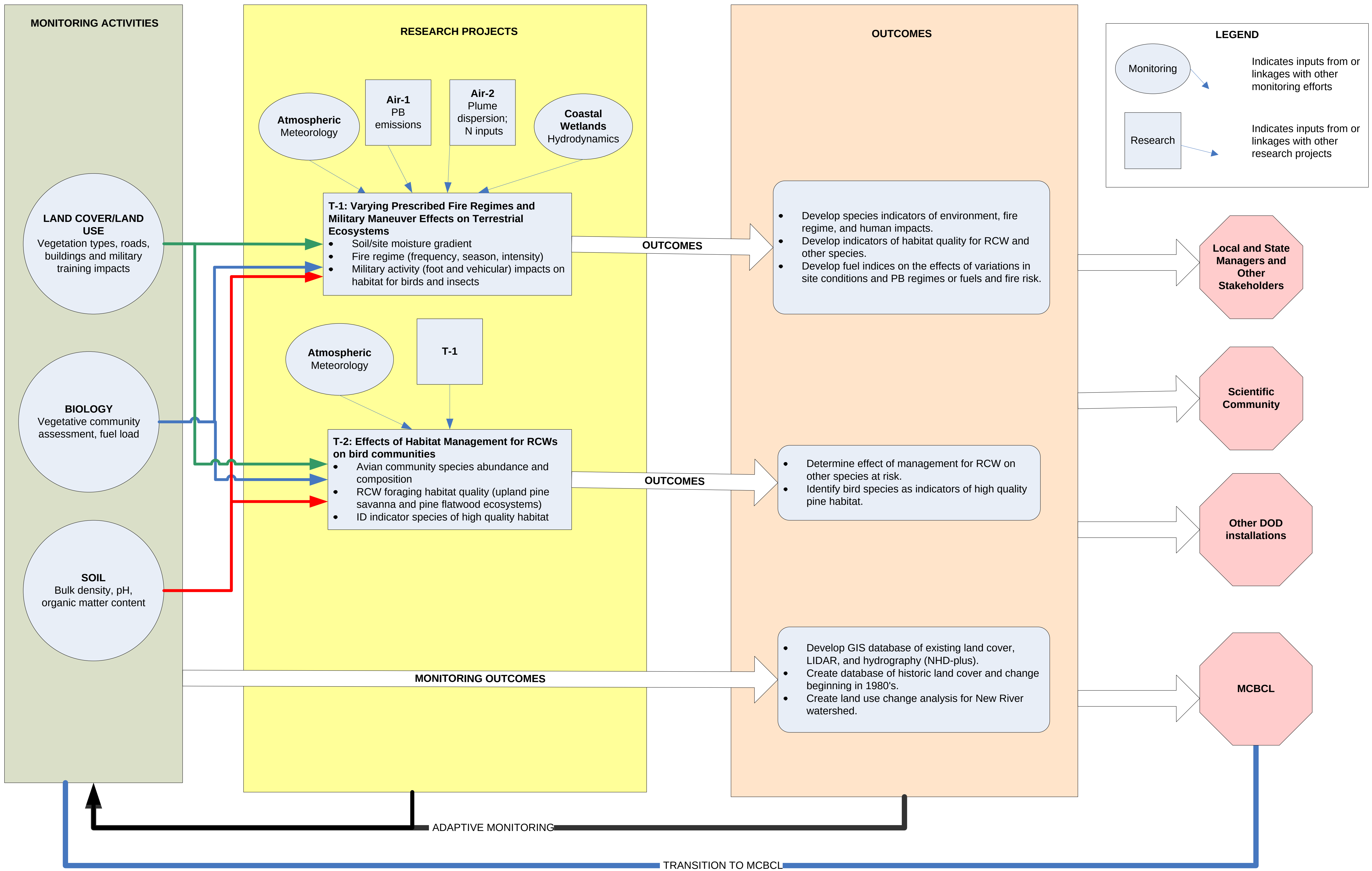


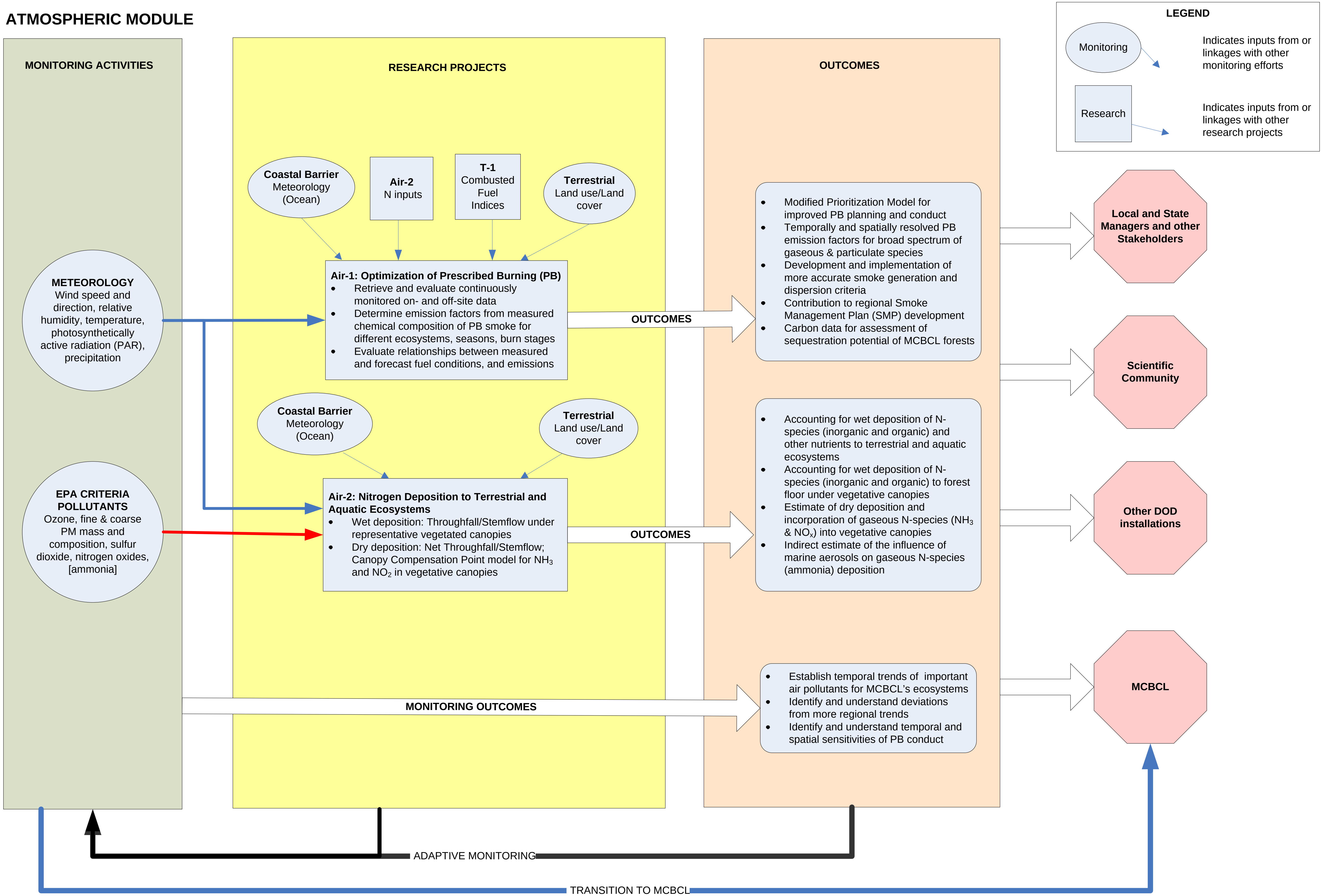

COASTAL WETLANDS MODULE
MONITORING ACTIVITIES
HYDRODYNAMICS
Tide gauges (hydroperiod); groundwater flow rates
WATER CHEMISTRY
(shallow groundwater) Nutrients, salinity, hydraulic conductivity
SEDIMENTOLOGY
Accretion rates, organic content, particle size
MARSH & SHORELINE DELINEATION
Distribution, composition, and elevation; establish tidal benchmarks
RESEARCH PROJECTS
Coastal Barrier Hydrodynamics Sedimentology
Air-2 N-Dep
CW-2 Physical Setting
CW-3 Water Chemistry
Atmospheric Meteorology
Terrestrial Land use/Land cover
CW-1: Determine Responses of Marsh Vegetation and Surface Elevation to Nutrients
• Monthly marsh sediment accretion rates in fertilized vs. control sites
• Salt marsh net primary productivity (NPP)
• Marsh elevations for NRE
OUTCOMES
Aquatic/ Estuarine Sedimentology
Coastal Barrier Hydrodynamics Morphology
CW-1 Sediment loading
CW-3 Hydraulic Exchange
AE-3 Benthic
Atmospheric Meteorology
Terrestrial Land use/Land cover
CW-2: Forecasting Susceptibility of Base Shorelines to Wind and Boat Wakes
• Determine relative impact of wind wave and boat wave energy
• Assess sediment accretion/shoreline erosion rates at selected sites
• Evaluate effectiveness of shoreline stabilization structures
• Estimate sediment loading from shoreline erosion
OUTCOMES
Aquatic/ Estuarine Sedimentology Water Chemistry
Coastal Barrier Hydrodynamics Morphology
CW-1 Nutrient retention; accretion rates
AE-2 Sediment & Nutrient Inputs
Atmospheric Meteorology
Terrestrial Land use/Land cover
CW-3: Hydraulic Exchange and Nutrient Reactivity in the NRE Wetlands
• Water/nutrient flux
• Nutrient reactivity in the sediments
OUTCOMES
MONITORING OUTCOMES
OUTCOMES
• Develop user-friendly model to test environmental or management changes to the productivity and sustainability of marshes.
• Develop a map of wetland elevations.
• Develop a GIS tool to assess vulnerability of marshes to stress.
• Report on how amphibious training exercises are affecting sediment accretion and marsh primary productivity.
• Develop shoreline stabilization and protection plan.
• Develop predictive model of estuarine shoreline erosion.
• Develop a map of wetland elevations.
• Provide GIS map indicating relative wave energy for NRE shoreline.
• Identify site-specific factors influencing erosion in vulnerable areas.
• Prepare a report on the overall contribution of the marsh to mediation of NRE water quality via regulation of water fluxes and nutrient transformations.
• Maps and GIS layers of marsh distribution and species composition, elevations, shoreline delineations, and wave energy.
• Digital Elevations Models
• Sea level and tidal amplitude record
LEGEND
Monitoring
Indicates inputs from or linkages with other monitoring efforts
Research
Indicates inputs from or linkages with other research projects
State and Local Managers and Other Stakeholders
Scientific Community
Other DOD installations
MCBCL
ADAPTIVE MONITORING
TRANSITION TO MCBCL

COASTAL BARRIER MODULE



TERRESTRIAL MODULE




ATMOSPHERIC MODULE
MONITORING ACTIVITIES
RESEARCH PROJECTS
OUTCOMES
LEGEND
Monitoring
Indicates inputs from or linkages with other monitoring efforts
Research
Indicates inputs from or linkages with other research projects
METEOROLOGY Wind speed and direction, relative humidity, temperature, photosynthetically active radiation (PAR), precipitation
EPA CRITERIA POLLUTANTS Ozone, fine & coarse PM mass and composition, sulfur dioxide, nitrogen oxides, [ammonia]
Coastal Barrier Meteorology (Ocean)
Air-2 N inputs
T-1 Combusted Fuel Indices
Terrestrial Land use/Land cover
Air-1: Optimization of Prescribed Burning (PB)
• Retrieve and evaluate continuously monitored on- and off-site data
• Determine emission factors from measured chemical composition of PB smoke for different ecosystems, seasons, burn stages
• Evaluate relationships between measured and forecast fuel conditions, and emissions
OUTCOMES
• Modified Prioritization Model for improved PB planning and conduct
• Temporally and spatially resolved PB emission factors for broad spectrum of gaseous & particulate species
• Development and implementation of more accurate smoke generation and dispersion criteria
• Contribution to regional Smoke Management Plan (SMP) development
• Carbon data for assessment of sequestration potential of MCBCL forests
Coastal Barrier Meteorology (Ocean)
Terrestrial Land use/Land cover
Air-2: Nitrogen Deposition to Terrestrial and Aquatic Ecosystems
• Wet deposition: Throughfall/Stemflow under representative vegetated canopies
• Dry deposition: Net Throughfall/Stemflow; Canopy Compensation Point model for NH_3 and NO_2 in vegetative canopies
OUTCOMES
• Accounting for wet deposition of N-species (inorganic and organic) and other nutrients to terrestrial and aquatic ecosystems
• Accounting for wet deposition of N-species (inorganic and organic) to forest floor under vegetative canopies
• Estimate of dry deposition and incorporation of gaseous N-species (NH_3 & NO_x) into vegetative canopies
• Indirect estimate of the influence of marine aerosols on gaseous N-species (ammonia) deposition
MONITORING OUTCOMES
• Establish temporal trends of important air pollutants for MCBCL's ecosystems
• Identify and understand deviations from more regional trends
• Identify and understand temporal and spatial sensitivities of PB conduct
Local and State Managers and other Stakeholders
Scientific Community
Other DOD installations
MCBCL
ADAPTIVE MONITORING
TRANSITION TO MCBCL

Defense Coastal/Estuarine Research Program (DCERP)

Research Plan: Addendum I

August 15, 2008

For the period 2006 through 2011

Prepared for:

Strategic Environmental Research and Development Program (SERDP)

Prepared by:

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RTI INTERNATIONAL

* RTI International is a trade name of Research Triangle Institute.

