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Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Cape Lookout National Seashore

Natural Resource Report NPS/SECN/NRR—2017/1434

ON THE COVER
Foal season begins at Cape Lookout. National Park Service photo.

Natural Resource Condition Assessment

Cape Lookout National Seashore

Natural Resource Report NPS/SECN/NRR—2017/1434

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Executive Summary

The two major goals of this report were to (i) inventory the natural resources of Cape Lookout National Seashore (CALO, or the seashore, or Cape Lookout NS) along the Outer Banks of North Carolina, including synthesis of available information and collection of geospatial data layers and maps; and (ii) develop a set of indicators, quantitative insofar as possible, for natural resource conditions that can be tracked over time. The natural resources that were evaluated included climate, air quality, geology and soils, groundwater, surface water, terrestrial, wetland, and aquatic biota, and species of special concern. This analysis emphasized the most recent years of available information through 2012, especially for water quality and biota, so that the national resource assessment and "Report Card" would target present/recent conditions.

Cape Lookout is a dynamic barrier island system that forms the southern portion of the Outer Banks, one of the nation's major natural, highly dynamic geological wonders, and among the most remote of national parks despite its close proximity to the mainland. It is about 11,430 hectares (28,244 acres [ac] or 44.1 mi^2]) in extent, and more than one-third of the area is water. Its ocean side beaches span a length of 91 kilometers (56.5 miles [mi]), stretching from Ocracoke Inlet southwest to Beaufort Inlet. The three main barrier islands or "banks" of Cape Lookout—also known as part of the "Crystal Coast of North Carolina"—are only 1–2 kilometers (0.6–1.2 mi) wide. From north to southwest, they include North Core Banks, South Core Banks, and Shackleford Banks. The highest topographic features of Cape Lookout, sand dunes, rise approximately 3.7 meters (12.1 ft) above mean sea level on North and South Core Banks, and about 10–13 meters (32.8–42.7 ft) on Shackleford Banks. The seashore headquarters, on Harkers Island, hugs the mainland and is accessible by automobile, but the three barrier islands are accessible to the general public only by ferry service and there are no connecting roads. The ocean side seashore boundary is mean low tide, and the sound side boundary extends 45.7 meters (150 ft) from the shore into the water. Given this definition of park boundaries, together with accelerating sea-level rise from climate change, Cape Lookout NS boundaries area constantly shifting.

Climate change is rapidly advancing in the Southeast—including Cape Lookout—and is manifested through warming temperatures, altered patterns and amounts of precipitation (droughts, floods), and storm frequency. The seashore sustains a high frequency of naturally occurring storm-, wind-, tide-, and wave-driven processes of erosion, accretion, and overwash that cause it to migrate landward. The narrow barrier islands of sand, very near to mean sea level, are extremely vulnerable to climate change impacts such as inundation from sea-level rise. The predicted changes would dramatically impact the natural resources of this seashore. Park staff and the Southeast Coast Network are proactively engaged in planning efforts to better prepare for those impacts.

The Cape Lookout barrier islands are separated from the mainland by two shallow, narrow sounds, Core Sound and Back Sound, which are only 3.2–6.4 kilometers (2–4 mi) wide. In addition, the northwestern edge of North Core Banks abuts the wide expanse of Pamlico Sound (24–48 kilometers [15–20 mi]) in width. Moderate noise and light pollution from the Morehead City-Beaufort population center on the mainland likely adversely affect the closest barrier island, Shackleford

Banks, which has been proposed as and is managed as a Wilderness Area by the National Park Service. Mainland water pollution impacts, such as chemical substances and sea trash, are a potential concern on the barrier islands. Air pollution from mainland urban and agricultural areas has caused poor air quality as an ongoing, serious problem in the seashore. Low fecal coliform bacterial densities indicate good water quality for the seashore both sound side and ocean side. Available data (sound side) for dissolved oxygen and suspended algal biomass as chlorophyll *a* also suggest good water quality. Data were too sparse for evaluation of dissolved inorganic nitrogen, but phosphorus data show degraded water quality in some sound side areas due to phosphorus over-enrichment. Limited data on surface sediments suggest good quality sound side, with generally low levels of toxic metals, polycyclic aromatic hydrocarbons, and other chemical contaminants. However, limited data for fish tissue (whole fish body) revealed high contamination by arsenic and polycyclic hydrocarbons. Groundwater is the only potable water source at the seashore; while groundwater supply is in good condition, very little information is available about groundwater quality.

These barrier islands and adjacent waters are one of few remaining havens in the Southeast for many species of special concern. In addition, this seashore and Cape Hatteras National Seashore to the north also contain nearly all of the remaining critical seagrass habitat in North Carolina. The sensitive flora and fauna are threatened by many pressures that are not possible for the National Park Service to control. Loss of some species of special concern due to predation, such as sea turtles, piping plovers, American oystercatchers, and various colonial shorebirds, is another concern. Diverse exotic/invasive species pose an additional threat to sensitive species and park ecosystems. Exotic/invasive taxa represent 38% (8 of 21 species) of mammals at Cape Lookout, at least five of which are predators of sea turtles and sensitive shorebirds. One exotic species, the feral horse, is charismatic and popular with the general public. The wild horse herd, maintained on Shackleford Banks, has a target population of 120–130 animals, which is achieved by park staff through the use of humane measures such as birth control and removal and turnover to a management partner, who can adopt them out. While the horse herd appears to be generally healthy, eastern equine encephalitis has caused recent deaths.

This in-depth analysis of the natural resources of Cape Lookout considered available information for all natural resource categories ranging from climate and surrounding land use to species of special concern. In selecting the suite of indicators that we developed for natural resource status at Cape Lookout, a foremost consideration was to ensure insofar as possible that the indicators are scientifically sound, clear to the general citizenry, and logistically assessable for park personnel with minimal time and additional resources required. We also strove to ensure that the indicators meet the specific needs of this park as described by park staff. In total, 66 indicators were used to evaluate the 20 categories of natural resources for which sufficient information was available to allow some level of assessment. The overall condition of ten categories was rated as good; six were in fair condition, and four were in poor condition, as shown by the report card for natural resource conditions in Cape Lookout (see next page).

Major knowledge gaps prevented or seriously restricted evaluation of the present condition of fish tissue quality and groundwater quality in the seashore, as well as several other natural resource categories. These gaps and efforts needed to fill them include:

- *Visitation*—Cape Lookout is in need of a targeted recreational carrying capacity for visitation based on optimal protection of its natural resources. In addition, data on trash left in the seashore, and improved quantification of violations of park regulations by pedestrians, off-leash pets, off-road vehicles (ORVs) etc. would strengthen the assessment of visitation condition.
- *Air Quality*—It would be helpful for the National Park Service to install at least one air quality monitor at Cape Lookout, which would greatly facilitate tracking air quality changes over time. In addition, eight plant species at the seashore (sweetgum, yellow poplar, Virginia creeper, loblolly pine, black cherry, sassafras, smooth cordgrass, and northern fox grape) have been identified as especially sensitive to ozone. The National Park Service should consider tracking selected populations of these species, or a subset (including saltmarsh cordgrass since it is the dominant saltmarsh species), over time as sentinels of potentially harmful ozone levels.
- *Surface Water Quality*—In addition to the current continuous monitoring being conducted at two sites, the synoptic (coastal assessment) sites surveyed in recent NPS efforts (Gregory and Smith 2011, Wright 2016) should be sampled at least monthly every other year to better characterize surface-water quality. It would be helpful to include measurement of water temperature, salinity, pH, dissolved oxygen, water clarity, fecal coliform bacteria (more samples sound side are needed), total nitrogen, total phosphorus, ammonium, nitrate, orthophosphate, and suspended micro-algal biomass as chlorophyll *a*.
- *Groundwater Supply*—Groundwater recharge/discharge areas in and around Cape Lookout should be re-mapped and quantified so that this critically important resource can be more accurately evaluated over time.
- *Groundwater Quality*—Only sparse information on groundwater quality, at few locations, is available for this seashore. Monthly sampling at least every other year is needed to characterize pH, salinity, conductivity, chloride, and concentrations of potential pollutants known to contaminate groundwater from septic effluent leachate, especially nitrate+nitrite, total phosphorus, soluble reactive phosphate, and fecal bacteria. Contamination of ground-water as well as soil from known sources, should be characterized to determine the nature, extent, and persistence of hazardous substances.
- *Vascular Plant Communities*—A thorough, vouchered plant survey should be conducted at Cape Lookout to update and scientifically verify the NPS Certified Species List for the seashore. The major expanse of maritime forest on Shackleford Banks is a national treasure, considering that maritime forests are among the rarest and least studied coastal biological communities. In general, as in this park, what is known about maritime forests is mainly descriptive information; the ecology is still poorly understood. The network and partners should conduct research on this important community to strengthen insights about the causes of plant zonation, the patterns of ecological succession, the degree of genetic isolation among animal populations, the ecological significance of native biota, and the extent of impacts from invasive biota.

- *Seagrass Meadows*—Seagrass meadows have gone unmentioned in nearly all recent NPS reports about the natural resources of Cape Lookout, yet the seagrass meadows along the sound side of this seashore are vitally important to the ecology and commercial/recreational fishing activities of the entire U.S. Atlantic Coast. Seagrasses are excellent integrators of environmental stress from nutrient pollution, increasing turbidity, and other factors. The seagrass *Zostera marina* (marine eelgrass) in particular is highly sensitive to increasing temperature, and therefore it is an excellent indicator of rising temperatures from global warming in climate change. In fact, marine eelgrass is considered an excellent indicator of the health of the overall shallow marine coastal areas. Seagrass habitats, and the abundance/ distribution of *Zostera marina* in sound side seashore waters should be tracked over time by the National Park Service and agency partners, at least at decadal intervals.
- *Benthic Estuarine/Marine Macroinvertebrates*—Benthic macroinvertebrate fauna are routinely used nationwide to indicate aquatic ecosystem health. A complete, validated list of present-day taxa within this important community is needed for Cape Lookout.
- *Fish*—Fish communities of Cape Lookout are a valued but neglected component of the seashore biota. Limited fish tissue contaminant data for the seashore, while sparse, is concerning because it suggests that fish health may be compromised from high contamination by toxic substances (e.g., arsenic and polycyclic aromatic hydrocarbons). Fish tissues such as brain, gill, kidney and liver (which tend to accumulate toxic substances) should be assessed for toxic substance content at multiple stations sound side and ocean side to evaluate the status of fish tissue quality more rigorously, and to assist in tracking contaminant sources that are in or near the seashore. A second issue of concern is the extent to which highly invasive lionfish may be altering fish communities and, more generally, the marine coastal biota of Cape Lookout. Park staff should take advantage of the NPS Lionfish Response Plan to assist in tracking this species and its impacts in Cape Lookout marine waters.
- *Feral Horse Herd*—The seashore has a management plan and a strong monitoring program for feral horses. Continued genetic testing and evaluation are vital. Assessment of the population condition would be strengthened by obtaining the data needed to develop additional indicators of horse health, such as nutrition and disease which could be tracked over time.
- *Predator Management Plan*—Cape Lookout would benefit long-term from a formal Predator Management Plan (including ghost crabs as well as mammals) to strengthen predator control.

Overall Report Card of Natural Resource Conditions in Cape Lookout National Seashore as of 2014

[Green —good; yellow —fair; red —poor; ssc—Species of Special Concern]

Natural Resource Category	Indicators	Cape Lookout
Adjacent human population impact	3	Fair
Visitation—Human population in the seashore	3	Fair
Wilderness condition in the seashore	3	Good
Air quality	8	Fair
Soundscape	3	Good
Lightscape	2	Good
Geology and soils, including sea-level rise	5	Poor
Surface-water quality	4	Good
Surficial sediment quality	3	Good
Groundwater supply	2	Fair
Vascular flora	5	Poor
Benthic estuarine/marine macroinvertebrates	2	Fair
Fish	2	Fair
Herpetofauna	3	Fair
Birds	5	Good
Mammals	2	Poor
American oystercatcher sentinel ssc	4	Good
Piping plover ssc	3	Fair
Sea turtle ssc	2	Good
Feral horse population	2	Good

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Acronyms

AAL—acceptable ambient level (of an airborne toxic pollutant concentration), set by NCDENR-DAQ

ALR—Anthropogenic Light Ratio (measure of light pollution)

API—Air Pollution Index (kilograms or pounds; calculated as total pounds of the six most hazardous air pollutants (arsenic, benzene, carbon tetrachloride, lead, and mercury)

AQI—Air Quality Index (of the EPA; scale from 0 to 500, with higher numbers indicating poorer air quality)

ARD—automated recording device (for a study of anuran amphibians)

ATV—all-terrain vehicle

Bd—*Batrachochytrium dendrobatidis* (chytrid fungal pathogen of amphibians)

BDSS—Bortle Dark-Sky Scale

BLSK—black skimmer(s)

BMP—best-management practice

brl—below reporting limit

°C—degrees Celsius

CAAE—Center for Applied Aquatic Ecology (of North Carolina State University, NCSU)

cfs—cubic feet per second

CFU—colony-forming units

CHARTS—Compact Hydrographic Airborne Rapid Total Survey system (of the USACE)

CHPP—Coastal Habitat Protection Plan (of North Carolina)

CI—confidence interval

Cl^-—chloride

COOP—Cooperative Observer Program (national network of stations taking climatological data)

CO_2—carbon dioxide, a major greenhouse gas contributing to global warming

COTE—common tern(s)

CSI—channel stability index (a type of rapid geomorphic assessment)

CVI—Coastal Vulnerability Index

D_{high} —the crest of the most seaward sand dune

D_{low} —the base of the most seaward sand dune

DAQ—Division of Air Quality (of NCDENR)

dB(A)—A-weighted decibels, wherein a decibel is a unit of sound production; decibel(A) refers to sound production level on an A-weighted scale according to sound frequency

dbh—diameter at breast height

DCM—Division of Coastal Management (of NCDENR)

DDE—dichlorodiphenyldichloroethylene

DDT—dichlorodiphenyltrichloroethane

DO—dissolved oxygen

DWQ—Division of Water Quality (of NCDENR); this division no longer exists as of 2014.

EEE—eastern equine encephalitis

EMAP—Estuarine Monitoring and Assessment Program (of the EPA)

ERL—effects range low (sediment quality guideline)

ERM—effects range medium (sediment quality guideline)

ESA—Endangered Species Act

°F—degrees Fahrenheit

ft—foot or feet

GDD—growing degree days

GIS—Geographic Information System

HMW—high-molecular-weight (in reference to PAHs)

HPD—human population density

HPG—human population growth

hr—hour

Hz—cycles per second, a measure of pitch in noise analysis

I—potential inundation (of CALO—vulnerability to sea-level rise)

I&M Program—Inventory and Monitoring Program (of the NPS)

I.D.—inadequate data for evaluation

IPCC—United Nations Intergovernmental Panel on Climate Change

ITIS—Integrated Taxonomic Information System

IUCN—International Union for Conservation of Nature and Natural Resources

k—Water Clarity Index

kHz (or KHz)—kilohertz, unit of alternating current or electromagnetic wave frequency equal to one thousand hertz (Hz)

km—kilometer

km^2—square kilometer

L—liter(s)

lat.—latitude

LETE—least tern(s)

LME—large marine ecosystem

LMW—low-molecular-weight (in reference to PAHs)

long.—longitude

LRIP—Long-Range Interpretive Plan

m—meter

Ma—megaannum (plural, Megaannums), a period of one million years from the present

mcd—millicandela(s)

mile^2—square mile

mg/L—milligrams per liter

µg/L—micrograms per liter

MOA—military operations area (of the U.S. Marine Corps)

MOM—Maximum of the Maximum Envelope of Water mph—miles per hour

MPN—most probable number (pertaining to fecal bacteria)

MSL—mean sea level

N—nitrogen (nutrient; excessive enrichment can degrade water quality)

NAAQS—National Ambient Air Quality Standards

NADP—National Atmospheric Deposition Program (of the EPA)

NAVD88—North American Vertical Datum of 1988 (a fixed datum derived from a simultaneous, least squares, minimum constraint adjustment of Canadian/Mexican/ U.S. leveling observations; local mean sea level at Father Point/Rimouski, Canada was held fixed as the single initial constraint)

N.C.—North Carolina

NCDAQ—North Carolina Division of Air Quality

NCDENR—North Carolina Department of Environment and Natural Resources

NC DMF—North Carolina Division of Marine Fisheries (of NCDENR)

NC DOT—North Carolina Department of Transportation

NCGA North Carolina General Assembly

NCGS—North Carolina Geological Survey

NC RQRP—North Carolina Recreational Water Quality Program (of NCDENR)

NCSU CAAE—North Carolina State University Center for Applied Aquatic Ecology

NCNERR—North Carolina National Estuarine Research Reserve

NC WRC—North Carolina Wildlife Resources Commission

NGDC—National Geophysical Data Center (of NOAA; now known as National Centers for Environmental Information [NCEI])

NH_4^+—ammonium (inorganic form of nitrogen, ionized from ammonia; excessive enrichment can degrade water quality)

nL—nanolamberts(s) [nL], a measure of luminance

NLCD—National Land Cover Data

NMFS—National Marine Fisheries Service (of NOAA)

NOAA—National Oceanic and Atmospheric Administration

NOS—National Ocean Service

NO_3^- + NO_2^-—nitrate + nitrite (Also known as NO_x— inorganic forms of nitrogen; excessive enrichment can degrade water quality)

NO_x—nitrate + nitrite (inorganic forms of nitrogen; excessive enrichment can degrade water quality)

NPDES—National Pollutant Discharge Elimination System

NPS—National Park Service

NRCA—Natural Resource Condition Assessment (of the NPS)

NRCS—Natural Resources Conservation Service (of the USDA)

NRHP—National Register of Historic Places

NRS—National Resource Strategy (of parks in the NPS)

NSNSD—Natural Sounds & Night Skies Division (of the NPS)

NVCS—National Vegetation Classification Standard

NWI—National Wetlands Inventory

NWIS—National Water Information System (of the U.S. Geological Survey)

NWS—National Weather Service (of NOAA)

OMA—Office of Oceanography and Marine Assessment (of NOAA NOS)

ORV—any motor vehicle used off paved roads

O_3—ozone

P—phosphorus (nutrient; excessive enrichment can degrade water quality)

PACE—park protected-area centered ecosystem

PAH—polycyclic aromatic hydrocarbon

PDSI—Palmer Drought Severity Index (PDSI, a scale ranging from -3 to +3; sometimes called the Palmer Drought Index)

$PM_{2.5}$—particulate matter, diameter $\leq$ 2.5 µm (air pollutant)

PM_{10}—particulate matter, diameter $\leq$ 10 µm (air pollutant) ppb—parts per billion (in water, the same as µg/L)

ppm—parts per million (in water, the same as mg/L)

PZP—Porcine Zonae Pellucidae (contraceptive used by the National Park Service for feral horses when necessary; see Section 3.7.11.1)

QA/QC—quality assurance/quality control (in water and sediment quality analyses)

R_{high}—the maximum water level attained during a storm

R_{low}—the mean water level attained during a storm

RGA—rapid geomorphic assessment

ROTE—royal tern(s)

RSS—Resource Stewardship Strategy (being developed for Cape Lookout)

SATE—sandwich tern(s)

SAV—submersed aquatic vegetation

SC—sediment contamination

SCECAP—South Carolina Estuarine and Coastal Assessment Program

SECN—Southeast Coast Network of the National Park Service

SELC—Southern Environmental Law Center

SLOSH—Sea, Lake, and Overland Surges from Hurricanes model (of NOAA)

SO_2—sulfur dioxide (air pollutant)

spec. cond.—specific conductivity or specific conductance

SSC—species of special concern (endangered, threatened, etc.—federal and/or state)

SSHS—Saffir/Simpson Hurricane Scale

SSURGO—Soil Survey Geographic database

STORET—STOrage and RETrieval Environmental Data System (of the EPA)

TD—tropical depression

TDN—total dissolved nitrogen (includes both inorganic and organic N forms)

TDP—total dissolved phosphorus (includes both inorganic and organic P forms)

TN—total nitrogen

TP—total phosphorus

TSS—total suspended solids

UNC CH—University of North Carolina Chapel Hill

USACE—United States Army Corps of Engineers

USDA—United States Department of Agriculture

USDI—United States Department of the Interior

EPA—United States Environmental Protection Agency

USGS—United States Geological Survey

USMC—United States Marine Corps

UTV—off-road utility vehicle

VCP—variable-circular plot technique (for studying bird communities)

VES—visual encounter survey (in amphibian and reptile studies)

WRD—Water Resources Division (of the NPS)

yr—year

1. NRCA Background Information

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks." NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement—not replace—traditional issue-and threat-based resource assessments. As distinguishing characteristics, all NRCAs:

- Are multi-disciplinary in scope;[1]
- Employ hierarchical indicator frameworks;[2]
- Identify or develop reference conditions/values for comparison against current conditions;[3]
- Emphasize spatial evaluation of conditions and GIS (map) products; [4]
- Summarize key findings by park areas; and [5]
- Follow national NRCA guidelines and standards for study design and reporting products.

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for

[1] The breadth of natural resources and number/type of indicators evaluated will vary by park.

[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition summaries by broader topics and park areas

[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-up response (e.g., ecological thresholds or management "triggers").

[4] As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

[5] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.
Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject-matter experts at critical points during the project timeline is also important. These staff will be asked to assist with the selection of study indicators; recommend data sets, methods, and reference conditions and values; and help provide a multi-disciplinary review of draft study findings and products.

NRCAs can yield new insights about current park resource conditions, but, in many cases, their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is both credible and has practical uses for a variety of park decision making, planning, and partnership activities.

Important NRCA Success Factors

- *Obtaining good input from park staff and other NPS subject-matter experts at critical points in the project timeline*
- *Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures ⇨ indicators ⇨ broader resource topics and park areas)*
- *Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings*

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What a NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park’s desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[6] and help parks to report on government accountability measures.[7] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] For example, NRCAs can provide current condition estimates and help establish reference conditions, or baseline values, for some of a park's vital signs monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

NRCA Reporting Products…

Provide a credible, snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:

- *Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations* ***(near-term operational planning and management)***
- *Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values* ***(longer-term strategic planning)***
- *Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public* ***("resource condition status" reporting)***

Over the next several years, the NPS plans to fund an NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information visit the NRCA Program website.

[6] An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project.

[7] While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

[8] The I&M program consists of 32 networks nationwide that are implementing "vital signs" monitoring in order to assess the condition of park ecosystems and develop a stronger scientific basis for stewardship and management of natural resources across the National Park System. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

2. Introduction and Resource Setting

2.1. Introduction

A little more than 4.8 kilometers (km; or 3 miles [mi]) wide at most, and barely 91.4 meters (m; or 300 feet [ft]) at the narrowest point, the Outer Banks is a “string” or succession of narrow islands that shelter the North Carolina mainland from the sea. The Outer Banks are dynamic barrier islands, one of the nation’s major natural geologic wonders. The northern/central Outer Banks consists of Cape Hatteras National Seashore (total ocean side distance 119 kilometers or 74 mi), whereas Cape Lookout National Seashore (CALO, or Cape Lookout NS, or the seashore) forms the southern Outer Banks area (total ocean side distance, 91 kilometers [56.5 mi]). The sand dunes at Cape Lookout are the highest topographic features, and are usually up to 3.0-3.7 meters (10-12 ft) tall (Pompe 2010); in general the Cape Lookout islands are 0.9–1.8 meters (3–6 ft) in elevation and only 1–2 kilometers (0.6–1.2 mi) in width.

Cape Lookout National Seashore spans an area of 11,430 hectares (28,243 acres [44.1 mi^2]. About 64% of the seashore area is land and 36% is water (USDA NRCS 2006). In marked contrast to Cape Hatteras National Seashore immediately to the north, Cape Lookout is one of the most remote parks in the network system. This section of the southern Outer Banks in Carteret County is sometimes called the Crystal Coast of North Carolina. It extends from Ocracoke Inlet to the northeast (on the other side of this inlet is the southern tip of Cape Hatteras National Seashore) to Beaufort Inlet to the southwest (NPS 2006a) (Figure 1). The three barrier islands or “banks” that form most of this seashore are separated from the mainland by Core Sound and Back Sound, two shallow bodies of water ranging from 3.2 to 6.4 kilometers (2-4 mi) wide. In addition, Pamlico Sound abuts the northeastern edge of North Core Banks. The seashore headquarters and visitors center (NPS 2015d), on Harkers Island (most of which is not part of Cape Lookout), hugs the mainland and is accessible by automobile. In contrast, the three barrier islands are accessible to the general public only by ferry, and there are no connecting roads among the islands.

Two of the three islands included in this seashore are undeveloped, microtidal, transgressive barrier islands that form Core Banks (Mallin et al. 2004) (Figures 2 and 3). These islands are about 1–2 kilometers in width (Watson 2005), and very low in elevation (generally 1–2 meters), with a northeast-to-southwest orientation; its highest dunes seldom exceed 3 meters (10 ft) except near Cape Lookout Point. The islands are mostly open and treeless, and windblown salt spray can be carried across the entire width (Watson 2005). Due to inlets created by recent storms, parts of North Core Banks and South Core Banks are currently sub-divided into several smaller islands: (i) the northernmost island in Cape Lookout, North Core Banks (length 30.6 kilometers [19 mi], extending from Ocracoke Inlet to Old Drum Inlet); (ii) Middle Core Banks (length 4.8 kilometers [3 mi], from Old Drum Inlet to New Drum Inlet); (iii) Ophelia Banks (prior to Hurricane Ophelia in 2005 this island was part of South Core Banks; its present length is 1.2 kilometers [0.75 mi]); and (iv) South Core Banks (length 40 kilometers [25 mi]), extending southward from the inlet created by Hurricane Ophelia to the Cape Lookout bight area (NPS 2006a). The fifth island, Shackleford Banks, is 14.5 kilometers (9 mi) long, and it is a regressive barrier island (Mallin et al. 2004). It has an east-west orientation, a higher dune system (with dunes reaching 10.7 meters [35 ft] in elevation), and larger areas of vegetation including maritime forests that now include some invasive species (NPS 1982, 2006a).

The barrier islands of Cape Lookout are wide, bare beaches with low dunes covered by scattered grasses, flat grasslands bordered by dense vegetation, and large expanses of saltmarsh on the sound-side (NPS 2006a). Natural processes such as wave action, winds, and major storms continually reshape the barrier islands of this park. In addition, gradual migration of sand blown by winds and carried by waves constantly alters the shape and location of Cape Lookout so that, within a few decades, even with only a few small-scale storms, the landscape can radically change (NPS 2015b).

On Core Banks, the seashore includes the remnants of two small historic villages with no permanent residents: Portsmouth Village and Cape Lookout Village. The abandoned Portsmouth Village, at the northernmost end of North Core Banks, has about 20 remaining structures (of, originally, more than 100). At the south end of South Core Banks, the southernmost edge 71 kilometers (44 mi) southwest of Portsmouth Village, is Cape Lookout. This distance, and several transient inlets, separate Cape Lookout from Portsmouth Village. The Cape Lookout area includes the seashore's famous lighthouse (1859–) with its distinctive black-and-white diamond pattern, a small museum, maintenance buildings, and a few residences. Shackleford Banks (length 13 kilometers [8 mi]) is west of Cape Lookout across Barden Inlet. A village called Diamond City was once located on the east end of that barrier island, but no permanent structures remain. A herd of wild horses on Shackleford Banks were likely introduced by locals. The Headquarters and Visitor's Center for the seashore (NPS 2015d) are on Harkers Island, which is connected to the mainland by road but not to the seashore (Figure 2). The few remaining privately owned structures within the seashore are being purchased by the National Park Service.

Most of Core Banks is narrow, low in relief, and has low habitat diversity. It is much more susceptible to damage from storms than Shackleford Banks, and can quickly change over time. An example of rapid change on Core Banks is the beach area just south of Long Point, which has a history of inlet (Old Drum, New Drum, and Ophelia) openings and closings. In contrast, the Cape Lookout area of Core Banks as well as Shackleford Banks are relatively wide, with extensive dunes and much greater habitat diversity. They are much more stable over time because their east-west orientation makes them less susceptible to storm damage. The Cape Lookout area and Shackleford Banks were only separated when Barden Inlet opened in 1933 (Mallinson et al. 2008).

During hurricanes and nor'easters, Core Banks sustains overwash, inlet formation/migration/closure, and therefore supports sparse maritime forest. In contrast, Shackleford Banks is somewhat protected by Cape Lookout and still maintains a substantial maritime forest. There are no freshwater rivers or lakes in the seashore but various freshwater ponds are present, most on North Core Banks and western Shackleford Banks (Mallin et al. 2004). Cape Lookout sustains a high frequency of naturally occurring storm-, wind-, tide-, and wave-driven processes of erosion, and overwash that result in a remarkably dynamic environment (Byrne et al. 2012). Cape Lookout has been recognized nationally and internationally for its outstanding natural resources: it is designated as a unit of the Carolinian-South Atlantic Biosphere Reserve, United Nations Educational, Scientific and Cultural Organizations (UNESCO 1985), and Man and the Biosphere Reserve Program (NPS 2011a).

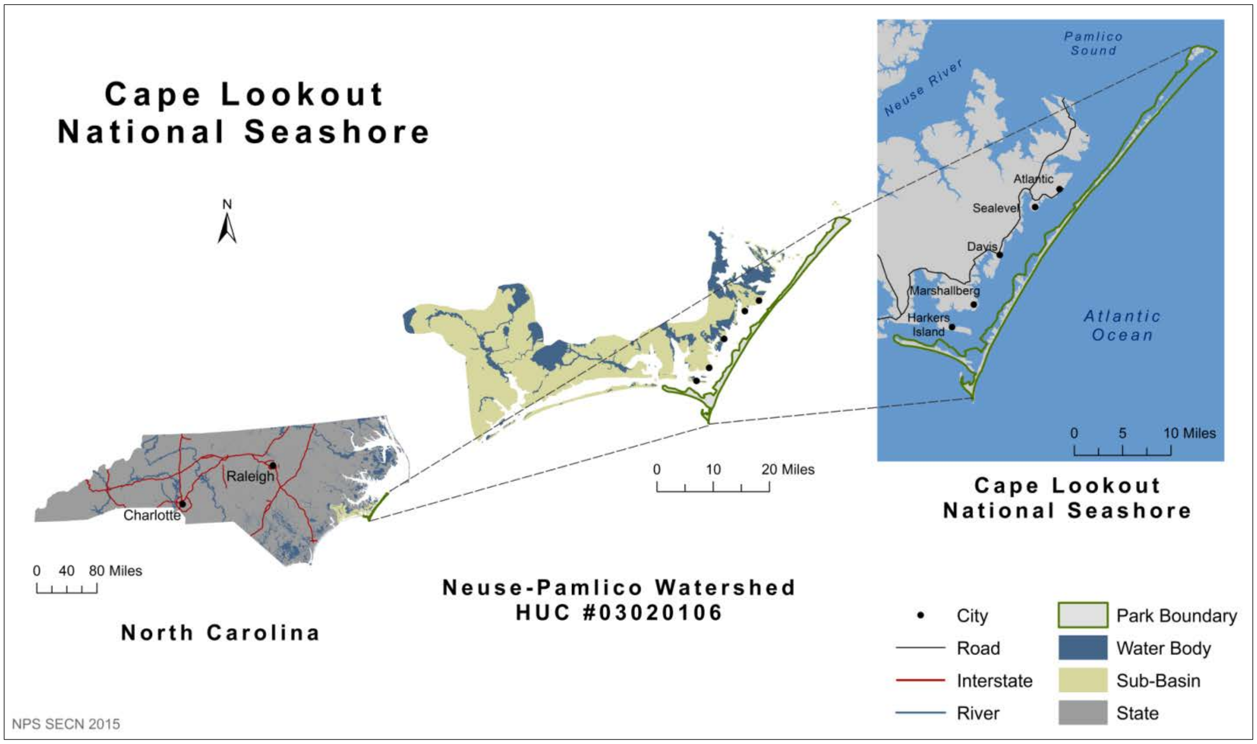

Figure 1. Map showing the location of CALO in the state of North Carolina and within the Neuse-Pamlico Watershed.

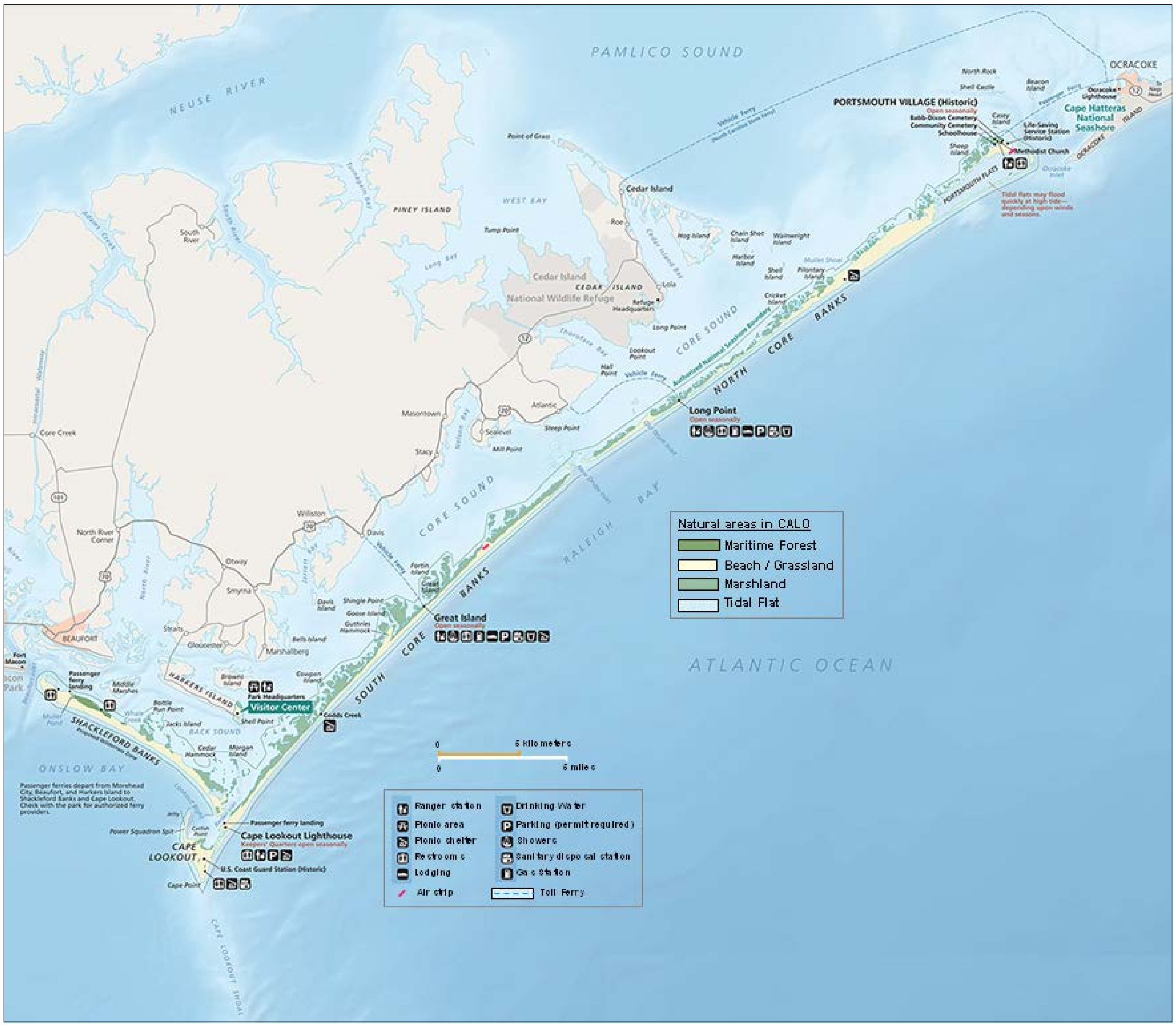

Figure 2. Map of CALO, including Core Banks and Shackleford Banks, showing more detailed features of the seashore. Modified from NPS (2015i).

2.1.1. Park History, Enabling Legislation, and Examples of Other Legislation and Actions Affecting CALO Natural Resources

> *…the national parks must be maintained in absolutely unimpaired form for the use of future generations as well as those of our own time; second, that they are set apart for the use, observation, health, and pleasure of the people; and third, that the national interest must dictate all decisions affecting public or private enterprise in the parks.*
>
> —Franklin K. Lane, Secretary of the Interior, 1913–1920 (NPS 2015a)

<u>Park History</u>

Central-eastern North Carolina has a rich history and cultural heritage. The first colonizers were Iroquois-speaking Tuscarora tribes, who were forced out by European-descended settlers mostly from northern American colonies beginning in 1706 (Carteret County Health Department 2014). Carteret County split from Craven County in 1722 (Figure 3). Beaufort, the county seat, is the third oldest town in North Carolina and was first called “Fishtown” because the fishing industry was so important in the area. The area was also known for lumber and naval stores, a port (Portsmouth harbor, which was abandoned as a port of entry and a town as the depth of the harbor there decreased), pirates such as Blackbeard, and the “Graveyard of the Atlantic” (more than 2,000 shipwrecks along the treacherous shallow shoals). Whaling, menhaden, mullet, sea trout, diamond-back terrapin, oysters, bay scallops, crab, and shrimp fisheries have played a role in development and commerce of the fishing industry, and fishing and other water-related activities continue to be the main commercial activity in the county (Carteret County Health Department 2014). The old fishing culture, going back at least six generations, continues to hold on to the traditions and values of the past.

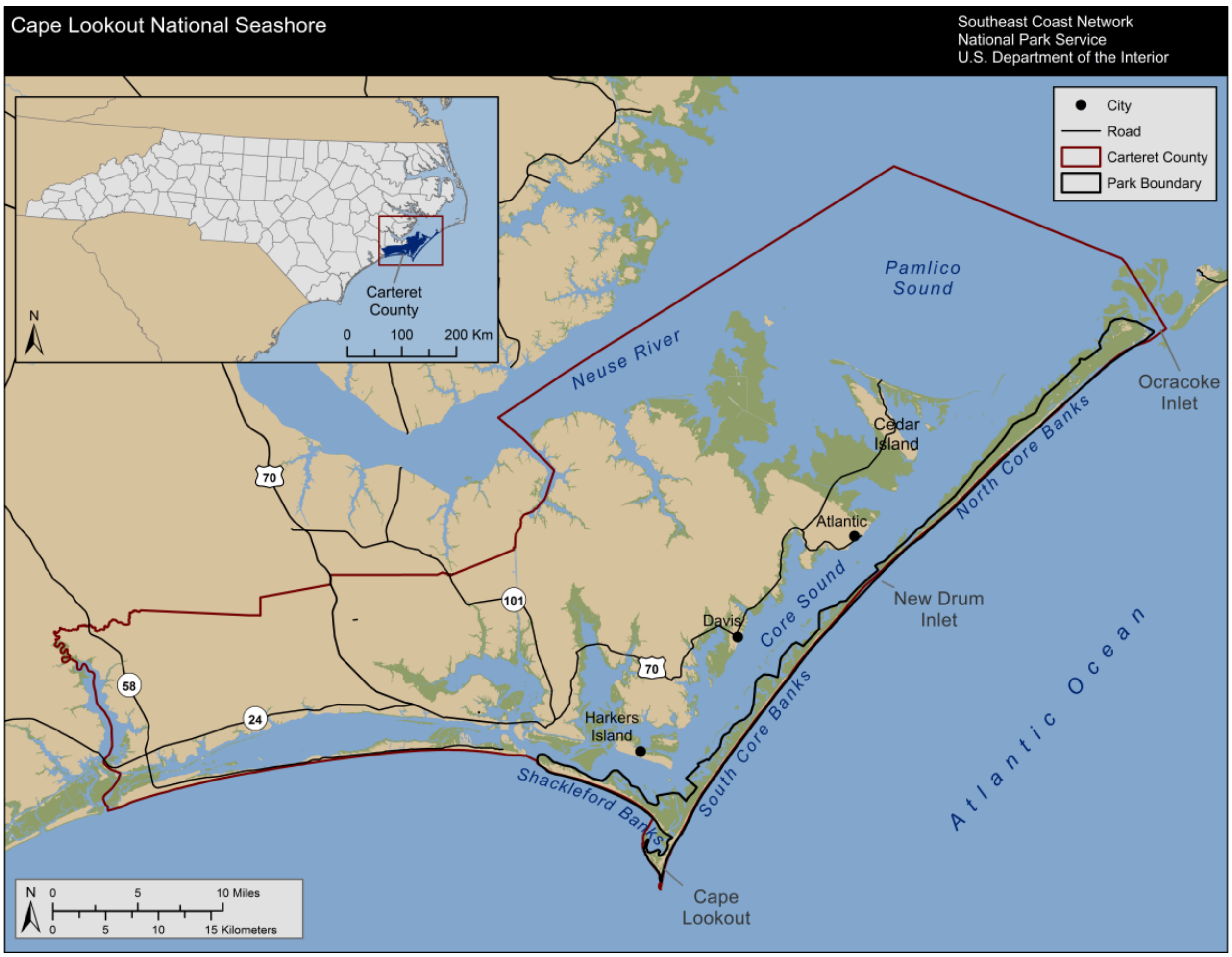

Figure 3. Map of Carteret County, North Carolina, including Cape Lookout NS.

Cape Lookout NS was authorized as a unit of the National Park Service on 10 March 1966, but did not gain ownership of the land until 1976 (NPS 2006a). Thus, about a decade passed between Congressional authorization of the seashore and the point at which the State of North Carolina officially transferred the state property to the National Park Service. The enabling legislation (Public Law 89-366, § 1, 80 Stat. 33; 16 USCS § 459g), authorized the creation of Cape Lookout "to preserve for public use and enjoyment an area in the State of North Carolina possessing outstanding natural and recreational values." The enabling legislation includes provisions for hunting, fishing, and other outdoor recreation and enjoyment opportunities (NPS 2014a). The legislation has been amended several times (i.e., 1974, 1983, 1998, and 2005 as outlined below). Early efforts to secure permanent protection of the seashore area through federal coastal acquisitions heavily involved the North Carolina Cape Hatteras Seashore Commission in interactions with the North Carolina Board of Conservation and Development (NPS 1984). Other legislation and actions mentioned below include efforts, not yet realized, to establish Shackleford Banks as a Wilderness Area (which is how the National Park Service maintains it), and legislation involving the wild horse herd on Shackleford Banks.

<u>Enabling Legislation</u>

Below is a list of Federal and state legislation, and related legislation and actions involved in creating Cape Lookout National Seashore, as well as efforts towards the goal of establishing a portion of the seashore, Shackleford Banks, as a wilderness area.

Summarized from the National Park Service (NPS 1982, 2011a; Bender 2005). (**—the enabling legislation)

- 1955-1965—The State of North Carolina concluded that it was too expensive to rehabilitate and develop the Outer Banks as a public seashore (NPS 1982); and the NPS (1955) became increasingly concerned about development on natural seashores.
- 1964—The Wilderness Act (Public Law 88–577, September 3), passed by the U.S. Congress, created a means to designate "wilderness areas," which represent the nation's highest form of land protection: no roads, vehicles, or permanent structures are allowed in designated wilderness, and activities such as logging and mining are prohibited. This legislation also created the National Wilderness Preservation System to manage the nation's protected wilderness areas.
- 1966—**Congressional Action (Public Law 89-366, § 1, 80 Stat. 33, March 10) authorized establishment of CALO "to preserve for public use and enjoyment an area in the State of North Carolina possessing outstanding natural and recreational values."
- 1974—Congressional Action (Public Law 93-477, Title IV, § 406(1), 88 Stat. 1448, October 26) amended Public Law 89-366 Boundary Map for CALO was created (March), #623-20,009. The total acreage within the boundary was 28,400 acres including the 91-acre administrative site on Harkers Island, and excluded small areas of property owned by the U.S. Coast Guard and private landowners (Thomas Gold heirs). The emergent land (above mean high water) of the barrier islands was 18,400 acres; more than one-third of the total area also was represented by small scattered islands on the south sides of Shackelford Banks and Core Banks/Portsmouth Island and of nearshore waters surrounding the barrier islands. This legislation (§459g–6a) additionally required subsequent recommendation from the Secretary of the Interior as to whether a portion of CALO should be designated as Wilderness Area. The USDI was authorized to spend up to $7,903,000 for acquisition of lands and interests for the seashore, of which no more than $1

million was to be spent to acquire lands owned by Core Banks Properties, Inc., and up to $2,935,000 was authorized for essential public facilities.

- 1976—USDI Action (16 U.S. Code § 459g, 89 Stat. 1445; Federal Register, September 10): The USDI Secretary declared establishment of the seashore, once there was enough land to sufficiently administer it. The seashore was defined to include "the outer banks of Carteret County, North Carolina, between Ocracoke Inlet and Beaufort Inlet, plus adjoining marshlands and waters. The park was to be administered "for the general purposes of public outdoor recreation, including conservation of natural features contributing to public enjoyment." The legislation required that a master plan be created for full development of the seashore, consistent with the preservation objectives of the Act. It also authorized $2,935,000 for seashore facilities development.
- 1983—Congressional Action (Public Law 98-141, Public Lands and National Parks Act of 1983, 97 Stat. 909) amended Public Law 89-366 to authorize the USDI to spend up to $13,903,000 (not $7,903,000) for acquisition of lands and interest for the seashore.
- 1985—The NPS (1985) recommended that the 1,210-hectare (2,990 acre) Shackleford Banks of Cape Lookout be designated as a Wilderness Area, with about 0.81 hectare (2 acres) as potential wilderness (still with private owners, as a small area of the island had been built upon previously); and that the legislation designating Shackleford Banks include a special provision authorizing the Secretary of the Interior to declare wilderness established on the potential wilderness when all uses on those lands prohibited by the Wilderness Act have ceased and the lands are found suitable for wilderness status. Note that although the NPS has since managed Shackleford Banks as a Wilderness Area, it has not yet received that designation from the U.S. Congress.
- 1998—Congressional Action (Public Law 105-229) directed the NPS to enter into an agreement with the Foundation for Shackleford Horses, Inc., a nonprofit organization, to provide for the management of the wild horses living within Cape Lookout. The purpose of the legislation was to ensure that a viable population of free-roaming wild horses, 100–110 (later changed to 120–130) in total number, remained in the seashore, with strictly limited human contact, socialization, and intervention.
- 2005—Congressional Action (H.R. 126, Cape Lookout National Seashore Free-Roaming Horse Law Amendment, October 19)—amended Public Law 105–229 to increase the population of free-roaming horses at Cape Lookout to a minimum of 110 horses, with a target population of 120–130 horses. In addition, this legislation requires the Secretary of the Interior not to remove or assist in the removal of free-roaming horses from the seashore unless removal is carried out as part of a plan to maintain the viability of the herd. Also, the Secretary is not required to replace horses in the seashore when the population falls below a minimum threshold as a result of natural causes.

Cape Lookout has been described as

> *…something of an anachronism in this day of the almighty, and much sought, tourist dollar. The seashore's lack of paved roads, of air-conditioned rental units, of marinas bobbing with catamarans, fishing fleets and yachts, and of seafood-dispensing shacks, is as refreshing as the sea breeze. Compared to most of its siblings—Cape Hatteras, Cape Cod, Gulf Islands, Padre Island, and Point Reyes national seashores—how the National Park Service manages Cape Lookout perhaps comes closest to the agency's prime directive to preserve the resources. That the Park Service is able to hew so closely to that mandate best at Cape Lookout no doubt is due to this seashore's isolated nature.*
> —Repanshek (2011a)

Even so, the National Park Service has sustained increasing political pressure to allow off-road vehicles (ORVs) in expanded park areas (Siceloff 2014). Thus, ORV management merits special mention here. ORV management is a serious issue at this seashore (e.g., Siceloff 2014).

Republican President R. Nixon's Executive Order 11644 of 1972, amended by Democratic President J. Carter's Executive Order 11989 in1977, requires federal agencies permitting ORV use on agency lands to publish regulations designating specific trails and areas for this use, among other things. Title 36, section 4.10 of the Code of Federal Regulations codified the executive orders by providing that routes and areas designated for ORV use shall be promulgated as special regulations. Section 4.10 also provides that the designation of routes and areas shall comply with E.O. 11644 and with section 1.5 of Title 36 of the Code of Federal Regulations (NPS 2014a). Thus, ORV plans have been required for national parks since 1972.

ORVs at Cape Lookout have been managed through an Interim Protected Species Management Plan/Environmental Assessment (NPS 2006a) and the Superintendent's Compendium (NPS 2013a). The effort to create a long-term ORV Management Plan for Cape Lookout began in 2005 as part of a settlement of a lawsuit filed by the National Park Conservation Association and the Friends of The Earth Bluewater Network Division. The long-term ORV management planning effort is based on the premise that ORVs must be regulated in a manner which is not only consistent with applicable law, but which also appropriately addresses resource protection (including protected, threatened and endangered species), potential conflicts among the various seashore users, and visitor safety. The goal of the ORV Management Plan will be to carefully manage ORV use and access to the seashore (excluding Shackleford Banks, managed as a Wilderness Area) in order "to protect and preserve natural and cultural resources and natural processes, to provide a variety of visitor use experiences while minimizing conflicts between and among various users, and to promote the safety of all visitors" (NPS 2014a, p.ii). The alternative selected for implementation will become the long-term ORV Management Plan for Cape Lookout; it will form the basis for a special regulation to guide management of ORV use at the seashore for the next 15–20 years (NPS 2014a).

ORVs are presently used at Cape Lookout to provide vehicular access onto beaches for recreational purposes, including surf fishing; surfboarding; sunbathing; swimming; bird watching; scenic driving;

etc. (NPS 2005a). ORVs are in use from 15 March through 31 December. Use is most concentrated during autumn (September through November; Wouter Ketel, Education and Public Programs at Cape Lookout, pers. comm., 2014; Shutak 2014). Present ORV use at the park requires a vehicle permit without cost, and there is no limit on the number of permits the seashore can issue. Present management allows ORV and all-terrain vehicle (ATV) access to 75.6 kilometers (47 mi) or 96% of Core Banks, except for temporary closures during nesting, hatching, and fledgling seasons for protected SSCs (NPS 2014a). A vehicle permit is required; nighttime driving is allowed; long-term parking is permitted with a weekly fee, and the number of parking permits is not limited. Pedestrian-only areas include 3.2 kilometers (2 mi) of beach (4% of Core Banks, 15 March to 31 December).

NPS-preferred Alternative C in the Draft ORV Management Plan (NPS 2014a) would reduce ORV access from present management by only 8 kilometers (5 mi) to a total of 64.4 kilometers (40 mi); thus, ORVs would retain access to 85% of the beach length of Core Banks. A vehicle permit with a weekly and/or annual fee would be required (estimated cost, $80 for 10 days and $150 for the calendar year); the number of permits would be limited to maintain ORV density at present levels (2,136 permits/year and 2,403 permits/year at North and South Core Banks, respectively). Long-term parking would be eliminated, and after a five-year grace period ATV and trailer use would be eliminated as well. Pedestrian-only areas would be increased to 11.3 kilometers (7 mi) of beach (15 March to 15 December). The Cape Lookout Village Historic District would be closed to through traffic, and a backroad would be added to bypass the Cape Lookout point (favored for nesting by many SSCs) from MM44 to MM45 during the period of 15 March through 15 December. Nighttime driving would be banned from 1 May through 14 September in order to strengthen protection of SSCs such as nesting and hatchling sea turtles.

The draft ORV Management Plan and NPS-favored Alternative C have attracted unfavorable notice by the new federal senator of North Carolina (as of November 2014), who was described as having encouraged the state to challenge it on the premise that it could hurt coastal tourism businesses (Siceloff 2014). Following a lengthy comment period, the Plan is scheduled to be finalized in 2016.

2.1.2. Geographic Setting

Cape Lookout NS is in Carteret County in an area along the central North Carolina coast that is often referred to by the tourism industry as the “Crystal Coast.” As mentioned, this seashore extends 90 kilometers (56 mi) between Ocracoke Inlet and Beaufort Inlet. The northern border of the county is Pamlico Sound, and the eastern and southern borders are the Atlantic Ocean. Carteret County is 2,756 km^2 (1,064 mi^2) in area, of which about 48% (1,311 km^2 [506 mi^2]) is land. The average elevation in the county is only 2.7 meters (9 ft) above mean sea level (MSL); thus, 47% of the total land area, 33% of the population, 24% of critical facilities, and 39% of roads lie within a Special Flood Hazard Area (CC undated). In addition to Cape Lookout, other substantial protected areas in the county include Croatan National Forest (64,345 hectares [159,000 ac] of hardwood forest, longleaf pine, pocosin, and estuary; EDPNC 2015) and Cedar Island Wildlife Refuge (4,451 hectares [11,000 ac] which includes irregularly flooded brackish marsh and 1,408 hectares [3,480 ac] of pocosin and woodland habitat; USFWS 2014).

A current copy of the park boundaries was obtained in digital format from the NPS Water Resources Division (WRD) in Fort Collins, Colorado. The enabling legislation for Cape Lookout (Title 16—Conservation § 459g) describes this seashore as consisting of the "lands and adjoining marshlands and waters…between Ocracoke Inlet and Beaufort Inlet, as generally depicted on the map entitled, "Boundary Map, Cape Lookout National Seashore," dated March 1974 and numbered 623-20,009." The seashore boundary on the ocean side is mean low tide, and on the side facing the mainland the boundary extends 45.7 meters (150 ft) from shore into the water. Given this definition of park boundaries, together with consideration of recently accelerating sea-level rise from climate change, the park boundaries are constantly shifting (PL 89-366 80 Stat. 33).

2.1.3. Visitation and Demographics

Visitation

The Amended General Management Plan (GMP) for Cape Lookout (NPS 2001a) describes the attractions for the general public at this seashore as excellent opportunities for fishing (surf and boat), motorized and other boating, shell fishing, shell collecting, nature-eco studies (birding, horse-watching), hunting, beachcombing, hiking, photography, swimming, windsurfing, sunbathing, and camping in a remote setting (NPS 2014a). Overnight accommodations are limited and rustic, although there are plans in progress to update and improve them. The only ways to reach the barrier islands are by ferry or private watercraft (PWC). There is a gateway marina facility at the east end of Harkers Island, where visitors can take a ferry to south Core Banks and Shackleford Banks. An on-island transportation system is available from the ferry dock to Cape Lookout Point (4.8 kilometers [3 mi]). Private motorized vehicles are allowed in some park areas excluding Shackleford Banks, and excluding dunes, vegetation, and sea turtle/shorebird nesting areas (NPS 1982). The park contains only a few roads, all unpaved. Two concessionaire-operated ferries transport people and their vehicles to the Core Banks, and small craft operators from Harkers Island bring visitors to the Keeper's Quarters area (NPS 2001a). Other operators leave from Beaufort and Morehead City, and an additional service travels between Ocracoke and Portsmouth Island.

Despite these difficulties for access, Cape Lookout is a very popular park, with an average of about 600,000 visitors per year over the 14-year period from 2000 through 2013 (Figure 4). The maximum annual number of visitors during that time was 860,602 in 2007. The recession, which has adversely affected the nation from 2008 to the present, clearly impacted visitor numbers to the park, which declined to 486,899 that year and has remained below 600,000 per year thereafter , except that visitation was slightly above 600,000 in 2009 (601,954; Figure 4). In fact, as shown in Figure 4, the annual number of recreational visitors in 2013 (416,568) was the lowest since 2000. On a seasonal basis, visitor numbers are highest in summer (July–August). For example, during 2012, there were more than 70,000 visitors in each of those months, whereas in 2013 the maximum number of visitors was 52,037 (August) to 61,505 (July). The winter season (December, January and February) generally has the lowest number of visitors per month, as few as 2,500–5,700 per month in some years.

A new National Park Service report shows that 416,569 visitors to Cape Lookout in 2013 spent $17.6 million in communities near the seashore. That spending supported 246 jobs in the local area (Ketel

2014a). For comparison, in 2012, 480,294 visitors to Cape Lookout spent $20 million in nearby communities, which supported 297 local jobs (Cullinane-Thomas et al. 2014; Ketel 2014b).

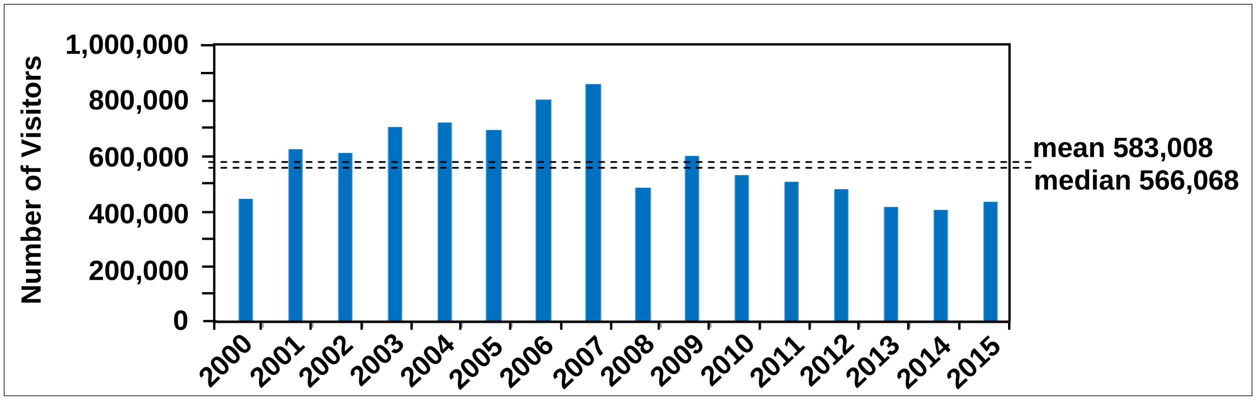

Figure 4. The annual number of recreationist visitors per year at CALO 2000–2015 (around 580,000 visitors, NPS 2015n).

Demographics

Carteret County has a land area of 1,311.2 square kilometers (506.25 mi^2) and as of 2010, (50.7 people per km^2 or 131.3 people per $mile^2$). Its population density is considerably lower than the average for the state (75.7 people per km^2 or 196 people per $mile^2$). The county includes the Morehead City Micropolitan Statistical Area (population between 10,000 and 50,000), with most of the population in Morehead City and the Town of Beaufort (Figure 4). As of 2013 the population of this county was 68,434, 3% higher than three years before in 2010 (UNC Carolina Population Center; see Tippett 2013). It increased overall by 13.9% from 2000 through 2013 (CCHD 2014). The population is 89.8% Caucasian, 6.3% African-American, 4% Hispanic, and the remainder Asian, Native American, and mixed racial.

The major industries in Carteret County are tourism, marine trades, and commercial and recreational fishing. The median household income ($47,506) is a little higher than the North Carolina average ($46,450). During 2008–2012, 14.1% of the population was below the poverty level, better than the state average of 16.8% (USCB 2015a). Although Carteret County maintains a “Tier 3 Designation” as one of the least economically disadvantaged counties in the state, several areas in the county have “pockets” of much higher poverty rates, which range from 14% in the western part of the county to 55% in the east (CCHD 2014).

2.2. Natural Resources

2.2.1. Land Use in the Watershed of the Albemarle-Pamlico Estuarine Complex

Cape Lookout is physically separated from the North Carolina mainland by the Pamlico Sound at its northern end, and by Core Sound and Back Sound along most of its length. These waters are components of the Croatan-Roanoke-Albemarle-Pamlico-Core Sounds Estuarine System (CAPES, total open water 5,300 km^2 [2,046 mi^2]) (Lin et al. 2007) (Figures 5 and 6). The portion of the CAPES known as the Albemarle-Pamlico Estuarine Complex (or Albemarle-Pamlico Estuarine

System) is, without other components, the second largest estuary on the U.S. mainland and the largest coastal lagoonal estuary in the United States. (Steel 1991).

Consideration of the entire watershed of the Albemarle-Pamlico Estuarine complex also gives an inaccurate conception of land use on the mainland nearest the park (Figure 5 versus Figure 6 and Table 1a and 1b). Nearly half of the land cover adjacent to the western (Pamlico Sound) side of the park is open water, and the eastern shores are entirely bordered by the Atlantic Ocean (Table 1a and 1b, Figure 6). Only 1.1% of the land cover in the entire complex is occupied by agriculture, whereas a much larger percentage, 16.6%, of the land cover on the mainland near Cape Lookout is agricultural. Forested (woody) wetland represents 32.2% of land cover in the complex, 10% higher than land cover of woody wetlands on the mainland nearest the seashore. Comparison of the 2006 and 2011 NLCDs indicate that developed urban land uses have increased from 2.7% to 4.2%, expected considering the human population growth in the area; agricultural and forestry land uses have decreased; and interestingly, a decrease of 4.9% in open water land cover has been roughly balanced by an increase in wetlands (by 4.1%).

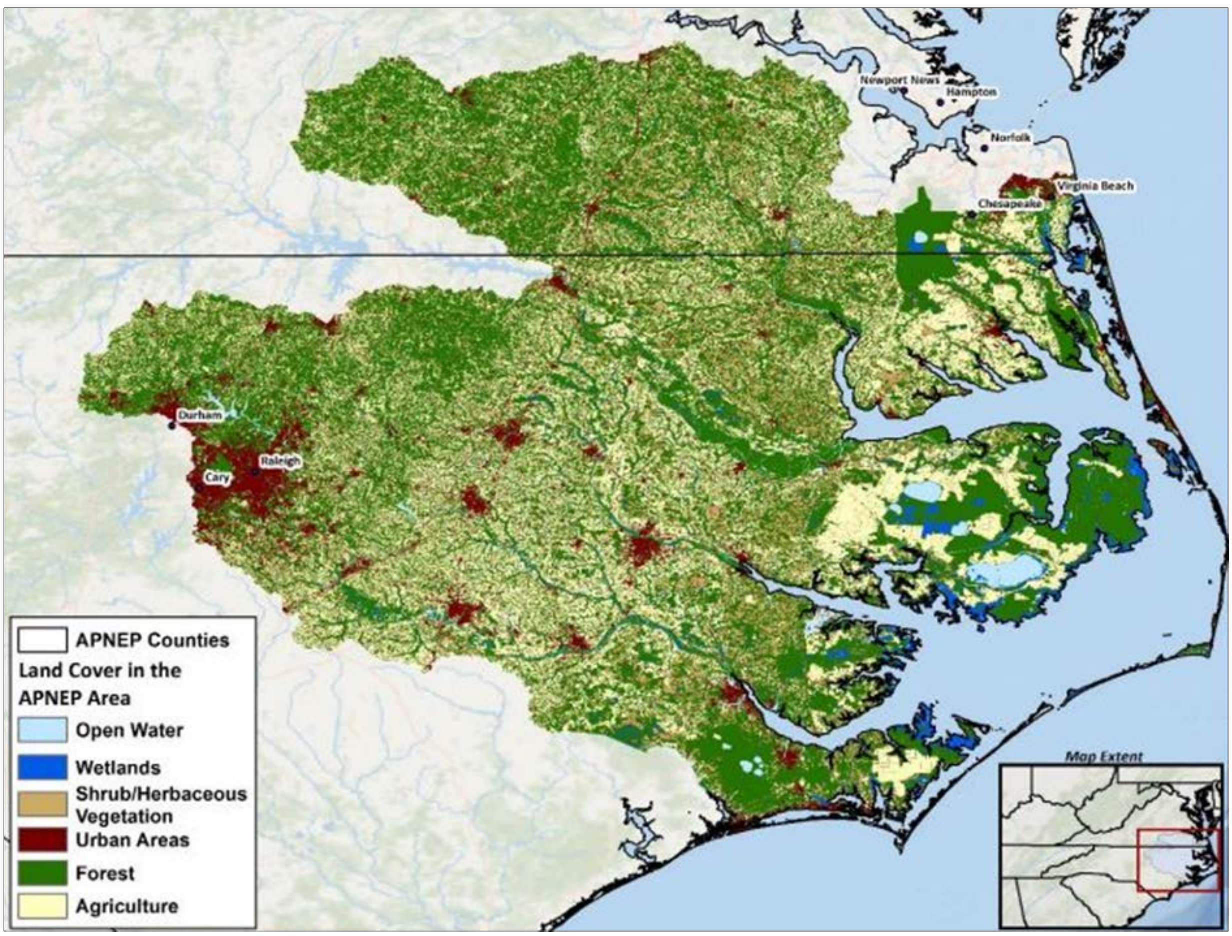

Figure 5. Map showing the watershed and land use/land cover of the entire CAPES. From RTI International, at the North Carolina Coastal Federation website (NCCF 2016).

Table 1a. Land use in the lower Albemarle-Pamlico Estuarine System watershed in 2006 (sub-watersheds HUC8 03010205 and HUC8 03020105, separated from CALO by Pamlico, Core, and Back Sounds. Data are summarized from the 2006 and 2011 National Land Cover Datasets (Fry et al. 2011; Homer et al. 2015).

Land Cover—2006	Area (km^2)	Area (mi^2)	Percentage
Open Water	6,396	2,470	46.8%
Developed Open Space	270	104	2.0%
Urban	94	36	0.7%
Barren/Rock	152	59	1.1%
Forested	631	244	4.6%
Scrub/Shrub/Grassland	285	110	2.1%
Agricultural—Pasture (animal production)	231	89	1.7%
Agricultural—Cropland	2,028	783	14.9%
Woody Wetlands	2,896	1,118	21.2%
Herbaceous Wetlands	664	256	4.9%
Total:	**13,647**	**5,269**	**100%**

Table 1b. Land use in the lower Albemarle-Pamlico in 2011. Estuarine System watershed (sub-watersheds HUC8 03010205 and HUC8 03020105, separated from CALO by Pamlico, Core, and Back Sounds). Data are summarized from the 2006 and 2011 National Land Cover Datasets (Fry et al. 2011; Homer et al. 2015).

Land Cover—2011	Area (km^2)	Area (mi^2)	Percentage
Open Water	5,718	2,208	41.9%
Developed Open Space	355	137	2.6%
Urban	218	84	1.6%
Barren/Rock	205	79	1.5%
Forested	532	206	3.9%
Scrub/Shrub/Grassland	464	179	3.4%
Agricultural—Pasture (animal production)	218	84	1.6%
Agricultural—Cropland	1,815	701	13.3%
Woody Wetlands	3,303	1,275	24.2%
Herbaceous Wetlands	819	316	6.0%
Total:	**13,647**	**5,269**	**100.0%**

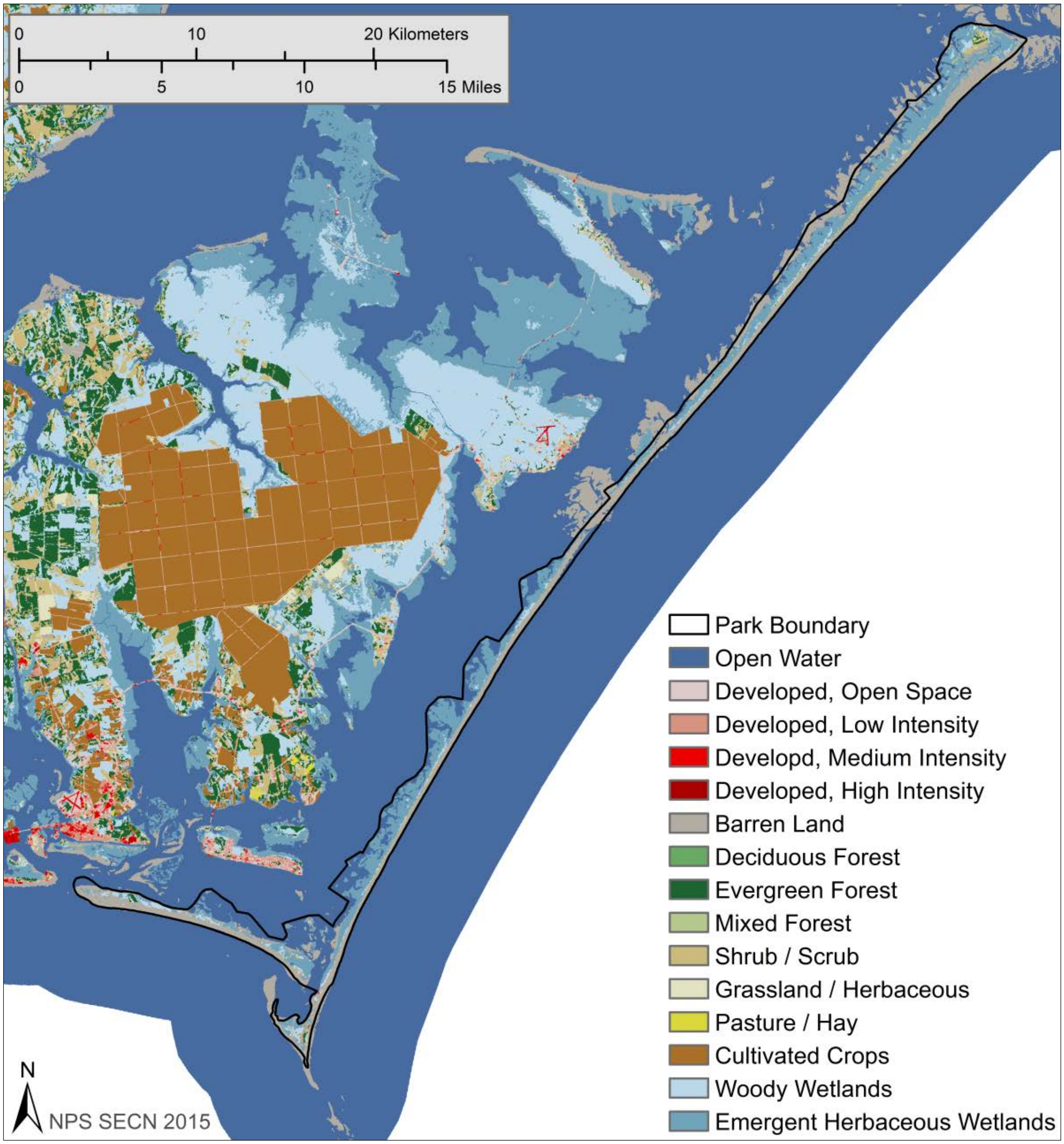

Figure 6. Map of land use/land cover in the portion of the watershed of CALO in North Carolina. Land use/land cover data are summarized from the 2011 National Land Cover Dataset (Homer et al. 2015, and see Appendix A.

2.2.2. Natural Resource Descriptions

Air Quality

Federal Criteria for Major Air Pollutants, and a Federal Index Scale

The EPA (2012a) maintains National Ambient Air Quality Standards (NAAQS) under the federal Clean Air Act (EPA 2016). The Clean Air Act has set standards for six "criteria" pollutants (including two categories for one of these, particulate matter) that must meet a health-based regulatory standard (Table 2). The regulatory air quality standards are health-based, and concentrations above the standards are considered unhealthy for sensitive groups. For example, the eight-hour (hr) ozone standard is attained when the average of the 4th highest concentration measured is equal to or below 0.08 parts per million (ppm; 0.085 ppm with the EPA rounding convention), averaged over three years. The standards for the six criteria pollutants are fairly straightforward except for the $PM_{2.5}$ standard: To be in compliance with the federal air $PM_{2.5}$ standard, an area must have an annual arithmetic mean concentration of less than or equal to 15 µg $PM_{2.5}/m^3$. An additional requirement imposed a stricter standard for fine particulate matter as of 2007, wherein the 98^{th} percentile 24-hour concentration must be $\leq$ 35 µg $PM_{2.5}/m^3$ to protect sensitive groups (Table 2).

Table 2. National ambient air quality (AQ) standards (NAAQS, 40 CFR part 50), set by the EPA (2014a) for six principal ("criteria") pollutants considered harmful to public health and the environment (P—primary; S—secondary).

Pollutant [final rule cited]	Primary / Secondary[5]	Averaging Time	Level	Form
Carbon Monoxide [76 FR 54294, Aug 31, 2011]	P	8-hour 1-hour	9 ppm 35 ppm	Not to be exceeded more than once per year
Lead [73 FR 66964, Nov 12, 2008]	P and S	Rolling 3 month average	0.15 µg/m[c (a)]	Not to be exceeded
Nitrogen Dioxide [75 FR 6474, Feb 9, 2010] [61 FR 52852, Oct 8, 1996]	P P and S	1-hour Annual	100 ppb 53 ppb [(b)]	98th percentile, average over 3 years Annual Mean
Ozone [73 FR 16436, Mar 27, 2008]	P and S	8-hour	0.075 ppm [(c)]	Annual fourth-highest daily maximum 8-hr concentration, averaged over 3 years
Particle pollution Dec 14, 2012	$PM_{2.5}$ P	Annual	12 µg/m[c]	annual mean, averaged over 3 years
	$PM_{2.5}$ S	Annual	15 µg/m[c]	annual mean, averaged over 3 years
	$PM_{2.5}$ P and S	24-hour	35 µg/m[c]	98th percentile, average over 3 years
	PM_{10} P and S	24-hour	150 µg/m[c]	Not to be exceeded more than once per year on average over three years

[a] Final rule signed October 15, 2008. The 1978 lead standard (1.5 µg/m[c] as a quarterly average) remains in effect until one year after an area is designated for the 2008 standard, except that in areas designated nonattainment, the 1978 standard remains in effect until implementation plans to attain or maintain the 2008 standard are approved.

[b] The official level of the annual NO_2 standard is 0.053 ppm, equal to 53 ppb, which is shown here for the purpose of clearer comparison to the one-hour standard.

[c] Final rule signed March 12, 2008. The 1997 ozone standard (0.08 ppm, annual fourth-highest daily maximum eight-hour concentration, averaged over three years) and related implementation rules remain in place. In 1997, the EPA revoked the one-hour ozone standard (0.12 ppm, not to be exceeded more than once per year) in all areas, although some areas have continued obligations under that standard ("anti-backsliding"). The 1-hour ozone standard is attained when the expected number of days per calendar year with maximum hourly average concentrations higher than 0.12 ppm is one day or less.

[d] Final rule signed June 2, 2010. The 1971 annual and 24-hour SO_2 standards were revoked in that same rulemaking. However, these standards remain in effect until 1 year after an area is designated for the 2010 standard, except in areas designated non-attainment for the 1971 standards, wherein the 1971 standards remain in effect until implementation plans to attain or maintain the 2010 standard are approved.

[e] The Clean Air Act identifies two types of national ambient AQ standards: Primary standards provide public health protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly. Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings (EPA 2016).

Table 2 (continued). National ambient air quality (AQ) standards (NAAQS, 40 CFR part 50), set by the EPA (2014a) for six principal ("criteria") pollutants considered harmful to public health and the environment. (P—primary; S—secondary)

Pollutant [final rule cited]	Primary / Secondary[5]	Averaging Time	Level	Form
Sulfur Dioxide [75 FR 35520, June 22, 2010] [38 FR 25678, Sept 14, 1973]	P	1-hour	75 ppb [(d)]	99th percentile of one-hour daily maximum concentrations, averaged over three years
	S	3-hour	0.5 ppm	Not to be exceeded more than once per year

[a] Final rule signed October 15, 2008. The 1978 lead standard (1.5 µg/m[c] as a quarterly average) remains in effect until one year after an area is designated for the 2008 standard, except that in areas designated nonattainment, the 1978 standard remains in effect until implementation plans to attain or maintain the 2008 standard are approved.

[b] The official level of the annual NO_2 standard is 0.053 ppm, equal to 53 ppb, which is shown here for the purpose of clearer comparison to the one-hour standard.

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National Park Service Indices for Air Quality

Ozone is monitored in March through October, since that period is when ozone production mostly occurs (EPA 1994). This pollutant is a serious health concern because it attacks the respiratory system, causing coughs, chest pain, throat irritation, increased susceptibility to respiratory infections, and impaired lung functioning. Moderate ozone levels can interfere with performance of normal daily activities by people who have asthma or other respiratory diseases (National Research Council 1991 and references therein). Chronic effects of repeated exposure to ozone, which can lead to lung inflammation and permanent scarring of lung tissue, loss of lung function, and reduced lung elasticity, are more concerning than acute effects.

Fine particulate matter ($PM_{2.5}$) is produced by various sources including industrial combustion, residential combustion, and vehicle exhaust, or when combustion gases are chemically transformed into particles. Recent research has indicated that $PM_{2.5}$ is a human health concern because it can penetrate into sensitive areas of the lungs and cause persistent coughs, phlegm, wheezing, more serious respiratory and cardiovascular disease, cancers, and premature death at particle levels well below the existing standards (Schwela 2000). Mounting evidence indicates that $PM_{2.5}$ enhance delivery of other pollutants and allergens deep into lung tissue where the effects are exacerbated. Especially sensitive groups include children, the elderly, and people with cardiovascular or lung diseases such as asthma. $PM_{2.5}$ also impairs visibility, and contributes to haze in humid conditions characteristic of the eastern North Carolina climate (EPA 1994).

The EPA Air Quality Index (AQI; scale from 0 to 500 with lower values indicating less pollution) was designed to help inform the general citizenry about potential health impacts from air quality degradation (Tables 3 and 4). The goal is to provide accurate, timely, easily understandable information about daily levels of air pollution with a uniform system for the major air pollutants regulated under the Clean Air Act. The index allows the general citizenry to assess whether air pollution levels in the location of interest are good, moderate, unhealthy for sensitive groups, or worse. For example, an AQI value of 50 indicates good air quality with low potential for adverse public health effects, whereas an AQI of more than 300 indicates hazardous air quality. An AQI less than 100 generally is used as the acceptable level set by the EPA to protect public health (AirNow 2015a). Information is also provided about precautions that should be taken if air pollution levels are unhealthy or worse.

Table 3. EPA Air Quality Index (AQI) criteria (modified from AirNow 2015a).

$PM_{2.5}$ (24 hr) µg/m^3	PM_{10} (24 hr) µg/m^3	SO_2 (1 hr) ppm	O_3 (8 hr) ppm	CO (8 hr) ppm	NO_2 (1 hr) ppm	AQI Value	Descriptor	EPA Health Advisory
0.00–15.4	0–54	0–0.035	0.00–0.059	0.0–4.4	0.0–0.053	0–50	GOOD	Air quality satisfactory; little or no risk from air pollution
15.5–40.4	55–154	0.036–0.075	0.060–0.075	4.5–9.4	0.054–0.100	51–100	MODERATE	Air quality acceptable, but for some pollutants there may be a moderate health concern for a small number of unusually sensitive people
40.5–65.4	155–254	0.0766–0.185	0.076–0.095	9.5–12.4	0.101–0.360	101–150	UNHEALTHY for Sensitive Groups	Sensitive groups (people with greater risk from exposure to particulate pollution, ozone
65.5–150.4	255–354	0.186–0.304	0.096–0.115	12.5–15.4	0.361–0.64	151–200	UNHEALTHY	Everyone may begin to sustain health effects; members of sensitive groups may experience more serious health impacts
150.5–250.4	355–424	0.305–0.604	0.116–0.374	15.5–30.4	0.65–1.24	201–300	VERY UNHEALTHY	AQI values trigger a health alert; everyone sustains more serious health effects. If related to high ozone, outside activities should be restricted to morning or late evening to minimize exposure
250.5–500.4	425–604	0.605–1.004	None	30.5–50.4	1.25–2.04	301–500	HAZARDOUS	AQI values over 300 trigger health warnings of emergency conditions; the entire populace is more likely to be affected

Table 4. The Air Quality Index (AQI) of the EPA, translated into actions that citizens can take to protect their health from potentially harmful levels of major air pollutants. From EPA (2009).

AQI Value	Actions To Protect Your Health From Particle Pollution	Actions to Protect Your Health From Ozone	Actions To Protect Your Health From Carbon Monoxide	Actions to Protect Your Health From Sulfur Dioxide
Good (0–50)	None	None	None	None
Moderate (51–100)	Unusually sensitive people should consider reducing prolonged or heavy exertion.	Unusually sensitive people should consider reducing prolonged or heavy outdoor exertion.	None	None
Unhealthy for Sensitive Groups (101–150)	The following groups should reduce prolonged or heavy outdoor exertion: - People with heart or lung disease - Children and older adults Everyone else should limit prolonged or heavy exertion.	The following groups should reduce prolonged or heavy outdoor exertion: - People with lung disease, such as asthma - Children and older adults - People who are active outdoors	People with heart disease, such as angina, should reduce heavy exertion and avoid sources of carbon monoxide, such as heavy traffic.	People with asthma should consider reducing exertion outdoors.
Unhealthy (151–200)	The following groups should avoid all physical activity outdoors: - People with heart or lung disease - Children and older adults Everyone else should avoid prolonged or heavy exertion.	The following groups should avoid prolonged or heavy outdoor exertion: - People with lung disease such as asthma - Children and older adults - People who are active outdoors Everyone else should limit prolonged outdoor exertion.	People with heart disease, such as angina, should reduce moderate exertion and avoid sources of carbon monoxide, such as heavy traffic.	Children, asthmatics, and people with heart disease should reduce exertion outdoors.
Very Unhealthy (201–300)	The following groups should remain indoors and keep activity levels low: - People with heart or lung disease - Children and older adults Everyone else should avoid all physical activity outdoors.	The following groups should avoid all outdoor exertion: - People with lung disease, such as asthma - Children and older adults - People who are active outdoors Everyone else should limit outdoor exertion.	People with heart disease, such as angina, should avoid exertion and sources of carbon monoxide, such as heavy traffic.	Children, asthmatics, and people with heart or lung disease should avoid outdoor exertion. Everyone else should reduce exertion outdoors.

National Park Service Indices for Air Quality

The National Park Service (2011b,c) has developed guidance for assessing air quality conditions within its parks, including information for evaluating O_3 (ozone) as related to plant responses. The Air Resources Division of the National Park Service used all available monitoring data over the 2005–2009 period to generate interpolations for the parks throughout the continental United States. The National Park Service then determined an index for each type of air quality data considered, including ozone concentrations and exposures (mean annual fourth highest eight-hour ozone concentrations), nitrogen wet deposition, sulfur wet deposition, and visibility condition (Group 50 visibility minus estimated annual average natural conditions, where Group 50 is the mean of the 40th to 60th percentiles of observed measurements in deciview). Park AQ interpolated values are then assigned to one of three condition categories for each NPS AQ index:

- Air quality is in good condition
- Air quality is in moderate condition
- Air quality is a significant concern

The following procedures are taken from the National Park Service (NPS 2011b):

Ozone Condition

The O_3 human health standard (EPA 2016) requires that the three-year average of the fourth highest daily maximum eight-hour average ozone concentrations measured at each monitor within the area of interest over each year must not exceed 75 parts per billion (ppb). Accordingly, the National Park Service assigned five-year average values as in Table 5:

Table 5. The National Park Service ranks for ozone concentrations to protect human health in air quality condition assessment (NPS 2011b).

Ozone Condition (Human Health)	Ozone concentration
Significant Concern	≥ 76 ppb
Moderate	61-75 ppb
Good	≤ 60 ppb

Note that the moderate and good conditions are assigned to parks with average 5-year 4th-highest 8-hr ozone concentrations > 80% of the standard and < 80% of the standard, respectively. The 8-hr standard of 75 ppb is achieved when the annual 4th highest daily 8-hr concentration, averaged over 5 yr, is less than or equal to the standard. This value is referred to by the National Park Service (2011c) as the average 5-yr 4th-highest 8-hr 24 ozone concentration. In the National Park Service ranks for ozone concentration, moderate condition is assigned when the value is higher than 80% of the standard (i.e., higher than 60 ppb), and good condition is assigned when the value is less than 80% of the standard (i.e., less than 60 ppb).

The National Park Service has incorporated vegetation sensitivity, as well as human health, into its park air quality rating, in consideration of the fact that some plant species have been shown to be more sensitive to O_3 than humans, so use of an O_3 standard for humans would not be sufficiently protective of those plant species. The National Park Service completed a risk assessment in 2004 that rated parks at low, moderate, or high risk for ozone injury to vegetation based on the presence of sensitive plant species, O_3 exposures, and environmental conditions (especially soil moisture). For O_3 condition assessment, parks that were evaluated at high risk are moved into the next worse condition category. For example, a park with an average O_3 concentration of 72 ppb, but evaluated at high risk for vegetation injury, would be moved from *moderate condition* to *significant concern*.

The National Park Service also developed a method for rating O_3 condition considering only plant response, based on the EPA proposed approach—use of the metric W126 for a secondary O_3 standard designed to protect vegetation. The W126 measures cumulative O_3 exposure over the growing season and is considered a better predictor of plant response than the eight-hour human health standard metric. A similar metric, SUM06, also measures cumulative exposure. The thresholds below for both metrics are based on recommendations from an expert workgroup (Table 6): W126 in the range of 7–13 ppm-hr would protect growth effects to tree seedlings in natural forest stands, whereas W126 ranging from 5–9 ppm-hour would protect plants in natural ecosystems from foliar injury (Heck and Cowling 1997).

Table 6. The National Park Service ranks for ozone concentrations to protect sensitive plant species in air quality condition assessment. (NPS 2011b).

Ozone Concentration (Ecological)	Ozone Exposure—W126	Ozone Exposure—SUM06
Significant Concern	> 13 ppm-hr	> 15 ppm-hr
Moderate	7–13 ppm-hr	8–15 ppm-hr
Good	< 7 ppm-hr	< 8 ppm-hr

Nitrogen and Sulfur Conditions:

Wet deposition is calculated by multiplying the N (nitrogen) or S (sulfur) concentration in precipitation by a normalized precipitation amount (note: dry deposition data are not available). Factors considered in rating the deposition condition include natural background deposition estimates (0.25 kilograms per hectare per year [kg/ha/yr] for either N or S), and deposition effects on ecosystems. Certain sensitive ecosystems respond to levels of N or S deposition at 1.5 kg/ha/yr whereas information is not available indicating that wet deposition of < 1 kg/ha/yr causes ecosystem harm. Therefore, the National Park Service ranks parks with wet N or S deposition as in Table 7:

Table 7. The NPS ranks for wet deposition of nitrogen (N) or sulfur (S) in air quality condition assessment, in order to protect park ecosystems (NPS 2011b).

Deposition Condition	Wet Depostion of N or S (kg/ha/yr)
Significant Concern*	> 3
Moderate	1–3
Good	< 1

*The basis for the level of deposition ranked as *Significant Concern* was not given by National Park Service (2011b). Values for parks with ecosystems that are potentially more sensitive to N or S are adjusted up one category.

Visibility Condition:

This rating is based on the deviation of the current Group 50 visibility conditions from the estimated Group 50 natural visibility conditions, where Group 50 is the mean of the visibility observations within the range from the 40th through the 60th percentiles. Current visibility is estimated from interpolating the five-year averages of the Group 50 visibility. Visibility is expressed in terms of a Haze Index (derived from calculated light extinction—see report #EPA-454/B-03-005 [EPA 2003a]), in deciviews (dv):

Visibility = present Group 50 Condition visibility – estimated Group 50 visibility under natural conditions

The dv ranges for these categories were described as somewhat subjective but selected to reflect, insofar as possible, the variation in visibility conditions across the monitoring network. The National Park Service criteria for visibility were finalized as shown in Table 8:

Table 8. The National Park Service ranks for visibility in air quality condition assessment. (NPS 2011b).

Visibility Condition	Current Group 50–Estimated Group 50 Natural (dv)
Significant Concern	> 8
Moderate	2–8
Good	< 2

State Criteria for Major Air Pollutants

States must meet the federal standards and can set additional standards. North Carolina's ambient monitoring standards for criteria pollutants are shown in Table 9. The North Carolina Department of Environment and Natural Resources (NCDENR) Division of Air Quality (DAQ) has based its program for toxic air pollutants (TAPs) on acceptable ambient levels (AALs) of airborne concentrations above which a given substance may be considered to have an adverse effect on human health (see NCDAQ undated-b). AALs are expressed in weight per unit volume, usually as milligrams per cubic meter of air (mg/m^3). The state has developed AALs for 97 toxic air pollutants (see NCDAQ 2014, section 2D .1104).

Table 9. NCDENR DAQ standards for criteria pollutants (NCDAQ 2014).

Compound	Criteria
Sulfur oxides (SOx)	Primary 1-hr ambient standard, 75 ppb as SO2—met when the 3-year average of the 99th percentile of the daily maximum 1-hr conc. is ≤ 75 ppb Secondary criteria: 80 µg/m^3 (0.03 ppm, annual arithmetic mean); 365 µg/m3 (0.14 ppm, maximum 24-hr conc.*; and 1,300 µg/m3 (0.5 ppm) maximum 3-hr conc.*
Particulate matter ($PM_{2.5}$)	Primary: 15 µg/m^3, arithmetic mean conc. Secondary: 35 µg/m^3, 24-hr average conc.—met when the 98th percentile 24-hr conc. is ≤ 35 µg/m^3
Particulate matter (PM_{10})	150 µg/m^3, 24-hr average conc.—met when 150 µg/m^3 is not exceeded more than once per year on average over a 3-year period.
Total suspended particulates	Primary: 75 µg/m^3 annual geometric mean Secondary: 150 µg/m^3 maximum 24-hr conc.*
Carbon monoxide (CO)	Primary: 10 mg/m^3 (9 ppm) maximum 8-hr average conc.* Secondary: 40 mg/m^3 (35 ppm) maximum 1-hr average conc.*
Ozone (O_3)	0.075 ppm, daily maximum 8-hr average—attained at a monitoring site when the average of the annual 4th highest daily maximum 8-hr average ozone conc. is ≤ 0.075 ppm
Nitrogen dioxide (NO_2) andnitrogen oxides (NOx)	Primary for NO_2: 53 ppb, annual average conc. Primary for NOx: 100 ppb, 1-hr annual average conc. Secondary for NO_2: 100 µg/m^3 (0.053 ppm), annual arithmetic mean conc.
Lead (Pb)	0.15 µg/m^3—met when the maximum arithmetic three-month mean conc. for a three-month period

*—Not to be exceeded over the course of a year.

For health effects other than cancer, AALs were determined by taking occupational exposure standards and lowering exposure guidelines to acceptable concentration levels by safety factors of 10 to 160. Highly toxic chemicals such as mercury usually have larger safety factors and lower AALs. For carcinogenic chemicals, AALs are set at levels calculated to represent an increment of "one in a million" risk over a person's lifetime (estimated at 70 years). Acceptable ambient levels are used in pollution permitting, in an attempt to ensure that toxic air pollutants from new or modified facilities do not make toxic air pollution levels worse. Monitoring for toxic air pollutants by the state generally is limited to specific areas and specific pollutants.

For example, the North Carolina Division of Air Quality (NCDAQ) has monitored atmospheric trends in mercury (Hg) since 1996. Elemental mercury vapor (Hg^0) is present globally in ambient air at concentrations of 1.5–2.0 ng/m^3. Hg^0 is the least water-reactive atmospheric species of mercury, which allows it to persist in the ambient air and travel over long distances. Hg^0 emissions may contribute to the world-wide atmospheric pool of mercury, making it a global concern. The atmospheric concentration of Hg^0 likely has increased over the past century because of human activities. Mercury can also exist in ambient air as particulate or reactive gaseous forms, which are considered to have more local or regional scale impacts. NCDAQ has a wet deposition site and elemental mercury vapor monitors at the rural location of Lake Waccamaw State Park. The site is also part of the national Mercury Deposition Network, and is characterized by elevated levels of methylmercury in fish (Butler et al. 2007).

Air Quality in Cape Lookout and Vicinity

Cape Lookout is within a Class II airshed (NPS 2012a) under the Clean Air Act, wherein modest increases in air pollution are allowed beyond baseline levels for particulate matter, sulfur dioxide, nitrogen and nitrogen dioxide, provided that the national ambient air quality standards, established by the EPA, are not exceeded. The seashore fire management program manages smoke in compliance with the Clean Air Act and North Carolina State requirements, so as to minimize its effects on park visitors, firefighters, adjoining lands and neighbors, natural and cultural resources, and roads and highways (NPS 2012a).

Principal sources of air pollutants west of the park include agricultural operations, motor vehicles, and various industrial operations (NPS 2012a). The park is a substantial distance from the state's major areas of mercury (Hg) air emission point sources, two of which are in the Wilmington area about 177 kilometers (110 mi) from the park (Harker's Island area; Figures 2 and 3). These two sources, International Paper Riegelwood Mill, of Columbus County, and Progress Energy in New Hanover County, contributed 55.8 and 52.6 kilograms (123 and 116 pounds [lb]), respectively, of total mercury to the atmosphere in 2010 (NCDAQ 2010 a,b) (Figures 2 and 3). It was estimated that in this area of southeastern North Carolina, a 75% reduction in the mercury content of freshwater and estuarine finfish and shellfish tissue would be required in order to meet the federal methylmercury criterion (0.3 mg/kg wet weight of fish tissue) for safe consumption by the general population (EPA 2001).

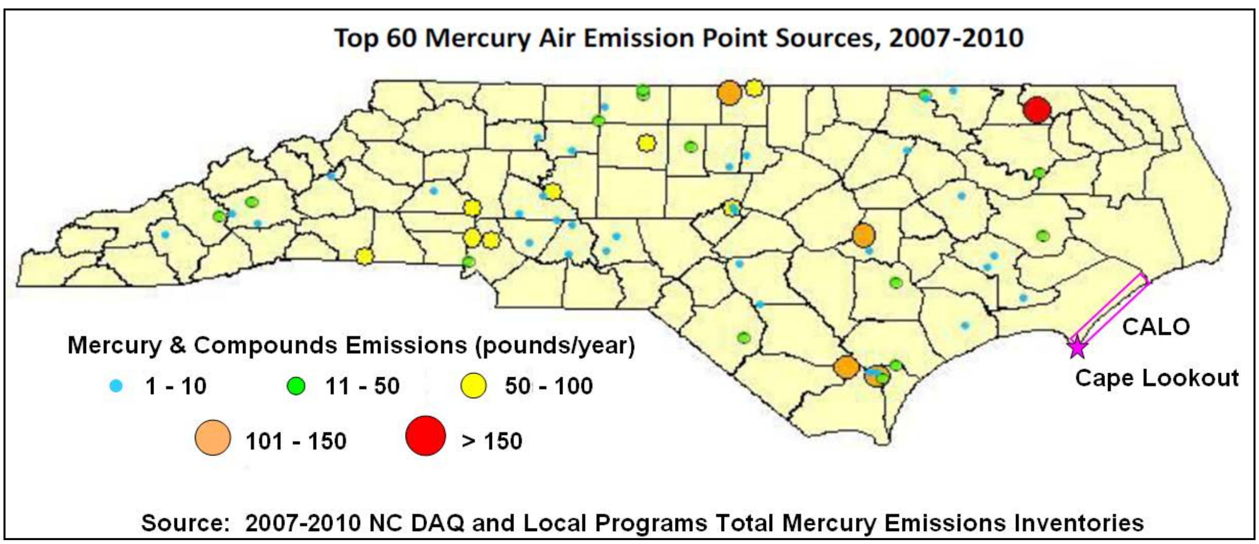

Figure 7. Top 60 mercury air emission point sources in North Carolina, 2007–2010. From NCDAQ (2010a).

The North Carolina Department of Natural Resources Division of Air Quality has various air quality monitoring stations in its Wilmington Air Quality Region, which includes Cape Lookout (Figure 8).

A request form on the NCDAQ website can be submitted for data from individual sites in the region. The NCDAQ website also has a color-coding system to indicate air quality is related to ozone and $PM_{2.5}$ in the Wilmington metropolitan area (e.g., Table 10, showing a good day and a moderate day).

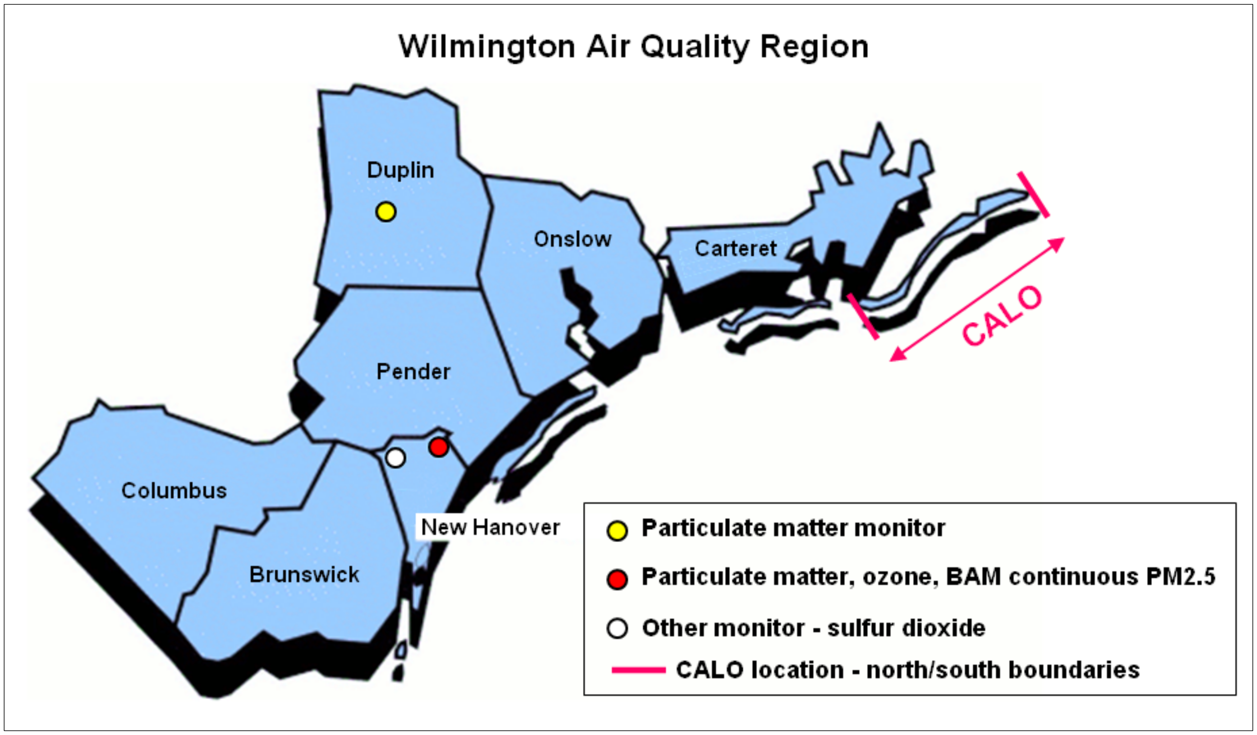

Figure 8. Map showing locations of air monitoring sites nearest the seashore, and parameters monitored per site. Modified from the NCDENR Division of Air Quality (NCDAQ undated-a). (BAM—beta attenuation monitoring)

Table 10. Examples of the NCDAQ color coding system to indicate air quality as related to ozone and $PM_{2.5}$ in the Wilmington, N.C. area, the major monitored population center nearest CALO (20–21 October 2012 and 5–6 May 2014) (see AirNow 2015b). The North Carolina Department of Natural Resources Division of Air Quality provides this information daily for the past 24 hours (note—the raw, real-time data are not QA-QC'd).

Area	AQI	Responsible Pollutant	Pollutant Concentration	Color Code	Air Quality	Time of Maximum
Wilmington	34	ozone	40 ppb	green	good	10/22/12 6:00 PM
	30	particulate matter ($_{2.5}$)	9.3 µg/m^3	green	good	10/21/12 9:00 AM
Wilmington	169	particulate matter ($_{2.5}$)	90.0 µg/m^3	red	unhealthy	5/6/14 10:00 AM
	58	ozone	62 ppb	yellow	moderate	5/5/14 9:00 PM
	0	sulfur dioxide	0 ppb	green	good	5/6/14 8:00 PM

While the NCDAQ sites provide instructive information on a regional basis, they are at substantial distances from the park and, therefore, do not provide data for the specific area in and around the seashore. They also do not provide information about some of the most important air pollutants in the region, ammonia and hydrogen sulfide from the swine industry (EPA 1998; Aneja et al. 2003; Wing et al. 2008, 2012; Liu et al. 2014). North Carolina is the second largest producer of swine in the United States, after Iowa (Figure 9). The industrialized swine production that occurs in eastern North Carolina has caused human health impacts because of air pollutants such as hydrogen sulfide (Wing et al. 2008, 2012), as well as documented, major increases in the toxic air pollutant, ammonia down-airshed (Walker et al. 2000a,b; Aneja et al. 2003). Cape Lookout is due east, and the prevailing winds often move west-to-east (SCONC 2016a).

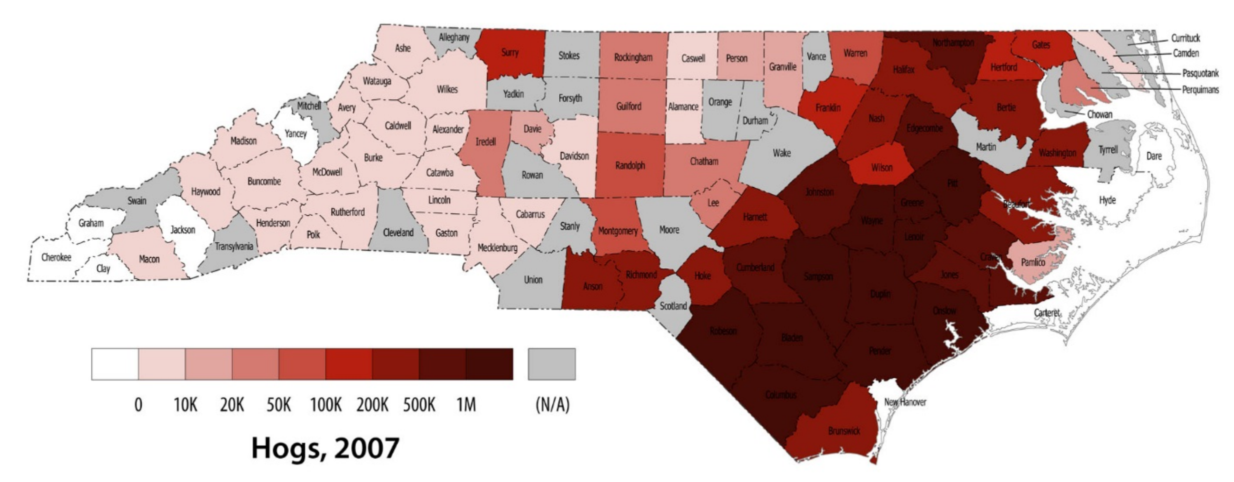

Figure 9. Hogs sold in North Carolina counties during 2007 (K—thousands; M—millions; U.S. Census data), modified from Learn N.C., a program of the University of North Carolina School of Education (Duke 2007). The darker area “down east” on the Coastal Plain of the state has the highest concentration of swine per unit area in the nation (National Hog Farmer. 2014.). This area, due west of CALO, has caused a significant increase in air pollutants such as ammonia (Aneja et al. 2003, Wing et al. 2012).

A number of air quality issues were identified for Cape Lookout in DeVivo et al. (2008), including increasing ammonium concentration and wet deposition, excessive ozone (Sum06 in particular), increased risk of foliar injury (terrestrial plants), and increasing acidification and metals in surface waters (Table 11). Acid precipitation can adversely affect or kill aquatic life and harm human health (Abelson 1987; Herlihy et al. 1991; Baker and Christensen 1992), and can act synergistically with ozone to harm human health as well (Abelson 1987). The major pollutants from coal-fired power plants, including those involved in acid deposition (SO_2, mostly from coal-fired power plants, and NO_x from coal-fired power plants, car exhausts and other sources) can be transported long distances across airsheds (Schwela 2000). Acid precipitation can act synergistically with toxic metals to adversely affect aquatic life in estuarine/marine as well as freshwater environments (Fabry et al. 2008; Pascal et al. 2010; Roberts 2012 and references therein).

Table 11. Air quality issues identified by DeVivo et al. (2008) in Cape Lookout. [Y—yes; N—no; F—frequently or consistently surpasses air quality thresholds; I— infrequently surpasses air quality thresholds; M—Medium risk; NA—not applicable]. From DeVivo et al. (2008) and Sullivan et al. (2011a,b).

Type	Contaminant	Type of contamination	Code
Wet deposition	Ammonium	Deposition	Y
	Ammonium	Concentration	Y
	Nitrate	Deposition	F
	Nitrate	Concentration	NA
	Sulfate	Deposition	F
	Sulfate	Concentration	NA
Dry deposition	Nitrogen	Overall dry deposition	F
	Nitrogen	Percentage of total N that is dry	NA
	Sulfur	Overall dry deposition	F
	Sulfur	Percentage of total S that is dry	NA
Surface water chemistry	Acidification	Concern for Park	F
	Mercury	Potential aerial deposition	F
	Nutrients	Potential aerial deposition	Y
Ozone	Sum06	Frequency standard surpassed	F
	W126	Frequency standard surpassed	I
	Foliar injury	Risk based on conditions	M

In 2001–2003, Sullivan et al. (2011a,b) assessed the threat of acid deposition and related nitrogen pollution to national parks across the nation, including Cape Lookout. First, they compiled and mapped data for total sulfur (S) and total nitrogen (N) emissions from the EPA from the National Atmospheric Deposition Program (NADP) for wet deposition (2001–2003—kg/hectare/yr), and from the 12-km Community Multiscale Air Quality (CMAQ) model projections for dry deposition for 2002. The area of southeastern North Carolina including the park was mapped for S and N emissions and S and N deposition (Figures 10a–10b). Sullivan et al. (2011a) then ranked the 32 NPS networks and also the individual parks within each network considering four metrics (not further defined or explained): (1) pollutant exposure, (2) ecosystem sensitivity, (3) park protection, and an overall metric, (4) summary risk to acid deposition. This analysis indicated that the Southeast Coast Network ranked at the top of the second highest quintile (about the 80th percentile) in pollutant exposure among the NPS networks. Emissions and deposition of S and N within the Southeast Coast Network were evaluated as fairly high. The SECN Ecosystem Sensitivity ranking was low, in the bottom quintile (below the 20th percentile) among the networks, and at the bottom of the second lowest quintile (about the 40th percentile) in park protection because it has only limited amounts of protected lands. The SECN overall summary risk ranking was relatively low among the networks.

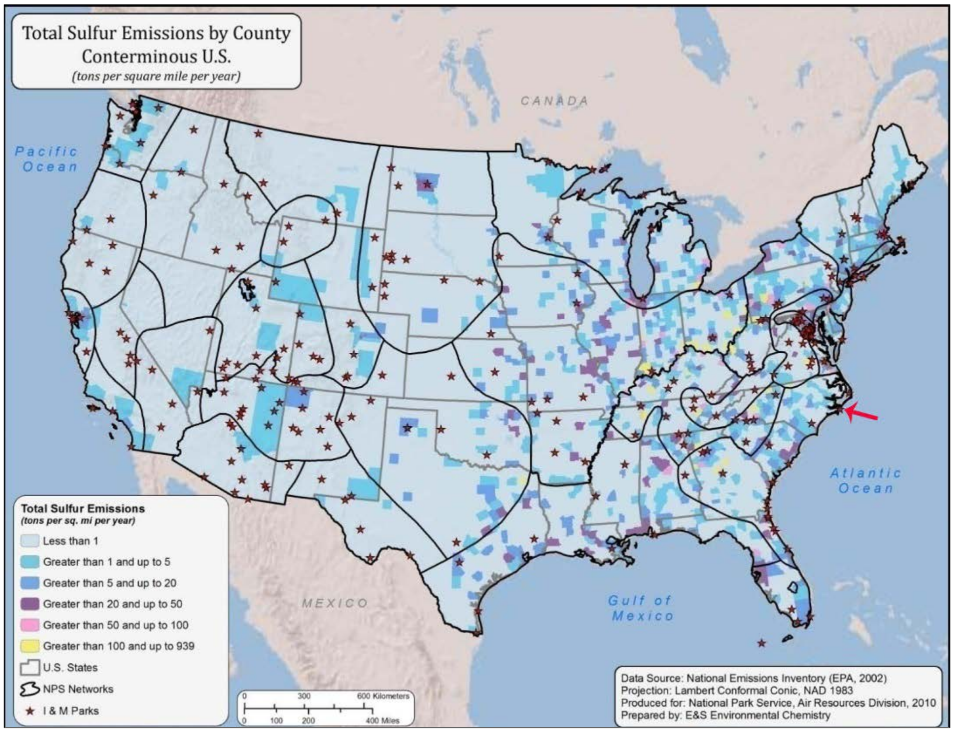

Figure 10a. Map of total sulfur (S) emissions (tons/mi^2/yr) by county as of 2002 (Cape Lookout NS —red arrow). From Sullivan et al. (2011a).

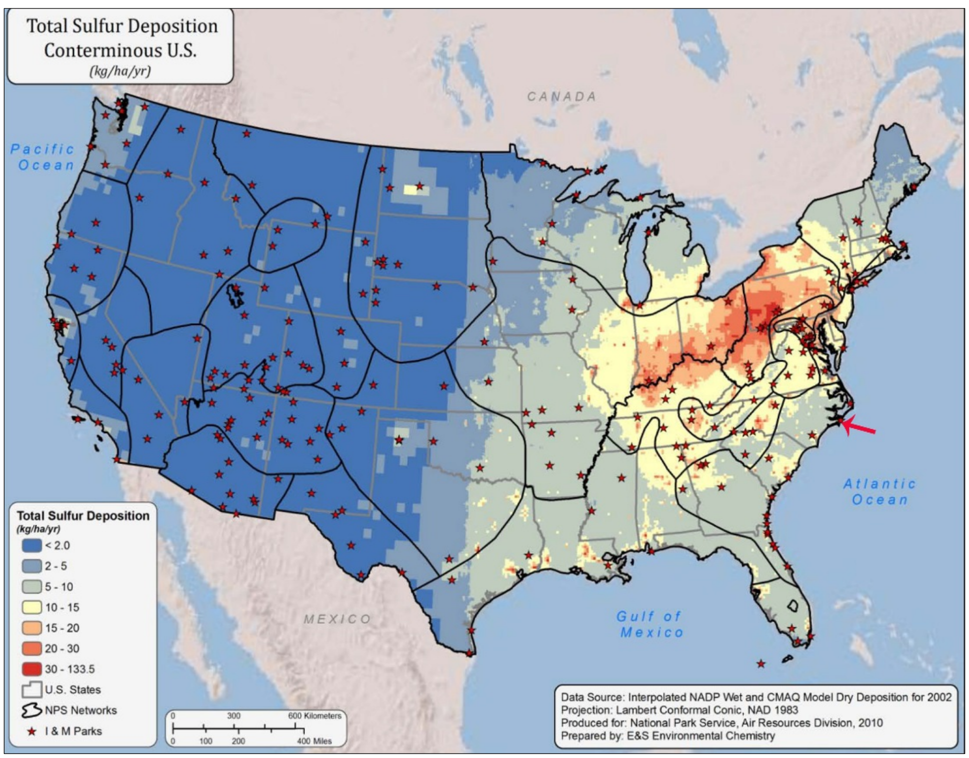

Figure 10b. Map of total sulfur (S) emissions (kg/ha/yr) by county as of 2002 (Cape Lookout NS —red arrow). From Sullivan et al. (2011a).

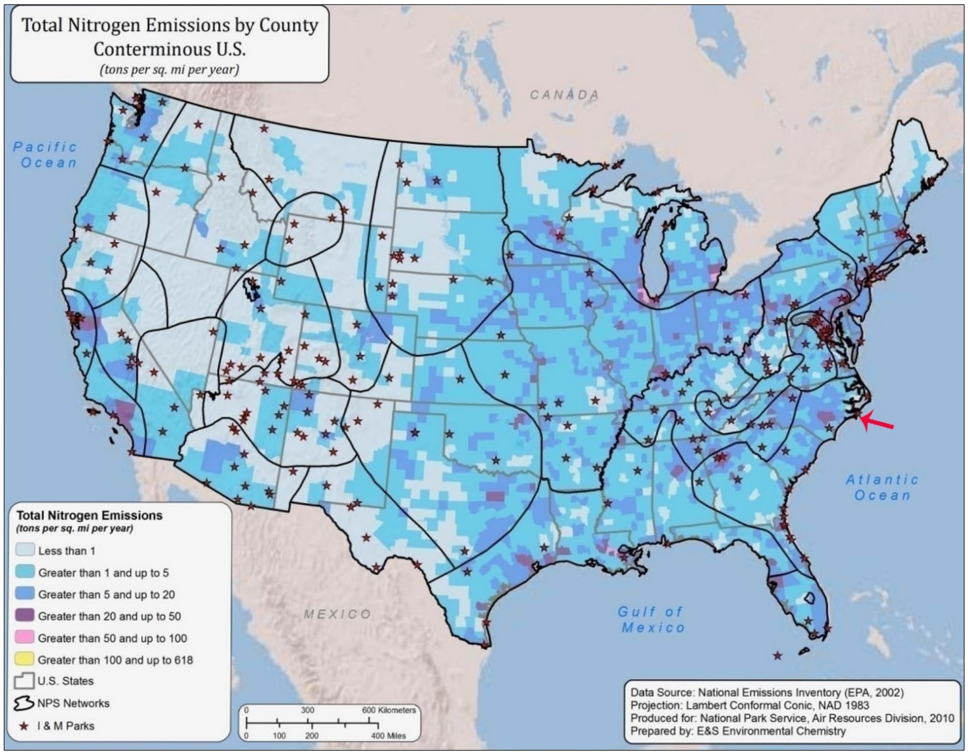

Figure 10c. Map of total nitrogen (N) emissions (tons/mi^2/yr) by county as of 2002 (Cape Lookout NS —red arrow). From Sullivan et al. (2011a).

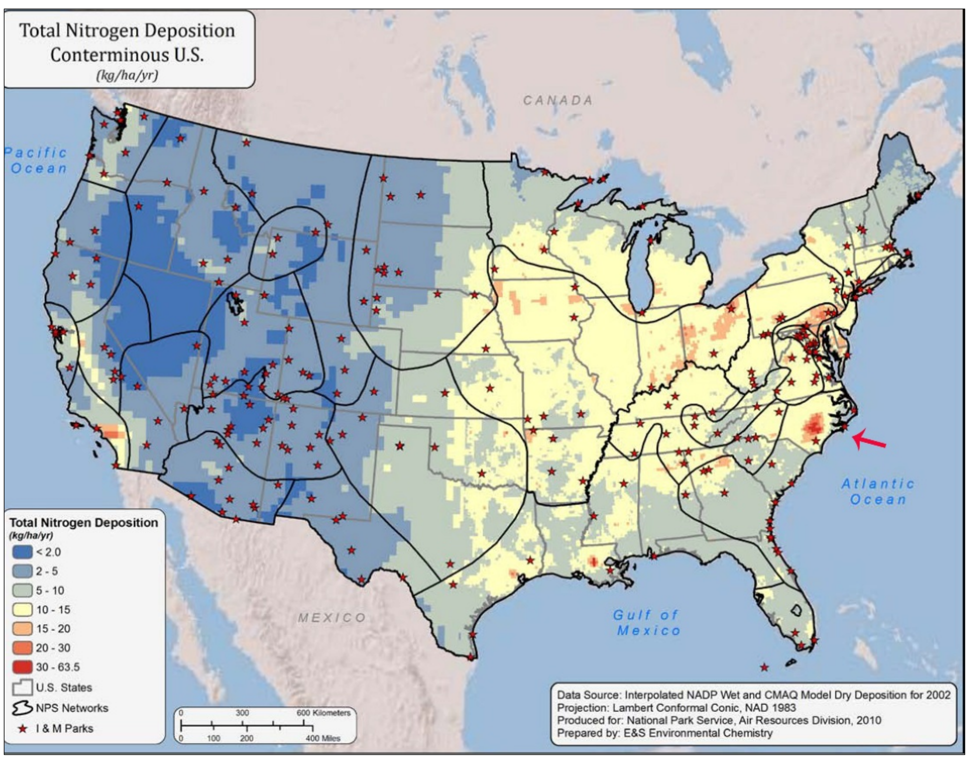

Figure 10d. Map of total nitrogen (N) emissions (kg/ha/yr) by county as of 2002 (Cape Lookout NS—red arrow). From Sullivan et al. (2011a).

The Sullivan et al. (2011a) assessment ranked Cape Lookout high (i.e., in the second highest quintile ranking) for pollutant exposure. Cape Lookout was evaluated as very low (the lowest quintile ranking) for ecosystem sensitivity, moderate in park protection, and overall moderate in summary risk from acid deposition. As noted, the data used for this study were from 2001–2003, now a decade or more outdated.

Sullivan et al. (2011b) also considered N deposition from the perspective of causing adverse effects of nutrient over-enrichment. That is, they conducted a preliminary assessment to estimate the relative risk of nitrogen (N) enrichment impacts from atmospheric N deposition, considering three factors: N pollutant exposure, inherent ecosystem sensitivity, and park protection mandates. Because N is often the most important nutrient limiting algal and plant growth in brackish wetlands and estuarine/marine coastal environments, N enrichment significantly influences the entire wetland or aquatic ecosystem (Day et al. 1989, Burkholder and Glibert 2013). High levels of nitrate can adversely affect sensitive plants such as the dominant seagrass, *Zostera marina* (Burkholder et al. 1992). Increasing ammonia from sources such as aerosolized swine effluent can stimulate certain harmful algae (Burkholder and Glibert 2013). Ammonia from aerosolized swine effluent likely reaches the park as a common condition (Costanza et al. 2008). Relative to other national parks, Sullivan et al. (2011b) evaluated Cape Lookout as high in nitrogen pollutant exposure, high in ecosystem sensitivity, moderate in park protection, and high in overall summary risk. These findings update the previous NPS evaluation (DeVivo et al. 2008—Table 12) which had not identified nitrogen enrichment to surface waters as an impact affecting the seashore.

The NPS Air Resources Division more recently evaluated the air quality of Cape Lookout (NPS 2009a). Because the seashore has no air quality monitoring sites, the National Park Service estimated several parameters from regional data by interpolating values at the location of the seashore center (NPS 2011b). The five-year average (2005–2009) air quality conditions for Cape Lookout were evaluated as moderate for ozone and poor for N deposition, S deposition, and visibility (Table 12).

Table 12. Evaluation of air quality conditions (2005-2009) at Cape Lookout (NPS 2009a).

Parameter	Condition
Ozone Condition[a]	Moderate concern
N Deposition Condition[b]	Significant concern
S Deposition Condition[c]	Significant concern
Visibility Condition[d]	Significant concern

[a] Ozone condition assessments are derived from interpolated five-year (2005–2009) values of the mean annual 4th-highest 8-hour ozone concentrations.

[b] Nitrogen (N) deposition condition assessments are derived from interpolated five-year (2005–2009) values of nitrogen wet deposition.

[c] Sulfur (S) deposition condition assessments are derived from interpolated five-year (2005–2009) values of sulfur wet deposition.

[d] Visibility condition assessments are derived from interpolated five-year (2005–2009) values of Group 50 visibility minus estimated annual average natural conditions, where Group 50 is the mean of the 40th-60th percentiles of observed measurements in deciviews(dv).

Soundscape

Definitions and Interpretations

Sound is defined as an auditory sensation perceived by humans, and created by pressure variations that move in waves through a medium such as air or water (NPS 2014d). Sound is measured in terms of frequency and amplitude. Noise is defined as sound that is unwanted or inappropriate in an environment (Kim et al. 2012). Frequency (sometimes referred to as pitch; units, hertz [Hz]) is the number of times per second that a sound pressure wave repeats itself. Humans with normal hearing can hear sounds ranging from 20 to 20,000 Hz; bats can hear up to 120,000 Hz. Amplitude is defined as the relative strength of sound waves (or transmitted vibrations), perceived as loudness or volume. Amplitude, or the sound pressure level (intensity), is measured in decibels (dB). The terms dB(A) or dB(C) designate two frequency-response functions (weighting characteristics) that filter sounds detected by a microphone in a sound-level meter. Each emphasizes or de-emphasizes sounds of certain pitches relative to others (Figure 11).

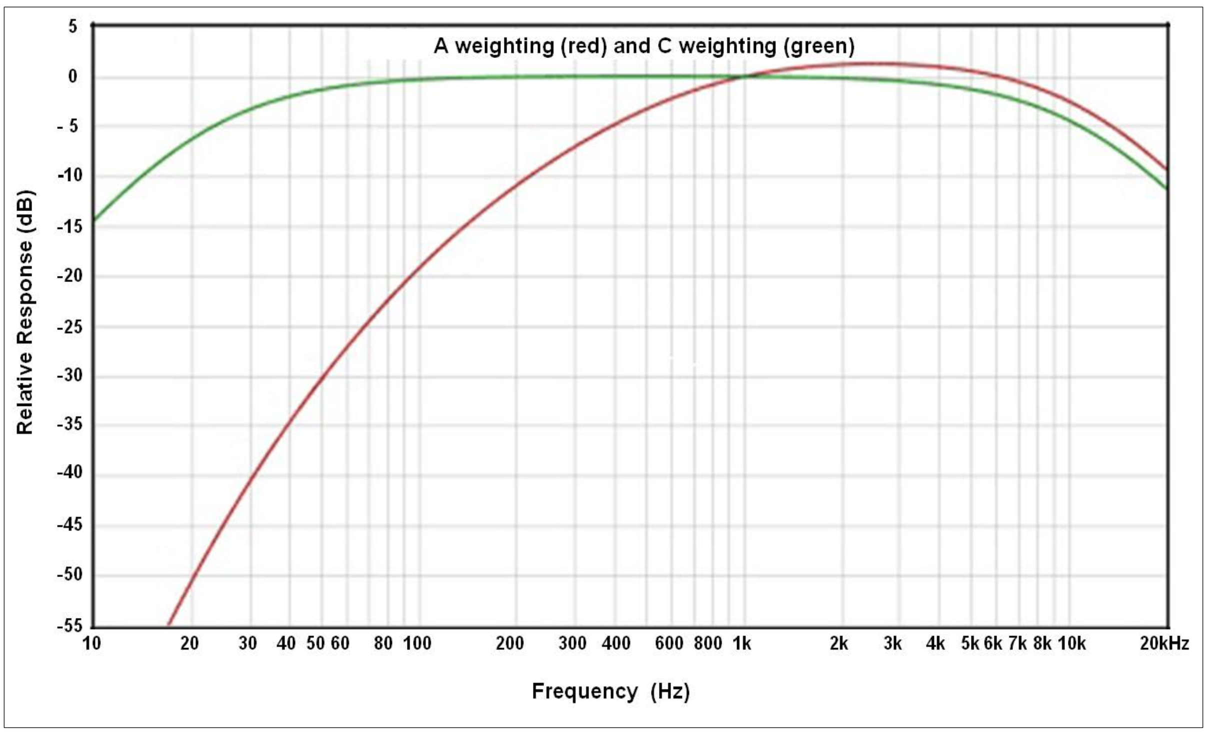

Figure 11. Influence of A- and C-weighting curves on the relationship between dB and frequency (pitch, Hz). Modified from Sengpiel (2016).

The “A” weighting, relevant to Cape Lookout, filters out the low frequencies and slightly emphasizes upper-middle frequencies at two to three kilohertz (kHz). A-weighting, used to assess noise impacts on wildlife, measures hearing risk and compliance with Occupational Safety and Health Administration and Mine Safety and Health Administration regulations that specify permissible noise exposures as a time-weighted average sound level or daily noise “dose” that can be tolerated without appreciable health risks. Thus, the World Health Organization (WHO 2009) has recommended that outdoor environmental noise should not exceed 55 dB(A) and 40 dB(A) for daytime and nighttime activity, respectively, to prevent potential adverse psychosocial and physiological effects. For perspective, the lower threshold of human hearing is 0 dB; moderate sound levels (e.g., normal speaking voice) are less than 60 db; a typical suburban area is 50–60 dB(A); thunder is 100 dB(A); and a military jet flying at 100 meters above ground level is 120 dB(A) (NPS 2014m; Crocker 1997).

Because dB are on a logarithmic scale, an increase of 10 dB causes a doubling of perceived loudness and represents a ten-fold increase in sound level. Sound levels adjusted for human hearing are expressed as dB(A). “Soundscape” is used here in accord with the NPS definition, that is, the human perception of these physical sound resources. The acoustical environment is the combination of all of the acoustic resources within a given area, including both natural and non-natural (human-caused) sounds. Thus, it is important to consider the entire acoustical environment in efforts to protect natural sounds.

Sound is an important component of natural park ecosystems; the acoustical environment influences a wide array of animal behavior, such as finding desirable habitat and mates, avoiding predators, protecting young, and establishing territories (Monroe et al. 2007; Lynch et al. 2011, and references therein; and NPS 2014b). National parks in all regions of the United States are under increasing noise pressure from ground transportation, air transportation, and other human activities (Lynch et al. 2011). Much of the noise measured in national parks is from outside park boundaries or otherwise beyond the management jurisdiction of the National Park Service (Lynch et al. 2011). As examples, noise levels in park transportation corridors are often 1,000-fold higher than natural sound levels (Barber et al. 2009, 2011). Noise from airplanes can cause as much as a 70% reduction in the size of the hunting area where predatory animals are able to hear their prey (Barber et al. 2009). There is no question that parks are becoming noisier from human activities, even in remote areas, in conflict with the fact that 70% of Americans have indicated that one of the most important reasons for preserving national parks is to provide opportunities to experience natural peace and the sounds of nature (Haas and Wakefield 1998). The problem is growing to the extent that national parks are presently sustaining what has been described as “an ongoing acoustic assault” by human-related noise (see above website). Thus, the National Park Service has determined that “increasingly, careful consideration of the impacts of human-generated noise on wildlife is a critical component of management for healthy ecosystems in our parks” (NPS 2014b).

Wildlife, like humans, is stressed by the increasing noise and must adapt (Radle 1998 and references therein). As examples, robins in suburban and urban environments are now singing at night in order to be heard by other members of their population (Fuller et al. 2007); males of at least one frog species have adapted to traffic noise by calling at a higher pitch, although females have been shown to prefer lower-pitched calls which apparently are indicative of larger, more “fit” males; bats avoid hunting in areas with road noise (Barber et al. 2009; Parris et al. 2009). Noise stress can exacerbate the impacts of other stressors in national parks, with important ramifications for wildlife populations.

The Cape Lookout Soundscape

Human-related environmental noise reaches Cape Lookout from external sources such as aircraft and boat traffic, and internally from ORVs and other recreationists. The NPS Management Policies (NPS 2006b) and Director’s Order #47, *Sound Preservation and Noise Management*, direct the protection of the natural ambient soundscape so as to minimize and optimally manage noise and maintain the natural quiet. Noise is defined as unwanted sound, especially dissonant human-caused sounds. However, most noise sources measured in national parks (e.g., highways, airplane traffic) originate outside park boundaries, beyond NPS management jurisdiction (Lynch et al. 2011). The National Park Service recognizes that no single metric is adequate to characterize acoustic resources; thus, the Natural Sounds and Night Skies Division of the National Park Service works with several metrics and considers sound pressure level data, spectral data, audibility data, source identification data, and meteorological data (Lynch et al. 2011).

Potential impacts of ORVs and associated recreational noise on the Cape Lookout soundscape are a major concern to the National Park Service because these sounds are often incompatible with other recreational uses involving natural resources, such as bird watching, or enjoying solitude on the seashore beaches (NPS 2014a). In addition, engine and recreational noise create unsuitable habitat for seashore wildlife during breeding seasons. Fortunately, the ambient sound levels or background noise levels at the seashore are usually louder than in other natural seashore environments because the background sound of ocean surf is 65 dBA (Komanoff and Shaw 2000). All-terrain vehicles average 72 dBA at 15.2 meters (50 ft) when moving more slowly than 56 kilometers (35 mi) per hour (NPS 2014a). Soft sand surfaces would produce much less tire-related noise than a highway or a hard-packed trail, especially at the slow speeds (less than 25 miles per hour) required by the National Park Service in Cape Lookout. These factors would reduce ORV vehicular noise to less than the 65 dBA from ocean surf, and at a distance of 15.2 meters (50 ft) or more, the natural sounds from the ocean would likely mask ORV sounds (NPS 2014a).

The National Park Service (2014a) summarized sound levels from various sources and locations at Cape Lookout as follows:

- 130–140 dB(A)—Gun blasts from permitted hunting on designated islands;
- 100 dB(A)—Airplanes flying overhead near the west end of Cape Lookout, or Boat congestion in Barden Inlet on Memorial Day weekend;
- 90 dB(A)—Standing near a passing ORV on the ocean side of South Core Banks;
- 80 dB(A)—Standing on the beach on a windy day, or touring Cape Lookout lighthouse on a busy day;
- 70 dB(A)—Walking along the ocean side of the point at Cape Lookout;
- 60 dB(A)—Sitting on Whale Creek on Shackleford Banks during a weekday;
- 50 dB(A)—Walking along the sound side of the islands at Cape Lookout;
- 40 dB(A)—Viewing a sound side marsh; and
- 30 dB(A)—In a tent on the sound side of North Core Banks.

In addition, the National Park Service (2014a) analyzed impacts to the soundscape of Cape Lookout that would occur as a result of implementing various alternatives of the draft Off-Road Vehicle

Management Plan for the seashore, mainly involving vehicle noise and pedestrian noise. Vehicle noise was assessed as not dominating the soundscape above surf and wind sounds ocean side.

Other activities involved in park management—including hazard fuels reduction, hazard tree removal, prescribed fires, and fire suppression—can involve use of noise-generating equipment such as chainsaws, trucks and helicopters (NPS 2013a). Some of this equipment can be loud (in excess of 100 decibels), but the impacts occur over very short periods (hours to a few days per decade). Such disturbance was evaluated as too infrequent to substantively interfere with wildlife behavior, human activities in the area, or the general solitude and tranquility of the park (NPS 2013a).

Although the NPS (2011a, 2014a) assessments were encouraging, soundscape characterization was recently identified as a data need for the seashore (NPS 2014e), both with respect to identification of point sources of noise pollution and analysis of noise pollution impacts on natural resources. Concern has especially arisen over harm by ORVs to endangered species and other species of concern (SSCs). Accordingly, the National Park Service (2014a) is finalizing an ORV Management Plan for Cape Lookout (see Section 2.2). To further protect wildlife, the NPS-preferred alternative in the draft plan would prohibit night driving at the seashore during nesting seasons (Comay et al. 2013).

The U.S. Marine Corps (USMC) has conducted training flights in the Core Military Operations Area (MOA) over the North Carolina barrier islands for decades. In 2008 the USMC and the National Park Service forged an agreement to lower the minimum allowed altitude for tactical flight speeds in the Core MOA from 3,000 meters (10,000 ft) to 900 meters (2,953 ft [0.56 mi]) above ground level (Hillman 2012, and references therein). The National Park Service requested a three-year study to assess possible impacts on state-protected beach-nesting bird species from a reduced Core MOA floor for tactical speed overflights. Thus, noise pollution from military flyovers by the U.S. Marine Corps was recently assessed at Cape Lookout (Simons and Borneman 2011; Hillman 2012; Borneman 2013). At the average altitude of these overflights (3,291 meters [10,561 ft, 2 mi]), the mean sound exposure level and maximum one-second equivalent average sound level were 77.8 dBA and 65.5 dBA, respectively. At the closest point of approach, overflights below the 3,000-meter floor for tactical flight speeds contributed, on average, > 10 dBA (Hillman 2012). The low-altitude military flyovers significantly increased the average heart rate of American oystercatchers by 13 beats per minute, with unknown biological significance (Borneman 2013). Other biota or parameters examined at the seashore in that study were not adversely affected, but concernes remain about potential adverse impacts on seashore biota from military overflights, considering that Hillman's (2012) study provided information on the May–August period but not the rest of the annual cycles, and given the array of adverse effects from overflights in national parks that have reported by the NPS (1994). These effects have included wildlife behavioral responses such as alert posture, alarm, and panic; escape tactics such as flushing, swimming, and diving; altered movement patterns; decreased foraging success; decreased ability to respond to predators; and abandonment of noise-disturbed habitat by some species (NPS 1994).

Lightscape

The NPS Natural Sounds and Night Skies Division (NSNSD) defines lightscape as the human perception of the nighttime scene, including both the night sky and the faintly visible terrain. The photic environment is defined as the total pattern of light at night, considering all wavelengths. The lightscape is considered to be integral to natural resources, whereas the photic environment affects many species, is integral to ecosystems, and is a natural physical process (Moore et al. 2013). Light pollution is considered here as the upward “spill” of light that is scattered and reflected by water vapor, dust, and other particles to create “sky glow” (NPS 2007b; NPS 2015g). The National Park Service uses the term “natural lightscape” to describe resources and values that exist in the absence of human-caused light at night.

The NPS Management Policies (NPS 2006b) direct the National Park Service to conserve natural lightscapes, in part because protection of natural darkness is important for ecological integrity and sustainability—that is, the natural lightscape is critical for maintaining nocturnal habitat. Light from cities can be visible from more than 322 kilometers (200 mi) away (NPS 2007b, and references therein). Thus, to maintain a natural nocturnal lightscape, it is essential to minimize the sky glow from artificial light. There is clear evidence that human health is adversely impacted by artificial light at night. Although research on light pollution versus wildlife is relatively sparse, the available studies suggest that artificial light also adversely affects the natural environment and the biological rhythms of flora and fauna. Nocturnal predators are especially affected, with “cascading” effects on prey species. Many bird species migrate at night and, thus, are prone to disorientation by artificial lights. Some biomes are more sensitive than others, such as wetlands, ponds, and shorelines.

The National Park Service is committed to minimizing light from park facilities at night, and to restricting the use of artificial light insofar as possible. As with noise pollution, the problem of artificial light pollution at night is caused by sources beyond National Park Service control, such as highways and suburban areas immediately adjacent to the park boundaries. The burgeoning light pollution of the eastern United States has been increasing over time, and began to be especially noticeable in the 1970s (Figure 12). Significantly increasing light pollution has been forecast for the nation by 2025 (Cinzano et al. 2001).

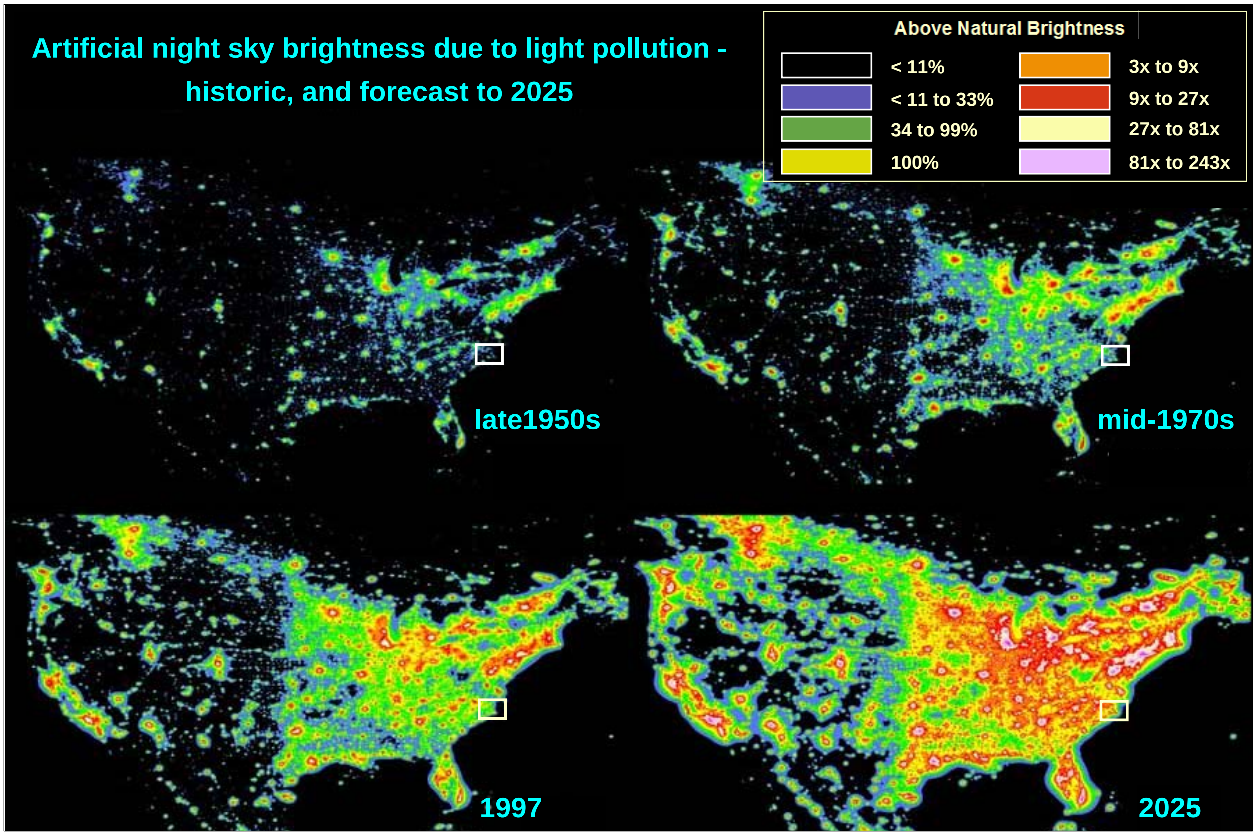

Figure 12. Artificial night sky brightness due to light pollution in the 1950s, 1970s, 1997, and projected to 2025. Modified from Cinzano et al. (2001).

For nocturnal animals, light pollution causes disruption of habitat because darkness is essential for hunting by predators, concealing location by prey, and navigating and/or reproducing by some species. A major concern at Cape Lookout is the effects of light pollution on sea turtles. Light pollution on nesting beaches adversely impacts sea turtles because it alters critical nocturnal behaviors—how sea turtles choose nesting sites, how they return to the sea after nesting, and how hatchlings find the sea (Witherington and Martin 2003). If females encounter a light-polluted beach, they sometimes do not emerge from the ocean to nest, or they return to the ocean without laying their eggs (NPS 2014a and references therein). Hatchlings instinctively crawl toward the brightest horizon, -which historically was the moon or stars reflected on ocean water (Witherington and Martin 2003). When artificial lights from human activities make a horizon that is brighter than the water, hatchlings will crawl in the wrong direction and, thus, will not reach the ocean.

Although various instruments are available for measuring light in the night sky (NPS 2012k), few data have been collected near Cape Lookout National Seashore. Two alternatives for providing baseline information are considered here: First, the Bortle Dark-Sky Scale (BDSS, range 1–9) was developed to assess light pollution using a numerical scale that is easily understood by the general citizenry, policymakers, etc. (Table 13). Fortunately, through the concerted efforts of NPS park staff, Cape Lookout has remained minimally impacted by light pollution in much of the seashore, so that its habitat is equivalent to typical, truly dark skies (BDSS 7.1–7.5). The National Park Service has stated that “some of the darkest skies in the U.S. east of the Mississippi River” are found in the seashore (NPS 2011a; NPS 2014a).

Table 13. The Bortle Dark-Sky Scale for assessing artificial light pollution. The column labeled “Naked-eye Limiting Magnitude” indicates the dimmest stars visible under each class of light pollution. The larger the magnitude number, the dimmer the star. Each whole number represents a factor of 5 in brightness—thus, a magnitude-5 star appears to be five-fold brighter than a magnitude-6 star, whereas a magnitude-4 star appears to be ten-fold brighter than a magnitude-6 star (see Bortle 2001).

Class	Color Key	Naked-eye Limiting Magnitude	Sky Description	Milky Way (MW)	Astronomical Objects	Zodiacal Light/ Constellations	Airglow and Clouds	Night Time Scene
1		7.6–8.0	Excellent, truly dark skies	MW shows great detail and light from the Scorpio/ Sagittarius region—casts obvious shadow on the ground	M33 (Pinwheel Galaxy) is an obvious object	Zodiacal light has an obvious color and can stretch across the entire sky	Bluish airglow is visible near the horizon and clouds appear as dark blobs against the backdrop of the stars	The brightness of Jupiter and Venus is annoying to night vision; ground objects are barely lit and trees and hills are dark
2		7.1–7.5	Typical, truly dark skies	Summer MW shows great detail and has veined appearance	M33 is visible with direct vision, as are many globular clusters	Zodiacal light bright enough to cast weak shadows after dark and has an apparent color	Airglow may be weakly apparent and clouds still appear as dark blobs	Ground is mostly dark, but objects projecting into the sky are discernible
3		6.6–7.0	Rural sky	MW still appears complex, dark voids and bright patches and meandering outline are all visible	Brightest Globular Clusters are distinct, but M33 only visible with averted vision; M31 (Andromeda Galaxy) obviously visible	Zodiacal light is striking in spring and autumn, extending 60 degrees above the horizon	Airglow is not visible and clouds are faintly illuminated, except at the zenith	Some light pollution evident along the horizon; ground objects are vaguely apparent
4		6.1–6.5	Rural/ suburban transition	Only well above the horizon does the MW reveal any structure; fine details lost	M33 is difficult to see, even with averted vision; M31 still readily visible	Zodiacal light is clearly evident, but extends less than 45 degrees after dusk	Clouds faintly illuminated except at the zenith	Light pollution domes are obvious in several directions; sky is noticeably brighter than the terrain
5		5.6–6.0	Suburban sky	MW appears washed out overhead and is lost completely near the horizon	The oval of M31 is detectable, as is the glow in the Orion Nebula	Only hints of zodiacal light in spring and autumn	Clouds are noticeably brighter than the sky, even at the zenith	Light pollution domes are obvious to casual observers; ground objects are partly lit
6		5.1–5.5	Bright suburban sky	MW only apparent overhead and appears broken as fainter parts are lost to sky glow	M31 is detectable only as a faint smudge; Orion Nebula is seldom glimpsed	Zodiacal light is not visible; constellations are seen and not lost against a starry sky	Clouds anywhere in the sky appear faintly bright as they reflect back light	Sky from horizon to 35 degrees glows with grayish color; ground is well lit
7		4.6–5.0	Suburban/ urban transition	MW is totally invisible or nearly so	M31 and the Beehive Cluster are rarely glimpsed	The brighter constellations are clearly recognizable	Clouds brilliantly lit	Entire sky background appears washed out, with a grayish or yellowish color
8		4.1–4.5	City sky	MW is not visible at all	The Pleiades Cluster is visible, but very few other objects can be detected	Dimmer constellations lack key stars	Clouds brilliantly lit	Entire sky background has an orange glow and it is bright enough to read at night
9		4.0 at best	Inner city sky	MW is not visible at all	Only the Pleiades Cluster is visible to all but the most experienced observers	Only the brightest constellations are discernible and they are missing stars	Clouds brilliantly lit	Entire sky background has a bright glow, even at the zenith

Second, the National Park Service has begun to use the anthropogenic light ratio (ALR) to assess the lightscape of national parks. For its State of the Parks Program, the National Park Service recently developed a stoplight indicator system (green—good, yellow—fair, red—poor) to evaluate the overall light regime condition using a single parameter, the amount of anthropogenic light averaged over the entire sky, measured in the green (human visual) spectral band. If the horizon is fairly unobstructed while the measurement is taken, the measure will not vary significantly because of the microenvironment where it was taken. The average anthropogenic light (anthropogenic quanta) is calculated as the total observed sky brightness minus the natural night sky environment where it was taken. The average anthropogenic light (anthropogenic quanta) is calculated as the total observed sky brightness minus the natural night sky component (average brightness, 78 nanolamberts [nL], a measure of luminance by starlight). A ratio of 0.0 would indicate pristine natural conditions (anthropogenic component, 0 nL; natural component, 78 nL). A ratio of 1.0 would indicate that anthropogenic light was 100% brighter than natural light from the night sky, equating to a situation where both the anthropogenic component and the natural component = 78 nL).

The average anthropogenic sky luminance is derived from ground-based empirical data if available or, alternatively from a GIS model (calibrated to other ground-based measures) derived from data in the 2001 World Atlas of Night Sky Brightness (Cinzano et al. 2001). The World Atlas depicts zenith sky brightness, that is, the brightness of the sky directly above the observer. A neighborhood analysis is applied to determine the anthropogenic sky brightness over the entire sky. The modeled anthropogenic light over the entire sky is presented as the ALR.

The ALR has two levels of sensitivity, based on Natural Resource Stewardship and Science I&M Division natural resource designations (Table 14; Moore et al. 2013): Level 1 parks, including Cape Lookout, have significant natural resources, so that the night time photic environment has a greater potential influence on the natural resources and ecosystems (Moore et al. 2013). These areas tend to have higher-quality night sky conditions and lower levels of light pollution (anthropogenic light), and tend to be more sensitive to light pollution effects. The threshold separating green from yellow conditions is set at an ALR of 0.33 (i.e., one-third brighter than natural conditions), corresponding to the point wherein portions of the sky become sufficiently bright that humans cannot fully adapt to the dark when looking toward them (condition known as scotopic vision, an attribute of human night vision). Above this threshold, humans lose visual sensitivity and require time under dark conditions to re-adapt their eyes. This threshold also corresponds to the transition between Bortle Class 3 (rural and dark) and Class 4 (suburban skies). The threshold separating amber from red conditions is set at an ALR of 2.0, corresponding to the point wherein portions of the sky cast shadows so that the entire Milky Way cannot be seen, the Zodiacal light is seldom seen, and full dark adaptation is not possible regardless of which direction the observer looks (Table 15). For parks with lands managed as wilderness (i.e., proposed wilderness, such as Shackleford Banks in Cape Lookout), the thresholds for Level 1 standards must be met in more than 90% of the area.

Table 14. Thresholds for the Anthropogenic Light Ratio (ALR)[a] for Level 1 and Level 2 national parks. From Moore et al. (2013, and references therein) [b].

Threshold for Level 1 Parks	Additional Threshold for Areas Managed as Wilderness	Threshold for Level 2 Parks
ALR < 0.33 (< 26 nL avg. anthropogenic light in sky); ≥ 50% of the park area should meet this criterion	ALR < 0.33 (< 26 nL avg. anthropogenic light in sky); ≥ 90% of the wilderness area should meet this criterion	ALR < 2.00 (< 156 nL avg. anthropogenic light in sky); ≥ 50% of the park area should meet this criterion
ALR < 0.33 to 2.00 (26 to 156 nL avg. anthropogenic light in sky); 50% of the park area should meet this criterion	ALR < 0.33 to 2.00 (26 to 156 nL avg. anthropogenic light in sky); ≥ 90% of the wilderness area should meet this criterion	ALR 2.00 to 18.00 (< 156 to 1,404 nL avg. anthropogenic light in sky); ≥ 50% of the park area should meet this criterion
ALR > 2.00 (> 156 nL avg. anthropogenic light in sky); ≥ 50% of the park area should meet this criterion	ALR > 2.00 (> 156 nL avg. anthropogenic light in sky); ≥ 90% of the wilderness area should meet this criterion	ALR 2.00 to 18.00 (> 1,404 nL avg. anthropogenic light in sky); ≥ 50% of the park area should meet this criterion

[a] ALR = average anthropogenic all-sky luminance average (natural all-sky luminance, wherein the average natural all-sky luminance = 78 nL). Light flux is totaled above the horizon (the terrain is omitted) and the anthropogenic and natural components are expressed as a unit less ratio.

[b] Note that the 90% confidence interval (CI) for the ground-based data = + 8 nL (+ 0.1 ALR); the 90% CI for modeled data = + 40%; and 1 nL = 0.0031831 millicandelas (mcd)/m^2.

Table 15. Functional impacts of light regime determinations. From Moore et al. (2013, and references therein).

Qualitative Description	Sensitivity	Good Condition (Green)	Moderate Condition (Amber)	Poor Condition (Red)
Bortle Class	More Sensitive	Bortle Class 1–3	Bortle Class 4	Bortle Class 5–9
	Less Sensitive	Bortle Class 1–4	Bortle Class 5–6	Bortle Class 7–9
Typical Limiting Magnitude	More Sensitive	6.8–7.6	6.3–6.7	< 6.2
	Less Sensitive	6.3–7.6	5.6–6.2	< 5.6
Sky Quality Meter	More Sensitive	≧ 21.60	21.20–21.59	< 21.20
	Less Sensitive	≧ 21.20	19.70–21.19	< 19.70
Celestial Feature Appearance	More Sensitive	Zodiacal light can be seen under favorable conditions; Milky Way shows detail and stretch from horizon to horizon	Milky Way has lost most detail and is not visible near the horizon; Zodiacal light is rarely seen	Milky Way may be visible when directly overhead—otherwise not apparent; Andromeda Galaxy may be barely visible
	Less Sensitive	Milky Way is frequently visible	Milky Way is only visible when it is directly overhead, and is not generally apparent	No extended celestial features are visible; only the brightest constellations are visible

Table 15 (continued). Functional impacts of light regime determinations. From Moore et al. (2013, and references therein).

Qualitative Description	Sensitivity	Good Condition (Green)	Moderate Condition (Amber)	Poor Condition (Red)
Lightscape Appearance	More Sensitive	Most observers feel they are in a natural environment, with natural features of the night sky readily visible	Anthropogenic light dominates natural celestial features; some shadows from distant lights may be seen	Little sense of naturalness remains in the night sky; the landscape is clearly shadowed or illuminated and the horizon is aglow from light pollution
	Less Sensitive	From within a built environment, the sky appears largely intact	Discoloration of the sky is likely apparent; shadows are seldom noticed from within a built environment	The sky has lost all aspects of naturalness except for a few hundred (or less) visible stars
Human Vision	More Sensitive	Negligible impact to dark adaptation looking in any direction	Dark adaptation possible in at least some directions, although visible shadows likely are present	Full dark adaptation is not possible; substantial glare may be present; circadian rhythms may be disrupted
	Less Sensitive	Full dark adaptation possible in at least some direections, although visible shadows may be present	Full dark adaptation is not possible; shadows are obvious at night from light sources in the sky or along the horizon; circadian rhythms may be disrupted	Full dark adaptation is not possible; there is significant glare from the sky or sources near the horizon; and there is higher concern over impact to circadian rhythms
Sky Quality Index	More Sensitive	> 75	50–74	< 50
	Less Sensitive	> 50	25–50	< 25

Level 2 parks have fewer natural resources; thus, light pollution has less of an influence on biota and ecosystems. Level 2 parks are usually near urban or suburban areas. Although the parks themselves can be relatively dark, the night skies tend to be degraded from surrounding urban development contributing high levels of light pollution. The threshold separating green from amber conditions is set at an ALR of 2.0 (characteristics as described above). The threshold separating amber from red conditions is set at an ALR of 18.0, corresponding to the point wherein extended features of the night sky (e.g., the Milky Way and the Andromeda Galaxy) are invisible in nearly all situations, constellations are difficult to identify, and the sky is colored by the light from numerous light pollution sources. At this level of light pollution, photographs at night easily capture the altered appearance of the night sky.

These ALR thresholds are applied spatially to NPS parks; the designated condition corresponds to the ALR level that exists in at least half of (as the median condition) the park landscape, except for wilderness/proposed wilderness areas wherein the ALR level exists in more than 90% of the area. The National Park Service (2014a) evaluated the amount of light pollution in Cape Lookout relative to other locations nationwide to be of moderate concern based on the modeled ALR, which was 0.36 (amber range). Although Cape Lookout has one of the darkest night skies east of the Mississippi River, light pollution from the west is encroaching on the seashore (Figure 13).

Figure 13. NASA satellite image of the continental U.S. at night, representing a composite of data from April and October 2012 (left side). The southern Outer Banks has one of the darkest night skies east of the Mississippi River. Right side: Close-up of the same satellite image for N.C., showing the faintly lit Outer Banks in the CALO area (arrow). From the NASA Earth Observatory/NOAA National Geophysical Data Center.

Geology and Soils

Available Maps and Other Resources

The Outer Banks are among the best-studied geologic resources in the world, including research partnerships and cooperatives involving the National Park Service, the North Carolina Geological Survey (NCGS), the USGS, and East Carolina University (ECU) in particular. A scoping study conducted by the National Park Service (2000a) compiled an extensive bibliography on the geology of Cape Hatteras National Seashore which included information on Cape Lookout as well.

Surprisingly, the scoping study revealed that there were no existing published 1:24,000-scale geologic quadrangles for the Outer Banks region. The only existing published map at that time was a 1:250,000-scale map of the Cape Lookout National Seashore area that was included in Mixon and Pilkey (1976). The general consensus of the experts present in the scoping group was that the map scale was not sufficiently detailed for park management resource needs, and that a 1:24,000 scale would be much more desirable. The scoping group recommended that the USGS-NCGS-ECU cooperative should produce a series of geologic maps of Cape Lookout, such as an offshore bathymetric/onshore topographic map (1:24,000 scale), "time-slice" paleogeographic maps, isopach and structural contour maps showing unit age breakdowns, shoreface/shelf maps, sediment texture maps (from side-scan), geologic cross-sections showing both aboveground- and bathymetric profiles, maps showing the distribution of geologic processes and hazards, a shoreline erosion and erosion rates map, etc. However, such maps would require very frequent updates because of the rapidly, constantly changing park geology (see below). Excellent maps and diagrams are presently available for areas specifically affected by a given major storm, and for the vulnerability of Cape Lookout to inundation from future major storms (below). Data considered for GIS maps in this report are included in Appendix A.

Geology of Cape Lookout

There are different theories proffered by geologists to explain the formation of the Outer Banks, but all are in agreement that these barrier islands are geologically young, 12,000 years old (Riggs et al. 1995). The shallow geology of the North Carolina Coastal Plain north of Cape Lookout is characterized by a thick Quaternary sequence (up to 90 meters [295 ft]) that fills a regional depositional basin called the Albemarle Embayment, centered under northern Pamlico Sound to eastern Albemarle Sound (Mallinson et al. 2009, and references therein; the following writing is largely from that document). The Quaternary section evidently filled the last remnants of the Aurora Embayment, a pre-Miocene depositional basin (basis—seismic and drill core data). The northern depositional embayment has a complex record of multiple cycles of coastal deposition and erosion in response to numerous glacial-eustatic sea level cycles (Riggs 2001; Parham et al. 2007; Mallinson et al. 2009). During each glaciation, fluvial channels severely dissected the coastal systems that previously had been deposited. The subsequent transgression sequentially backfilled the valleys with fluvial and estuarine sediments, and then produced a revinement surface that migrated landward. Shoreface erosion truncated large portions of previously deposited coastal sediments.

Two adjacent sets of islands formed because of differences in the rate of glacier melt: After a period of rapid sea-level rise, about 4,000–5,000 years ago sea-level rise slowed to 10–15 centimeters (4–6 in) per century. An older (Pleistocene) group of islands co-occurs with a more recent (Holocene) series of islands that are still forming. The newer islands are being pushed landward by prevailing winds and storms. They are distinct from the Pleistocene islands in areas where large rivers add sediment loads to the ocean, but elsewhere the new islands have fused with the Pleistocene islands. The sediment typically flows southward along the coast, accumulates at obstructions such as barrier islands, and flows around them. The northern boundaries of a given barrier island extend outward in shallow shoals that act as sand reservoirs. After every nor'easter, some sand moves along the shore and accumulates in curving ridges called longshore bars. These bars appear to be "anchored" in the northern shoals, but wing around to lie parallel with the shore. Along the southern end of the island, the waves bend around the tip, causing the formation of a recurved spit from deposits of fine silts and clays. Marsh forms in the bay landward of the island. The recurved spit is constantly renewed, so that the area is generally sandy and dominated by pioneering plants (Godfrey and Godfrey 1976). The older, northern end of the barrier island is often heavily forested, but as the shore deteriorates from erosion, the trees are washed out or inundated and killed by saltwater.

The present-day barrier islands that include Cape Lookout were created during the Pleistocene Epoch, when sea level was 91–152 meters (approximately 300–500 ft) lower and the ocean was about 80 kilometers (50 mi) farther east (seaward) than present conditions (Dolan and Lins 2000). During periods of stability (still stands), sediments were deposited and reworked by waves and currents to form the barrier islands and salt marshes. Sand built up to form the islands in areas of high wave energy, whereas salt marshes developed on deposits of silt and clay (smaller particles) in regions of low wave energy. About 18,000 years ago glaciers began to melt in the Arctic and

Antarctic regions, and sea level rose to cover the old shores and create a continental shelf about 113 kilometers (70 mi) wide. Holocene sea-level rise has produced a modern sequence of coastal sediments deposited unconformably over the eroded remnants of these Pleistocene sequences (Pierce and Colquhoun 1970). These units consist of sediments ranging from compact peat and mud to unconsolidated or semi-consolidated sands, gravels, and shell beds. The complex variation in the underlying geologic framework, together with the physical dynamics, ultimately controls the shoreface morphology, the composition and texture of beach sediments, and the shoreline recession rates (Riggs et al. 1995; Riggs and Ames 2009).

Thus, the most common theory of origin for the Outer Banks of North Carolina is that during the Pleistocene glacial period the shoreline was 80 kilometers (50 mi) seaward of its present position, with a dune ridge formed by wind and wave action (Dolan and Lins 2000; Leatherman 1988). As the glaciers retreated during the Holocene marine transgression, sea level rose, broke through the dune ridge, and formed lagoons and sounds (Mallin et al. 2004). The shoreline and associated dunes migrated shoreward with the rising sea level until sea-level rise slowed about 4,000 years ago, allowing wind, waves, and currents to form the basic Outer Banks configuration. The seashore islands continue to retreat shoreward (Dolan and Lins 2000; Pilkey 2003). Core Banks is a chain of transgressive barrier islands, meaning that they have a sand deficiency and tend to manifest shoreline retreat (Leatherman 1988). Shackleford Banks is a regressive barrier island, which is an island that shows sand accretion, and it contains multiple dune ridges (Leatherman 1988). In addition, a long spit extends from the western tip of Cape Lookout, where a jetty built in the early 1900s has promoted accretion in that direction (Dingle et al. 2012).

In total, Cape Lookout NS is actually part of a much longer barrier island which forms an extensive cuspate foreland, defined as a large crescent-shaped projection that forms from longshore currents along with sediment erosion. The deposited sediment moves out to sea until it reaches a point, or cape, beyond which the land falls away. Cape Lookout NS, together with Cape Hatteras and Cape Fear in North Carolina, may be the most extensive cuspate forelands in the world (Kaplan 1988).

Erosional Processes Affecting the Seashore, and Rates

As a general class, barrier islands are narrow, low-lying, exceptionally active landforms lying generally parallel to marine mainland coasts. They are named because they absorb the “first line” of energy from a storm coming in from the ocean, creating a “barrier” between the storm and the mainland. Barrier islands are separated from the mainland by the sea, and they are in a state of constant, often-rapid change, continually molded and recast by winds, waves, storms, ocean currents, and sea level changes that cause erosion and accretion of the shorelines; overwash across the island; and formation, migration (or “island rollover”), closure, and creation of inlets (NPS 2015f).

Five major processes cause continual erosion in the seashore, exacerbated during major storms (USGS 2015). Beach erosion occurs when waves and currents remove sand from the beach areas (defined as the land between the primary or most seaward dune and the shoreline), causing the beach to become narrower and lower in elevation. Storm waves carry the sand offshore to form large sandbars, and between storms the ocean waves return some of the sand to the beach. A series of storms, or one major storm, can cause significant retreat of the shoreline, leaving the park more vulnerable to future storms. At present some areas of Cape Lookout are eroding at a rate of up to 9.1 meters (30 ft) or more per year, with net annual average recession rates of 1.5 meters (4.9 ft) per year (Riggs and Ames 2003—basis, a study by East Carolina University 1960–2001, and a study by the North Carolina Division of Coastal Management 1946–1998).This is within the range of erosion defined as “severely eroding” (areas eroding at a rate of more than 1.5 meters [4.9 ft] per year), based on the evaluation of Bernd-Cohen and Gordon (1999) for erosion along the North Carolina Coast.

Dune erosion occurs when waves attack the front (ocean side) of the sand dune, reducing the dune volume and elevation (Figure 14). Overwash is caused when waves are higher than the dune elevation, so that sand is transported over the top of the dune and deposited inland in large layers called overwash fans (Figure 14). Overwash causes significant changes in the seashore landscape over time, such as covering coastal vegetation and filling inland ponds. The net result is barrier island rollover, wherein the island moves (“migrates”) inland over time.

Figure 14. Examples of dune erosion and impacts of Hurricane Irene on CALO. Upper photo: dune erosion at CALO (NPS 2015l). Middle and lower photos: Impacts of Hurricane Irene on CALO (Table 16): Middle photo—Overwash fans of sand (once part of dunes along the ocean side beach) across the barrier island to the marsh. Lower photo—Dunes destroyed and sand pushed across the barrier islands (Undated NPS photo).

Table 16. Recent major tropical storms that have affected North Carolina's Outer Banks.

Storm Name	Intensity (references)	Description	Damage
DENNIS (8 September 1999)	Tropical storm (Thompson 1999; Roth 2012)	Made landfall on 2 Sept. over CALO just east of Harkers Island, at just-below hurricane strength.	Wind gusts up to 145–162 km/hr (90–100 mph, pressure 977 mbar). Tides 0.9–1.5 meters (3–5 ft) above normal. Highest rainfall 48.6 centimeters (19.13 inches) occurred in Ocracoke and northern CALO area. Meandered off the North Carolina coast for several days, so the above-normal tides were unusually prolonged, resulting in extensive beach erosion. The overwash was so extensive that Core Banks migrated 0.3 meters (1 ft) inland (Pilkey 2003).
ISABEL (18 Sept. 2003)	Category 2 hurricane (Beven and Cobb 2003; National Climatic Center 2003)	Made landfall at Drum Inlet in CALO with winds of 165 km/hr (105 mph).	Heaviest damage from storm surge and strong winds along the ocean-side coastline. The storm opened a 518-m (1,700-ft or 0.32-mile) breach in Core Banks, now called Isabel I29 Inlet.*
ALEX (3 Aug. 2004)	Category 2 hurricane (Franklin 2004; NWS 2012)	Its center of circulation passed within 14.5 kilometers (9 mi) of Cape Hatteras, with winds up to 164 km/hr. The storm center remained just offshore.	Produced strong waves, a large amount of sound-side flooding, and significant beach erosion. Storm surge up to 0.9–1.8 meters (3–6 ft); most damage from flooding.
OPHELIA (14–16 Sept. 2005)	Category 1 hurricane (Beven and Cobb 2005; Mallinson et al. 2008)	Drifted just offshore of the Outer Banks; dropped heavy rainfall (maximum 44.5 centimeters or 17.5 inches). Maximum winds 140 km/hr (85 mph). Sound-side flooding was extreme, especially in the Bogue Banks (Carteret County) and Ocracoke Island (storm surge, wind-driven tides in Pamlico, Core, and Bogue Sounds produced 1.5- to 2.4-m (5- to 8-ft) storm tides for 30 hr.	Storm surges of 2–4 meters (7–12 ft) were recorded, especially in low-lying inlets of Pamlico Sound; parts of the sound actually were "blown dry" by water pile-up caused by the winds. Sound-side flooding was extreme, especially in the Bogue Banks (Carteret County) and Ocracoke Island (storm surge, wind-driven tides in Pamlico, Core, and Bogue Sounds produced 1.5- to 2.4-m [5- to 8-ft] storm tides for 30 hr). Opened New Drum Inlet on Core Banks.
GABRIELLE (9 Sept. 2007)	Tropical Storm (NWS 2012)	Made landfall at Cape Lookout; brought up to 23 centimeters (9 inches) of rain; maximal winds at 70 kilometers per hr (45 mi per hr).	Heavy rains but minimal damage.
EARL (3 Sept. 2010)	Category 1 hurricane (Cole 2010)	The storm center passed 140 kilometers (85 mi) east of Cape Hatteras; winds up to 169 kilometers (105 mi) per hr	Up to 1.8 meters (6 ft) of sound-side flooding; heavy rains.

* See Beavers 2004.

Table 16 (continued). Recent major tropical storms that have affected North Carolina's Outer Banks.

Storm Name	Intensity (references)	Description	Damage
IRENE (27 Aug. 2011)	Category 1 hurricane (USGS 2011; Repanshek 2011b)	Made landfall near Cape Lookout with 137-km/hr (85 mph) winds. Waves were (1.8–2.7 m, or 6–9 ft) The storm produced clouds and rain (35.6 centimeters or 14 inches) across an area 483 kilometers (300 mi) wide. Its large size and slow pace resulted in very high rainfall totals. The storm's eye tracked through Pamlico Sound.	Heavy damage in general—NPS dock at Harker's Island was destroyed; all cabins on Great Island were damaged to varying degrees; major damage to Cape Lookout Village; the dump station at Cape Point was destroyed etc. Part of Cape Point was eroded as well.
SANDY and aftermath (26–30 Oct. 2012)	Category 1 hurricane (NWS 2012)	The storm center passed 140 kilometers (87 mi) east of Cape Hatteras. Rain totals were up to 20 centimeters (8 inches) in parts of the Outer Banks, and significant water rises with major beach erosion and heavy overwash.	The southeast-facing coast from Cape Lookout to Cape Hatteras was exposed to ocean waves and surge. Flooding by the storm surge was minimal because the surge crested above dunes only in limited locations. The storm and overwash caused the most physical damage in the park at Long Point camp on North Core Banks; 15.2 meters (50 ft) of beach were eroded, and the ferry landing was filled in with 30.5 meters (100 ft) of sand.
ARTHUR (3–4 July 2014)	Category 2 hurricane (NWS 2012)	Made landfall at Shackleford Banks just west of Cape Lookout in Carteret County. Maximal winds were 160 km/hr (99 mph). Worst impact was storm surge in the central Outer Banks.	More than 1.5 meters (4.9 ft) of storm surge washed ashore on the sound side of Rodanthe; NPS docks at CALO were damaged, as well as some buildings and trees

* See Beavers 2004.