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Acronyms and Abbreviations

2-D	two-dimensional
3-D	three-dimensional
ADCIRC	Advanced Circulation (Model)
ADCP	Acoustic Doppler Current Profiler
ALPHA	Adapted Low-cost Passive High Absorption
ANOVA	analysis of variance
AOC	areas of concern
ASCP	stomatal compensation point
AVIRIS	Sea-viewing Wide Field-of-view Sensor
AVP	autonomous vertical profiler
AWAC	Acoustic Wave and Current
BBN	Bayesian Belief Network
BLH	boundary layer height
BMA	benthic microalgae
BMP	best management practice
C	carbon
CAA	Clean Air Act
CAFO	confined animal feeding operation
CDOM	colored dissolved organic matter
CFR	Code of Federal Regulations
CMS	Center for Marine Sciences
CO	carbon monoxide
CWA	Clean Water Act
CWSMB	Coupled Water and Salt Mass Balance
DCERP	Defense Coastal/Estuarine Research Program
DEM	digital elevations model
DIC	dissolved inorganic carbon
DIN	dissolved inorganic nitrogen
DIP	dissolved inorganic phosphorus
DO	dissolved oxygen
DOC	dissolved organic carbon
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DON	dissolved organic nitrogen
EF	emission factor
EOS	end of the season
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ESM	Estuarine Simulation Model
FAC	fractional aerosol coefficients
FIB	fecal indicator bacteria
GIS	geographic information systems
GPS	global positioning system
HAB	harmful algal bloom
HPLC	high performance liquid chromatography
HSPF	Hydrologic Simulation Program Fortran
ICW	Intracoastal Waterway
INRMP	*Integrated Natural Resources Management Plan*

IPCC	Intergovernmental Panel on Climate Change
IRMS	isotope ratio mass spectrometry
KBDI	Keetch-Byram drought index
LCAC	landing craft air cushion
LIDAR	Light Detection and Ranging
LTSC	Long-Term Shoreline Change
LVORI	low visibility occurrence risk index
MA	microalgal
MARDIS	Monitoring and Research Data Information System
MARIS	medium-spectral resolution, imaging spectrometer
MCASNR	Marine Corps Air Station New River
MCBCL	Marine Corps Base Camp Lejeune
MCE	modified combustion efficiency
MDN	Mercury Deposition Network
MEM2	marsh equilibrium model 2
MHW	mean high water
MODIS	Moderate Resolution Imaging Spectroradiometer
MOU	Memorandum of Understanding
N	nitrogen
NAAQS	National Ambient Air Quality Standards
NADP	National Atmospheric Deposition Program
NCDCM	North Carolina Division of Coastal Management
NCSU	North Carolina State University
NAVFAC ESC	Naval Facilities Engineering Service Center
NH_3	ammonia
NLM	nutrient load model
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NOAA	National Oceanic and Atmospheric Administration
NPP	net primary production
NRE	New River Estuary
NRESE	New River Estuary Shoreline Erosion
NWS	National Weather Service
O_2	oxygen
O_3	ozone
OC	organic carbon
OPTMOD	bio-optical model
OSC	On-site Coordinator
P	phosphorus
PAR	photosynthetically active radiation
Pb	lead
PB	prescribed burning
PCR	polymerase chain reaction
PI	Principal Investigator
PM	Program Manager, particulate matter
$PM_{2.5}$, PM_{fine}	(fine) particulate matter with aerodynamic diameter smaller 2.5 microns
PM_{10}	particulate matter with aerodynamic diameter smaller 10 microns
$PM_{10\text{-}2.5}$, PM_c	(coarse) particulate matter aerodynamic diameter with between 2.5 and 10 microns
POC	phase organic compound
QA	quality assurance

QC	quality control
QPCR	quantitative polymerase chain reaction
RCC	Regional Coordinating Committee
RCW	red-cockaded woodpecker
RDBMS	Relational Database Management System
RFMSS	Range Facility Management Support System
RTI	RTI International
RTK	real-time kinematic
RWE	Representative Wave Energy
SAV	submerged aquatic vegetation
SDI	smoke dispersion index
SeaWIFs	Sea-viewing Wide Field-of-view Sensor
SERDP	Strategic Environmental Research and Development Program
SET	surface elevation table
SMP	Smoke Management Plan
SO_2	sulfur dioxide
SOA	secondary organic aerosol
SOP	standard operating procedure
SPARROW	Spatially Referenced Regressions On Watershed Attributes
SSA	sea salt aerosol
STEBR	Short-Term, Event Beach Response Model
SWAN	Simulating Waves Nearshore (model)
TAC	Technical Advisory Committee
TBD	to be determined
TLZ	Tactical Landing Zone
TMDL	total maximum daily load
TSS	total suspended solids
UNC-CH	University of North Carolina at Chapel Hill
UNC-IMS	University of North Carolina Institute of Marine Sciences
UNC-W	University of North Carolina at Wilmington
USACE	U.S. Army Corps of Engineers
USC	University of South Carolina
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VCIS	Ventilation Climate Information System
VI	ventilation index
VIMS	Virginia Institute of Marine Sciences
VOC	volatile organic compound
VT	Virginia Tech
WEMo	Wave Exposure Model
WSM	Watershed Simulation Model
WWTP	wastewater treatment plant
YSI	Yellow Springs Instruments, Inc.

Note: The purpose of the Defense Coastal/Estuarine Research Program (DCERP) Research Plan is to describe the 13 research projects to be conducted at Marine Corps Base Camp Lejeune (MCBCL). The purpose of this research program is to increase the knowledge base and understanding of MCBCL-relevant ecosystem functioning, stressors and system responses to stresses and management actions. The RTI International (RTI) DCERP Team is using state-of-the-art techniques to test ecosystem response to stressors, to examine potential indicators, and to research and evaluate various management practices.

The purpose of this Research Plan Addendum is to indicate changes to the DCERP research program that have occurred since the implementation of the DCERP Research Plan in July 2007. This document retains the same numbering of sections, tables, and figures as the original DCERP Research Plan and should be used in conjunction with that document. As stated in the DCERP Research Plan, each research project will 1) provide clear technical goals and specific objectives to address key knowledge gaps, research needs, and management objectives; 2) incorporate scientifically sound, high-quality research principles that use state-of-the-art technologies that are transferable to MCBCL; and 3) translate research results into model, indicators, and tools to predict outcomes of potential management scenarios.

Executive Summary

In **Table ES-1**, the titles of the following two research projects have changed.

Table ES-1. DCERP Research Projects and Outcomes (Revised)

Research Project	Research Project Title and Outcome	Senior Researcher and Duration
CW-1	*Determine Responses of Marsh Vegetation and Accretion to Relative Surface Elevation*	Jim Morris
	Outcomes and Benefits to the Base: Data derived from these research activities will be used to parameterize a model of sediment accretion and forecast the marsh response to stressors (amphibious maneuvers and sea-level rise). These data will also quantify the marsh response to fertilization by nitrogen (N) and phosphorus (P) (a potential mitigation strategy).	7/2007–6/2011
T-1	*Varying Prescribed Fire Regimes and Forest Management Effects on Terrestrial Ecosystem Structure and Function*	Norman Christensen
	Outcomes and Benefits to the Base: Results from this research project will provide measures of the effects of military and forestry activities on plant and animal communities and guidance on how best to mitigate any adverse effects of such activities.	7/2008–6/2011

1.0 Introduction

No changes to this section.

2.0 Program Organization

The Defense Coastal/Estuarine Research Program (DCERP) is a collaborative effort between the Strategic Environmental Research Program (SERDP), the Naval Facilities Engineering Service Center (NAVFAC ESC), Marine Corps Base Camp Lejeune (MCBCL), and the RTI International (RTI) DCERP Team, which was selected to execute the objectives of SERDP's Ecosystem Management Project. **Figure 2-1** illustrates the overall organization and lines of communication of DCERP. This figure has been revised to update changes in personnel and changes to acronyms (e.g., NAVFAC ESC).

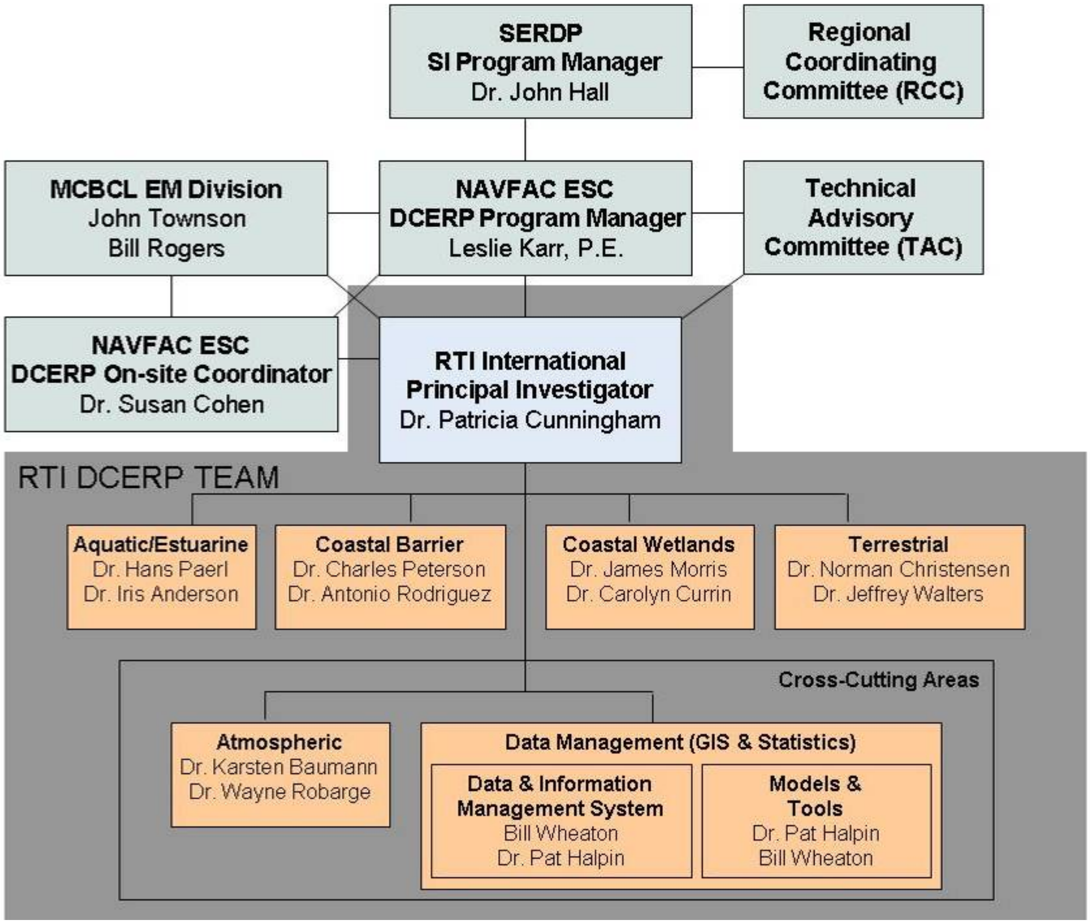

Figure 2-1. Organization of DCERP (revised).

3.0 DCERP Overarching Strategy

No changes to this section.

4.0 Purpose of the Research Plan

4.1 Objectives of the Research Plan

No changes to this sub-section.

4.2 Selection of Research Projects

Table 4-1 lists the title of each research project and the project's lead investigator; these projects will be discussed in detail in Section 5 of this report (*Module Research Projects*). The titles have changed for the following research project: CW-1 and T-1.

Table 4-1. DCERP Research Projects (2007–2011)

Research Project	Research Project Title	Senior Researcher(s)
AE-1	*Develop and Deploy Microalgal Indicators as Measures of Water Quality, Harmful Algal Bloom (HAB) Dynamics, and Ecosystem Condition*	Hans Paerl

Research Project	Research Project Title	Senior Researcher(s)
AE-2	*Quantifying and Predicting Watershed Inputs of Nutrients, Sediments, and Pathogens*	Mike Piehler
AE-3	*Developing Indicators of Ecosystem Function for Shallow Estuaries: Benthic Functional Responses in the NRE*	Iris Anderson
CW-1	*Determine Responses of Marsh Vegetation and Accretion to Relative Surface Elevation*	Jim Morris
CW-2	*Forecast Influence of Natural and Anthropogenic Factors on Estuarine Shoreline Erosion Rates*	Mark Fonseca
CW-3	*Hydraulic Exchange and Nutrient Reactivity in the NRE Wetlands*	Craig Tobias
CB-1	*Short-Term Barrier Evolution Related to Storms and Land Use*	Jesse McNinch
CB-2	*Long-Term Barrier Evolution Related to Variations in Underlying Geology, Land Use, and Inlet Dynamics*	Antonio Rodriguez
CB-3	*Understanding the Top-down and Bottom-up Drivers of Shorebird Nest Success and Habitat Use in Relation to Beach Management Practices on MCBCL*	Sarah Karpanty and Jim Fraser
T-1	*Effects of Different Understory Restoration Management Options on Terrestrial Ecosystem Structure and Function*	Norman Christensen
T-2	*Effects of Habitat Management for Red-Cockaded Woodpeckers (RCWs) on Bird Communities*	Jeffrey Walters
Air-1	*Optimization of Prescribed Burning (PB) by Minimizing Smoke Emissions and Maximizing Vitality of Fire-Adapted Ecosystems*	Karsten Baumann
Air-2	*Nitrogen Deposition to Terrestrial and Aquatic Ecosystems*	Wayne Robarge

4.3 Integrating DCERP Research and Monitoring

No changes to this sub-section.

4.4 Other Research and Monitoring Efforts Related to DCERP

No changes to this sub-section.

5.0 Module Research Projects

The following sections contain the description of the research projects for each of the five ecological modules (i.e., Aquatic/Estuarine, Coastal Wetlands, Coastal Barrier, Terrestrial, and Atmospheric). Specific information is provided for each research project, such as the research team, hypothesis to be tested, technical goals, technical approach, schedule and scheduling constraints, and budgetary information for each of the four implementation years.

5.1 Aquatic/Estuarine Module

5.1.1 Introduction

In the context of the MCBCL region, the Aquatic/Estuarine Module will examine the tidal reach of the NRE from the freshwater head of the NRE near Jacksonville, NC, to the tidal inlet at Onslow Bay. The following research projects (**Table 5-1**) address challenges that are associated with stresses imposed as a consequence of MCBCL or other direct anthropogenic activities. There have been no changes to Table 5-1.

Table 5-1. Aquatic/Estuarine Module Research Project Title, Senior Researcher, Benefit to MCBCL, and Duration of Project

Research Project	Research Project Title and Outcome	Senior Researcher and Duration
AE-1	*Develop and Deploy Microalgal Indicators as Measures of Water Quality, Harmful Algal Bloom Dynamics, and Ecosystem Condition*	Hans Paerl
	Outcomes and Benefits to the Base: This research project will establish baseline indicators against which to gauge the short- and long-term effects of management strategies aimed at protecting water quality and preserving the ecological integrity of the New River Estuary (NRE) and adjacent wetlands and coastal waters. This project will also produce a decision-support, Bayesian modeling tool for guiding adaptive monitoring and management and provide data needed to link watershed nutrient inputs to estuarine circulation and water quality simulation models.	7/2007–06/2011
AE-2	*Quantifying and Predicting Watershed Inputs of Nutrients, Sediments, and Pathogens*	Mike Piehler
	Outcomes and Benefits to the Base: This research project will provide the Base with information on the sources of identified pollutants to help avoid actions under the Clean Water Act (CWA) related to impairment from fecal indicator bacteria (FIB), sediments, or chlorophyll *a* exceedances by identifying emerging problems and using data to inform of remedial strategies. This project will also produce a decision-support modeling tool (i.e., Watershed Simulation Model [WSM]) for predicting watershed exports as a function of environmental forcing and land-use changes.	7/2007–6/2011
AE-3	*Developing Indicators of Ecosystem Function for Shallow Estuaries: Benthic Functional Responses in the New River Estuary.*	Iris Anderson
	Outcomes and Benefits to the Base: This research project will provide a cause-and-effect analysis or potential management actions that may be necessary to mitigate long- and short-term impacts of the Base on benthic processes responsible for modulating nutrient enrichment and supporting higher trophic levels in the NRE. This project will also produce a decision-support modeling tool (i.e., Estuarine Simulation Model [ESM]) for predicting estuarine responses to natural and anthropogenic disturbances.	7/2007–6/2011

5.1.2 Knowledge Gaps in Conceptual Model and Research Needs

No changes to this sub-section.

5.1.3 Benefit to MCBCL

No changes to this sub-section.

5.1.4 Proposed Research Projects—Aquatic/Estuarine

5.1.4.1 Research Project AE-1: Develop and Deploy Microalgal Indicators as Measures of Water Quality, Harmful Algal Bloom Dynamics, and Ecosystem Condition

There have been no changes to this research project.

5.1.4.2 Research Project AE-2: Quantifying and Predicting Watershed Inputs of Nutrients, Sediments, and Pathogens

Senior Researcher: Mike Piehler (University of North Carolina at Chapel Hill [UNC-CH])

Supporting Researchers: Rachel Noble (UNC-CH), Craig Tobias (University of North Carolina at Wilmington [UNC-W]) and Mark Brush (Virginia Institute of Marine Science [VIMS])

Hypotheses: No changes to this section.

Technical Goals: No changes to this section.

Technical Approach

(c) Methods: An array of tidal creeks and tributaries spanning both regional spatial gradients and disturbance gradients will be instrumented (**Figure 5-5**). The location of these stations has changed since the original DCERP Research Plan. The stations used for this research project are the same stations that are used for the tributary creek monitoring activity of the Aquatic/Estuarine Module. Eight of these stations have been divided into two groups: Group A and Group B. This grouping is necessary because we only have enough equipment to sample four stations at a time. The station names and grouping include the following:

Group A

- Oligohaline—Airport Creek (Site 3), Southwest Creek (Site 4)
- Mesohaline—French Creek (Site 8), Codgel Creek (Site 7)

Group B

- Polyhaline—Traps Creek (Site 6), Courthouse Bay (Site 5)
- Backbarrier—Freeman Creek (Site 9), Gillets Creek (Site 10)

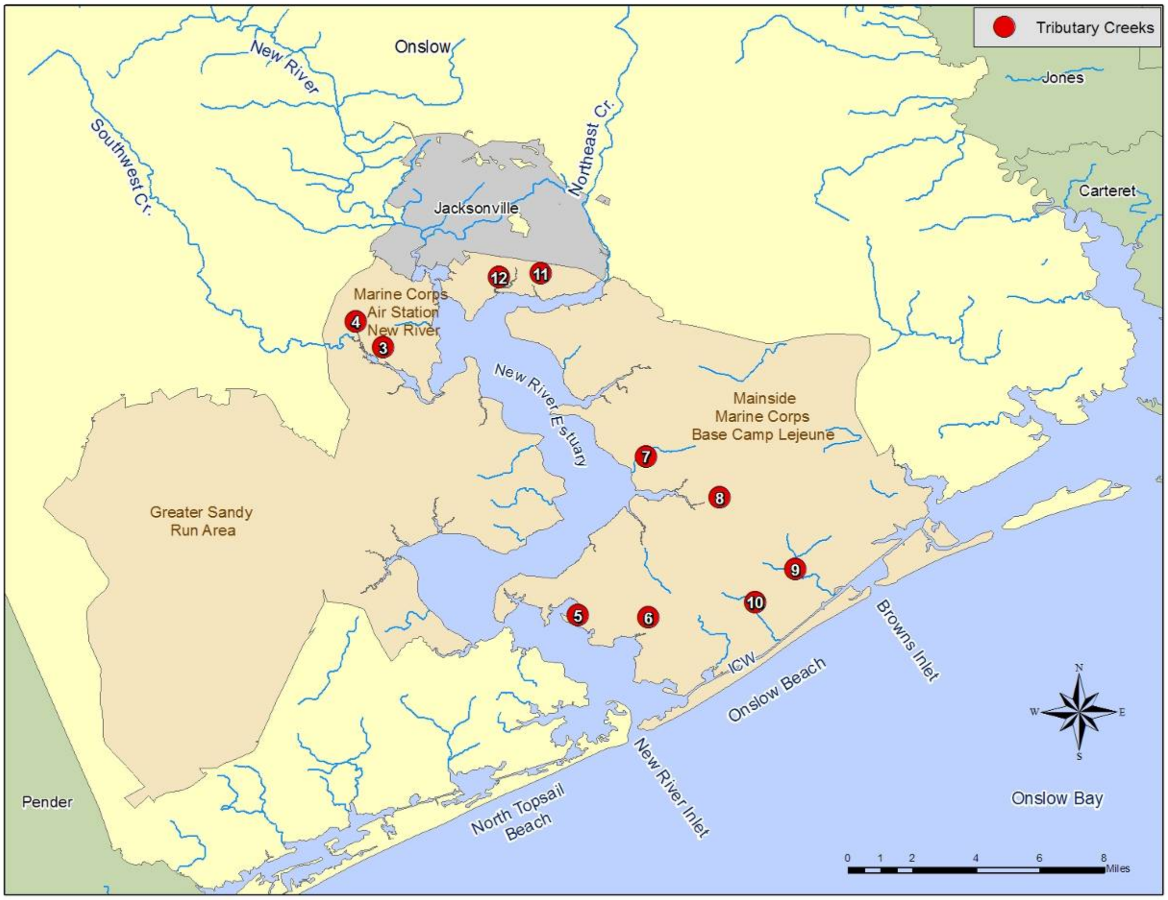

Figure 5-5. Tributary creek sampling stations.

Scheduling Constraints: No changes to this section.
Year 1 Go/No Go Decision Point: No changes to this section.
Budget (Estimated): No changes to this section.

5.1.4.3 Research Project AE-3: Developing Indicators of Ecosystem Function for Shallow Estuaries: Benthic Functional Responses in the New River Estuary

Senior Researcher: Iris Anderson (VIMS)
Supporting Researchers: Mark Brush (VIMS), Mike Piehler (UNC-CH), Carolyn Currin (National Oceanic and Atmospheric Administration [NOAA])

Hypotheses: No changes to this section.

Technical Goals: No changes to this section.

Technical Approach:

(c) Methods: The locations of two sites were changed since the original DCERP Research Plan. The first, Muddy Creek, was located in an artillery fan and was also not a good paired site with Traps Bay. This site was moved to the head of Courthouse Bay (Site 25) near two splash points and extensive shoreline development, making for an ideal impacted site to pair with the relatively pristine Traps Bay and including an active splash point in our design. The original Traps Bay (Site 26) site was moved to another section of the bay because it was too close to a detonation area. The other sampling sites are located at Jacksonville (Site 21), Southwest Creek (Site 22), Wallace Creek (Site 23), French Creek (Site 24), Freeman Creek (Site 27), and Gillets Creek (Site 28) (**Figure 5-7**).

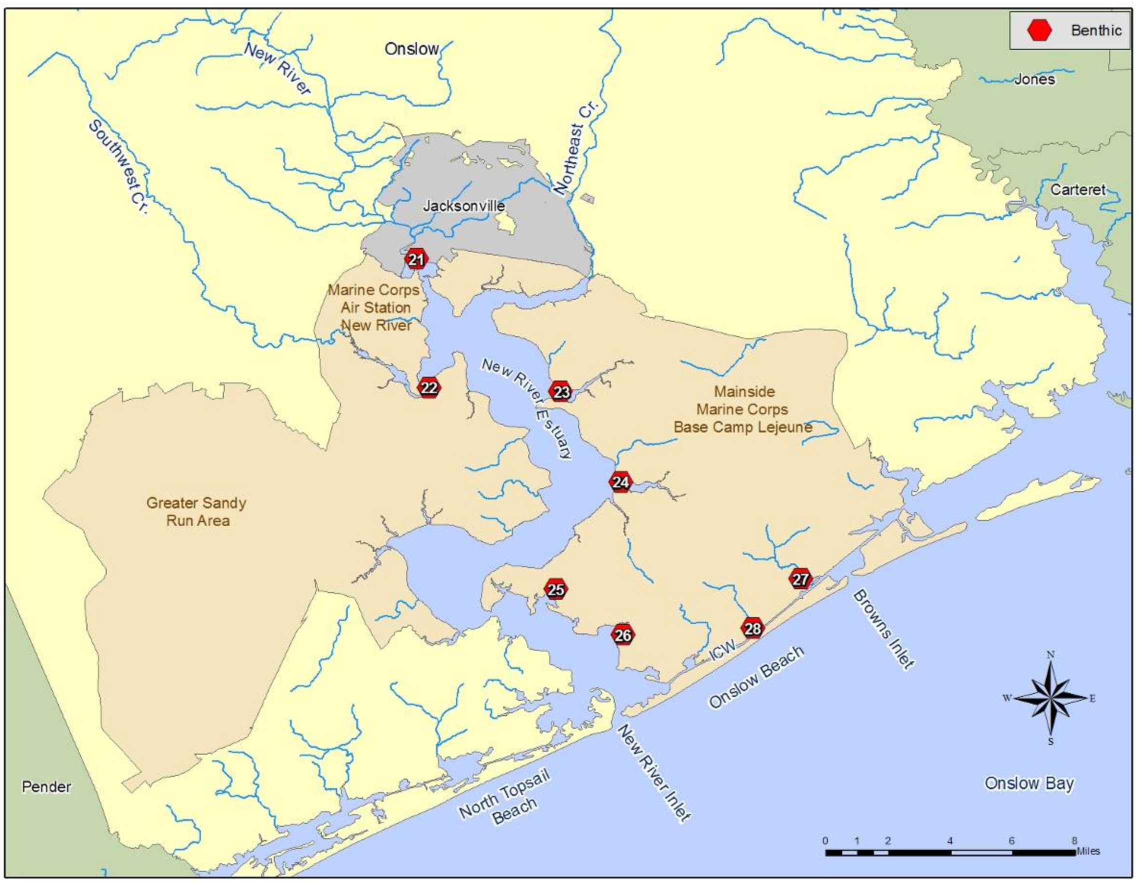

Figure 5-7. New River Estuary—benthic research stations.

Measurements will be collected using a DataFlow system to perform surface mapping of water quality parameters (e.g., dissolved oxygen [DO], chlorophyll *a*, turbidity, colored dissolved organic matter (CDOM), salinity, and temperature). This will allow us to obtain high-resolution data in the shallow waters and tributary creeks to complement the DataFlow monitoring in the main channel (from Aquatic/Estuarine monitoring activity). In addition, if conditions allow, continuous measurements of photosynthetically active radiation (PAR), light attenuation, turbidity, CDOM, and chlorophyll *a* will be performed during MCBCL training maneuvers at specific splash zones within the NRE. During these intensive studies, continuous data will be collected by deploying logging data sondes and light sensors.

The proposed experimental methods have been modified for Years 2 and 3 to improve the design and to obtain even more data than originally planned. Initially, experiments were going to be conducted at four stations in Year 2 and at four stations in Year 3. Now experiments will be conducted at six stations in Year 2 (excluding the Intracoastal Waterway [ICW] sites). This will open up Year 3 to conduct a factorial experiment in which we manipulate light quality and quantity and nutrient loading, which will allow us to more conclusively test our hypotheses.

During Year 2, study sites in the low- to mid-mesohaline zone will be chosen in conjunction with the Coastal Wetlands Module. Sites will be stratified to assess the impacts of local and regional land use, including the role that wetlands play in mitigating the impacts of land use and improving light quality and quantity. During Year 3, study sites will be chosen in the high mesohaline and polyhaline zones, including backbarrier sites. Development of the ESM will take place during all years of the study. During Year 4, analyses of samples taken during the previous years will be completed, and these data will be used to validate the ESM developed during Years 1–3 and to test various scenarios using the ESM. Stations will be chosen within individual salinity regimes that reflect the range of disturbance within that regime. Studies will be performed during each of the four seasons.

Seasonally, we will measure the inherent optical properties of the water column at each site using a WET Labs, Inc. ac-spectra instrument (Gallegos et al., 2005) and will measure the three optically active constituents (i.e., turbidity, chlorophyll and CDOM) in the water column by deploying both a WET Labs CDOM detector and a Yellow Springs Instruments, Inc. (YSI) data sonde that is fitted with wiped sensors for detecting PAR, light attenuation, DO, chlorophyll *a* fluorescence, turbidity, salinity, and temperature. We will supplement these measurements with laboratory analyses of particulate absorption, chlorophyll *a*, and total suspended solids (TSS). Radiative transfer modeling (Mobley, 1994) can then be used to predict apparent optical properties, specifically the diffuse attenuation coefficient K_d (Gallegos, 2001), which determines the amount and quality of light reaching the bottom, which in turn controls the rate of benthic microalgal production (Pinckney and Zingmark, 1993; MacIntyre and Cullen, 1996). We will measure the metabolism of benthic microalgae (BMA), the water column, and any dominant macroalgae by developing series of photosynthesis-irradiance curves in a light-gradient box (Goebel et al., 2006). Metabolic rates will be quantified from changes in DO concentrations over time as measured with a Hach optical DO sensor.

Concurrently, to determine the effects of ambient light conditions and nutrient enrichment on benthic–microalgal modulated fluxes of nutrients and on transformations of nutrients within sediments, sets of cores will be randomly taken at each sampling site, incubated in situ for 48 hours, and sampled at 6-hour intervals to determine metabolic and nutrient cycling rates, mineralization, and denitrification, as described by Anderson and colleagues (2003). Nitrogen mineralization will be measured using a $^{15}NH_4^+$ isotope-dilution technique (Anderson et al., 2003). Denitrification and N fixation will be measured following the addition of $^{15}NO_3^-$ and using a combination of isotope-pairing and membrane inlet mass spectrometry techniques (An and Joye, 2001). All isotopic analyses will be performed at UNC-W Center for Marine Science (CMS) via continuous flow on a Thermo Scientific Delta V isotope ratio mass spectrometer. To synthesize results from benthic and water column metabolic measurements and provide a useful indicator of disturbance, high-frequency time-series oxygen data from deployed sensors and the autonomous vertical profilers (Research Project AE-1) will be used to quantify total ecosystem metabolism.