Inundation occurs when the beach system or the land between the primary (most seaward) dune and the shoreline is completely submerged by the ocean or sound storm surge. Strong currents can erode a channel into or through the island; the latter situation is referred to as island breaching, which creates temporary or longer-term inlets (Figures 14 and 15). Marsh erosion happens on wetland coastlines that are directly adjacent to the open ocean or the sound. Waves and ocean or sound currents erode the wetland soil so that the wetland decreases in area.

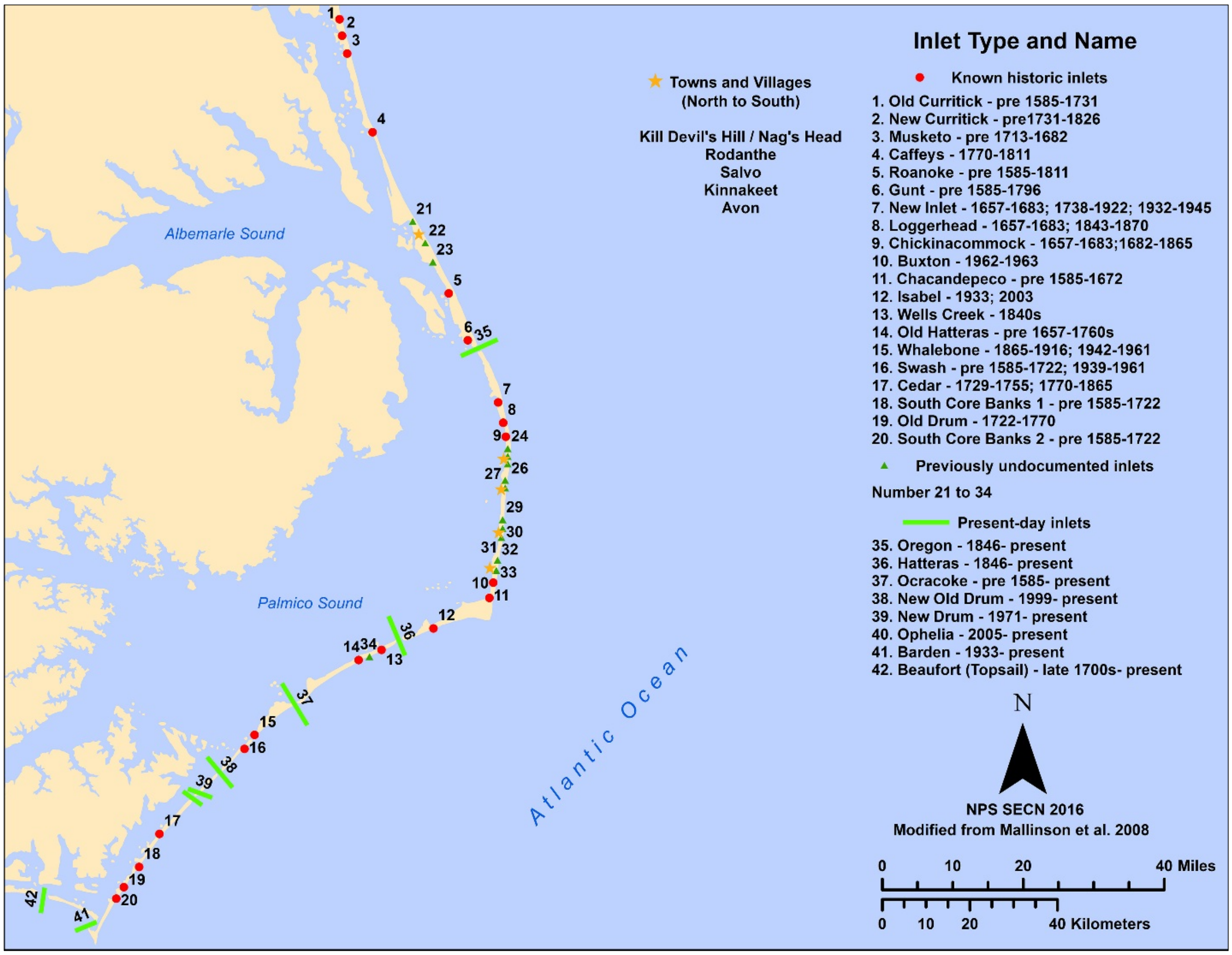

Figure 15. Map illustrating the highly dynamic character of the barrier islands, showing historic inlets and years present (red arrows); previously undocumented inlet channels discovered using ground-penetrating radar data; and present-day inlets, at least for the moment. Towns and villages are also indicated. Modified from Mallinson et al. (2008).

On the sandy coasts of the Outer Banks, beach sands are constantly being transported offshore, onshore, and in the direction of prevailing longshore currents in response to different tide, wave, and current conditions (Dolan and Lins 1986, and references therein). Impacts of major storms such as late fall-spring nor'easters (extra-tropical storms) and tropical storms such as hurricanes can be so major that inlets are cut by the winds and waves (Figure 15), dunes are destroyed, beaches are significantly eroded, and sand is pushed from the ocean side to the sound side of the islands. Strong winds during storms can create a surge of water that washes over the land, wherein the storm surge overtops or penetrates the fore dunes at various locations along the shoreline, usually carrying large amounts of sand from the ocean beaches to the marshes and beaches farther out into the sound. Wind and wave action in the absence of storms can have similar, although less severe, effects. A seasonal influence is also apparent: Wind and wave action erodes beaches more rapidly in the winter season, resulting in beaches with a shorter, steeper beach face. Gentler waves in summer can allow accretion (beach “growth”), so that summer beaches have a longer, more gently sloping profile.

In general, high, relatively continuous, extensive natural dune fields form on barrier islands that are oriented across (roughly perpendicular to) prevailing winds. Low, open, relatively scattered natural dunes form on islands that are oriented along (parallel to) prevailing winds. The ocean side beaches on Shackleford Banks face southwest, whereas the ocean side beaches on Core Banks face southeast. The east–west orientation affords this barrier island some protection from major storms. Because the prevailing winds are usually northeasterly or southwesterly, sand is often blown across Shackleford Banks from the ocean side to the sound side and blown up or down the beaches of Core Banks. This has allowed plants to trap more sand on Shackleford Banks, resulting in significantly larger dunes on this island than on any of the Core Banks islands. A maritime forest has thrived on Shackleford Banks because these large dunes protect the trees from the damaging effects of salt spray.

The Outer Banks are moving toward the mainland over time. As described, an inlet is created by extreme scouring and sand transport, so that the water and sand freely flush between the ocean and the sound. The sand is deposited in quieter waters of the sound side of the inlet; a marsh eventually develops, trapping more sediment; and eventually the inlet closes (NPS 1982). Periodic phases of erosion and deposition are superimposed on a longer-term trend of rising sea level, and this long-term rise submerges the beach, causes shoreline recession, and forces the barrier islands landward (Dolan and Lins 2000).

Overall, then, the barrier islands of Cape Lookout are low-lying, extremely dynamic landforms which constantly change in response mainly to storms in combination with ocean currents, sea level changes, waves and wind (NPS 2014a). They are built, maintained, and modified over time, mostly by high-energy oceanic storms (Riggs and Ames 2009). Overwash and inlet formation resulting from storm surges causes the barrier islands to migrate landward during periods of rising sea level. Storm waters that flow across the islands leave fans (sand layers) that build the interior island elevation (NPS 2014a). The fans can extend into the sound behind the barrier island (that is, on the side toward the mainland), building island width and contributing to island migration. In the quieter sound waters, sand that is swept through and inlet on a flood tide can be deposited as a flood tidal delta. After the inlet closes or migrates, the flood tidal deltas provide the foundation for saltmarsh development, and these backbarrier marshes also contribute to island widening and landward migration (Riggs and Ames 2009; NPS 2014a).

Natural coastal processes have been allowed to occur at Cape Lookout with minimal interference by human-imposed structures (Figure 16). Inlets along Core Banks have opened and closed naturally, and storm overwash has deposited large areas of sand. In the 41-year period between USACE surveys in 1960 and ECU surveys in 2001, there was a 72% net increase in Core Banks elevation. Up to 1962, Core Banks had been dominated by active overwash processes during a very stormy period, with large areas of non-vegetated sand overwash deposits and tidal or fan deltas and major overwash tidal channels across the islands. The overwash processes actively built island width during the stormy period. Low storm activity in 1962–1970, with minimal overwash and minor elevation change, was followed by a period of moderate to high storm activity (1971–2005) with frequent overwash events resulting in a major increase in island elevation (Riggs and Ames 2007). The higher elevation has led to a decrease in the frequency and extent of overwash events, and an increase in vegetation throughout most of the barrier island (NPS 2014a).

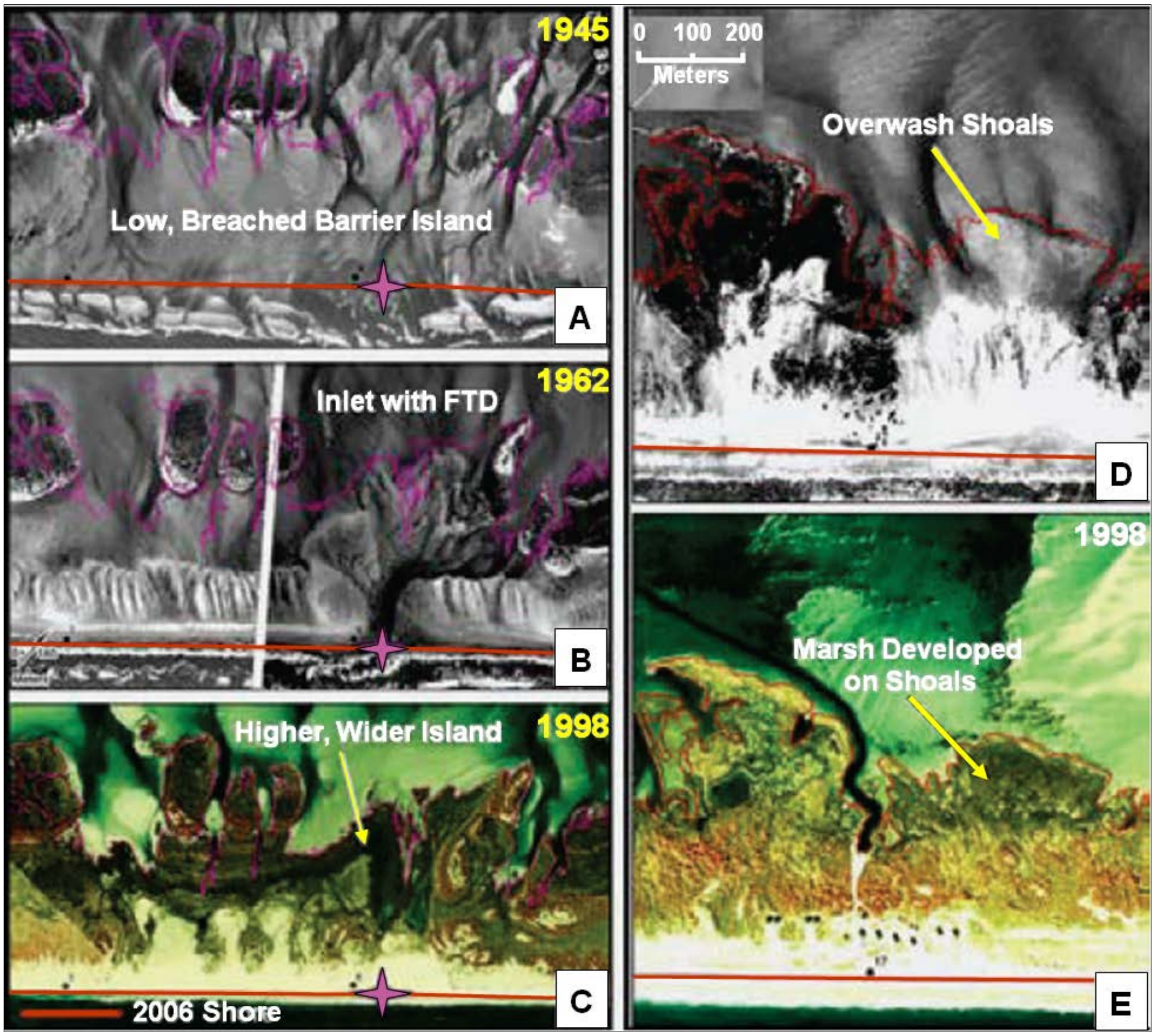

Figure 16. Aerial photos of Core Banks illustrating how storms build island elevation and width. Red lines are the 2006 superimposed ocean shoreline for comparison in (A,B,D), or the 1998 super-imposed estuarine shoreline in (C,E). Note that A–C are the same location over time, and D–E are in a second location over time. (A) 1945—a low, unvegetated island segment consisting of multiple breaches; (B) An inlet opened in 1962 and built flood-tidal delta shoals. (C) By 1998 the inlet had closed and developed into marsh that became part of a wider, vegetated island segment. (D) 1962—storm-deposited overwash fans extending across the island and into the sound; (E) 1998—marsh had developed on the overwash fans, which built elevation and widened the island. Modified from Riggs and Ames (2009).

Erosion rates at Cape Lookout are very high across time and regardless of the investigators: In an earlier study from 1940 to 1975, the net effect of these processes was to erode the ocean shoreline of Core Banks a total of 15.8 meters (52 ft) (average of 0.46 meters [1.5 ft] per year). During a similar period, from 1943 to 1976, the ocean shoreline of Shackleford Banks eroded 14.9 meters (49 ft), or 0.46 meters (1.5 ft) on average per year (Dolan and Heywood 1977). For the 41-year period from 1960 to 2001, Riggs and Ames (2007) reported that the North Core Banks area had higher average annual rates of both erosion and accretion relative to South Core Banks. Storm-dominated (i.e., "worst case") short-term shoreline erosion rates within that period (1960–1962) were 15.9 meters per year (52 ft/yr) at North Core Banks, versus 6.4 meters (21 ft/yr) at South Core Banks. Over the 41-year period (1960–2001), in contrast, average erosion rates were 2.4 meters (8 ft) per yr at North Core Banks and 0.91 meters per year (3 ft/yr) for South Core Banks. Average erosion rates varied substantially, from 0 to 9.1 meters per year (30 ft/yr), with an overall net annual average recession rate of 1.5 meters per year (5 ft/yr).

More recently, rates of shoreline change were calculated for the eight-year period from September 1997 to October 2005 by Stockdon and Thompson (2007). There was high variation in the horizontal movement of the shoreline, but the mean change over the eight-year period was negative 11.17 meters (36.6 ft), or a rate of negative 1.4 meters (4.6 ft) per year. Away from inlets, the magnitude of shoreline change ranged from 20.4 meters (66.9 ft) of accretion near the cape to 88.0 meters (288.7 ft) of shoreline retreat southwest of Old Drum Inlet. The most recent study available involved collection of annual beach profile data at Shackleford Banks from 2008 to 2012, and reported that annual loss of beach sediments has rapidly increased in comparison with earlier research. Most recent rates were annual loss of beach sediments of 4.26 cubic meters per linear foot of beach (1.7 cubic yards [yd^3] per foot) to 23.83 cubic meters per linear foot of beach (9.5 yd^3 per ft), coupled with 1.4 meters (4.6 ft) of inland migration of shoreline position at the Mean High Water datum (NPS 2014e). Overall, these data are in good agreement with net long-term changes (from 1946 to 2009) documented by the North Carolina Division of Coastal Management (NCCRC 2015). The recent 15 years of higher storm activity has resulted in evident sediment loss throughout Cape Lookout (NPS 2014e).

Present-Day Geomorphology

Nearly two-thirds of the land area of the present-day seashore consists of marshes ("marsh platforms") (30.0%), overwash flats in overwash complexes (25.5%), and sand flats in tidal complexes (10.7%) (Table 17, Figure 17). All of the ocean side of Core Banks is sandy beach, with tidal flats behind the ocean beach on the northern three miles. In most of the other areas behind the sandy beach there is a dune field of variable width. These natural beaches mostly have a wide berm zone (100–200 meters [328–656 ft]) consistently along the length of the barrier islands, and they are frequently reworked by storm tides (Godfrey and Godfrey 1976). The wide berm and low, scattered dunes are typical of overwash-influenced barrier islands that have not been altered by artificial structures. When storms occur, these dunes offer little resistance to flooding and erosion (Watson 2005).

Table 17. Cape Lookout NS geomorphology by type and areal coverage. Data from Appendix A.

GEOMORPH TYPE [GLG_SYM]	Hectares	Acres	Total (%)
Anthropogenic, Airport/Landing Strip [airport_land]	3.2	7.9	0.0
Beach [beach]	330.6	817.0	4.6
Back Barrier Berm [bk_br_bm]	286.2	707.1	4.0
Fore-island Dune Complex, Dune Ridge [dune_rdge, duneridge][a]	442.8	1,094.2	6.1
Inlet [inlet]	7.4	18.3	0.1
Interior Dune [intdune]	68.7	169.7	1.0
Interior Marsh [intmarsh]	45.5	112.3	0.6
Overwash Complex, Isolated Dune [isodune][b]	29.3	72.4	0.4
Overwash Complex, Overwash Fan [owfan]	7.6	18.8	0.1
Overwash Complex, Overwash Flat [owflat]	1,839.8	4,546.2	25.5
Marsh Platform [pf_marsh][c]	2,163.8	5,346.9	30.0
Marsh Platform, Fringing Berm [pf_mrsh_fbrm]	20.7	51.1	0.3
Relict Beach Ridge Complex [rel_bch_rdge][d]	69.5	171.7	1.0
Relict Spit Complex [rel_spit]	144.1	356.1	2.0
Spit Complex, Ridge and Swale [ridge_swale][e]	273.8	676.6	3.8
Spit Complex, Sand Flat [sand_flat]	171.4	423.6	2.4
Tidal Complex, Sand Flat [tidal_sflat][f]	771.6	1,906.8	10.7
Tidal Complex, Tidal Flat [tidal_tflat][g]	506.8	1,252.2	7.0
Water Body [water]	25.1	62.1	0.3
Total (incomplete):	7,207.9	17,811.0	99.9988
Gap area in source data; unit unknown	0.1	0.2	0.0012
Total	**7,208.0**	**17,811.2**	**100.0**

[a] Source data entry "ForeIslandDune, Dune Ridge" was interpreted to be Fore-Island Dune Complex, Dune Ridge (5.2 hectares [12.9 ac] 0.07%).

[b] Source data entry "Interior Dune, Isolated Dune" with "isodune" GLG_SYM was interpreted to be Overwash Complex, Isolated Dune (0.4 hectare [1.0 ac] 0.006%).

[c] Source data entries "Marsh Platform; Tidal Complex, Tide Flat?" and "Marsh Platform?" were interpreted to be Marsh Platform (0.1 hectare [0.3 ac] 0.002%).

[d] Source data entry "Relict Beach Ridge Complex?" was interpreted to be Relict Beach Ridge Complex (0.3 hectare [0.7 ac] 0.07%).

[e] Gap in source data with "ridge_swale" GLG_SYM was interpreted to be Spit Complex, Ridge and Swale (0.3 hectare [0.7 ac] 0.004%).

[f] Source data entry "Tidal Complex, Marsh Platform" was interpreted to be Tidal Complex, Sand Flat (9.1 hectares [22.5 ac] 0.004%).

[g] Source data entry "Tidal Complex, Tidal Flat?" was interpreted to be Tidal Complex, Tidal Flat (0.02 hectare [0.05 ac] 0.0003%).

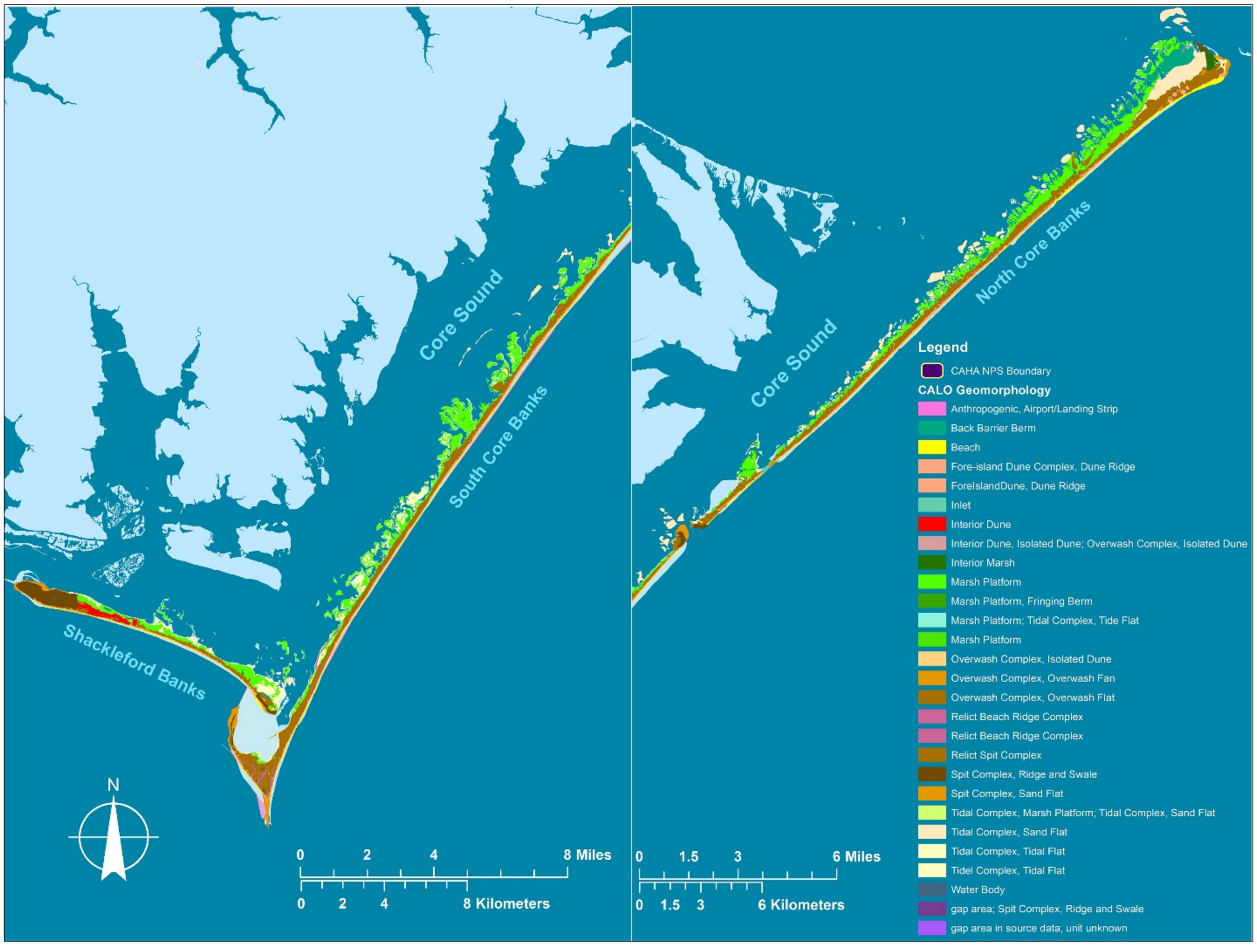

Figure 17. Map of the geomorphology of Cape Lookout (S. Flood, NCSU CAAE; GIS data sources listed in Appendix A).

The widest berm areas occur on Portsmouth Island, where the land slopes back across barren stretches of sand all the way to the high tide mark on the sound side. The demarcation between the berm and bare sand flats is difficult to discern because the slope is very gradual. In some sections small dunes begin to develop on the berm, but they are often reduced or buried by storm tides that wash over the berm crest and move across the island. Other areas have wide berms but no dunes. The sound side of the islands includes shallow bays with abundant seagrasses, tidal creeks, saltmarshes with lush vegetation, abbreviated beaches, and sparse low-lying woodlands (Mallin et al. 2004).

Paleo-Inlets and Present-Day Island Geology

The opening and closing of inlets has also shaped the barrier islands of Cape Lookout. Ground penetrating radar data have been used to determine the locations and features of old inlet channels (paleo-inlets) that no longer exist (Riggs et al. 2008). Sediment cores have been collected in these locations for use in assessing the age of inlet activity and the role of inlet formation in the barrier island evolution. The following description is presented in a north-to-south sequence.

At least six paleo-inlets were once open within the Cape Lookout area, including Whalebone Inlet (1865–1916 and 1942–1961), Swash Inlet (pre 1585–1722; and 1939–1961), Cedar Inlet (1729–

1955; and 1770–1865), South Core Banks 1 (pre-1585–1722), Old Drum Inlet (1722–1770), and South Core Banks 2 (pre 1585–1722) (Figures 15, 18 and 19). The three inlets that currently are open in the seashore (below) are all located between the locations of paleo-Swash Inlet and paleo-Cedar Inlet. The paucity of inlets is partly due to the low volume of freshwater discharge and small astronomical tidal prism (Mallinson et al. 2008). The present-day active inlets along the Outer Banks in Cape Lookout include (from north to south) Ocracoke Inlet separating Cape Lookout from Cape Hatteras National Seashore to the north, and New Old Drum Inlet, New Drum Inlet, and Ophelia Inlet in Core Banks (Figures 18 and 19). The following information is taken from Godfrey and Godfrey (1976) and Mallinson et al. (2008): Ocracoke Inlet (prior to 1585–) is located within a former river valley (Pamlico Creek) that drained the Pamlico Sound basin during the last glacial maximum (20,000 years ago). The occurrence of this underlying river valley probably has helped to stabilize this inlet over time. In 1715 this inlet was designated an official port of entry for access to mainland communities, and it has served as a navigable route for private and commercial vessels.

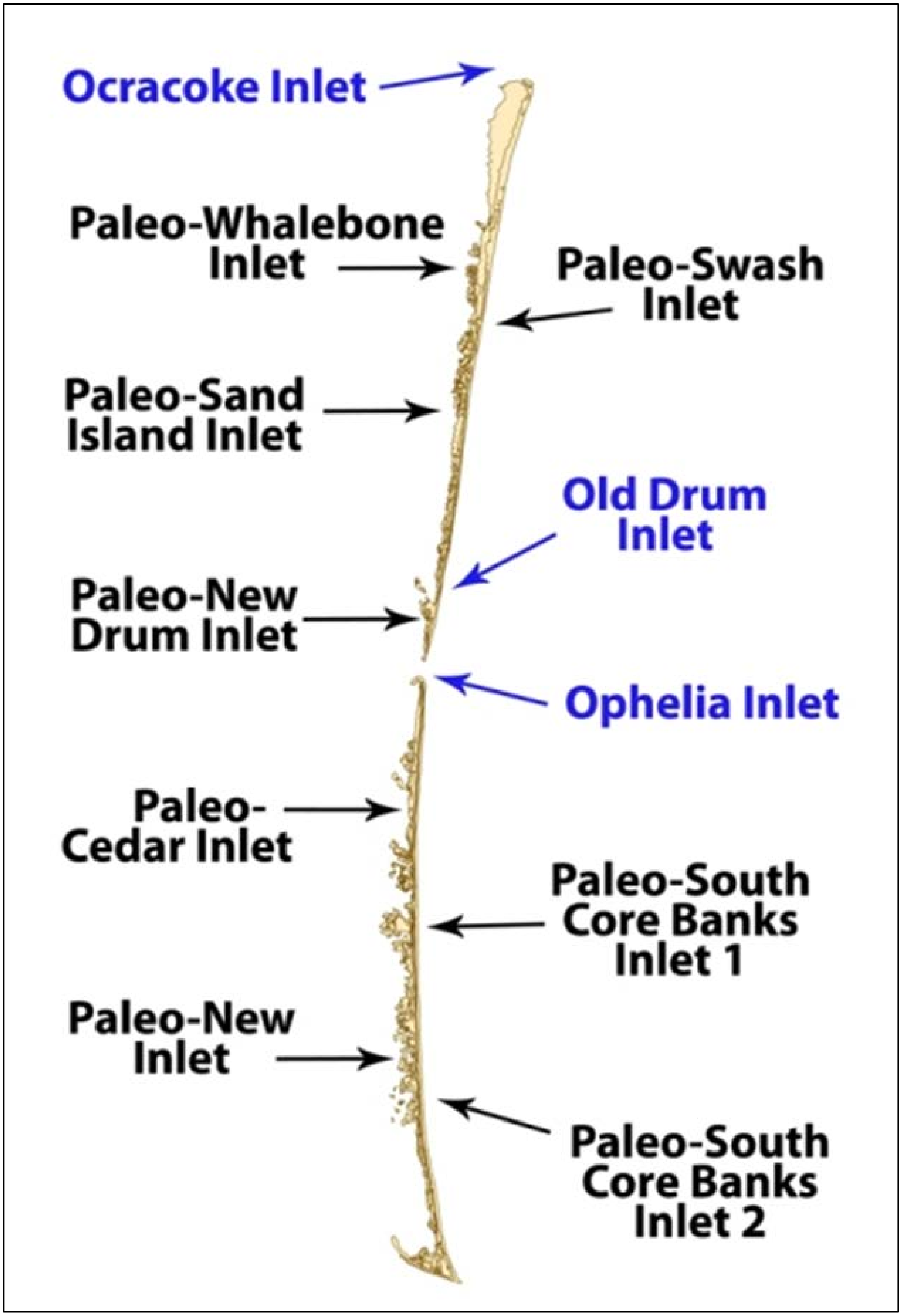

Figure 18. Inlets of Core Banks, past (black) and present (blue). From NPS (2015c).

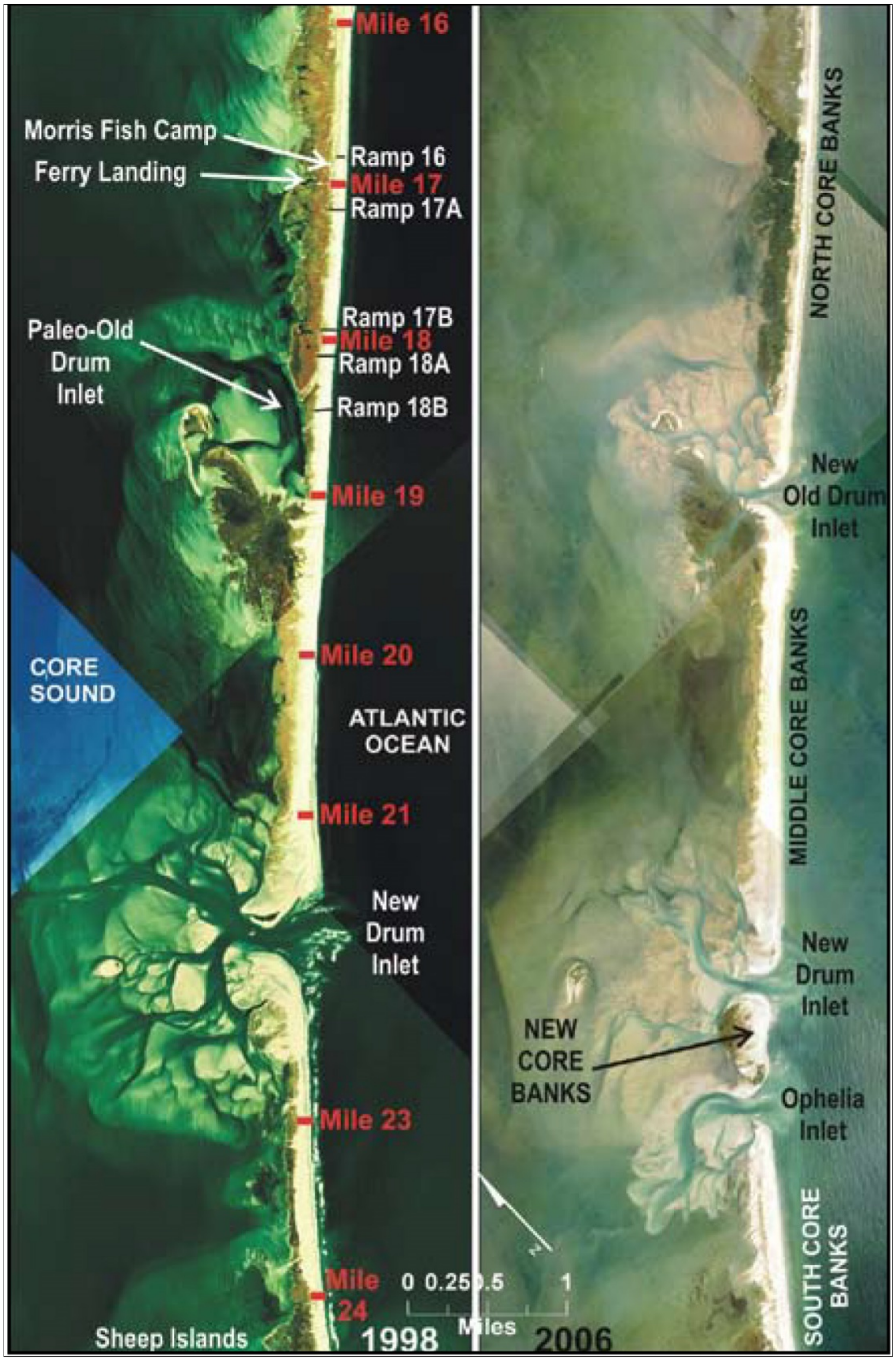

Figure 19. Aerial photos of Core Banks showing the location of New Drum Inlet in 1998, and Ophelia and New-Old Drum Inlets in 2006 (N.C. State Database). New-Old Drum Inlet was opened by Hurricane Dennis in 1999, in the same location where Old Drum Inlet had been (paleo-Old Drum Inlet is in the 1998 photo). Ophelia Inlet was opened by Hurricane Ophelia in 2005. From Mallinson et al. (2008).

Drum Inlet (1899–1919) reopened in 1933 but nearly closed naturally again by 1971, is in an area of high erosional activity. After the inlet reopened, attempts by the USACE to dredge it were unsuccessful in maintaining a navigable channel for commercial fishermen (Stick 1958; Riggs and Ames 2007).

New Drum Inlet (1971–) was artificially opened several kilometers southwest of Drum Inlet by the USACE dredging/blasting activities. It was created to provide a navigable channel for commercial fishing vessels. Unfortunately, due to rapid shoaling, commercial vessels have never used the inlet (Riggs and Ames 2007).

New Old Drum Inlet (1999–) is actually Drum Inlet, reopened by Hurricane Dennis in 1999. Ophelia Inlet (2005–) was opened by Hurricane Ophelia. This inlet is presently expanding and has nearly merged with New Drum Inlet.

Preliminary Analysis: the Coastal Vulnerability Index for Cape Lookout The impact of a hurricane on a beach has been shown to be highly variable over both large and small stretches of coast (Stockdon et al. 2003). Thieler and Hammar-Klose (1999) conducted a preliminary assessment of the vulnerability of the ocean side of Cape Lookout to inundation from sea-level rise, and associated coastal change. They used data compiled from various state and federal agencies (Table 18). Each of the six major variables involved in the analysis is described separately below. It should be noted that the analysis did not directly address the vulnerability of the bay-side shoreline of Cape Lookout to future sea-level rise because the methodology did not apply well to quieter waters or estuarine wetlands (instead, see Riggs 2001; Riggs and Ames 2003). Nevertheless, the Coastal Vulnerability Index (CVI) calculated from this analysis provides a very useful, quantitative evaluation of the susceptibility or collective risk of Cape Lookout to future sea-level change.

Table 18. Sources for variable data used by the USGS to estimate vulnerability of CALO to inundation from sea-level rise. From Pendleton et al. (2004), following a similar approach as that used by Thieler and Hammar-Klose (1999).

Variables	Source	URL
Geomorphology	1999 USGS Orthophotos (DOQQs) from the N.C. Corporate Geographic Database (CGIA 2016)	http://www.cgia.state.nc.us/DataResources.aspx
Shoreline erosion / accretion (m/yr)	Historical Shorelines for North Carolina coast (1866–2001) from the USGS (2014)	http://marine.usgs.gov/coastalchangehazards/
Coastal slope (%)	National Geophysical Data Center (NCEI 2016e) Coastal Relief Model Volume 02	http://www.ngdc.noaa.gov/mgg/coastal/coastal.html
Relative sea level change (mm/yr)	NOAA Technical Report NOPS CO-OPS 36 Sea level variations of the United States 1854–1999 (Zervas 2001)	NA
Mean wave height (m)	North Atlantic Region Wave Information Studies (WIS) Data (Phase II) (USACE 2015b) and NOAA National Data Buoy Center (NDBC 2016)	http://wis.usace.army.mil/
Mean tide range (m)*	NOAA/NOS CO-OPS Historical Water Level Station Index (NOAA/NOS 2016a)	http://www.co-ops.nos.noaa.gov/map

* NOAA maintains the following tidal gauges (also see Table 17 for sources of hydrologic and meteorological information)

Bodie Island—Station 8652648, NOAA Chart 12205, Old House Channel, Pamlico Sound—end of T-dock on northeast side of island, 35º46.6'N, 75º35.1'W) (NOAA/NOS 2016a);

Hatteras Island—Station 8654000, NOAA Chart 11555 Oregon Inlet Marina fishing pier (1974–present), 35º47.7'N, 75º32.9'W; mean range 0.27 meters (0.89 ft); diurnal range 0.36 meters (1.17 ft); MSL 0.98 meters (3.21 ft) (Mercado 2007).

Ocracoke Island—Station 8654572 (April–August 2012), NOAA Chart 11555; 35º10.3'N, 75º49'W mean range (0.36 ft), diurnal range (0.48 ft); at MSL met. site elevation 0.0 meters above MSL (NOAA 2013).

The database was constructed using a 1:70,000-scale shoreline for Cape Lookout (from NOAA Office of Ocean Resources Conservation and Assessment). Data for each of the six variables (geomorphology, shoreline change, coastal slope, relative sea-level rise, significant wave height, and tidal range) were added to the shoreline attribute table using a one-minute (approximately 1.5 km) grid. Each variable in each grid cell was assigned a vulnerability value from 1–5 (1 is very low vulnerability, 5 is very high vulnerability) based on the potential magnitude of its contribution to physical changes on the coast as sea level rises (Table 19).

The regional coastal slope was used to assess the relative vulnerability of inundation and the potential rapidity of shoreline retreat, considering that low-sloping coastal regions should retreat faster than steeper regions (Pilkey and Davis 1987). The regional slope of the coastal zone was calculated from a grid of topographic and bathymetric elevations extending 10 kilometers (6.2 mi) landward and seaward of the present-day shoreline. The elevation data were supplied by the National Geophysical Data Center (Table 18), as gridded topographic and bathymetric elevations at 0.1- meter (0.33-ft) vertical resolution for 3 arc-second (90-m [295-ft]) grid cells.

Shoreline erosion and accretion rates for Cape Lookout were calculated from existing shoreline data that were provided by USGS (Table 18). Shoreline rates of change (m/yr) were calculated at 200-meter (656-ft) intervals (transects) along the coast using Digital Shoreline Analysis System software, in order to derive the rate of shoreline change over time (Thieler et al. 2003). The rates for each transect within a one-minute grid cell were averaged to determine the shoreline change value, with positive numbers indicating accretion and negative numbers indicating erosion.

The relative sea-level change variable was derived from the increase or decrease in annual mean water elevation over time, as measured at tide gage stations along the coast. The rate of sea-level rise in the City of Beaufort, North Carolina (about 75 kilometers [46.6 mi]) southwest of Ocracoke Island) is 3.71 ± 0.64 millimeters (mm)/year (0.15 ± 0.03 inch) based on 27 years of data (Zervas 2001) (Table 18). This variable inherently includes both global sea-level rise and regional sea-level rise from isostatic and tectonic adjustments of the land surface. Relative sea level change data provide an historical record for the recent sea-level trend (less than 150 years). This variable inherently includes both global sea-level rise and regional sea-level rise from isostatic and tectonic adjustments of the land surface. Relative sea-level change data provide an historical record for the recent sea-level trend (less than 150 years). The rate of relative sea-level rise for Cape Lookout was found to be very high, approximately twice as high as the global average, based on water elevation data at Beaufort.

Mean significant wave height was used as a proxy for wave energy that controls the coastal sediment budget. Wave energy was defined as directly related to the square of wave height:

$$E = 1/8\ \rho g H^2$$

where E ≡ energy density, H ≡ wave height, ρ ≡ water density, and g ≡ acceleration due to gravity. That is, the ability to mobilize and transport coastal sediments is a function of wave height squared. Hindcast nearshore mean significant wave height data (1976–1995) from the USACE Wave Information Study (WIS) (Hubertz et al. 1996, and references therein) were used for the analysis (Stockdon et al. 2007a). The modeled wave heights were compared to historical measured wave height data from the NOAA National Data Buoy Center (Table 18) to make sure that model values were reasonable and representative of the study area. Mean significant wave heights for Cape Lookout were between 1.2 and 1.3 meters (3.9 and 4.3 ft), categorized as high vulnerability and very high vulnerability, respectively.

Mean tidal range is linked to both permanent and episodic inundation hazards. The tidal range data for the analysis were obtained from NOAA/NOS (Table 18). All of Cape Lookout was classified as very high vulnerability (> 1 m) with respect to tidal range.

The final step in the analysis was to calculate the CVI for Cape Lookout. The analysis followed the USGS (Pendleton et al. 2004; Thieler and Hammar-Klose 1999, Gornitz et al. 1994, and Shaw et al. 1998) and quantitatively related the six main variables (Table 19) to express the relative vulnerability of the seashore coast to physical changes due to future sea-level rise. This index is considered to provide insight about the relative potential of coastal change due to future sea-level rise, and can help to determine where the related physical changes will likely occur.

Table 19. Ranges for vulnerability rankings of variables on the U.S. Atlantic Coast. From Pendleton et al. (2004), updated from Thieler and Hammar-Klose (1999). Also see Stockdon and Thompson (2007).

Variables	Very Low: 1	Low: 2	Moderate: 3	High: 4	Very High: 5
Geomorphology	Rocky-cliffed coasts, fjords	Medium cliffs, indented coasts	Low cliffs, glacial drift, alluvial plains	Cobble beaches, estuaries, lagoons	Barrier beaches, sand beaches, salt marshes, mud flats, deltas, mangroves, coral reefs
Shoreline erosion (-) / accretion (+) (m/yr)	> + 2.0	1.0–2.0	-1.0–1.0	-2.0– (-1.0)	< -2.0
Coastal slope (%)	> 1.20	1.20–0.90	< 0.90–0.60	< 0.60–0.30	< 0.30
Relative sea level change (mm/yr)	< 1.8	1.8–2.5	> 2.5–3.0	> 3.0–3.4	> 3.4
Mean wave height (m)	< 0.55	0.55–0.85	0.86–1.05	1.06–1.25	> 1.25
Mean tide range (m)	> 6.0	> 4.0–6.0	> 2.0–4.0	1.0–2.0	< 1.0

Although the numerical data yielded cannot be equated directly to particular physical effects, areas are highlighted where the various effects of sea-level rise may be greatest. Once each section of coastline is assigned a vulnerability value for each specific data variable, the CVI is calculated as the square root of the product of the ranked variables divided by the total number of variables:

$$\mathbf{CVI} = \sqrt{\frac{(a*b*c*d*e*f)}{6}}$$

Figure 20. Formula for calculating the coastal vulnerability index.

where *a*—geomorphology, *b*—shoreline erosion/accretion rate, *c*—coastal slope, *d*—relative sea-level rise rate, *e*—mean significant wave height, and *f*—mean tide range.

The CVI values calculated for Cape Lookout NS were mapped (Figure 21), with scores divided into categories as low (CVI < 32.0), moderate (32.0–36.0), high (36.01–42.0), and very high vulnerability (> 42.0) categories based on the quartile ranges and visual inspection of the data. The value of the relative sea-level rise variable was constant at very high vulnerability for the entire study. Based on this analysis, most of Cape Lookout was evaluated as “very high vulnerability” to coastal change due to sea-level rise (Thieler and Hammar-Klose 1999; Stockdon and Thompson 2007; Saunders et al. 2012) (Figure 35). In fact, Cape Lookout and Cape Hatteras National Seashores were in the top tier of vulnerability among the seven national seashores on the U.S. Atlantic Coast.

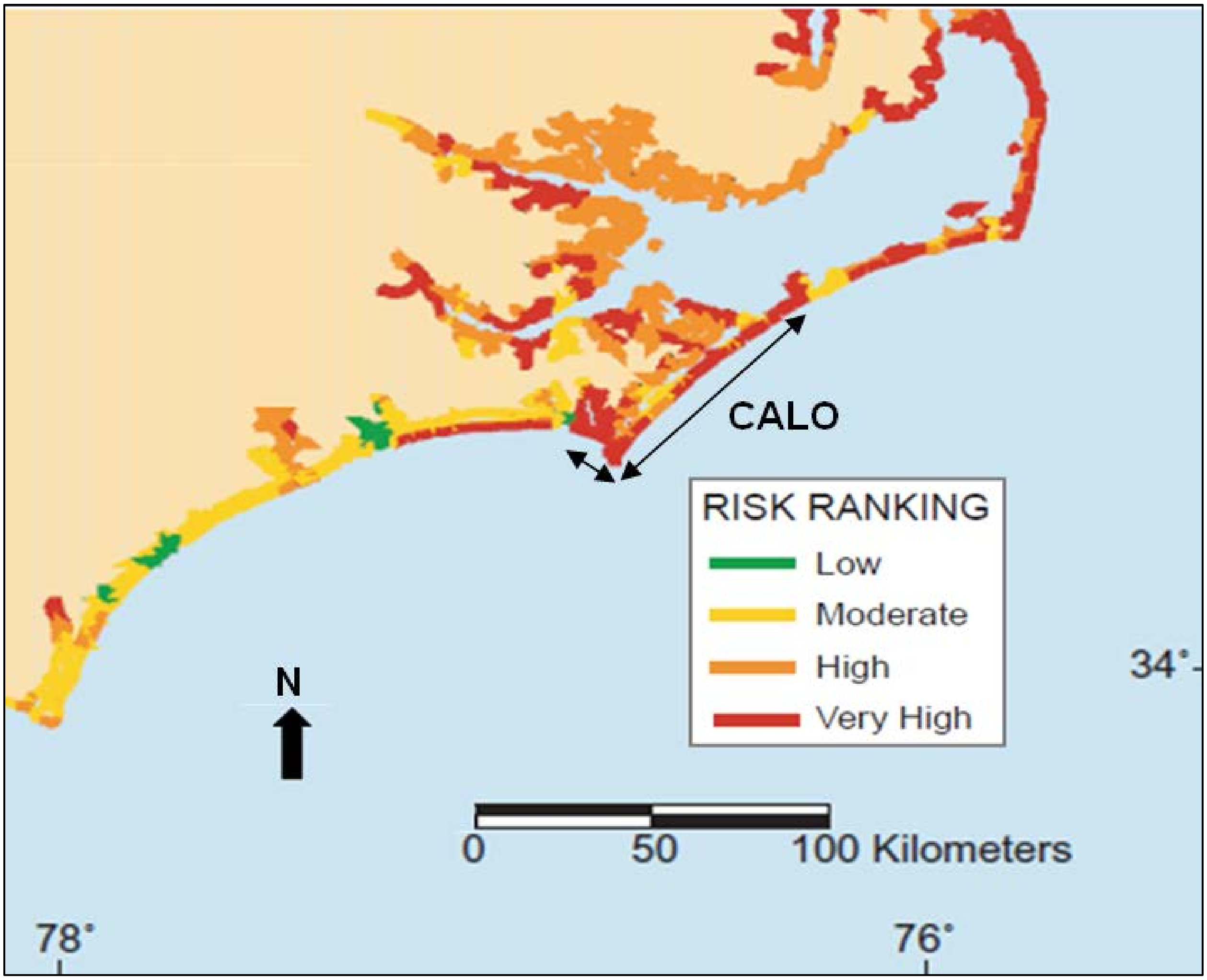

Figure 21. Preliminary analysis of the overall CVI for vulnerability of Cape Lookout (arrows), indicating vulnerability of seashore areas to future sea-level rises over the 21st century, showing most of this seashore as having the worst evaluation, very high vulnerability. Modified from Thieler and Hammar-Klose (1999).

Inundation Potential for Cape Lookout from Hurricanes

In a subsequent analysis, Stockdon and Thompson (2007) assessed the vulnerability of Cape Lookout to inundation and associated extreme coastal change during a direct hurricane landfall by comparing the elevations of storm-induced mean water levels (storm surge) to the elevations of the crest of the sand dune that defines the beach area of each coastal segment along the seashore. Their model was based on a simple storm-impact scale (from Sallenger 2000) that compares elevations of the most seaward sand dune to elevations of hurricane-induced water levels (Stockdon et al. 2007b). During such storms, the combined effects of three factors—the astronomical tide, the storm surge (elevated water levels associated with the large winds and low pressures of a hurricane), and wave run-up (the super-elevation of the water surface at the shoreline due to waves, both the time-varying and time-averaged components) move the erosive forces of the storm higher on the beach face than during typical wave conditions. The total elevation from these three factors defines the maximum water level (R_{high}) attained during a storm. The storm-induced mean water level (R_{low}) is defined only by two factors, storm surge and wave setup. These forces may reach the elevation of the base and crest (D_{low} and D_{high}, respectively) of the most seaward sand dunes that define the landward limits of the beach system and represent the first line of defense for a barrier island in a major storm coming in from the sea.

Stockdon and Thompson (2007) used these parameters to define four storm-impact regimes or thresholds for coastal change: _swash_ ($R_{high} < D_{low}$), _collision_ ($R_{high} > D_{low}$), _overwash_ ($R_{high} > D_{high}$), and _inundation_ ($R_{low} > D_{high}$). These storm impact regimes were used to provide a framework for examining the general types and relative magnitudes of coastal change that are likely to occur during hurricanes (Sallenger 2000; Stockdon and Thompson 2007). They then considered the most extreme of the four impact regimes, inundation, defined as occurring when the storm-induced mean water level (R_{low}) exceeds the elevation of the crest of the most seaward sand dune (D_{high}). Under such conditions the beach system (foredune ridge and beach) is completely submerged, and net landward transport of sediment is likely to occur (Sallenger 2000).

For the model to be useful in predicting the potential for inundation of Cape Lookout during a future hurricane landfall, accurate estimates of both the dune parameters and the expected hurricane-induced mean water level were obtained. The morphology of the beach and dunes at Cape Lookout was mapped based on an airborne lidar topographic survey conducted on 1–2 October 2005 by the USACE Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system. The elevation of the frontal dune (or, in the absence of a dune, the beach berm) was extracted at 20-meter intervals along the coast of Cape Lookout from cross-shore profiles of lidar topography. An automatic algorithm was used to select the peak of the most seaward dune within a prescribed beach width of 150 meters (492 ft) R_{low} was represented only by the storm surge. Wave setup was not considered because predictions of wave conditions (height, period) for a generic hurricane of each category (Saffir-Simpson 1–5) were not available. Predicted elevations of storm surge for category 1–5 hurricanes were extracted from the NOAA SLOSH (Sea, Lake, and Overland Surges from Hurricanes) model, a real-time forecast model for hurricane-induced water levels for the U.S. Atlantic and Gulf Coasts. The maximum surge within each grid cell was defined as the Maximum of the Maximum Envelope of Water (MOM) and is the worst-case, localized surge predicted to occur for landfall at a given location. The results are location-specific and accurate to ± 20% of the calculated value (NOAA 2007).

The potential inundation (I) of the beach system was defined every 20 meters (65.6 ft) along Cape Lookout (Figure 22). Negative values (blues) indicate that water levels are predicted to be lower than the dune crest, so that the section of beach likely would not be inundated during direct landfall of a hurricane (assumed to occur at mean astronomical tide given conditions in January 2006, and excluding effects of wave setup which, during Category 3–5 storms, can increase the storm-induced mean water level by more than 30% above the level due to storm surge alone). Positive values (reds) indicate areas where the CALO beach likely will be inundated by the storm surge. The longshore variability in I resulted from spatial variations in the height of the frontal dune. The mean elevation of D_{high} was 2.81 meters (9.22 ft) (NAVD88) with substantial longshore variability (standard deviation, σ, 0.95 m). In addition, modeled surge elevations were larger along Shackleford Banks, making the beach and dunes on this southwest-facing island more vulnerable. The spatially averaged surge for a Category 1 hurricane was 1.51 meters (4.95 ft), while the average surge for a Category 5 storm was 4.71 meters (15.45 ft) (Figure 22).

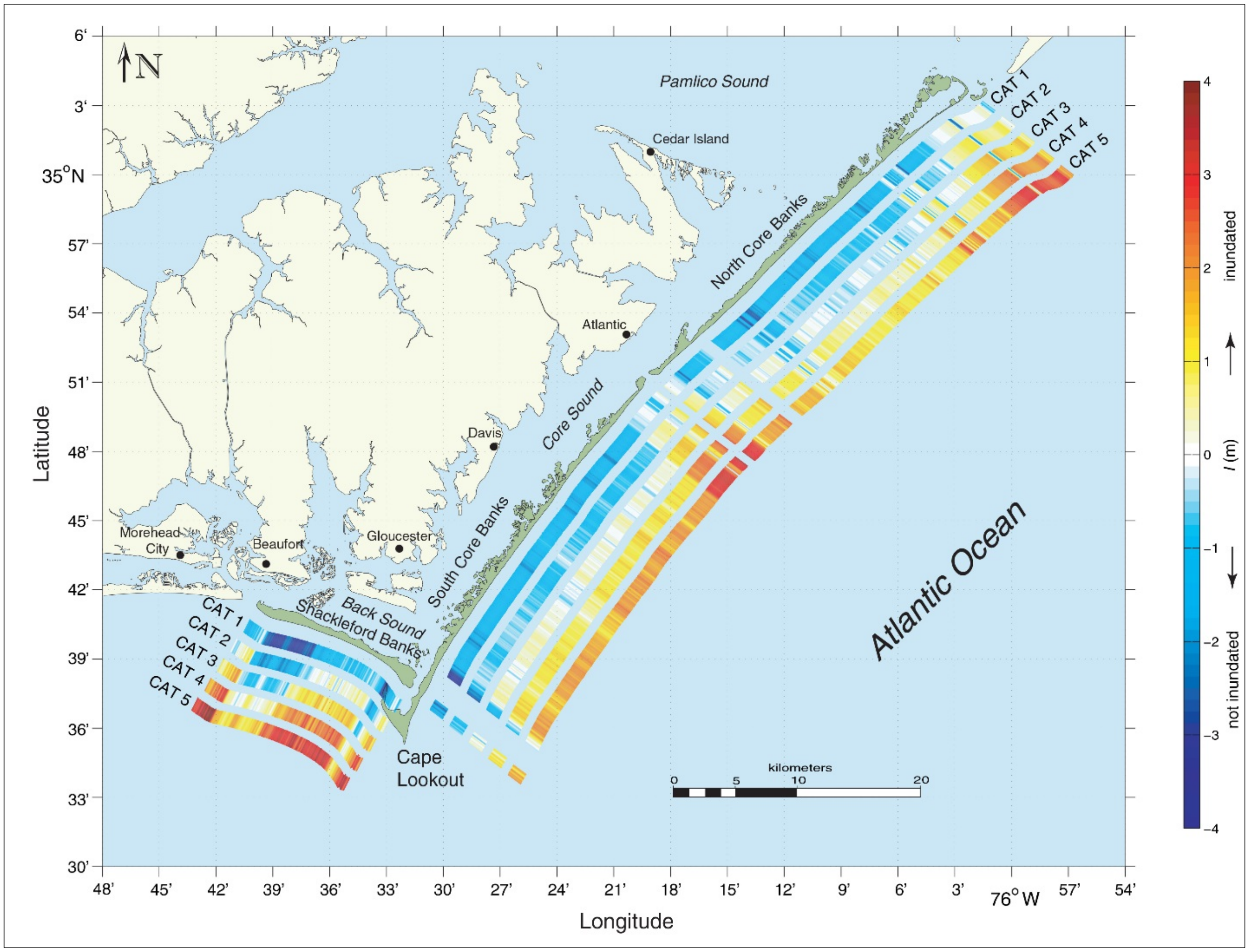

Figure 22. Map showing the modeled potential inundation (I) of the ocean-facing beach along CALO from a direct hurricane landfall (USGS 2013; additional information at Stockdon and Thompson 2007).

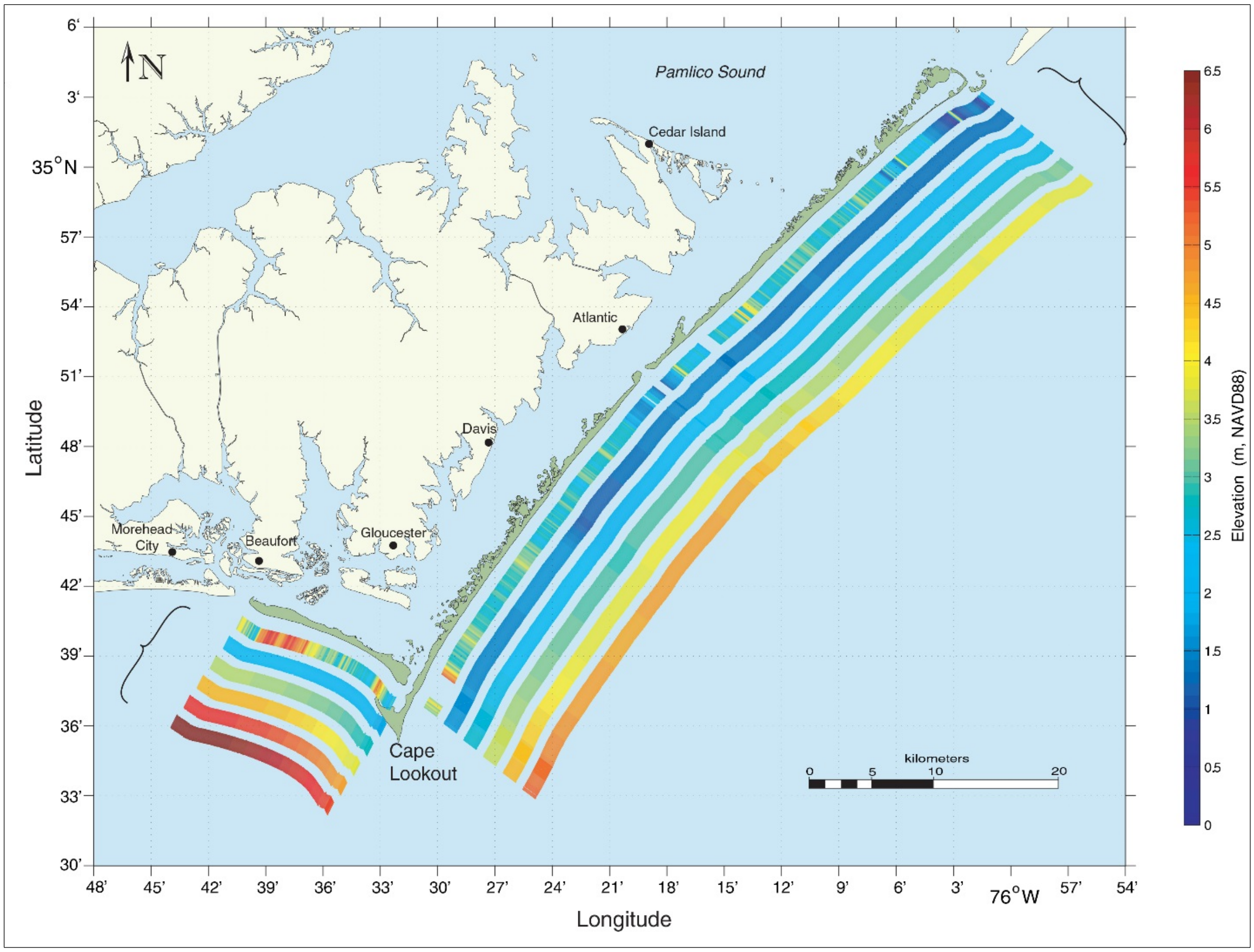

Figure 23. Map of dune elevations (D_{high}) for CALO, measured from a LiDAR topographic survey collected on 1–2 October 2005. The surge values ($R_{\mathbf{low}}$) for category 1–5 hurricanes were extracted from the NOAA SLOSH model and represent the open coast "maximum of the maximum." (USGS 2013, additional information at Stockdon and Thompson 2007).

For Cape Lookout, the model predicts that as of October 2005, only 11% of the coastline was vulnerable to inundation from a Category 1 storm, versus more than 91% vulnerable during a Category 5 storm (Figure 22). This is somewhat encouraging news, nevertheless, considering that most tropical storms affecting Cape Lookout in the past 15 years have been Categories 1–2 or weaker (Table 16). The eastern half and western 2 kilometers (1.2 mi) of Shackleford Banks were more susceptible to inundation: in those locations, $R_{low} > D_{high}$ for Category 3 and higher storms. In addition, areas around inlets were more vulnerable during hurricane landfall. The beaches extending 3.5 kilometers (2.2. mi) to the southwest and 1.2 kilometers (0.75 mi) to the northeast of New Drum Inlet, and also a 6-kilometer (3.7-mi) stretch of coast south of Ocracoke Inlet, were evaluated as the most vulnerable to inundation during a hurricane landfall. Those areas attained or exceeded the inundation threshold for Category 2 storms and higher. The mean elevation of D_{high} was 2.81 meters (NAVD88) with substantial longshore variability, standard deviation, σ, = 0.95 meters. Additionally, modeled surge elevations were larger along Shackleford Banks.

Most recently, Caffrey (2013) used the NOAA SLOSH model to re-estimate the storm surge from direct hit of a category 5 hurricane at Cape Lookout, and obtained a similar prediction as the previous efforts (Figure 24). From NOAA data over the period of 1953–2012 (60 years), sea level was estimated to have risen around Beaufort at a rate of 0.28 centimeters (0.11 in) per year. Caffrey's (2013) analysis indicated that direct hit of a category 5 storm at high tide would cause a 4.9-meter (16.0-ft) storm surge at the south end of Core Banks. If such a storm hit at mean tide, the model predicts a storm surge of 4.4-meters (14.4 ft) in the same location. The USACE (2013) predicted, as a moderate condition, that sea level will rise in the Beaufort area by 0.55 meters (1.8 ft) by 2100 (in Caffrey 2013).

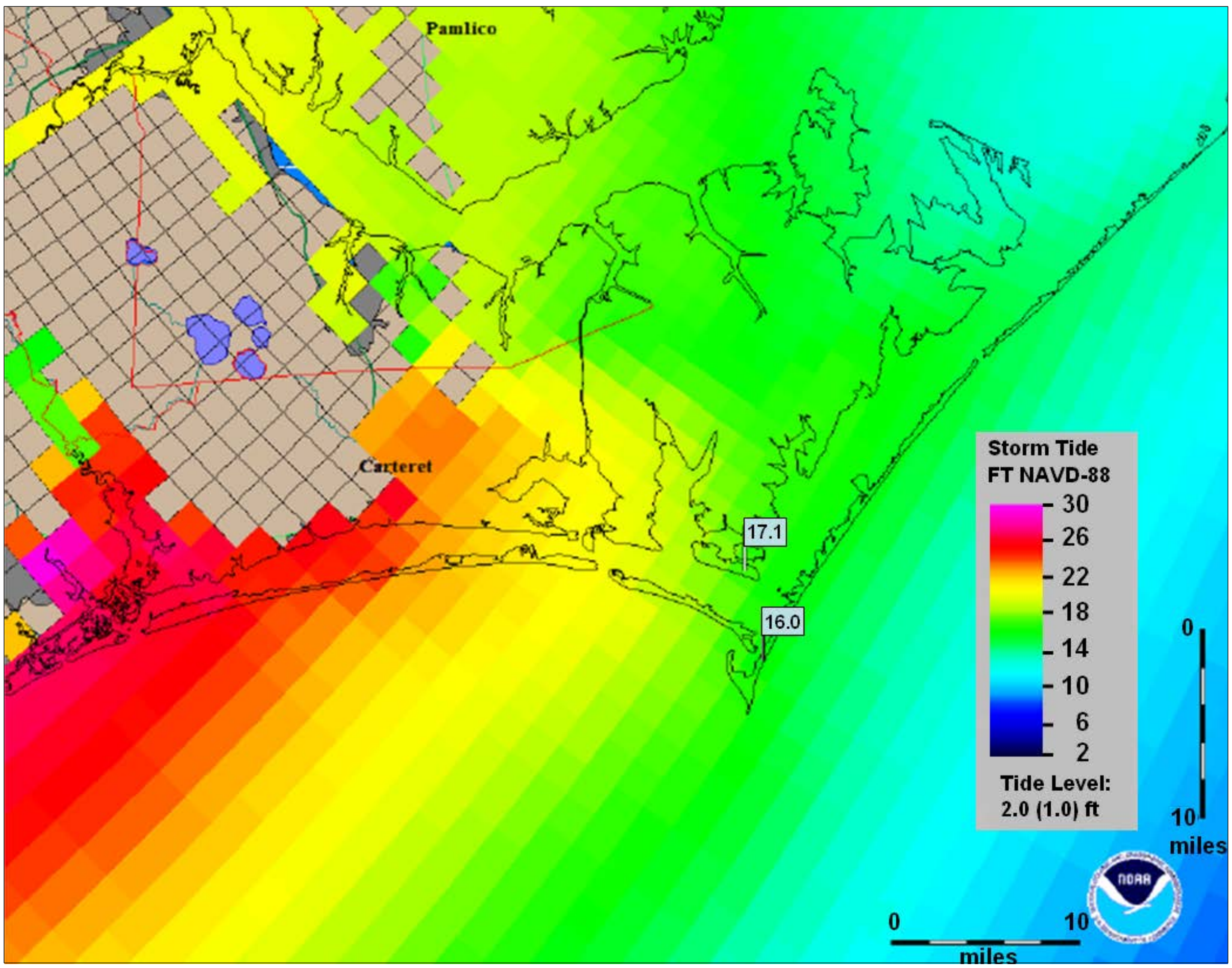

Figure 24. The storm surge (in feet) predicted by the NOAA SLOSH model for direct hit of a category 5 storm at high tide, that is, worst case scenario. Modified from Caffrey (2013).

Beyond inlet formation, areas with very high vulnerability to future sea-level rise also have the potential to erode catastrophically to the point of barrier island collapse, that is, erosion below sea level of long segments of the island (Culver et al. 2007; Mallinson et al. 2008). With continuing sea-level rise, a barrier island will either migrate landward or disintegrate if there is not enough sand volume to maintain it above sea level (Sallenger 2000). With predicted more frequent and/or more intense storms in this century, barrier collapse may occur more rapidly. Thus, Riggs and Ames (2003) hypothesized that large portions of the Outer Banks, including portions of Core Banks in particular for Cape Lookout, could disappear within the next several decades if sea level continues to rise at present rates, and/or if one or more major hurricanes impacts the Outer Banks (Figure 25). It is noteworthy that a collapse of the Outer Banks occurred about 1,000 years ago during a warm climatic interval (Culver et al. 2007).

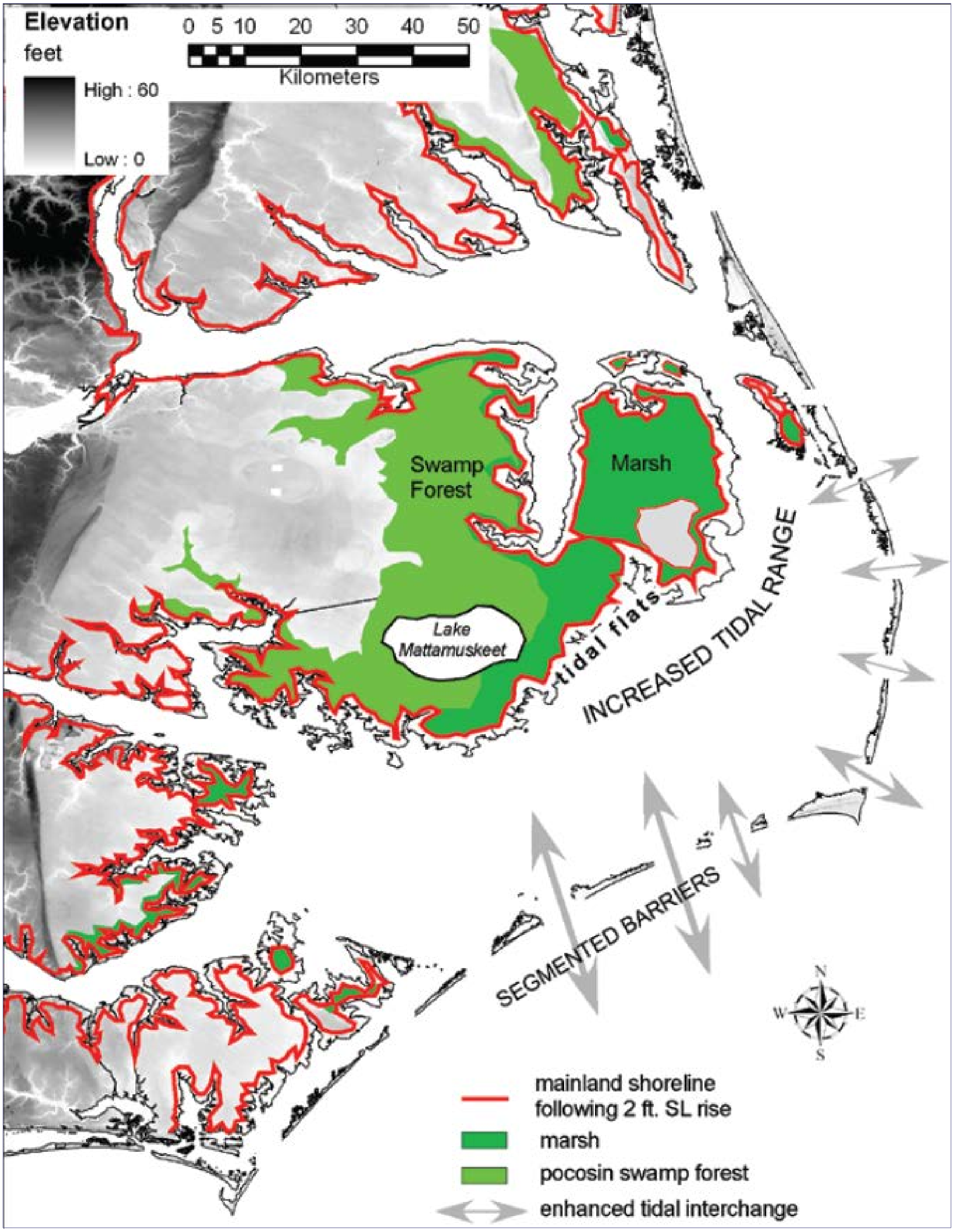

Figure 25. A conceptual model showing the potential evolution of coastal system that includes CALO, in response to a 0.61-meter (2-ft) rise in sea level per century and increased tropical storm intensity. Mallinson et al. (2008) predicts both phenomena occurring by 2100, and both will increase the tidal range. The future mainland shoreline and wetlands (marshes, pocosin swamp forests) are superimposed on the 2008 shoreline. Greater shoreline recession, ecosystem migration and marsh development in northern Pamlico Sound are expected, as well as segmentation of the barrier islands in various vulnerable locations. From Mallinson et al. (2008).

Human Alteration of Cape Lookout National Seashore

> *…the building of roads and bridges for easy access has often been stipulated in the seashores' enabling legislation; and when seashores are set up, the National Park Service is almost always given a mandate to control erosion and flood damage through cooperative efforts with the U.S. Army Corps of Engineers. Even though the National Seashores are protected from Coney Island-type development, they still face other, almost as dramatic, alterations in the name of recreation and erosion control….The main goal of a considerable part of past coastal research has been to find mechanical or biological ways to combat beach erosion…. Ironically, these projects often either make natural erosion worse or even start new erosion; ways must then be found to undo the damage…. The idea is to get that dune line up as high as possible, and not to allow any messy natural processes such as the wind blowing the sand around, the ocean overtopping dunes, or the beach continuing to retreat. In other words, total artificial control of the coastline is attempted. The trouble is, it doesn't work.*
>
> *—Godfrey and Godfrey (1976)*

The U.S. Congress authorized the Chief of Engineers, Department of the Army [i.e., the USACE] to "undertake or contribute to shore erosion control or beach protection measures" in Cape Lookout, "in accordance with a plan that is mutually acceptable to the Secretary of the Interior and the Secretary of the Army." This legislation was an attempt to protect Cape Lookout from major changes, which were considered destructive, due to severe storms. Unlike the situation at Cape Hatteras National Seashore to the north, Cape Lookout has sustained minimal shore erosion control and "beach protection" measures (Coburn et al. 2010; NPS 2014e). This seashore historically has maintained natural rather than artificially stabilized dunes (Godfrey and Godfrey 1976). Park staff have aptly maintained that the barrier island ecosystems are best able to function, and that the barrier islands can best protect the North Carolina mainland from hurricanes and other storm surges, when they are allowed to respond and change naturally (NPS 2014e). All of the barrier islands of Cape Lookout, including Shackleford Banks, have been allowed to naturally erode as part of the natural expansion/contraction of inlets and the natural response of the barrier island to storms and sea-level rise.

As a result of new information (2001 and 2006 studies) regarding the navigation channel impacts on Shackleford Banks, the National Park Service requested in 2010 that sand placement on Shackleford Banks be considered in the 20-year Dredged Material Management Plan (DMMP) that the Army Corps of Engineers (USACE) was preparing for Morehead City Harbor. The draft DMMP therefore evaluated placement of beach quality dredged material on Shackleford Banks along with placement on Bogue Banks (Atlantic Beach and Fort Macon State Park). However, following circulation of the Draft DMMP, the National Park Service requested dismissal of the alternative to place dredged material on Shackleford Banks because there was not adequate information to conclude that sand placement in the quantities and locations in the DMMP was the preferred solution to ameliorate potential dredging-related effects. Therefore, the National Park Service has determined that no sand will be placed on Shackleford Banks as part of this 20-yr DMMP, although the Corps of Engineers continues to recommend the beach placement. (Source: US Army Corps of Engineers, Morehead City Harbor, Morehead City, NC, Final Integrated Dredged Material Management Plan (DMMP) and Environmental Impact Statement, June 2016).

Seashore Soils

NPS policy is to strive to understand and preserve the soil resources of park units, and to prevent insofar as possible unnatural soil erosion, physical removal, or contamination, or soil contamination of other resources (NPS 2006b).

On the Outer Banks of North Carolina, the major determinant of soil differences is the characteristic of relief; it affects drainage, vegetation, and the length of time required for soil development. In Cape Lookout, ocean beaches merge with gently sloping to moderately steep, excessively drained soils on dune ridges (USDA 1986). Soils are moderately-well drained to poorly-drained in nearly-level to gently-sloping troughs between dunes, or in flats on the sound side of the seashore. Very poorly drained soils are found in the nearly level salt marshes beside tidal creeks and the sounds. In general, droughtiness, wind erosion, salt spray, wetness, and flooding in low areas make these soils best suited for use by wildlife. Most soils on Core Banks have poor bearing capacity, instability due to wind and water activity, and high water tables (NPS 1982). Conventional subsurface sewage disposal facilities (septic systems) can easily contaminate the shallow freshwater table, especially in low-lying areas. In contrast, most of Shackleford Banks has soils that would only slightly limit development, because of the occurrence of Newhan fine sand. Nevertheless, this sand is highly pervious (Brauer 1974) and would allow appreciable groundwater contamination. The only apparent mineral resource on the seashore is silica sand, but it is too far removed from inland markets to be of other than local value (NPS 1982).

The USDA NRCS (1986) surveyed the soils of Carteret County, including Cape Lookout, in terms of map units. A map unit is defined as an area dominated by one major type of soil, or an area dominated by several types of soils. Based on the USDA NRCS survey, of the 13 different soil map units in the seashore, nearly half of the land area is dominated by three map units (14.5–17.7%)—Coastal Beaches (Be); Carteret sand low, frequently flooded (CL); and Carteret sands, frequently flooded (CH) (Table 20, Figure 26 and Figure 27). Six of the 13 map units represent 10% or more of the total land area; the rest cover 0.04 to 5.6%.

Table 20. The 13 soil map unit types found in Cape Lookout, also showing areal coverage versus areal coverage of water (see Appendix 1 for the detailed data, which were provided by the USDA NRCS 2006).

Soil Map Unit (Abbreviation)	Soil (Map Unit Type)	Area (hectares)	Area (acres)	Percentage (land, %)
Be	Beaches, Coastal	1,198	2,960	17.7
Bf	Beaches, Storm Tidal	847	2,094	12.5
Bn	Beaches-Newhan complex, 0–30% slopes	44	108	0.6
BH	Belhaven Muck (0.04%, negligible)	3	7	0.0
CH	Carteret sands, frequently flooded	985	2,433	14.5
CL	Carteret sand, low, frequently flooded	1,094	2,704	16.1
Co	Corolla fine sand	379	937	5.6
Cd	Corolla-Duckston complex	227	562	3.3
Du	Duckston fine sand, frequently flooded	881	2,178	13.0
LF	Longshoal muck, very frequently flooded	18	44	0.3
Nh	Newhan fine sand (2–30% slopes)	258	638	3.8
Nd	Newhan fine sand, dredged (2–30% slopes)	40	100	0.6
Nc	Newhan-Corolla complex (0–30% slopes)		2,009	12.0
--	Total Land:	6,788	16,773	100.0
W	Water (36% of the total land and water)	3,811	9,417	

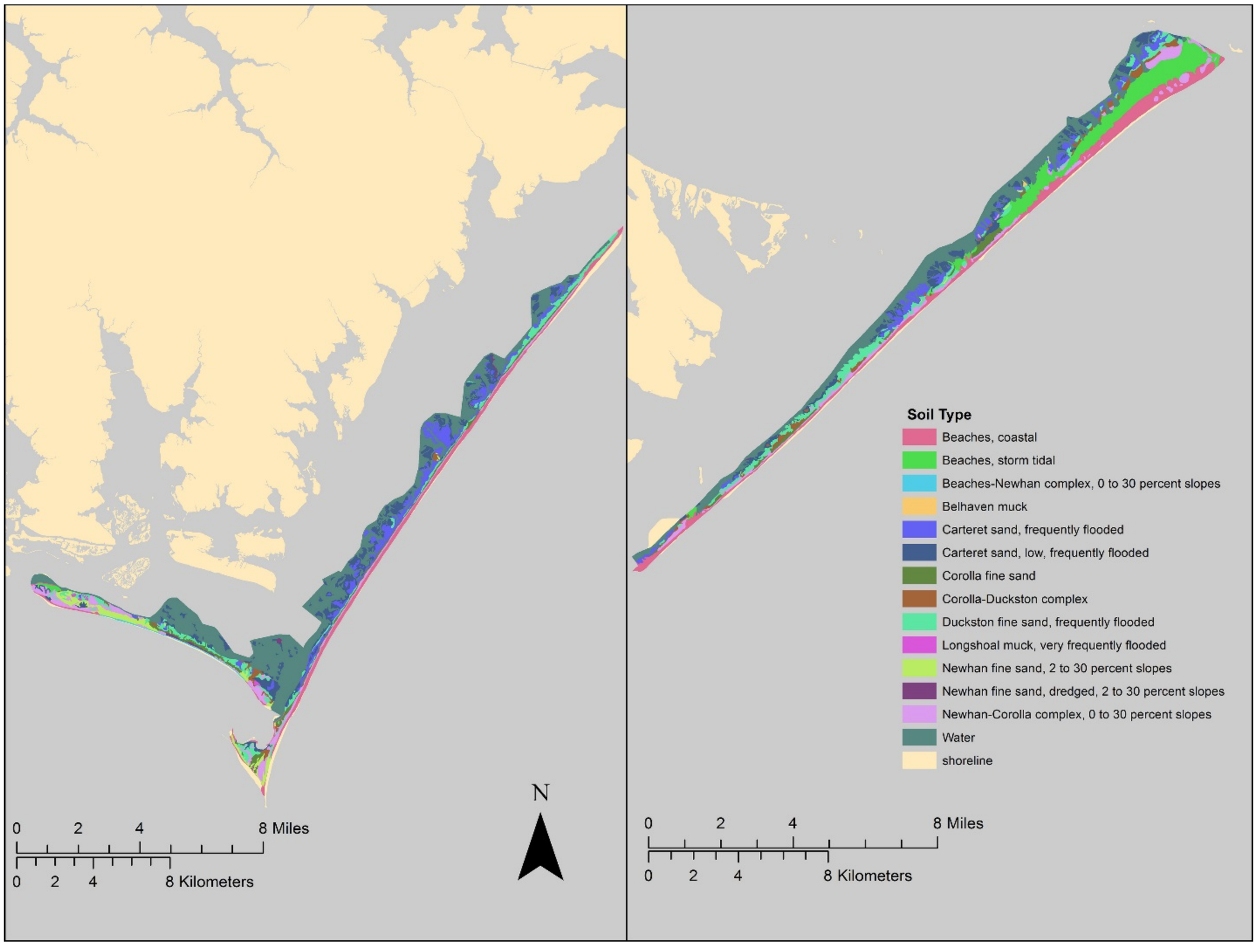

Figure 26. Map of the predominant soils in CALO. GIS data from the Soil Survey Geographic (SSURGO) database (USDA NRCS 2016). Map by S. Flood, NCSU CAAE.

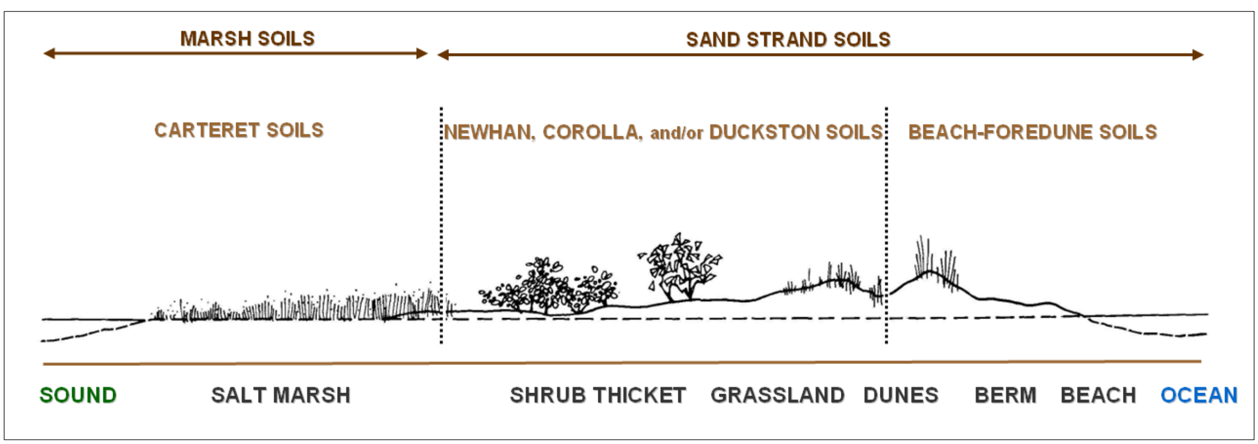

Figure 27. Schematic of CALO barrier islands in cross-section, showing characteristic soil types of the main ecosystems. Modified from the USDA Soil Conservation Service Soil Survey of the Outer Banks, N.C. (NPS 1982 GMP).