During Year 3, manipulation experiments will be performed to better understand the roles that nutrient enrichment and light quality and quantity play in regulating ecosystem metabolism and nutrient cycling. Unlike the in situ experiments performed during Year 2, these experiments will involve a full factorial design with multiple nutrient concentrations and light levels under controlled conditions within an environmental chamber.

The results from Research Project AE-3 will be integrated with the results from Research Projects AE-1 and AE-2, and all other DCERP modules, and they will be scaled to the entire NRE using a mechanistic, spatially explicit ESM to predict biogeochemical cycling of carbon (C), N, P, and DO and food web dynamics from nutrient and sediment inputs through secondary production available to fish and shellfish. The modeling methods remain the same as in the original DCERP Research Plan. First, a two-layered box model of the system will be created to predict hydrodynamic exchanges among relatively coarse boxes arranged along the estuarine salinity gradient. This box model will allow us to focus on developing the biogeochemical and ecosystem formulations, which will be coupled to the highly resolved Advanced Circulation (ADCIRC) Model in Year 4 to develop the ESM.

Scheduling Constraints: No changes to this section.
Year 1 Go/No Go Decision Point: No changes to this section.
Budget (Estimated): No changes to this section.

5.2 Coastal Wetlands Module

5.2.1 Introduction

The following three research projects (**Table 5-2**) of the Coastal Wetlands Module address challenges that are associated with stresses imposed as a consequence of MCBCL and other direct anthropogenic activities and of global climate change, particularly sea-level rise. The title of Research Project CW-1 is the only change in Table 5-2.

Table 5-2. Coastal Wetlands Module Research Project Title, Senior Researcher, Benefit to MCBCL, and Duration of Project

Research Project	Research Project Title and Outcome	Senior Researcher and Duration
CW-1	*Determine Responses of Marsh Vegetation and Accretion to Relative Surface Elevation*	Jim Morris
	Outcomes and Benefits to the Base: Data derived from these research activities will be used to parameterize a model of sediment accretion, forecast the marsh response to stressors (e.g., amphibious maneuvers, sea-level rise), and will quantify the marsh response to fertilization by N and P (a potential mitigation strategy).	7/2007–6/2011
CW-2	*Forecast Influence of Natural and Anthropogenic Factors on Estuarine Shoreline Erosion Rates*	Mark Fonseca
	Outcomes and Benefits to the Base: This work will inform about shoreline stabilization and wetland restoration efforts and will assess the impacts of tactical vehicles.	7/2007–6/2011
CW-3	*Hydraulic Exchange and Nutrient Reactivity in the NRE Wetlands*	Craig Tobias
	Outcomes and Benefits to the Base: Data derived from these research activities will provide information on the value of the marshes as nutrient transformers and the magnitude of sub-surface nutrient flux to the estuary.	7/2008–6/2011

5.2.2 Knowledge Gaps in Conceptual Model and Research Needs

No changes to this sub-section.

5.2.3 Benefit to MCBCL

No changes to this sub-section.

5.2.4 Proposed Research Projects—Coastal Wetlands

Research projects proposed by the Coastal Wetlands Module address three major themes. Two of these research projects, CW-1 and CW-2, address changes in geomorphology driven by sea-level change, impacts from amphibious maneuvers, and wave erosion. Research Project CW-3 addresses the flux of shallow groundwater from upland areas through the marshes and the transformation of nutrients in ground water that transits the marsh. Research sites are strategically chosen to take advantage of significant activity (e.g., amphibious operations, splash points), proximity to upland land uses (e.g., groundwater, nutrient flux), research and monitoring by other modules (e.g., barrier island migration), or other significant attributes (e.g., shoreline stabilization structures).

Marsh research areas (Sites 1 and 2 in **Figure 5-10**) on the seaward side of the ICW are behind the barrier island and will provide information on how these landforms interact. For example, does the dune complex provide a sediment subsidy to the wetlands? How fast are the dunes migrating? Sites at Mile Hammock Bay near Tactical Landing Zone (TLZ) Bluebird (Site 3 in Figure 5-10) are located near landing craft air cushion (LCAC) amphibious training zones. Operations at one LCAC training zone have been discontinued and will provide information on the recovery rates of marshes. Results on marsh accretion and erosion obtained at the active LCAC training site will be contrasted with measurements made in the relatively undisturbed Freeman Creek (Site 1) and Onslow Beach Backbarrier (Site 2).

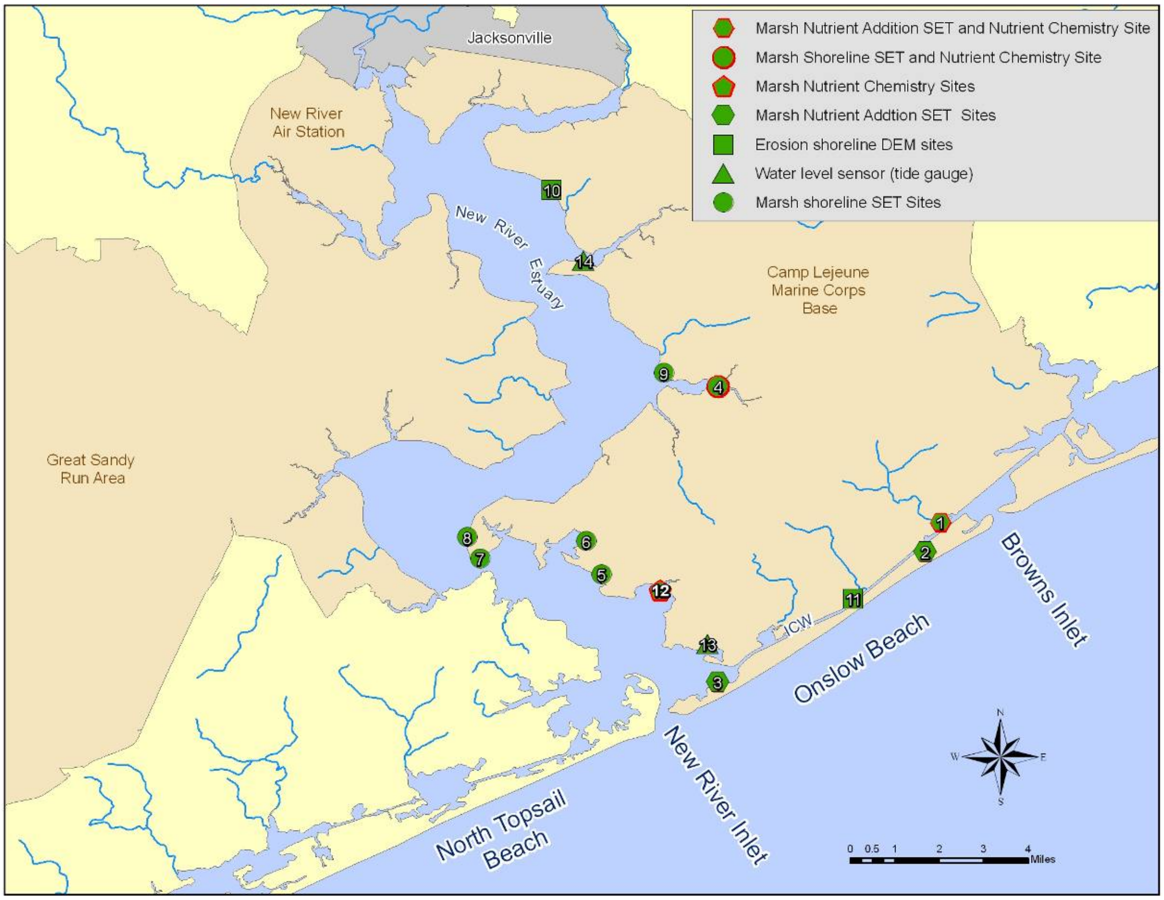

Figure 5-10. A site map with the approximate locations of research stations.

Figure 5-10 shows the locations of all of the research stations, as well as the monitoring stations because many of these activities are co-located.

- Site 1 (Freeman Creek): Moderate military use (G-10 impact zone runoff), higher salinity, and proximity to coastal barrier island
- Site 2 (Onslow Beach Backbarrier): Not-impacted by military use, high salinity, and proximity to coastal barrier island
- Site 3: (Mile Hammock Bay): High military use (LCAC): Closest proximity to the New River Inlet
- Sites 4 and 9 (French Creek, inside and outside splash point): Moderate impact (runoff from G-10 impact area, splash points at mouth) and lower salinity
- Sites 5 and 6 (Courthouse Bay, outside and inside splash point): Moderate impact from cantonment area and splash point and higher salinity

- Sites 7 and 8 (Highway 172 bridge, inside and outside): Moderate impact from boat traffic and moderate salinity
- Site 10 (Hospital Point): Area with a stabilized shoreline, low salinity, and wave exposure setting
- Site 11 (ICW): Area with a stabilized shoreline, high salinity, and wave exposure setting
- Site 12 (Traps Creek): Forested training lands and moderate salinity
- Sites 13 and 14 (Mile Hammock Bay and Gottschaulk Marina): Tide gauges.

5.2.4.1 Research Project CW-1: Determine Responses of Marsh Vegetation and Surface Elevation to Nutrients

Senior Researcher: Jim Morris (University of South Carolina [USC])
Supporting Researcher: Carolyn Currin (NOAA)

Hypotheses: No changes to this section.

Technical Goals: No changes to this section.

Technical Approach

(b) Experimental Design:

The overall experimental design for this research project has not changed; however, the following text reflects changes to the stations for this experiment.

Hypothesis 1) Intertidal salt marshes will equilibrate at an elevation within the tidal frame that is inversely proportional to the rate of sea-level rise. Stations for this experiment will be established at Sites 1, 2, and 3 (see Figure 5-10). The parameter values in the model will be derived by repeated measurements of marsh surface elevation in plots that vary in treatment (see Hypothesis 3), as well as through the use of experiments designed specifically to define various response variables. One of these is a type of planter known as a “marsh organ” that raises or lowers the marsh surface experimentally. The device is planted with recruits taken from the neighboring marsh, and after a season of growth, the harvest of roots and shoots gives the biomass response to relative elevation, which is a critical relationship in the MEM2.

Hypothesis 2) The equilibrium elevation of salt marshes in sites where amphibious training reduces standing biomass density will decrease relative to undisturbed controls. Replicate (2) surface elevation table (SET) plots will be established at TLZ Bluebird (Site 3 in Figure 5-10) and the results contrasted with results obtained in control areas (Sites 1 and 2 in Figure 5-10). The hypothesis will be rejected if the biomass of Site 3 is lower than Sites 1 and 2 and the elevation of Site 3 rises at a lower rate than at Sites 1 and 2. An SET experiment will also be established at an adjacent site where amphibious landings have been discontinued. At that site, we expect to find that the marsh is recovering (biomass and elevation increasing). SETs will be used opportunistically, as well to take advantage of episodic events such as storms or training exercises.

Hypothesis 3) The equilibrium elevation of salt marshes can be increased by raising biomass density either by fertilization or by modifying the training schedule. A fertilization experiment with N plus P nutrients added to 1.5- x 1.5-m^2 plots of salt marsh will be replicated (3) and instrumented with SETs. The experiment will be conducted over 5 years to allow time for equilibration and inter-annual variability in mean sea level. During this time, the marsh elevation in the fertilized plots and controls will be monitored with an SET every 2 months. The hypothesis will be rejected if the elevation of these experimental plots does not increase relative to controls.

Hypothesis 4) The skewness of the frequency distribution of relative marsh elevation is a diagnostic of its vulnerability to sea-level rise or disturbance (e.g., storms, amphibious maneuvers). Light detection and ranging (LIDAR) data that are taken from the marsh surface will be analyzed and frequency distributions will be plotted and a skewness statistic will be computed for spatially distributed subsets of data. These skewness distributions will be mapped and regressed against absolute normalized elevations. Hypothesis 4 can be rejected if no correlation is found between absolute elevation and skewness.

(c) Methods: SETs were established at Sites 1–3. At Freeman Creek (Site 1), six SETs were established to support fine-scale (±2-mm vertical resolution) measures of marsh elevation change in response to nutrient additions. For this research project, the marsh vegetation that surrounds three of the SETs will be fertilized with N and P, which should dramatically increase biomass density. Comparison of the sedimentation rates in the three fertilized and the three control SET plots will allow us to assess the influence of biomass density on sedimentation rate and will provide an important parameter value for the MEM2. Twelve 1.5- x 1.5-m plots were established along the Freeman Creek boardwalk to support a factorial design for determining the limiting nutrient for marsh primary production (**Figure 5-14b**). At the Mile Hammock Bay (Site 3) and Onslow Beach Backbarrier (Site 2), only two SETs were installed at each: one will serve as a control, and the other will receive the +N+P fertilizer treatment applied quarterly as P_2O_5 and $(NH_4)_2SO_4$ at a rate of 15 mol m^{-2} yr^{-1} of P and 30 mol m^{-2} $yr^{-1}$of N (Figure 5-14A). Additional 2- x 2-m plots have been established at each site to accommodate two more replicates of the control and +N+P treatments. At all 2- x 2-m plots, we will measure above-ground marsh primary production (end of season standing biomass) and sediment accretion using marker horizons.

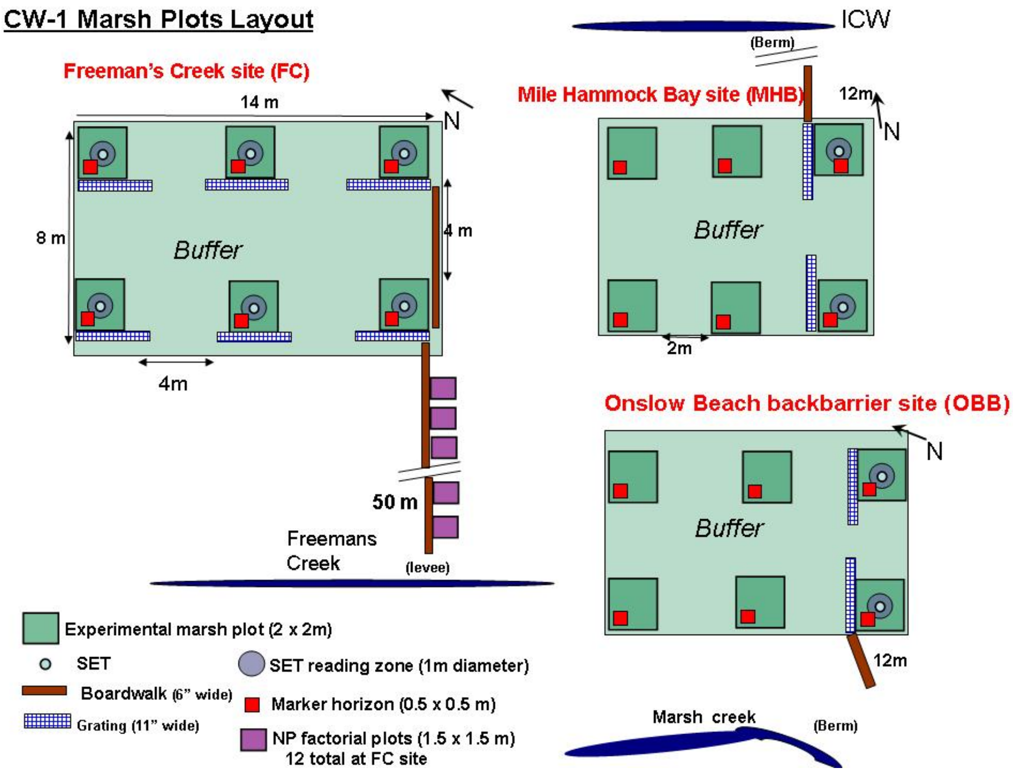

Figure 5-14b. Schematic of the three sites established to support the marsh surface elevation monitoring and Research Project CW-1. Each surface elevation table (SET) provides a means to measure changes in marsh surface elevation with a ±2-mm resolution.

Fertilizer treatment will be added seasonally during the growing season for 4 years. Biomass will be measured nondestructively in the plots, and marsh surface elevations will be measured every 2 months. At the conclusion of the experiment, the vegetation will be harvested and the model will be calibrated. Separate plots fertilized with only N or P will be used to determine the identity of the primary and secondary limiting nutrients, and plants will be harvested at the end of the season (EOS) for measurement of EOS biomass, and these measurements will be contrasted with EOS biomass measurements taken from nearby control plots.

The response of the marsh vegetation to relative marsh surface elevation will be measured using in situ, experimental planters (marsh organs) that simulate conditions at different positions within the tidal frame. Two marsh organs have been deployed at Freeman Creek (Site 1). One marsh organ will serve as the control and one marsh organ will be treated with N and P to determine if there is an interaction between relative elevation and fertility. The marsh organs will be harvested at the EOS, and the resulting data will show both the responses of above- and below-ground biomass to elevation. Below-ground biomass may have an important effect on marsh accretion or elevation change, and it is a variable that is needed to parameterize the MEM2.

Net primary production (NPP) will be measured nondestructively in plots where SET measurements are made. One nondestructive method requires a census and measurements of stem heights (Morris and Haskin, 1990). We have found that salt marsh NPP is highly correlated with EOS biomass (Morris, in press), as measured by summing stem heights, and we will use this technique, which will allow for a much greater spatial coverage than the labor intensive method of making monthly measurements.

High spatial resolution (ca. 1 m) multispectral data taken from satellite or aircraft will be classified to the level of major plant communities using a trained artificial neural network (Morris et al., 2005). Period imagery will be examined to identify changes in area, geometry, and position. LIDAR data will be used to map marsh elevations and to derive diagnostic frequency distribution, provided that LIDAR data with resolution less than 1 m are available.

(d) Data Analysis: (1) Marsh Sediment Accretion: No changes to the data analysis of this component. (2) Model Synthesis: There have been new theoretical developments on the MEM2. These new developments relate to the inclusion of organic matter production and a more realistic description of the biomass response curve in the model. We are using a more sophisticated software package (currently Mathematica) that has the capability of solving equations symbolically. This software has allowed us to derive a more complex and more realistic version of the MEM2. This new, improved model is the one that we are currently planning to implement for the Base. (3) Marsh Elevations: Preliminary analysis of current LIDAR data for MCBCL suggests that the spatial resolution of the data is on the order of 20 m. We need data that has a posting density of approximately 1 m. We have not yet obtained multispectral imagery needed to classify the LIDAR data. If high-resolution LIDAR data are not available, we will use the elevation response curve from the marsh organs with global positioning system estimates of the present marsh elevations (from monitoring activities) to evaluate where the marshes lie relative to the tipping point.
Scheduling Constraints: No changes to this section.
Year 1 Go/No Go Decision Point: No changes to this section.
Budget (Estimated): No changes to this section.

5.2.4.2 Research Project CW-2: Forecast Influence of Natural and Anthropogenic Factors on Estuarine Shoreline Erosion Rates

Senior Researcher: Mark Fonseca (NOAA) **Supporting Researcher:** Carolyn Currin (NOAA), Amit Malhotra (NOAA)
Hypotheses: No changes to this section.
Technical Goals: No changes to this section.
Technical Approach: No changes to this section.
Scheduling Constraints: No changes to this section.
Year 1 Go/No Go Decision Point: If we cannot successfully calibrate the WEMo model for the NRE shoreline, development of the New River Estuary Shoreline Erosion (NRESE) model will be a No Go because we will not be able to obtain a spatially explicit estimate of wave energy to accompany measures of shoreline erosion, vegetation, and sediment accretion for use in the NRESE model. We are on schedule to be able to successfully calibrate the WEMo and do not foresee any reason not to accomplish our research project goals.
Budget (Estimated): No changes to this section.

5.2.4.3 Research Project CW-3: Hydraulic Exchange and Nutrient Reactivity in the NRE Wetlands

Senior Researcher: Craig Tobias (UNC-W) **Supporting Researcher:** Jim Morris (USC)
Hypotheses: No changes to this section.
Technical Goals: No changes to this section.
Technical Approach: **(b) Experimental Design:** Linear arrays of piezometers will be established along transects through different three marsh sites parallel to the flow path. The sites originally proposed were Wallace, Freeman, and Gillets creeks. The site locations have been changed to French Creek, Traps Bay, and Freeman Creek. Freeman Creek (Site 1) was selected because it represents a tidally dominated euryhaline marsh, and it is co-located with other Coastal Wetlands Module monitoring activities and research projects. French Creek (Site 4) was selected because of its proximity to the G-10 impact area and its proximity to the MCBCL wastewater treatment plant. French Creek is also a representative meso-oligohaline, irregularly flooded marsh that is characteristic of the upper NRE. Traps Creek (Site 12) is a representative mesohaline, mixed-vegetation, pocket-marsh ecotype that is bisected by an incised stream channel. French and Traps creeks will serve nicely as model marshes because of their respective ecotypes in terms of geomorphology, biology, and hydrology.

Scheduling Constraints: No changes to this section.
Year 1 Go/No Go Decision Point: No changes to this section.
Budget (Estimated): No changes to this section.

5.3 Coastal Barrier Module

5.3.1 Introduction

The proposed research projects of the Coastal Barrier Module build upon the monitoring data, are linked within the module and between modules, and address the most pressing military drivers and goals (**Table 5-3**). The research projects will use the monitoring data to develop maps of shoreline change and the underlying cause for spatial variations in coastal retreat rates, as well as make recommendations to enhance the Base's shorebird monitoring protocol. Conceptual models that predict the morphology and location of the shoreline will be developed. Barrier response to extreme storm events and the rate of recovery will be derived. There have been no changes to Table 5-3.

Table 5-3. Coastal Barrier Module Research Project Title, Senior Researcher, Benefit to MCBCL, and Duration of Project

Research Project	Research Project Title and Outcome	Senior Researcher and Duration
CB-1	*Short-Term Barrier Evolution Related to Storms and Land Use*	Jesse McNinch
	Outcomes and Benefits to the Base: This project will help mitigate Onslow Beach erosion that results from natural impacts (e.g., storms, climate, and sea level), training activities, and management practices.	7/2009–6/2011
CB-2	*Long-Term Barrier Evolution Related to Variations in Underlying Geology, Land Use, and Inlet Dynamics*	Tony Rodriguez
	Outcomes and Benefits to the Base: This project will assess the principle drivers of Onslow Beach erosion, including natural (e.g., storms, climate, sea-level rise, underlying geology) and anthropogenic (e.g., training activities and management practices) stressors.	7/2009-6/2011
CB-3	*Understanding the Top-Down and Bottom-Up Drivers of Shorebird Nest Success and Habitat Use in Relation to Beach Management Practices on MCBCL*	Sarah Karpanty and Jim Fraser
	Outcomes and Benefits to the Base: Results will be used to develop efficient monitoring protocols and conservation management procedures for shorebirds and seabirds and to best design mitigation in the case of beach nourishment or the introduction of new uses to the coastal barrier ecosystem. Pilot studies of predator top-down influences will allow MCBCL to design the most efficient use of trapping resources and minimize the frequency of trapping and the co-occurrence of trapping efforts with human uses of the coastal barrier islands.	7/2007–7/2010

5.3.2 Knowledge Gaps in Conceptual Model and Research Needs

No changes to this sub-section.

5.3.3 Benefit to MCBCL

No changes to this sub-section.

5.3.4 Proposed Research Projects—Coastal Barrier

5.3.4.1 Research Project CB-1: Short-Term Barrier Evolution Related to Storms and Land Use

There have been no changes to this research project.

5.3.4.2 Research Project CB-2: Long-Term Barrier Evolution Related to Variations in Underlying Geology, Land Use, and Inlet Dynamics

There have been no changes to this research project.

5.3.4.3 Research Project CB-3: Understanding the Top-Down and Bottom-Up Drivers of Shorebird Nest Success and Habitat Use in Relation to Beach Management Practices on MCBCL

Senior Researchers: Sarah Karpanty (Virginia Tech [VT] and Jim Fraser (VT)
Supporting Researcher: Pete Peterson (UNC-CH)

Hypotheses: No changes to this section.

Technical Objectives/Goals: No changes to this section.

Technical Approach:
(c) Methods: There have been no changes to the methods of Research Project CB-3; however, the location of the stations was not indicated in the original DCERP Research Plan. **Figure 5-21** shows the location of the cameras for predator evaluation (Sites 22–37), as well as the other stations for the Coastal Barrier Module monitoring and research program. Sixteen camera sites are equally divided between the ocean side and marsh side of the coastal barrier island with eight sites in the northeast recreational use portion of the island and eight in the southwest military-use portion of the island (**Table 5-4b**).

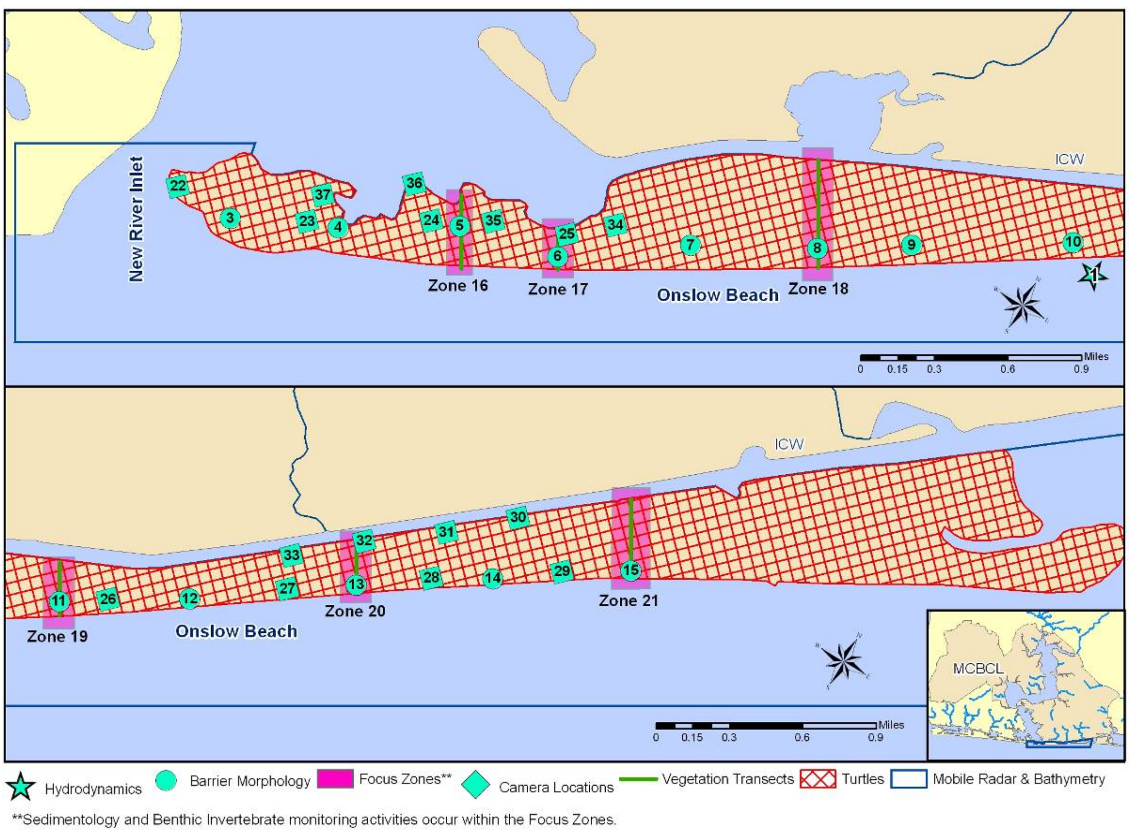

Figure 5-21. Coastal Barrier Module monitoring sites.

Table 5-4b. Monitoring and Research Stations for the Coastal Barrier Module

Hydrodynamics	
Site 1: Riseley Pier	
Barrier Morphology	
Site 3: South Onslow Beach, training	Site 10: South Onslow Beach, training
Site 4: South Onslow Beach, training	Site 11: North Onslow Beach, recreation (Focus Site 19)
Site 5: South Onslow Beach, training (Focus Site 16)	Site 12: North Onslow Beach, recreation
Site 6: South Onslow Beach, training (Focus Site 17)	Site 13: North Onslow Beach, recreation (Focus Site 20)
Site 7: South Onslow Beach, training	Site 14: North Onslow Beach, recreation
Site 8: South Onslow Beach, training (Focus Site 18)	Site 15: North Onslow Beach, recreation (Focus Site 21)
Site 9: South Onslow Beach, training	
Focus Sites (Sedimentology and Benthic Invertebrate Monitoring)	
Site 16: ORRVs with overwash behind the beach	Site 19: Amphibious landings (low-use training activity)
Site 17: ORRVs with salt marsh behind the beach	Site 20: Extensive human disturbance
Site 18: Amphibious landings (high-use training activity)	Site 21: Limited human disturbance
Camera-Trapping Locations	
Site 22: Oceanside, south training, facing southeast	Site 30: Marsh, north recreation
Site 23: Oceanside, south training, facing northeast	Site 31: Marsh, north recreation
Site 24: Oceanside, south training, facing southeast	Site 32: Marsh, north recreation
Site 25: Oceanside, south training, facing southeast	Site 33: Marsh, north recreation
Site 26: Oceanside, north recreation, facing southeast	Site 34: Marsh, south training
Site 27: Oceanside, north recreation, facing southeast	Site 35: Marsh, south training
Site 28: Oceanside, north recreation, facing southeast	Site 36: Marsh, south training
Site 29: Oceanside, north recreation, facing southeast	Site 37: Marsh, south training, facing northeast

Scheduling Constraints: No changes to this section.