Water Resources

Surface Waters

Hydrology Affecting the Seashore: Oceans and Sounds

Cape Lookout is bordered to the east and south by the Atlantic Ocean (Figures 2, 3, and 28). Raleigh Bay refers to the ocean waters southeast of Core Banks, whereas the Mid-Atlantic Bight is the nearshore area of the ocean east of the park. Seaward from the barrier islands, the continental shelf gradually deepens to 5–60 meters (16–197 ft) at the shelf break about 50–100 kilometers (31–62 mi) off shore, and from there the ocean rapidly deepens (Mallin et al. 2006). The mean wave height on Cape Lookout is 1.2–1.3 meters (3.9–4.3 ft), and the mean range of the semi-diurnal tides is 1.1 meters (3.3 ft) (Dolan and Lins 2000; Pendleton et al. 2004).

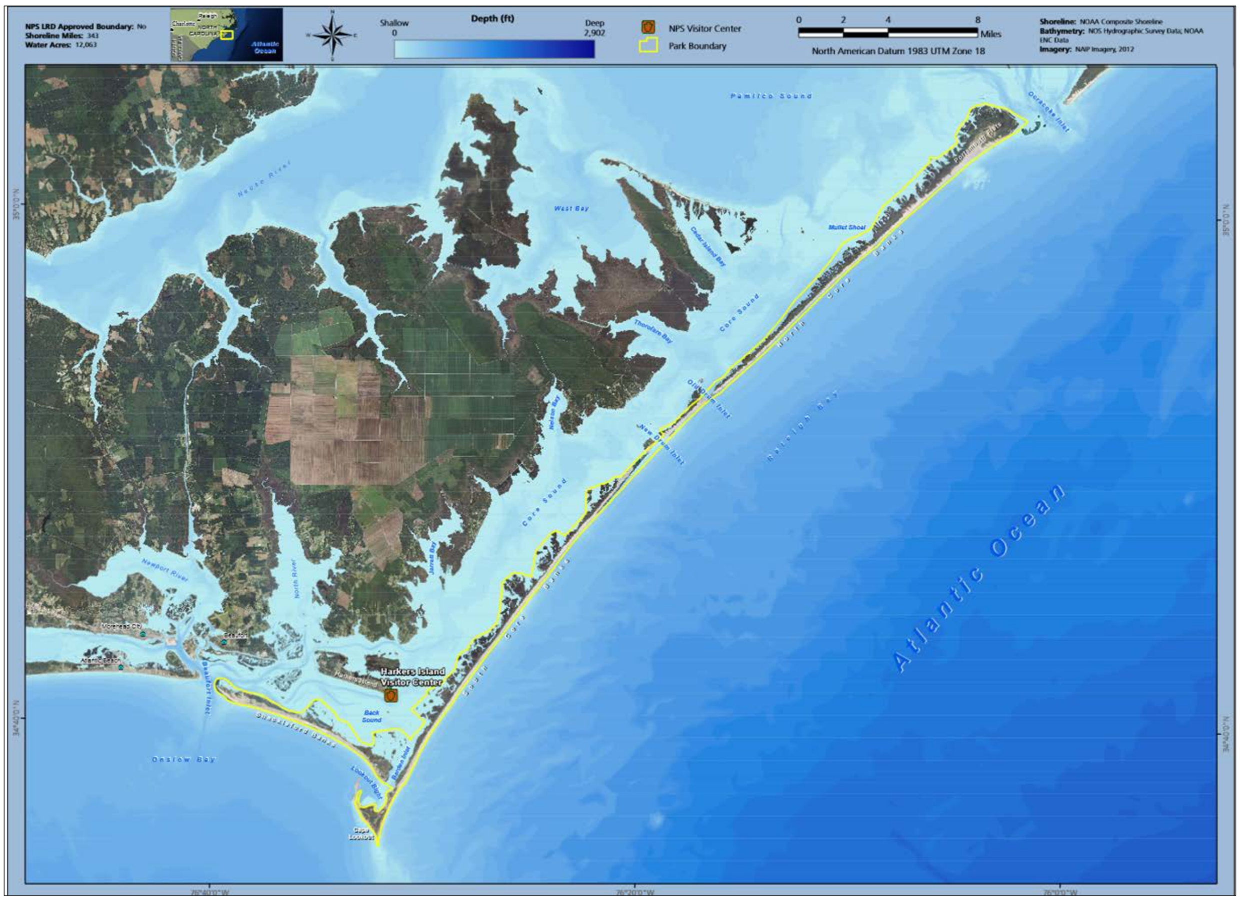

Figure 28. NOAA composite shoreline of CALO (note: this is not the NPS LRD approved boundary), with bathymetry information (depth contours in different blue colors) from the National Ocean Service (NOS) Hydrographic Survey Data (NOAA ENC Data); imagery, Dare County—2007, Hyde County—2006; and NAP imagery—2010. The CALO shoreline (ocean side and sound side) is approximately 190 kilometers (118 mi).

As mentioned, the entire CAPES is relatively shallow with an average depth of 4.5 meters (14.8 ft); depth ranges from less than 2 meters (6.6 ft) at the shoals to more than 7.5 meters (24.6 ft) in the center of the two basins in Pamlico Sound (Lin et al. 2007). The water residence time in the CAPES is about 11 months on average, although it can be as short as two months when affected by major storms (Burkholder et al. 2004; Lin et al. 2007 and references therein). On the sound side of the seashore, west of the northernmost portion of North Core Banks is Pamlico Sound. The remainder of the western shore of North Core Banks, and much of South Core Banks are bordered by Core Sound (Figure 2). The western shore of the southern portion of South Core Banks north of Shackleford Banks is bordered by Back Sound, which also borders the northern shore of Shackleford Banks. The south and west shores of Cape Lookout, and the southern shore of Shackleford Banks facing the ocean are both bordered by Onslow Bay. The polyhaline waters of the sounds have salinities ranging from 18–29, depending on the precipitation (Mallin et al. 2004, 2006). Pamlico Sound at the northern edge of North Core Banks is connected to the ocean by Ocracoke Inlet; Core Sound is connected to the ocean by Old Drum Inlet and Ophelia Inlet; and Back Sound is connected to the ocean by Barden Inlet.

The coastal fringes of east Harkers Island are also in the 100-year flood plain. The remaining area of the seashore (mostly portions of Shackleford Banks) is mainly located within AE zone of the 100-year floodplain, not directly adjacent to the ocean or sound. The ocean in the seashore area lies on a wide continental shelf, and the gently sloping coastal plain of the North Carolina mainland forms a lagoon system, the Albemarle-Pamlico Sounds (Inman and Dolan 1989). Except for the tallest dunes on Shackleford Banks and Cape Lookout Point, all of the seashore lands are within the 100-year floodplain and coastal high hazard area. Thus, the seashore is subject to high water table conditions and high wave actions so that drainage and flooding problems often result from storms. The dominant source of flooding, of course, is wind-driven storm surge in association with hurricanes, other tropical storms, and nor'easters.

The Gulf Stream, which originates in tropical waters, flows past North Carolina around the area of the shelf break, but this current is very dynamic (Mallin et al. 2006). Frictional forcing by the Gulf Stream drives the predominantly clockwise circulation in Raleigh Bay (Mallin et al. 2000a). Filaments of the Gulf Stream sometimes flow landward, bringing the warm, nutrient-enriched waters toward shore. Sometimes these filaments can come within 10 kilometers (6.2 mi) of the shore (Mallin et al. 2006). In an extremely dynamic area off Cape Hatteras, the warm waters of the Gulf Stream meet the southernmost extension of the cold waters of the Labrador Current, which originates in the vicinity of the coast of Norway (Figure 29). At Cape Point in Cape Hatteras National Seashore, immediately north of Cape Lookout, the Gulf Stream is closer to land than anywhere north of southern Florida. From that area, it turns away from the North American coast and moves out to sea (Pompe 2010). Cape Point on Cape Lookout is an extremely high-energy system that responds dramatically to changing energy regimes and manifests sometimes-daily as well as seasonal alterations. Close to the CALO shore, rip currents are common because of underwater sandbars that develop offshore and form a trough of water between the sandbar and the beach. Rip currents are powerful, channeled currents of water flowing away from the shore through the surf zone and past the line of breaking waves (NOAA—see NWS 2016).

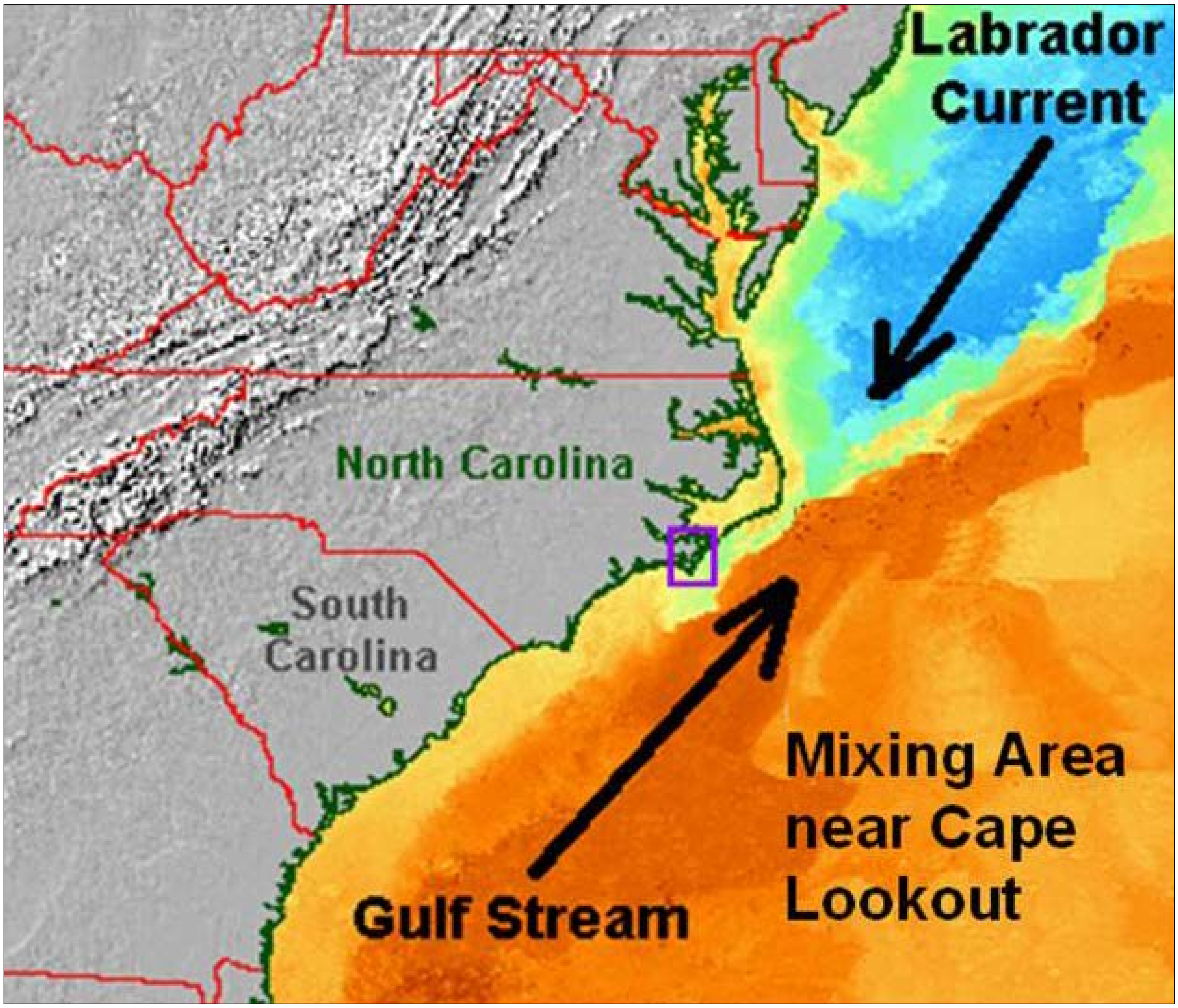

Figure 29. The mixing area of the Gulf Stream with the southernmost extension of the Labrador Current. Modified from CoastalGuide.com, and used with permission.

Waterbodies and Wetlands in Cape Lookout:

The polyhaline waters of the sounds can impart brackish salinities to the coves and the numerous tidal creeks on the sound side of Cape Lookout, depending on the local rainfall (Mallin et al. 2004). Another brackish area reported in the seashore was on the seaward beach of Cape Point about 1 kilometer from the abandoned U.S. Coast Guard station (coordinates N 34 59.452, W 76 53.760) (Mallin et al. 2004). This waterbody is a 5,000-m^2 (1.2-ac), extremely shallow brackish pool (depth 10 centimeters [3.9 in]) that commonly contained an extensive benthic algal mat. There are a number of small ephemeral ponds that form in or near marsh areas after periods of rainfall. On Shackleford Banks there is a small pond known as Mullet Pond formed by the closing of a former bay or lagoon (Rasmussen et al. 2009).

Wetlands are defined as areas that are inundated or saturated by water for sufficient time during the growing season to develop and support characteristic soils and vegetation (Cowardin et al. 1979).

Wetlands provide considerable ecological and economic benefit to the seashore and surrounding areas. Among many beneficial functions, they filter pollutants from runoff to help protect adjacent open waters; store large volumes of water to minimize flooding during storms; provide critical habitat for fish and wildlife; and help protect shorelines from erosion (NPS 2014a).

The National Park Service classifies wetlands based on the Cowardin Classification System (Cowardin et al. 1979, NPS 2014a), wherein:

- The habitat at least periodically supports predominantly hydrophytic vegetation;
- The substratum is predominantly undrained hydric soil; and
- The substratum is saturated with water or covered by shallow water at some time during the growing season (Cowardin et al. 1979).

Based on that system, Cape Lookout has diverse marine, estuarine, and palustrine forested and emergent wetlands, and most of the shoreline areas in the seashore are wetlands. Marine wetlands along the ocean side shoreline are exposed to the waves and currents of the open ocean. They include the landward limit of tidal inundation, measured based on the extreme high water of spring tides (Cowardin et al. 1979). Estuarine wetlands are abundant along the sound side shorelines of Cape Lookout as mentioned, and they sustain either regular or occasional flooding by tides. Tidal salt/brackish water emergent wetlands are closest to the sound, whereas estuarine scrub shrub habitats are more landward. The estuarine system includes low-wave energy, moist-substrata habitats known as intertidal mudflats and sand flats. Species of special concern (SSCs) such as piping plovers (*Charadrius melodus*), Wilson's plover (*Charadrius wilsonia*), red knot (*Calidris canutus*), and American oystercatchers (*Haematopus palliatus*) forage for invertebrates and other food in those habitats.

The seashore contains wide expanses of marine wetlands (saltmarshes), and Shackleford Banks especially has estuarine wetlands (emergent persistent and intertidal scrub-shrub) along with palustrine wetlands (emergent persistent, scrub-shrub). Palustrine wetlands are nontidal and may be dominated by trees, shrubs, or persistent emergent plants (including mosses or lichens). They also include wetlands without those types of vegetation, but having the following four features: (i) areas less than 8.1 hectares (20 ac); (ii) active wave-formed or bedrock shoreline features are lacking; (iii) the deepest water depth is less than 2 meters (1.9 ft) at mean low water; and (iv) salinity from ocean-derived salts is less than 0.5% (Cowardin et al. 1979).

Freshwater rivers and lakes do not exist on Core Banks, but there are numerous small freshwater ponds as mentioned, especially in the north (Portsmouth Island) (Schwartz 1982, Mallin et al. 2004). These ponds are highly variable in size, vegetation composition, pH, and water color (Schwartz 1982). Various freshwater ponds are also found on Shackleford Banks, especially on the west end of that barrier island (Mallin et al. 2004). Moreover, the (fresh) water table is very shallow and accessible to some fauna (Figure 30). Finally, a series of drainage ditches were dug on Core Banks in the 1970s to drain wetlands for mosquito control. They are no longer used, but hold water (Rasmussen et al. 2009).

Figure 30. Tidal creek and expanse of saltmarsh on Portsmouth Island (Top; Photo by Jim Fineman, Village Craftsmen 2013). Lower photo: Horses on Shackleford Banks digging a water hole. From Mallin et al. (2004).

Surface-Water-Quality Criteria

The State of North Carolina (North Carolina Department of Environment and Natural Resources (NCDENR 2003) has ambient water quality standards for common parameters including dissolved oxygen (DO, < 5 mg/L or, for swamp water, < 4 mg/L), turbidity (< 50 nephelometric turbidity units, NTU, for freshwaters and 25 NTU for brackish and salt waters), chlorophyll *a* (< 40 μg/L), and fecal bacteria (< 200 colony forming units [CFU] per 100 mL as a geometric mean [gm] based on at least 5 samples collected within 30 days) (Table 21). The state also has standards for metals and various toxic compounds (North Carolina Administrative Code 2003). Other recommended guidelines for acceptable water quality parameters—including turbidity, nutrients (nitrate+nitrite, NOx; total Kjeldahl nitrogen, TKN; and total phosphorus, TP), polychlorinated biphenyls (PCBs), toxic metals, and fecal bacteria—in waters designated for use as Fishing and General Recreation have been published by the EPA (e.g., 2000a, 2002b, 2012a) and other sources (Tables 22 and 23).

Table 21. North Carolina surface water use classifications and water quality standards, excluding trout waters[h] [DO—dissolved oxygen; Chl*a*—corrected chlorophyll *a*; Entero—Enterococcus, GM—geometric mean; NTU—Nephelometric turbidity units].

USE CLASSIFICATION	**Temperature (°C [°F])**	**pH[a]**	**DO (mg/L)[b]**	**Turbidity (NTU)[c]**	**Chl*a* (µg/L)[d]**	**Fecal Bacteria (GM #/100 mL)[e]**
Class C Freshwaters (aquatic life; secondary recreation)	≤ 2.8°C (5.04°F) above natural; never > 32°C (89.6ºF) in Coastal Plain	6.0–9.0	≥ 5.0 average ≥ 4.0 minimum instantaneous	50 (streams); 25 (lakes, reservoirs)	≤ 40	Fecal coliform: ≤ 200; and ≤ 400 in ≤ 20% of samples
Class B Freshwaters (primary recreation)[i]	≤ 2.8°C (5.04°F) above natural; never > 32°C (89.6ºF) in Coastal Plain	6.0–9.0	≥ 5.0 average ≥ 4.0 minimum instantaneous	50 (streams); 25 (lakes, reservoirs)	≤ 40	Fecal coliform: ≤ 200; and ≤ 400 in ≤ 20% of samples
Class SC Saltwaters[f] (shellfishing)	≤ 8.0°C (14.4°F) above natural during June-Aug., or > 2.2°C (3.96°F) in other months; and never > 32°C (89.6°F) due to discharge of heated liquids	6.8–8.5	same as Class C freshwater	25	≤ 40	Fecal coliform: ≤ 14 median; and ≤ 43 in ≤ 10% of samples[g] Entero: 35
Class SB Saltwaters[f,I] (primary recreation)	≤ 2.8°C (5.04°F) above natural; never > 32°C (89.6ºF) in Coastal Plain	6.0–9.0	≥ 5.0 average ≥ 4.0 minimum instantaneous	50 (streams); 25 (lakes, reservoirs)	≤ 40	Fecal coliform: same as Class C freshwater Entero: 35
Class SA Saltwaters[f,j] (aquatic life, secondary recreation)	≤ 8.0°C (14.4°F) above natural during June-Aug., or > 2.2°C (3.96°F) in other months; and never > 32°C (89.6°F) due to discharge of heated liquids	6.8–8.5	same as Class C freshwater	25	≤ 40	Fecal coliform: same as Class C freshwater Entero: 35

[a] Shall be normal for waters in the area; swamp waters may have a pH as low as 4.3 if it is the result of natural conditions.

[b] Swamp waters—narrative only; swamp waters, poorly flushed tidally influenced streams or embayments, lake bottom or estuarine bottom waters may have lower DO if caused by natural conditions.

[c] If turbidity exceeds these levels due to natural background conditions, the existing turbidity level cannot be increased.

[d] In violation if 10% of samples taken in the photic zone exceed 40 µg/L.

[e] Units as number of organisms per 100 mL as a MF (membrane filter) count. The GM of a series of N terms is the Nth root of their product. Example: the GM of 2 and 18 is the square root of 36. The GM is based on > 5 consecutive samples examined during a 30-day period. No more than 20% of samples during the 30-day period can exceed 400 organisms/100 mL. All samples are to be analyzed using the membrane filter technique unless high turbidity or other adverse conditions necessitate use of the tube dilution method. In case of controversy over results, the MPN 5-tube dilution technique shall be used as the reference method. Note: "Violations of the fecal coliform /standard are expected during rainfall events and, in some cases, this violation is expected to be caused by uncontrollable nonpoint source/pollution." EPA (2003) recommended consideration of 400 mpn/100 mL as the highest acceptable level of fecal coliforms if samples are taken less frequently.

Beaches are separately considered: The state uses the Enterolert® method for analysis, rather than membrane filtration, and results are given as Most Probable Number (mpn) rather than CFU. During the "swimming season" (May 1 to September 30), standards at Tier 1 beaches (located in resort areas or other high-use areas, monitored daily) are a single-sample maximum of 104 mpn/100 mL and a running GM of 35 mpn/100 mL. At Tier 2 beaches (in Cape Lookout, tidal creeks, used most frequently on weekends), the standard is a single-sample maximum of 276 mpn/100 mL; at Tier 3 beaches (used on average 4 times per month), the standard is a single-sample maximum of 500 mpn/100 mL. Alerts are issued for Tier 1 beaches when enterococcus densities are 104–500 mpn/100 mL; if this occurs, a second sample is taken and if levels in that sample exceed 104 mpn/100 mL, an advisory is issued. An analogous procedure for alerts and advisories is followed at Tier 2 and Tier 3 beaches.

[f] Salinity, narrative only: Changes in salinity due to hydrological modifications shall not result in removal of the functions of a primary nursery.area.

[g] Same as "e" above regarding methodologies. Note that the criterion of 14/100 mL "in those areas most probably exposed to fecal contamination during the most unfavorable hydrographic and pollution conditions."

[h] From NCDENR (2003—N.C. Administrative Code (NCAC), updated in 2012: 15A NCAC 02B .0211, Fresh Surface Water Quality Standards for Class C waters; 15A NCAC 02B .0220, Tidal Salt Water Quality Standards for Class SC Waters; 15A NCAC 02B .0221, Tidal Salt Water Quality Standards for Class SA Waters; and 15 NCAC 02B .0222, Tidal Salt Water Quality Standards for Class SB Waters—and see NCDENR 2012)

[i] No sewage, industrial wastes or other wastes unless effectively treated

Table 22. Recommendations for reference (minimally impacted) conditions for nutrients, turbidity, and suspended microalgal biomass as chlorophyll *a* concentrations in freshwater streams and rivers (F—fluorometric technique; S—spectrophotometric technique) in streams in level III nutrient sub-ecoregion #63, which includes Cape Lookout. These recommendations were based on the 25th percentile of all available streams data for the previous decade.

Parameter	25th Percentiles based on all seasons data for the decade
TKN (mg/L)	0.51
NO_2+NO_3 (mg/L) = NO_3	0.04
TN (mg/L)—calculated	0.55
TN (mg/L—reported	0.87
TP (mg/L)	0.0525
Turbidity (NTU)	3.89
Turbidity (FTU)	4.5
Turbidity (JCU)	4.73
Chlorophyll *a* (µg/L) -F	0.44
Chlorophyll *a* (µg/L) -S	3.75

Table 23. Two sets of threshold criteria recommended by the EPA for enterococci and *Escherichia coli* fecal bacteria to protect human health safety in waters used for primary contact recreation (EPA 2012a). These microbes are considered to be better general indicators of fecal contamination than fecal coliform bacteria (National Research Council 2004) [GM—geometric mean; STV—statistical threshold value*].

Criteria Elements	Estimated Illness Rate of 36 / 1000 primary contact recreators	Estimated Illness Rate of 32 / 1000 primary contact recreators
Enterococci (marine & fresh)	35 GM /130 STV	30 GM / 110 STV
Escherichia coli (fresh)	126 GM / 410 STV	100 GM / 320 STV

* A statistical value threshold approximates the nintieth percentile and should not be exceeded in more than ten percent of the samples.

The federal Clean Water Act requires the EPA to develop recommended criteria for water, which are designed in part to protect aquatic life. The criteria are supposed to reflect accurately the up-to-date scientific knowledge. Whereas the State of North Carolina has imposed regulations, an EPA water quality criterion is not a regulation; it does not impose legally binding requirements on the EPA or the states. States have the discretion to adopt approaches that differ from the EPA water quality criteria, but these criteria (recommendations) are meant to provide useful guidance. North Carolina's present stance is far from protective; in the past four years the state has weakened or eliminated many of its environmental laws (Environment North Carolina 2013), and has made little progress toward developing numeric nutrient criteria mandated by the EPA (2000a), as assessed by the EPA Office of the Inspector General (EPA 2009).

An attempt was made by Parman et al. (2012) to compile fish kill reports in waters affecting Cape Lookout, but that effort was abandoned when the evaluation revealed major kills, often involving millions of fish, are common in estuarine waters (Glasgow et al. 2001). The lack of reliable fish kill records has characterized the state, at least as far back as the 1980s when Lowe et al. (1991) evaluated North Carolina as the state with the worst fish kill records in the Southeast

General Approach in NPS Studies of Surface Water Quality and Sediment Quality, and Applications:

Cape Lookout is relatively isolated from nonpoint sources pollution on the mainland (Parman et al. 2012) other than atmospheric, but just across the narrow sounds at the southern end of the seashore are the cities of Morehead City and the City of Beaufort, and point and nonpoint sources associated with these population centers. Each of these cities has a municipal wastewater treatment plant with secondary treatment, which removes only about half of the nitrogen and phosphorus in the raw wastes (EPA 2004a, Tilley 2011). In addition, many summer residences in the area are not connected to the municipal wastewater treatment plants, and instead rely on septic systems to treat the wastes (e.g., Humphrey et al. 2012). As the leachfields are sandy and the groundwater is shallow, various pollutants in the wastes would be expected to move into coastal waters (Mallin and McIver 2012, and references therein).

Some shellfish beds across the narrow sounds from the seashore have been closed to shellfish harvest for human consumption). Within the past 15 years, advisories commonly have been issued during “swimming season” (May through September) for various locations along the mainland opposite Cape Lookout (e.g., a swimming area 91 meters or 100 yards south of the NPS service dock near Barden Inlet, Harkers Island near the seashore headquarters, Atlantic Beach, etc.). Moreover, within the park, during 2010 three advisories were issued (20 May, 3 June, 23 September) for an ocean side beach 3.2 kilometers (2 mi) north of Cape Point at Cape Lookout in the seashore because of high fecal coliform densities (NCDMF 2015).

As a general approach, monitoring of water quality in and near Cape Lookout is conducted by the Southeast Coast Network and partners using methodologies adopted from the National Estuarine Research Reserve Program and the EPA, and which are summarized by Gregory et al. (2013). The Southeast Coast Network collects monitoring data for four specific objectives (NPS 2013b):

1) Determine daily and seasonal water quality patterns for five core parameters (DO, salinity, temperature, pH, and turbidity) at fixed monitoring stations using continuous data loggers;
2) Determine monthly and seasonal patterns in nutrients (N, P, and chlorophyll *a*) at fixed monitoring stations by collecting discrete water samples;
3) Determine status and spatial variability of water and nutrient chemistry conditions in estuarine waters every 5 years; and
4) Determine status and spatial variability of benthic sediment quality (organic contaminants, carbon, and metal levels) every 10 years in estuarine waters.

At each sampling location, basic physical information is recorded including weather conditions, habitat types, and the presence of submerged aquatic vegetation or marine debris. Water-column (depth) profiles are obtained at 0. 5–1-m (3.3-ft) intervals including temperature, salinity, turbidity, conductivity, pH, and DO concentrations. Discrete water samples are also collected at 1–3 depths per site depending on the total depth, and they are analyzed for TDN, TDP, and suspended microalgal biomass as chlorophyll *a*, (Day et al. 1989; Wetzel and Likens 2000; NPS 2013b). The National Park Service also plans to collect sediments every 10 years for grain size, total organic carbon (TOC), selected metals, mercury, selected polycyclic aromatic hydrocarbons (PAHs), PCBs, and selected pesticides (NPS 2013b; note that sediments are sampled infrequently due to the overall cost of sediment analyses and the expected slower response time for sediment contaminants to accrue). These parameters are meant to be representative of the well-over-600 toxic contaminants added to waterways and sediments by human activities (Nriagu and Lakshminarayana 1989; Miller 2004; EPA 2010a). Parman et al. (2012) explained the infrequency of sampling (10-year intervals) as related to the high overall cost of sediment analysis, and an expected slower response time for sediment contaminants to accrue.

The Southeast Coast Network uses EPA (2005, 2008b, 2012b) assessment criteria to evaluate water quality and sediment quality (as percent organic content) conditions, which the EPA describes as having been based on published literature (Tables 24a, 24b, and 25a, 25b, and 25c). We report NPS findings and interpretations using these assessment criteria (e.g., NPS report by Parman et al. 2012, below), but we suggest modifications for a more protective evaluation system in Chapter 6.3.1 of this report.

Table 24a. Indices used by Parman et al. (2012) to evaluate water and sediment quality in and near CALO for water quality and total organic carbon (TOC) sediment ratings for sampling efforts every five years, based on the EPA (2008b) assessment criteria.

Water Quality and Sediment TOC (5-year sampling frequency)	*Good*	*Fair*	*Poor*
Dissolved oxygen (DO) (mg/L)[a]	> 5	2–5	< 2
Chlorophyll a (chla) (µg/L)[b]	< 5	5–20	> 20
Dissolved inorganic nitrogen (DIN), summer (mg/L) [c]	< 0.1	0.1–0.5	> 0.5
Dissolved inorganic phosphorus (DIP), summer (mg/L) [c]	< 0.01	0.01–0.05	> 0.05
Water clarity (% surface light at one meter); Naturally high turbidity (a = 1.0)	< 2.30	2.30–2.99	> 3.00
Normal turbidity (a = 1.4)	< 1.61	1.61–2.30	> 2.30
Naturally low turbidity (a = 1.7)	< 0.92	0.92–1.61	> 1.61
TOC (% dry weight of sediment)	< 2	2–5	> 5

[a] Indicator values for DO were based on Diaz and Rosenberg (1995) and EPA (2000b).

[b] Indicator values for suspended microalgal chl*a* were determined by Bricker et al. (1999), with additional consideration of selected state criteria.

[c] Indicator values for DIN and DIP were derived from Bricker et al. (1999) in EPA (2008b).

Table 24b. Indices used by Parman et al. (2012) to evaluate water and sediment quality in and near CALO. Sediment contaminant ratings for sampling efforts every 10 years, based on the effects range for sediment contaminants from the NCCR III (EPA 2008b). Site condition is rated as good if the contaminant concentration is less than the ERL, fair if it is between the ERL and ERM, and poor if it is greater than the ERM [Conc.—concentration; LMW—low-molecular-weight; HMW—high-molecular-weight].

Category	Sediment Contaminants (10-year sampling frequency)	< ERL	ERL < Conc. < ERM	> ERM
Metals (µg/g or ppm)	Arsenic	< 8.2	8.2–< 70	≥ 70
	Cadmium	< 1.2	1.2–< 9.6	≥ 9.6
	Chromium	< 81	81–< 370	≥ 370
	Lead	< 46.7	46.7–< 218	≥ 218
	Mercury	< 0.15	0.15–< 0.71	≥ 0.71
	Nickel	< 20.9	20.9–< 51.6	≥ 51.6
	Silver	< 1	1–< 3.7	≥ 3.7
	Zinc	< 150	150–< 410	≥ 410
Organics (ng/g or ppb)	Acenaphthene	< 16	16–< 500	≥ 500
	Acenaphthylene	< 44	44–< 640	≥ 640
	Anthracene	< 85.3	85.3–< 1,100	≥ 1,100
	Fluorene	< 19	19–< 540	≥ 540
	2-Methylnaphthalene	< 70	70–< 670	≥ 670
	Naphthalene	< 162	162–< 2,100	≥ 2,100
	Phenanthrene	< 240	240–< 1,500	≥ 1,500
	Benz(a)anthracene	< 261	261–< 1,600	≥ 1,600
	Benzo(a)pyrene	< 430	430–< 1,600	≥ 1,600
	Chrysene	< 384	384–< 2,800	≥ 2,800
	Dibenzo(a,h)anthracene	< 63.4	63.4–< 260	≥ 260
	Fluoranthene	< 600	600–< 5,100	≥ 5,100
	Pyrene	< 665	665–< 2,600	≥ 2,600
	LMW PAHs	< 552	552–< 3,160	≥ 3,160
	HMW PAHs	< 1,700	1,700–< 9,600	≥ 9,600
	-tal PAHs	< 4,020	4,020–< 44,800	≥ 44,800
	4"4 DDE	< 2.2	2.2–< 27	≥ 27
	DDT	< 1.6	1.6–< 46.1	≥ 46.1
	PCBs	< 22.7	22.7–< 180	≥ 180

Table 24c. Fish tissue contamination indices based on the EPA Advisory Guidelines Concentration range (ppm; set here to indicate fair conditions) associated with "non-cancer" health endpoints for all parameters except PAHs (benzo(a)pyrene), which was set to a "cancer" health endpoint. Note that these endpoints relate to humans, without consideration for the health of aquatic life.

Fish Tissue Contaminants (µg/g or ppm)	Good	Fair	Poor
Arsenic (inorganic)	< 0.35	0.35–0.70	> 0.70
Cadmium	< 1.2	1.2–2.3	> 2.3
Mercury (methylmercury)[d]	< 0.12	0.12–0.23	> 0.23
Selenium	< 5.9	5.9–12.0	> 12.0
Chlordane	< 0.59	0.59–1.2	> 1.2
DDT	< 0.59	0.59–1.2	> 1.2
Dieldrin	< 0.059	0.059–0.12	> 0.12
Endosulfan	< 7.0	7.0–14.0	> 14.0
Endrin	< 0.35	0.35–0.70	> 0.70
Heptachlor epoxide	< 0.015	0.015–0.031	> 0.031
Hexachlorobenzene	< 0.94	0.94–1.9	> 1.9
Lindane	< 0.35	0.35–0.70	> 0.70
Mirex	< 0.23	0.23–0.47	> 0.47
PAHs (benzo(a)pyrene)[e]	< 0.0016	0.0016–0.0032	> 0.0032
PCBs	< 0.023	0.023–0.040	> 0.040

[d] The conservative assumption was made by Parnell et al. (2012) that all mercury is present as methylmercury, with the rationale that most mercury in finfish and shellfish is present as methylmercury, and because the analysis for methyl-mercury is less expensive (EPA 2000b).

[e] Benzo(a)pyrene does not have a non-cancer range (EPA 2008b).

Table 25a. Condition criteria used for water quality assessment summaries at individual sampling sites and for CALO overall. From Gregory and Smith (2011).

Rating	Site Water Quality Index Rating	Park Water Quality Index Rating
Good	< 1 indicator is fair, and no indicators are poor	< 10% of sites are in poor condition, and < 50% of sites are in fair or poor condition
Fair	1 indicator is poor, or > 2 indicators are fair	10–20% of sites are in poor condition, or > 50% of sites are in fair or poor condition
Poor	> two of the five indicators are Poor	> 20% of sites are in poor condition
Missing	Two components of the indicator are missing and the available indicators do not suggest a fair or poor rating	--

Table 25b. Condition criteria used for sediment quality assessment summaries at individual sampling sites and for CALO overall. From Gregory and Smith (2011).

Rating	Sediment Contaminants Rating (SC) and % TOC	Site Sediment Quality Index	Park Sediment Quality Index
Good	No ERM concentrations are exceeded and < 5 ERL concentrations are exceeded; TOC is < 2%	SC is Good, TOC is Good	< 5% of the sites are in poor condition; and < 50% of the sites are in fair or poor condition
Fair	≥ 5 ERL concentrations are exceeded; an TOC is 2–5%	SC is Fair or TOC is Fair	5–15% of the sites are in poor condition, or > 50% of the sites are in fair or poor condition
Poor	An ERM concentration is exceeded for ≥ 1 contaminant; TOC is > 5%	SC is Poor or TOC is Poor	> 15% of sites are in poor condition

Because there are no absolute chemical concentrations that correspond to sediment toxicity, the National Park Service uses Effects Range Low (ERL) and Effects Range Median (ERM) values as guidelines in assessing sediment contamination (SC) (Table 25b). The ERM is the median concentration of a contaminant observed to have adverse biological effects in the literature studies examined (Long and Morgan 1990; Long et al. 1995; O'Connor 2004; Gregory and Smith 2011). A more protective indicator of contaminant concentration is the ERL criteria, which is the 10th percentile concentration of a contaminant represented by studies demonstrating adverse biological effects in the literature. Ecological effects are not likely to occur at contaminant concentrations below the ERL criterion (Gregory and Smith 2011). Sediment contaminant availability or organic enrichment largely depends on the amount of organic matter present, which can be assessed by measuring TOC.

Probabilistic Survey of Water Quality, Sediment Quality, and Fish Tissue Quality in and Around Cape Lookout (2000–2009)

A probabilistic survey of water quality, sediment quality, and fish tissue contamination was conducted by the National Park Service jointly with the EPA (Parman et al. 2012), with a regional perspective. Data covering a 10-year period (2000 to 2009; except that chlorophyll *a* data covered a five-year period from 2000 through 2004), from Cape Lookout and within a 32.2-kilometer (20-mi) boundary surrounding the park boundaries, were obtained from federal, state, and local agencies. The data were evaluated using EPA (2008b) assessment criteria (below). In total, 13 stations inside the seashore were considered (Figure 31). The 32-kilometer distance seems to us a questionable approach because it could easily include areas remote from Cape Lookout with extremely poor water quality. Such a scenario was, in fact, the case, as shown in the example in Figure 32). Conditions in the upper Pamlico Estuary (arrow) have been degraded since the 1980s, partly because the world's largest phosphate mine is located there (Mallin et al. 2000a). For an actual evaluation of water quality in and near the seashore, it seems to us more instructive to use a 4.8- to 8-kilometer (3- to 5-mi) radius closer to the seashore.

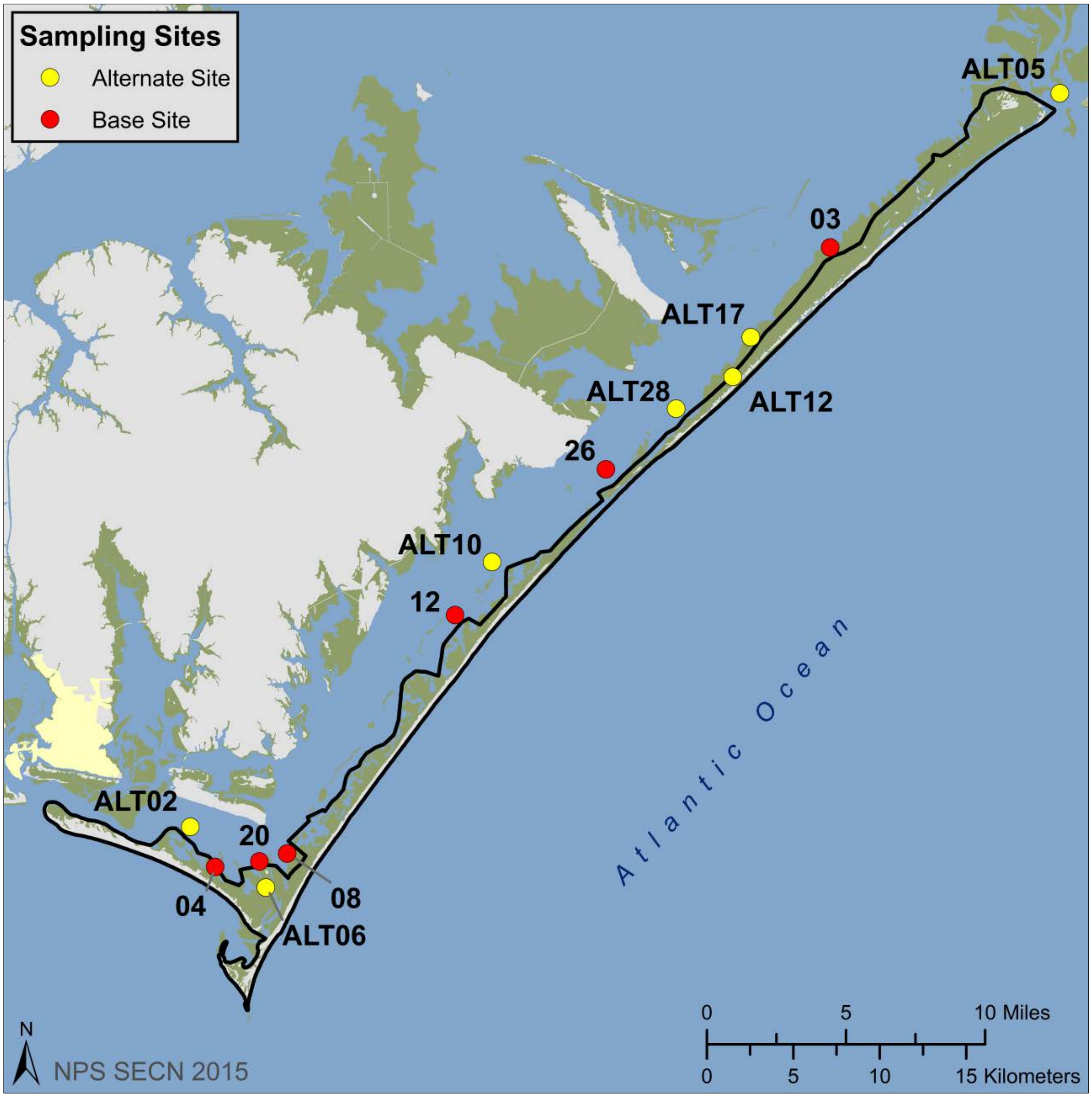

Figure 31. The 13 sites in CALO that were surveyed for water quality and sediment quality by the network with the University of Georgia in July 2010. From Gregory and Smith (2011).

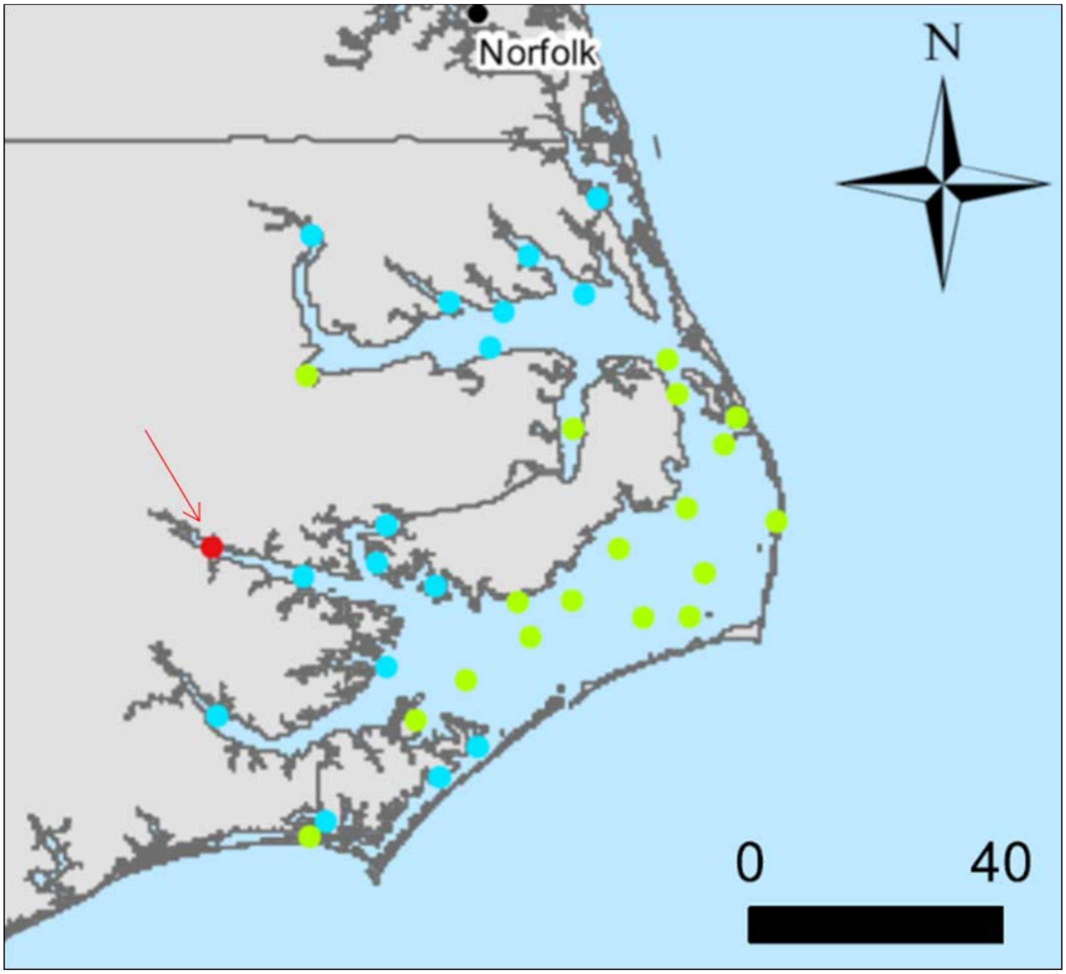

Figure 32. Example (2002) of station evaluations by Parman et al. (2012) within a 32.2-kilometer radius of CALO (green—good; blue—fair; red—poor). Cape Lookout and Cape Hatteras National Seashores were evaluated collectively with respect to outside stations but, some stations appear to be much farther than 20 miles from the seashores, such as the poor water quality station in the Pamlico Estuary (red dot, arrow).

The data synthesis was limited by different sampling designs and time scales among the source agencies, different methods/detection limits used and varying quality control/quality assurance (QA/QC) among laboratories, high variability in sampling frequency depending on the parameter, and lack of consistency across years. Furthermore, there was high uncertainty about the location of sampling, which is especially important for DO: "…samples at some sites were only collected at the surface, or the metadata did not specify where the samples were taken. While some discrepancies exist in the comparison of DO levels among sites due to inconsistent sampling protocols, all DO data were used" (Parman et al. 2012).

Another important consideration is that most of the water quality and sediment data for sites considered outside the seashore boundaries were retrieved from the EPA STOrage and RETrieval System (STORET) database (EPA 2014), a "user beware" water quality database system. The EPA imposes minimal QC criteria on the data deposited into this system by public agencies. There are known issues with STORET data (double to quadruple entries of the same data, decimal points in the wrong place, inappropriate rounding, erroneous location entries, etc.), and we view additional checks of QA/QC as an essential requirement preceding the use of any data from STORET. Parman et al. recognized these issues, and used this data accepting these limitations (Parman et al. 2012).

As a shortcoming in the approach, DIN and DIP were not actually measured except quarterly, and the DIN:TDN and DIP:TDP ratio from quarterly (“seasonal”) measurements was “applied” to the measured TDN and TDP concentrations to estimate what the DIN and DIP concentrations might have been. We refer here to estimated DIN and DIP concentrations. In addition, Parman et al. (2012) used estimates of DIN and DIP during the summer season for their assessment, and stated that “in general, there is more phytoplankton uptake and growth during the summer months, thus DIN and DIP concentrations are expected to be lower than at other times of the year.” Yet, they apparently did not use summer chlorophyll *a* values; rather, they used annual average chlorophyll *a* concentrations. Such an approach effectively “dilutes” the chlorophyll *a* values used for assessing water quality status by using an overall annual average that would be expected to be much lower than the summer values.

Parman et al. (2012) assessed sediment quality as well as water quality, and also evaluated available data for fish tissue contamination, which can integrate water and sediment quality. Marine organisms become exposed to toxic chemical pollutants by direct uptake from polluted water, consumption of polluted sediment, or consumption of contaminated organisms. Many toxic contaminants or their breakdown products are highly persistent, difficult to chemically and/or biologically degrade, and remain in sediments and organisms in particular for decades (Long et al. 1995, 1998). Many of them also bioaccumulate (biomagnify) up the food web to higher-level predators. In addition to causing many insidious, adverse health impacts for aquatic organisms, birds, and wildlife (for example, serious disease or death for a mink that consumes a highly contaminated fish), bioaccumulated chemicals can also directly threaten the health of humans who consume contaminated finfish and shellfish (Wilson and Kazmierczak 2007). The EPA (2008a) developed risk-based advisory guidance values for recreational fishers (Table 26c), but Parman et al. (2012) considered values for the “whole fish body” rather than “fillets” (the muscle tissue usually consumed by recreational fishers). Parman et al. (2012) additionally pointed out that the methods used to obtain the fish contaminants data varied among sampling programs, which can lead to serious limitations in attempts to interpret and compare data. There was no attempt to account for this problem (for example, by limiting the analysis to data that had been obtained using the same methods). Instead, all data available for the selected parameters were included. Parman et al. (2012) then expressed the fish tissue contaminants index as a percentage of stations where fish were caught, without further explanation.

Parman et al. (2012) evaluated Cape Lookout as “relatively pristine” using the above approach (Table 26 a-c) for the 13 stations inside and outside the seashore. The data indicated that water quality is much better inside the seashore than in surrounding waters (Table 26a). DO conditions inside and outside Cape Lookout were comparable, whereas conditions indicated by nutrients (estimated DIN, estimated DIP), water clarity, and chlorophyll *a* concentrations were much better inside the seashore than in the outside area (Table 26a, Figure 33). These findings suggest that runoff from the mainland has not yet had a major influence on sound side water quality in Cape Lookout, but more research is needed.

Table 26a. Water quality parameters and percent of sampling sites ranked good, fair, and poor for the seashore and sites within 32.2 kilometers (20 mi) outside of the seashore (EPA 2008b; Parman et al. 2012).

Water-quality Parameter*	Evaluation (CALO)*	Within 32.2 kilometers of CALO
Dissolved Oxygen	92% good (12 sites) 8% fair (1 site)	92% good (161 sites) 7% fair (12 sites) 1% poor (1 site)
Dissolved Inorganic Nitrogen	100% good (13 sites)	71% good (87 sites) 10% fair (13 sites) 19% poor (23 sites)
Dissolved Inorganic Phosphorus	100% good (13 sites)	29% good (34 sites) 42% fair (51 sites) 29% poor (34 sites)
Water Clarity (at one meter depth)	100% good (13 sites)	40% good (37 sites) 60% fair (56 sites)
Chlorophyll *a* (suspended microalgal)	95% good (19 sites) 5% fair (1 site)*	39% good (36 sites) 57% fair (52 sites) 4% poor (4 sites)

* n = 13 sites inside the seashore for all water quality parameters except chlorophyll *a* (n = 20 sites).

Table 26b. Sediment parameters and percent of sampling sites ranked good, fair, and poor for the seashore, and sites within 32.2 kilometers (20 mi) outside of the seashore (EPA 2008b, Parman et al. 2012) [DDT—dichlorophenyltrichloroethane; "----"—data not available].

Sediments	Evaluation (CALO)	Within 32.2 kilometers of CALO
2-Methylnaphthalene	100% good (25 sites)	100% good (81 sites)
4'4'-DDE	100% good (25 sites)	99% good (80 sites), 1% fair (1 site)
Acenaphthene	100% good (25 sites)	100% good (81 sites)
Acenaphthylene	100% good (25 sites)	100% good (81 sites)
Anthracene	100% good (25 sites)	100% good (81 sites)
Arsenic	100% good (25 sites)	82% good (66 sites), 18% fair (15 sites)
Copper	100% good (25 sites)	100% good (82 sites)
Fluorene	100% good (25 sites)	100% good (81 sites)
Fluoranthene	100% good (25 sites)	100% good (81 sites)
Mercury	100% good (25 sites)	94% good (76 sites), 6% fair (5 sites)

Table 26b (continued). Sediment parameters and percent of sampling sites ranked good, fair, and poor for the seashore, and sites within 32.2 kilometers (20 mi) outside of the seashore (EPA 2008b, Parman et al. 2012) [DDT—dichlorophenyltrichloroethane; "----"—data not available].

Sediments	Evaluation (CALO)	Within 32.2 kilometers of CALO
Naphthalene	100% good (25 sites)	100% good (81 sites)
Phenanthrene	100% good (25 sites)	100% good (63 sites)
Total DDT	----	96% good (74 sites); 4% fair (3 sites)
TOC	100% good (25 sites)	84% good (69 sites),10% fair (8 sites), 6% poor (5 sites)
Total PCBs	*100% good (25 sites)*	*100% good (77 sites)*

Table 26c. Fish contaminant parameters and percent of sampling sites ranked good, fair, and poor for the seashore, and sites within 32.2 kilometers (20 mi) outside of the seashore (EPA 2008a; Parman et al. 2012) [PAH—polycyclic aromatic hydrocarbon, PCB—polychlorinated biphenyls].

Fish Contaminants	Evaluation (CALO)	Within 32.2 kilometers of CALO
Arsenic	0% good 0% fair 100% poor (7 sites)	6% good (6 sites) 17% fair (17 sites) 77% poor (79 sites)
PAHs	57% good (4 sites) 43% poor (3 sites)	68% good (70 sites) 3% fair (3 sites) 28% poor (29 sites)
PCBs	100% good (7 sites)	99% good (101 sites) 1% fair (1 site)

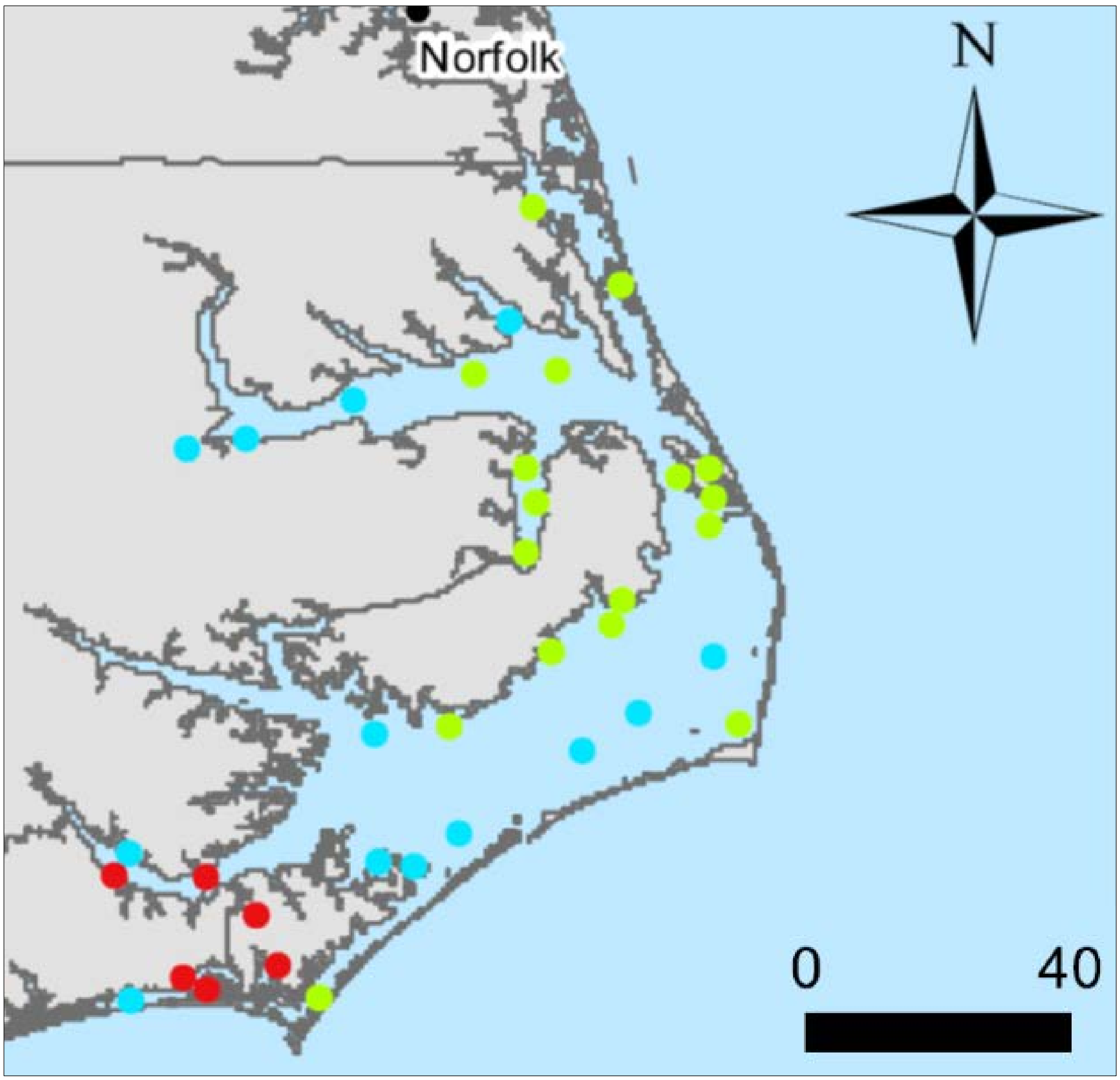

Figure 33. Example (2003, DIP) of station evaluations by Parman et al. (2012) within a 32.2-kilometer (20-mi) radius of the seashore (green—good; blue—fair; red—poor). Note the poor condition of several sites on the mainland near the seashore, versus the good condition for DIP at a site within the seashore.

Sediment conditions were also evaluated by Parman et al. (2012) as good in Cape Lookout. Conditions inside versus outside the seashore were generally comparable except for two parameters, arsenic and TOC. This general finding calls the sediment data for toxic contaminants, or the analysis, into question because the higher amounts of contaminants coming into the water from mainland point and nonpoint sources were not reflected in the sediment data outside the park. On the other hand, the TOC data indicated more enriched conditions outside the seashore, as would be expected; 100% of sites within Cape Lookout were in good condition for TOC, versus 84% of sites outside the seashore.

Fish tissue data for Cape Lookout unfortunately showed a higher percentage of sites ranked as fair and poor for arsenic and PAHs than sites outside the seashore (Parman et al. 2012). Thus, the fish tissue data indicated poorer conditions inside the seashore.

Probabilistic Survey of Cape Lookout NS Water Quality (July 2010)

The Southeast Coast Network partnered with the University of Georgia to complete a survey of water quality and sediment quality at 13 stations in Cape Lookout (Figure 44), as part of the NPS Vital Signs Monitoring Program (Gregory and Smith 2011; and see Smith 2011 for methodological details). The monitoring, parameters etc. followed the approach described in this report, including laboratory analyses for chlorophyll *a*, TDN, and TDP, and field measurements (depth profiles at 0.5-meter intervals) of temperature, salinity, pH, and DO. Water clarity was estimated using Secchi depth measurements, adjusted for naturally occurring water clarity conditions. This adjustment was not further explained; regardless, water clarity was missing for most stations.

Using the evaluation approach in Tables 24 and 25, overall water quality in Cape Lookout was fair; 10 sites were in fair condition and 3 were in good condition (Table 31, Figure 44). Chlorophyll *a* and DO concentrations were good at 92% and 100% of the sites, respectively, with one site evaluated as fair with respect to chlorophyll *a*. TDN and TDP concentrations could not be evaluated. Sediment data (SC, TOC), available for 92% (12) sites, indicated overall good conditions.

Table 27. July 2010 water quality parameter values and assessment conditions for the 13 sites sampled at Cape Lookout (note that DO was measured during the day, which would have minimized detection of hypoxia). Stations are listed proceeding from north to south as in Figure 33. Note that water clarity index (k) values were calculated using a constant for estuarine water with naturally turbid conditions (Smith et al. 2006). The condition of the assessed parameter is also shown, following the approach in Tables 25a and 25a. From Gregory and Smith (2011). (Green[a]—good; yellow[b] —fair; blue[c]—data not collected).

Station	Water Clarity	Chlorophyll *a* (µg/L)	TDN (mg/L)	TDP (mg/L)	DO (mg/L)
CALO ALT-05	0.585[a]	3.37[a]	0.255	0.016	6.78[a]
CALO 03	[c]	7.12[b]	0.618	0.012	5.62[a]
CALO ALT-17	[c]	2.92[a]	0.408	0.013	8.09[a]
CALO ALT-12	[c]	3.28[a]	0.443	0.011	9.23[a]
CALO ALT-28	[c]	1.87[a]	0.194	0.012	7.23[a]
CALO 26	[c]	2.89[a]	0.191	0.011	5.15[a]
CALO ALT-10	[c]	1.97[a]	0.288	0.011	5.69[a]
CALO 12	[c]	1.17[a]	0.259	0.008	4.41[a]
CALO 08	[c]	0.85[a]	0.314	0.011	7.18[a]
CALO 20	[c]	0.58[a]	0.160	0.009	6.68[a]
CALO ALT-06	[c]	0.58[a]	0.139	0.007	6.06[a]
CALO 04	[c]	1.37[a]	0.159	0.012	6.26[a]
CALO ALT-02	0.386[a]	1.65[a]	0.177	0.008	6.62[a]

NPS SECN Continuous Monitoring Data and Augmented Water Quality Sampling (2008–present)

The Southeast Coast Network samples water-quality parameters in 30-minute intervals at two fixed station sites (Gregory et al. 2013). This effort has been conducted in partnership with the North Carolina National Estuarine Research Reserve (Rinehart 2014, Wright and Gregory 2014). Continuous data at two stations (CALO01 or CALOshak1, Shackleford Banks Dock, sound side near the western end of the island, since 2007; and CALO02 or CALOshak2, Middle Marsh, 1.6 kilometers [1 mi] north of the northern (sound side) shore of Shackleford Banks—Figure 47) are been in near-real-time at 30-minute intervals, and include relative depth/tidal range, salinity, DO, temperature, pH, and turbidity. These data are augmented by monthly sampling of water at the same site for Secchi depth (measure of water-column transparency/ clarity or light availability), TDN, TDP, and chlorophyll *a* (Dingle et al. 2012, Wright et al. 2012), and quarterly collection of DIN and DIP (Gregory et al. 2013). Here we summarize the three most recent years of available data at the time (2010, 2011, and 2012).

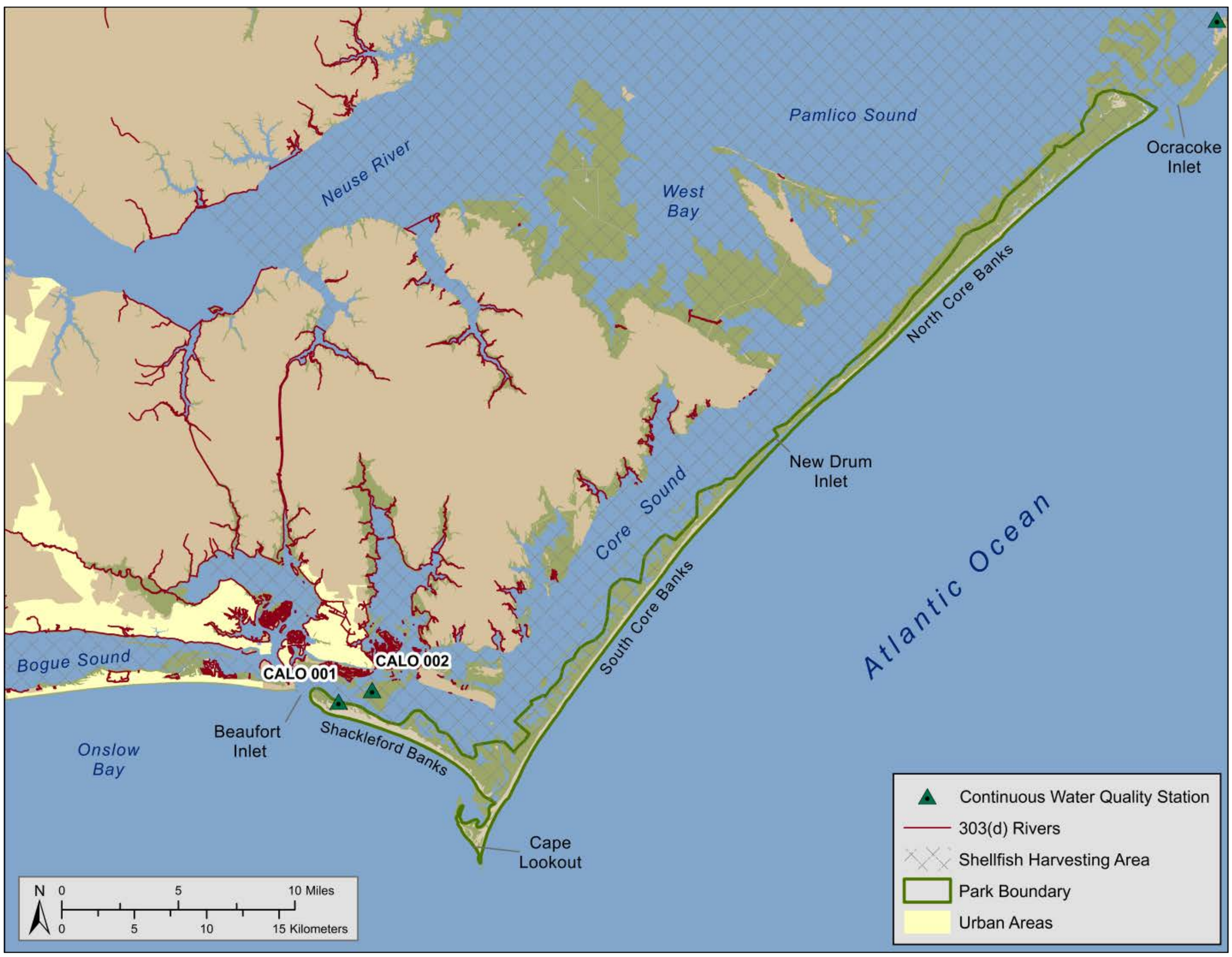

Figure 34. Map showing the location of the two continuous monitoring stations near the southern end of CALO. CALO01 is at the northwest end of Shackleford Banks and CALO02 is in Middle Marsh. Map also indicates areas of saltmarsh (USFWS 2013), impaired waters (303(d)-listed water bodies from NCDENR (2014b), and general shellfish benthic habitat/harvesting waters (hatched areas).

The continuous monitoring data show that, of the two stations, CALO02 (Middle Marsh) was noticeably shallower and lower in DO throughout the summer (below the state standard of 5 mg/L especially from June through September) than CALO01 (Shackleford Banks, sound side) (Figures 35–46). In 2010, June as well as October through December were drier than average, whereas January–February were wetter than average. The associated differences in depth are more clearly evident at CALO02. Below-average depths occurred during a brief period in April 2010, due to a combination of low tide and high winds. At the two continuous monitoring stations, samples collected for water clarity, chlorophyll *a*, and DO generally indicated good conditions (Table 28) following the assessment approach used in Tables 25a and 25a). The nutrient data (TDN, TDP—Table 28) could not be evaluated for indications about water quality conditions.

Regarding water clarity measurements (Table 28) , light attenuation coefficients (*k*) were used to assess water clarity conditions according to criteria categories in Smith et al. (2006). Those categories are comparable to those in the EPA (2008b) criteria for water quality. It should be noted, however, that EPA (2005—National Coastal Condition Report, version II—criteria for assessing water clarity differed from those of EPA (2008b), shown in Table 25, and version IV (EPA 2012b). In version II, the Water Clarity Index ratio WCI, (i.e., the observed clarity at depth 1 meter) was evaluated as good if the WCI exceeded 2, fair if it was between 1 and 2, and poor if it was less than 1. In version IV, Water Clarity is instead considered for three different types of areas. For sites in coastal waters with “naturally high turbidity” (not further defined or clarified), Water Clarity at depth 1 meter is good if there is > 10% surface (incident) light (I_o); fair if there is 5–10% of I_o, and poor if there is < 5% of I_o. For sites in coastal waters with “normal turbidity,” Water Clarity at depth 1 meter is good if there is > 20% of I_o, fair if there is 10–20% of I_o, and poor if there is < 10% I_o. For sites in coastal waters that support submersed aquatic vegetation, water clarity is good if there is > 40% I_o, fair if there is 20–40% I_o, and poor if there is < 20% I_o.

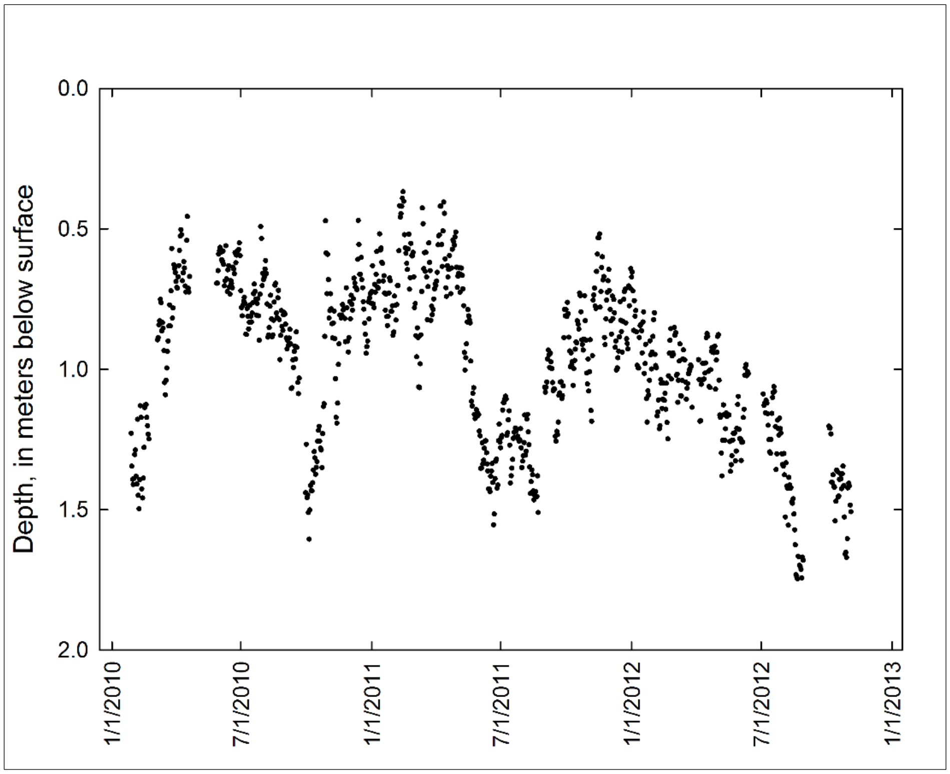

Figure 35. Mean daily values for depth at Shackleford Banks (CALO01) 2010–2013.

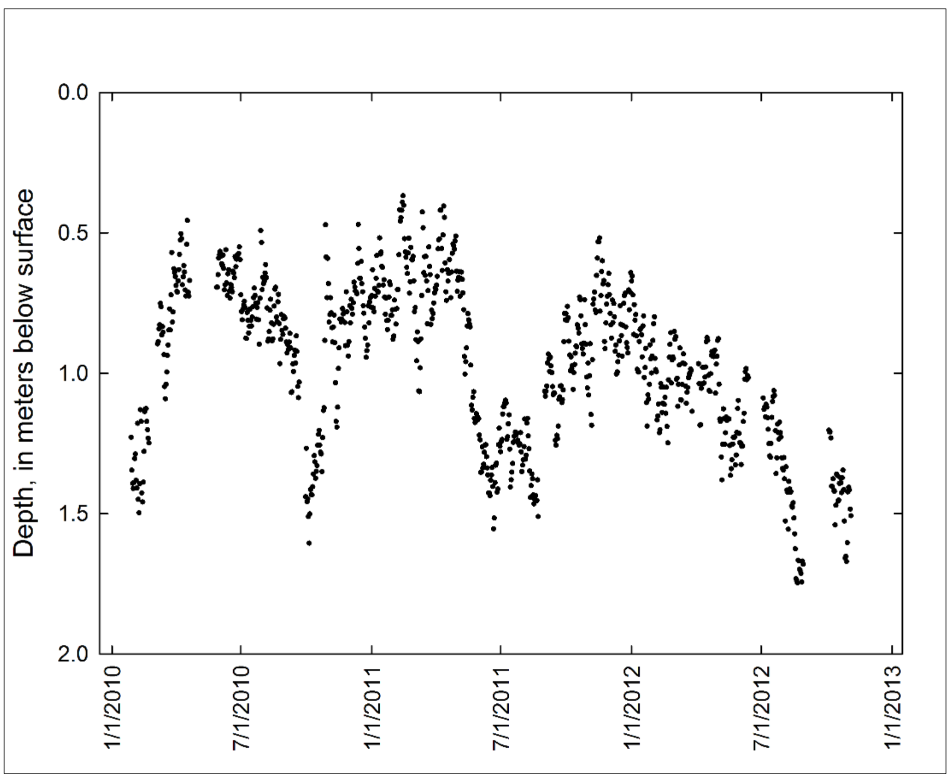

Figure 36. Mean daily values for depth at Middle Marsh (CALO02) 2010–2013.

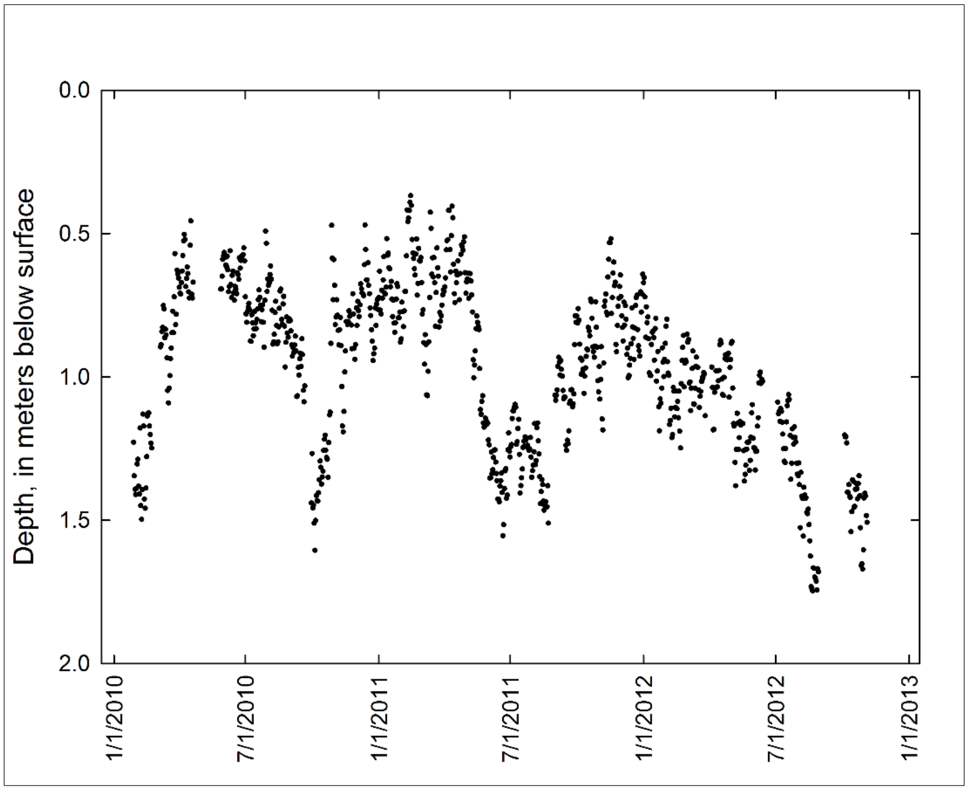

Figure 37. Mean daily values for salinity at Shackleford Banks (CALO01) 2010–2013.

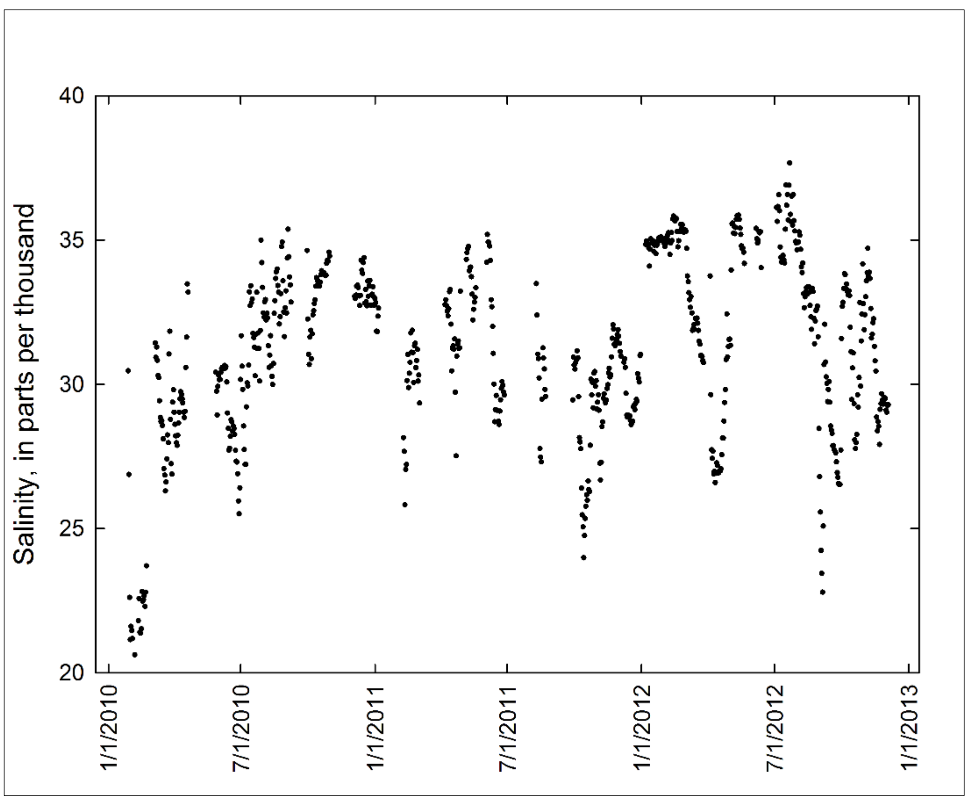

Figure 38. Mean daily values for salinity at Middle Marsh (CALO02) 2010–2013.

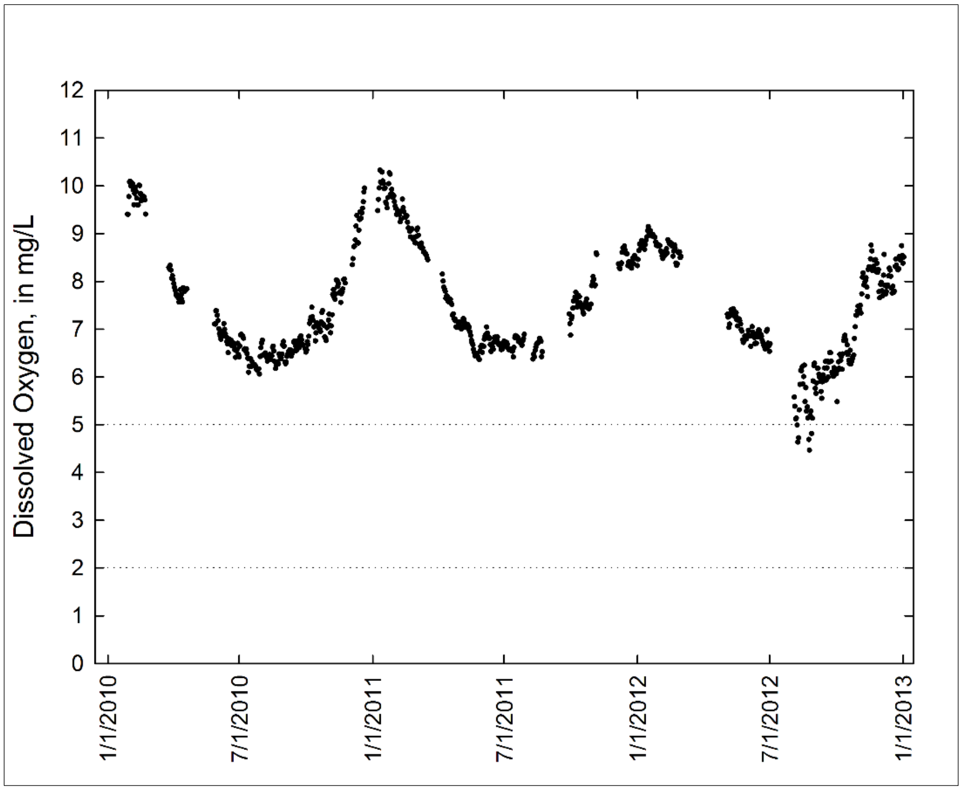

Figure 39. Mean daily values for dissolved oxygen at Shackleford Banks (CALO01) 2010–2013.

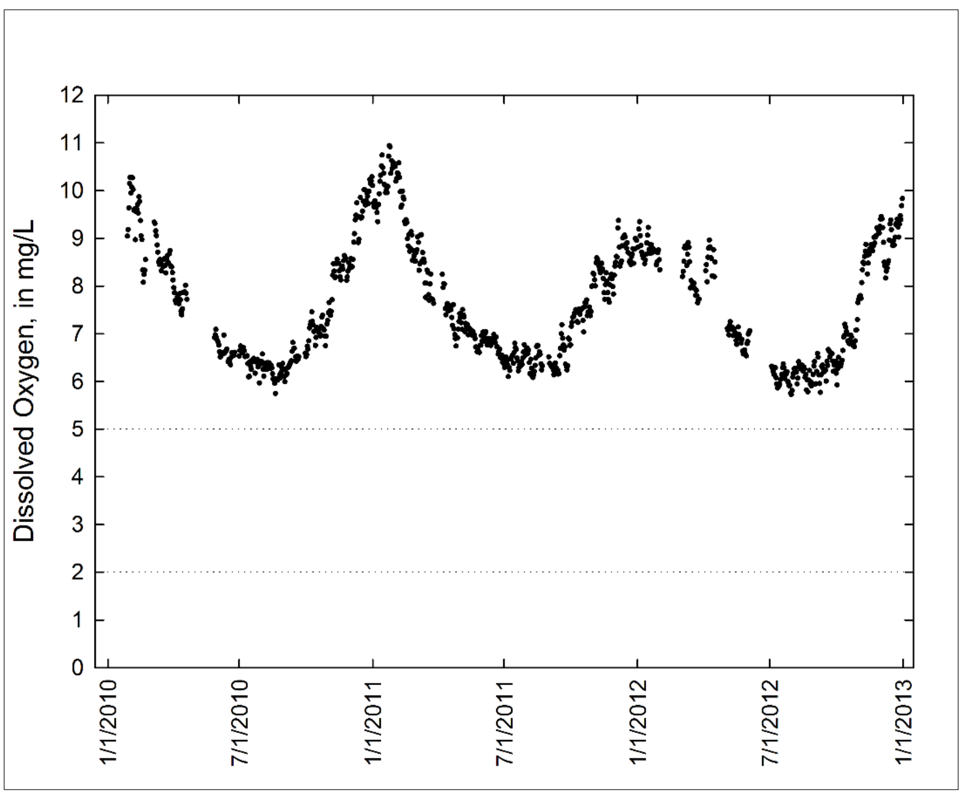

Figure 40. Mean daily values for dissolved oxygen at Middle Marsh (CALO02) 2010–2013.