Year 1 Go/No Go Decision Point: No changes to this section.

Budget (Estimated): No changes to this section.

5.4 Terrestrial Module

5.4.1 Introduction

The two research projects proposed for the Terrestrial Module (**Table 5-5**) constitute an integrated program that is designed to provide a greater understanding of how forest management, and especially PB, affect plant and animal communities across the soil-moisture gradient. The relationship between RCW foraging habitat quality and community composition will be an outcome of this understanding. These research projects build upon the vegetation monitoring proposed for the Terrestrial Module, which will provide much of the data to be used in assessing relationships between management and community composition.

Table 5-5. Terrestrial Module Research Project Title, Senior Researcher, Benefit to MCBCL, and Duration of Project

Research Project	Research Project Title and Outcome	Senior Researcher and Duration
T-1	*Varying Prescribed Fire Regimes and Forest Management Effects on Terrestrial Ecosystem Structure and Function*	Norman Christensen
	Outcomes and Benefits to the Base: The results of this research project will provide measures of the effects of military and forestry activities on plant and animal communities and guidance on how best to mitigate any adverse effects of such activities.	1/2008–6/2011
T-2	*Effects of Habitat Management for Red-Cockaded Woodpeckers on Bird Communities*	Jeffrey Walters
	Outcomes and Benefits to the Base: The outcomes of this research project will be an efficient method to measure quality of RCW habitat over a large spatial extent and analysis of effects of management on not only the endangered RCW, but also another species at risk, the Bachman's sparrow.	1/2008–6/2011

5.4.2 Knowledge Gaps in Conceptual Model and Research Needs

No changes to this sub-section.

5.4.3 Benefit to MCBCL

No changes to this sub-section.

5.4.4 Proposed Research Projects—Terrestrial

5.4.4.1 Research Project T-1: Effects of Different Understory Restoration Management Options on Terrestrial Ecosystem Structure and Function

This research project was revised and submitted to SERDP in June 2008.

Senior Researcher: Norm Christensen (Duke)
Supporting Researcher: Jeff Walters (Virginia Tech)

Hypotheses:

1. Herbaceous cover, productivity, and species diversity will increase with increasingly aggressive measures to remove understory hardwood shrubs and trees and control the reproduction of these trees and shrubs (mechanical thinning, herbicide, and mechanical thinning plus herbicide).
2. These effects will vary depending on the season of mechanical thinning (growing season versus dormant season).
3. Effects of restoration treatments will be further augmented by mechanical removal of forest floor and thick organic duff.
4. Artificial seeding of native herbaceous species will significantly accelerate the restoration of understory herbaceous communities and will facilitate the restoration of low-intensity, high-frequency fire regime.

5. Changes in the composition, productivity, and diversity of the herbaceous community will be highly correlated with variations in the composition of insect and bird communities.
6. Forest management activities will have their greatest impacts on species richness and composition in moister sites compared to dryer sites.

Technical Objectives/Goals: Measure impacts of different forest understory and midstory control techniques (mechanical operations with HydroAx, herbicide, mechanical plus herbicide) and different seasons (growing versus dormant) of mechanical operations on forest stand and herbaceous layer cover, composition, production, and diversity, and the abundance of key insect and bird species. Research Project T-1 will provide an understanding of the mechanistic connections among trophic levels that determine avian habitat (particularly RCW). This research will focus on numerous data gaps including the following:

1. Effects of variations in understory forest restoration techniques
2. Impacts of forest restoration management on herbaceous communities and the interaction of those activities with fire management
3. Connections between restoration of herbaceous communities and habitat for insect and bird communities
4. Improved understanding of the variations in these effects among different site conditions within the general loblolly pine plantation forest type.

These results will bear directly on Base forest management objectives, including the following:

1. Restoration of longleaf pine habitat
2. Recovery of RCW populations
3. Conservation of native biological diversity
4. Support for military maneuvers—Expansion of available training area by opening understory, facilitating troop movement
5. Promoting sustainable forest management
6. Improving knowledge of fire and fuel management

Conditions for the Project: Thirty- to 60-year-old stands dominated by loblolly pine with a robust understory and hardwood midstory are widespread at MCBCL and are a central target for restoration management by the MCBCL staff.

Technical Approach

(a) Background: The research projects in the Terrestrial Module primarily focus on critical knowledge gaps related to efforts to restore longleaf pine ecosystems on sites across MCBCL that have been modified by past forest management activities. Specifically, the Terrestrial Module team will examine the effects of alternative understory restoration strategies (e.g., mechanical operation, herbicide application, prescribed fire) on understory plant and insect communities and, ultimately, on avian habitat (particularly habitat for RCWs). Land use and forestry activities over the past two centuries have converted tens of thousands of acres of the MCBCL terrestrial landscape from longleaf pine dominated forests to forests dominated by loblolly pine and hardwoods. This transformation has been extensive on many of the most productive sites that occur along the soil moisture gradient between well-drained sandy soils and organic soils in pocosins.

Over the past 50 years, many areas were purposefully planted in loblolly pine following harvest activities. Most of these sites were protected from fire, resulting in substantial in-growth of intermediate height hardwoods, such as wax myrtle, and the accumulation of a thick organic forest floor and duff. These forests support considerably less herb-layer diversity and productivity than their pre-disturbance counterparts. Little is known about their insect fauna, but current conditions in these forests do not provide a suitable habitat for those avian species that are typically found in longleaf pine ecosystems. Furthermore, hardwood in-growth and forest floor accumulation are significant challenges to the restoration of the high frequency, low-intensity fire regimes necessary to restore longleaf pine ecosystems (ESA 2007; Nowacki and Abrams, 2008).

In some parts of MCBCL, restoration has taken the form of clear cutting, followed by planting of longleaf pine and eventual reestablishment of an appropriate prescribed fire program. Restoration of mature longleaf habitat by this approach will require many decades. As an alternative strategy to accelerate habitat restoration, MCBCL staff has implemented thinning treatments to reduce overstory tree density (40–60 ft^2/acre), remove mid-story hardwoods, and create open-stand structure and understory composition and fuels that are more typical of longleaf pine ecosystems. Such management is currently being applied to hundreds of MCBCL acres each year. Variations on this management theme include different seasons (growing/dormant) of mechanical control of the woody understory and the use (or not) of herbicides. All such areas receive a late winter/early spring prescribed fire in the year following treatment.

Currently, restoration treatments do not include specific actions related to reducing forest floor duff or exposing mineral soil, even though these features are known to influence both fire behavior and patterns of understory plant establishment and growth. Prescribed fire is used to reduce duff and coarse woody over time, but may result in more intense soil heating. In moist situations, this duff layer resists burning. In addition, patterns of vegetation change following such treatments are likely influenced by the availability of seed of longleaf ecosystem species.

Dr. Joan Walker of the USDA Forest Service is currently performing other SERDP-sponsored research to examine patterns of establishment of longleaf pine in response to overstory and midstory thinning treatments. Their specific effects on other understory components (e.g., vegetation, forest floor, and fuels), insects, and avifauna have not been studied. The needs of RCWs are well known, but virtually nothing is known about the community dynamics between the plants at the base of the food chain and the RCW at the top or within the consumer community at the top, beyond the RCW (U.S.

FWS, 2003). New regulations from the FWS require MCBCL to convert most of the pine acreage on the Base into high-quality foraging habitat for RCWs and to be able to quantify habitat quality; therefore, a greater understanding is needed about how intensive management for RCW may affect other species. The effects of restoration treatments on understory vegetation are especially relevant because the composition of this community is a major determinant of RCW habitat quality (U.S. FWS, 2003).

The two research projects (T-1 and T-2) planned for the Terrestrial Module constitute an integrated program designed to provide a greater understanding of how forest restoration treatments (e.g., mechanical and herbicide removal of woody understory, manipulation of the forest floor, and additions of seeds of herbaceous species) affect plant and animal communities across the soil-moisture gradient relevant to such management. The relationship between the RCW foraging habitat quality and herb and insect community composition will be an outcome of these projects. These research projects will build on the vegetation monitoring proposed for the Terrestrial Module, which will provide much of the data to be used in assessing relationships between management and plant community composition. The two Terrestrial Module research projects include more components that add to that foundation, specifically experimental plots and sampling of more plant, insect and avian components of the community.

(b) Experimental Design:

Independent variables will include:

- Midstory and understory hardwood removal using growing season and dormant season HydroAx treatments, herbicide, and the combination of HydroAx and herbicide treatments.
- Soil/site moisture. A range of soil/site moisture conditions exists in each stand. These conditions will be measured and treated as a continuous variable and characterized by soil organic matter and depth to water table.
- Addition of native herbaceous seed. To be done on small (10 x10 m) plots within the experimental plots
- Manipulation of forest floor and surface organic duff. To be done on small (10x10 m) plots within experimental plots.

Dependent variables will include:

- Herbaceous layer species composition and relative abundance (annually sampled). In addition, fuel amounts will be measured after Andrews and Bradshaw (1997).
- Herbaceous biomass and fuels (continuous)
- Insect species composition and abundance (sampled throughout each year)

This research will be carried out in 30-60 year old loblolly pine stands that are slated for eventual restoration to longleaf pine. A series of experimental treatment areas spanning the range of species composition and management activities will be monitored for vegetation change, structure, and species richness. There will be six treatments: 1) no woody understory/midstory removal, 2) mechanical understory/midstory removal—dormant season, 3) mechanical understory/midstory removal—growing season, 4) herbicide application, 5) mechanical plus herbicide application—dormant season, and 6) mechanical plus herbicide application—growing season. Understory restoration treatments will be performed in conjunction with MCBCL's on-going forestry restoration management program. Restoration treatment units will be sufficiently large (>20 acres) to accommodate simultaneous bird community studies to be undertaken by Research Project T-2. All treatments will receive non-growing season prescribed burns (PBs) at 3-year intervals. Each of the six treatments will be replicated at three different locations (i.e., 18 treatment areas). Differences among treatments will be tested using a combination of ANVOVA, ANCOVA and multiple regressions analyses.

(c) Methods:

1. Working with MCBCL staff, stands slated for forest management restoration will be identified across MCBCL. This will mostly involve areas now dominated by loblolly pine, although some areas now supporting longleaf pine or pond pine might also be included. Past fire and land use history will be determined and herb/shrub layer compositional variations will be sampled in identified stands for which such information is currently unavailable. Such stands typically comprise many tens of acres and extend across a gradient of soil-moisture conditions.
2. Within each treatment area, three 1 ha experimental plots will be monitored before and after the treatment applications for species abundance, diversity, cover of herbs, and biomass of woody plants using the methodology established by the North Carolina Vegetation Survey protocol (Peet et al., 1998) as described in the DCERP Baseline Monitoring Plan (RTI, 2007b). In each experimental plot insect/arthropod populations will be monitored in soil-level pit-fall or sticky traps, by sweep-netting surface vegetation, and in traps positioned at standard heights on tree boles (Provencher et al., 2000a & b). Insects will be euthanized and identified in the laboratory to the lowest taxon possible. Bird composition and abundance will be assessed from point vocal samples located across each treatment area at several times throughout the breeding season.
3. Within the 1-ha experimental plots in each treatment, smaller scale (10- x 10-m treatment plots) experiments will be designed to examine the effects of soil surface organic layer removal and addition of seed of native herbaceous species on the development of understory communities. Herb sampling will be adapted from the CVS protocols (Peet et al., 1998). Such treatments will include raking of forest floor duff, soil tilling/disking, and planting seeds of native longleaf ecosystem herbs collected on MCBCL. These treatments cannot be established until the year following mechanical/herbicide treatments. These effects are likely to be significant and might be the focus of future experiments undertaken at much larger scales.

(d) Data Analysis: Data will be analyzed using standard parametric approaches such as analysis of variance and regression. Novel multivariate analyses will include non-metric multidimensional scaling (McCune and Grace, 2002), CART® analysis and Mantel's comparisons (Mantel, 1967). Changes in fuel conditions will be measured and used to estimate fire risk in the context of USFS fire danger rating models (Andrews and Bradshaw, 1997).

(e) Environmental Tools, indicators and other Outcomes:

Potential environmental tools and indicators to come from this project include the following:

- Refinement of forest restoration protocols for pine stands that accelerate restoration to herb, insect, and bird communities typical of longleaf pine ecosystems.
- Species indicators (including alien species) of environment and management regime. This will address Base needs to understand consequences of variation in forest restoration activities on plant and animal abundance and diversity and provide the basis for optimizing management activities with respect to location and timing.
- Indicators of habitat quality for RCW and other avian species. This will include a mechanistic understanding of the connection between fire, management, and the RCW by providing information on trophic connections.

(f) Linkages to other Modules:
This research project will provide direct linkages to the following:

- Directly supports Research Project T-2 related to RCW recovery and management.
- Research Project Air-1 will likely take advantage of prescribed burn activities associated with this research to evaluate optimization of prescribed burnings evaluate optimization of prescribed burnings by minimizing smoke emissions and maximizing vitality of fire-adapted ecosystems
- Results will improve the design and interpretation of terrestrial vegetation baseline monitoring program.

(g) Military Drivers: This project directly addresses military drivers #4, ensuring that MCBCL supports all required military training activities while complying with the ESA, and other wildlife requirements.

(h) Benefit to MCBCL: **Benefits to MCBCL**: Results from this research will be directly applicable to MCBCL's forest restoration program, as well as efforts to restore and manage at-risk (e.g., RCW) species. (Military Driver #4) Compliance with the ESA is an important part of protecting Camp Lejeune's primary mission of training and maintaining combat ready troops. Successfully complying with the ESA enhances the future training uses of the Camp Lejeune ranges, training areas and airspace.