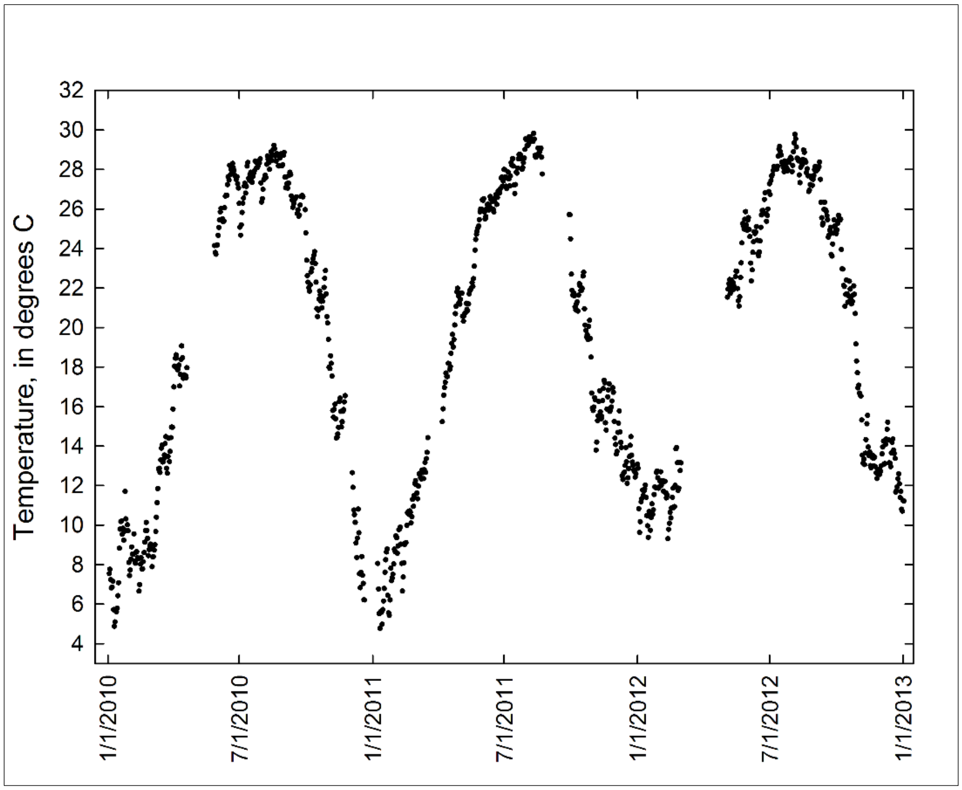

Figure 41. Mean daily values for temperature at Shackleford Banks (CALO01) 2010–2013.

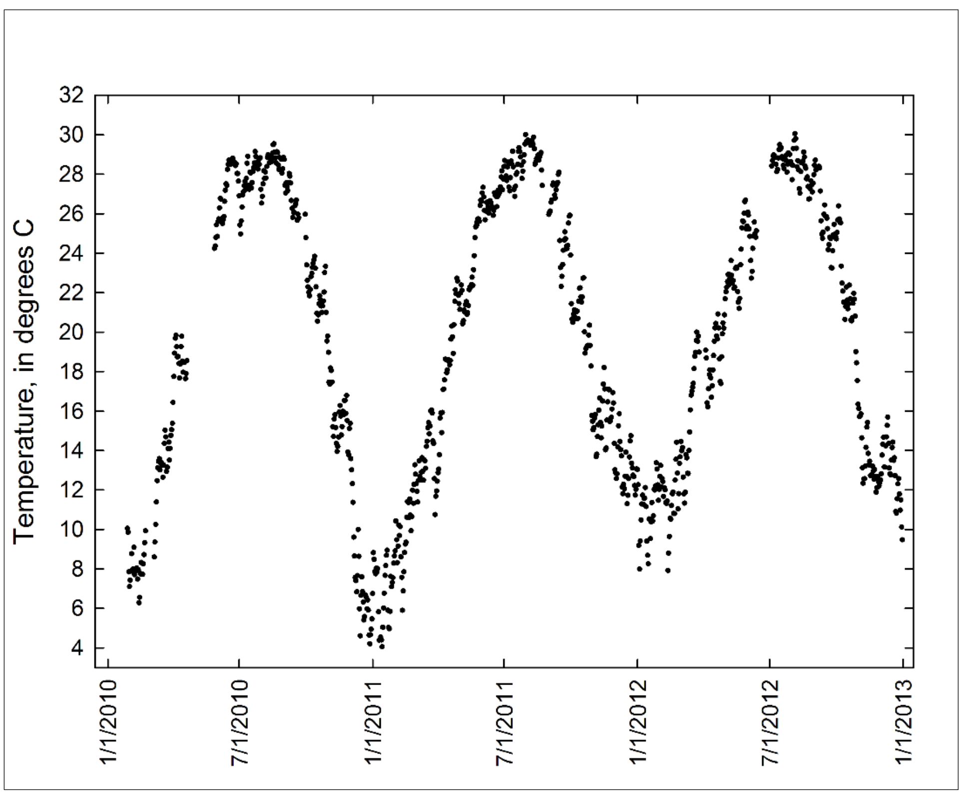

Figure 42. Mean daily values for temperature at Middle Marsh (CALO02) 2010–2013.

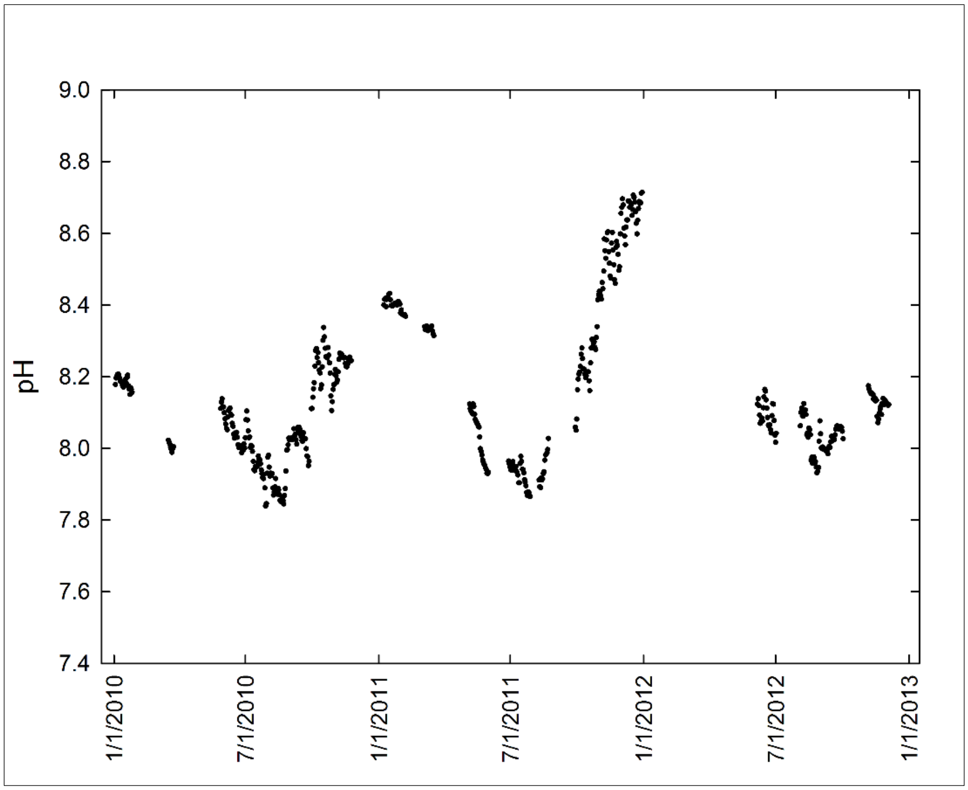

Figure 43. Mean daily values for pH at Shackleford Banks (CALO01) 2010–2013.

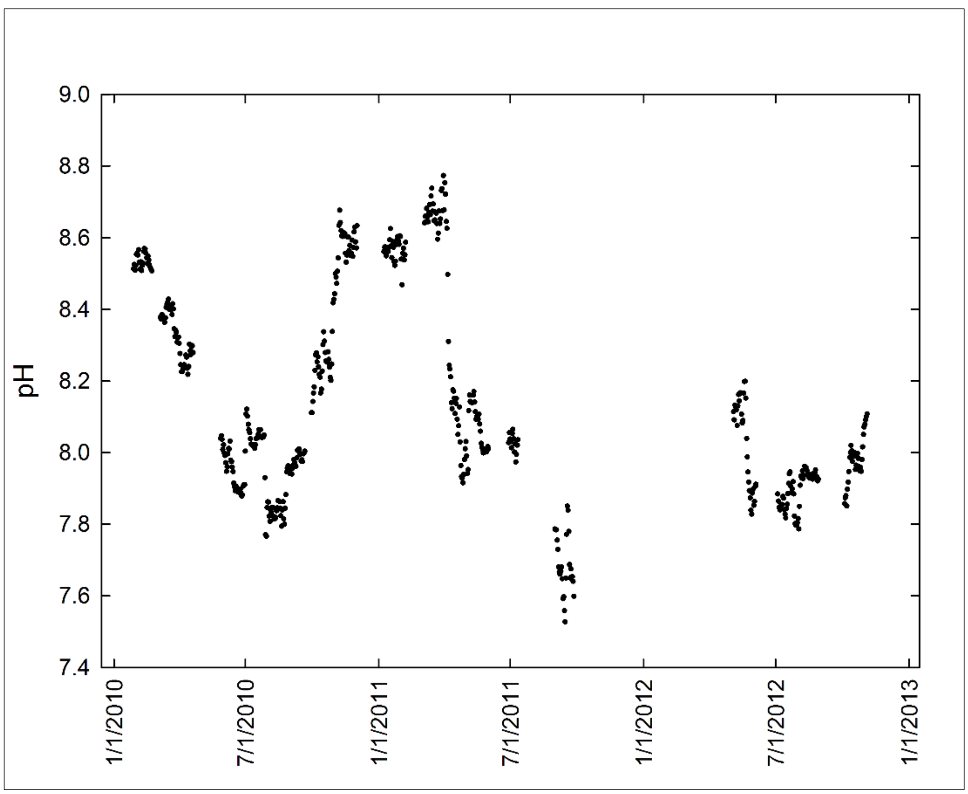

Figure 44. Mean daily values for pH at Middle Marsh (CALO02) 2010–2013.

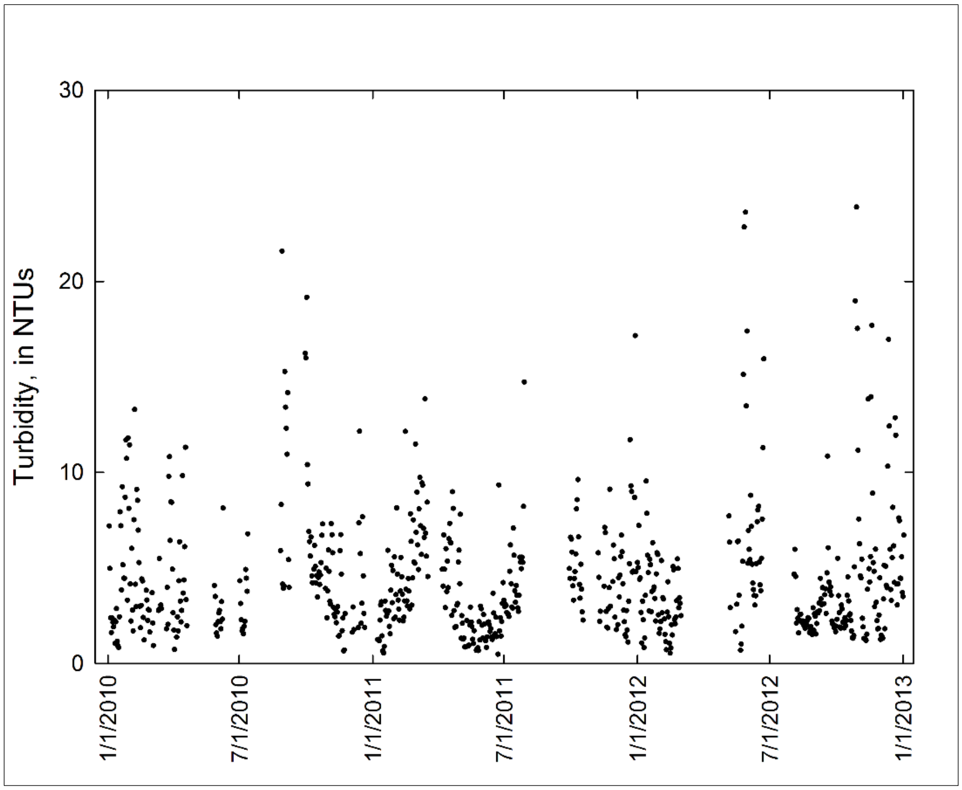

Figure 45. Mean daily values for turbidity at Shackleford Banks (CALO01) 2010–2012.

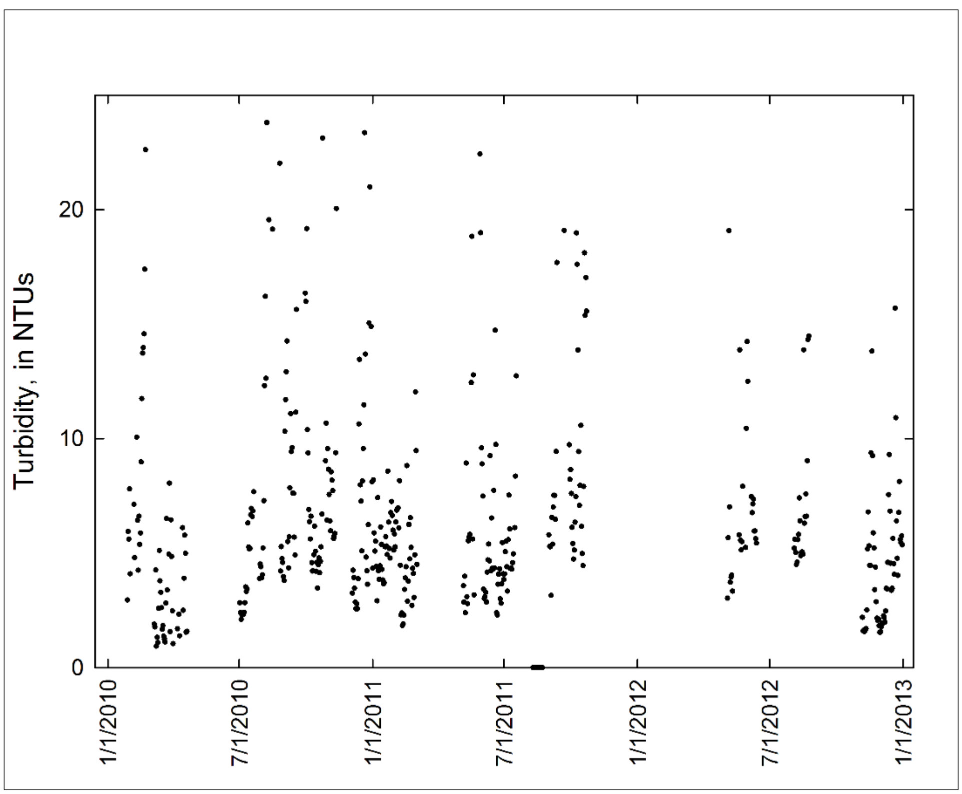

Figure 46. Mean daily values for turbidity at Middle Marsh (CALO02) 2010–2012.

Table 28. Monthly water quality data collected by the network in and near CALO during 2010, 2011, and 2012 to augment the continuous monitoring information. Data collected in CALO at CALO01, northwestern Shackleford Banks and at CALO02, Middle Marsh. Water clarity was assessed by light attenuation values (*k*), using a constant for estuarine water with naturally turbid conditions (Smith et al. 2006). Assessment categories followed those shown in Table 24a from EPA (2008b, 2012a). Modified from Dingle et al. (2012), Rinehart et al. (2014) and Wright and Gregory (2014) [Green[a]—good; yellow[b]—fair; blue[c]—missing data, "--"—data not collected].

Site and year	Date	Water Clarity	Chlorophyll *a* (µg/L)	DO (mg/L)	TDN (mg/L)	DIN (mg/L)	TDP (mg/L)	DIP (mg/L)
2010 CALO 01	January 29	--	--	9.4[a]	--	--	--	--
	February 23	1.0[a]	1.24[a]	9.1[a]	0.19	--	0.010	--
2010 CALO 01 (continued)	March 25	1.1[a]	1.61[a]	8.3[a]	0.28	--	0.011	--
	April 21	1.3[a]	1.09[a]	7.5[a]	0.21	--	0.016	--
	May 28	1.0[a]	2.09[a]	7.5[a]	0.26	0.011[a]	0.021	0.003[a]
	June	--	--	--	--	--	--	--
	July 1	--	1.19[a]	6.8[a]	0.23	--	0.016	--
	July 28	--	3.2[a]	6.8[a]	0.27	--	0.015	--
	August 26	1.2[a]	1.55[a]	7.2[a]	0.28	0.012[a]	0.014	0.003[a]
	September 28	0.7[a]	4.23[a]	6.7[a]	0.4	--	0.025	--
	October 27	0.7[a]	3.44[a]	7.2[a]	0.27	0.012[a]	0.02	0.004[a]
	November	--	--	--	--	--	--	--
	December 3	0.3[a]	2.95[a]	8.0[a]	0.29	--	0.017	--
2010 CALO 02	January 27	0.5[a]	--	8.6[a]	--	--	--	--
	February 23	--	0.66[a]	8.0[a]	0.18	--	0.012	--
	March 25	--	0.51[a]	8.1[a]	0.20	--	0.011	--
	April 21	--	0.9[a]	6.5[a]	0.22	--	0.022	--
	May 27	--	2.24[a]	7.2[a]	0.26	0.009[a]	0.018	0.003[a]
	June	--	--	--	--	--	--	--
	July 1	--	1.04[a]	7.6[a]	0.25	--	0.014	--

[d] Light attenuation coefficients (k) were used to assess water clarity conditions according to criteria categories in Smith et al. (2006).

[e] Secchi disk hit bottom—value estimated or not calculated.

Table 28 (continued). Monthly water quality data collected by the network in and near CALO during 2010, 2011, and 2012 to augment the continuous monitoring information. Data collected in CALO at CALO01, northwestern Shackleford Banks and at CALO02, Middle Marsh. Water clarity was assessed by light attenuation values (*k*), using a constant for estuarine water with naturally turbid conditions (Smith et al. 2006). Assessment categories followed those shown in Table 24a from EPA (2008b, 2012a). Modified from Dingle et al. (2012), Rinehart et al. (2014) and Wright and Gregory (2014) [Green[a]—good; yellow[b]—fair; blue[c]—missing data, "--"—data not collected].

Site and year	Date	Water Clarity	Chlorophyll *a* (µg/L)	DO (mg/L)	TDN (mg/L)	DIN (mg/L)	TDP (mg/L)	DIP (mg/L)
2010 CALO 02 (continued)	July 28	--	1.26[a]	7.0[a]	0.27	--	0.017	--
	August 26	--	1.84[a]	6.6[a]	0.23	0.016[a]	0.015	0.023[b]
	September 28	0.7[a]	2.87[a]	6.1[a]	0.45	--	0.062	--
	October 27	0.7[a]	1.82[a]	7.4[a]	0.27	0.014[a]	0.020	0.005[a]
	December 3	0.7[a]	1.98[a]	8.2[a]	0.25	--	0.019	--
2011 CALO 01	January 7	--	1.08[a]	9.7[a]	0.35	--	0.024	--
	February 8	1.1[a]	1.72[a]	9.4[a]	0.26	--	0.014	--
	March 4	1.4[a]	0.87[a]	9.5[a]	0.28	--	0.049	--
	April 6	--	7.30[b]	8.2[a]	0.25	--	0.018	--
	May 5	0.9[a]	1.15[a]	7.2[a]	0.25	--	0.014	--
	June 2	--	--	7.2[a]	--	--	--	--
	June 27	--	2.34[a]	6.6[a]	--	--	--	--
	July	--	--	--	--	--	--	--
	August 9	--	--	6.5[a]	--	--	--	--
	September 28	0.9[a]	--	7.3[a]	--	--	--	--
	October	--	--	--	--	--	--	--
	November 7	1.6[a]	--	8.89[a]	--	--	--	--
	December 5	--	--			--	--	--

[d] Light attenuation coefficients (k) were used to assess water clarity conditions according to criteria categories in Smith et al. (2006).

[e] Secchi disk hit bottom—value estimated or not calculated.

Table 28 (continued). Monthly water quality data collected by the network in and near CALO during 2010, 2011, and 2012 to augment the continuous monitoring information. Data collected in CALO at CALO01, northwestern Shackleford Banks and at CALO02, Middle Marsh. Water clarity was assessed by light attenuation values (*k*), using a constant for estuarine water with naturally turbid conditions (Smith et al. 2006). Assessment categories followed those shown in Table 24a from EPA (2008b, 2012a). Modified from Dingle et al. (2012), Rinehart et al. (2014) and Wright and Gregory (2014) [Green[a]—good; yellow[b]—fair; blue[c]—missing data, "--"—data not collected].

Site and year	Date	Water Clarity	Chloro-phyll *a* (µg/L)	DO (mg/L)	TDN (mg/L)	DIN (mg/L)	TDP (mg/L)	DIP (mg/L)
2011 CALO 02	January 7	--	2.26[a]	10.0[a]	0.41	--	0.018	--
	February 9	--	1.32[a]	11.4[a]	0.25	--	0.014	--
	March 4	--	0.61[a]	9.3[a]	0.29	--	0.058	--
	April 6	--	1.34[a]	9.7[a]	0.28	--	0.022	--
	May 5	--	1.48[a]	8.9[a]	0.28	--	0.02	--
	June 2	--	1.84[a]	7.8[a]	0.29	--	0.023	--
	June 27	--	2.29[a]	6.2[a]	--	--	--	--
	July	--	c	c	c	c	c	c
	August 9	--	c	5.6[a]	c	c	c	c
	August 31	--	c	6.5[a]	c	c	c	c
	September 28	--	c	7.1[a]	c	c	c	c
	October	--	c	8.6[a]	c	c	c	c
	November 7	--	c	c	c	c	c	c
	December 5	1.4[a]	c	10.0[a]	c	c	c	c
2012 CALO 01	January 6	0.67[a]	c	8.9[a]	c	c	c	c
	February 3	2.00[b]	c	8.6[a]	c	c	c	c
	March 2	0.74[a]	c	8.2[a]	c	c	c	c
	April 3	1.40[e]	c	c	c	c	c	c
	May 3	0.56[a]	c	8.3[a]	c	c	c	c

[d] Light attenuation coefficients (k) were used to assess water clarity conditions according to criteria categories in Smith et al. (2006).

[e] Secchi disk hit bottom—value estimated or not calculated.

Table 28 (continued). Monthly water quality data collected by the network in and near CALO during 2010, 2011, and 2012 to augment the continuous monitoring information. Data collected in CALO at CALO01, northwestern Shackleford Banks and at CALO02, Middle Marsh. Water clarity was assessed by light attenuation values (*k*), using a constant for estuarine water with naturally turbid conditions (Smith et al. 2006). Assessment categories followed those shown in Table 24a from EPA (2008b, 2012a). Modified from Dingle et al. (2012), Rinehart et al. (2014) and Wright and Gregory (2014) [Green[a]—good; yellow[b]—fair; blue[c]—missing data, "--"—data not collected].

Site and year	Date	Water Clarity	Chlorophyll *a* (µg/L)	DO (mg/L)	TDN (mg/L)	DIN (mg/L)	TDP (mg/L)	DIP (mg/L)
2012 CALO 01 (continued)	June 5	1.40[a]	3.28[a]	6.8[a]	0.25	--	0.018	--
	July 3	0.80[a]	3.80[a]	7.0[a]	0.18	--	0.013	--
	August 3	0.70[a]	2.40[a]	5.9[a]	0.16	0.008	0.010	0.002
	August 30	0.88[a]	4.09[a]	6.7[a]	0.19	--	0.106	--
	October 2	1.12 [a]	6.13[b]	7.6[a]	0.19	--	0.014	--
	November 5	0.80 [a]	1.40[a]	8.6[a]	0.31	0.004	0.017	0.004
	December 5	0.62 [a]	2.07[a]	9.3[a]	0.17	--	0.015	--
2012 CALO 02	January 6	1.40[a,e]	[c]	9.2[a]	[c]	[c]	[c]	[c]
	February 3	1.40[a]	[c]	10.7[a]	[c]	[c]	[c]	[c]
	March 2	[c,e]	[c]	7.3[a]	[c]	[c]	[c]	[c]
	April 3	0.56[a,e]	[c]	7.3[a]	[c]	[c]	[c]	[c]
	May 3	1.40[a,e]	[c]	6.9[a]	[c]	[c]	[c]	[c]
	June 5	1.12[a]	2.71[a]	6.7[a]	0.21	--	0.014	--
	July 3	1.40[a,e]	2.75[a]	7.3[a]	0.26	--	0.019	--
	August 3	1.27[a]	1.93[a]	6.6[a]	0.16	0.015	0.013	0.002
	August 30	1.40[a]	3.81[a]	5.8[a]	0.19	--	0.014	--
	October 2	[e]	2.91[a]	5.9[a]	0.28	--	0.016	--
	November 5	1.40[a,e]	1.01[a]	8.9[a]	0.20	0.004	0.014	0.018[b]
	December 5	[e]	0.91[a]	8.7[a]	0.26	--	0.015	--

[d] Light attenuation coefficients (k) were used to assess water clarity conditions according to criteria categories in Smith et al. (2006).

[e] Secchi disk hit bottom—value estimated or not calculated.

Water Quality at Stations Within 8 kilometers (5 mi) of Cape Lookout (2000–2014

We also summarized available water quality data (all in STORET) from stations within eight kilometers (five mi) of Cape Lookout over the period from 2000 to 2014. The STORET data considered here were georeferenced and checked by each individual entry for quality control/assurance. The analysis for the sound side of Cape Lookout included 13 NPS stations, nine from the North Carolina Recreational Water Quality Program (NCRWQP, of NCDENR) stations (*Enterococcus* only), and seven EPA Estuarine Monitoring and Assessment Program (EMAP) stations, 29 stations in all (Parman et al. 2012) (Figure 47). By general location from north to south on the sound side, the stations included two NPS and two EMAP stations in Pamlico Sound waters of Cape Lookout; six NPS stations, five EMAP stations, and two NCRWQP stations in Core Sound waters of the seashore; and five NPS and four NCRWQP stations in Core Sound waters. With exception of the NCRWQP, stations were only sampled on one date.

Figure 47. Map showing the locations of the 14 NPS stations, 9 NCRWQP stations, and 6 EPA EMAP stations with available water quality data summarized from 2000–2014. S. Flood, NCSU CAAE.

The sound side stations throughout Cape Lookout had fair conditions for DIP, but generally good conditions for DO, chlorophyll *a*, and DIN (Appendix B). For the ocean side of Cape Lookout, the only data available were from 3 NCRWQP stations at Cape Lookout in the Lookout Bight vicinity (*Enterococcus* only; N = 172–363 samples per station). Only 2% (18) of the total 847 samples exceeded the state criterion of 104 CFU/100 mL.

Sources of Pollutants Linked to Water Quality Degradation

Cape Lookout is somewhat isolated from mainland runoff sources of water pollution other than atmospheric nonpoint sources, although the sounds that mostly distance the seashore from the mainland are narrow in comparison to the wide expanse of Pamlico Sound adjacent to Cape Hatteras National Seashore (Figures 1 and 2).

Cape Lookout entirely relies on septic tanks for waste treatment and receives more than 600,000 visitors per year, the majority during warmer months. The seashore maintains 55 septic systems, most of which are on Core Banks and are maintained in good condition (NPS 2014a). The septic system for the Administration Visitor Center and housing area on Harkers Island, however, was evaluated to be in poor condition, and park staff have submitted a funding request to connect to a sewer system in 2014–2015 (NPS 2014a).

Despite the fact that the seashore septic systems are in good condition, the sandy soils and shallow fresh groundwater table are characteristics that frequently lead to groundwater contamination because the soils simply do not hold and treat the wastes sufficiently prior to percolation into the shallow aquifer and nearby surface waters (Mallin and McIver 2012, and references therein). There is little if any information from the past 15 years about effects of septic tanks, the wild horse herd on Shackleford Banks, and other potential pollution sources on the water quality of Cape Lookout. Elsewhere in the Outer Banks, there is substantial information that septic tank leachfields cause increased nutrient and fecal coliform concentrations in shallow surface waters (Mallin and McIver 2012) and downslope groundwater wells (Evans and Houston 2000). The resulting nitrate levels in potable water wells can exceed the NCDENR (2003) drinking water criterion of 10 mg/L (Evans and Houston 2000). The sandy soils, high water tables, and proximity to beach areas are conducive to potentially serious pollution impacts from septic tank leachate on both the environment and public health safety (Mallin and McIver 2012, and references therein). The summer population is about ten-fold higher than that of the winter population, which is important because it is a short distance from Shackleford Banks, and at several sites off eastern Harkers Island. The prevalence of closed areas near urban and more developed areas indicates that population centers are contributing elevated densities of fecal bacteria from various sources such as septic tanks, partially treated sewage, pet wastes and road runoff, and land disturbance (Fletcher et al. 1998, Mallin et al. 2000b, Kirby-Smith and White 2006). Fecal contamination typically co-occurs with nutrient pollution as well. Beaches at the Coast Guard dock, the NPS dock, and Shackleford Banks are routinely monitored for fecal bacteria, and closures have not occurred.

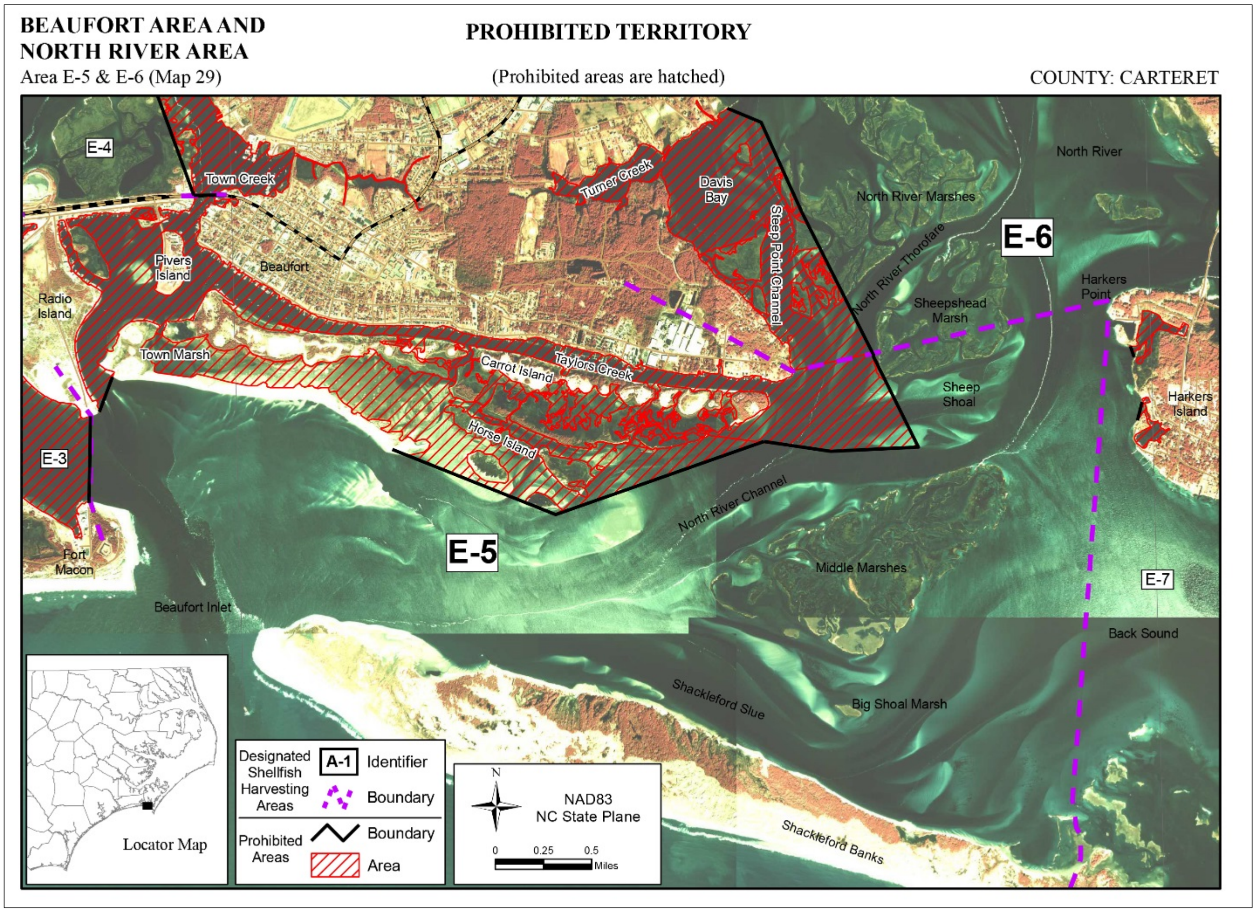

Figure 48. Example of shellfish bed closures on the mainland only a short distance from CALO (here, Shackleford Banks). From Shellfish Sanitation and Recreational Water Quality Section of NCDENR (NCDMF 2016b).

Another, more pervasive and significant source of nonpoint pollution, the airshed from the mainland, also affects CALO waters. There is substantial air quality degradation in the seashore from nitrogen and sulfur emissions and other pollutants. Atmospheric sources of nutrients and other pollutants is a well-known phenomenon affecting coastal waters (Seitzinger and Sanders 1999; Hicks et al. 2000 and references therein). A potential source of these pollutants is industrialized swine and poultry agriculture on the Coastal Plain of North Carolina (Aneja et al. 2000, 2003).

Groundwater

Cape Lookout drinking water supplies for visitors and park operations are supplied from groundwater wells (NPS 2014a). Knowledge of groundwater supplies and quality is critically important to enable sound assessment of the status of water resources in most ecosystems:

> *Long-term, systematic measurements of water levels provide essential data needed to evaluate changes in the resource over time; develop groundwater models and forecast trends; and design, implement, and monitor the effectiveness of groundwater management and protection programs (Taylor and Alley, 2001). Groundwater quality data are necessary to ensure that public water supplies meet health standards;*

deterioration of groundwater quality may be virtually irreversible, and treatment of contaminated groundwater can be expensive (Alley 1993) [in USGS 2008a].

<u>*Groundwater Supplies:*</u>

Winner (1978) characterized the groundwater resources of Cape Lookout, and mapped the most favorable areas for development of fresh groundwater in the park at a scale of 1:24,000, and Wright and Byrne (2012) evaluated data for USGS wells on the mainland near the seashore. The information below is taken from those two sources unless otherwise noted. Barrier islands contain a lens of freshwater floating on seawater beneath the island surface (Leatherman 1988, Mallin et al. 2004). Slacks are areas of low elevation between dunes, likely formed originally by wind blowouts, which are in contact with the water table (Leatherman 1988). Most of the ponds on Cape Lookout National Seashore appear to have this origin (Mallin et al. 2004). High-precipitation periods expand the ponds, whereas droughts reduce them. An exception is Mullet Pond in western Shackleford Banks; this waterbody formerly was part of Back Sound, and was formed by the closing of a former bay or lagoon (Schoenbaum 1982, Leatherman 1988, Mallin et al. 2004). Wells with freshwater are defined as having a chloride (Cl^-) concentration below 250 mg/L, and saltwater influence can cause concentrations of up to 4,000 mg Cl^-/L. Fresh groundwater in Cape Lookout occurs in an unconfined sand aquifer which extends down to the uppermost beds of silt and clay; an upper confined aquifer; and a lower confined aquifer (Winner 1978) (Figures 49 and 50). At a given site, the estimated freshwater yield depends on the position of the saltwater interface. The unconfined aquifer in dune areas can yield up to 114 L (30 gal) per minute of freshwater to a horizontal well. In non-dune areas if not protected by tall dunes (exceeding 3 meters [10 ft], which occur on Shackleford Banks and Cape Lookout), this aquifer sustains periodic overwash from the ocean, which temporarily contaminates the aquifer with seawater. The unconfined aquifer consists of surficial sands of Quaternary age (Mixon and Pilkey 1976), and it can be up to 30.5 meters (100 ft) thick, but usually the uppermost beds of confining silt and/or clay occur at depths of 3–15 meters (10–50 ft).

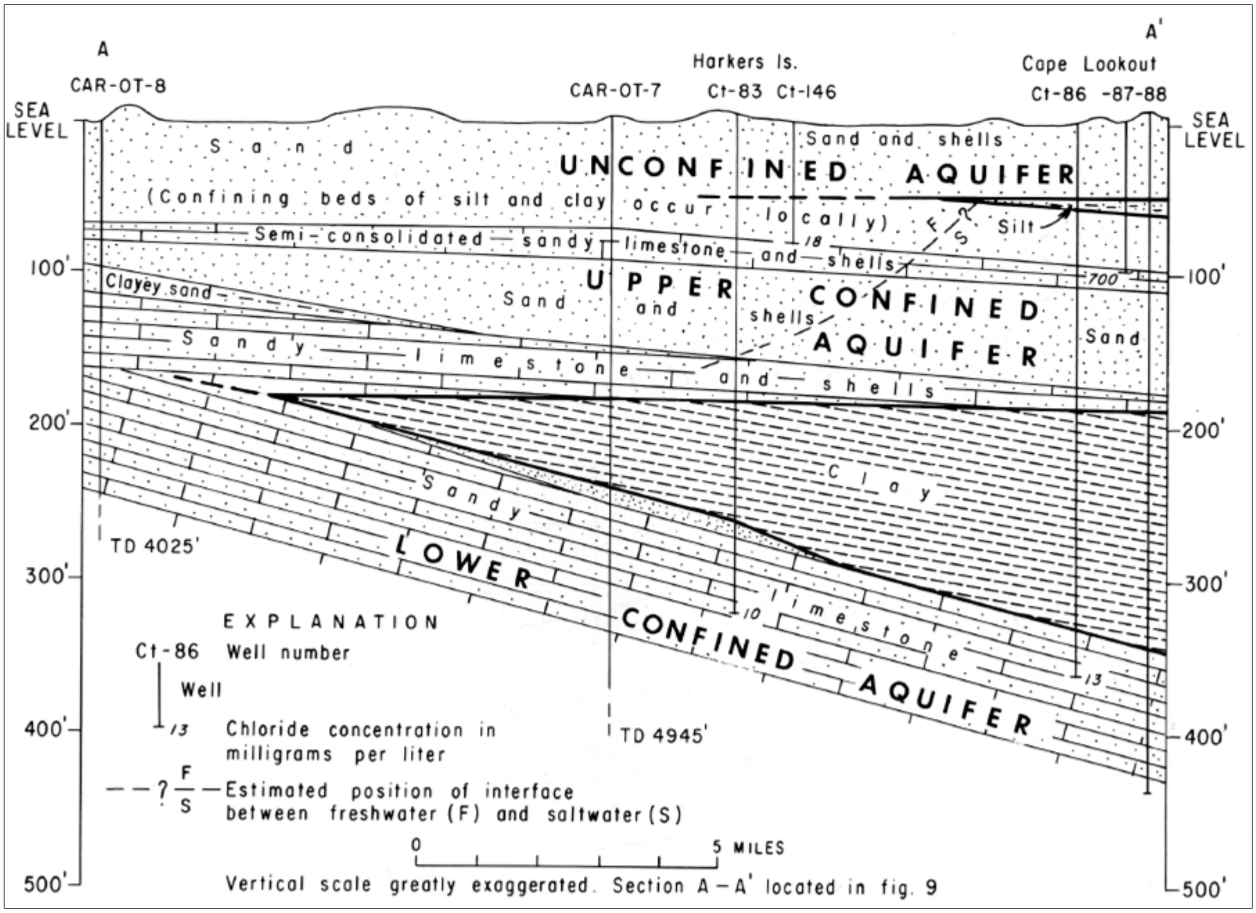

Figure 49. Hydrogeologic section from 8 kilometers (5 mi) northwest of Morehead City to Cape Lookout. From Winner (1978).

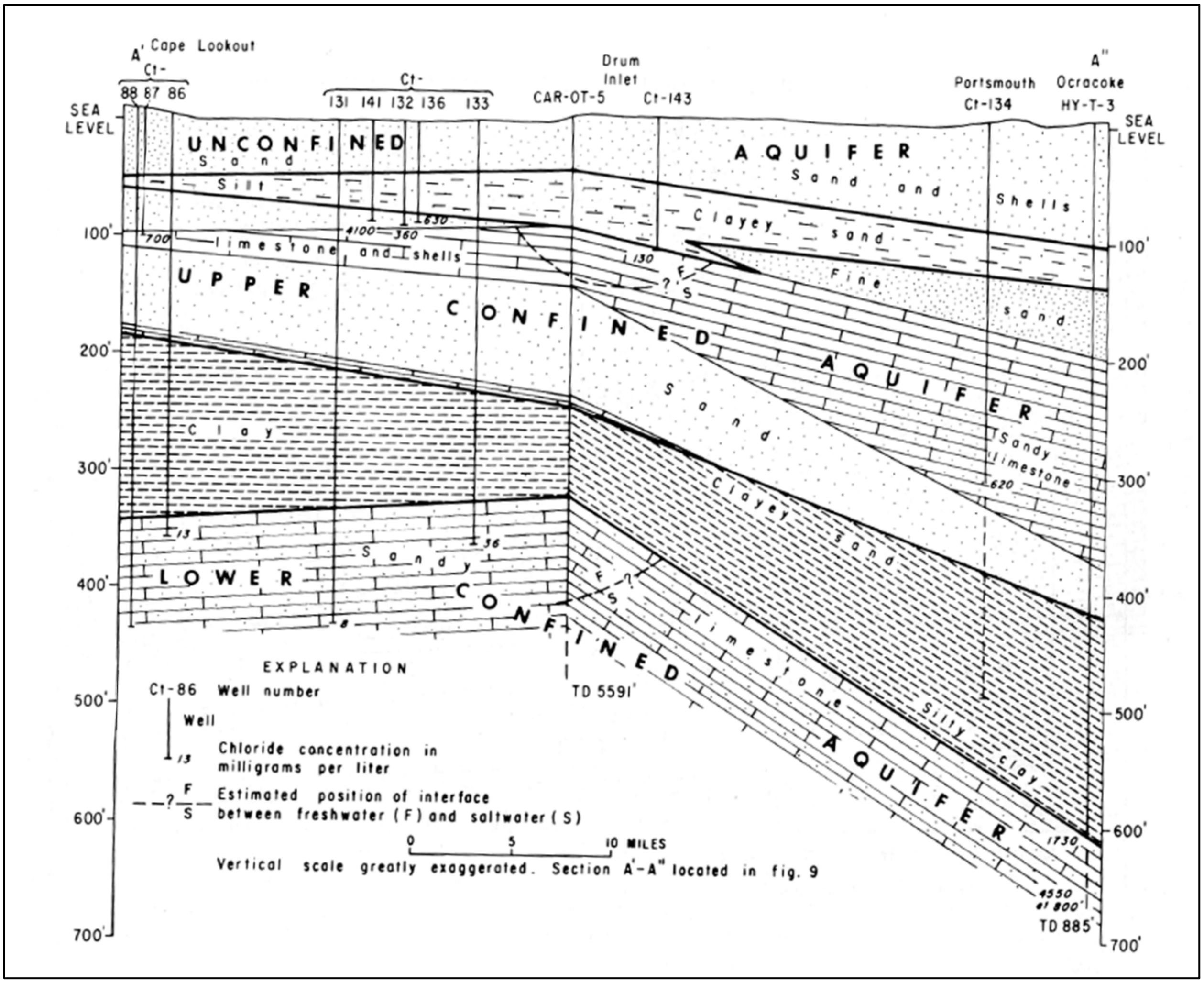

Figure 50. Hydrogeologic section from Cape Lookout to Ocracoke. From Winner (1978).

The confined aquifers consist of sand, loosely cemented shell beds, and sandy limestone. Two of them contain freshwater on Cape Lookout: The upper confined aquifer (depths 27.4–45.7 meters [90–150 ft]) has freshwater only in the Drum Inlet area and in the vicinity of Harkers Island. The potential yield is likely low, only 38–57 L (10–15 gal) per minute. The lower confined aquifer (depths > 45.7 to 168 meters [> 150 to 550 ft]) contains freshwater south of Drum Inlet, and its yield is estimated to be as high as 1,893 L (500 gallons) per minute per well. This massive aquifer is more than 61 meters (200 ft) thick and consists of medium- to coarse-grained limestone of Oligocene age. It is 104 meters (340 ft) below MSL at Cape Lookout. The beds of clay, silty clay, and clayey sand that overlie and confine it coincide with the Pungo River Formation of the early-middle Miocene. Precipitation is entirely responsible for the occurrence and maintenance of fresh groundwater in the unconfined aquifer. Rain seeps into this aquifer with minimal surface runoff. The freshwater moves downward and away from the central part of the barrier islands toward discharge points in the ocean and sound. The major limiting factor in development of freshwater supplies from the unconfined aquifer is storm overwash of the ocean. After an overwash event, it requires weeks to months to flush the saltwater from the aquifer and restore the freshwater lens.

A total of seven water supply wells and one onsite monitoring well (at the Hunt Club site) are located in Cape Lookout NS (Rasmussen et al. 2009). The screened zone, well depth, and depth to water at the monitoring well are unknown. Well water is presently drawn from 27.4 meters (90 ft) down for use at the Core Banks fish camps and park facilities (Mallin et al. 2004). Service use of the groundwater is not expected to increase, and shortages are not likely to become an issue. Surface waters on Shackleford Banks are not used for human consumption, and there are no groundwater withdrawals there except for two non-potable wells used for washing (Mallin et al. 2004). Annual water consumption at Cape Lookout ranged from 1,287,000 L to 1,514,000 L/year (0.34 to 0.40 million gallons/year) in 2008–2012 (NPS Annual Energy Report, as described in NPS 2014e). In 2012 (most recent year of available data), water consumption was 5% lower than the four-year average for 2008–2011.

In contrast, on the adjacent mainland, groundwater use was examined in wells near the seashore by considering changes in depth to groundwater over time (Wright and Byrne 2012). Four wells near Cape Lookout were included in that analysis (Table 29, Figure 51), but only one of them had a long period of record (more than 10 years) with at least 12 measurements per year (well #354418076463601 in Figure 51). The groundwater level in that well has significantly decreased over the period considered in trend analysis (1986 through 2010) (Figure 52).

Table 29. Mainland SECN wells closest to CALO (note: the datum for all wells is NGVD29), also including significant trends in groundwater level through 2010 for the one well with more than 10 years of data and at least 12 observations per year. From (Wright 2012a) and Wright and Byrne (2012).

Well Number (USGS)	Description	Aquifer	Significant Trend in Groundwater Level
354418076463601	WS-100 (NC-158) near Hoke, N.C. (latitude 35.73889, longitude -76.77538; well depth 4.6 meters (15 ft); 12/17/1986 to 12/31/2011; 8,571 observations)	Surficial	Negative ($P < 0.01$)
353747077052001	BO-419 Rsk near Washington, N.C. (latitude 35.6297, longitude -77.08889; well depth 25 meters (82 ft); 8/14/2003 to 7/08/2011; 20 observations)	Castle Hayne	----
352545077012601	BO-438 LU-14A (latitude 35.42917, longitude -77.02389; well depth 8.5 meters (28 ft); 7/3/2007 to 7/7/2011; 6 observations)	Surficial	----
351019077184102	CR-543 Cove City RS 2 (latitude 35.17194, longitude -77.31139; well depth 29.9 meters (98 ft); 3/13/1985 to 5/26/2011; 33 observations)	Castle Hayne	----

Figure 51. Locations of the four mainland USGS monitoring wells with most relevance to CALO. From Wright and Byrne (2012).

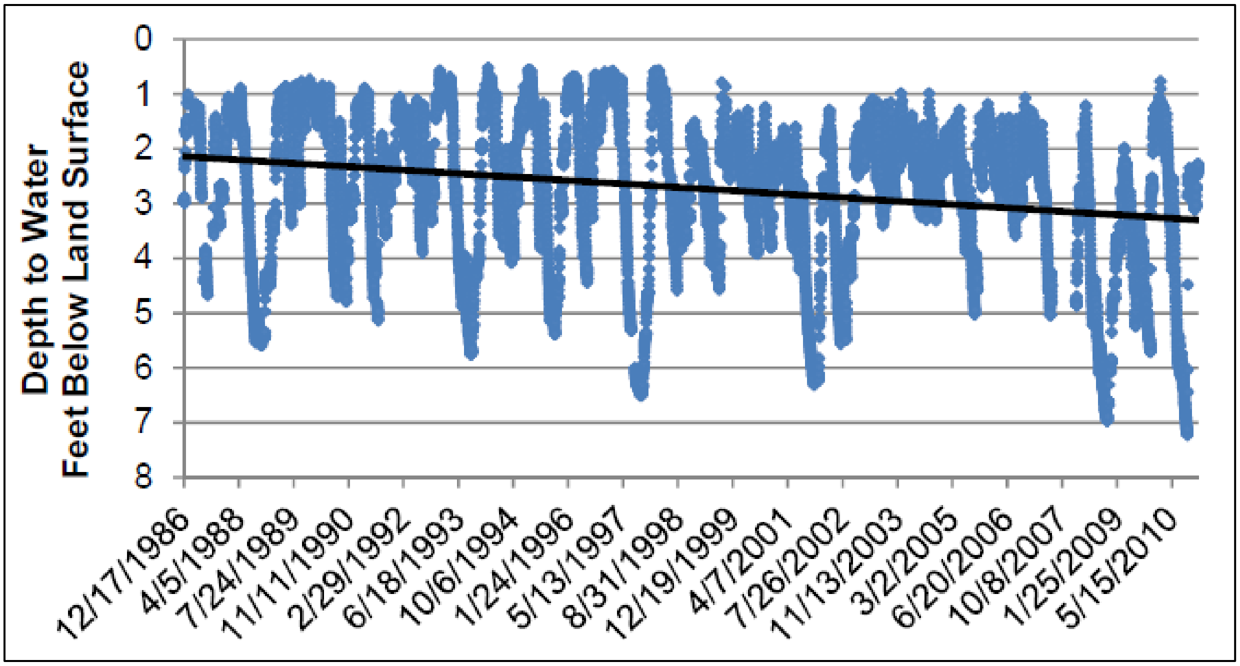

Figure 52. Depth to groundwater over time (well #354418076463601 in Figure 51 and Table 29) from December 1986 through mid-May 2010, indicating a significant decrease. From Wright and Byrne (2012).

Groundwater Quality

Well before the 1970s, bacterial pollution was a frequent water quality problem in CALO wells (Winner 1978). Shallow wells in the unconfined aquifer were especially susceptible to pollution sources. At some campsites, the discharge ends of sewage pipes were at the ground surface only 1 meter from water supply wells. That situation has been corrected, but the highly porous soils make the aquifers vulnerable to contamination from pollution sources such as fecal matter from the wild horse herd on Shackleford Banks.

In general, the unconfined aquifer has < 120 mg/L total hardness and < 200 mg/L dissolved solids, but the water can sometimes have elevated iron and chloride, and it can be darkly colored if taken from wells in marshy areas (Winner 1978). The upper confined aquifer can have total hardness exceeding 200 mg/L, and it can also contain excessive iron and manganese.

A water quality survey of eight well water sites was completed in December 1998–June 2001 (Mallin et al. 2004) (Table 30). The EPA drinking water standard for nitrate-N (< 10 mg/L to prevent methemoglobinemia) was exceeded in the Great Island well #2 (GI-2), and was approached in GI-I and Portsmouth Village well #1 (PV-1). High concentrations of ammonium-N and total phosphorus were also found in GI-2 and PV-1, comparable to levels that were reported for wells located near barrier island experimental septic systems with drain fields 30 centimeters (12 in) from the water table, and characterized by saturated and anoxic conditions (Cogger et al. 1988). Under drier conditions the drain fields were well above the water table and oxygenated, wherein nitrate concentrations higher than 10 mg/L were detected up to 3 meters (9.8 ft) from drain field trenches. These two wells likely were contaminated by septic system leachate (Mallin et al. 2004). The other seashore wells tested had better water quality

Table 30. Well water quality at Cape Lookout, December 1998–June 2001 (N = 10 dates/site). Adapted from Mallin et al. (2004) [GI—Great Island; KQ—Keeper's Quarters; SCB—South Core Banks; DY—David Yeoman; LG—Long Cabin; PV— Portsmouth Village; LP—Long Point.

Well	Statistic	Salinity	Fecal Coliform (CFU/100 mL)*	Nitrate (mg N/L)	Ammonium (mg N/L)	TN (mg N/L)	TP (mg P/L)
Great Island-1	mean (sd)	0.4 (0.5)	1	0.74 (2.23)	0.18 (0.26)	3.14 (4.54)	0.40 (0.67)
	range	0.0–1.4	1–1	0.01–7.10	0.05–0.82	0.25–14.10	0.04–1.70
	median	0.2		0.05	0.05	0.94	0.06
Great Island-2	mean (sd)	0.9 (0.7)	1	1.3 (3.44)	4.05 (7.00)	9.13 (9.49)	2.02 (4.65)
	range	0.1–2.0	1–36	0.01–11.00	0.05–21.40	1.19–25.51	0.02–15.00
	median	0.6		0.05	0.75	5.35	0.07
Keeper's Quarters	mean (sd)	0.1 (0.1)	1	0.30 (0.79)	0.11 (0.13)	1.37 (1.51)	0.55 (0.65)
	range	0.0–0.3	1–45	0.01–1.90	0.05–1.41	0.18–4.70	0.03–2.86
	median	0.1		0.05	0.05	0.50	0.05
South Core Banks David Yeoman	mean (sd)	0.3 (0.4)	2	0.23 (0.59)	0.20 (0.43)	1.39 (1.48)	0.49 (0.76)
	range	0.0–0.7	1–145	0.01–1.90	0.05–1.41	0.25–5.10	0.03–2.12
	median	0.3		0.05	0.05	0.80	0.13
South Core Banks Long Cabin	mean (sd)	4.2 (1.5)	1	0.27 (0.68)	0.32 (0.42)	1.56 (1.80)	0.51 (0.59)
	range	1.7–6.6	1–5	0.01–2.20	0.05–1.43	0.25–6.20	0.05–1.88
	median	4		0.05	0.17	0.89	0.3
Portsmouth Village-1	mean (sd)	5.3 (4.0)	3	1.06 (2.31)	1.73 (2.34)	4.02 (3.12)	1.36 (1.29)
	range	1.2–14.9	1–478	0.01–7.00	0.2–7.89	0.50–9.75	0.05–3.63
	median	4.8		0.05	0.82	2.93	0.97
Long Point-1	mean (sd)	0.4 (0.3)	1	0.30 (0.74)	0.14 (0.14)	1.63 (2.66)	0.34 (0.52)
	range	0.0–0.9	1–52	0.01–2.40	0.05–0.46	0.25–9.10	0.04–1.72
	median	0.3		0.05	0.05	0.69	0.12
Long Point-2	mean (sd)	1.4 (2.0)	2	0.04 (0.02)	0.13 (0.18)	0.82 (0.59)	0.98 (1.31)
	range	0.1–5.4	1–190	0.01–0.06	0.05–0.62	0.25–2.10	0.05–3.86
	median	0.5		0.05	0.05	0.54	0.31

* data for fecal coliform bacteria are given as the GM / range.

The high PAH, arsenic, and mercury concentrations that have been found in fish from Core Banks (Table 26c) may reflect contamination from an aboveground storage tank (AST), incinerator, and refueling pad on the island (Mallin et al. 2004). One area with locally contaminated soils and groundwater is the Gun Club site on South Core Banks, where ASTs formerly occurred. In Portsmouth Village, three ASTs formerly occurred in an area behind the U.S. Coast Guard Maintenance Building. The soil and groundwater in that localized area were extensively contaminated with petroleum hydrocarbons. In addition, an incinerator site had groundwater with excessive arsenic, chromium, and lead (Bhate Environmental Associates 2004; Mallin et al. 2004). Mallin et al. (2004) pointed out that, despite the fish tissue data for fish from Core Sound, comparison of multiple condition indicators for fish collected from those waters versus the eutrophic lower Neuse River Estuary led to evaluation of fish from Core Sound as much healthier (Adams et al. 2003). It should also be noted, however, that there are statewide consumption advisories on fish due to high mercury content (NC DHHS 2015).

Biologic Inventory

Cape Lookout lies within one of the most biodiverse marine coastal regions along the Eastern Seaboard, just south of the major mixing area where the southernmost edge of the colder, north temperate Virginia marine biogeographical province (sometimes referred to as the Northeast U.S. Continental Shelf large marine ecosystem) meets the northernmost edge of the warmer, south temperate Carolinian marine biogeographical province (or the Southeast U.S. Continental Shelf LME) (Ray 1996; Fautin et al. 2010) (Figure 53). In the Cape Hatteras/Diamond Shoals area, the cold waters of the Labrador Current meet the warm waters of the Gulf Stream (Figure 29). The Cape Point (Hatteras Island)/Diamond Shoals system separates not only two major ocean currents, but also two major biological regimes—cold water biota from the Labrador Current mixing with warm water biota from the tropical Gulfstream. The fact that Cape Lookout is favorably affected by this mixing area is demonstrated by the high species richness of fish fauna (294 species).

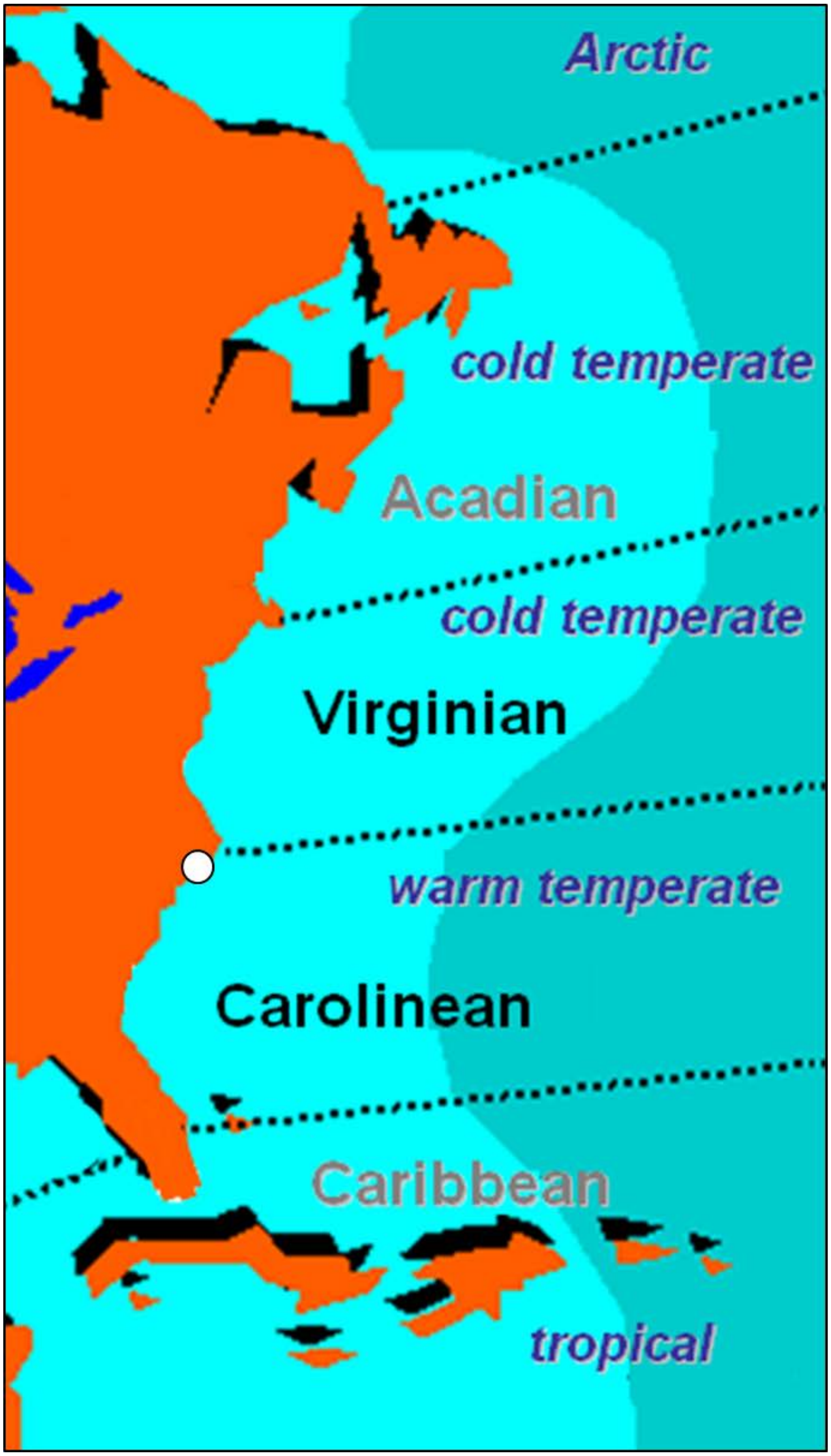

Figure 53. Map showing the locations of the Virginian and Carolinian marine biogeographic provinces (white dot—location of CALO). Modified from PIE LTER (undated).

While there have been many studies of the geology of the Outer Banks including the seashore area, at present the biota at this seashore are mostly known through species lists that represent a compilation of vouchered and non-vouchered observations, some 20–30 years old or more (NPS 2013c, Appendix C). Few ecological studies are available from the past 15 years. The major exception to that statement is a concerted effort to track the status of a selected group of species of special concern (SSCs, threatened or endangered species including the vascular plant sea beach amaranth, sea turtles, and selected species of colonial shorebirds, and one species of special management concern (SSMC), wild horses. Seashore staff began to track the status of selected SSCs in the 1980s (NPS 2013e). Each year park staff complete a detailed annual report on each of these species or species groups. The seashore is a haven for species of special concern (SSCs); a total of 82 SSCs including 13 vascular plants, four fish, two amphibians, 11 reptiles, and 52 birds are reported to occur in this park (NPSpecies—NPS 2013c). On the other hand, 73 exotic/invasive species have also been reported in Cape Lookout, including 42 vascular plants, six birds, and eight mammals.

Cape Lookout has been the focus of extensive scientific explorations over the past 50 years, which have yielded various species lists (e.g., see NPS 1977, Webster 2010 and references therein). The Southeast Coast Network has expended considerable effort over the past 15 years to provide updated surveys and ecological assessments of the biological resources of Cape Lookout. In 2003 the Southeast Coast Network funded a project by Webster (2010) to survey Cape Lookout for mammalian fauna. In 2010 the Southeast Coast Network also began to characterize the vegetation, amphibians and birds of the seashore (Byrne et al. 2011a,b). In 2007 a survey of the available data for marine coastal benthic macroinvertebrates in and near the seashore was conducted (Hymel 2009), followed by a survey of estuarine/marine macroinvertebrates in the park in 2010 (DeVivo and Gregory 2012). Collectively, these efforts represent significant progress within the past decade to characterize the species of seashore biota under present-day ecological conditions.

The various ecosystems in Cape Lookout include beaches, berms, tidal flats, dunes, open grasslands, closed grasslands, high saltmarshes, low saltmarshes, woodlands (shrub thickets, maritime forests), and shallow marine waters with submersed (subtidal) seagrasses. A few freshwater wetlands and ponds also occur; moreover, the (fresh) water table is close to the surface and readily accessible (Figure 54). The species lists suggest rich diversity of both flora and fauna (especially reptiles and birds), in Cape Lookout: Thus far a total of 1,234 taxa have been reported to occur there (Appendix 3), including 600 vascular plant taxa and at least 634 animal taxa (incomplete list of fauna, considering only vertebrates—fish, amphibians, reptiles, birds, and terrestrial, freshwater, and wetlands mammals). Dated surveys conducted in 1994–1997 indicated that at least 83 macroinvertebrate taxa occur in or near Cape Lookout (Hymel 2009), and an additional 21 marine mammals apparently occur there, at least occasionally, based on strandings data (Outer Banks Marine Mammals Stranding Network 2014).

Regarding species extirpated from Cape Lookout, mountain lions (*Puma concolor*) apparently are no longer in the region although reports of them continue to persist. Hispid cotton rats (*Sigmodon hispidus*) also apparently have been eliminated from the seashore (Webster 2010). Red wolves (*Canis lupus rufus*) have not been reported at the seashore. The U.S. Fish and Wildlife Service, together with the North Carolina Wildlife Resources Commission, recently attempted to re-establish red wolves in the region (Red Wolf Recovery Program—see USFWS RWRP 2015b). Four species of domesticated livestock (feral pig—*Sus scrofa*, European mouflon sheep—*Ovis orientalis orientalis*, goat—*Capra aegagrus hircus*, and domestic cattle—*Bos primigenius*) were brought to the park area by European settlers and have been removed (Webster 2010). The Virginia opossum (*Didelphis virginiana*) also apparently has been extirpated from the park within the past 30 years (Webster 2010). The American black bear (*Ursus americanus*), although included in the NPS Certified Species List (NPS 2013c), has not been confirmed within the past 15 years as a permanent resident of Cape Lookout (Webster 2010).

Vascular Flora

> *Vegetation communities provide many ecosystem services. Among their many functions, they are an important component of food webs and wildlife habitat for many species, serve as a carbon sink, produce oxygen, cycle nutrients and energy through an ecosystem, influence the local climate, improve water quality, and moderate flooding and erosion. Plant communities also respond to multiple stressors such as changes in air quality, hydrology, disturbance regimes, and climate. Determining trends in vegetation communities is vital to understanding the ecological processes occurring at a site, and identifying stressors and their impacts.*
>
> *—Byrne et al. (2012)*

Vegetation also imparts the stability, minimal though it might be, that exists on the barrier islands of Cape Lookout. The extensive root systems of maritime grasses help stabilize and trap sediments, so that dunes build naturally and the topography eventually is elevated high enough to support other species (NPS 1982).

Among the most fundamentally important datasets for vascular plants in Cape Lookout, as in any SECN park unit, is a valid, up-to-date species list supported by voucher specimens. Voucher specimens provide a way for researchers to verify the identities of plants encountered or used in a previous study, and to ensure the accuracy, consistency, and repeatability of the work (Carter et al. 2007, Reynolds and McDiarmid 2012). There have been no comprehensive, vouchered studies of the vascular plant vegetation of Cape Lookout published over the past 15 years[1]. Thus, the NPS Certified Species List of vascular vegetation (NPS 2013c) is based largely on older studies (e.g., Lewis 1917; Au 1974; Snow and Godfrey 1978), some of which were vouchered while others were not.

The nomenclature and taxonomy of the NPS Certified Species List (NPS 2013c) relied upon the Integrated Taxonomic Information System (ITIS 2016). We emphasized the NPS certified species list but updated the taxonomy using the USDA PLANTS Database (also called the PLANTS database or

[1] A vegetation inventory project was completed for Cape Lookout, and is currently in review (as of April 2017). The data will be available on the National Park Service Vegetation Mapping Inventory Program website (http://science.nature.nps.gov/im/inventory/veg/mapviewer/mapviewer.html) when it is approved.

national plants database) of the USDA's Natural Resources Conservation Service (USDA NRCS 2015). Toward the goal of making it easier for the Southeast Coast Network to track taxonomic changes and supporting rationale, we detailed all differences between the NPS Certified Species List and our species lists of terrestrial, wetland, and aquatic vegetation using an extensive list of footnotes (see Appendix 3—Tables A3-1 through A3-4). Our determination of terrestrial versus wetland status was made following Godfrey and Wooten (1979, 1981), the USDA Plants Database (also called the PLANTS Database or National Plants Database) of USDA's Natural Resources Conservation Service (NRCS 2015), and The National Wetland Plant List (Lichvar 2013; USACE 2015a).

Based on this modified NPS Certified Species List (largely taken from NPS 2013c, which includes angiosperms, gymnosperms and allies, and pterophytans [ferns] and allies—augmented with information from recent surveys, described below), as of 2013 a total of 600 taxa (570 species) of vascular plants were reported to occur in Cape Lookout, including at least 238 terrestrial taxa (232 species), 355 wetland taxa (338 species), and 7 aquatic taxa (7 species) (Appendix C—Tables C-1 through C-8). These floras represent 39.7%, 59.2%, and 1.1% of the total taxa, respectively. Although some bryophyte taxa (mosses and liverworts) have been reported in various previous studies at the genus or species level (see below), bryophytes were excluded from this tally because they have not been added to the NPS Certified Species List (NPS 2013c).

Most of Cape Lookout is open and treeless with typical barrier island zonation including a wide berm, low dunes, grasslands, shrub thickets, and saltmarsh (see below). The northern end of Portsmouth Island differs, however, in having expanses of tidal sand flats (averaging 0.8 kilometers [0.5 mi] in width) located between the berm and the dunes of a series of marsh-fringed islands. In addition, continuous dunes similar to those on Shackleford Banks occur on the southwest side of triangular Cape Lookout, and several small freshwater marshes have developed in depressions between the dunes. The high dunes have substantially reduced over wash, and shrub thickets have further stabilized the flats of the Cape interior. Otherwise, the vegetation of the seashore forms typical, distinctive ecological zones across the barrier islands (Snow and Godfrey 1978) (Figure 54), and the plant communities provide the habitat for a rich diversity of fauna.

The following description of the vegetation communities of these ecological zones was largely taken from Godfrey and Godfrey (1976), and from accounts of similar communities at Cape Hatteras National Seashore (NPS 2015k), including updated modifications in species taxonomy where necessary.

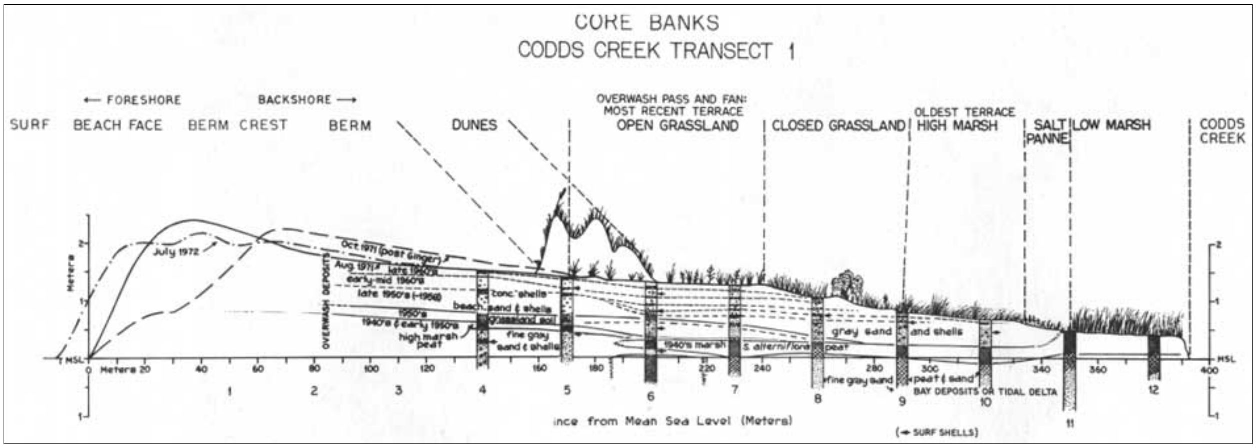

Figure 54. Diagrammatic cross-section of ecosystem zonation on Core Banks in CALO (Codds Creek area) in relation to elevation and distance from the beach (the ocean is at the left, tidal creek flowing into Core Sound is at the right). The vegetation is closely related to the ages of overwash terraces and the frequency of overwash. Species indicated within each zone represent the most important members of that community and the relative positions along this cross-transect (one meter in width across the island; NPS 1982).

Beach, Berm, Tidal Flats, and Dune Plant Communities:

Beaches are generally devoid of primary producers (photosynthetic vegetation) except for algae; berms are created by a few plant species (especially sea oats [*Uniola paniculata*] growing in the driftline) which can help build small dunes. Tidal flats are intertidal areas that typically occur at inlets, supporting stands of saltmarsh cordgrass (*Spartina alterniflora*) (NPS 1982). Low, scattered dunes formed by sea oats occur in overwash-influenced areas, whereas higher dune fields with dense vegetation occur on the back side (NPS 1982).

Intertidal sand beaches are the most rapidly changing, semi-terrestrial habitat (Godfrey and Godfrey 1976, and references therein). The primary producers in all but the upper beaches are suspended (in the water column) and interstitial/epipsammic (among sand grains) microalgae and, subtidally, macroalgae. On the upper beaches rooted vegetation covers 20% or less of the area. The beach fauna include burrowing organisms such as coquina (*Donax* spp.), mole crabs (*Emerita* spp.), interstitial amphipods and isopods, and feeding shorebirds (Godfrey and Godfrey 1976). Berm environments are largely controlled by storm frequency, and are only slightly more stable than beaches. Shorebirds commonly nest on berms, and fauna such as ghost crabs (*Ocypode quadrata*) scavenge.

Rooted vegetative cover on the upper beaches and dunes varies depending on the degree of exposure to waves and winds, and the plant species generally are well adapted to harsh conditions. Annuals such as American searocket (*Cakile edentula* ssp. *edentula*), Russian thistle (*Salsola kali*), seaside spurge (*Euphorbia polygonifolia*), and seaside knotweed (*Polygonum glaucum*), and the perennial beachgrass, seaoats, commonly germinate from seeds in drift lines washed up during winter storms (Godfrey and Godfrey 1976). Vegetative cover on dune slopes ranges from sparse to dense (30–80% cover) patches of easily recognizable species, including seaoats, shore little bluestem (*Schizachyrium littorale*), saltmeadow cordgrass (*Spartina patens*), largeleaf pennywort (*Hydrocotyle bonariensis*) and firewheel (*Gaillardia pulchella*), lanceleaf greenbrier (*Smilax smallii*), and prickly pear cactus (*Opuntia pusilla*).

Dune strands initiate on the berm where seedlings of sea oats, the most important dune-building plant species, together with saltmeadow cordgrass, American searocket, and others take hold in drift lines or other areas. Sea oats usually requires burial and stratification to germinate (Wagner 1964). The drift with seeds acts as the first barrier to sand movement, so that small dunes form as sand is blown off the beach, berm, and overwash terraces. By the second year, the dunes grow as the sea oats trap more sand and grow up through it. The major stresses to plant growth are moving sand and salt spray; other stressors can include drought, temperature fluctuations, and a depauperate nutrient regime (Oosting 1954).

Natural dune-strand plant communities can develop on the berm, on overwash terraces, and/or on old inlet shoals wherever sand is blown. The grass is sparse enough that the sand can be moved by the wind, which maintains rounded rather than steep-sided dunes. The rounded shape is advantageous in withstanding the physical abrasions of wind and waves. The rounded dunes tend to migrate over other vegetation, action that imparts dynamic stability to the barrier islands. The natural dunes are scattered in a field rather than a line or solid wall so that storm waves flow among them and dissipate energy gradually, minimizing destructive forces.

The low, open dunes (elevation 1–2 meters [3.3–6.6 ft]) on Core Banks are well back from the beach on old overwash terraces. They form a maze with overwash passes between dunes. This relatively restricted dune zone was is dominated by *Spartina patens*. The vegetation is mostly sparse, and saltmeadow cordgrass co-occurs with species such as sandgrass (*Triplasis purpurea*), Canadian horseweed (*Conyza canadensis* var. *pusilla*), largeleaf pennywort, Walter’s groundcherry (*Physalis walteri*), gulf croton (*Croton punctatus*), seabeach evening primrose (*Oenothera humifusa*), and the exotic/invasive species Indian lovegrass (*Eragrostis pilosa*). Patches of seaoats are also present, and new dunes forming on the berm mostly contain seaoats. This species, rather than saltmarsh cordgrass, is dominant on Cape Lookout and Shackleford Banks.

In contrast, the seaoats-dominated natural dunes on Cape Lookout and Shackleford Banks are oriented across prevailing winds, and the dune system is much more extensive. These dunes grow rapidly, and the plants respond well as long as fresh sand continues to be deposited. Continuous dune lines form on accreting beaches or other deposition areas, or during relatively long periods without major storms. In those intervals the earlier dunes can become stabilized by the beach grasses; other species colonize as more favorable conditions develop, and a classical pattern of salt-spray plant zonation becomes evident (Wells 1939; Oosting and Billings 1942; Boyce 1954). Spray-resistant species such as sea oats, seashore elder (*Iva imbricata*), and American searocket face seaward, whereas the backslope is colonized by less salt spray-tolerant taxa such as little bluestem (*Schizachyrium scoparium* var. *scoparium*), Virginia creeper (*Parthenocissus quinquefolia*), Canadian horseweed, camphorweed (*Heterotheca subaxillaris*), wild bean (*Strophostyles helvola*), and peppervine (*Ampelopsis arborea*). The foredunes lie relatively close to the beach and are continually accruing sand.

Like the Core Banks dunes, the Shackleford foredunes are like a maze, with overwash passes between dunes. Storm tides cause little damage in the dune zone; rather than expending energy on a single dune line, the waves roll through the maze of overwash passes and lose energy within the zone. The dunes have become relatively stabilized by seaoats, and are dominated by that species; in addition, a new rear dune system has become stabilized in the center of the island. Shackleford Banks, dominated by dunes/grasslands, is the most stable land in the seashore. The island faces the prevailing winds so that sand is blown into the dunes, which increases their height and protects the maritime forest at the western end. East of the maritime forest are expanses of salt marsh. Core Banks is fairly uniform with a wide berm, low dunes, grasslands, and extensive salt marshes. It is less stable because it is influenced by overwash, and the prevailing winds blow sand parallel to the beach rather than into the dunes. Extensive shrub thickets occur only near Cape Lookout Point and at Merkle Hammock, the Evergreens, and Portsmouth Village. Guthries Hammock is the only natural maritime forest on Core Banks. The northern portion of Core Banks and Portsmouth Island are mostly tidal flats. At Portsmouth Village the shrub thickets are bordered by salt marsh on the north, and dunefields are expanding eastward onto the adjoining flats.

Maritime Grasslands

Open grasslands are sparsely vegetated by salt meadow cordgrass and pennywort, which grow up through the sand after burial in overwash (NPS 1982). Closed grasslands have greater coverage by salt meadow cordgrass, pennywort, broomsedge, and hairgrass, and they are closer to the water table. Species of rushes also occur in standing water areas (NPS 1982).

In the central, supratidal areas of the barrier islands are four basic types of intergrading terrestrial grasslands—barrier flats, dune strands, dune slacks, and mesic meadows (Godfrey and Godfrey 1976). In general, the dominant species are well-adapted to seawater flooding and salt spray. Barrier flats are extensive overwash terraces with dunes that formed later. For islands oriented across prevailing winds, which characterizes much of Cape Lookout, the dune strand community predominates rather than the barrier flat community. Dune slacks (or interdune slacks), the depressions between dunes, are usually formed by blow-outs when sand is removed down to the water table. Rich floras develop in their relatively mesic conditions. Mesic meadows are neither freshwater marshes nor tidal flats; instead, they are low, flat grasslands that form below the elevation of barrier flat communities, maintained by ocean-related environmental stressor such as salt spray, overwash flooding and burial, moving sand, and groundwater. If the stressors are alleviated, mesic meadows may succeed to woody vegetation.

Barrier flat grasslands, sometimes referred to as an “overwash subclimax,” are controlled by oceanic overwash and salt spray; the land is flooded frequently by the ocean and buried by the sand, so that the plants grow in more harsh conditions than plants on dunes. The barrier flat grassland community predominates on the flat, extensive overwash terraces that characterize low barrier islands. Its elevation is set by the most severe storms of each storm cycle, and this ecosystem persists for long periods—as long as overwash is operative in the area. The grassland begins on the berm backslope between or in front of low, open dunes where there is a balance between wave action/deposition forces and plant colonization. It eventually covers the flats behind the dunes with broad, flat meadows. Storm waters frequently sweep down the berm slope and submerge the grassland, as reflected by numerous drift lines among the vegetation.

Plant species in barrier flat grasslands are mostly grasses, sedges, and a few forbs that can survive overwash burial and the "rolling-over" process involved in barrier island retreat. Toward the berm where flooding and burial are most frequent, the typically open grassland grows on the most recent terraces. The dominant species, although sparse, is usually saltmeadow cordgrass (< 20% cover, and usually < 50 g dry weight per m^2 or 4.65 g per ft^2 [NPS 2015k]) along with scattered annuals such as seaside sandmat (*Chamaesyce polygonifolia*) and American searocket. Near the berm slope, the vegetation is sparser because of regular overwash waves that hold the vegetation in check and prevent the grassland from expanding toward the ocean. Back from the berm zone and in-between the dunes where overwash is less severe, saltmeadow cordgrass is more abundant and co-dominates with seaside goldenrod (*Solidago sempervirens*).

On lower and older terraces (deposited during severe storms of the late 1950s–early 1960s) back from the more recent overwash surfaces, the salt content is low and the water table is closer to the land surface. In these areas, species from maritime grasslands and the high salt marsh mix, and the open grassland grades into a closed community with more dense growth (> 50% cover and up to 1,500 g/m^2 or 139.4 g/ft^2 [NPS 2015k]). Abundant vascular plant taxa include saltmeadow cordgrass, seaside goldenrod, hot springs fimbry (*Fimbristylis thermalis*), hairgrass (*Muhlenbergia capillaris*), sanddune sandbur (*Cenchrus tribuloides*), finger grass (*Eustachys patraea*), firewheel (*Gaillardia pulchella*), cure for all (*Pluchea carolinensis*), sea-pink (*Sabatia stellaris*), Gulf coast swallow-wort (*Cynanchum angustifolium*), saltmarsh morning-glory (*Ipomoea sagittata*), spring lady's tresses (*Spiranthes vernalis*), the exotic/invasive species love-grass (*Eragrostis pilosa*) and Bermuda grass (*Cynodon dactylon*), and others. The high abundance and species diversity suggest that this flat terrain habitat is the most benign of those that sustain occasional seawater flooding. If there is low frequency of overwash and flooding (e.g., as dunes build in the overwash passes), shrub savanna or shrub thickets form with species such as marsh-elder (*Iva frutescens*), small wax-myrtle (*Morella cerifera*), eastern redcedar (*Juniperus virginiana*), and the exotic/invasive species eastern baccharis (*Baccharis halimifolia*). Mosses such as *Trichostomium* sp. and *Barbula convoluta* can form thick carpets on more protected sand flats and interdune sites. Other mosses that may co-occur include *Bryum, Physcomitrium, Funaria, Ephemeium,* and *Tortella*.