(i) Schedule:

1. Identify and locate experimental locations (3) (working with MCBCL staff) treatment areas (6) within each of these locations. Work with MCBCL staff to develop specific management prescriptions. (7/2008 –12/2009)
2. Establish experimental plots. 1 ha plots will be located and sampled within each treatment area (4/2009).
3. Experimental treatments will be implemented winter and late spring of 2009. Within plot treatments such as seeding and forest floor manipulations will be initiated in summers of 2009 and 2010.
4. Monitor experimental plots and monitor results for all subsequent seasons (5/2009–2/2011)
5. Prepare interim report (2/2011).
6. Prepare final report (6/2011).

Scheduling Constraints: Site identification and pre-sampling will begin in July 2008 in order to implement initial treatments in the late winter and spring of 2009.

Year 1 Go/No Go Decision Point: None identified.

Budget (Estimated):

- Year 1 (July 2007 – June 2008): 0
- Year 2 (July 2008 – June 2009): $ 136,934
- Year 3 (July 2009 – June 2010): $ 141,226
- Year 4 (July 2010 – June 2011): $ 123,380
- Total (July 2007 – June 2011): $ 401,540

5.4.4.2 Research Project T-2: Effects of Habitat Management for Red-Cockaded Woodpeckers on Bird Communities

Senior Researcher: Jeffrey R. Walters (VT)

Hypotheses: No changes to this section.

Technical Objectives/Goals: No changes to this section.

Technical Approach: No changes to this section.

Scheduling Constraints: No changes to this section.
Year 1 Go/No Go Decision Point: None specified; however, this project depends on the success of Research Project T-1 to establish appropriate vegetation plots. If a sufficient number of treatment plots for T-1 cannot be identified, so that T-1 cannot go forward, then the project will have to be redesigned as a purely descriptive study. We anticipate reaching this decision point in June 2009.
Budget (Estimated): No changes to this section.

5.5. Atmospheric Module

5.5.1 Introduction

Research Projects Air-1 and Air-2 represent research in the areas of prescribed burning and nitrogen deposition, respectively (**Table 5-6**). These areas will enable MCBCL to understand its ecosystem's sensitivity to proper forest management, nutrient loadings to sensitive waters, and impacts from off-site sources, such as confined animal feeding operations. The location of Research Project Air-1 studies will be a function of vegetation monitoring sites and research sites selected for the Terrestrial Module.

Table 5-6. Atmospheric Module Research Project Title, Senior Researcher, Benefit to MCBCL, and Duration of Project

Research Project	Research Project Title and Outcome	Senior Researcher and Duration
Air-1	*Optimization of Prescribed Burning (PB) by Minimizing Smoke Emissions and Maximizing Vitality of Fire-Adapted Ecosystems*	Karsten Baumann
	Outcomes and Benefits to the Base: This project will provide an innovative land management tool that can also be used for implementing the Smoke Management Plan (SMP) of the NRE region and other populated regions in the southeastern United States.	7/2008–6/2011
Air-2	*Nitrogen Deposition to Terrestrial and Aquatic Ecosystems*	Wayne Robarge
	Outcomes and Benefits to the Base: The results from this research project will provide information on the amount and composition of atmospheric deposition (especially for N) to the terrestrial and aquatic ecosystems that will be used to model the atmospheric N contribution to the total N budget for the NRE. This project will also provide information on the amount and distribution of rainfall across MCBCL.	7/2007–6/2011

5.5.2 Knowledge Gaps in Conceptual Model and Research Needs

No changes to this section.

5.5.3 Benefit to MCBCL

No changes to this section.

5.5.4 Proposed Research Projects—Atmospheric

5.5.4.1 Research Project Air-1: Optimization of Prescribed Burning (PB) by Minimizing Smoke Emissions and Maximizing Vitality of Fire-Adapted Ecosystems

Senior Researcher: Karsten Baumann (Atmospheric Research & Analysis, Inc)
Hypotheses: No changes to this section.
Technical Objectives/Goals: No changes to this section.
Technical Approach: This research contributes data to help fill gaps, including the following:

1. Effects of variations in fire regimes (e.g., frequency, season, intensity of fire) along fuel and moisture gradients
2. Connections between fire regimes, herbaceous communities, and habitat for insect and bird communities
3. Improved understanding of these PB effects at the moist (e.g., pocosin, end of the moisture) gradient.

The goal of this research is to collaborate with Research Project T-1 and MCBCL land managers to identify the critical points in the fuel model that allow the implementation of a parameterization scheme. This requires that the research field measurements cover a minimum level of fuel variability to enable a statistically robust parameterization of PB emissions towards the development of an accurate emissions forecasting tool.

Since the development of Research Project Air-1, Research Project T-1 has been re-designed and the burn season is no longer an independent variable in T-1. Instead, all T-1 plots will experience only dormant season burns subject to the Base's normal 3-year PB rotation. PBs are conducted exclusively by the MCBCL foresters, so that the Air-1 PB emission measurements will need to be coordinated with MCBCL. Plots from the Terrestrial Module's vegetation monitoring and Research Project T-1 will provide the estimates of the actual fuel consumption, which is critically important for determining PB species' emission factors and links to fuel condition and other direct and indirect combustion parameters, such as carbon monoxide/carbon dioxide (CO/CO_2) (combustion intensity) and terrain and meteorology, respectively. Of greatest interest to the MCBCL land managers, and the most important objective of Research Project Air-1, is to capture PB emissions during both growing and dormant seasons and to compare their respective atmospheric effects. The experimental design and methods for Research Project T-1 will be evaluated and potentially re-designed before the anticipated start of this project in July 2009.

Scheduling Constraints: No changes to this section.

Year 1 Go/No Go Decision Point: None specified; however, Research Project Air-1 depends on the success of Research Project T-1, as well as the Terrestrial Module's monitoring program to establish an appropriate number of vegetation plots. If an appropriate number of vegetation plots cannot be established, then Air-1 will be a NO GO. We anticipate reaching this decision point in June 2009.

Budget (Estimated): No changes to this section.

5.5.4.2 Research Project Air-2: Nitrogen Deposition to Terrestrial and Aquatic Ecosystems

Senior Researchers: Wayne P. Robarge (North Carolina State University)

Hypothesis: No changes to this section.

Technical Objectives/Goals: No changes to this section.

Technical Approach:

Wet Deposition: This project originally planned to use National Atmospheric Deposition Program (NADP)-certified wet deposition collectors to obtain rainfall samples. However, a decision was made to switch to an approved Mercury Deposition Network (MDN) collector after receiving comments during the poster presentation at the 2007 NADP Technical Meeting and during extensive discussions with Dr. David Gay, who is the NADP Acting Program Coordinator and MDN Coordinator. Dr. Gay indicated that results from the MDN collector would be acceptable for characterizing wet deposition chemistry without making any special modifications, and if emphasis changed in the near future to mercury deposition, the needed equipment would already be in place and would conform to existing MDN collection protocols. He also emphasized that the current design of the existing NADP-certified collectors may be changed in the near future; therefore, any collectors purchased for this project may no longer be certified in 4 or 5 years as approved for rainfall collection and certification. The switch from the NADP-style rainfall collectors to the approved MDN collectors was possible without incurring any additional costs to the project. Samples will be collected at four locations each week and analyzed for pH, soluble cations (i.e., ammonium, magnesium, calcium, sodium potassium), soluble anions (i.e., chloride, nitrate, nitrite, sulfate), and total DON and DOC.

There has been no change in the approach for measuring the spatial variability of rainfall using tipping bucket gauges. The location of the gauges will be slightly different than shown in **Figure 5-25** of the DCERP Research Plan; the revised locations were not available at time of this addendum.

There have been no changes to the methods for determining dry deposition.

(i) Schedule: The start of Research Project Air-2 was delayed until May 2008 due to delays in equipment. The project should be back on schedule by the end of the year.
Scheduling Constraints: No changes to this section.
Year 1 Go/No Go Decision Point: No changes to this section.
Budget (Estimated): No changes to this section.

6.0 Data Management Module

No changes to this section.

7.0 Military Activity Impact

To be able to make appropriate management decisions about the effects of military training activities on MCBCL's natural resources, it is important to understand the military stressors that impact the environment, assess the site-specific impact of those stressors, and evaluate their contribution to site degradation in comparison to those impacts resulting from non-military, legacy, and natural perturbations.

This approach will include a five-step process. For Step 1, RTI staff will identify, acquire, and review existing literature on military impacts to the various ecosystem types present at MCBCL (e.g., estuarine, wetlands, coastal barrier, and terrestrial). Step 2 will involve meetings with the Terrestrial Module Team that will be developing a land cover/land use geographic information systems (GIS) data layer; MCBCL range control staff; and the DCERP On-site Coordinator (OSC) to discuss the nature and extent of the observed impacts of training activities, what training activities or vehicles result in observable ecosystem impacts, and the extent of movements of troops and various training vehicles across MCBCL. There have been no changes to these first two steps.

In Step 3**,** RTI's contractor (URS Corporation), the designer of the Range Facility Management Support System (RFMSS), was originally proposed to develop and conduct queries to extract real-time data from RFMSS on use of the Base's land and estuarine and coastal waters, including the vehicles/watercraft types used and the number of troops involved in individual training maneuvers in various ecosystems. In meeting with MCBCL and reviewing RFMSS data, it was determined that Dr. Pat Halpin of the Terrestrial Module could query this database; therefore, it would not be necessary to contract with the URS Corporation to complete this step. As a result of prelimnary queries, it was determined that RFMSS is used as a planning tool and adequately provides information on usage at the necessary spatial and temporal scales. Therefore, the RFMSS cannot be combined with GIS data to determine spatial dispersion of military training impacts as initially planned for Step 4. Instead, a scientific framework is being developed by SERDP and the DCERP OSC for each DCERP Module Team to evaluate the potential impact of military training activities on each ecosystem at various temporal and spatial scales. At the time of this addendum, the framework had not yet been developed. This framework would be used to determine potential indicators of military impacts for each module to fulfill Step 5 of the process.

8.0 Quality Assurance

No changes to this section.

9.0 Transition Plan for Research Results

No changes to this section.

10.0 Measures of Success

No changes to this section.

11.0 Literature Cited

No changes to this section.