Dune slacks are inter-dune (between-dune) areas with lower elevations, sometimes as low as the water table. In these areas, distinctive marsh-like grasslands often develop because the depressions are protected from salt spray and, if back within the dune zone, from overwash. During most of the year, they usually do not have standing water. They tend to be dominated by saltmeadow cordgrass along with hot springs fimbry, bulrush (*Schoenoplectus americanus*), broomsedge bluestem (*Andropogon virginicus*), starrush whitetop (*Rhynchospora colorata*), marsh bristlegrass (*Setaria parviflora*), bighead rush (*Juncus megacephalus*), and often black needle rush (*Juncus roemerianus*). Other common herbaceous plants include largeleaf pennywort, water hyssop (*Bacopa monnieri*), the SSC seaside knotweed, erect dayflower (*Commelina erecta*), Virginia buttonweed (*Diodia virginiana*), sea-pink, turkey tangle frogfruit (*Phyla nodiflora*), narrowleaf evening-primrose

(*Oenthera fruticosa*), and vines such as climbing hempvine (*Mikania scandens*) and Gulf coast swallow-wort.

Mesic meadows, extensive low, moist flats that are close to the water table but not associated with dunes, are usually very old overwash terraces or old tidal deltas that are no longer in the intertidal zone, or they are protected by seaward dunes and have not been overwashed for some time. They frequently occur where islands are relatively wide, such as Guthrie's Hammock on South Core Banks (Figure 2). On the barrier islands they are second only to forests in species diversity, and are especially species-rich in grasses, sedges, and other herbaceous plants. Water can flood the lower areas of mesic meadows especially after heavy precipitation. The species mix includes taxa found in all of the other grassland communities, except for characteristic dune or intertidal marsh plants. The floristic composition is similar to that of dune slack communities, except that the vegetation is much more extensive and species-rich. Species dominance depends on the season—in late summer broomsedge bluestem is most abundant, along with other species inhabiting dune slacks and, additionally, several goldenrods (*Solidago* spp.), southern beeblossom (*Gaura angustifolia*), Canada lettuce (*Lactuca canadensis*), wand lythrum (*Lythrum lineare*), the creeping, exotic/invasive species, spadeleaf (*Centella asiatica*), and grasses such as *Paspalum* spp. and *Panicum* spp. Shrubs such as the exotic species, eastern baccharis invade the flats as well.

Woodland Communities on Higher and Protected Lands

Cape Lookout woodlands generally consist of shrub thickets dominated by wax myrtle, marsh elder, and silvering, yaupon, and live oak; and maritime forests are dominated by live oak, Virginia redcedar, and American holly (NPS 1982).

Woody vegetation can grow only where the land is protected from salt spray, seawater flooding, and moving sand. Woodland communities have developed on the barrier islands in five general locations (Figure 55) (Godfrey and Godfrey 1976). They mostly occur (i) behind barrier dunes where the vegetation is at least somewhat protected. They are also found (ii) along beaches with relatively low wave energy, wherein the forest extends down to the primary dune zone with thicket vegetation acting as the leading edge; (iii) in hammocks, that is, on low barriers well back from the beach without substantial dune building, where they are protected from most storms—but not by major floods—by being on the backside of the island; (iv) in hammocks on islands that may previously have been part of an inlet delta or some other land form, but is now separated from the main barrier by a tidal marsh; and (v) in hammocks on small dunes or dune ridges that are part of the main barrier and separated from each other by freshwater marshes, or on small islands that were once part of a tidal delta but are now connected to the main barrier.

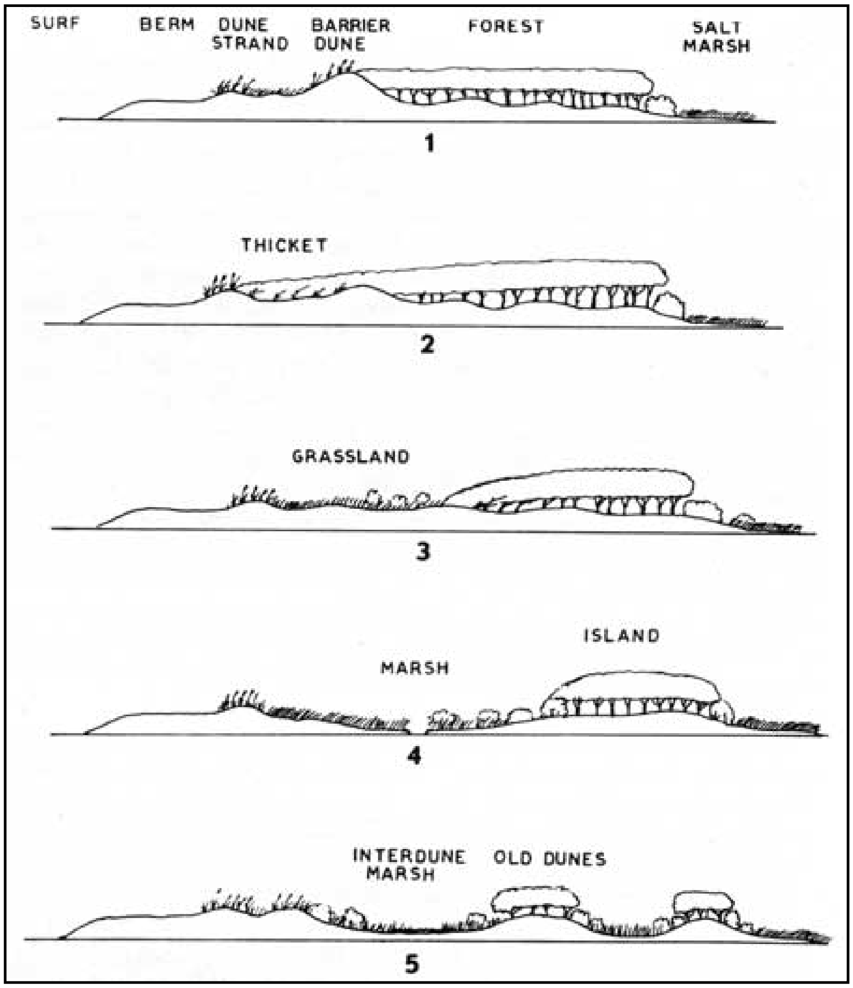

Figure 55. Diagrammatic cross-sections of locations of barrier island woodlands in the Cape Lookout area: (1) Forest growing behind a high barrier dune that may have migrated over some of the trees; (2) Forest with thicket extending out to the first dune line; (3) Forest with a sloping front and a thicket-type of leading edge, separated from the dunes by grassland; (4) Forest on old dunes on the high part of a marsh island, separated from the main island by salt marshes; and (5) Forest on old dune ridges, with interdune freshwater marshes and ponds. From Godfrey and Godfrey (1976).

Shrubland Thickets

Shrub thicket types of woody vegetation are earlier seral stages of woodlands, sometimes persisting for a long time. Many different types of shrub thickets occur in Cape Lookout, each with moderate to very dense vegetative cover (50–90%). During periods of relatively little storm flooding, scattered individual plants of *Morella cerifera*, eastern baccharis, and Jesuit's bark (*Iva frutescens*) grow on overwash terraces and on the high marsh. The high marsh is occasionally flooded, so it tends to remain in the open, savanna-like shrub stage, and these three species grow rapidly to recolonize the marsh if a major storm eliminates most of the populations. As the seaward dunes continue to build, on overwash terraces and more stabilized dunes the above three earlier colonizing species co-occur with eastern redcedar, Hercules' club (*Zanthoxylum clava-herculis*), persimmon (*Diospyros virginiana*), yaupon (*Ilex vomitoria*), several woody vines including earleaf greenbrier (*Smilax auriculata*), peppervine (*Ameplopsis arborea*), saw greenbrier (*Smilax bona-nox*), and eastern poison ivy (*Toxicodendron radicans*), and eventually shrubby live oak (*Quercus virginiana*). In addition to these species, other taxa that may dominate the various shrub thicket types at the seashore include Jesuit's bark or bushy seaside tansy (*Borrichia frutescens*). This vegetation eventually becomes a thicket, which is often an impenetrable mass. Thus, open shrubland or savanna is characteristic of low-lying areas whereas thickets occur at higher elevations such as on stabilized dunes or well-protected flats. Shrub thickets commonly form boundaries around marshlands, and they are often classified as wetlands by the National Park Service and the U.S. Army Corp of Engineers.

Maritime Forests and other Woodlands

The final stage in vascular plant succession on stabilized barrier islands (that is, areas that are no longer affected or minimally affected by ocean flooding, salt spray, or migrating dunes) is a woodland or forest (Godfrey and Godfrey 1976). Shackleford Banks is unique in Cape Lookout as having the major expanse of maritime forest (defined as containing live oak trees more than 4.6 meters [15 ft] in height) (Stuska et al. 2009). The best-developed maritime forest communities are limited to a few areas that have a long history of dune-building and general accretion, especially where the beaches are roughly perpendicular to prevailing winds. More commonly, hammock-type forests develop well back from the beach on old tidal delta deposits or old, extensive overwash areas. Maritime forests may be relicts from when rising sea level first isolated stabilized, wooded dune ridges from the mainland. Alternatively, new maritime forests can develop on recently emerged lands such as an accreting spit (e.g., at Shackleford Banks), wherein the oldest dunes are stabilized and then colonized by the tree species. Dunes that develop on the shoals of old inlets can grow high enough to be colonized eventually by woodland species and form hammocks (e.g., at Guthrie's Hammock and the Portsmouth Village area on Core Banks). Where extensive overwashes create wide terraces and a series of protective seaward dunes, woodlands may develop as stability increases. The forest species may migrate along stable sections of barrier islands, and then may be cut off from older woodlands as the islands migrate and change position.

Maritime forests on barrier islands characteristically have moderate to dense vegetative cover. The overstory is dominated by live oak (*Quercus virginiana*) along with loblolly pine and eastern redcedar (*Juniperus virginiana*). Common epiphytes on the trees are Spanish moss (*Tillandsia usneoides*), resurrection fern (*Pleopeltis polypodioides*), the parasitic species oak mistletoe (*Phoradendron leucarpum*), and rich growth and diversity of lichens such as golden lichen (*Teloschistes flavicans*); grayish-green strigose beard lichen (*Usnea strigosa*); yellow-green, finely branched lace lichens (*Ramalinas* spp.); leafy, grayish-green lichens (*Parmelia* spp.), and the bright red brigantiaea lichen (*Brigantiaea leucoxantha*; Au 1974). Various species form the sub-canopy and shrub layers, such as Hercules' club, willow oak (*Quercus phellos*), laurel oak (*Quercus laurifolia*), hornbeam (*Carpinus caroliniana*), flowering dogwood (*Cornus florida*), black cherry (*Prunus serotina*), redbay (*Persea orbonia*), buckthorn bully (*Sideroxylon lycioides*), blackgum (*Nyssa sylvatica*), American holly (*Ilex opaca*), swamp bay (*Persea palustris*), small wax myrtle, yaupon, American beautyberry (*Callicarpa americana*), red mulberry (*Morus rubra*), sabal palmetto (*Sabal minor*), and black highbush blueberry (*Vaccinium fuscatum*). Commonly occurring vines include Virginia creeper, greenbrier (*Smilax* spp.), yellow jessamine (*Gelsemium sempervirens*), eastern poison ivy, muscadine (*Vitis rotundifolia*), winged sumac (*Rhus copallinum*), rattan-vine (*Berchemia scandens*), peppervine, and climbing hempvine (*Mikania scandens*).

The ground surface may be thick with pine needles, leaves, or sparsely to moderately vegetated with herbaceous species such as beaked spikerush (*Eleocharis rostellata*), slender woodoats (*Chasmanthium laxum*), black oat-grass (*Piptochaetium avenaceum*), partridge-berry (*Mitchella repens*), the exotic/invasive species beggars ticks (*Bidens bipinnata*), smooth elephant's foot (*Elephantopus nudatus*), *Lepidium virginicum* (poor man's pepper grass), spurge nettle (*Cnidoscolus stimulosus*), various *Panicum* spp., bushy seaside tansy, blood panicgrass (*Dichanthelium consanguineum*), largeleaf pennywort, needlegrass rush, and royal fern (*Osmunda regalis*). Lichens are also common, such as the British soldier lichen (*Cladonia cristatella*) and other grayish, finely branched "reindeer mosses" (*Cladonia* spp.) (Au 1974).

Maritime forest has formed on old, curving dune lines (in a pattern characteristic of spit development) at Shackleford Banks. Much of this forest was buried in the early 1900s during a period of migrating dunes. The present-day forest survives as a remnant on the sound side of the barrier island. In some areas migrating sand dunes are still slowly burying the forest and creating a new dune strand.

A large hammock-type forest is Guthrie's Hammock on Core Banks. Here, the woody vegetation slopes down to the general level of the barrier flat with no dunes in front. The aerodynamic leading edge has thus been formed by salt-spray pruning, and the trees are taller as one proceeds into the hammock from the seaward side. Some hammock areas appear similar to savanna vegetation, such as near Guthrie's Hammock on Core Banks where the oaks grow on small, old dunes that are only slightly higher than the surrounding flats of marsh and mesic meadow vegetation.

Freshwater Marshes

Large and small ponds, wetlands, and marshes in Cape Lookout are mainly found on Shackleford Banks (e.g., Mullet Pond—Figure 3). Several types of freshwater wetlands tend to form where spit growth has caused curving lines of dunes, and the depressions between the dunes are cut off from the ocean, or when sand bars or spits build across the mouth of a small bay and eventually isolate it from the ocean. Alternatively, they form in swales, that is, in low-lying troughs between sandy ridges where there is access to shallow freshwater aquifers. These lenses float atop more dense saline water and often seasonally inundate the low-lying swales (Rheinhardt and Faser 2001).

Swale wetlands are dominated by emergent and submersed vegetation in deepest areas, and by woody shrubs in shallower areas. Areas dominated by herbaceous vegetation generally have significantly longer flooding regimes than areas dominated by woody shrubs (Rheinhardt and Faser 2001).

The freshwater ponds and marshes in Cape Lookout often dry during low-precipitation periods, but when filled they support an especially rich diversity of plant and animal life. The vegetation commonly includes southern cattail (*Typha domingensis*) and other *Typha* spp., inland saltgrass (*Distichlis spicata*), the exotic/invasive species Jamaica swamp grass (*Cladium mariscus* ssp.

jamaicense), marsh fimbry (*Fimbristylis castanea*), broomsedge bluestem, largeleaf pennywort, black needle rush, other rushes (*Juncus* spp.), saltmeadow cordgrass, chairmaker's bulrush (*Schoenoplectus americanus*), seaside goldenrod, *Polygonum* spp., *Cyperus* spp., marsh bristlegrass (*Setaria parviflora*), arrowhead (*Sagittaria latifolia*), and many other species. Unfortunately, some areas of intermittently flooded brackish flats in Cape Lookout contain abundant growth of the exotic/invasive species, common reed (*Phragmites australis*).

Salt Marshes

Saltmarshes form on the lowest terraces sound-side, and are flooded by tides from the sound. The most extensive saltmarshes form by inlets; alternatively, as sea level rises they can form on areas that previously were higher in elevation (e.g., Shackleford Banks—where marsh plants now surround old stumps). Small fringe areas of saltmarsh can also form as fringe areas where overwash sediments pour into a bay area, if the slope is conducive. The marsh surface typically grows upward by accumulating organic matter. If sediment sources from the sound are available, the saltmarsh will expand with gradually sloping edges. Otherwise, the marsh edges continue to break down and disintegrate until a new inlet forms or overwash provides more sediments.

High saltmarsh areas ("the high marsh") are flooded only to a depth of a few centimeters, and only during spring or storm tides. They are dominated by saltmeadow cordgrass (*Spartina patens*), along with co-dominant hot springs fimbry (*Fimbristylis thermalis*). Broad expanses of the high marsh can also be dominated by black needle rush (*Juncus roemerianus*), an aggressively growing plant with broad salinity tolerance down to freshwater. Black needle rush can out-compete and replace saltmeadow cordgrass and hot springs fimbry. Saltmarsh cordgrass (*Spartina alterniflora*) commonly grows around the outer edges of black needle rush patches.

The low marsh boundary is usually at the lower edge of the saltmeadow cordgrass-hot springs fimbry vegetation. Salt pannes, defined as depressions where saltwater accumulates, evaporates, and creates a highly saline habitat, often form between the high marsh and the low marsh. These areas are dominated by halophytes such as glasswort (*Salicornia*).

The low marsh, dominated by saltmarsh cordgrass, is flooded at mean high tide (NPS 1982). The saltmarsh cordgrass meadow also contains relatively small amounts of glasswort (*Salicornia* spp.), inland saltgrass (*Distichlis spicata*), and sea lavender (*Limonium carolinianum*). Low marsh production tends to vary with elevation. Saltmarsh cordgrass can be up to 2 meters (6.6 ft) high, and the highest production generally occurs on overwash deposits (e.g., Codd's Creek on South Core Banks). Saltmarsh cordgrass can quickly colonize new sediment by rapid rhizome growth or by seeds, sometimes moving into the sound at a rate of one meter per year (Godfrey and Godfrey 1976).

Subtidal Marine Vegetation—Seagrass Meadow

The seagrass meadows extending out from the shallow sound side waters of the two national Seashores on the Outer Banks of North Carolina contain nearly all of the remaining seagrass habitat in North Carolina (e.g., Figure 56 and Figure 57). Through maintenance of these seagrass beds, Cape Lookout and Cape Hatteras National Seashore are very important not only to the entire coastal economy of the state, but to the entire Atlantic seaboard of the U.S.—because the Albemarle-Pamlico

Estuarine system is used as nursery grounds for fish from Maine to Florida (Steel 1991). Seagrass meadows are designated as “critical habitat” by the North Carolina Marine Fisheries Commission because this habitat is so vital to the commercially and ecologically important finfisheries and shellfisheries of the state. Because many finfish and shellfish depend on this habitat during some phase of their life histories, seagrass meadows directly support recreational and commercial fisheries which, in turn, have been estimated to contribute $1.75 billion and 24,000 jobs to the state’s economy (Albemarle-Pamlico National Estuary Program [APNEP] 2011). In consideration of the significance of seagrass meadows to fisheries and overall aquatic coastal ecosystem health, natural resource economists have conservatively estimated that submersed aquatic vegetation (SAV) habitats are worth at least $30,000 per hectare (approximately $12,000 per acre) (APNEP 2011).

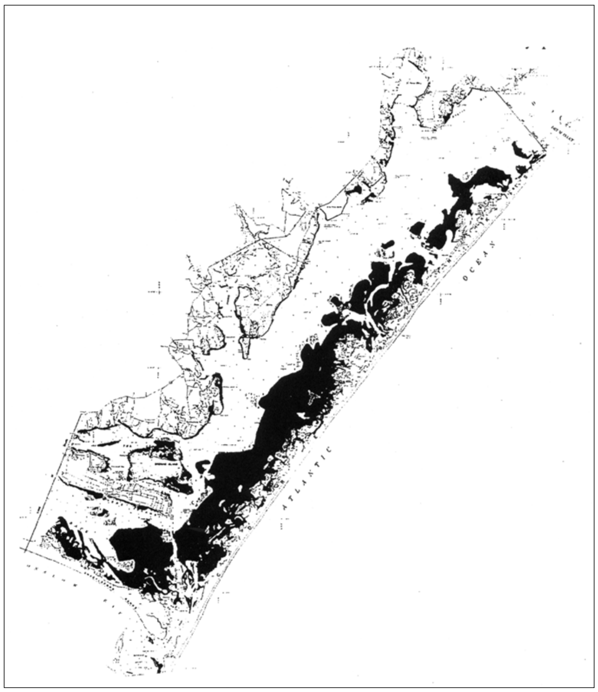

Figure 56. “Baseline” map of submersed aquatic vegetation habitat in shallow seashore waters, extending into the sounds, and in the adjacent mainland as of the mid-1980s–early 1990s (Ferguson et al. 1992).

The dominant seagrass, marine eelgrass (*Zostera marina*), is the most valuable seagrass habitat along the North Carolina coast; subdominant species include shoalgrass (*Halodule wrightii*) and widgeongrass (*Ruppia maritima*) (Burkholder et al. 1992, 1994 and references therein). Of these, *Z. marina* and *R. maritima* occur in Cape Lookout (Appendix C). In this area *Z. marina* grows at the southernmost extension of its geographic range where it grows stunted from high temperature stress (Den Hartog 1967). Eelgrass shoots in Cape Lookout are only about 40 centimeters (15.7 in) in length (Burkholder et al. 1992), whereas in Alaskan waters shoots of the same species are three meters (9.8 ft) in length (Den Hartog 1967; Green and Short 2003).

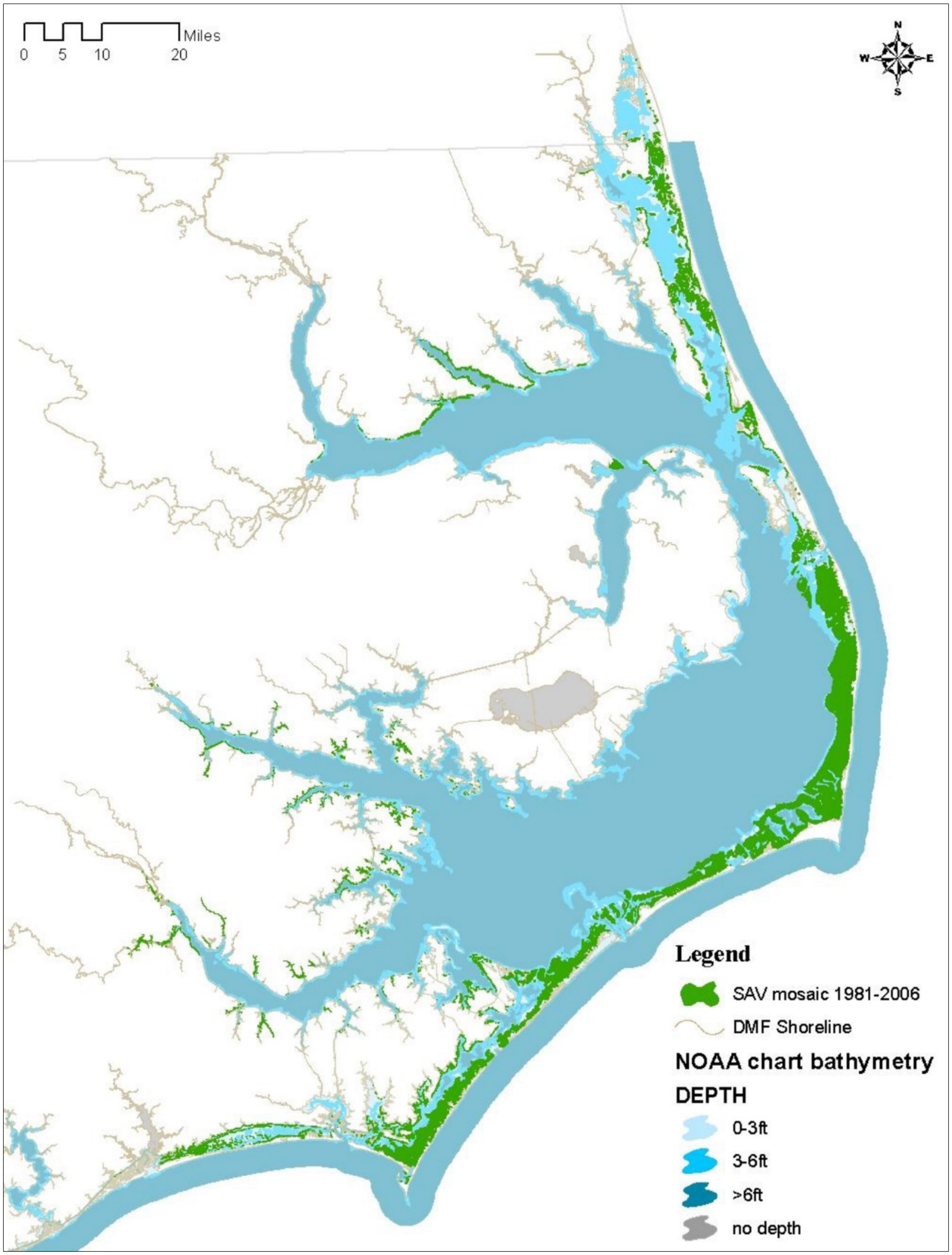

Figure 57. Map showing the distribution of seagrasses and oligohaline submersed aquatic vegetation in N.C. (compiled by Scott Chappell, NC DMF in 2007). Published sources include Carroway and Priddy (1983), Ferguson and Wood (1990), and Ferguson et al. (1992); unpublished data sources were from NC DWQ, the bottom mapping program of NC DMF, Elizabeth City State University, and N.C. State University). Available at SAFMC (undated).

Submersed aquatic vegetation of coastal North Carolina, much of it consisting of marine seagrasses, was mapped in 1985–1990 by the National Oceanic and Atmospheric Administration (Ferguson and Wood 1990; Ferguson et al. 1992), and serves as a belated "baseline" for seagrass conditions in the state (Figure 56). The North Carolina Division of Marine Fisheries (NC DMF) compiled available information on SAV distribution from data and observations taken in 1981–2006 (Figure 57). This effort extended the earlier work and confirmed that the overwhelming majority of the remaining seagrass meadows in North Carolina extend out from the shallow sound side waters of Cape Lookout and Cape Hatteras National Seashores.

The second actual mapping effort of coastal SAV in the Albemarle-Pamlico Estuarine System was conducted in 2006–2007 by the APNEP through partnership of several state and federal agencies (Figure 58). The work was based on aerial photos, which have limited utility in the relatively turbid waters (visibility usually < 1.5 meters [4.9 ft] in nearshore waters where seagrasses occur; NPS 2012d) which characterize most of the North Carolina coast. In an attempt to avoid interference with detection caused by winds, waves, excessive humidity, and suspended sediments, volunteers sampled the water for clarity before the high-altitude flights were conducted. Ground truthing consisted of boat crews who directly surveyed SAV at locations under the flight lines. The recent map appears to show only small patches of SAV along the mainland. Thus, although anecdotal reports from decades past describe lush, extended areas of seagrass meadows along the mainland (Steel 1991), a significant amount of that habitat appears to be gone. This information collectively suggests that the state has lost much of its seagrass meadows and that, if not for the sound side areas along the Outer Banks, nearly all of the seagrass habitat in North Carolina would be gone. The seagrass loss along the mainland has been related to coastal development and two of its key effects—associated light reduction from suspended sediment loading/ resuspension, and nutrient pollution (Burkholder et al. 1992, 2007b and references therein). Among the three seagrasses mentioned, *Z. marina* is by far the most highly sensitive to nutrient pollution and turbidity from sediment loading/resuspension (Burkholder et al. 1992, 1994, 2007b).

Other than the above efforts, seagrasses in North Carolina have received little attention. The North Carolina Coastal Habitat Plan (CHPP 2004; NCDMF 2016a), created by the NCDMF, attempted to place new emphasis on an ecosystem approach to fisheries management, and highlighted seagrass meadows, but the program has been unfunded or very poorly funded since its inception. There is major concern that as the waters surrounding Cape Lookout become 1°C warmer from climate change, eelgrass meadows—the most valuable coastal SAV habitat in the state—will be eliminated because it will not be able to survive at this latitude (Touchette and Burkholder 2002). As mentioned, predictions from scientific consensus are that there will be an average global increase in temperature of at least 1.7°C (3°F) this century (IPCC 2014).

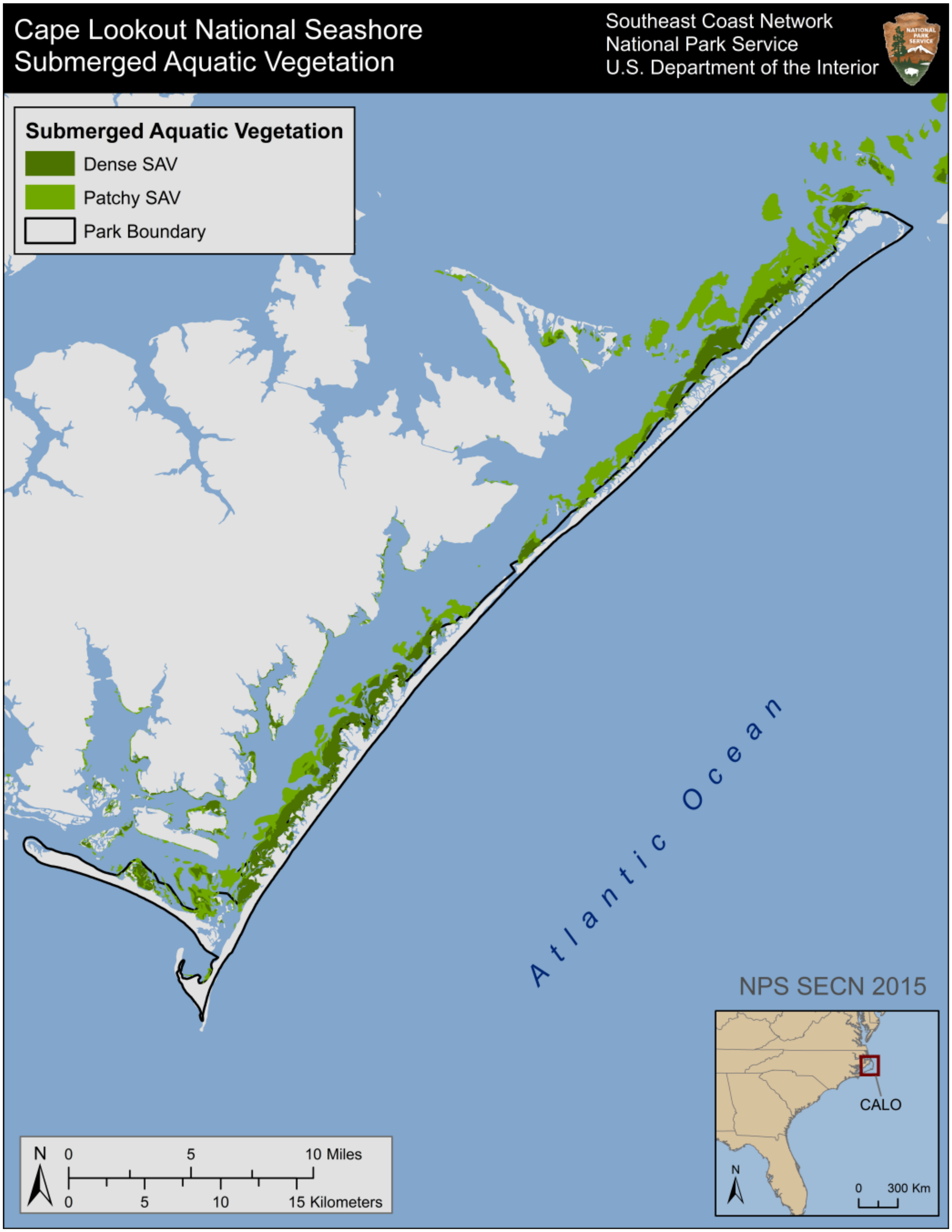

Figure 58. Map of submersed aquatic vegetation produced from an effort conducted in 2006–2008 (APNEP 2011).

Recent Characterization of Vascular Plant Communities in Cape Lookout (2010)

During a three-week period from 12 July to 3 August in 2010, the Southeast Coast Network initiated data collection on the terrestrial and wetland vascular plant vegetation of Cape Lookout as part of the NPS Vital Signs Monitoring Program. The overall goal of this ongoing program is to assist park managers in "making better-informed decisions by understanding trends and variability related to plant species, frequency of occurrence, percent cover, diversity, and distribution in the groundcover, shrub, and canopy strata" (Byrne et al. 2012).

Within each stratum, plant communities were sampled using a hybrid of methods from the North Carolina Vegetation Survey nested subplot design (Peet et al. 1998), within a circular plot similar to that of the Forest Inventory and Analysis protocol (Bechtold and Patterson 2005). To enable park-wide inferences, the seashore area within its administrative boundaries was divided into a systematic 0.5-hectare (1.2-ac) grid. The center point of each grid cell was the potential sampling site, and the grid cell represented the macroplot. A spatially balanced sample was drawn from the grid using the Reversed Randomized Quadrant-Recursive Raster algorithm (Theobald et al. 2007). Alternate points were used when the selection criteria were not met.

This short survey detected 135 taxa, and 10% (14 species, subspecies, or varieties) were newly reported for the seashore; these were added to the species list that we modified from the National Park Service (NPS 2013c; Appendix C). In the canopy layer, Virginia live oak had the largest DBH. Yaupon holly was the most frequently detected seedling species. In the shrub stratum, wax myrtle was the most frequently occurring species, and had the highest absolute and relative cover. In the groundcover substratum (excluding wet areas such as open water and low saltmarsh), saltmeadow cordgrass, greenbriar, poison ivy, and climbing hempvine occurred most frequently. Saltmeadow cordgrass had the highest absolute and relative cover. Largeleaf pennywort and saltmeadow cordgrass were the most frequently occurring groundcover species. Sea oats had the highest relative cover; and saltmeadow cordgrass had the highest absolute cover, followed closely by sea oats (Byrne et al. 2012).

Vegetation Mapping by the National Park Service and NatureServe (2005–2016)

The most recent publication about the vegetation of Cape Lookout is an important document by McManamay et al. (2014), which describes extensive effort to map the vascular plant vegetation of Cape Hatteras National Seashore. Aquatic taxa were excluded from the mapping effort. The Southeast Coast Network worked with support of the NPS Vegetation Mapping Inventory Program, through collaboration with NatureServe. Remote sensing was used at a 1:12,000 scale with color infrared aerial photography (flown 31 May 2009) and digital orthophotography. NatureServe (2007) identified plant associations, from the National Vegetation Classification System (NVCS), which were representative of the floristic types found at both parks. A detailed accuracy assessment indicated an overall accuracy of 80.1% (Kappa statistic, 69.9%).

The mapping effort involved development of 27 map classes for vegetation and general land cover of the two parks and adjacent areas, including the 13 map classes for natural/semi-natural vegetation at the association level in the NVCS, along with 14 map classes for non-vegetated units (e.g., open waters, buildings, roads etc.). Heads-up digitizing in ArcGIS (Version 10.0, © 2010 Environmental

Systems Research Institute, Redlands, California was used, and polygons were mapped to a 0.5-hectare minimum mapping unit. The geodatabase that was developed contains various feature-class layers and tables showing locations of vegetation types and general land cover (vegetation map), vegetation plot samples, AA sites, project boundary extent, and aerial photographic centers.

Unfortunately, the only vegetation map available from this major effort was for Cape Hatteras National Seashore, but the 13 main, final vegetation associations of the NVCS (map classes, with their assigned Map Codes) were described in detail (McManamay et al. 2014, Appendix B) and the descriptions included information for Cape Lookout. The following brief summary of that information is included to provide more physiognomy about Cape Lookout, in addition to the general vegetation descriptions given above.

Estuarine and Marine Benthic Macroinvertebrates

> *There are no comprehensive inventories of BMIs [benthic macroinvertebrates] in the Southeast Coast Network, yet there are compelling reasons to include BMI among checklists of park biota. BMI represent a foundation of biomass that is often used as food for larger vertebrates and invertebrates. Sessile BMIs also provide substrata and habitat stabilization in estuarine environments. Because most BMIs are either sessile or of limited motility, they can also serve as indicators of local habitat conditions and the impact of natural and anthropogenic stressors. Also, nuisance and invasive BMI introduced from shipping and recreational boating activities pose a threat to native BMI communities, as well as park infrastructure.*
>
> —*Hymel (2009)*

Cape Lookout National Seashore Benthic Macroinvertebrates

A literature-based inventory of marine and estuarine benthic macroinvertebrates was conducted for Cape Lookout, in order to provide a baseline of BMI abundance and community composition in the seashore from recent studies within or adjacent to the park boundaries (Hymel 2009). Other goals were to determine the predicted distributions of BMIs with respect to habitat type and geography; to document species occurrences using vouchered national, state, and private museum records in the Carolinas, Georgia, and Florida; to assess the status of any BMI SSCs; and to suggest strategies for continued and future monitoring efforts for BMIs in seashore habitats. The sources considered included the National Benthic Inventory, the South Carolina Estuarine and Coastal Assessment Program (SCECAP), and several smaller studies, supplemented from numerous literature reports published over the last 25 years, or similar habitat types throughout the South Atlantic Bight. Species names were verified through the ITIS, and data from the EPA Estuarine Monitoring and Assessment Program (EMAP, data ≤≤ 12 years old) and the SCECAP (data from 1999–2002) were used to create maps of (potential) BMI abundance and distribution in Cape Lookout (Hymel 2009). A Shannon-Wiener Diversity Index (*H'*) value (Shannon and Weaver 1949) was calculated for all sites. This widely accepted, classic index accounts for the total number of species and their abundance (or relative abundance—the proportion of individual species in a given sample—Llansó 2002). For BMI communities, values between 0 and 2.5 are considered low, 2.5–3.8 moderate, and greater than 3.8 high (Dent et al. 1998).

Hymel's (2009) inventory documented 68 BMI taxa from three EMAP stations in or near the seashore. One station was in Core Sound, another was in the Shackleford Channel, and a beach area sample was also taken. The Shannon-Weiner Diversity Index (*H'*) for BMIs at these stations ranged from 3.03 (moderate) to 4.09–4.13 (high); the mean and median *H'* for the eight sites were 3.73 and 4.09, respectively. Dominant BMI taxa at the Core Sound station included *Acteocina canaliculata* (gastropod—snail) and polychaetes *Mediomastus ambiseta* and *Streblospio benedicti*. The beach station was also dominated by *A. canaliculata* along with a bivalve mollusc (*Parvilucina multilineata*). At the Shackleford Channel station, dominant taxa included oligochaetes, the polychaete *Hesionura elongata*, and unidentified nemerteans (bloodworms). Unfortunately, these stations had been sampled from 1994–1997, 20 years ago, and this interesting and informative approach has not been repeated using more recent data.

Survey of Marine Benthic Macroinvertebrates (July 2010)

During 2010, the Southeast Coast Network collected marine benthic invertebrate samples at Cape Lookout using EPA (2005a) National Coastal Assessment protocols at a subset of sites (Figure 59) where water quality and sediment quality data were also being collected. In addition, the EPA Southeast Coast Benthic Index (Van Dolah et al. 1999) was used to provide a measure of benthic habitat quality (Table 31). That index includes measures of mean abundance, mean number of taxa, 100 minus percent abundance of the two most numerically dominant taxa, and percent abundance of pollution-sensitive taxa. Condition assessments from EPA (2008b) that were applied to site- and seashore-wide EPASoutheast Coast Benthic Index scores are shown in Table 32.

All sampling locations were within the northern latitudes (> 35°N) of the EPA EMAP Carolinian Province. Benthic invertebrates were collected at 22 sites within sound and inlet habitats in Cape Lookout and Cape Hatteras National Seashore waters. Twelve sites were located in Cape Lookout NS (Table 33). Except for two brackish (oligohaline to mesohaline) sites in Roanoke Sound, all samples were from polyhaline-euhaline waters (salinity > 18). Water temperatures were similar among sites, and the presence of SAV and marine debris was not correlated with habitat type. Water depths at collection sites ranged from 0.5 meters to nearly 6 meters (1.6–19.7 ft), but at 18 of the 22 sites the depth was 0.5–1.5 meters (1.6–4.9 ft). Sediments were collected following methods in EPA (2010b); samples were filtered through a 0.5-millimeter (0.02-in) mesh and the remaining material was preserved for taxonomic identification to the lowest practical level.

A total of 4,677 individual macroinvertebrates were collected during this study (Table 33). The gem clam (*Gemma gemma*) was the clear dominant species. Four species were found in at least half the samples, including seed shrimps (Ostracoda), the polychaete *Leitoscoloplos fragilis*, the channeled barrel-bubble (*Acteocina canaliculata*), and the gem clam. Applying the EPA Benthic Index, the overall benthic macroinvertebrate community condition was evaluated as good (healthy benthos), with only 1 of the 12 sites having an overall rating of fair (some stress).

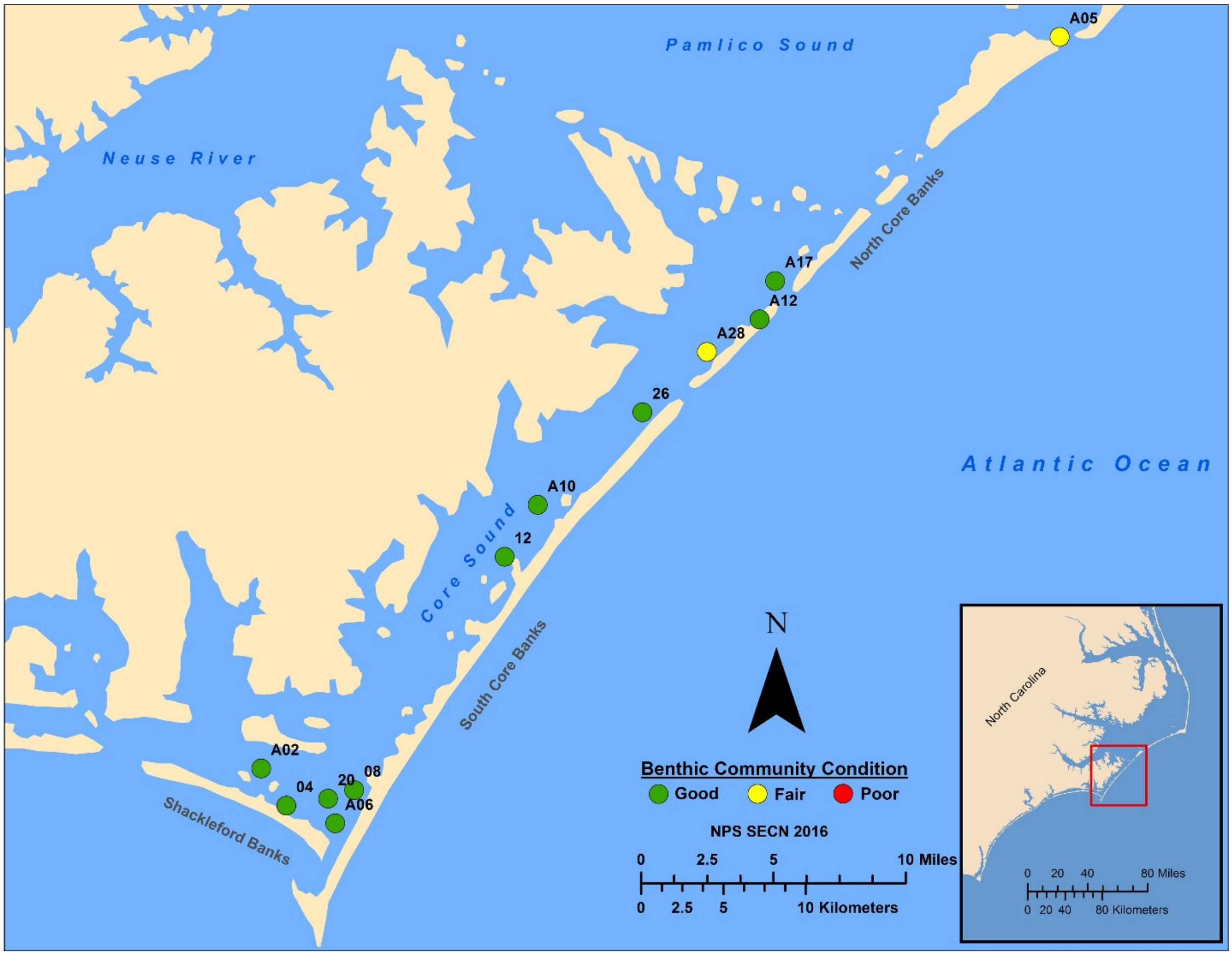

Figure 59. Map of the 12 estuarine and marine sites sampled in July 2010 for benthic macroinvertebrates at CALO; color-coded sites also indicate the overall score for Benthic Macroinvertebrate Community Condition. Modified from DeVivo and Gregory (2012).

Table 31. Metrics and scoring criteria (Van Dolah 1999) applied to estuarine and marine benthic macroinvertebrate samples collected at Cape Lookout in 2010 (DeVivo and Gregory 2012) [*—.

Metric	1 [a]	3 [a]	5 [a]	1 [b]	3 [b]	5 [b]
Number of individuals per 0.04 m^2	< 53.50	53.50–93.00	> 93.00	< 26.00	26.00–109.75	>109.75
Number of taxa per 0.04 m^2	< 7.00	7.00–8.50	> 8.50	< 7.5	7.5–17.00	> 17.00
100 minus % of the two most abundant taxa	< 9.62	9.62–25.45	> 25.45	< 28.94	28.94–51.53	> 51.53
% Pollution-sensitive taxa[c]	< 0.61	0.61–5.04	> 5.04	0	0–12.83	> 12.83

[a] Oligohaline-mesohaline (brackish); all latitudes

[b] Polyhaline-euhaline (marine); northern latitudes

[c] Percentage of individuals within the taxa Ampeliscidae, Haustoriidae, Lucinidae, Hesionidae, Cirratulidae, *Cyathura polita*, or *Cyathura burbancki*.

Table 32. Condition assessments applied to site- and CALO-wide Southeast Coast Benthic Index scores. (EPA 2008b in DeVivo and Gregory 2012).

Rating	Index Score	Inferred Site Quality
Good	3.0–5.0	Healthy Benthos
Fair	2.0–2.5	Some Stress
Poor	1.0–1.5	Unhealthy Benthos

Table 33. Values for Southeast Coast Benthic Index metrics, and average scores, at 12 sites sampled for estuarine and marine benthic macroinvertebrates at Cape Lookout NS in July 2010. From DeVivo and Gregory (2012).

Waterbody Name	Site	Number of Individuals	Number of Taxa	% Dominance	% Sensitive	Average Score
Pamlico Sound	A05	24	7	20.8	16.7	2.0
Pamlico Sound	A17	2828	16	1.1	0.5	3.0
Pamlico Sound	A12	882	14	5.3	0.1	3.0
Pamlico Sound	A28	100	10	20.0	3.0	2.5
Core Sound	8	228	45	79.8	8.8	4.5
Core Sound	12	140	22	50.0	10.0	4.0
Core Sound	26	81	20	61.7	12.4	4.0
Core Sound	A06	64	21	59.4	9.4	4.0
Core Sound	A10	42	16	42.9	14.3	3.5
Core Sound / Back Sound	20	83	18	54.2	13.2	4.5
Back Sound	4	114	22	60.5	32.5	5.0
Back Sound	A02	91	29	83.5	16.5	4.4
Average:	**---**	**390**	**20**	**44.9**	**11.5**	**3.7**

The North Carolina Division of Marine Fisheries (NC DMF) includes seven estuarine/marine macroinvertebrate species that are both commercially and recreationally important (Table 34)—the bay scallop, blue crab, eastern oyster, three shrimp species (brown, white, and pink), and the northern quahog. Fishing practices can have major impacts on species populations, and overfishing is known to be a major problem for many species in the western Atlantic Ocean, including the southeastern United States (Pauly et al. 1998; National Research Council 1999, 2006; Myers et al. 2007). Stock assessment has not been done for some commercially/ recreationally important species. Of these seven macroinvertebrate species, the status of their populations has been evaluated by the NC DMF as viable (three species), species of concern (three species—i.e., stressed populations), or status unknown (one species). Overall, oyster production in the area is considered poor and clam production is considered fair in the Hatteras Island area. Northern quahog production and oyster production are generally fair around Ocracoke Island (Mallin et al. 2012).

Table 34. Commercially and/or recreationally important finfish (46) and shellfish (7) species reported from CALO estuarine and marine waters, and population status in N.C. (NCDMF 2014). Asterisks indicate SSC (Atlantic sturgeon) or candidate considered for SSC status (American eel).

Category	Species	Common Name	Importance and Status as Designated by NC DMF
Finfish	*Acipenser oxyrinchus***	Atlantic sturgeon	commercially and recreationally important—depleted
	Alosa sapidissima	American shad	commercially important—species of concern
	*Anguilla rostrata***	American eel	catadromous; commercially important—depleted
	Archosargus probatocephalus	Sheepshead	commercially important—status unknown
	Brevoortia tyrannus	Atlantic menhaden	commercially important—species of concern
	Coryphaena hippurus	Dolphin, dolphinfish	offshore—commercially and recreationally important—viable
	Cynoscion nebulosus	Spotted seatrout	commercially and recreationally important—depleted
	Cynoscion regalis	Weakfish	commercially and recreationally important—depleted
	Dorosoma cepedianum	Hickory shad	commercially important—status unknown
	Epinephelus morio	Red grouper	commercially and recreationally important—species of concern
	Epinephelus nigritus	Warsaw grouper	commercially and recreationally important—species of concern
	Leiostomus xanthurus	Spot	commercially and recreationally important—species of concern
	Lophius americanus	Monkfish	commercially and recreationally important—recovering
	Lutjanus campechanus	Red snapper	commercially and recreationally important—species of concern
	Menticirrhus americanus	Southern kingfish	commercially important—status unknown
	Menticirrhus saxatilis	Northern kingfish	commercially important—status unknown
	Microgobius thalassinus	Green goby	commercially important—status unknown
	Micropogonias undulatus	Atlantic croaker	commercially and recreationally important—species of concern
	Morone saxatilis	Striped bass	commercially and recreationally important—species of concern
	Mugil cephalus	Striped mullet	commercially and recreationally important—viable

Table 34 (continued). Commercially and/or recreationally important finfish (46) and shellfish (7) species reported from CALO estuarine and marine waters, and population status in N.C. (NCDMF 2014). Asterisks indicate SSC (Atlantic sturgeon) or candidate considered for SSC status (American eel).

Category	Species	Common Name	Importance and Status as Designated by NC DMF
Finfish (continued)	*Mycteroperca microlepis*	Gag grouper	commercially and recreationally important—species of concern
	Paralichthys dentatus	Summer flounder	commercially and recreationally important—viable
	Paralichthys lethostigma	Southern flounder	commercially and recreationally important—depleted
	Pogonias cromis	Black drum	commercially and recreationally important—status unknown
	Pomatomus saltatrix	Bluefish	commercially and recreationally important—viable
	Sciaenops ocellatus	Red drum	commercially and recreationally important—recovering
	Scomberomorus cavalla	King mackerel	commercially and recreationally important—species of concern
	Scomberomorus maculatus	Spanish mackerel	commercially and recreationally important—viable
	Stenotomus chrysops	Scup, porgy	commercially and recreationally important—viable
Finfish/Sharks	*Carcharhinus acronotus*	Blacknose shark	commercially and recreationally important—species of concern
	Carcharhinus brevipinna	Spinner shark	commercially and recreationally important—species of concern
	Carcharhinus falciformis	Silky shark	commercially and recreationally important—species of concern
	Carcharhinus leucas	Bull shark	commercially and recreationally important—species of concern
	Carcharhinus limbatus	Blacktip shark	commercially and recreationally important—species of concern
	Carcharhinus obscurus	Dusky shark	commercially and recreationally important—species of concern
	Carcharhinus plumbeus	Sandbar shark	commercially and recreationally important—species of concern
	Carcharias taurus	Sand tiger shark	commercially and recreationally important—species of concern
	Carcharodon carcharias	Great white shark	commercially and recreationally important—species of concern
	Galeocerdo cuvier	Tiger shark	commercially and recreationally important—species of concern

Table 34 (continued). Commercially and/or recreationally important finfish (46) and shellfish (7) species reported from CALO estuarine and marine waters, and population status in N.C. (NCDMF 2014). Asterisks indicate SSC (Atlantic sturgeon) or candidate considered for SSC status (American eel).

Category	Species	Common Name	Importance and Status as Designated by NC DMF
Finfish/Sharks (continued)	*Ginglymostoma cirratum*	Nurse shark	commercially and recreationally important—species of concern
	Negaprion brevirostris	Lemon shark	commercially and recreationally important—species of concern
	Rhincodon typus	Whale shark	commercially and recreationally important—species of concern
	Rhizoprionodon terraenovae	Atlantic sharpnose shark	commercially and recreationally important—species of concern
	Squalus acanthias	Dogfish	commercially and recreationally important—viable
	Squatina dumeril	Atlantic angel shark	commercially and recreationally important—species of concern
	Centropristis striata	Black sea bass	commercially important—recovering North of Cape Hatteras; recovered south of the Cape
Shellfish	*Argopectens irradians*	Bay scallop	commercially and recreationally important—species of concern
	Callinectes sapidus	Blue crab	commercially and recreationally important—species of concern
	Crassostrea virginica	Eastern oyster	commercially and recreationally important—species of concern
	Farfantepenaeus aztecus	Brown shrimp	commercially and recreationally important—viable
	Farfantepenaeus duorarum	Pink shrimp, spotted shrimp	commercially and recreationally important—viable
	Litopenaeus setiferus	White shrimp	commercially and recreationally important—viable
	Mercenaria mercenaria	Northern quahog, hard clam	commercially and recreationally important—status unknown

Fish

Estuarine fish species richness in and surrounding Cape Lookout is very high, reflecting the location of this national seashore in the waters where the Virginian and Carolinian marine biogeographic provinces meet. The NPS Certified Species List (NPS 2013c) includes 293 species, and we have added two more, the striped bass and the lionfish (Appendix C). About 16% of them (46 species) are commercially and/or recreationally important (Table 34).

North Carolina marine waters, including the Outer Banks area, have been a location for classic studies of overfishing. For example, the following information is from Myers et al. (2007):

> *The longest continuous shark survey, conducted annually since 1972 off the North Carolina coast, has shown such large declines in great sharks (length > 2 meters [6.6 ft]) that they likely have been functionally eliminated. Fishing pressure on great sharks has intensified worldwide in the past few decades due to increased demand for shark fins and meats, and also because of bycatch in various fisheries (Myers et al. 2007 and references therein). Declines in seven shark species range from 87% (sandbar sharks) to more than 99% for bull sharks, dusky sharks and smooth hammerheads. There have also been major losses in the largest of blacktip, bull, dusky, sandbar, and tiger sharks, suggesting that because of overfishing, there are few mature individuals remaining in the populations. These shark losses have coincided with a dramatic increase in the prey of great sharks (14 species of rays, skates, and small sharks) by about ten-fold. The biggest increase is by cownose rays (Rhinoptera bonasus, found seashore waters—NPS 2013c), which in turn consume large quantities of bivalve shellfish. Moreover, rays consume bay scallops before the scallops spawn (Myers et al. 2007). Not surprisingly, bay scallop populations have substantially decreased. As a "cascade effect" down the food web, elimination of most great sharks along the North Carolina coast has a high potential for broader ecosystem impacts.*
>
> *—Myers et al. 2007*

Fishing practices vary in the estuaries, sounds, and ocean waters near Cape Lookout—recreational fishers angle from boats and surf fish, whereas commercial fishers use pound nets to target flounder; trawl for shrimp and finfish; catch menhaden using haul seines off ocean beaches and sometimes in the sounds; and engage in "clam kicking" (using outboard motors to dislodge clams from the sediments) and hydraulic dredging to harvest shellfish sound side (Mallin et al. 2004). The Gulf Stream is only an hour away, where recreational fishers catch trophy fish such as white marlin, blue marlin, sailfish, and bluefin tuna (Mallin et al. 2012), most of which have stressed populations in many parts of the world from fishing pressure (Safina 1995, Montaigne 2007).

The overall status of fisheries in and around Cape Lookout is highly stressed from overfishing: Of the 46 species of finfish that are commercially and/or recreationally important in North Carolina and reported to occur in seashore waters (NPS 2013c), the populations ("stocks") of only 15% (7 species) were recently assessed by NC DMF as viable (i.e., healthy), including bluefish, dogfish (type of shark), dolphin, scup, Spanish mackerel, striped mullet, and summer flounder (Table 34). Three species (7%) are recovering (black sea bass, monkfish, and red drum); five species (11%) are depleted (SSCs Atlantic sturgeon and American eel, and spotted seatrout, southern flounder, and weakfish); and six species (13%) are status unknown (black drum, green goby, hickory shad, northern kingfish, southern kingfish, and sheeps-head). The remaining 25 species (54%) are assessed as stocks of concern.

Herpetofauna

> *Amphibian communities in the southeastern U.S. are widely considered to be among the most diverse in the world, and they are a valued resource in Southeast Coast Network parks….Several factors are attributable to [amphibian] population declines and localized extinctions…[including] disease and anthropogenic stressors such as habitat loss and degradation, non-native predators, acid precipitation, altered hydrology and hydroperiod, ultraviolet radiation, and chemical contaminants*
>
> *—Collins and Storfer 2003*

North Carolina presently has 98 amphibian and 80 reptilian taxa (Beane and Braswell 2011). Its high diversity is attributed to the extensive habitat diversity and the mild, moderate climate (Tuberville et al. 2005). The Southeast Coast Network has identified one of its long-term objectives for herpetofauna in Cape Lookout as determining trends in amphibian species occupancy, distribution, diversity, and community composition in each park (Byrne et al. 2013). The National Park Service uses herpetofauna species richness as part of a multi-species approach used to inform park staff about habitat condition and strategic management of park ecosystems. Considering their known population declines, sensitivity to anthropogenic stressors, and their diversity in the southeastern United States, amphibian communities are a priority for SECN monitoring efforts (Byrne et al. 2013).

At present, 12 amphibian and 30 reptilian taxa (12 species and 26 species, respectively) have been reported to occur at the seashore (Appendix C—Tables C-1 through C-8). The amphibians consist of ten species of frogs and toads, one salamander, and one newt. Reptiles are presently represented by 15 taxa of snakes (two venomous; the eastern cottonmouth [*Agkistrodon piscivorus piscivorus*], and the pygmy rattlesnake [*Sistrurus miliarius*]), ten species of turtles, and five species of lizards. All of these taxa are native. Cape Lookout has two amphibian SSCs (17% of the total taxa), the oak toad (*Bufo quercicus*) and Mabee's salamander (*Ambystoma mabeei*). Of the 30 herpetofauna taxa in Cape Lookout, 37% (11 species) are SSCs.

<u>Survey Conducted in 2001–2003</u>

In 2001–2003, with funding support from the National Park Service, Tuberville et al. (2005) surveyed herpetofauna at Cape Lookout—augmented by historical data from museums, published literature, and personal collections. Their survey was the basis for the NPS Certified Species List (NPS 2013c) which has been augmented since that time by more recent NPS surveys (below).

Low species richness was expected in Cape Lookout relative to inland parks because most habitats at the seashore are brackish and marine, and few amphibian taxa occur in salty habitats (Vences and Köhler 2008). Both Cumberland Island National Seashore and Timucuan Ecological and Historic

Preserve have more freshwater habitats than Cape Lookout (see this report versus Alber et al. 2005 and Anderson et al. 2005).

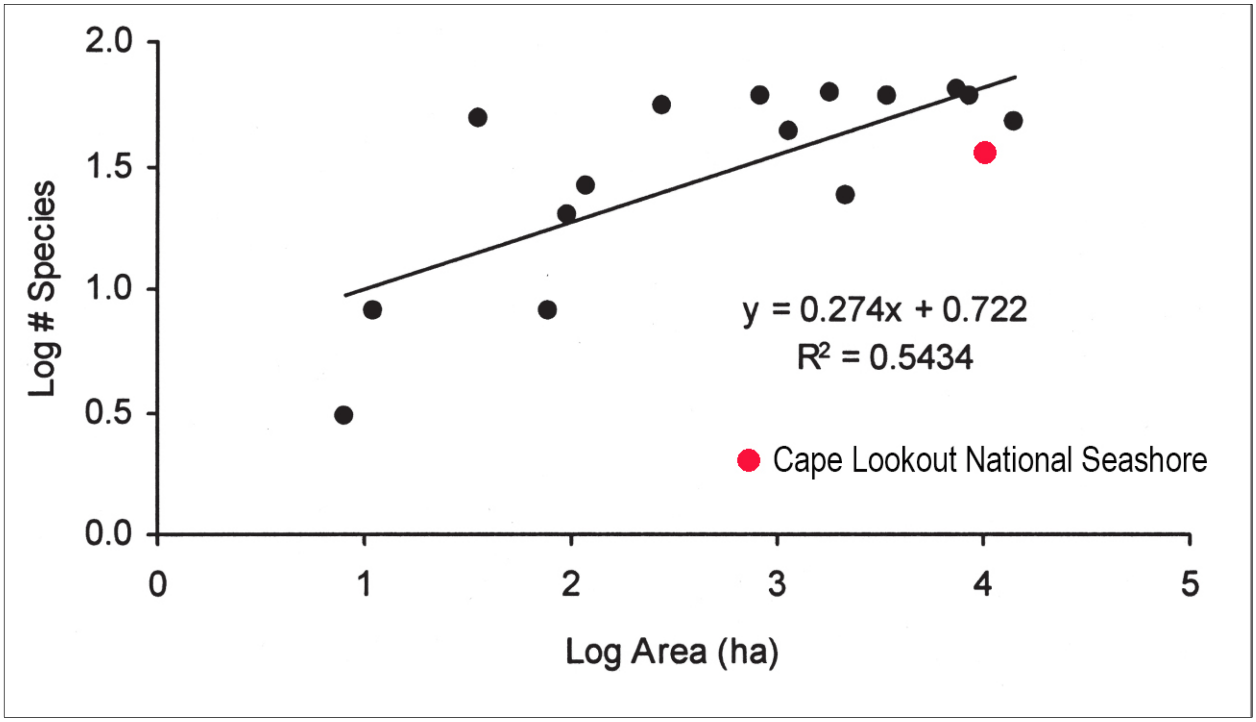

Figure 60. Relationship between land area (in hectares) and species richness, excluding exotic (introduced) species, among 16 parks within the NPS SECN including Cape Lookout. Modified from Tuberville et al. (2005).

National Park Service 2010 Study of Vocal Anuran Amphibians

An Amphibian Community Monitoring Protocol (Byrne et al. 2013) was recently implanted in all SECN park units. The long-term objective is to determine trends in amphibian species occupancy, distribution, diversity, and community composition in each park. The protocol was used to collect data from 30 spatially balanced, random locations at the seashore (Figure 61) during 5–29 May and 13–29 July 2010, using two techniques—automated recording devices (ARDs, deployed during the May sampling period) and visual-encounter surveys (conducted during the July sampling period). Visual encounter surveys are not part of ongoing monitoring.The two techniques used are not considered effective tools for surveying many reptile species; nevertheless, reptiles encountered were noted.

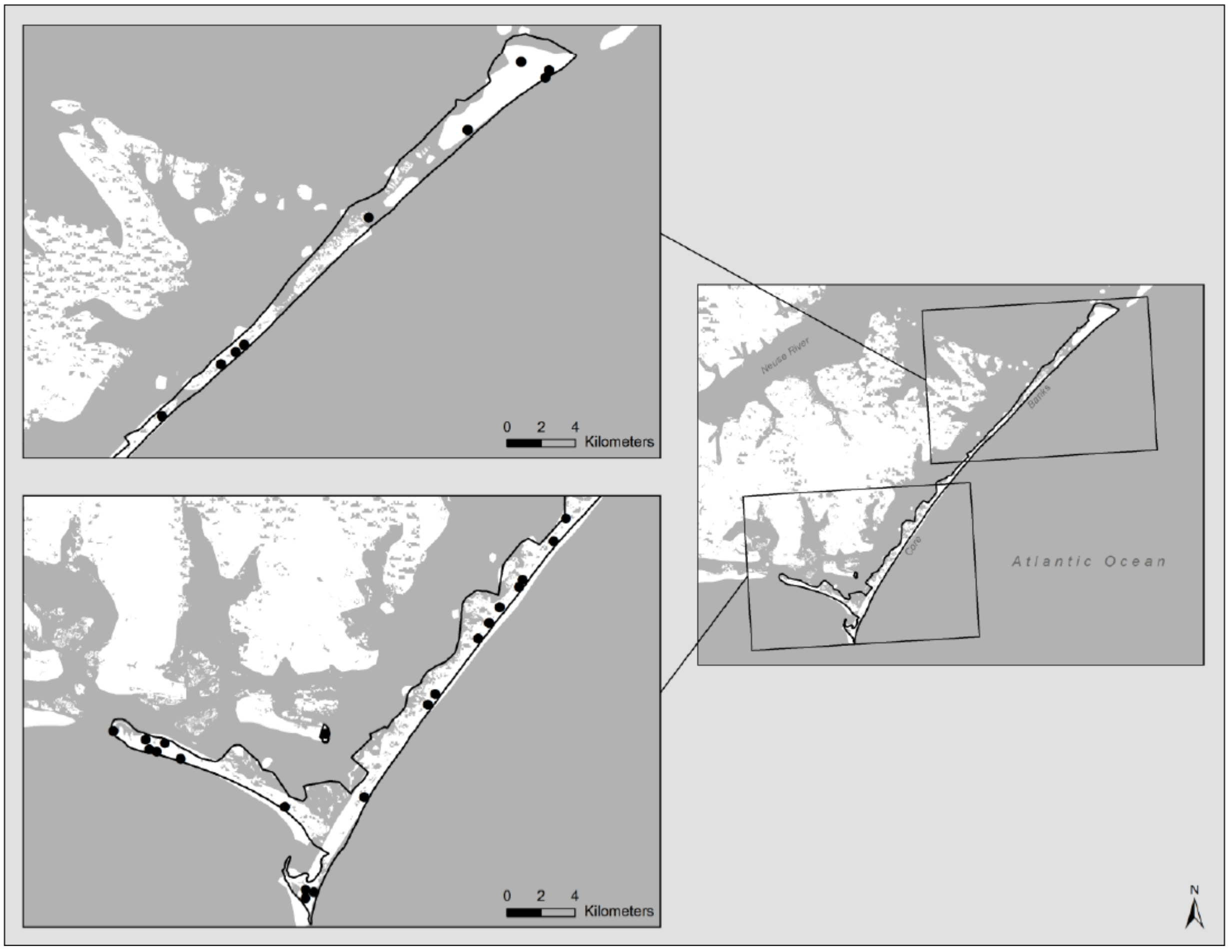

Figure 61. Map of spatially balanced, random sampling locations for amphibians and reptiles at Cape Lookout during May and July of 2010. From Byrne et al. (2011a).

Species were identified to the most refined taxonomic level possible; where there was uncertainty, organisms were grouped at the genus or group level. To allow for park-wide inference, the park's administrative boundary was used as the sampling frame.

A total of 52 post-metamorphic amphibians within three species and 100 larval amphibians within one species (*Hyla squirrella*, the squirrel treefrog) were detected during the survey. More than 95% of the sample consisted of larval and post-metamorphic squirrel treefrogs, and this species occurred at one-third of the sampling locations. The green treefrog (*Hyla cinerea*) was second in abundance, and Fowler's toad (*Bufo fowleri*) was the least frequently encountered amphibian species. Diversity indices were calculated for the amphibian data as reflective of community composition (number of species) and structure (number of individuals), which include species richness and evenness estimates.

Byrne et al. (2011a) also detected 35 reptiles and reptile signs, representing seven species. The most widely distributed reptile was the six-lined racerunner (*Cnemidophorus sexlineatus*). Exotic/invasive herpetofauna were not found.

National Park Service 2012 Survey of Herpetofauna

A similar survey was completed in 2012 (Smrekar et al. 2013) at 30 spatially balanced, random locations in somewhat different locations than those used during the 2010 survey, also including a station at Portsmouth Island as requested by Cape Lookout natural resources staff (Figure 62). ARDs were deployed from 29 March through 18 June (77 days), whereas visual surveys were conducted from 16–29 June.

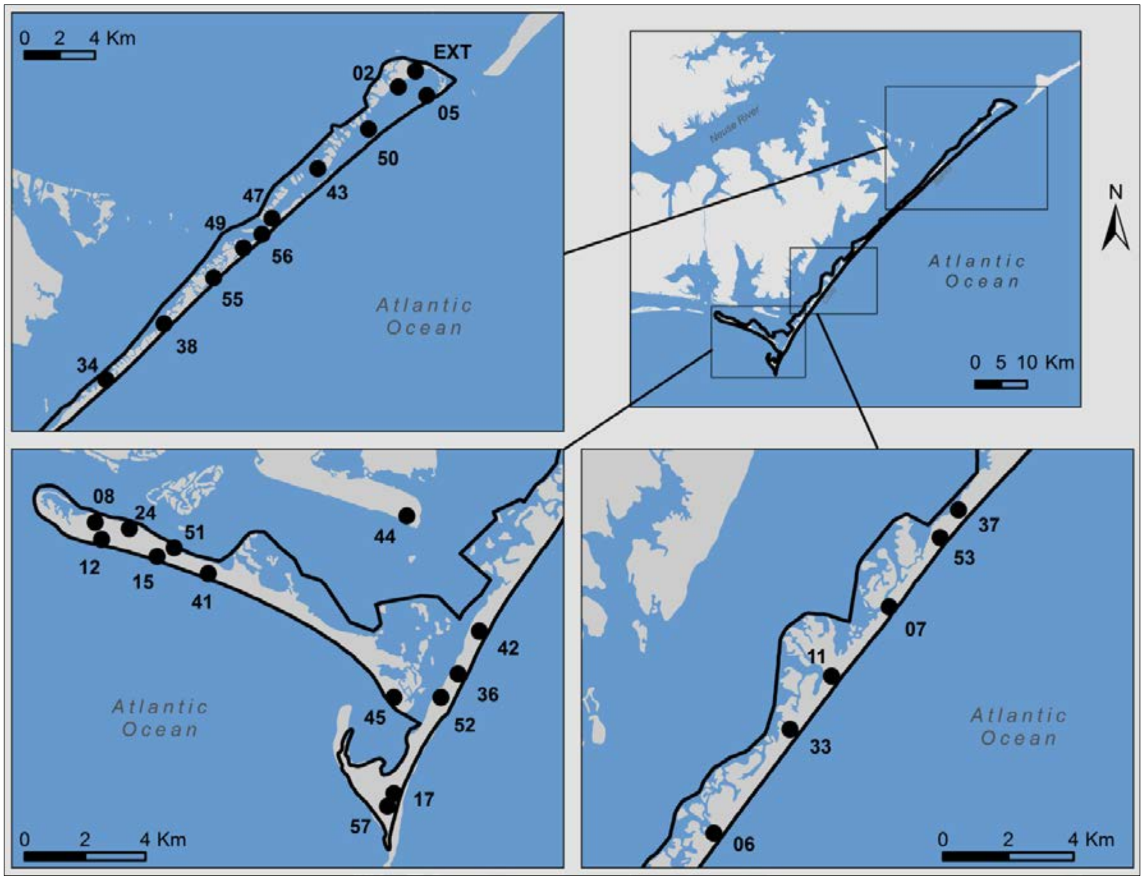

Figure 62. Map of spatially balanced, random sampling locations for amphibians and reptiles at CALO during May and July of 2012. From Smrekar et al. (2013).

The ARDs yielded 140 vocalizations of seven identifiable anuran amphibian species, while 126 post-metamorphic amphibians within two species were detected from VESs. The squirrel treefrog and Fowler's toad (*Anaxyrus fowleri*) were most frequently encountered. Squirrel treefrogs and green treefrogs had the highest relative detection frequencies of vocalizations. The squirrel treefrog was also the most widely distributed amphibian species in 2012, and was detected on North Core Banks, South Core Banks, Shackleford Banks, and Harkers Island. Two amphibian species, the southern toad (*Anaxyrus terrestris*) and the bullfrog (*Lithobates catesbeianus*) were detected for the first time at Cape Lookout.

During the VESs, Smrekar et al. (2013) also detected 53 reptiles within eight identifiable species and two families, including one species found for the first time in Cape Lookout, the corn snake or red rat snake (*Elaphe guttata*). No exotic/invasive herpetofauna were detected during this 2012 survey.

Birds

> *Birds are the most visible vertebrates in the seashore because of its location on the Atlantic Flyway, varied habitats, strong winds that drive oceanic birds onto land, and lack of development (NPS 1982).*
>
> *Birds are an important component of park ecosystems, and their high body temperature, rapid metabolism, and high ecological position in most food webs make them a good indicator of the effects of local and regional changes in ecosystems. Long-term trends in the community composition, relative abundance, distribution, and occurrences of breeding-bird populations provide a measure for assessing the ecological integrity and sustainability in southeastern systems. Further, long-term patterns of these attributes in relation to changes in the structural diversity of vegetation resulting from fire and other management practices will improve our understanding of the effects of various management actions.*
>
> *—Byrne et al. (2014)*

General Information

Cape Lookout serves several vital functions in both landbird and shorebird conservation. Located along the Atlantic Flyway, the seashore provides a wealth of varied breeding habitats, foraging habitats, important stop-over areas for migrating birds, and wintering habitat for various species (Byrne et al. 2011b). The seashore is renowned worldwide for its rich avian fauna, including SSCs such as the piping plover, colonies of nesting terns and various other shorebirds, and dramatic stopovers of migrating shorebirds and passerines (Watson 2005). Nesting season is generally from April to October, and several significant, large nesting areas (e.g., 6.4 kilometers [4 mi] long x 0.8 kilometers [0.5 mile] wide) of colonial nesting shorebirds (least terns, gull-billed terns, common terns, black skimmers) have occurred for many years on beaches, berms, scattered low dunes and tidal flats north of New Drum Inlet (NPS 1982) and Cape Point. Least terns also nest on the barren sand behind the dunes south of New Drum Inlet. The Wilson's plover is widespread, and has a major nesting site near the lighthouse. Brown pelicans nest on three islands in Ocracoke Inlet, the northernmost breeding colony, and at Oregon Inlet.

In consideration of this rich habitat diversity for both landbirds and seabirds, and the value of Cape Lookout for protecting avian fauna, the American Bird Conservancy designated the seashore a Globally Important Bird Area as of 2001 (Watson 2005). A total of 276 bird species have been reported to occur seasonally or year-round in Cape Lookout, including 141 wetland/shore/ aquatic species (Appendix C—Table C-1–C-8). Only six exotic/invasive avian taxa occur in Cape Lookout; the seashore remains a haven for 50 SSCs comprising 18% of the bird fauna. The seashore provides vitally important support for many colonial waterbird species whose populations are generally in decline. They depend on the park's nearshore waters for feeding, and on its relatively undisturbed lands for nesting. It should be noted that waterfowl hunting is permitted at the seashore except in the Portsmouth Village and Cape Lookout Village historic districts (Mallin et al. 2004).

An Avian Conservation Implementation Plan was developed for Cape Lookout to help identify and prioritize bird conservation opportunities, and to provide counsel and information for successful implementation of needed conservation activities (Watson 2005). Cape Lookout is not obligated to follow any of the proposed actions in the plan; rather, the intent was to offer guidance about how Cape Lookout can voluntarily support important local, regional, and broader bird conservation projects. The plan considered seashore participation in existing bird conservation planning/ implementation efforts associated with the American Bird Conservation Initiative, aligned with Partners in Flight, the North American Waterfowl Management Plan, the U.S. Shorebird Conservation Plan Waterbird Conservation for the Americas, and the South Atlantic Migratory Bird Initiative. The plan included many constructive suggestions about how to strengthen bird conservation and protection at the seashore, as well as excellent appendices with information on the seasonal/year-round status of many species, their breeding periods, priority species by habitat, etc.

National Park Service Landbird Assessment in spring 2010

Following the SECN Landbird Community Monitoring Protocol (Byrne et al. 2014), data on landbirds in Cape Lookout were collected monthly in April–May 2010 at 30 spatially balanced, random locations (Figure 63, Byrne et al. 2011b) using an adaptation of the variable-circular plot (VCP) technique with distance estimation. The overall goal was to establish a baseline for determining trends in landbird species occupancy, distribution, diversity, and community composition.

A total of 646 birds were detected, representing 66 species. All species were native except one, the ring-necked pheasant, which was found at 13% (4 of 30) of the sampling locations. Two species newly reported for the seashore included the northern gannet (*Morus bassarus*) and the tufted titmouse (*Baeolophus bicolor*). The total sample was dominated by red-winged blackbirds (15.2%) and laughing gulls (9.1%). Occupancy was considered to provide insights about species distributions across the seashore and about whether a species was commonly or uncommonly encountered, although it is strongly influenced by detectability (which is affected by habitat features). Red-winged blackbirds occupied 93% of the sampling locations, followed by laughing gulls and willets (77%), and boat-tailed grackles and mourning doves (76%). These five species were the most widely distributed at the seashore. An evaluation of sampling effort relative to the number of species detected indicated that the sample adequately characterized bird fauna diversity. In addition, the species accumulation curve generated from the data had an asymptote at 29 samples, less than the total number of samples collected. This information validated the sample size as acceptable for characterizing bird diversity at the seashore.

A total of 33 species identified by the South Atlantic Migratory Bird Initiative Implementation Plan (USFWS—Watson and Malloy 2006) as priority species were detected during this sampling effort, including the black skimmer, bobolink, brown pelican, brown thrasher, clapper rail, common loon, common tern, dunlin, eastern kingbird, eastern meadowlark, eastern towhee, great egret, greater yellowlegs, gull-billed tern, least tern, lesser yellowlegs, little blue heron, mallard, northern gannet, northern parula, orchard oriole, prairie warbler, red-bellied woodpecker, royal tern, sanderling, sandwich tern, seaside sparrow, sedge wren, tricolored heron, whimbrel, white ibis, willet, and yellow-billed cuckoo.

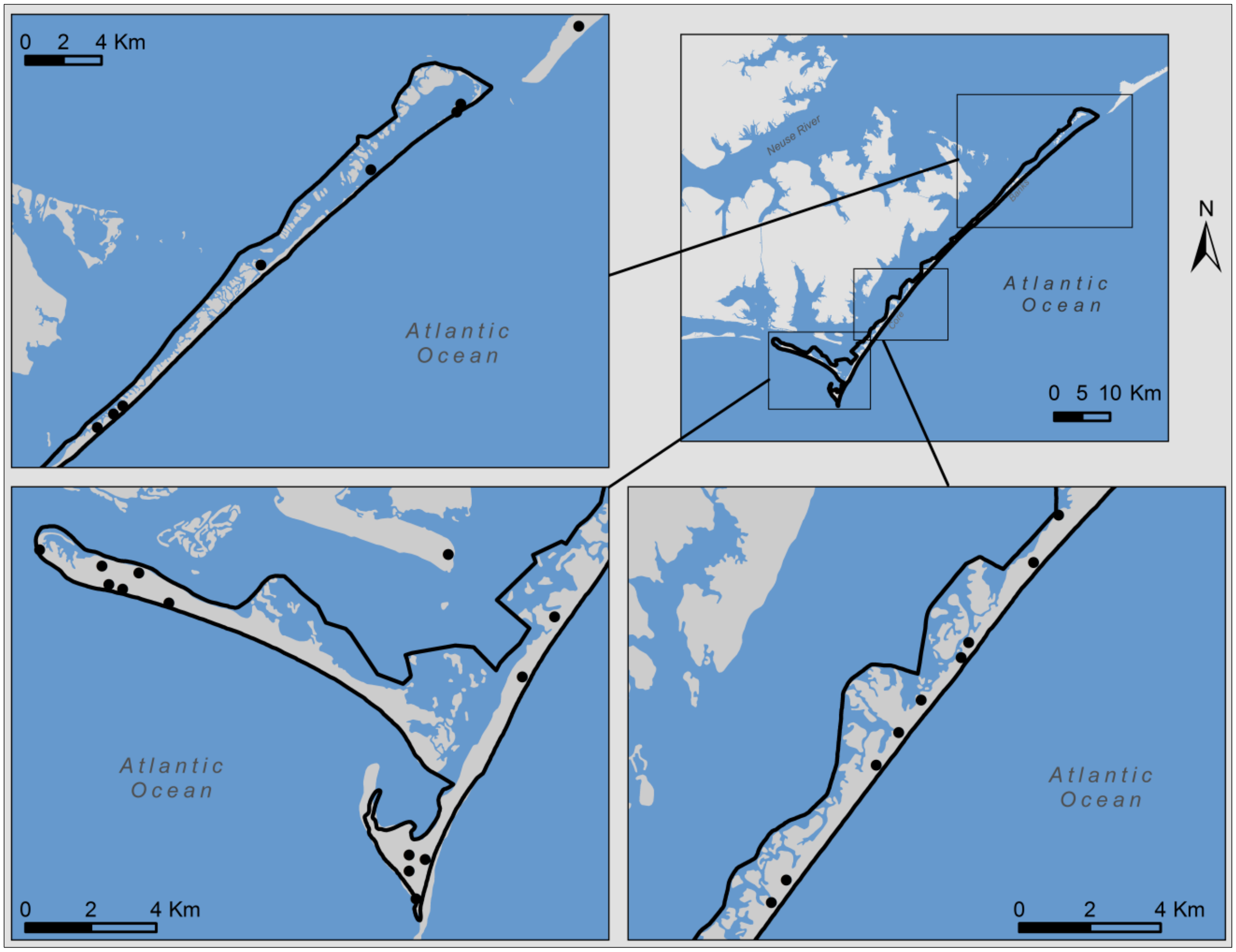

Figure 63. Map showing locations of the 17 spatially balanced, random sampling stations for bird fauna in the northern and central areas of Cape Lookout.

In addition, various species designated by Partners in Flight as high-priority species for the south Atlantic coastal plain were detected during this sampling effort, most prominently the red knot, saltmarsh sharp-tailed sparrow, piping plover, gull-billed tern, common tern, least tern, black skimmer, Wilson's plover, American oystercatcher, black rail, brown-headed nuthatch, Nelson's sharp-tailed sparrow, Wilson's plover, seaside sparrow, white ibis, American black duck, clapper rail, short-eared owl, and many migrant passerines and shorebirds.

Diversity indices calculated from the data were selected to reflect community composition and structure (number of species and number of individuals, respectively), including species richness and evenness estimates. Rank-abundance plots, frequency distributions, and other descriptive approaches were used to examine the abundance distributions and patterns in the dataset, and to evaluate the utility of selected indices as well as abundance equitability among species. The data were best fit by a log-series abundance model. The dispersion (variance/mean) suggested that most species tend to be aggregated, expected due to the variable distribution of species-specific habitat types in Cape Lookout. The observed native-species richness (S_{obs}) was 65 (95% CI: 57.12, 72.87).

Mammals

Upland mammal species are somewhat limited in number on barrier islands because of difficulty of access from mainland areas, and limited diversity of vegetation (NPS 2007c). The only large animals present in the seashore are the wild horses on Shackleford Banks, and occasionally deer and coyotes which are found throughout the seashore (NPS 2007c). According to NPS data, 25 species of mammals have been documented on seashore property based on tangible evidence, and 40 species are listed as possibly occurring in the park (Webster 2010, NPS 2013c). Most are terrestrial and wetland or freshwater/estuarine taxa, but two marine mammals (finback whales and harbor seals) are also included. One species included in the NPS Certified Species List (NPS 2013c), the evening bat, has not actually been documented in the seashore but there is a high probability that it occurs there (Webster 2010).

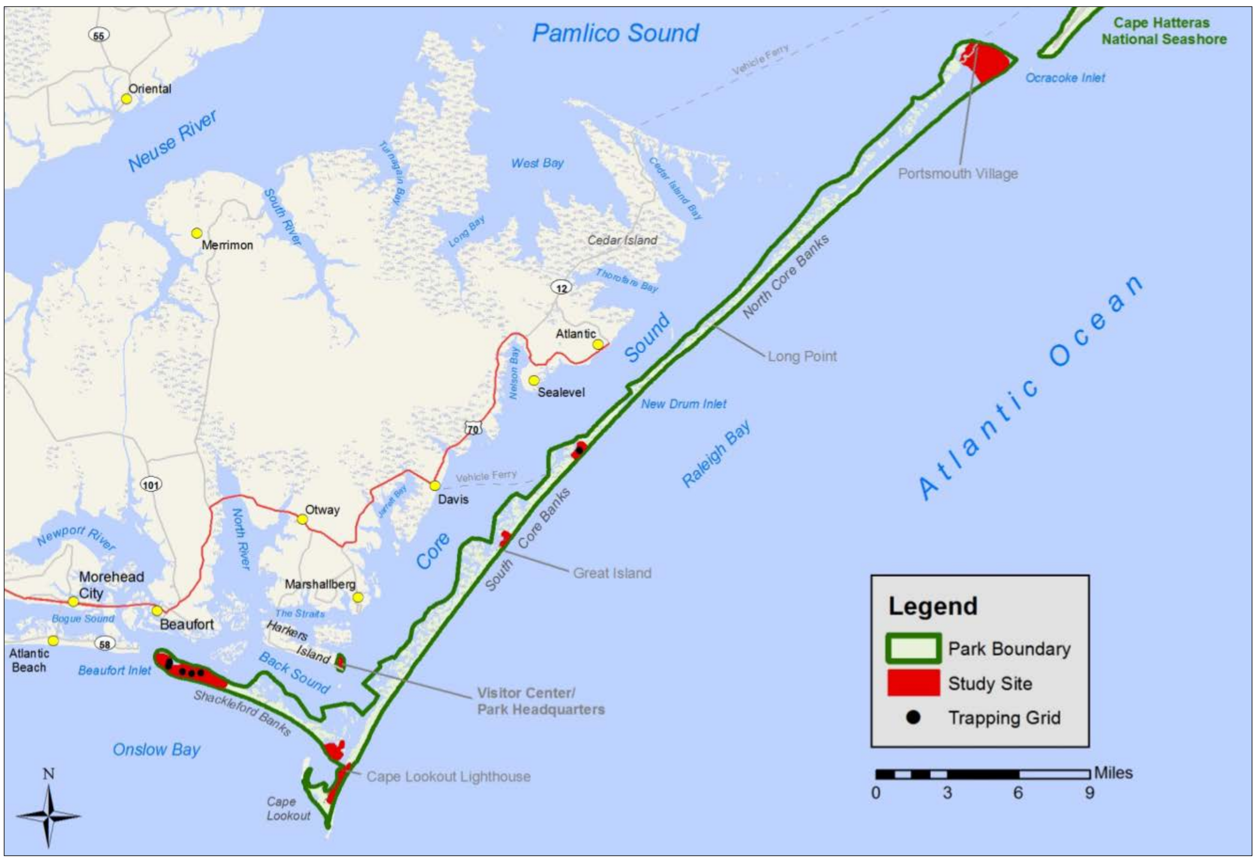

Figure 64. Map of study sites used in the 2005 survey of mammalian species at Cape Lookout (Webster 2010).

Webster (2010) conducted a field survey of mammalian species in Cape Lookout from 25 June to 5 November 2005, including seven man-days (Figure 64). The field work focused mostly on extensive surveying for spoor in the Portsmouth Village area, the Cape Lookout region, and both ends of Shackelford Banks. Two man-nights were also included to survey bats at Mullet Pond in western Shackleford Banks (Figure 3). Five major terrestrial habitats for mammals were considered, including dunes and overwash terraces, maritime forests and shrub thickets, swales and ponds, estuarine marshes, and disturbed habitats as out-buildings and piles of debris. Seventeen species of terrestrial or freshwater wetland mammals were documented in the seashore during the survey. Three additional species (silver-haired bat, hoary bat, and evening bat) are widely distributed in the southeastern United States and were considered to "probably occur" at Cape Lookout.

Species of Special Concern

General Information about Species of Special Concern at Cape Lookout

As stated, at least 82 SSCs are reported to occur in Cape Lookout, including 13 vascular plant species, four fish, two amphibians, 11 reptiles, and 52 birds (Table 35; Appendix C). The federal Endangered Species Act of 1973 (ESA: 7 U.S.C. §136, 16 U.S.C. § 1531) includes a set of listing status levels). Two other ranking systems are also instructive in considering species of concern in Cape Lookout; both are conservation status ranks that are assessed and determined by scientists at NatureServe. The seashore is world-renowned especially as a haven for sea turtles, piping plovers, and various other shorebirds and seabirds. It has an interim Protected Species Management Plan/Environmental Assessment (NPS 2006a) where the monitoring procedures are also described. The National Park Service is expected to report annually on threatened and endangered species populations as directed by the Recovery Plans and the ESA. Park staff produce excellent annual reports on the status of selected SSCs, summarized below. Monitoring of SSCs at the seashore has focused on sea turtle nesting activities (since the 1990s), piping plover nesting activities (since 1989), American oystercatcher nesting activities (since 1995), sea beach amaranth (since 1992), seasonal migration surveys of red knots and Wilson's plovers (since 2006), colonial nesting shorebird areas (since 2006), and sea turtle and marine mammal strandings (since 1989).

Table 35. The N.C. Wildlife Resource Commission evaluation system for faunal species of special concern (SSCs). Note that n.a.—not applicable. "Status" indicates the degree of protection (if any), based on rarity of a species; "rank" is a numerical scale of the rarity of a species, regardless of legal protection (LeGrand et al. 2013).

Status Code	Status	Definition
E	Endangered	"Any native or once-native species of wild animal whose continued existence as a viable component of the State's fauna is determined by the Wildlife Resources Commission to be in jeopardy or any species of wild animal determined to be an 'endangered species' pursuant to the Endangered Species Act." (Article 25 of Chapter 113 of the General Statutes; 1987).
T	Threatened	"Any native or once-native species of wild animal which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range, or one that is designated as a threatened species pursuant to the Endangered Species Act." (Article 25 of Chapter 113 of the General Statutes; 1987).
SC	Special Concern	"Any species of wild animal native or once-native to North Carolina which is determined by the Wildlife Resources Commission to require monitoring but which may be taken under regulations adopted under the provisions of this Article." (Article 25 of Chapter 113 of the General Statutes; 1987).
SR	Significantly Rare	Any species which has not been listed by the N.C. Wildlife Resources Commission as an Endangered, Threatened, or Special Concern species, but which exists in the state (or recently occurred in the state) in small numbers and has been determined by the N.C. Natural Heritage Program to need monitoring. (This is a N.C. Natural Heritage Program designation.) Significantly Rare species include "peripheral" species, whereby North Carolina lies at the periphery of the species' range (such as Hermit Thrush), as well as species of historical occurrence with some likelihood of re-discovery in the state. Species considered extirpated in the state, with little likelihood of re-discovery, are given no N.C. Status (unless already listed by the N.C. Wildlife Resources Commission as E, T, or SC).
W	Watch List	Any other species believed to be rare and of conservation concern in the state but not warranting active monitoring at this time (see the Watch List section for a more complete discussion). (This is a N.C. Natural Heritage Program designation.)
G	n.a.	Species is a game animal or a furbearer, and therefore (by law) cannot be listed for State protection as E, T, or SC.

Table 36. The N.C. State ranking system for species of special concern (SSCs), developed by the NCDENR Natural Heritage Program and NatureServe as summarized in LeGrand et al. (2013).

Rank	Number of Extant Occurrences	Description
S1	1–5	Critically imperiled—Critically imperiled in North Carolina due to extreme rarity or some factor(s) making it especially vulnerable to extirpation (local extinction) from the state. Typically 5 or fewer occurrences or very few remaining individuals (<1,000).
S2	6–20	Imperiled—Imperiled in North Carolina due to rarity or some factor(s) making it very vulnerable to extirpation from the state. Typically 6 to 20 occurrences or few remaining individuals (1,000 to 3,000).
S3	21–100	Vulnerable—Vulnerable to extinction in North Carolina either because rare or uncommon, or found only in a restricted range (even if abundant at some locations), or due to other factors making it vulnerable to extirpation. Typically 21 to 100 occurrences or between 3,000 and 10,000 individuals.
S4	100–1000	Apparently secure—Apparently secure and widespread in North Carolina, usually with more than 100 occurrences and more than 10,000 individuals.
S5	1000 +	Secure—Common, widespread, and abundant in North Carolina. Essentially ineradicable under present conditions. Typically with considerably more than 100 occurrences and more than 10,000 individuals.
SH	0 ?	Historical—Of historical occurrence in North Carolina, with some expectation that it may be rediscovered. Its presence may not have been verified in the past 20 years. Upon verification of an extant occurrence, SH-ranked elements would typically receive an S1 rank. Note: an element is not automatically assigned an SH (or SX) rank if it has not been verified in the past 20 years; some effort must have been made to locate or relocate occurrences.
SX	0	Presumed extirpated—Believed to be extirpated in North Carolina. Has not been located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered.
SU	Unknown	Unrankable—Currently unrankable in North Carolina due to lack of information or substantially conflicting information about status or trends. Need more information.
SNR	Unknown	Not Ranked—Rank in N.C. not yet assessed.
SNA	N/A	Not Applicable—A conservation status rank is not applicable because the element is not a suitable target for conservation for one of the following reasons: Hybrid—an interspecific hybrid without conservation value; Exotic Origin—not native to North Carolina; Accidental/nonregular—outside usual range and not regularly found in North Carolina; Not confidently present—never documented as present in North Carolina; Synonym—the taxon is not recognized by the N.C. Natural Heritage Program.
_B	1–?	Rank of the breeding population in the state. Used for migratory species only.
_N	1–?	Rank of the non-breeding population in the state. Used for migratory species only.
-?	---	Uncertain—Denotes inexact or uncertain numeric rank.

Table 37. Complete list of 82 species of concern (SSCs) reported to occur in Cape Lookout [FSC—federal SoC]. From NatureServe (2007), the North Carolina Department of Agriculture and Consumer Services" (2010) Protected Plant List (NCDA&CS 2010), the Natural Heritage Program (Buchanan and Finnegan 2010), the U.S. Fish and Wildlife Service (2010), LeGrand et al. (2013), and NPS (2013c). Note that dune habitat is included within wetlands.

Category	Species (common name)	General Habitat	State/Federal Status[a]	State/Global Rank[b,c]
Vascular Plants	*Amaranthus pumilus* (seabeach amaranth, seaside amaranth)	wetland	T / T	S2 / G2
	Arenaria lanuginosa[d] (spreading sandwort)	wetland	SR-P / ---	S1 / G5T4T5
	Clematis catesbyana (satincurls, coastal virgin's-bower)	wetland	SR-P / ---	S2 / G4G5
	Corallorrhiza wisteriana (coralroot, spring coralroot)	wetland	SR-O / ---	S1S2 / G5
	Cyperus tetragonus (fourangle flatsedge)	wetland	SR-P / ---	S1 / G4?
	Eleocharis robbinsii (Robbins spikerush)	wetland	SR-P / ---	S2 / G4G5
	Myrica gale (sweetgale)	wetland	E / ---	S1 / G5
	Parietaria praetermissa (large-seed pellitory, clustered pellitory)	wetland	FSC / E	S2 / G3
	Pityopsis graminifolia var. *graminifolia* (silkgrass, narrowleaf silkgrass)	terrestrial	SR-P / ---	S1 / G5T4
	Polygonum glaucum (seaside knotweed)	terrestrial	SR-T / ---	S1 / G3
	Rhynchospora odorata (fragrant beaksedge)	wetland	E / ---	S1 / G4
	Spiranthes laciniata (lacelip-ladies'-tresses)	wetland	SR-P / ---	S2 / G4G5
	Sporobolus virginicus (seashore dropseed, saltmarsh dropseed)	wetland	SR-P / ---	S1 / G5
Fish	*Acipenser oxyrinchus* (Atlantic sturgeon, Gulf sturgeon)[e]	marine/estuarine	SC / E	S3 / G3
	Anguilla rostrata (American eel)	catadromous—freshwater, marine	---- / FSC	---

[a] Federal rank definitions: T—threatened (USFWS); T-USDA—threatened (USDA); FSC—Federal species of concern [SSC] (USFWS).

[b] North Carolina rank definitions (S, state): S1—critically imperiled, S2—Imperiled, and S3—Vulnerable; SR-L—significantly rare—limited (to North Carolina and adjacent states (endemic or near endemic); SR-P—Significantly Rare—peripheral; SR-O—range is sporadic and is not described in the other Significantly Rare categories; W1—/ Watch List, rare but relatively secure; W7—Watch list, rare and poorly known.

[c] Global Rank system (GRank—from nonprofit organizations): G1—critically imperiled; G2—imperiled, G3—vulnerable, G4—apparently secure, G5—secure. T1-5 series can be used together with the GRank system; that is, infraspecific taxa (subspecies, plant varieties, etc. below the species level) can be assigned global T-ranks. The.numbers for T designations are: 1—critically imperiled; 2—imperiled; 3—vulnerable; 4—apparently secure (uncommon but not rare, but with some cause for long-term concern); and 5—secure.

[d] *Arenaria lanuginosa* var. *lanuginosa* is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

[e] Subspecies *Acipenser oxyrinchus oxyrinchus* is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

[f] Subspecies *Malaclemys terrapin terrapin*, the northern diamondback terrapin, is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

[g] Subspecies *Caldris canutus rufa* is a proposed FSC (P). The U.S. Shorebird Conservation Plan lists this species as of "high concern," whereas the IUCN Red List (International Union for Conservation of Nature and Natural Resources) indicates that it is of "least concern."

[h] Subspecies *Passerina ciris ciris* is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

[i] *Setophaga coronata* is listed as the synonym *Dendroica coronata* in the NPS Certified Species List (NPS 2013c).

[j] Subspecies *Setophaga virens waynei* is the specific listing of the federal SSC.

[k] Subspecies *Sterna dougallii dougallii* is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

Table 37 (continued). Complete list of 82 species of concern (SSCs) reported to occur in Cape Lookout [FSC—federal SoC]. From NatureServe (2007), the North Carolina Department of Agriculture and Consumer Services" (2010) Protected Plant List (NCDA&CS 2010), the Natural Heritage Program (Buchanan and Finnegan 2010), the U.S. Fish and Wildlife Service (2010), LeGrand et al. (2013), and NPS (2013c). Note that dune habitat is included within wetlands.

Category	Species (common name)	General Habitat	State/Federal Status[a]	State/Global Rank[b,c]
Fish (continued)	*Fundulus confluentus* (marsh killifish)	freshwater, estuarine	W2 / ---	S3 / G5
	Fundulus luciae (spotfin killifish)	freshwater, estuarine	W2 / ---	S3 / G4
Amphibians	*Ambystoma mabeei* (Mabee's salamander)	freshwater / terrestrial	SR / ---	S2 / G4
	Bufo quercicus (oak toad)	freshwater / terrestrial	SR / ---	S3 / G5
Reptiles	*Caretta caretta* (loggerhead sea turtle)	marine; nests on beaches	T / T	S3B, S3N / G3
	Chelonia mydas (green sea turtle)	marine; nests on beaches	T / T	S1B, SUN / G3
	Clemmys guttata (spotted turtle)	freshwater wetlands, vernal pools, small streams	W1 / ---	S3 / G5
	Dermochelys coriacea (leatherback sea turtle)	marine; nests on beaches	E / E	S1B, SUN / G2
	Eretmochelys imbricata (hawksbill sea turtle, carey)	marine; nests on beaches	E / E	SUN / G3
	Lampropeltis getula sticticeps (Outer Banks kingsnake)	barrier islands—edges of marshes and swamps	SC / ---	S2 / G5T2Q
	Lepidochelys kempii (Atlantic ridley, Kemp's ridley)	marine; nests on beaches	E / E	S1B, SUN / G1
	Malaclemys terrapind (diamondback terrapin)[f]	coastal marine	SC / FSC in part	S3 / G4
	Nerodia sipedon williamengelsi (Carolina water snake)	near freshwaters and freshwater marshes	SC / ---	S3 / G5T3
	Rhadinaea flavilata (pine woods snake)	mainly damp pine flatwoods or nearby hardwood hammocks; along wooded edges of wet prairies; dry live-oak woodlands	W2 / ---	S3 / G4
	Sistrurus miliarius (pigmy rattlesnake)	flatwoods, sandhills, mixed forests, flood- plains; also near freshwaters (lakes, marshes	SC / ---	S3 / G5

[a] Federal rank definitions: T—threatened (USFWS); T-USDA—threatened (USDA); FSC—Federal species of concern [SSC] (USFWS).

[b] North Carolina rank definitions (S, state): S1—critically imperiled, S2—Imperiled, and S3—Vulnerable; SR-L—significantly rare—limited (to North Carolina and adjacent states (endemic or near endemic); SR-P—Significantly Rare—peripheral; SR-O—range is sporadic and is not described in the other Significantly Rare categories; W1—/ Watch List, rare but relatively secure; W7—Watch list, rare and poorly known.

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[d] *Arenaria lanuginosa* var. *lanuginosa* is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

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[f] Subspecies *Malaclemys terrapin terrapin*, the northern diamondback terrapin, is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

[g] Subspecies *Caldris canutus rufa* is a proposed FSC (P). The U.S. Shorebird Conservation Plan lists this species as of "high concern," whereas the IUCN Red List (International Union for Conservation of Nature and Natural Resources) indicates that it is of "least concern."

[h] Subspecies *Passerina ciris ciris* is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

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[j] Subspecies *Setophaga virens waynei* is the specific listing of the federal SSC.

[k] Subspecies *Sterna dougallii dougallii* is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

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Category	Species (common name)	General Habitat	State/Federal Status[a]	State/Global Rank[b,c]
Birds	*Accipiter striatus* (sharp-shinned hawk)	forests and woodlands	SR / ---	S2?B,S4N / G5
	Ammodramus caudacutus (saltmarsh sparrow)	salt marshes; sometimes fresh marshes or fields adjacent to coast	W3 / ---	SUB,S4N / G4
	Ammodramus savannarum (grasshopper sparrow)	moist grasslands	W1,W5 / ---	S3B,S1N / G5
	Anas discors (blue-winged teal)	saltmarshes with adjoining ponds or streams	W3 / ---	SHB,S2N / G5
	Asio flammeus (short-eared owl)	open, treeless coastal marshes and bogs	W3 / ---	SUB,S3N / G5
	Botaurus lentiginosus (American bittern)	fresh or brackish marshes	SR / ---	S1B,S3N / G4
	Calidris canutus[g] (red knot)	intertidal beaches with significant wave action	--- / proposed FSC	---
	Catharus guttatus (hermit thrush)	coastal scrubs	SR / ---	S2B,S5N / G5
	Catharus ustulatus (Swainson's thrush)	dense wooded areas	SR / ---	S1B,S5N / G5
	Certhia americana (brown creeper)	pine savannah-like areas	SC / ---	S3B,S5N / G5
	Charadrius melodus (piping plover)	marine sandy shores, beaches	T / T	S1B, S1N / G3
	Charadrius wilsonia (Wilson's plover)	sand beaches, intertidal sand flats	SC / ---	S2B / G5
	Chondestes grammacus (lark sparrow)	saltmarshes, coastal dunes	SR / ---	S1B / G5
	Circus cyaneus (northern harrier)	wetland meadows, marshes, tidal swamps	SR / ---	S1B,S4N / G5
	Dolichonyx oryzivorus (bobolink)	freshwater marshes and meadows, saltmarshes	SR / ---	S1B / G5
	Egretta caerulea (little blue heron)	barrier island forests or thickets	--- / SC	S3B,S3N / G5
	Egretta thula (snowy egret)	barrier island forests or thickets	--- / SC	S2S3B,S3N / G5

[a] Federal rank definitions: T—threatened (USFWS); T-USDA—threatened (USDA); FSC—Federal species of concern [SSC] (USFWS).

[b] North Carolina rank definitions (S, state): S1—critically imperiled, S2—Imperiled, and S3—Vulnerable; SR-L—significantly rare—limited (to North Carolina and adjacent states (endemic or near endemic); SR-P—Significantly Rare—peripheral; SR-O—range is sporadic and is not described in the other Significantly Rare categories; W1—/ Watch List, rare but relatively secure; W7—Watch list, rare and poorly known.

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[g] Subspecies *Caldris canutus rufa* is a proposed FSC (P). The U.S. Shorebird Conservation Plan lists this species as of "high concern," whereas the IUCN Red List (International Union for Conservation of Nature and Natural Resources) indicates that it is of "least concern."

[h] Subspecies *Passerina ciris ciris* is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

[i] *Setophaga coronata* is listed as the synonym *Dendroica coronata* in the NPS Certified Species List (NPS 2013c).

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Category	Species (common name)	General Habitat	State/Federal Status[a]	State/Global Rank[b,c]
Birds (continued)	*Egretta tricolor* (tricolored heron)	salt marshes, marine coastal lagoons, mudflats, tidal creeks; forests or thickets on maritime islands	--- / SC	S3B, S3N / G5
	Elanoides forficatus (swallow-tailed kite)	fresh and brackish marshes and swamp forests	SR / FSC	S1B / G5
	Eudocimus albus (white ibis)	shallow ponds or freshwater wetlands	W2 / ---	S3B,S3N / G5
	Falco peregrinus (peregrine falcon)	coastal ponds and mudflats	E / ---	S1B,S2N / G4
	Falco sparverius (American kestrel)	open country; nests in cavities (large trees)	W1, W5 / ---	S3B, S5N / G5
	Gelochelidon nilotica (gull-billed tern)	saltmarshes, fields; sandy beaches	T/---	S1/G5
	Haematopus palliatus (American oystercatcher)	estuaries, oyster beds, mudflats	SC / ---	S2S3B, S3N / G5
	Haliaeetus leucocephalus (bald eagle)	mature forests near large water bodies; lakes and sounds	T / ---	S3,S3N / G5
	Himantopus mexicanus (black-necked stilt,Hawaiian stilt)	sandy beaches (exposed or protected); fresh or brackish ponds	SR / ---	S1B / G5
	Ixobrychus exilis (least bittern)	tall, dense stands of emergent freshwater or brackish marsh vegetation	SC / ---	S2S3B / G5
	Laterallus jamaicensis (black rail)	brackish marshes; rarely (breeding season) freshwater marshes	SC / FSC	S2S3B, S2N / G4
	Lophodytes cucullatus (hooded merganser)	coastal marshes, wooded ponds	W3 / ---	S1B,S4N / G5
	Nyctanassa violacea (yellow-crowned night-heron)	scrub/shrub thickets, forested wetlands, tidal creek and tide pool shores, mud flats	SR / ---	S2B / G5
	Nycticorax nycticorax (black-crowned night-heron)	coastal dune forests, scrub thickets	W1 / ---	S3B,S3N / G5
	Passerculus sandwichensis (savannah sparrow)	saltmarsh edges, grasslands	SR / ---	S2B,S5N / G5

[a] Federal rank definitions: T—threatened (USFWS); T-USDA—threatened (USDA); FSC—Federal species of concern [SSC] (USFWS).

[b] North Carolina rank definitions (S, state): S1—critically imperiled, S2—Imperiled, and S3—Vulnerable; SR-L—significantly rare—limited (to North Carolina and adjacent states (endemic or near endemic); SR-P—Significantly Rare—peripheral; SR-O—range is sporadic and is not described in the other Significantly Rare categories; W1—/ Watch List, rare but relatively secure; W7—Watch list, rare and poorly known.

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[j] Subspecies *Setophaga virens waynei* is the specific listing of the federal SSC.

[k] Subspecies *Sterna dougallii dougallii* is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

Table 37 (continued). Complete list of 82 species of concern (SSCs) reported to occur in Cape Lookout [FSC—federal SoC]. From NatureServe (2007), the North Carolina Department of Agriculture and Consumer Services" (2010) Protected Plant List (NCDA&CS 2010), the Natural Heritage Program (Buchanan and Finnegan 2010), the U.S. Fish and Wildlife Service (2010), LeGrand et al. (2013), and NPS (2013c). Note that dune habitat is included within wetlands.

Category	Species (common name)	General Habitat	State/Federal Status[a]	State/Global Rank[b,c]
Birds (continued)	*Passerina ciris*[h] (painted bunting)	maritime shrub thickets and forest edges (breeding season only)	SC / FSC	S3B / G5T3T4
	Pelecanus occidentalis (brown pelican)	waterfront coastal areas (brackish or marine beaches, lagoons)	SR / ---	S3B,S4N / G4
	Phalacrocorax auritus (double-crested cormorant)	shallow brackish or freshwaters	SR / ---	S1B,S5N / G5
	Plegadis falcinellus (glossy ibis)	maritime forests or thickets	SC / ---	S1S2B / G5
	Podilymbus podiceps (pied-billed grebe)	fresh or brackish ponds, wetlands	W2 / ---	S3B,S5N / G5
	Rallus elegans (king rail)	saltmarshes	W1,W3 / ---	S3B,S3N / G4
	Rallus limicola (Virginia rail)	fresh and brackish marshes	W3 / ---	S3B,S5N / G5
	Regulus satrapa (golden-crowned kinglet)	swamp and scrub habitats	W2,W5 / ---	S3S4B,S5N / G5
	Riparia riparia (bank swallow)	soft, sandy banks along coastal areas; saltmarshes, grasslands	SR / ---	S1B / G5
	Rynchops niger (black skimmer)	sand flats on barrier islands	SC / ---	S2B,S3N / G5
	Setophaga coronata (yellow-rumped warbler)[i]	maritime forest, shrub habitat	SR / ---	S1B,S5N / G5
	Setophaga virens (black-throated green warbler)[j]	non-alluvial forested wetlands or transitional zones between uplands and wetlands	SR / FSC	S2S3B / G5T3
	Sitta canadensis (red-breasted nuthatch)	coastal conifer and scrub habitats	W2,W5 / ---	S3B,S4N / G5
	Sphyrapicus varius (yellow-bellied sapsucker)	coastal scrub habitats, maritime forests	W2 / ---	S3B,S5N / G5
	Sterna dougallii (roseate tern)[k]	sand flats on maritime islands	E / E	SHB / G4
	Sterna forsteri (Forster's tern)	fresh and brackish marshes, saltmarshes	W2 / ---	S3B,S5N / G5

[a] Federal rank definitions: T—threatened (USFWS); T-USDA—threatened (USDA); FSC—Federal species of concern [SSC] (USFWS).

[b] North Carolina rank definitions (S, state): S1—critically imperiled, S2—Imperiled, and S3—Vulnerable; SR-L—significantly rare—limited (to North Carolina and adjacent states (endemic or near endemic); SR-P—Significantly Rare—peripheral; SR-O—range is sporadic and is not described in the other Significantly Rare categories; W1—/ Watch List, rare but relatively secure; W7—Watch list, rare and poorly known.

[c] Global Rank system (GRank—from nonprofit organizations): G1—critically imperiled; G2—imperiled, G3—vulnerable, G4—apparently secure, G5—secure. T1-5 series can be used together with the GRank system; that is, infraspecific taxa (subspecies, plant varieties, etc. below the species level) can be assigned global T-ranks. The.numbers for T designations are: 1—critically imperiled; 2—imperiled; 3—vulnerable; 4—apparently secure (uncommon but not rare, but with some cause for long-term concern); and 5—secure.

[d] *Arenaria lanuginosa* var. *lanuginosa* is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

[e] Subspecies *Acipenser oxyrinchus oxyrinchus* is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

[f] Subspecies *Malaclemys terrapin terrapin*, the northern diamondback terrapin, is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

[g] Subspecies *Caldris canutus rufa* is a proposed FSC (P). The U.S. Shorebird Conservation Plan lists this species as of "high concern," whereas the IUCN Red List (International Union for Conservation of Nature and Natural Resources) indicates that it is of "least concern."

[h] Subspecies *Passerina ciris ciris* is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

[i] *Setophaga coronata* is listed as the synonym *Dendroica coronata* in the NPS Certified Species List (NPS 2013c).

[j] Subspecies *Setophaga virens waynei* is the specific listing of the federal SSC.

[k] Subspecies *Sterna dougallii dougallii* is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

Table 37 (continued). Complete list of 82 species of concern (SSCs) reported to occur in Cape Lookout [FSC—federal SoC]. From NatureServe (2007), the North Carolina Department of Agriculture and Consumer Services" (2010) Protected Plant List (NCDA&CS 2010), the Natural Heritage Program (Buchanan and Finnegan 2010), the U.S. Fish and Wildlife Service (2010), LeGrand et al. (2013), and NPS (2013c). Note that dune habitat is included within wetlands.

Category	Species (common name)	General Habitat	State/Federal Status[a]	State/Global Rank[b,c]
	Sterna hirundo (common tern)	sand flats on barrier islands	SC / ---	S2B / G5
	Troglodytes troglodytes (winter wren)	coastal grassland and shrub areas	W2,W5 / ---	S3B,S5N / G5
	Tyto alba (barn owl)	coastal grasslands and wetland edges	SR / ---	S2S3B,S3N / G5
	Vermivora pinus (blue-winged warbler)	shrub thickets	SR / ---	S2B / G5

[a] Federal rank definitions: T—threatened (USFWS); T-USDA—threatened (USDA); FSC—Federal species of concern [SSC] (USFWS).

[b] North Carolina rank definitions (S, state): S1—critically imperiled, S2—Imperiled, and S3—Vulnerable; SR-L—significantly rare—limited (to North Carolina and adjacent states (endemic or near endemic); SR-P—Significantly Rare—peripheral; SR-O—range is sporadic and is not described in the other Significantly Rare categories; W1—/ Watch List, rare but relatively secure; W7—Watch list, rare and poorly known.

[c] Global Rank system (GRank—from nonprofit organizations): G1—critically imperiled; G2—imperiled, G3—vulnerable, G4—apparently secure, G5—secure. T1-5 series can be used together with the GRank system; that is, infraspecific taxa (subspecies, plant varieties, etc. below the species level) can be assigned global T-ranks. The.numbers for T designations are: 1—critically imperiled; 2—imperiled; 3—vulnerable; 4—apparently secure (uncommon but not rare, but with some cause for long-term concern); and 5—secure.

[d] *Arenaria lanuginosa* var. *lanuginosa* is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

[e] Subspecies *Acipenser oxyrinchus oxyrinchus* is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

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[g] Subspecies *Caldris canutus rufa* is a proposed FSC (P). The U.S. Shorebird Conservation Plan lists this species as of "high concern," whereas the IUCN Red List (International Union for Conservation of Nature and Natural Resources) indicates that it is of "least concern."

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[j] Subspecies *Setophaga virens waynei* is the specific listing of the federal SSC.

[k] Subspecies *Sterna dougallii dougallii* is the specific listing of the federal SSC; the listing on the NPS Certified Species List (NPS 2013c) is given above.

It is important to note that, because of their migration patterns, these species cannot be protected by NPS efforts alone; the populations sustain many pressures outside of park boundaries. All of these species are in danger because of habitat loss and habitat degradation. In addition, sea turtles have been heavily impacted by commercial fishing, to the extent that commercial fishers have been required by state regulations (since the early 1990s) to use turtle exclusion devices in their nets—but these devices are only partially effective (SFCC 2016). Even at the seashore there are pressures on the populations of these SSCs by ORVs, light pollution (especially a threat to sea turtles), and predators (below). Shorelines are closed to motor vehicles seasonally or temporarily to protect SSCs, except for Shackleford Banks (to protect SSCs and wild horses), Ramp 41a to Ramp 41b (lighthouse swim beach), Power Squadron Spit west of the Jetty (to protect SSCs), and Portsmouth Village (to protect cultural resources and SSCs). Seashore staff go to great lengths to try to provide the most protection possible for SSCs within park boundaries, and work in partnership with various state and federal agencies. Each year data are collected, analyzed, and presented to management, in hopes of better protecting SSC populations at the seashore.

Sea Turtle Nesting Success

Five endangered or threatened sea turtle species occur at Cape Lookout (NPS 2002a, 2005a). Cape Lookout is a significant northern nesting beach, and it supports among the highest number of loggerhead sea turtles in North Carolina (NPS 2014a). Nesting habitat is also afforded for leatherback, green, and Kemp's ridley sea turtles. Seashore beaches have characteristic preferred nesting habitat for sea turtles, including a moderate dune system; wide, gently sloped, natural beaches (not "renourished") with little or no vegetation; and sand of appropriate size and texture (NPS 2005a).

Sea turtles at Cape Lookout are threatened by ORVs, light pollution, and predation by mammals (e.g., raccoons and red foxes), birds, and ghost crabs; in addition, fire ants can kill hatchlings about to emerge from the nest cavity. Exclosures and other efforts are used by park staff to prevent predation; for example, raccoon predation is discouraged by placing wire screens, anchored by rebar, over all nests. Storms can destroy nests due to flooding or burial by eroded sand. Nests in locations subject to repeated flooding are relocated to higher-elevation areas on the primary dune. Nests can also be destroyed by indirect effects of storms through beach erosion that reduces available, suitable habitat. Various human activities can cause sea turtle decline: Crowding of nesting beaches by pedestrians can disturb nesting females and prevent egg-laying, and use of flashlights and campfires, ORV headlights, and other light pollution can cause failure of hatchlings to find the sea (NPS 2005a). In an attempt to prevent light pollution, camping and campfires are not permitted in the closure areas. Off-road vehicles can also run over nests, hatchlings, adult females, and live stranded turtles; leave ruts that trap hatchlings that are trying to reach the ocean; and disturb adult females so that they do not nest. Vehicle re-routings are used to reduce ORV threats, so that the major remaining threats to nesting success are tidal flooding and predation. The vehicle closures provide a rut-free corridor from the nest site to the ocean, and prevent hatchlings from being run over or becoming entrapped in tire ruts and dying from desiccation or predation. Increased human presence can also coincide with an increase in the presence of domestic pets that attack the nests, and an increase in litter that can attract wild predator (NPS 2005a).

Cape Lookout has monitored sea turtle populations since 1976, when a baseline study was initiated on South Core Banks. Nesting activities have been monitored by the National Park Service since the 1990s, and strandings have been tracked since 1989 (NPS 2014a). Surveying and management efforts follow the guidelines set forth in individual sea turtle recovery plans (National Marine Fisheries Service and U.S. Fish and Wildlife Service 1991, 1992) and the North Carolina Wildlife Resources Commission (NC WRC 2003) (and see NPS 2005a, 2006a). Park staff use the USFWS Index Beach standards as the protocol for sea turtle monitoring. Three categories of nesting activities are tracked: “Nests” are confirmed by digging to locate the egg chamber or potential nest; “crawls” are tracks above the high tide line with no digging by the female; and “digs” are activities where the sand has been disturbed and eggs potentially were laid but confirmatory eggs could not be found (NPS 2005a). Since 1984 the seashore has conducted daytime monitoring to document strandings, protect nest sites, relocate nests that are threatened with flooding, and protect hatchlings. Seashore staff and volunteer assistants search North and South Core Banks ocean shores daily, and Shackleford Banks ocean shores three times a week, for sea turtle nesting activity from May through November. The procedures (outlined in NPS 2006a as mentioned) follow the U.S. Fish and Wildlife Service Index Nesting Beach program, which has been used consistently by the National Park Service since 1990. If a nest fails to show hatching activity after 75–80 days, the site is excavated to determine success. Data are recorded in detail, and strandings are also documented. Summaries of data considered in developing indicators to assess sea turtle condition in Cape Lookout are given in Tables 38 and 39, and in Figure 65).

Table 38. Sea turtle nesting at Cape Lookout (2000–2013). From NPS (2000b, 2001b, 2002a, 2003a, 2004a, 2005b, 2006c, 2007d, 2008a, 2009b, 2010a, 2011c, 2012c, 2013d, 2014e). Efforts to document violations vary.

Year	Total Nests (% of State Total)[a]	Mean Clutch	Incubation (avg. # days)	Hatchling Success[b]	Emergence Success[c]	Predation of Nests[d]	Crawls	ORV Violations (recorded)
2000	190 (N.A.)	111	67	N.A.	65 %	12 L; 18 D	135	70
2001	119 (N.A.)	113	65	> 75 %	79 %	6 L; 9 D	51	45
2002	123 (N.A.)	119	61	> 75 %	79 %	2 L; 7 D	79	23
2003	161 (N.A.)	119	65	60 %	61 %	13 D	129	39
2004	77 (N.A.)	104	64	< 60%	43 %	2 D	107	10
2005	142 (N.A.)	111	60	< 60 %	53 %	3 L; 17 D	148	45
2006	131 (N.A.)	125	61	> 60 %	73 %	2 D	127	9
2007	85 (N.A.)	109	60	76 %	72 %	22 D	86	84
2008	107 (16%)	111	60	64 %	62 %	1 L; 20 D	116	15
2009	141 (20%)	116	64	51 %	50 %	17 D	157	20
2010	157 (21%)	105	57	54 %	54 %	8 D	134	12
2011	157 (20%)	114	56	N.A.	63 %	1 L; 8 D	161	2
2012	228 (27%)	111	62	N.A.	64 %	17 D	223	4
2013	192 20%)	108	64	N.A.	68 %	1 D	182	0

[a] The percentage of state total is given as a 5-year average. The Cape Lookout annual reports on sea turtles from 2001–2007 do not provide information on the percentage of sea turtle nests annually at the seashore relative to the state total, and the NC WRC (seaturtle.org 2016) has only incomplete information prior to 2010 (N.A.—not available).

[b] Storm events prevented high hatch rates: 2004—Hurricane Isabel in the previous year, and flooding from Hurricane Alex; 2005—flooding from Hurricane Ophelia; 2008—Hurricanes Bertha, Kyle, and Hanna produced swell and aberrantly high tides; 2009—Hurricanes Bill and Danny, and other low-pressure storm swells and aberrantly high tides, and also a relatively cool summer; 2010—Hurricane Earl, Tropical Storm Nicole, and other low-pressure storm swells and aberrantly high tides. In 2001, 2002, and 2004–2006 the exact hatch rate was not specified in the NPS annual reports (2015n)

[c] Emergence success data are given for nests with known egg and hatch totals.

[d] L—lost; D—disturbed, with some loss of eggs and/or hatchlings

Table 39. Sea turtle strandings per year at (or near) Cape Lookout by species (2008–2013;NPS 2013d).

Year	Stranding Totals*	Loggerhead	Green	Kemp's Ridley	Leatherback	Hawksbill	Unknown
2008	149	29	116	2	0	0	3
2009	117	36	66	14	0	0	1
2010	275	131	116	27	0	0	0
2011	88	18	44	26	0	0	0
2012	124	25	73	25	1	0	0
2013	238	26	187	23	1	0	1

* Total stranding numbers for 2008–2011 include some strandings outside of seashore boundaries.

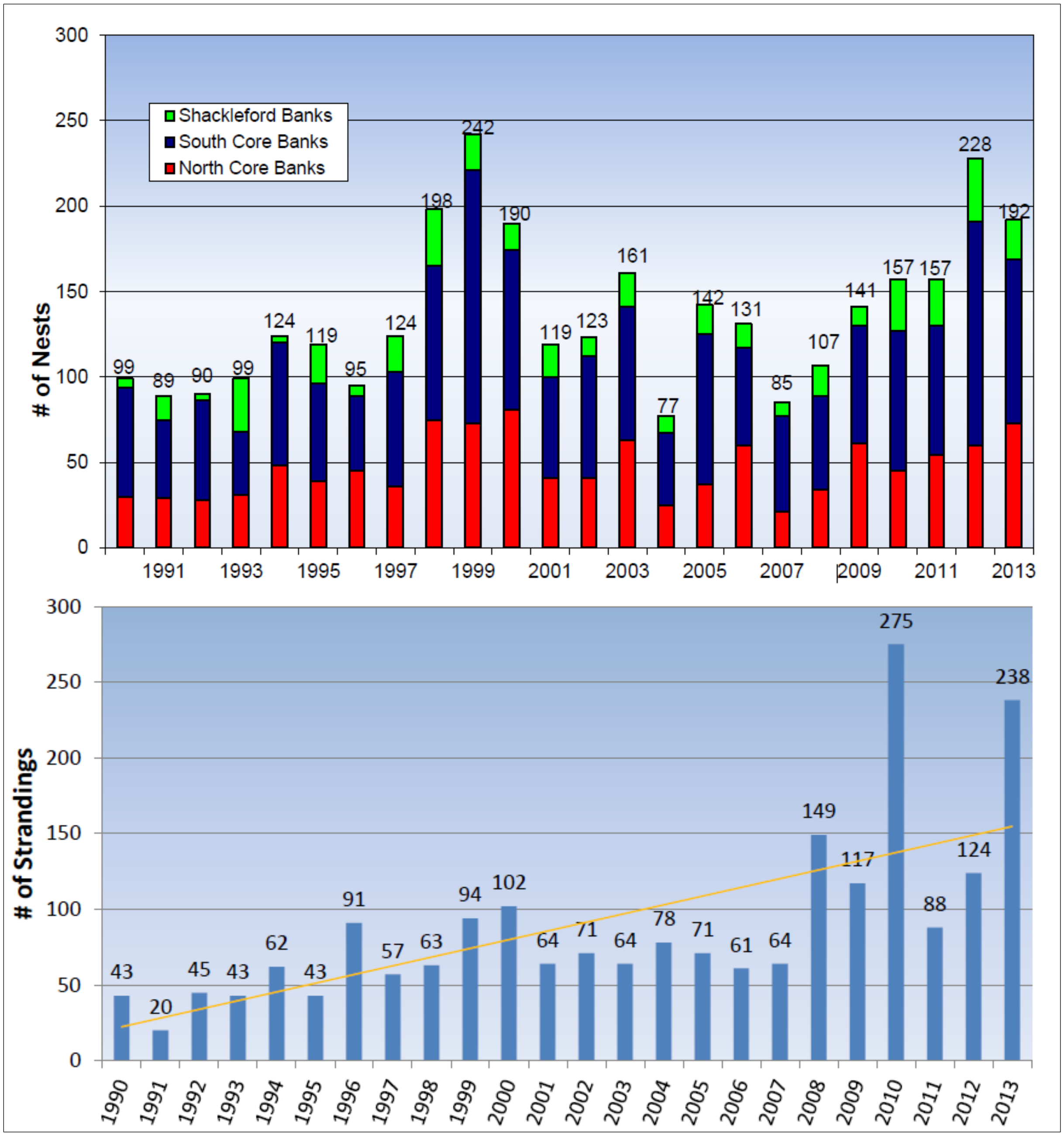

Figure 65. Total number of sea turtle nests per year at Cape Lookout. Upper panel—1990–2013 for Shackleford Banks, South Core Banks, and North Core Banks. Lower panel—Total number of annual sea turtle strandings at Cape Lookout over the same period. Note that strandings have increased in the past five years, mostly as juvenile greens and Kemp's Ridleys (NPS 2013d).

Piping Plover Status

Piping plovers nearly disappeared due to excessive hunting for the millinery trade during the nineteenth century (NPS 2015j). At Cape Lookout they are mainly threatened by predation from ghost crabs, opossums, red foxes, coyotes, feral cats, raccoons, gulls, crows, and grackles; by ORVs and beach equipment; and by adverse weather (NPS 2005a, 2014a). North Carolina lies at the southern edge of the breeding range and the northern edge of the wintering range for the piping plover (NPS 2001a). Cape Lookout hosts individuals from all three U.S. breeding populations—Atlantic Coast (threatened), Great Plains (threatened), and Great Lakes (endangered)—during migrations and during the winter season. This is also the only state on the U.S. Atlantic Coast that hosts piping plovers during all phases of their annual life history (Cohen et al. 2010). There are three designated wintering critical habitat units within the seashore. The area near Ocracoke Inlet is also important to migrating piping plovers. Residency on the wintering grounds occurs from mid- July through early May (NPS 2005a). For nesting populations, courtship begins in late March, nests are initiated beginning in late April, and the brood-rearing period extends from late May to mid-August. Critical habitat for piping plovers has been designated for areas near all of the inlets in the park, as well as Portsmouth Flats, Kathryne Jane Flats, and Cape Point (NPS 2005a). These habitats include ocean beach, mudflats, sandflats, and sound side beach used as foraging areas, as well as sparsely vegetated low dunes.

Cape Lookout is a significant nesting area as well, and generally has 70% of the nesting pairs of piping plovers in North Carolina. Seashore staff monitor the reproductive success of piping plovers (courtship and nesting) at the park from first arrival to post-fledgling (Watson 2005). Seashore staff have monitored nesting activities of piping plovers since 1989, from first arrival of breeding birds to post-fledgling (Watson 2005); they also implement methods to increase the productivity of piping plovers, and they conduct non-breeding surveys of park use by this species. By April 1, bird sanctuary signs are used to close all known piping plover nesting habitat to pedestrian and vehicular entry through August 31. Signs are also posted to prohibit boaters at inlets and points, and boaters are encouraged to land within 0.4 kilometers (0.25 mi) of inlets to allow pedestrians to walk the inlet shoreline for access to the ocean shoreline. From early April on, nesting areas are surveyed daily for territorial pairs and nests. Potential habitat outside posted areas is monitored and posted as necessary with a minimum 45.7-meter (150-ft) buffer distance from scrapes and nests. Nest locations are recorded and nests are monitored daily until the eggs hatch or are lost (e.g., to predation). If the topography is suitable and sufficient monitoring can be conducted, the nests are protected with predator exclosures. Because raccoons cause high rates of losses, nest exclosures are sometimes constructed before the clutch is complete. Broods are monitored daily until the chicks fledge or are lost. While chicks are present, ocean beach foraging areas are closed to vehicles. Broods forage in the dunes and ocean surf zone, or on the sound side beach, sand flats, mudflats, and ephemeral pools. The foraging areas are closed to vehicles.

Counts of wintering and migrating birds on ocean beaches, inlets, and sound side sandy beaches are made monthly from August to March. Individuals banded in other regions are searched for more frequently during the fall migration. The detailed data include the number of nesting pairs by island and nesting area, number of nests, number of pairs, number of eggs, nests hatched, eggs hatched, chicks fledged, fledge rate (number of chicks per breeding pair), likely causes of nest losses (predators, storms, abandoned nests, or unknown) by nesting area. The data have yielded encouraging news for piping plovers at Cape Lookout, as the annual number of nesting pairs, number of chicks fledged, and ratio of total number of chicks fledged to the total number of breeding pairs have all increased from initiation of consistent monitoring (1989) to the present (2013) (Table 40, Figure 66), but are still below recovery goals (NPS 2014a).

Table 40. Piping plover nest and chick success at Cape Lookout (2000–2013). From NPS (2000c, 2001c, 2002b, 2003b, 2004b, 2005c, 2006d, 2007e, 2008b, 2009c, 2010b, 2011d, 2012f, 2013e).

Year	Breeding Pairs	Total Nests	Nests Hatched	Nests Lost[a] / Abandoned	Total Eggs	Total Eggs Hatched	Total Chicks Fledged	Chicks Lost	Fledge Rate (chicks/pair)	# enclosed	% of total nests	Violations[b]	Warnings
2000	16	18	12 (67%)	6 (33%)	65	43 (66%)	8 (19%)	35	0.50	1 (6%)	(14–78%)	N.A.	N.A.
2001	16	19	8 (42%)	11 (58%)	64	24 (38%)	5 (21%)	19	0.31	4 (21%)	(13–68%)	N.A.	N.A.
2002	15	20	13 (65%)	7 (35%)	65	43 (66%)	4 (9%)	39	0.27	5 (25%)	(13–65%)	N.A.	N.A.
2003	14	15	7 (47%)	8 (53%)	55	23 (42%)	6 (26%)	17	0.43	3 (20%)	(11–73%)	N.A.	N.A.
2004	13	13	11 (85%)	2 (15%)	44	37 (84%)	12 (32%)	25	0.92	1 (8%)	(10–77%)	71	---
2005	27	31	24 (77%)	7 (23%)	105	69 (66%)	23 (33%)	46	0.85	N.A.	N.A.	N.A.	N.A.
2006	33	37	29 (78%)	8 (22%)	125	87 (70%)	29 (33%)	58	0.88	5 (14%)	(21–57%)	39	---
2007	45	58	29 (50%)	29 (50%)	173	79 (46%)	11 (14%)	68	0.24	8 (14%)	(35–78%)	363	---
2008	46	57	31 (54%)	26 (46%)	179	88 (49%)	9 (10%)	79	0.20	31 (67%)	(12–21%)	97	34
2009	36	45	24 (53%)	21 (47%)	145	83 (57%)	30 (36%)	53	0.83	5 (11%)	(36–80%)	110	8
2010	43	58	34 (59%)	24 (41%)	204	98 (48%)	31 (32%)	67	0.72	13 (22%)	(46–79%)	39	215
2011	41	48	35 (73%)	13 (27%)	157	102 (65%)	37 (36%)	65	0.90	6 (13%)	(34–71%)	71	171
2012	51	66	36 (54%)	30 (46%)	207	98 (47%)	29 (30%)	69	0.57	7 (11%)	(27–40%)	52	130
2013	45	52	30 (58%)	22 (42%)	173	97 (56%)	47 (48%)	50	1.04	3 (6%)	(25–48%)	31	256

[a] Predation (% total nests lost). Major predators—raccoons, ghost crabs, feral cats; others include foxes, mink, coyotes, herring gulls, and boat-tailed grackles suspected.

[b] Violations—pedestrian violations, ORV violations (whether formally cited or not), and off-leash dog citations. Most violations were usually for off-leash dogs in piping plover nesting areas (in some years 25% or more of dogs were observed off-leash, and up to 600 dogs/year visited the seashore). Exceptions: 2004—data not available for warnings or for off-leash dogs. 2007—174 records of pedestrian violations and 76.records of ORV violations (evidence of vehicles or tracks within bird closures, conservative since tire tracks often disappear after moderate wind, tide changes, and/or rain before they can be recorded); 2008—55 records of ORV violations. Warnings include verbal and written.

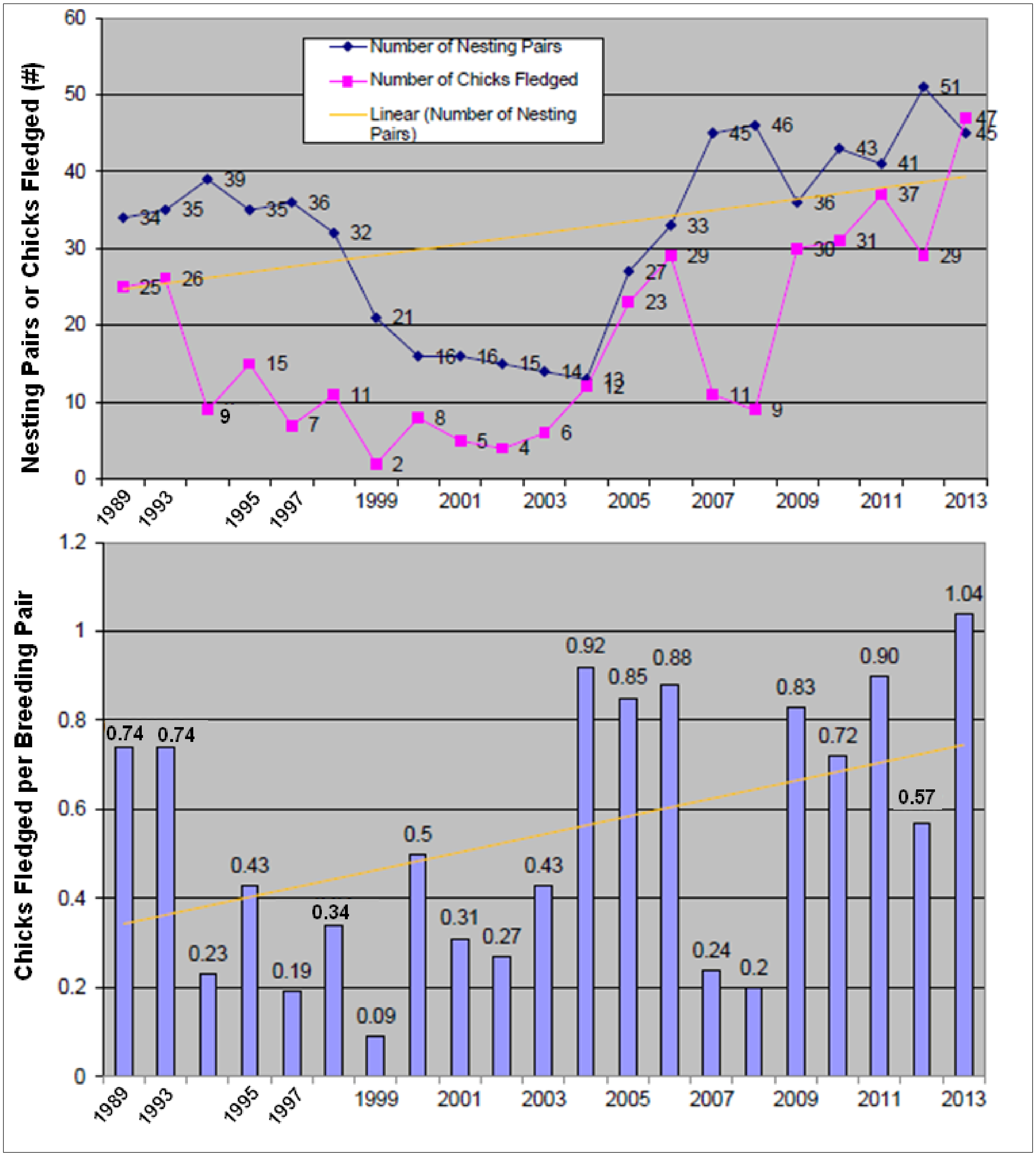

Figure 66. Upper panel—Number of nesting pairs or number of piping plover chicks fledged annually at Cape Lookout (1989–2013). Lower panel—the ratio of the total number of piping plover chicks fledged to the total number of breeding pairs per year (NPS 2013e; NPS 2014a).

American Oystercatcher Nesting Success

The American oystercatcher is listed as a "Bird of Special Concern" by the U. S. and the North Carolina Wildlife Resources Commission (NPS 2014a). Its nesting habitat makes it especially vulnerable to disturbance by ORVs and park visitors (Schulte et al. 2007). Predation is also common from feral cats, raccoons, foxes, and coyotes.

Monitoring of this species at Cape Lookout began in 1995, and since 1997 the park staff and colleagues have conducted censuses, monitored nesting success, and banded individuals every year. All of the seashore has been monitored regularly since 2004 (Figure 67).

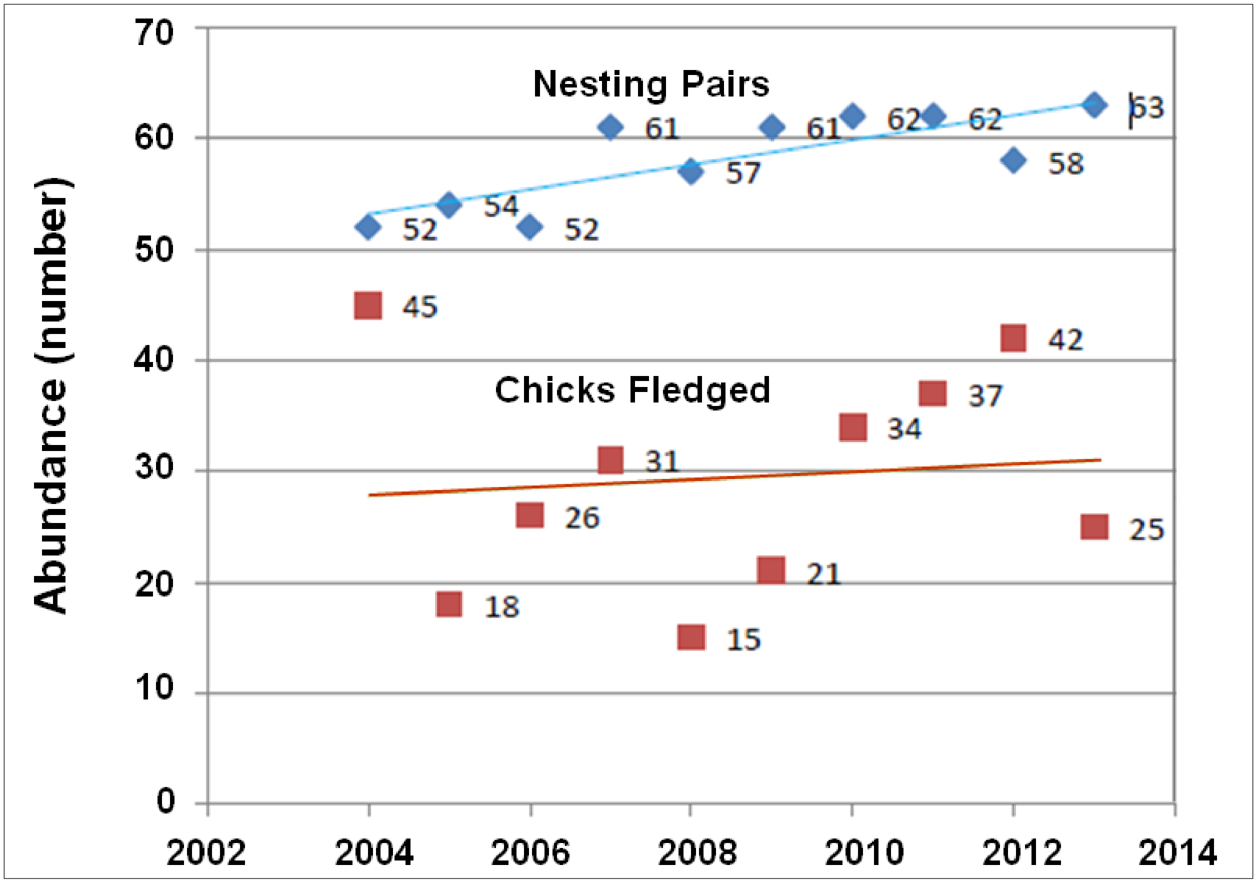

Figure 67. The number of seashore American oystercatcher nesting pairs and chicks fledged by year covering the period from 2004 to 2013. Modified from NPS (2013 f, 2014a). (diamonds—nesting pairs; squares—chicks fledged)

Park staff survey Shackleford Banks for nesting birds twice weekly beginning in April, and weekly on North and South Core Banks. They also monitor for breeding daily, seven days per week, until the end of the nesting season. Nesting areas are closed using “Bird Sanctuary” signs if the nests are in danger of being run over by ORVs or stepped on by pedestrians. Nests found in dune areas usually are not posted, due to concern that predators may learn to associate posts with nests, and also because small posted areas could attract curious visitors and cause disturbance. In addition to the closures around nests, a 183-meter (600-ft) buffer is established around each nest, which allows vehicle and pedestrian traffic to pass by on the lower beach by the ocean shoreline, but prevents stopping, parking, or camping near the nests. Nest locations are recorded with GPS units and the seashore mile marker system, and are marked inconspicuously to facilitate follow-up checks. Habitat type is also noted. Nests are checked at one- to three-day intervals, and the day before the expected time of hatch, the ocean beach in the area is closed to vehicles. If the area does not have a backroad for vehicles behind the primary dunes, signs are posted on the beach to warn ORV drivers about the presence of flightless chicks, and reducing the speed limit to 24 kilometers (15 mi) per hour. Chicks are monitored daily until they fledge or are lost. Since 2010, chicks have been considered fledged at age 35 days for productivity records (although chicks cannot fly at age 35 days, and the range of fledgling age ranges from 35 to 45 days—NPS 2014a), or when strong flight is observed for management purposes.

During the period from 2004 through 2013, the number of nesting pairs of American oystercatchers across the seashore has increased from 52 to 63 with relatively little fluctuation (Table 41, Figure 67). The number of chicks fledged has been more variable, and has ranged from 15 (in 2008) to 42 in 2012; in 2013 there was a substantial decrease to 25 chicks fledged. Overall, annual fledgling success of American oystercatchers at Cape Lookout is low, and increased slightly from an average of 0.49 chick per pair (2004–2008) to 0.52 chick per pair (2009–2013). Shackleford Banks chronically has low fledgling success, and on that barrier island and in general, predation is suspected to be the major cause (NPS 2014a).

Table 41. American oystercatcher reproductive success at CALO (2000–2013). From NPS (2000d, 2001d, 2002c, 2003c, 2004c, 2005d, 2006e, 2007f, 2008c, 2009d, 2010c, 2011e, 2012g, 2013f).

Year	Breeding Pairs	Total Nests	Nests Hatched	Number of Chicks Fledged[a]	Fledge Rate (chicks/pair)	Predation (% of nest failures)[b]	Human Disturbance (nest loss, % of total)
2000	59	75	25 (33%)	9	0.15	9 (12%)	2 (3%)
2001	59	109	19 (17%)	1	0.02	50 (46%)	1 (1%)
2002	48	90	10 (11%)	6	0.12	40 (44%)	3 (3%)
2003	51	106	17 (16%)	8	0.16	31 (29%)	1 (1%)
2004	52	71	38 (54%)	45	0.86	16 (23%)	0
2005	54	66	26 (39%)	18	0.33	11 (17%)	1 (2%)
2006	52	70	23 (33%)	26	0.50	8 (11%)	0
2007	61	99	21 (21%)	31	0.51	13 (13%)	2 (2%)
2008	57	91	17 (19%)	15	0.26	26 (30%)	3 (3%)
2009	61	83	20 (24%)	21	0.34	18 (22%)	2 (2%)
2010	62	113	28 (25%)	34	0.55	28 (25%)	2 (2%)
2011	62	114	29 (25%)	37	0.60	46 (40%)	1 (1%)
2012	58	99	31 (31%)	42	0.72	26 (26%)	1 (1%)
2013	63	104	32 (31%)	25	0.40	21 (20%)	1 (1%)

[a] Defined as the number of chicks that survived to day 35 post-hatch (NPS 2014a).

[b] Predators—raccoon, feral cat, muskrat, grey fox, red fox, coyote, mink, striped skunk, domestic dog, gulls, fish crow, and ghost crab (see the annual reports listed above, and NPS 2014a; note that opossums were not included as per Webster 2010).

Red Knot and Wilson's Plover Status

The red knot breeds in the Canadian Arctic and visits Cape Lookout only as a migrant and occasional winter resident (Harrington 2001). The U.S. Fish and Wildlife Service proposed "Threatened" status for this species in 2013 (ECOS 2015). This species uses the Outer Banks, including Cape Lookout, as a stopover in spring and fall migrations. Red knots have been monitored at Cape Lookout since 1992; in that year and 1993, the effort was limited to surveys as part of a broader shorebird study, and areas south of New Drum Inlet were not covered. Since 2006, personnel experienced in shorebird identification have surveyed the entire ocean beach and inlet areas of North Core Banks and South Core Banks for red knots every year beginning in mid-March. The frequency and timing follow International Shorebird Census guidelines for spring and fall. Counts are conducted on the 5th, 15th, and 25th of the month from 15 March to 5 June, and from 15 July to 15 October. The surveys have occurred at different times of day, and different tidal weather conditions.

Most red knots have been found on North Core Banks, up to 1,111 birds on a census day, distributed over the length of the barrier island. Cape Lookout is especially important as a stopover site for red knots during the spring migration. During the years monitored, red knot abundance has ranged from 14 birds per kilometer of seashore (approximately 8.7 per mile; 2009) to 46 birds per kilometer (28.5 per mi) of seashore (2012) (Table 42). The highest counts consistently have occurred from Ocracoke Inlet to mile 6 on North Core Banks, and from Ophelia Inlet to mile 28 on South Core Banks.

Table 42. Red knot maximum count per kilometer on North Core Banks, 1992–2013. Note that abundance is rounded to the nearest integer. The area between Old Drum Inlet and Ophelia Inlet was not monitored in 2013. From NPS (2006f, 2007g, 2008d, 2009e, 2010d, 2011f, 2012f, 2013f).

Year	Date	Maximum Count	Kilometers (mi) Assessed	Relative Abundance (Max. Count/km)
1992–1993	---	---	34 (21.1)	34
2006	May 5	618	30.3 (18.8)	20
2007	May 15	718	30.6 (19)	23
2008	April 15	1,287	30.6 (19)	42
2009	May 25	525	36 (22.4)	14
2010	May 15	927	36 (22.4)	26
2011	May 15	648	36 (22.4)	18
2012	April 25	1,370	29.8 (18.5)	46
2013	May 25	854	29.8 (18.5)	29

The Wilson's plover is listed in the U.S. Shorebird Conservation Plan as a Species of High Concern (Brown et al. 2001) and is in apparent decline (Andres et al. 2012, Zdravkovic 2013). Wilson's plovers do not winter at Cape Lookout, but use its habitats during migration from breeding grounds in Maryland and Virginia during spring and fall (Harrington et al. 1989). A window census of

Wilson's plovers has been conducted at Cape Lookout annually during early June since 2007. The number of breeding pairs has ranged from 76 to 91 in the annual window census (9–10 days in June 2007–June 2013) (Table 43).

Table 43. Data for Wilson's plovers based on an annual window census of single adults and breeding pairs (June 1–9 or June 1–10, 2007–2013). From NPS (2008e, 2009f, 2010e, 2011g, 2012i, 2013h, 2014e).

Year	Breeding Pairs	Single Adults
2007	76	3
2008	90	6
2009	76	2
2010	76	9
2011	76	3
2012	85	11
2013	91	10

Colonial Shorebird Monitoring

Cape Lookout hosts various species of colonial waterbirds (CWB) such as terns, gulls, pelicans, skimmers, and cormorants, which depend on nearshore waters for feeding, and on relatively undisturbed islands for nesting (NPS 2006a). These species nest in large groups or colonies and obtain their food from the water (NPS 2014a). A colony is commonly considered as including 10 or more nests. Many colonial waterbird species which use habitats in North Carolina are in jeopardy, as they have significantly declined in abundance over the past several decades (Erwin 2005, Cameron and Allen 2008). At the seashore, recent nesting by colonial shorebirds has been limited in comparison to population levels in the 1970s (Erwin 2005).

Colonial nesting shorebird areas have been monitored by the National Park Service at Cape Lookout since 2006 (NPS 2006a, Byrne et al. 2009). Colonial waterbirds are surveyed in cooperation with the NC WRC, consisting of colony surveys and counts of nests and eggs for all nesting species at the seashore including least terns, common terns, gull-billed terns, black skimmers, sandwich terns, and royal terns (NPS 2014a). Recurring nesting sites include Power Squadron Spit, Cape Point, Ophelia Inlet, New Drum Inlet Flats, Kathryn-Jane Flats, Portsmouth Flats, and Ocrocoke Inlet tip. Potential nesting habitat is monitored and posted by 1 April each spring as the birds colonize a site. Posted closures usually include the upper beach, interior, and/or sound side to provide a 45.7-meter (150-ft) buffer. If flightless chicks are present on the lower ocean beach, vehicles are restricted and/or detoured (NPS 2014a).

An annual window census of breeding pairs, incubating adults, adults, and/or nests of several CWB species has been made, usually during 5–20 June, since 2007 (Table 44), including black skimmer, least terns, common terns, royal terns, and sandwich terns. The number of nesting sites by CWBs at

Cape Lookout has ranged from 11 to 22 in 2007–2013 (mean 16, median 17; Table 44). Fluctuations in the number of CWB nesting sites appears to be controlled to a major extent by the presence/absence of aberrantly high tides due to major storms and other factors, although predation has decimated some colonies as well.

Table 44. Colonial waterbird (CWB) nesting data at CALO (2007–2013). From NPS (2007i, 2008f, 2009g, 2010f, 2011h, 2012i, 2013i) [BLSK—black skimmer; COTE—common tern; LETE—least tern;ROTE—royal tern; SATE—sandwich tern].

Year	Nesting Sites	Locations of Largest, Most Productive Colonies (abundance)	LETE Breeding Pairs	Notes
2007	17	*New Drum Inlet Spit* (169 BLSK, 191 LETE, 71 COTE, 59 GBTE breeding pairs)	285	Cape Point colony decimated by repeated raccoon predation
2008	19	*Old Drum Inlet Spit* (30 BLSK, 296 LETE, 1 COTE, 3 GBTE breeding pairs)	502	New Drum Inlet colony decimated by repeated raccoon predation
2009	14	*Old Drum Inlet Flats* (75 BLSK, 202 LETE, 2 GBTE adults)	288	-----
		New Drum Inlet Flats (167 BLSK, 127 LETE, 22 COTE, 4 GBTE adults)		
		Ophelia Inlet (100 LETE, 21 COTE—but flooding event washed out nests)		
		Cape Point (small colony in June; by late July, 94 BLSK, 143 LETE, 22 COTE, 4 GBTE)		
2010	11	*Old Drum Inlet Flats* (6–7 BLSK, 461–501 LETE, 2 COTE incubating adults)	789	-----
		Ophelia Inlet (267 BLSK, 80 LETE, 25 COTE, 21 GBTE adults)		
		Cape Point (140 BLSK, 419 LETE, 4 COTE, 2 GBTE adults)		
2011	13	*Blowfish Island* (Ophelia Inlet—6 BLSK, 306 LETE, 2 COTE, 4 GBTE incubating adults)	608	-----
		Cape Point (155 BLSK, 127 LETE, 96 COTE, 7 GBTE, 167 ROTE nests)		
2012	22	*New Drum Inlet* (346 LETE breeding pairs)	577	-----

Table 44 (continued). Colonial waterbird (CWB) nesting data at CALO (2007–2013). From NPS (2007i, 2008f, 2009g, 2010f, 2011h, 2012i, 2013i) [BLSK—black skimmer; COTE—common tern; LETE—least tern;ROTE—royal tern; SATE—sandwich tern].

Year	Nesting Sites	Locations of Largest, Most Productive Colonies (abundance)	LETE Breeding Pairs	Notes
2012 (continued)		*Ophelia Island* (49 BLSK, 117 LETE, 17 COTE, 24 GBTE breeding pairs) *Cape Point* (72 BLSK, 18 LETE, 33 COTE, 33 ROTE breeding pairs)	577	-----
2013	19	*Old Drum Inlet spit* (64 LETE breeding pairs) *Power Squadron spit* (32 LETE, 1 GBTE breeding pairs) *Cape Point* (21 BLSK, 89 LETE, 26 COTE breeding pairs *Morgan Island* (dredge spoil, heavily vegetated but 846 ROYT, 7 SATE breeding pairs; on a small sandy beach, >1,140 ROYT nests and 10 SATE nests. Not known to have been used by ROYT since 1977).	322	—Tropical Storm Andrea (early June) and flooding in late June prevented nesting success for the Cape Point colony; — Two BLSK chicks and one COTE chick eaten by greater black-backgulls (Cape Point)

The most detailed data are from the annual window census of least terns, conducted from June 5–20 (Figure 68). Breeding pairs are counted by either a perimeter count of incubating pairs or a total number adult count (divided by two), with the assumption that all birds present within and near a breeding colony site are breeders. In addition, monitoring is extended throughout the summer and includes weekly counts of adults, incubating nest pairs, ground nests, and chicks and fledglings, along with buffer distance checks. Fledge success is based on observations and qualitatively rated as high, medium, low, none, or unknown. Based on window census data, least tern abundance over the past eight years reached a maximum of 789 in 2010. The years of lowest abundance occurred in 2006–2009 and 2013.

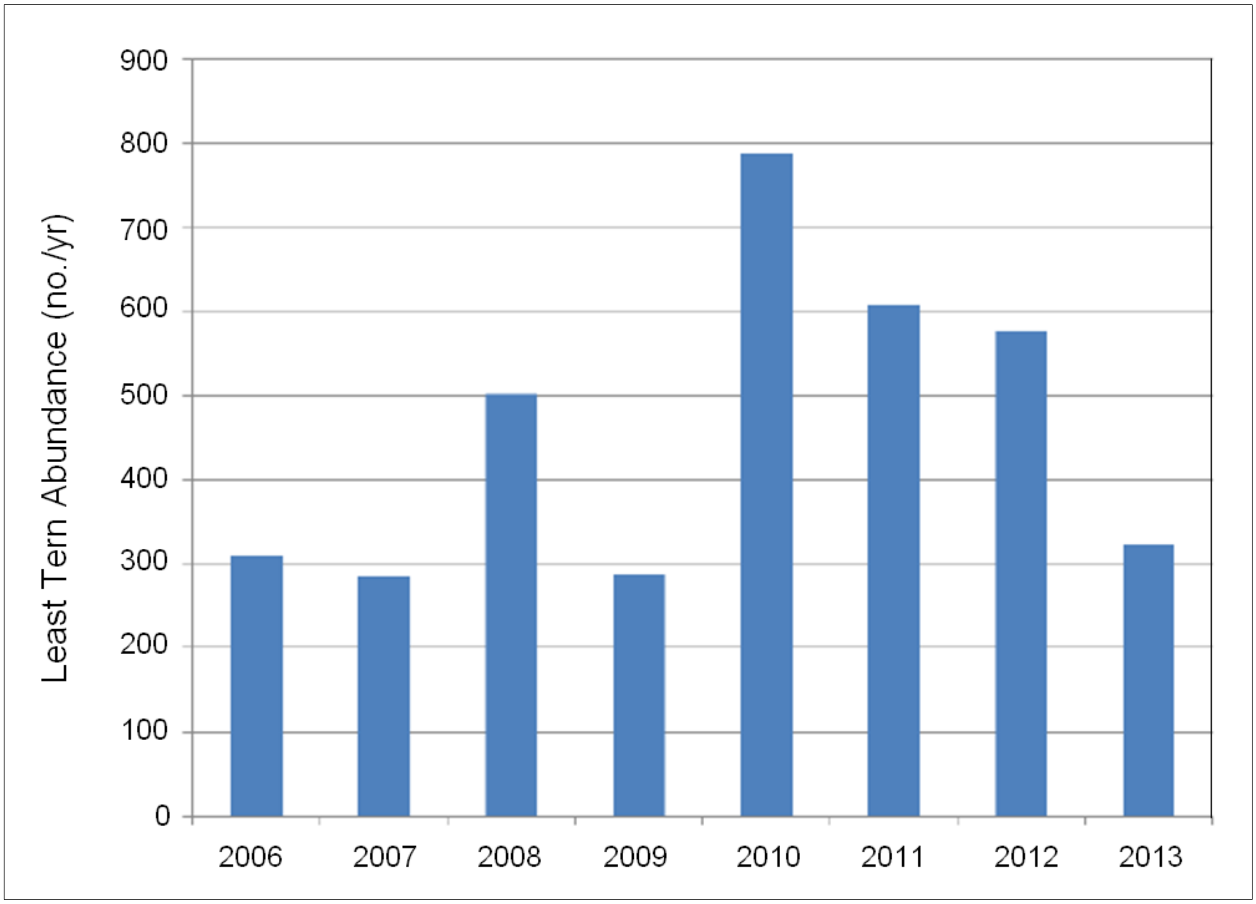

Figure 68. Least tern window census, June 5–20, counts from 2006 to 2013. Modified from NPS (2014a).

The National Park Service (2014a) summarized trends for four colonial waterbird SSCs at Cape Lookout as follows:

- Least tern—apparently stable, long-term; the number of nesting pairs has ranged from 583 (1994) to 218 (2004). Accurate counts of nesting birds is difficult due to high rates of nest losses. North Carolina status: “High Conservation Concern” (North Carolina Bird Watchlist—Le Grand et al. 2013).
- Common tern—declining; the number of nesting pairs has decreased from 582 (1993) to only 28 (2004). North Carolina status: “High Conservation Concern” (North Carolina Bird Watchlist—Le Grand et al. 2013).
- Gull-billed tern—declining; this species rarely nests at the seashore. The number of nesting pairs has decreased from more than 50 (1992, 1993) to none (2004). North Carolina status: “Threatened” (LeGrand et al. 2013).
- Black skimmer—declining; the number of nesting pairs has decreased from more than 300 (1993) to 72 (2004). North Carolina status: State Species of Concern (LeGrand et al. 2013).

Seabeach Amaranth Status

The seabeach amaranth (*Amaranthus pumilus*), native to U.S. Atlantic Coast beaches, is an annual species without vegetative reproduction (NPS 2005a). It grows mainly on coastal overwash flats at the accreting ends of barrier islands and lower foredunes, on ocean beaches above mean high tide, and occasionally on sound side beaches. It is known as a “fugitive species”—it poorly competes with other plant species and does not occur on well-vegetated sites (Sellars et al. 2003), and apparently it needs extensive, dynamic natural areas of barrier island beaches and inlets to thrive (Weakley and Bucher 1991; NatureServe 2007; NPS 2005a). Thus, it occupies a narrow, precarious elevation niche bounded by its relative intolerance to flooding on the lower beach, and competition with other plants in the upper beach and dunes. Remaining habitats in upper beach and overwash areas are severely limiting because these habitats tend to be absent on barrier islands that are sustaining beach erosion (NPS 2005a).

The seabeach amaranth was federally listed as threatened in 1993 (Weakley et al. 1996). Park staff began to monitor this species in 1992. Its abundance in Cape Lookout has varied greatly due to habitat changes and impacts of hurricanes. In years following major storms, few plants were found in the park, but the populations recovered if the following year did not have a major storm (NPS 2005a).

Surveys to locate and count all plants have been conducted at Cape Lookout annually in late July and early August to track plant numbers and distribution and to identify areas for closure to ORVs (although most plants were located in areas that were already closed to ORVs). Most plants at Cape Lookout were found on the south-facing beaches of Shackleford Banks and the area between Cape Point and Power Squadron Spit. In the early 1990s there was a large population on the south side of New Drum Inlet. The seed bank in that area was lost in Hurricane Gordon in 1994 and the population did not recover. The major threat to seabeach amaranth in Cape Lookout is loss of suitable habitat because of storm-related erosion. Other threats were grazing by nutria and webworms (caterpillars), ORVs, and flooding. Regarding ORVs, “the brittle, fleshy stems of sea amaranth are easily broken, and growing plants (May–December) do not generally survive a single pass by a truck tire” (USFWS 1996b; also see USFWS 2007a). Unfortunately, seabeach amaranth was found in very small numbers (34, 10, and 7 plants) in 2010, 2011, and 2012, respectively, and no plants were found in 2013 (NPS 2013j) (Figure 69). Overall, the data suggest decline to extirpation, but perhaps the seed bank remaining in Cape Lookout will produce more plants in favorable years.

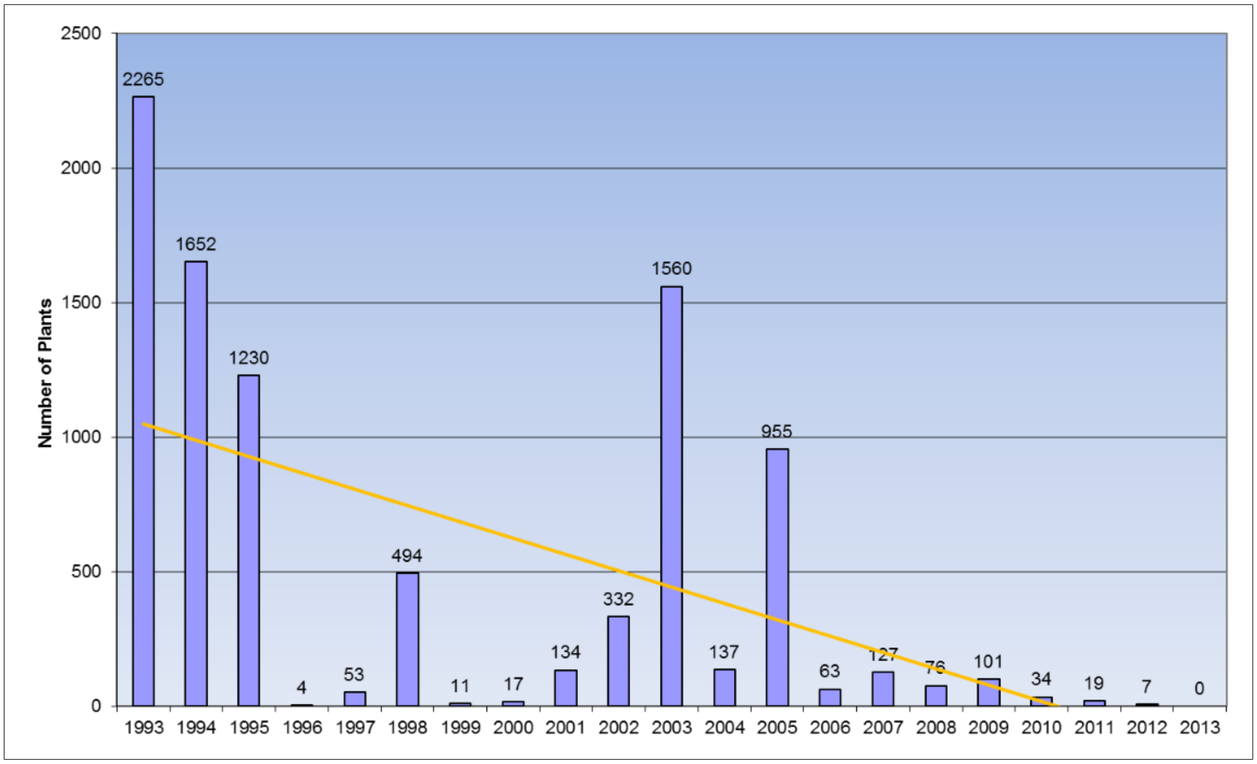

Figure 69. Sea amaranth abundance at Cape Lookout from 1993–2013. The populations previously have recovered from a total of only four plants at the seashore (1996), but 2013 marked the first year in which no plants were found, with only seven plants documented in the previous year (2012). From NPS (2013j).

Exotic/Invasive Species

> *Invasive exotic species fragment native ecosystems, displace native plants and animals, and alter ecosystem function. Invasive species are second only to habitat loss as threats to global biodiversity (Scott and Wilcove 1998). Such species negatively affect park resources and visitor enjoyment by altering landscapes and fire regimes, reducing native plant and animal habitat, and increasing trail maintenance needs.*
>
> *—Young et al. (2007).*

The National Park Service mandates control of invasive species and prevention of new introductions whenever possible. Exotic/invasive species have been identified by the Southeast Coast Network as a concern for the natural resources of Cape Lookout, since they compete with native biota, threaten or eliminate rare species, alter fire regimes, and reduce food sources for native wildlife. A total of 73 exotic/invasive species inhabit Cape Lookout as mentioned, representing 19.3% of the seashore terrestrial vascular plant taxa (46 species) and 9.8% of the total vascular plant flora (59 of 600 taxa) (Table 45). Exotic/invasive vertebrate fauna include 1 fish species, 5 birds, and 8 mammals, which is only 2% (14) of the total 663 taxa, but 36% (8 of 22 species) of the mammalian fauna. (It should be noted that one exotic mammalian species, the horse, is considered beneficial by park visitors and is considered in this report as a SSMC).