Appendix E

Ecosystem Module Roadmaps

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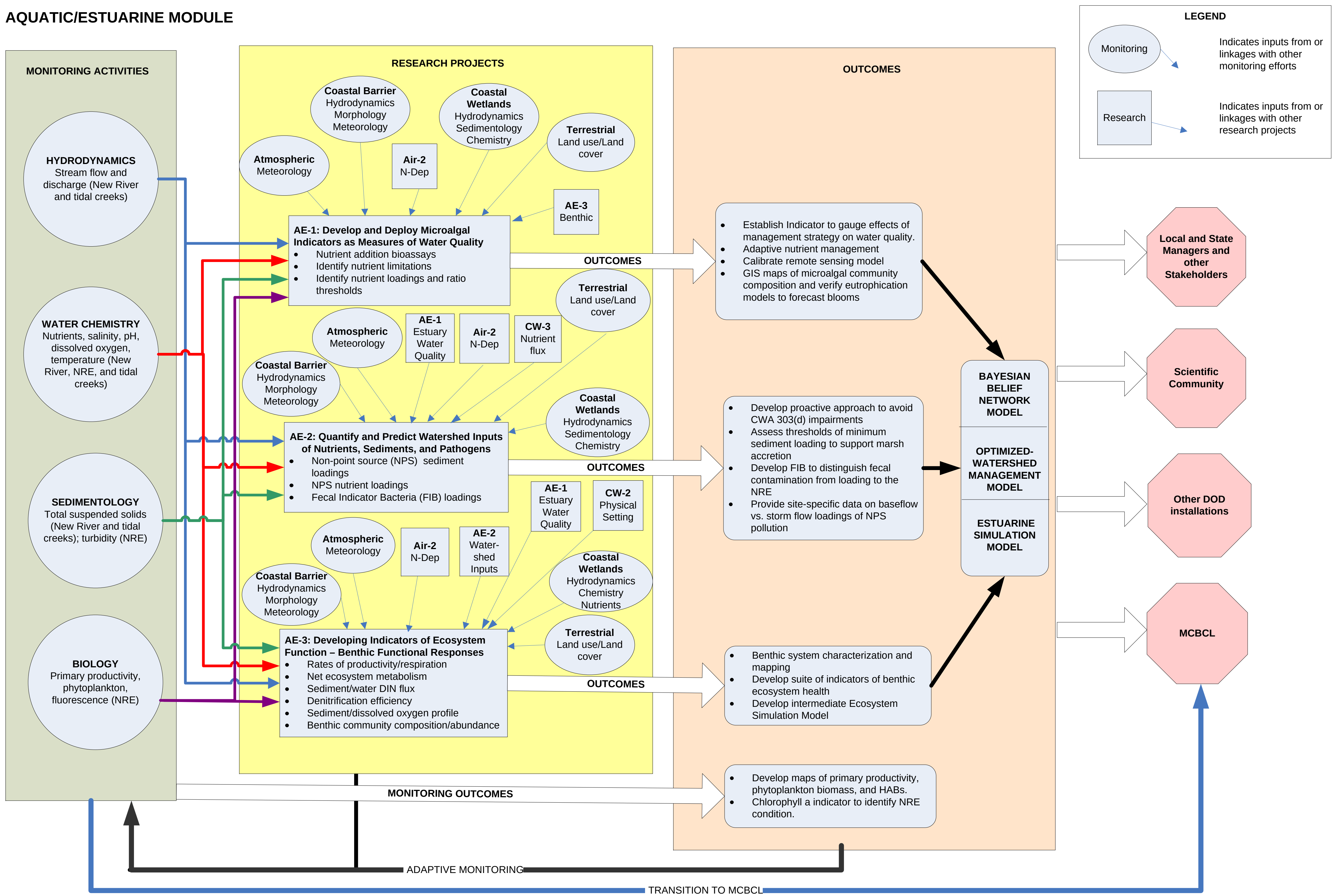
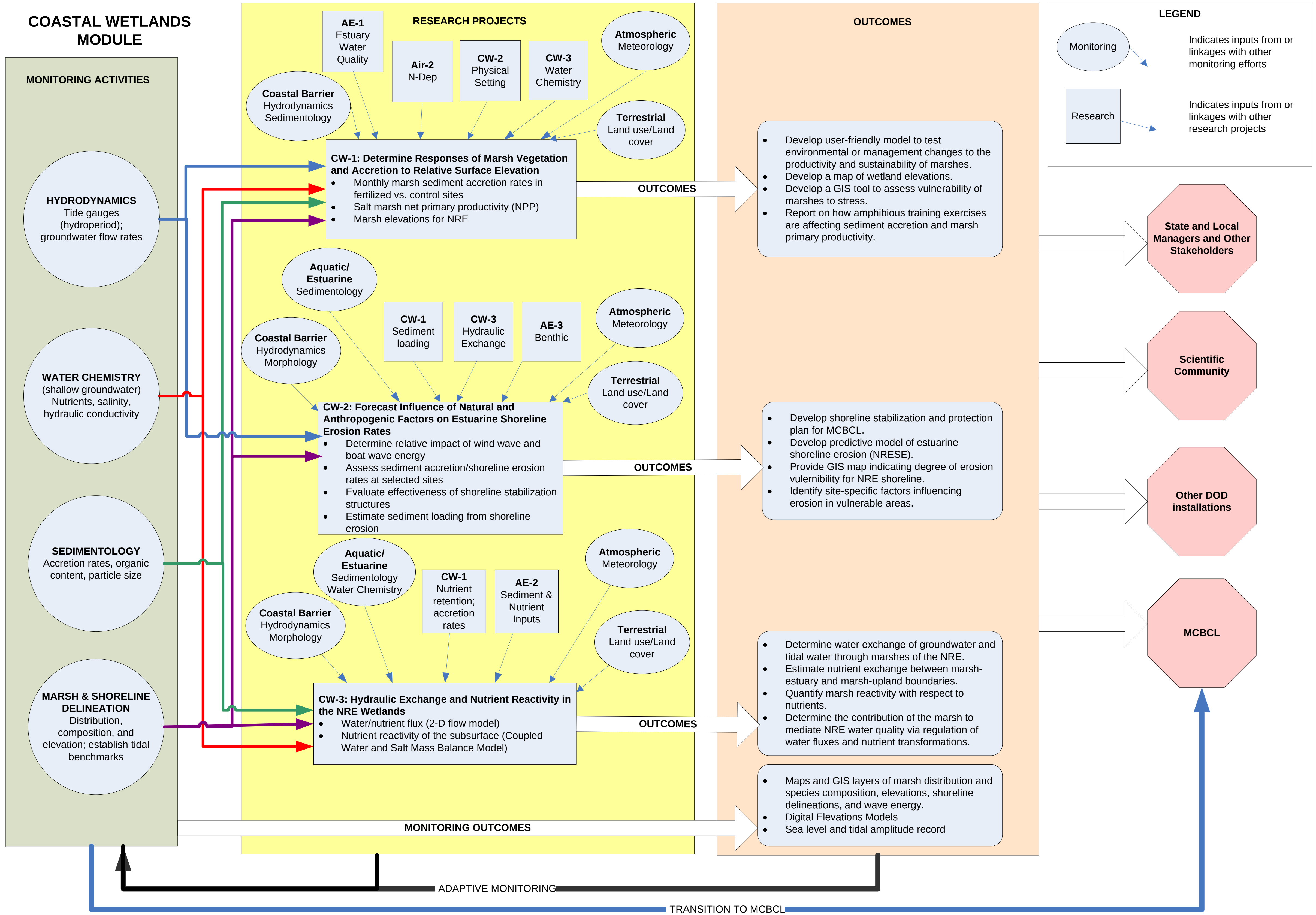
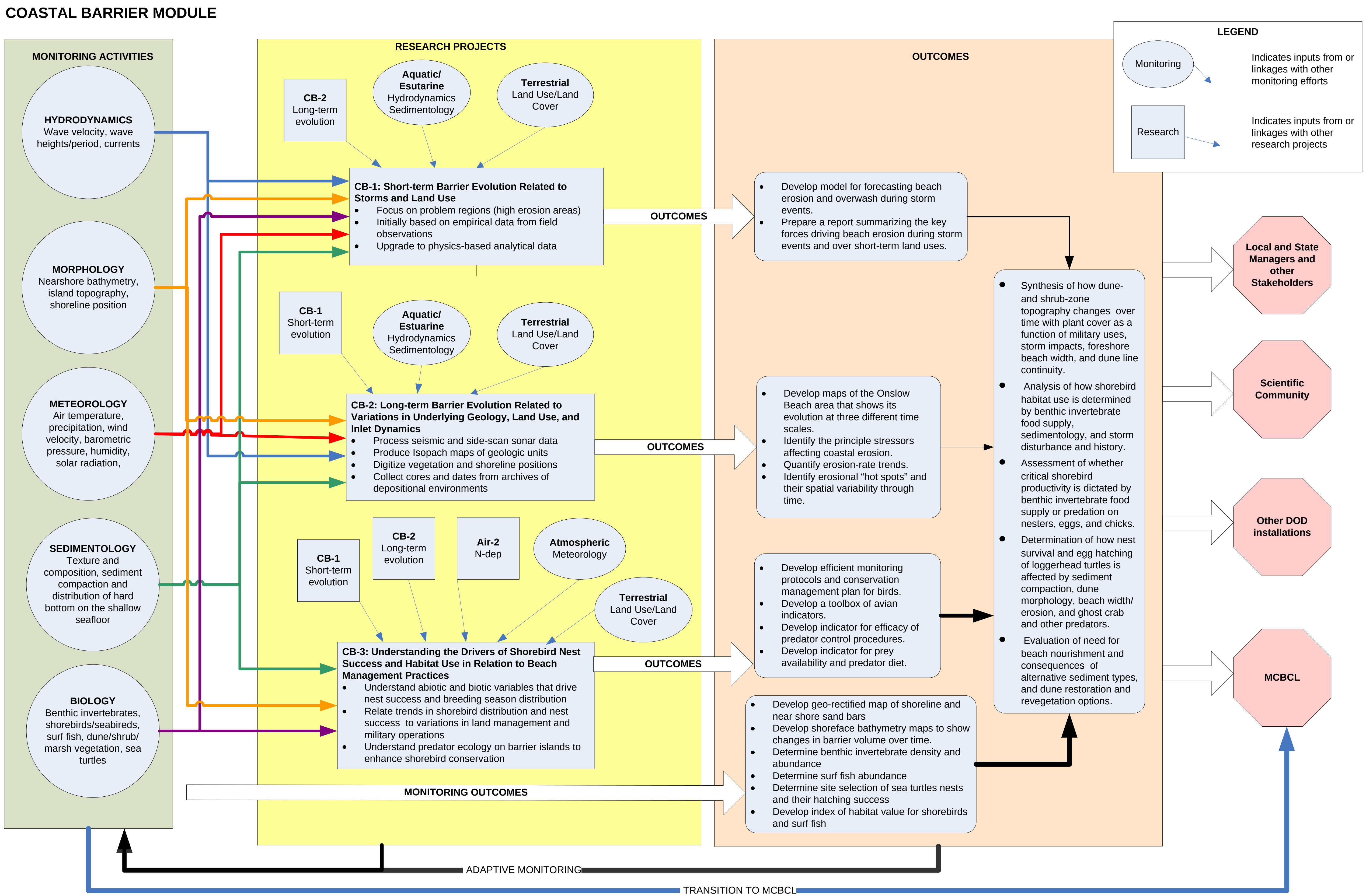


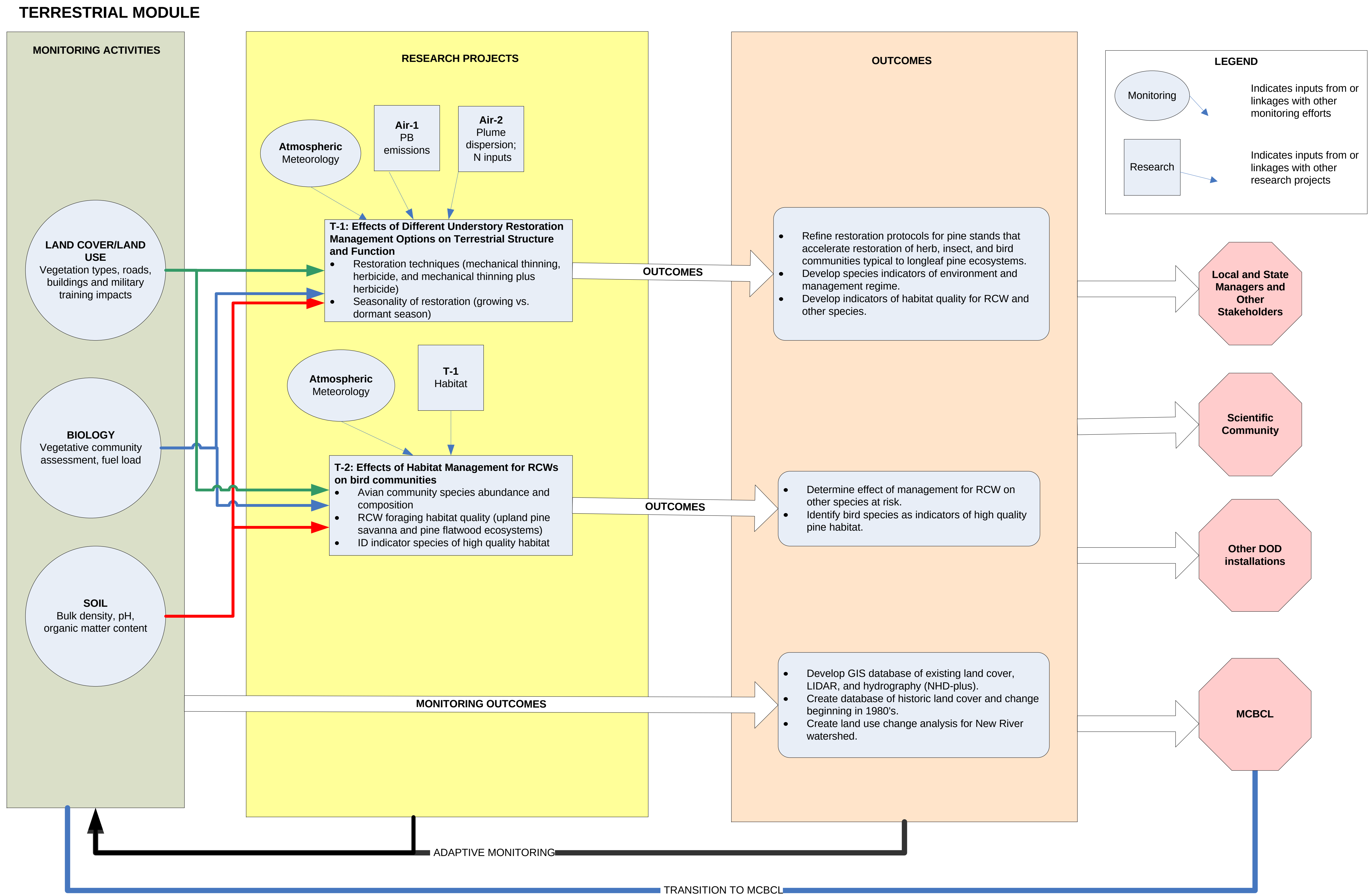
Aquatic/Estuarine Module



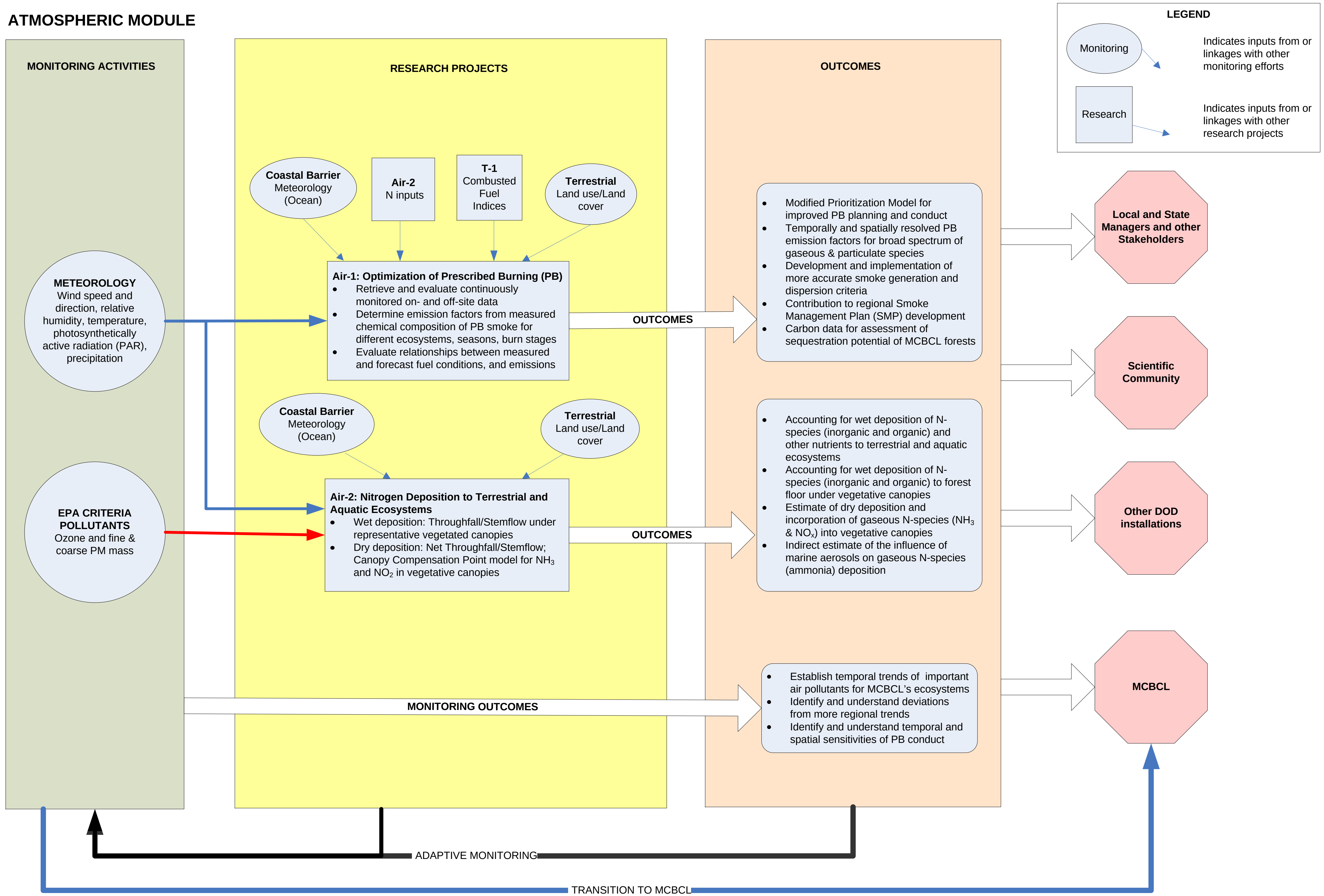
Coastal Wetlands Module



Coastal Barrier Module



Terrestrial Module



Atmospheric Module