Table 45. Exotic/invasive species (73 taxa total) reported to occur in Cape Lookout National Seashore, based on the NPS Certified Species List (NPS 2013c and Byrne et. al 2012).

Type	Scientific Name	Common Name	Invasive Status (plants)
Terrestrial Plants (46 species)	*Ailanthus altissima*	Ailanthus, copal tree, tree of heaven, tree-of-heaven	R1; Threat; NPS Top 10
	Allium vineale	Wild garlic	R3
	Arthraxon hispidus	Small carpetgrass	R2
	Baccharis halimifolia	Eastern baccharis	---
	Bidens bipinnata	Spanish needles, spanish-needles	---
	Bromus japonicus	Japanese brome, Japanese bromegrass, Japanese chess	---
	Cerastium glomeratum	Sticky chickweed	---
	Chenopodium ambrosioides	Mexican tea, Mexican-tea	---
	Chenopodium botrys	Jerusalem oak, Jerusalem oak goosefoot	---
	Cynodon dactylon	Bermudagrass, chiendent pied-de-poule, common bermudagrass	CULT
	Digitaria sanguinalis	Crabgrass, hairy crab grass	---
	Eclipta prostrata	Eclipta, false daisy, yerba de tago, yerba de tajo	---
	Eleusine indica	Crowsfoot grass, goose grass	---
	Eragrostis pilosa	India lovegrass, Indian love grass, Indian lovegrass	---
	Eremochloa ophiuroides	Centipede grass	---
	Ficus carica	Common fig, edible fig, fiku, piku	CULT
	Gladiolus x gandavensis	Gladiolus	CULT
	Hypericum perforatum	Common St. Johnswort, Klamath weed	WL-A
	Kummerowia striata	Common lespedeza, Japanese clover	R3

* As described by Wilcox (2013); also see Morris and Whitfield (2009), and Morris (2012).

Table 45 (continued). Exotic/invasive species (73 taxa total) reported to occur in Cape Lookout National Seashore, based on the NPS Certified Species List (NPS 2013c and Byrne et. al 2012).

Type	Scientific Name	Common Name	Invasive Status (plants)
Terrestrial Plants (continued; 46 species)	*Lamium amplexicaule*	Common henbit, giraffehead, henbit, henbit deadnettle	---
	Lantana camara	Lantana, largeleaf lantana	---
	Lespedeza cuneata	Chinese lespedeza, sericea lespedeza	R1; Threat
	Maclura pomifera	Bois d'arc, osage orange, osage-orange, osageorange	---
	Melia azedarach	Chinaberry, Chinaberry tree, Chinaberrytree	WL-B; Watch List
	Opuntia ficus-indica	Indian fig, Indian-fig, tuna cactus	---
	Oxalis rubra	Oxalis rubra, windowbox woodsorrel	---
	Petunia x *atkinsiana [axillaris* x *integrifolia]*	Garden petunia	CULT
	Phlox drummondii	Annual phlox, drummond phlox	CULT
	Plantago lanceolata	Narrowleaf plantain, English plantain, buckhorn plantain, lanceleaf plantain, ribgrass, ribwort	High/Low
	Poa pratensis	Kentucky bluegrass	may be invasive
	Populus alba	White poplar	R3
	Rosa multiflora	Multiflora rose	R1;Severe Threat; NPS Top 10
	Salsola kali	Prickly Russian thistle, Russian thistle, tumbleweed	----
	Senecio vulgaris	Common groundsel, old-man-in-the-Spring	R3
	Sida rhombifolia	Arrowleaf sida, cuban jute, Cuban-jute	----
	Sonchus asper	Perennial sowthistle, prickly sowthistle, spiny sowthistle	----
	Sonchus oleraceus	Annual sowthistle, common sow-thistle	----

* As described by Wilcox (2013); also see Morris and Whitfield (2009), and Morris (2012).

Table 45 (continued). Exotic/invasive species (73 taxa total) reported to occur in Cape Lookout National Seashore, based on the NPS Certified Species List (NPS 2013c and Byrne et. al 2012).

Type	Scientific Name	Common Name	Invasive Status (plants)
Terrestrial Plants (continued; 46 species)	*Stellaria media*	Chickweed, common chickweed, nodding chickweed	R2
	Stenotaphrum secundatum	St. Augustine grass	----
	Trifolium aureum	Golden clover	----
	Trifolium dubium	Hop clover, smallhop clover, suckling clover	----
	Trifolium repens	Dutch clover, ladino clover, white clover	----
	Typha angustifoila	Narrowleaf cattail	----
	Verbascum thapsus	Big taper, common mullein, flannel mullein	WL-A
	Veronica arvensis	Common speedwell, corn speedwell, rock speedwell	----
	Vulpia myuros	Foxtail fescue, rat-tail fescue, rat-tailed fescue, rattail fescue	----
Wetland/Aquatic Plants (13 species)	*Arenaria serpyllifolia*	Thymeleaf sandwort	----
	Baccharis halimifolia	Eastern baccharis	----
	Cardamine hirsuta	Hairy bittercress	----
	Centella asiatica	Spadeleaf	----
	Cladium mariscus ssp. *jamaicense*	Jamaica sawgrass, Jamaica swamp sawgrass	----
	Cuphea carthagenensis	Colombian waxweed	----
	Echinochloa crus-galli	Barnyard grass, cockspur, Japanese millet	----
	Lonicera japonica	Chinese honeysuckle, Japanese honeysuckle	R1 Moderate Threat NPS Top 10
	Mollugo verticillata	Carpetweed, green carpetweed	----
	Paspalum notatum	Bahia grass, bahiagrass	----

* As described by Wilcox (2013); also see Morris and Whitfield (2009), and Morris (2012).

Table 45 (continued). Exotic/invasive species (73 taxa total) reported to occur in Cape Lookout National Seashore, based on the NPS Certified Species List (NPS 2013c and Byrne et. al 2012).

Type	Scientific Name	Common Name	Invasive Status (plants)
Wetland/Aquatic Plants (continued; 13 species)	*Paspalum urvillei*	Vasey grass, Vasey's grass, vaseygrass	----
	Sisyrinchium rosulatum	Annual blueeyed grass, annual blue-eyed grass	----
	Taxodium distichum	Bald cypress, baldcypress	----
Fish (1 species)	*Pterois volitans*	Lionfish	"worst Atlantic invasion ever"*
Birds (5 species)	*Branta canadensis*	Canada goose	----
	Bubulcus ibis	Cattle egret	----
	Carpodacus mexicanus	House finch	----
	Columba livia	Rock dove	----
	Sturnus vulgaris	European starling	----
Mammals (8 species)	*Canis latrans*	Coyote	----
	Canis lupus familiaris	Domestic dog, feral dog	----
	Equus caballus	Horse (feral)	----
	Felis catus	Domestic cat, feral cat	----
	Mus musculus	House mouse	----
	Myocastor coypus	Nutria, coypu	----
	Rattus norvegicus	Norway rat	----
	Vulpes vulpes	Red fox	----

* As described by Wilcox (2013); also see Morris and Whitfield (2009), and Morris (2012).

The vegetative species can be extensive; as mentioned above, some lower and older terraces of barrier flat grasslands and low, open dunes of Cape Lookout have abundant Indian lovegrass (*Eragrostis pilosa*) and Bermuda grass. In addition, areas with low frequency of overwash and flooding are characterized by shrub savannas with abundant eastern baccharis (*Baccharis halimifolia*). Quantitative information and maps of present distribution/coverage of species of interest such as highly invasive taxa apparently are lacking.

The park also has highly invasive, destructive red fire ants (*Solenopsis invicta*), which was introduced to the United States in the 1930s from South America (Porter and Savignano 1990). Since that time, red fire ants have infested more than 1.2 million square kilometers (468,625 square mi, or 300 million ac) across the southeastern United States, despite federal quarantine measures (Hawaii Ant Group 2001). The red imported fire ant largely displaced the two fire ant species native to the Southeast, the tropical fire and (*Solenopsis geminata*) and the southern fire ant (*Solenopsis exloni*) (Porter and Savignano 1990). In the United States, millions of people are stung each year, including some visitors to Cape Lookout. Red imported fire ants additionally can threaten wildlife and significantly depress biodiversity (Porter and Savignano 1990; Wojnik et al. 2001; Hawaii Ant Group 2001). In Cape Lookout they most commonly are found along roadways, pastures and other open, sunny areas.

Special mention is included here of lionfish, which have been described along the southeastern U.S. Atlantic coast as “the worst marine invasion ever (Wilcox 2013).” Lionfish were introduced from reefs of the Indo-Pacific to coastal marine waters in the Caribbean. They are sexually mature at age one year, and females produce 30,000 to 40,000 eggs at three- to four-day intervals (Morris and Whitfield 2009, McCreedy et al. 2012, Morris 2012, and references therein). Densities along the North Carolina coast up to the northern extension of the geographic range for lionfish—which is Cape Hatteras (McCreedy et al. 2012)—increased 700% between 2004 and 2008 (Albins and Hixon 2013), and are estimated to average 150 lionfish per hectare.

The lionfish body is covered with spines that, except for the caudal area, contain apocrine- type venom glands. Their venom adversely affects humans as well as fish prey and predators. For humans, the sting is extremely painful and can cause nausea and breathing difficulties. Fortunately, most lionfish along the North Carolina coast are offshore, but they have been found at depths as shallow as one meter and have been reported from Cape Lookout waters (NOAA Ocean Service Education 2011). Lionfish are now among the most numerous predatory reef fishes off the southeastern U.S. coasts; they have become a threat to the structure of native reef fish communities, and could impede stock-rebuilding efforts for the snapper-grouper complex (McCreedy et al. 2012; Morris 2012). In an effort to derive some benefit from the invasive species, the NCDMF recently initiated a Lionfish Derby, and the “First Annual Cape Lookout Lionfish Rodeo” was held on May 18–19, 2014 (SportHelpNow 2015).

The National Park Service has developed a Lionfish Response Plan to serve as a guide to the agency and partners in aggressive efforts to adequately address the lionfish invasion in marine waters of all affected park units along U.S. coasts through population monitoring and suppression (McCreedy et al. 2012). Among various points, the Plan provides counsel to park units about setting control targets for reducing lionfish populations. The Plan aptly states that “Aquatic resources in parks are no less vulnerable than terrestrial ecosystems to invasive species and require the National Park Service to sharpen its focus on the profound ecological impacts of aquatic nuisance species” (McCreedy et al. 2012).

Early settlers inadvertently brought house mice, rats, and feral cats to Cape Lookout (Godfrey and Godfrey 1976). There have been various deliberate introductions of plants as well as animals (e.g., pheasants for hunting) on the Outer Banks. Silverleaf poplar (*Populus alba*) and the colorful blanket flower, *Gaillardia*, were brought to the barrier islands as ornamentals by early European settlers. The poplar survives in the Portsmouth Village area. Blanket flower has become widespread and helps bind sand. Several *Pinus* species were planted in the Cape Lookout area historically in an attempt to control sand movement. Raccoons became a significant predator of nesting shorebirds and sea turtles at Cape Lookout. The seashore has worked with the USGS to conduct major raccoon removal efforts in predator management.There is little available information about other exotic/invasive species at the seashore, including some of the worst known of these taxa which are insects (USGS 2012).

Other Issues of Special Management Concern

The Feral Horses of Shackleford Banks

Shackleford Banks is home to a herd of feral (wild) horses; the target number of animals was set at 120–130 by Congressional action in 1998, and a Memorandum of Understanding updated in 2007 (NPS 2013k). The same federal legislation that protects these horses in the park also requires an annual report on the status of the herd.

The feral horses remained when residents of Shackleford Banks abandoned it in the late nineteenth century (NPS 2014a and references therein). There is no clear account of their arrival on the barrier island, and they have been there for centuries (Stuska et al. 2009). The horses are cooperatively managed by the seashore and the Foundation for Shackleford Horses, Inc., pursuant to the legislation and a Memorandum of Understanding updated in 2007 (NPS 2007i). The National Park Service developed a Horse Management Plan for Cape Lookout in 2006 (NPS 2007c). The size of the herd is being maintained at 110 horses at a minimum, with a target range of 120–130 (Figures 70 and 71), achieved by Cape Lookout NS staff through use of immuno-contraceptives (Porcine Zonae Pellucidae, PZP; this substance is authorized for use by the U.S. Food and Drug Administration and regulated by the Humane Society of the United States—NPS 2010g) as necessary, and also through removal of selected young horses to adopted homes on the mainland in order to prevent over-grazing of marshes, grasslands, and beach habitats, and other damage (Nuñez et al. 2010, NPS 2013j). Cape Lookout and partners also participate in a program called the Wild Horse Public Education Campaign (2011–present) toward the goal of educating park visitors to watch the horses safely, without interacting with them or interrupting their natural behavior.

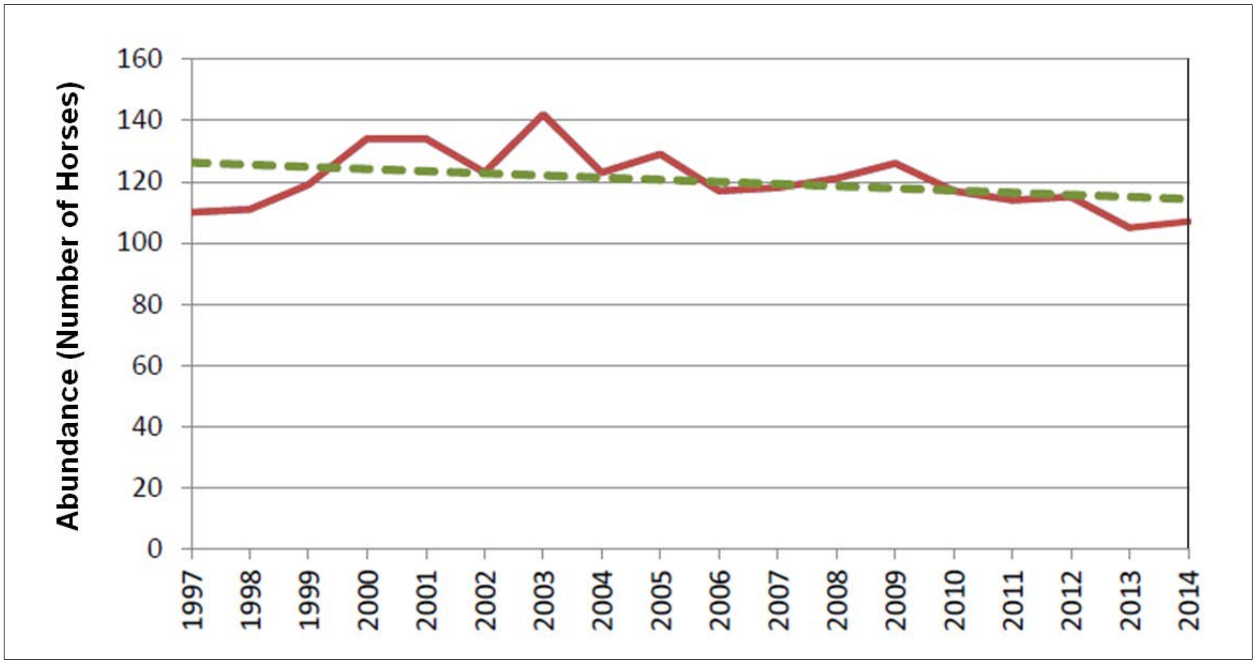

Figure 70. The annual population size of the herd of wild horses on Shackleford Banks (1997–2013; NPS 2013j).

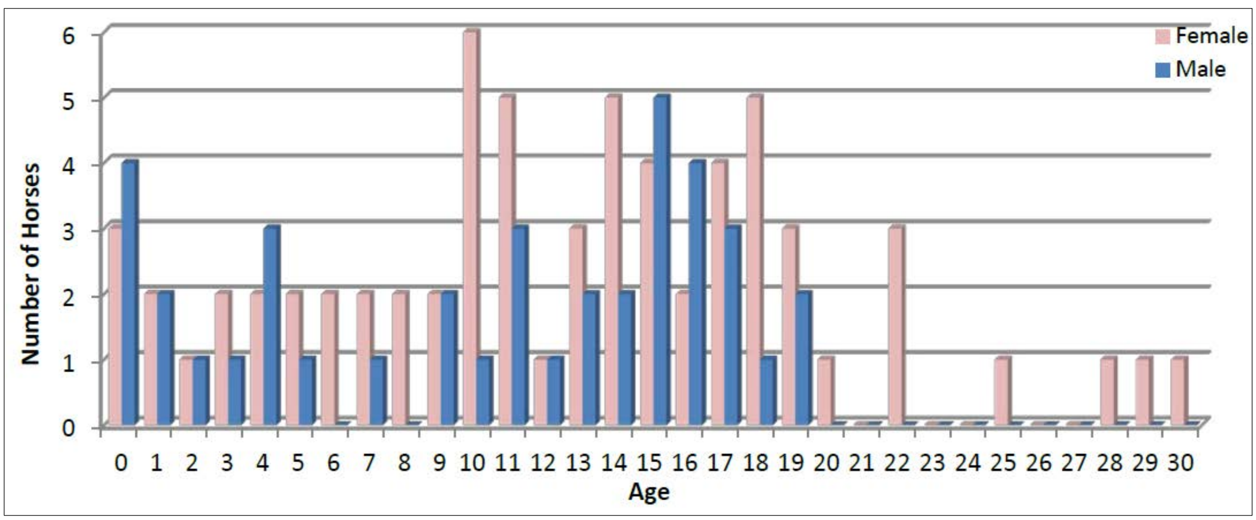

Figure 71. Age structure of male and female horses in the wild herd on Shackleford Banks as of January 2013. Note that contraception generally increases the lifespan of female horses, as reflected in the age 20-and-older animals which are all female (NPS 2013j).

The generally decreasing birth rate in the wild horse herd is an indication of the success of the contraception program (NPS 2013j, 2014a). The overall goal of the National Park Service in managing the horses is to use contraception adaptively to maintain the population without having to remove horses. Cape Lookout staff have done well at achieving that goal. The population has been maintained at fewer than 130 horses since 2003 (median from 1997 through 2013, 120) (Figure 70).

Moreover, since 2009 contraception has not been used and horses have not been removed. Five or more foals were expected in 2014–2015 (2013j).

Since the wild horses have been managed by the seashore and FSH, mortality has averaged 6%, but mortality in 2012 was unusually high (17%), the maximum recorded since 1997 (NPS 2013k). Exposure of the herd to eastern equine encephalitis (EEE), a viral disease carried by certain mosquitoes, was first documented at Cape Lookout in 2012 (NPS 2013j). An autopsy of one of the horses that died in late summer 2012 revealed extensive internal damage due to parasites, colic, and a positive test for exposure to EEE. Of 15 adults (age four and older) that were lost, nine died in June–August when the mosquitoes were most active, suggesting that these horses could also have been exposed to EEE.

The virus that causes EEE in horses is widespread in wild bird populations (Crans 1993, America's Horse Daily 2011, Putnam and Holt 2011). Signs in infected horses vary but usually begin with fever and listlessness, progressing to more serious neurological signs such as lack of coordination, stumbling, circling, head pressing, coma and death (Putnam and Holt 2011). Once the horse begins to develop neurological signs, the disease is fatal in about 90% of cases. Seizures leading to death usually occur within 48 to 72 hours of the first indication of illness, and there is no effective treatment. A vaccine is available which prevents EEE, but it is effective for only one year, so booster shots are required on an annual basis (America's Horse Daily 2011). Newly vaccinated animals additionally require a two-shot series administered two to four weeks apart to ensure protection. Foals should be re-vaccinated in summer as well.

A vaccination program against EEE is incompatible with wild horse herd maintenance. The situation, a potential serious concern for the wild horse herd at Cape Lookout, has occurred due to circumstances beyond National Park Service control such as entry of infected birds and/or mosquito vectors into the seashore, which cannot be regulated, controlled, or monitored.

The nutrient intake of the horse herd was estimated by Stuska et al. (2009) through forage analysis of the nutrients available in plants selected by the horses, and through study of the diet components as discerned from fecal material. In spring and summer, sea oats, smooth cordgrass, centipede grass, and pennywort comprise up to 69% of the horses' diet. In fall and winter, sea oats, centipede grass, and smooth cordgrass are up to 78% of the diet. The diet in winter contains more diversity of plant species; consumption of sea oats decreases by about half from fall, and consumption of smooth cord grass decreases by about two-thirds.

In each season, the plant nutritive content was available for 78.0% (spring), 70.4% (summer), 63.5% (fall), and 73.3% (winter) of the horses' diet (based on fecal data). The portions represented by the major forage components were known as well, and from that information the total diet nutrients were estimated. The data were compared to the National Research Council (1989) requirements for horses, assuming a standard consumption rate of 2% of the body weight per day. The National Research Council requirements for horses are considered to err on the low side of actual requirements, but were used by Stuska et al. (2009) as a baseline for comparison to the wild horse diets. The analysis indicated that digestible energy and calcium needs for the horses are met on Shackleford Banks year-round. Crude protein needs are met only in spring and summer. The calcium-to-phosphorus ratio is within the recommended range, but phosphorus needs are met only in spring and summer. Phosphorus is an essential component of the "energy currency" of cells, ATP (adenosine triphosphate); it is the structural "backbone" of deoxyribonucleic acid (DNA), needed to form genes; it is a key component of cell membranes; and it is essential for many metabolic functions (National Research Council 1989). Copper and zinc, important in equine diets, are also marginal to low in the diets of the Shackleford Banks horses. Copper is essential in synthesis/maintenance of elastic connective tissue; zinc deficiencies depress growth rates; and both are needed for healthy bones (National Research Council 1989). Thus, overall the wild horses' diet apparently meets their energy and calcium needs, but the diet is deficient in crude protein and other essential nutrients.

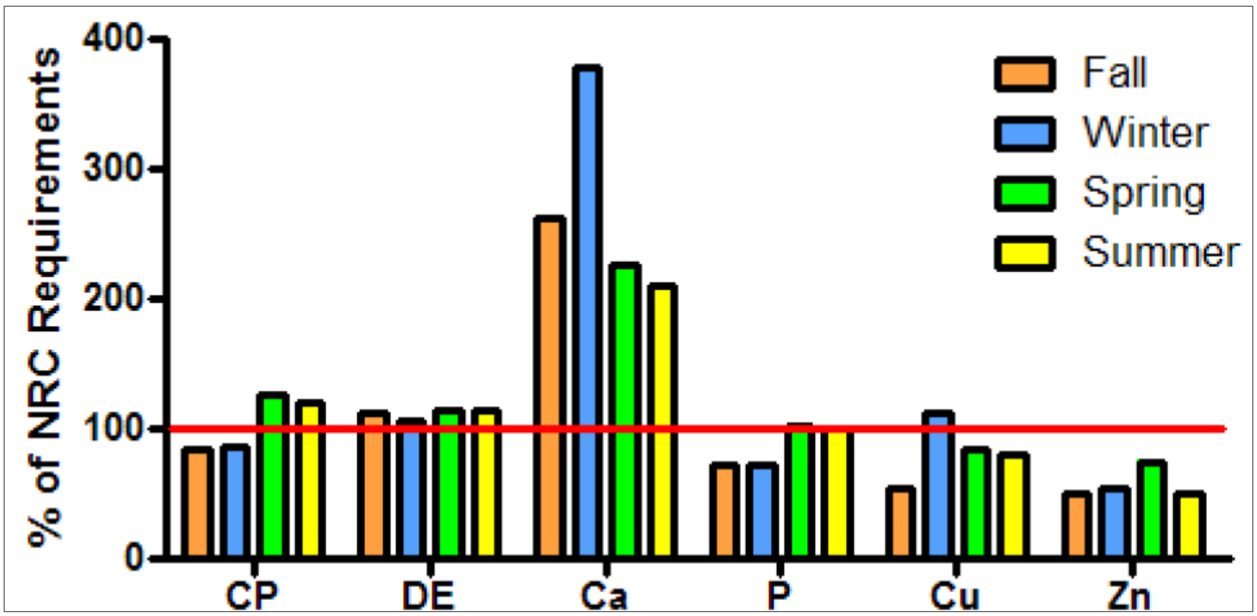

Figure 72. Comparison of estimated nutrient composition in the diet of the Shackleford Banks wild horse herd, versus the National Research Council general dietary requirements for horses (1989) (CP—crude protein; DE—digestible energy; Ca—calcium; P—phosphorus; Cu—copper; Zn—zinc). Note that a more recent edition (2007) of the National Research Council dietary requirements for horses was not used because it contained comparable general information but did not provide values in percentages; instead, requirements were given in grams and calculations require the body weight of the horse. From Stuska et al. (2009).

Impacts on Saltmarsh and Adjacent Marine Coastal Communities

The feral horses at Cape Lookout are charismatic to human visitors, but they also represent an unnatural, long-term disturbance to saltmarshes and ecological processes through their grazing pressure (Levin et al. 2002). Historically on the barrier islands of Cape Lookout, various types of livestock caused overgrazing in localized areas (Godfrey and Godfrey 1976) (Figure 73). Free-ranging horse herds can also damage wetland ecosystems through trampling and defecation (Noon and Martin 2004). In addition, their wastes pose a localized but substantial threat to receiving surface water and groundwater (Mallin et al. 2004). In the dunes the herds graze selectively on little bluestem (*Schizachyrium scoparium*) and also reduce sea oats (*Uniola paniculata*) cover (Godfrey and

Godfrey 1976). They also can cause soil compaction, blowouts and open sand due to trampling, which can accelerate dune movement and erosion (Godfrey and Godfrey 1976).

Figure 73. A feral horse grazing smooth cordgrass, which has been consumed to such an extent that the area has the general appearance of a mowed lawn. From Stuska et al. (2009).

Whereas most studies of wild horse impacts on saltmarshes have focused on plants, Levin et al. (2002) assessed the indirect effects of grazing by feral horses at Shackleford Banks on saltmarsh animals and adjacent subtidal communities. As expected, horse-grazed saltmarshes had less vegetation, but also were characterized by higher diversity of foraging birds, higher crab densities, and lower density and species richness of fishes in comparison to saltmarshes that were not grazed. In addition, fish density was lower in subtidal habitats that were adjacent to horse-grazed saltmarshes. Levin et al. (2002) experimentally manipulated smooth cordgrass abundance and determined that the potential for predation on fishes in ungrazed marshes was higher than in grazed marshes because the removal of the vegetative shelter causes behavioral shifts that make the fish more susceptible to predators.

Interestingly, Levin et al. (2002) also “took a step back” and considered the ecology of estuarine and adjacent marine areas affected by horse grazing from a natural history perspective. They noted that, while large herbivores are absent from present saltmarsh ecosystems (except for Shackleford Banks), now-extinct large ungulate herbivores (in the families Camelidae, Bovidae, and Equidae; also Proboscids) were common natural members of Pleistocene-era saltmarsh communities (Koch et al. 1998). Thus, perhaps the feral horses at Shackleford Banks could be considered as modern “surrogates” for large herbivores that once were natural inhabitants of saltmarsh and adjacent coastal marine ecosystems.

Predator Management in Attempts to Protect Species of Special Concern

As described above, predators cause substantial loss of some endangered and threatened SSCs at Cape Lookout (Tables 46–48). Predator management is used by Cape Lookout staff, mainly through exclosure cages to protect some bird SSCs (1994–present), and live traps (2002–present), to target certain predators of SSCs in order to prevent them from disrupting or killing the SSCs (references given in Tables 46–48). Mammalian predators of sea turtle, piping plover, American oystercatcher, and/or colonial shorebird SSCs include feral cats, feral dogs, raccoons, red foxes, gray foxes, coyotes (recent invaders), nutria, mink, and fish crows (Cohen et al. 2009, Cohen et al. 2010, NPS 2012b; note that according to Webster 2010, opossums no longer occur in Cape Lookout). Indicative of this entrenched problem is Webster's (2010) writing which describes the following predatory species as typically associated with major ecosystem types at Cape Lookout:

- Dunes and overwash fans— nutria, raccoons, and feral cats;
- Maritime shrub thickets and forests—raccoons and feral cats;
- Swales and ponds—nutria, raccoons, American mink, and feral cats;
- Estuarine marshes—nutria, northern raccoons, and American mink.

The ghost crab (invertebrate species) is another major predatory species on sea turtle and shorebird nests (NPS 2014a). Birds are also predators of these SSCs, including peregrine falcons and other birds of prey, great black-back gulls, herring gulls, laughing gulls, fish crows, and owls (NPS 2014a and references therein).

Federal recovery plans, conservation initiatives etc. have been developed for SSCs (piping plover—USFWS 1996a; sea turtle species, NMFS and USFWS 1991, 1992, 1993, 2008, 2011; American oystercatcher—Simons and Stocking 2011), all of which list predation as a serious threat to recovery. For example, the recovery plan for the green sea turtle states that depending on the location, raccoons may consume up to 96% of turtle nests on a beach (NMFS and USFWS 1991). As an added complication, human activities, such as introduction of native/exotic species, or leaving garbage on the beaches that attracts predators, can exacerbate the impacts from natural predation (USFWS 1996a, Cohen 2010).

In winter 2008 through spring 2009, 149 raccoons (about half of the population) were removed from South Core Banks as part of predator population study by researchers from NCSU and the USGS (USGS 2009; Waldstein 2010; Parsons et al. 2013; Stocking 2012). Raccoon predation on South Core Banks has been a persistent problem. Over the previous 10 years (1999 to 2008), raccoon predation was recorded for all but one year (2004). Following the raccoon removal effort, in 2009 the productivity of nesting shorebird prey species increased, and raccoon predation was reduced (Stocking 2012) (Figure 74).

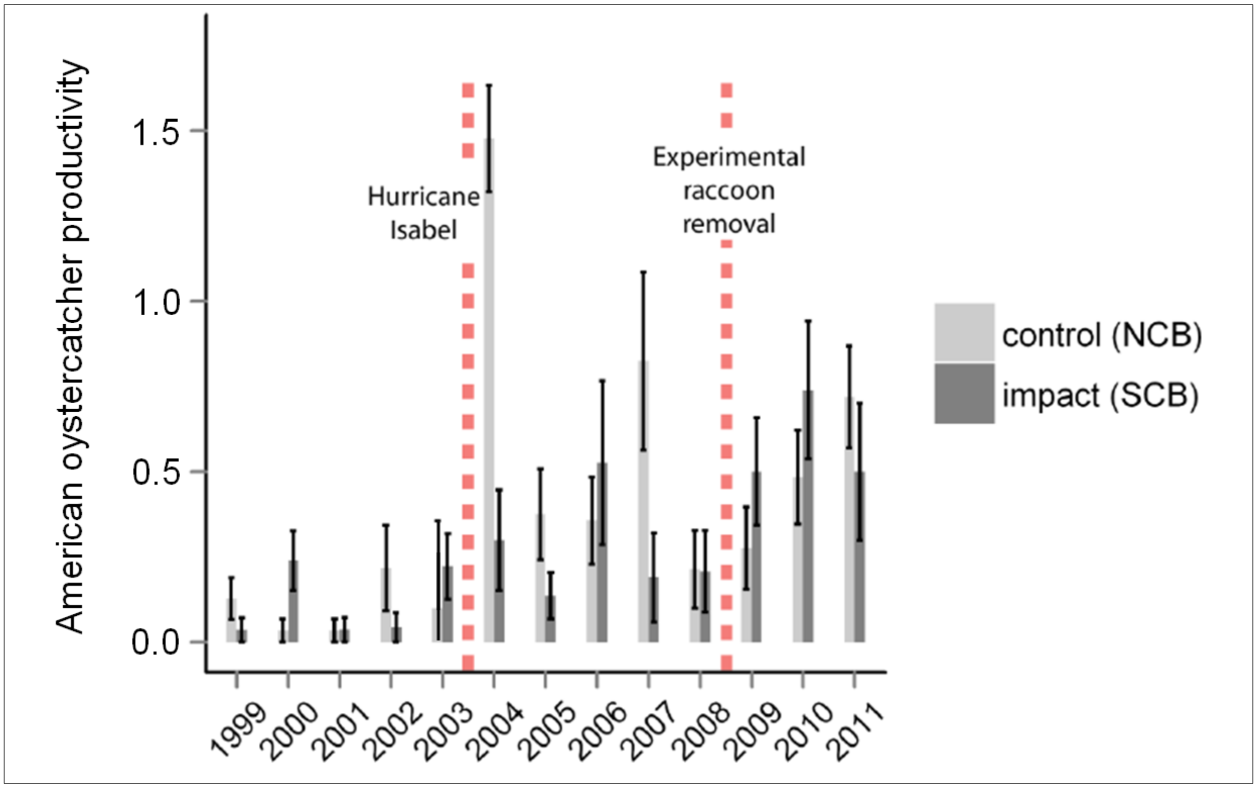

Figure 74. Productivity (number of fledglings per breeding pair) of American oystercatchers on North Core Banks (NCB) and South Core Banks (SCB) from 1998 through 2011. Dashed lines indicate Hurricane Isabel, which naturally reduced predator abundance on NCB, and a 50% reduction in the raccoon population on SCB following predator removal (means ± 1 standard error). From Stocking (2012).

2.3. Resource Stewardship

2.3.1. Management Directives and Planning Guidance

<u>The NPS Mission, and Reinforcing Policies and Regulations</u>

The mission of the National Park Service is to preserve "the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations (U.S.C. 16 § 1) (NPS 2013k)." National Park Service management policy is to maintain all components and processes of naturally occurring ecosystems, including the natural abundance, diversity and ecological integrity of plants and animals (NPS 2006a).

The National Park Service Omnibus Management Act of 1998, and other reinforcing policies and regulations, require park managers "to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources (Title II, Sec. 204)." In the late 1990s the National Park Service developed an action plan to address the "Natural Resource Challenge" of protecting and preserving the natural resources of national parks nationwide (NPS 1999). In that spirit, the NPS Inventory and Monitoring Division was developed to provide management-driven scientific information to national park managers so that natural (and cultural) resources can be adequately protected (Fancy et al. 2009). Considering the widespread anthropogenic influences in SECN park units and the importance of park biota to the nation, evaluation of natural resource condition over time is a high priority (DeVivo et al. 2008). The National Park Service has done considerable work to identify natural resources and indicators that are important from the perspective of the I&M Program.

The Southeast Coast Network developed a suite of conceptual models to support and guide development of a monitoring program for the parks, using a general ecosystem model as a template for specific models of the six dominant ecosystem types found in SECN park units. Cape Lookout has three of these—salt marshes and coastal wetlands, estuaries and nearshore marine systems, and barrier islands. Each model includes a set of system drivers, local drivers, and park resources. Importantly as well, the Southeast Coast Network identified 25 vital signs, most of which are being monitored or are planned to be monitored as part of the I&M Program (De Vivo et al. 2008) (Table 46). The ecosystem-centered vital signs span all categories of the ecological monitoring framework: air & climate, geology and soils, water, biological integrity, human use, and ecosystem patterns and processes. Most—air quality, climate, geology and soils, water, and biological integrity (biological resources)—have been discussed in Chapters 2 and 3 of this report. The inventory also covers ecosystem patterns (geomorphology) and various aspects of human use. Many of the measures were on our preliminary list of potential indicators for the seashore. For some of these parameters, however, information for Cape Lookout is not yet available, underscoring the importance of the I&M Program to establish present natural resource conditions in the park and track them over time to assess park ecosystem health.

Table 46. Vital signs identified by the SECN for its coastal parks including Cape Lookout [1—Vital Sign for which the SECN will develop protocols and implement monitoring; 2—Vital Sign that is monitored by a network park, another NPS program, or another federal or state agency; 3—monitoring deferred]. Modified from DeVivo et al. (2008).

Ecological Monitoring Framework Subcategories	Network Vital Sign	Measures	CALO
Air Quality[a]	Ozone	Atmospheric ozone concentration, damage to sensitive vegetation	2
	Wet and Dry Deposition	Wet and dry sulfate and nitrate deposition	2
	Visibility and Particulate Matter	IMPROVE suite for visibility and fine particulates, particle size analyses: pm 10, pm 2.5, haze index	2
	Air Contaminants	Concentration of mercury, semi-volatile organic compounds, acidic (N,S) and nutrient (N) components of contaminants	2
Weather and Climate[a]	Weather and Climate	Air temperature, precipitation, relative humidity, tides, location and magnitude of extreme weather events	2
Geomorphology[b]	Coastal Shoreline Change	Shoreline position	1
	Saltmarsh Elevation	Sediment elevation, salinity	1
Hydrology[c]	Groundwater Dynamics	Water table levels for freshwater and saltwater	2
Water Quality[c]	Estuarine Water Quality and sediment	pH, temperature, dissolved oxygen, turbidity, salinity; concentrations of chlorophyll a, TDN, TIN, TDP, TIP, toxic chemical contaminants, and volatile organic compounds	1
Invasive Species[d]	Invasive/Exotic Plants	Occurrence of invasive plant species	1

[a] Air and Climate Framework

[b] Geology and Soils Framework

[c] Water monitoring Framework

[d] Biological Integrity Framework

[e] Human Use Framework

[f] Landscapes Framework

Table 46 (continued). Vital signs identified by the SECN for its coastal parks including Cape Lookout [1—Vital Sign for which the SECN will develop protocols and implement monitoring; 2—Vital Sign that is monitored by a network park, another NPS program, or another federal or state agency; 3—monitoring deferred]. Modified from DeVivo et al. (2008).

Ecological Monitoring Framework Subcategories	Network Vital Sign	Measures	CALO
Focal Species or Communities[d]	Marine Benthic Macroinvertebrates	Occurrence of selected marine benthic macro-invertebrate species	3
	Fish Communities	Fish community diversity, relative abundance, Index of Biotic Integrity; percentage of non-native species	3
	Amphibians	Species occurrence, diversity, percent area occupied, disease incidence.	1
	Landbirds	Species occurrence, diversity, relative abundance	1
	Small Mammals	Species occurrence, diversity, percent area occupied, relative abundance	3
	Plant Communities	Plant species occurrence, diversity; percent cover by herbaceous, shrub and overstory; occurrence of disease, occurrence of non-native species; NVCS class	1
At-Risk Species and Communities[d]	Shorebirds	Number and location of piping plover, American oystercatcher, and colonial shorebirds such as Wilson's plover, red knot	3
	Other T&E Species	Abundance, distribution, and recruitment of rare species such as sea beach amaranth, sea turtles	2
Consumptive Use[e]	Fisheries Take	Species occurrence, weight, size based on compilation of existing data from NC DMF and other sources as appropriate	2
Visitor and Recreation Use[e]	Visitor Use	Monthly and annual visitor attendance compiled from existing seashore data and other sources	2

[a] Air and Climate Framework

[b] Geology and Soils Framework

[c] Water monitoring Framework

[d] Biological Integrity Framework

[e] Human Use Framework

[f] Landscapes Framework

Table 46 (continued). Vital signs identified by the SECN for its coastal parks including Cape Lookout [1—Vital Sign for which the SECN will develop protocols and implement monitoring; 2—Vital Sign that is monitored by a network park, another NPS program, or another federal or state agency; 3—monitoring deferred]. Modified from DeVivo et al. (2008).

Ecological Monitoring Framework Subcategories	Network Vital Sign	Measures	CALO
Fire and Fuel Dynamics[f]	Fire and Fuel Dynamics	Down woody debris, duff depth	1
Landscape Dynamics[f]	Land Cover and Use	Extent and distribution of land cover and use types, fragmentation, extent and distribution of management actions (compiled from park records)	1

[a] Air and Climate Framework

[b] Geology and Soils Framework

[c] Water monitoring Framework

[d] Biological Integrity Framework

[e] Human Use Framework

[f] Landscapes Framework

Cape Lookout Plans, Purpose Statement, and Significance Statements

Most basic to management of this seashore is the General Management Plan (GMP) for Cape Lookout NS (NPS 1982, amended in NPS 2001a) (Table 47). The GMP for Cape Lookout NS sets the underlying philosophy of the National Park Service for management of this seashore (NPS 1982):

> *The sea produced these islands, and the plants and animals that live here have adjusted themselves to the harsh environment. The islands and the life thereon will maintain themselves best if man interferes least. For the most part, man is a visitor who does not remain. Thus, the seashore will be mainly a natural area, some of it having a wildland character. Therefore, development will be minimal and recreational uses will be compatible with the natural setting…*

Table 47. Management plans developed for CALO. From NPS (2015a).

Year	Plan	Description
1982	General Management Plan (GMP)	Detailed the general management practices for Cape Lookout.
1984	Wilderness Suitability Study and Proposal—Environmental Assessment	Congressionally mandated study to assess whether a part of Cape Lookout is suitable for designation as a wilderness zone
1985	Wilderness Recommendation	
2001	Amended General Management Plan	Amended the 1982 GMP to improve overnight accommodations and transportation services for the general public.
2006	Interim Protected Species Management Plan and Environmental Assessment	Temporary plan that allows protected species, human recreational activities, and vehicles to share the seashore responsibly; this plan will guide management practices until the long-term Off-Road Vehicle Management Plan is completed.
	Special Regulation—Personal Watercraft (PWC) Use	A plan to manage use of PWCs within Cape Lookout boundaries; includes a map of permitted PWC access points.
2011	Long-Range Interpretive Plan	A plan which builds on existing planning and recommends programs, media, and partnerships to be implemented in the next 5–7 years; includes strong outreach education.
In progress	Off-Road Vehicle (ORV) Management Plan	This plan will guide the management decisions which allow the use of vehicles and still protect the wildlife and other resources in the seashore.

The two main objectives of the GMP were to administer the seashore for general purposes of public outdoor recreation, including conservation of natural features contributing to public enjoyment (Public Law 89-366); and to provide the facilities needed to accommodate the health, safety, and recreational needs of the visiting public (Public Law 93-477). The GMP describes a systematic approach to balance recreational use with long-term preservation of natural resources, processes and values. It perpetuates levels of use of each barrier island. The amended GMP improved overnight accommodations and transportation services for visitors to Core Banks (excluding the Portsmouth Island area). The *Cape Lookout National Seashore Resources Management Plan and Environmental Assessment* was completed for the park at about the same time (NPS 1983).

The seashore has a strategic plan (under the Government Performance and Results Act—public law 103-62) which states, as its mission goal, that natural "resources and associated values are protected, restored, and maintained in good condition and managed within their broader ecosystem and cultural context" (NPS 2005a, 2012k). Cape Lookout has a long-range interpretive plan (NPS 2011a), which includes a Purpose Statement and Significance Statements. The purpose of this seashore is:

> *…to preserve the outstanding natural, cultural, and recreational resources and values of a dynamic, intact, natural barrier island system*
>
> *—NPS 2011*

The purpose statement was based on a thorough analysis of the enabling and other legislation for Cape Lookout, and it documents shared assumptions about what the legislation really means for the park.

Significance statements "describe the distinctiveness of the combined resources [natural, cultural, scientific, recreational, inspirational, etc.] of a national park…They embody the power of the place and summarize the importance of the park's resources to our natural and cultural heritage (NPS 2011a, p.11)." In short, they express why the park's resources and values are important enough to warrant national park unit designation (NPS 2014 a; NPS 2011a; NPS 2012k; NPS 2014e). The following six significance statements, five of which pertain to natural resources, have been identified for this seashore (NPS 2011a), based on Cape Lookout's amended GMP (NPS 2001a):

- Cape Lookout National Seashore is nationally recognized as an outstanding example of a dynamic natural coastal barrier island system (NPS 2011a). [Note: NPS (2014e) added to that statement, "where ecological processes dominate."]
- Cape Lookout National Seashore preserves in an nearly natural state 90.1 kilometers (56 mi) of barrier islands, which combined with Cape Hatteras' 122.3-km (76-mile) length, forms and shelters the second largest estuarine system in [on] the United States [mainland]. NPS 2014e includes two other Significance Statements instead of this one:
    - Cape Lookout National Seashore is one of the few remaining locations on the Atlantic Coast where visitors can experience and recreate in a primarily undeveloped, remote barrier island environment, which can be reached only by boat; and
    - Cape Lookout National Seashore provides a remote setting for visitors to experience unobstructed ocean views and one of the darkest publicly accessible areas along the East Coast for nighttime vantages.]
- Cape Lookout National Seashore is designated as a unit of the Carolinian-South Atlantic Biosphere Reserve, United Nations Educational, Scientific and Cultural Organizations (UNESCO) and Man and the Biosphere Reserve Program.
- Cape Lookout National Seashore contains cultural resources rich in the maritime history of humankind's attempt to survive at the edge of the sea.

- Cape Lookout National Seashore contains critical habitat for endangered and threatened species and other unique wildlife including the legislatively protected wild horses of Shackleford Banks. Note: NPS (2014e) includes two other significance statements rather than this one:
    - Cape Lookout National Seashore preserves a diversity of coastal habitats, which support aquatic and terrestrial plant and animal life, including several protected species, such as piping plovers, American oystercatchers, sea turtles, black skimmers, terns, and seabeach amaranth; and
    - Cape Lookout National Seashore provides an outstanding natural laboratory for studying ecological and geological processes, as well as the effects of climate change and sea-level rise on the Atlantic Coast.
- The park also represents a conscious decision to restrict/control development, keeping the vast majority of the park natural and allowing to the greatest extent possible for natural processes/forces to take their course.

Finally, as mentioned, when finalized the ORV Management Plan (NPS 2014a) will guide management decisions that allow use of vehicles while also effectively protecting the SSCs and other natural resources of Cape Lookout.

Biological Resources and Management

Attributes Used in Assessment

The NPS Omnibus Management Act of 1998, and other reinforcing policies and regulations, require park managers “to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources (Title II, Sec. 204).” A first step toward meeting that mandate is to inventory the species diversity of park biota. Understanding changes in species distributions is integral to informed management of species and their habitats—changes in species distributions over time provide valuable insights at local and landscape scales about how species respond to influences such as changing land use, climate, hydrology, or habitat quality/availability. Climate change, for example, influences the distribution, phenology, population demographics, and abundance of individual species. In turn, the cascading effects through altered species interactions and altered food web structure can impact ecosystem processes (Montoya and Raffaelli 2010). It is also valuable to capture the number of species (species richness) and their relative abundance (species evenness or dominance) within a given community (here, Cape Lookout). These two components describe the species diversity, often communicated as various diversity indices.

Diversity, defined as “the variety and abundance of species in a defined unit of study” (Magurran 2004, p.8 in Byrne et al. 2011b), is a community property that is broadly related to trophic structure, productivity, stability (McIntosh 1967, McNaughton 1977), immigration / emigration (Colwell and Lees 2000), and ecological condition (i.e., ecological integrity as defined by Karr and Chu 1995). Diversity indices respond differently to various mechanisms that influence community structure, so the National Park Service uses a suite of alpha diversity indices (the diversity of species within a defined area, community or ecosystem—Whittaker 1972) in order to fully characterize diversity in SECN parks (Haedrick 1975; Boyle et al. 1984 in Byrne et al. 2011b (Table 35).

2.3.2. Synopsis of Stressors to Cape Lookout Natural Resources

The present and potential stressors that are affecting or may affect Cape Lookout are summarized in Table 48. There are three major, overarching stressors to this seashore and various other stressors within that framework. The first two are accelerating sea-level rise and increasing major storms related to global warming, which are exacerbating the processes of accretion and erosion that are the primary environmental influence on the barrier islands and their natural resources. The barrier islands continue to sustain flooding and damage from major storm events, and scientists have reached consensus that these stressors are likely to increase in the coming decades (IPCC 2014).

The third major stressor is the high level of recreational use, from 400,000–500,000 visitors per year, which is conflicting with the need for habitat use by sensitive flora and fauna. Although the number of human visitors to Cape Lookout has remained at 600,000 or less in the past six years, representing a decline from 2003–2008, the breeding population of the federally threatened piping plover (*Charadrius melodus*) and the occurrence of the endangered plant, seabeach amaranth (*Amaranthus pumilus*) had already declined at Cape Lookout by about the turn of this century (NPS 2014a, j). Moreover, as mentioned, statewide declines have been documented for the American oystercatcher, least tern, common tern, gull-billed tern, and black skimmer (NPS 2014a.)

Recreational pressure and other human-related disturbance has generally been implicated in the low reproductive success and population declines for all of these species (NPS 2014a). Human-related disturbance has also been linked to increased mortality of migrating and wintering piping plovers, colonial waterbirds, and oystercatchers, as well as declines in federally endangered or threatened sea turtle adults, nests, and hatchlings. Therefore, seashore staff have increased management efforts to strengthen protection of these species insofar as possible.

Various other stressors affecting Cape Lookout are mostly linked directly or indirectly with the major stressors mentioned above. Area marketing of tourism is increasing (NPS 2011i, NPS 2012k). As mentioned, the park is on septic systems for waste treatment (Mallin et al. 2004). Inadequately treated septic effluent leachate rapidly percolates through the sandy soils to cause localized degradation of surface water and groundwater from high nutrient and fecal bacteria pollution (Mallin and McIver 2012). NPS (2014e) noted that “some wells in Cape Lookout contain elevated nitrate levels, most likely due to septic leachate.” Moreover, Back Sound off Shackleford Banks drains the populated areas of Morehead City and Beaufort, where numerous waterbodies near the seashore are impaired for elevated bacterial pathogen densities which have caused shellfishing areas to be closed or only conditionally approved for shellfish harvest (NCDENR 2014a). The critical habitat species, marine eelgrass (*Zostera marina*) along the Back Sound shore of Shackleford Banks would be expected to be especially sensitive to degraded waters encroaching from the mainland.

Solid waste from human inhabitants and visitors is a problem at Cape Lookout and has been for decades (Godfrey and Godfrey (1976).

Table 48. Current and potential stressors that are affecting or may affect Cape Lookout [ND—no data to make judgment; NP—not a problem; "---"—not applicable; EP—existing problem; PP—potential or pending problem].

Stressor	Airshed	Surface Waters	Groundwater	Terrestrial Habitats and/or Biota	Wetland Habitats and/or Biota	Aquatic Habitats and/or Biota	Human Health
Acidification	EP	EP	ND	PP	EP	EP	PP
Air pollution (other)	EP	EP	ND	EP	EP	EP	EP
Algal blooms	---	EP	---	---	EP	EP	PP
Toxic algae	---	EP	---	---	EP	EP	PP
Erosion (including dust)	---	EP	---	EP	EP	EP	---
Excessive nutrients	EP	EP	EP	EP	EP	EP	PP[a]
Exotic/invasive species[b]	---	---	---	EP	EP	EP	ND (PP)
Fecal bacteria, other microbial pathogens	---	EP	EP	PP	PP	PP	PP
Habitat disruption[c]	---	EP	ND	EP	EP	EP	EP
Hypoxia	---	EP	ND	---	---	NP	---
Light pollution	---	---	EP	EP	EP	EP	---
Metals contamination	ND (PP)	EP	ND (PP)	ND (PP)	ND (PP)	EP	ND (PP)
Noise pollution	---	ND (PP)	---	EP	ND (PP)	ND (PP)	ND (PP)
Other toxic substances	EP	EP	ND (PP)	ND (PP)	ND (PP)	EP	ND (PP)
Ozone pollution	EP	---	---	EP	---	---	EP
Particulate matter pollution	EP	EP	---	---	---	ND (PP)	EP
Saltwater intrusion into groundwater	---	---	EP	---	---	---	EP

[a] Excessive ammonia and pathogenic bacteria in the airshed from swine CAFOs represent a human health threat (Donham et al. 2007, Gilchrest et al. 2007, Heederik et al. 2007, Greger and Koneswaran 2010).

[b] Suspected for aquatic resources; known for terrestrial resources

[c] From erosion/accretion, ORVs, and other disturbance.

Table 48 (continued). Current and potential stressors that are affecting or may affect Cape Lookout [ND—no data to make judgment; NP—not a problem; "---"—not applicable; EP—existing problem; PP—potential or pending problem].

Stressor	Airshed	Surface Waters	Groundwater	Terrestrial Habitats and/or Biota	Wetland Habitats and/or Biota	Aquatic Habitats and/or Biota	Human Health
sea-level rise	---	EP	EP	EP	EP	EP	EP
Trash/refuse pollution	---	ND (PP)	ND (PP)	EP	EP	ND (PP)	ND (PP)
Visibility (air pollution)	EP	---	---	ND (PP)	---	---	EP
Water demand	---	---	EP	ND (PP)	ND (PP)	---	ND (PP)

[a] Excessive ammonia and pathogenic bacteria in the airshed from swine CAFOs represent a human health threat (Donham et al. 2007, Gilchrest et al. 2007, Heederik et al. 2007, Greger and Koneswaran 2010).

[b] Suspected for aquatic resources; known for terrestrial resources

[c] From erosion/accretion, ORVs, and other disturbance.

Although Cape Lookout is relatively isolated from mainland water pollution, the prevailing westerly winds have brought air pollution from the mainland to the barrier islands, resulting in generally poor air quality at the seashore at times. Looking west from the park, this author has seen a brown layer over the mainland whereas the opposite view, looking east over the ocean, seems clear (author's personal observation).

A major, ongoing concern expressed by park staff is the predation of sensitive SSCs such as sea turtles and various shorebirds by ghost crabs and by mammals such as raccoons, opossums, foxes and, more recently, coyotes (NPS 2014a). Some of this predation is exacerbated by human activities such as leaving garbage on beaches. Another concern is that there is a limited knowledge base and a limited inventory on various species.

The influx and expansion of exotic/invasive plants are a threat to the natural vegetation of the seashore. Other stresses to terrestrial vegetation communities are feral hogs that cause damage, and over-browsing by white-tailed deer (Byrne et al. 2012). Saltmarshes at Cape Lookout are threatened by the rising sea; in addition, the filtering function of wetlands that receive runoff from developed areas can transfer pollutants and debris into the sediments and, thus, adversely affect benthic communities (Hymel 2009 and references therein). Boat wakes can cause sediment deposition and resuspension in seagrass beds, reducing light availability and eliminating the habitat (Bishop 2005 and references therein). Boat wakes can also deposit sediments onto shellfish beds, disturb soft-bottom benthic habitat, cause shoreline erosion, and alter the grain size distribution of sediments (Bishop 2005, Hymel 2009). Seagrass meadows can sustain damage from certain fishing practices as well (Waycott et al. 2009), which are conducted in and near Cape Lookout waters (e.g., Peterson et al. 1987). Shallow-set fishing nets additionally have caused waterbird bycatch; that is, the nets have been linked to hundreds of waterbird mortalities per incident along the barrier islands (American Bird Conservancy 2013). This happens because various birds dive down to catch fish trapped in the nets, become entangled in the mesh, and drown.

Other stressors that have been identified for Cape Lookout are military overflights and the potential for energy development in nearby areas, including "wind farms" and fossil fuels (oil drilling). The USMC has conducted training flights in the military operations area (MOA) over the North Carolina barrier islands for decades. Recent research at Cape Lookout reported little apparent impact from military overflights on American oystercatchers as a sentinel species, but park staff remain concerned about possible impacts, not yet examined, from military overflights on other seashore biota.

Wind farms are planned for installation along the North Carolina coast by 2017–2018 (Queram 2012). The coastal zone out to at least 3.2 kilometers (2 mi), the areas within an 8.0-kilometer (5-mi) radius around each inlet, Cape Hatteras, The Point northeast of Cape Hatteras, and all waters shallower than 4 meters in depth have been evaluated as incompatible with wind farming because of unacceptably high risk to birds, sea turtles, and/or marine mammals (UNC Chapel Hill 2009) (Figure 75). Birds (especially brown pelicans and juvenile gulls and terns) and bats are at greatest risk of harm from wind turbines over water (University of North Carolina Chapel Hill [UNC CH] 2009).

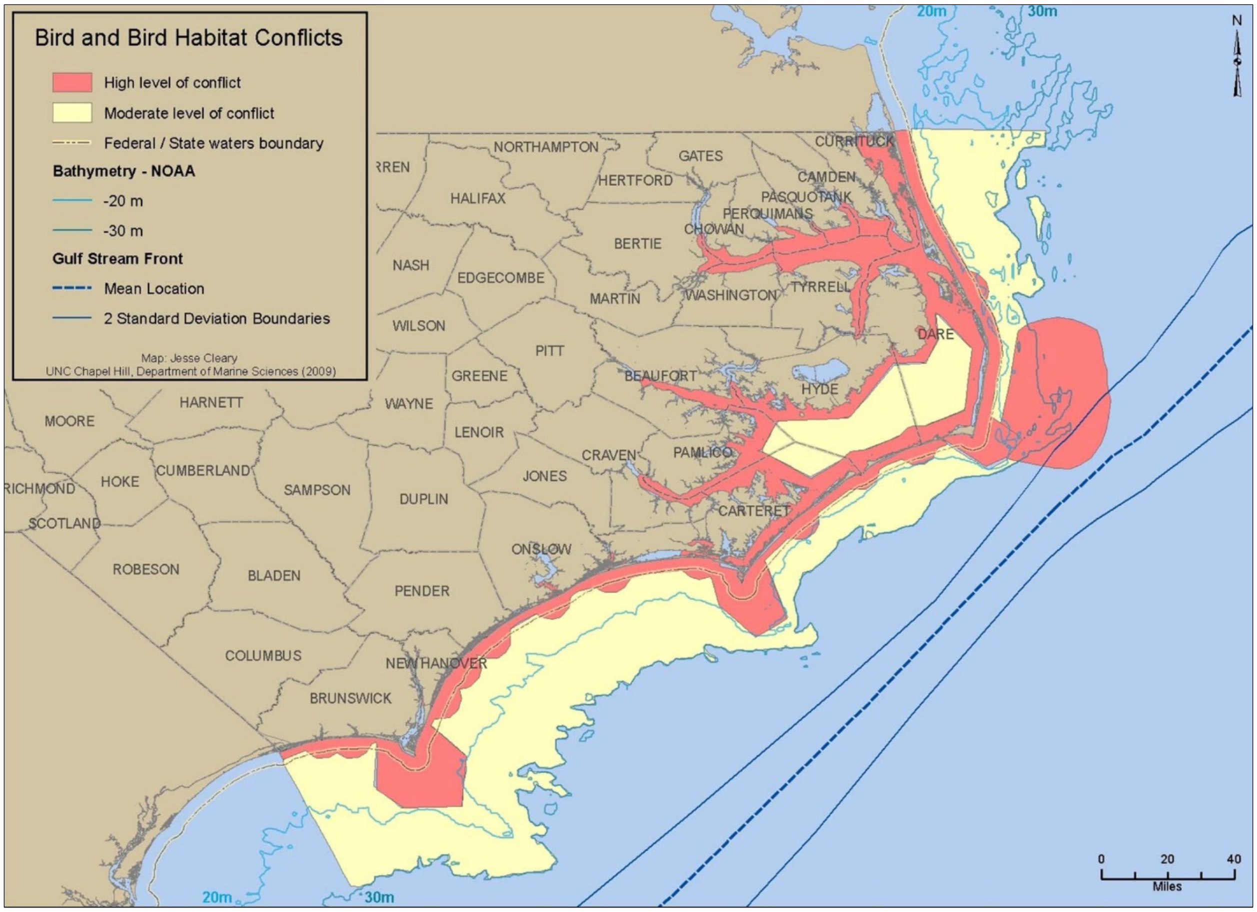

Figure 75. Map of risk to birds and bird habitats in CALO from wind farms (UNC CH 2009).

Sea turtles may be adversely affected from noise pollution during installation of piles for wind turbine structures, which may have to be up to 30 meters (98.4 ft) deep into the sedimentary sea floor to stabilize the wind turbine above. Bottlenose dolphins have retreated to 10 kilometers (6.2 mi) away from similar noises, thereby temporarily depriving them of use of the area for habitat. Marine mammals and sea turtles may be affected, as well, by the electromagnetic fields around the transmission cables running from the wind farm into shore. Sea turtles navigate back to natal beaches based on following the natural magnetic field; thus, the buried transmission cables from wind turbines may disrupt sea turtle navigations and lead to failure to reach nesting sites. Other organisms may be similarly affected, such as the American eel which is a SSC at Cape Lookout. The coastal zone out to at least 3.2 kilometers (2-mi), the areas within an 8.0-kilometer (5-mi) radius around each inlet, Cape Lookout and all waters shallower than 4 meters (13.1 ft) in depth have been evaluated as incompatible with wind farming because of unacceptably high risk to birds, sea turtles, and/or marine mammals.

3. Study Scoping and Design

3.1. Preliminary Scoping

Southeast Coast Network Program Manager J. DeVivo organized an initial workshop for this project in Atlanta, wherein we received guidance about the background and foundation of NPS Natural Resource Condition Assessments. We also received counsel about the best NPS specialists to contact about various aspects of the project, available NPS data, and NPS websites with important information. This meeting addressed project objectives, which included determining the subset of NPS-identified and author-identified data and information sources that are most pertinent and useful for developing indicators and performance measures, and conducting a series of workshops to assist in project completion.

In recognition of the fact that park staff have, by far, the most advanced and detailed, comprehensive understanding about the natural resources of Cape Lookout, we then visited the seashore and spent several hours with park staff. We discussed each category of natural resources with them, and learned their knowledgeable views about issues for each category that would need to be considered in inventory and assessment efforts. Their input was essential to enable us to select an optimal set of natural resource indicators that would be the most useful to the park staff both short-term and long-term. We additionally were given their guidance on which indicators should be emphasized as major priorities for the park. We all were in accord that the indicator framework needed for Cape Lookout should follow an ecosystem approach as in DeVivo et al. (2008).

An extensive, continued effort over the entire span of the project was then conducted to obtain all manner of natural resource information pertinent to the park—historic information, reports, books, peer-reviewed publications, management plans, GIS data, etc. All of this information was carefully considered in writing the final synthesis of the inventory and status of Cape Lookout natural resources. The findings were presented within an ecosystem framework (Figure 76), considering Cape Lookout as the ecosystem. Following a hierarchical framework patterned after Unnasch et al.'s (2009) Ecological Integrity Assessment Framework, we first considered the overall goal(s) of the park staff for the desirable status (i.e., the ecological integrity, of each category of natural resources in Cape Lookout). Ecological integrity is defined here as the ability of an ecological system to support and maintain a community of organisms with species composition, diversity, and functional organization comparable to those of the natural/historic habitats in the park. We then conducted a macroscale inventory of landscape/ waterscape pattern (geologic processes, sea-level rise etc.) surrounding the park; the "human biological factor," i.e., human population demographics in the area surrounding Cape Lookout and visitor statistics within the park; air quality (airshed level), water quality (within and near the park), the soundscape, and the lightscape; and other stressors on the natural resources within the park. This included a concerted effort to gather and organize existing databases for multiple GIS data layers describing seashore natural resources. Next, we inventoried what is known about the present composition and condition of the vegetation, habitat structure, and including the natural communities, SSCs, exotic/invasive species, and species of special management concern (predators, wild horses). For each category of natural resources, we then identified a suite of indicators and measures for tracking natural resource health in Cape Lookout.These indicators were carefully selected to be scientifically sound while also providing the most "user friendly," straightforward, and easily accomplished method for evaluation that we could find.

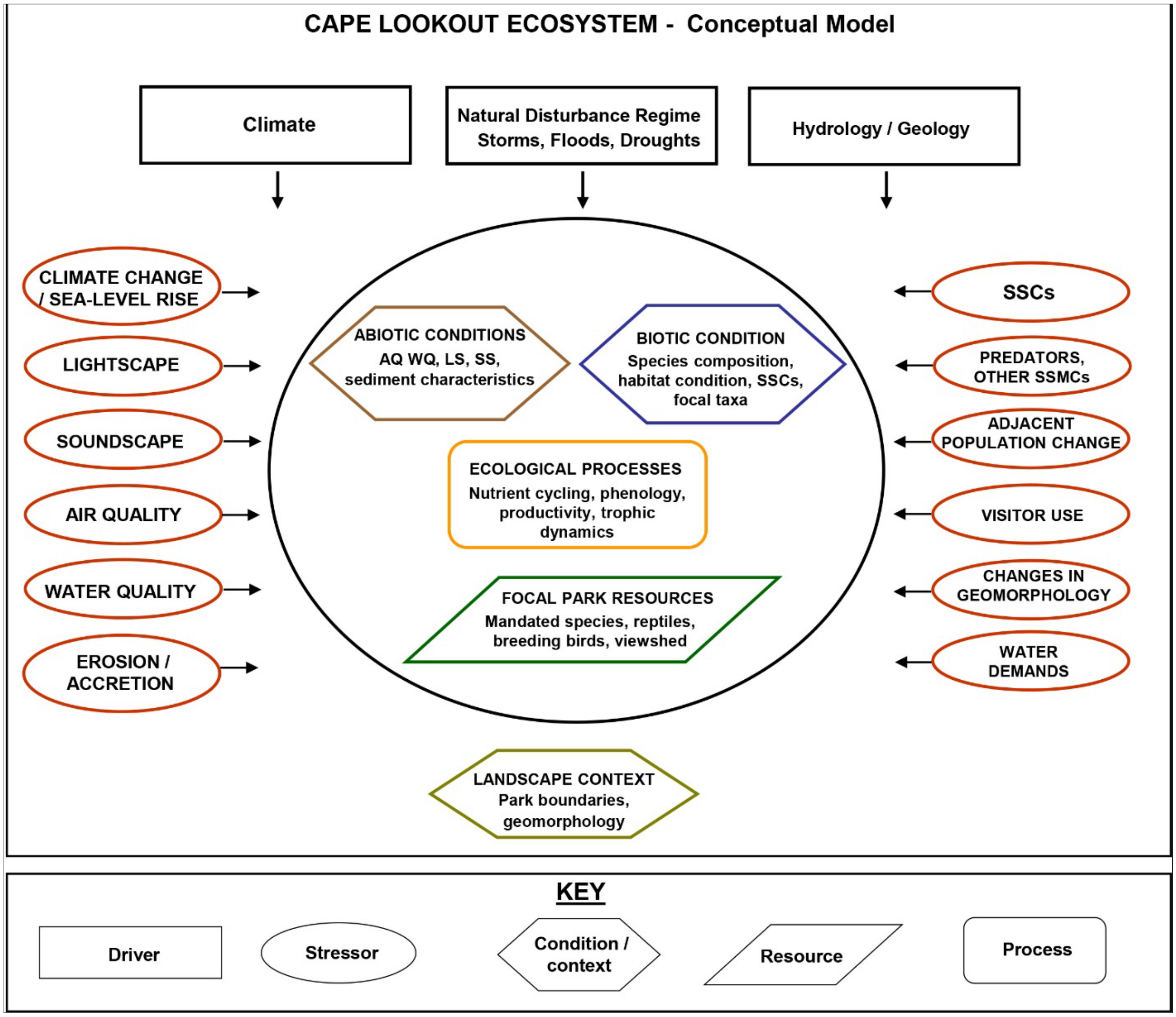

Figure 76. Conceptual model of the CALO ecosystem, used as a general framework to select indicators of natural resource health for the seashore. Modified from DeVivo et al. (2008, Appendix: Conceptual Ecological Models; examples of stressors are shown).

Selecting indicators and establishing target values is a difficult task, often pursued with imperfect or sometimes inadequate information. In some cases, future research and monitoring are required to evaluate the resource condition. Consequently it is not possible to determine whether or not target values have been met in some cases, but resource managers in the park should have new information to assess targets in the future.

Our intentions in meeting the latter requirement were two-fold: First, to provide, insofar as possible, a suite of indicators and the methods to assess them that park staff and the National Park Service in general will find clear, simple and rapid, and relatively inexpensive to conduct; and second—in this world where information must be conveyed in sound bites and one-page bullets—to provide an indicator system with powerful messages that are easy/fast to explain to policy-makers who often have dramatic influence over our nation's increasingly precious national parks.

As noted by the South Florida Ecosystem Restoration Task Force (2011) from its "System-wide Indicators for Everglades Restoration—2010 Report,"

> *Any method of communicating complex scientific and findings to non-scientists [for Cape Lookout, the general citizenry, visitors to the park, and politicians who strongly influence critically needed funding for the park] must 1) be developed with consideration for the specific audience, 2) be transparent as to how the science was used to generate the summary findings, 3) be easy to follow the simplified results back through the analyses and data to see a clear and unambiguous connection to the information used to roll-up the results, 4) maintain the credibility of the scientific results without minimizing or distorting the science, and 5) should not be, or appear to be, simply a judgment call (Norton 1998, Dale and Beyeler 2001, Niemi and McDonald 2004, Dennison et al. 2007)….[T]he system must be effective in quickly and accurately getting-the-point-across to the audience in order for the information to be used effectively (Rowan 1991, 1992; Dunwoody 1992; Weigold 2001; Thomas et al. 2006; Dennison et al. 2007).*
>
> *— U.S. Department of the Interior Office of Everglades Restoration Initiatives*

Thus, here we use a "stoplight report card system" approach (e.g., Doren et al. 2009, NPS 2009a) of good (green), fair (yellow), and poor (red) to summarize our evaluation of present natural resource conditions at Cape Lookout (Table 49). This system has been used with great success to assess natural resource conditions systems such as Chesapeake Bay and its watershed (Williams et al. 2007), and the Florida Everglades ecosystem (Ferriter et al. 2007; Doren et al. 2008, 2009). It is important to note that various indicators developed and used here to track natural resource conditions in Cape Lookout over time are for factors that are not possible for the National Park Service to control. There are usually external factors that may significantly affect the seashore.

Table 49. The color-coded "stoplight report card" system used to succinctly convey the status of Cape Lookout natural resources.

Good	Fair	Poor
Green	Yellow	Red

We were instructed by the National Park Service to design indicators that were quantifiable and supported by peer-reviewed science literature. We therefore clarify when indicators are suggested for which quantitative information was not available. This stipulation, while logical, greatly restricted the suite of indicators that could be proposed. We also include discussion of data gaps that we view as especially important to fill so that certain much-needed indicators can be developed in the future. Finally, to ensure that the data used to develop the indicators and assessment were of acceptable quality, we restricted our inventory and this analysis to reliable sources (e.g., NPS, peer-reviewed literature, QA-QC'd data, etc.), and to data collected by those sources within the past 15 years. This indicator framework and suite of indicators for Cape Lookout support the identified goals of the National Park Service to "develop service-wide products that improve management of biological resources in parks, and maintain a broad ecosystem-based framework for park management" (Unnasch et al. 2009).

It should be noted, in addition the National Park Service (2014e) recently developed a State of the Park report for Cape Lookout to provide a summary of overall status and trends of six categories of park natural resources, which included air quality, dark night sky, geologic features and processes, water quality, plant and wildlife communities, and protected species of concern. The information was contributed toward improving park priority-setting, and facilitating communication about resource status to the general public. The State of the Park report for Cape Lookout uses a similar stoplight system with additional information overlain about the trend in condition based on park and I&M staff's general knowledge, and about general confidence in the assessment. We considered assessments available in the State of the Park report (NPS 2014e) for some of the natural resources in Cape Lookout, and included the NPS assessments in developing the suite of indicators presented here.

Table 50. Schematic of the Status and Trends system developed by the NPS (2014e) for evaluating the status of natural (and cultural) resources at CALO: The background color represents the current condition status; the direction of the arrow summarizes the trend in condition, where sufficient data are available for assessment; and the thickness of the outside line represents the degree of confidence in the assessment. From NPS (2014e).

Condition Status		Trend in Condition		Confidence in Assessment	
	Resource is in Good Condition		Condition is Improving		High
	Warrants Moderate Concern		Condition is Unchanging		Medium
	Warrants Significant Concern		Condition is Deteriorating		Low

3.2. Study Design

3.2.1. Data Sources

Data files available through NPS GIS personnel were parsed down to those relevant to natural resource management concerns (see Appendix B and C1). An FTP site was set up for file transfer from NPS personnel to the CAAE server. Data considered necessary for specific analytical or display purposes, but unavailable from NPS files, were obtained from external databases.

Databases that provided statewide data for use in assessing Cape Lookout included:

- National Land Cover Database 2006 and 2011 (Fry et al. 2011, Homer et al. 2015) provided through the Multi-Resolution Land Characterization (MRLC) consortium (MRLC 2015);
- Statewide hydrology, elevation, geographic names and government unit file were obtained from the Geospatial Data Gateway (NRCS 2014);
- National Wetlands Inventory (NWI), Critical Habitat, National Wildlife Refuge Boundaries, and Wilderness Preserve Boundaries were obtained from the U.S. Fish and Wildlife Service (USFWS 2015a);
- 305(b) and 303(d) waterbody listings for 2010 were obtained from the North Carolina Department of Environment and Natural Resources (NCDENR 2014b, NPS 2016b)
- 2010 U.S. Census Population Density data obtained from the U.S. Census Bureau (USCB 2015c).
- NPScape: A landscape dynamics monitoring project of the National Park Service that produces and delivers to parks a suite of landscape-scale datasets, maps, reports, and other products to inform resource management and planning at local, regional, and national scales. Initial analyses include six major categories (population, housing, roads, land cover, pattern, and conservation status) that broadly address the environmental drivers, natural attributes, and conservation context of the parks. In aggregate, these measures contribute to assessments of current natural resource status, potential threats, and conservation vulnerability and opportunity. See NPScape (NPS 2014c) and the NPS Integrated Resource Management Applications (IRMA) data system.

Each GIS file obtained for the park and surrounding area was accessed and reviewed for spatial reference and availability and correctness of metadata. Where necessary, files were copied and post-processed to marry into a cohesive database for across-the-board integration in map-making and analyses. Aerial imagery was examined in ArcMap and orthorectified where necessary.

Organizational efforts were made to maintain copies of NPS data in an “unadulterated” form digitally segregated from data that had been geoprocessed or created by the North Carolina State University Center for Applied Aquatic Ecology (CAAE), while maintaining a logical directory structure. We separately maintained oversight of CAAE GIS systems (software and hardware), GIS computer hardware upkeep and maintenance, troubleshooting/updating of ArcGIS software, and, as needed, addressed any other database management requirements for spatial data amassed by CAAE staff.

Maps depicting various geographic themes were developed for Cape Lookout, including soils, geology, hydrology, wetlands, population density, impervious surfaces, urban encroachment and social trails, and land use coverage/change in the park, sub-watershed, and/or overall river basin. The maps were designed to address points of interest specific to the park, and to illustrate geographic positioning of known site localities and/or regional relationships. In many cases low-resolution draft maps were provided to SECN staff who then made high-resolution publication-quality maps that were used in the report.

4. Indicators to Assess Natural Resource Conditions

4.1. Adjacent Human Population and Visitors to the Seashore

4.1.1. Human Population in the Area

Issue: Population size and rate of growth have been strongly linked to adverse ecosystem impacts. The population of Carteret County is growing. Development is continuing to expand, and related stresses affecting CALO natural resources are expected to continue to increase.

As explained, Carteret County has steadily increased in human population, overall by 13.9% since 2000. The population is expected to grow by 1.33% annually, from 67,000 people in 2010 to more than 86,000 by 2030 (Department of City and Regional Planning 2011) (Figure 77).

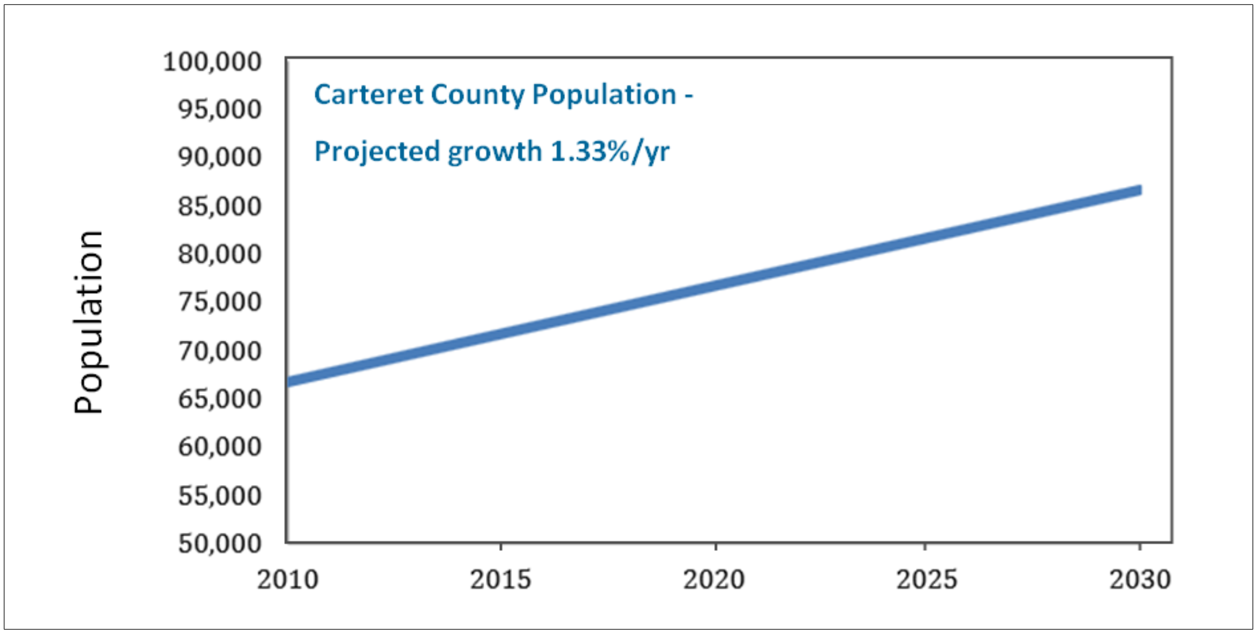

Figure 77. Projected human population growth in Carteret County from 2010 to 2030. From the N.C. Office of State Budget and Management in the Department of City and Regional Planning (2011).

Human-related land transformation is the primary driving force in the loss of biological diversity worldwide (Vitousek et al. 1997). The size, density, and rate of growth of the human population in a given area have been strongly linked to rapidly escalating environmental disruption (Ehrlich and Holdren 1971) and exotic/invasive plant species diversity and abundance (McKinney 2001). As noted by Meyer and Turner (1992), “population remains one of the few candidate driving forces that is readily measured and for which statistical associations have been found with ecosystem decline.” The human population size, growth, and density surrounding national parks are unquestionably major influences on the park ecosystems. Thus, Rivard et al. (2000) found that species richness, extirpations, and alterations within other national parks were all strongly related to characteristics of the lands surrounding the parks. In addition, species invasions and introductions were more frequent in parks that were subject to the most human influence.

Although the science literature is replete with reports about environmental degradation linked to increasing human population density (HPD), information is mostly lacking about the quantitative level of HPD that acts as a threshold triggering significant damage to the adjacent natural ecosystem. Luck (2007) summarized the issue as follows: "…clear and predictable links between human population dynamics and environmental change remain elusive largely because of the complexity of the human enterprise and its many and varied impacts on nature" (see schematic in Figure 78). Viewed from a quantitative standpoint, impacts of high human population density can extend many kilometers beyond city boundaries (Myers 1994, Repetto 1994), but the effects can vary from minor to major in areas of lower human population density, largely depending on the main land use (Luck 2007, and references therein). Context is important: For example, a marked increase in human population density near a wilderness reserve would be expected to have quite different impacts than if the increase occurred near a city park. Socioeconomics are also important influences on the degree of environmental impact.

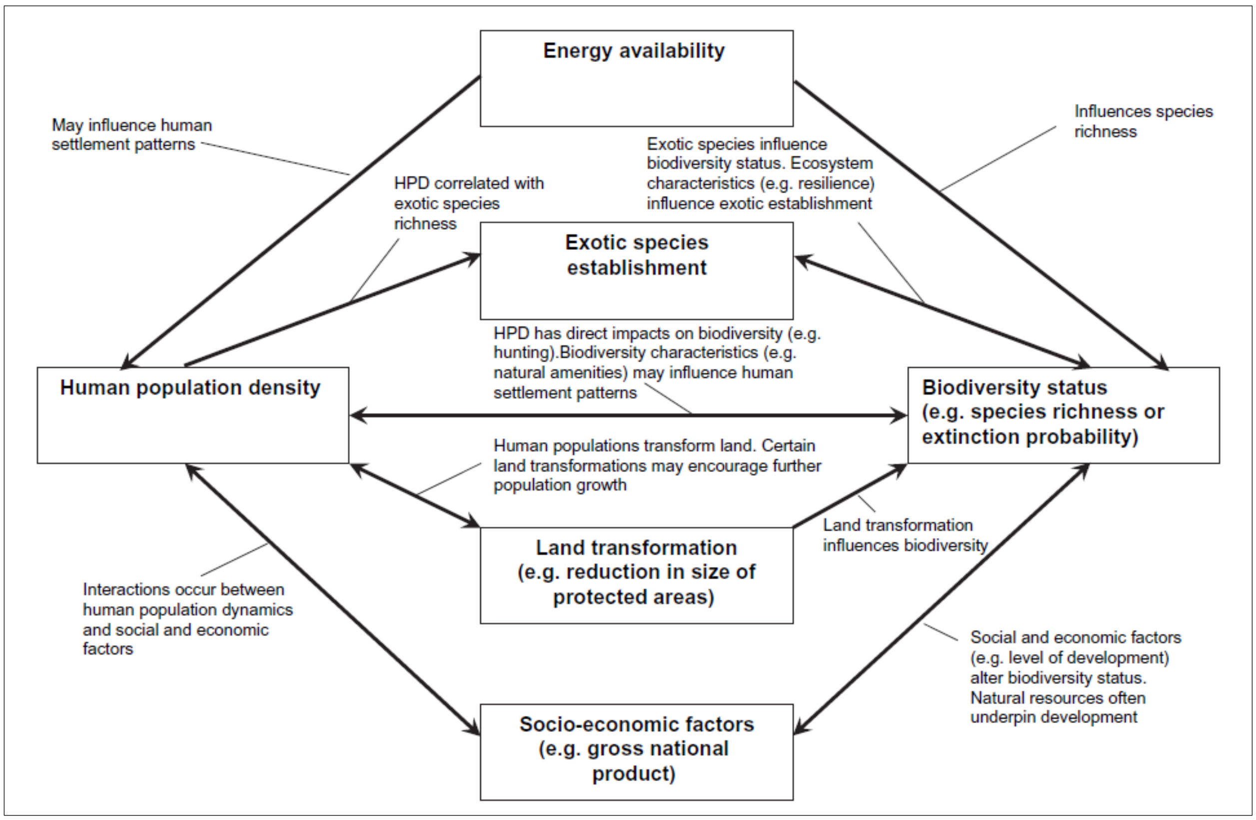

Figure 78. A schematic of possible relationships between human population density and biodiversity, especially focusing on the negative impacts of human population growth. The evidence for each of these relationships varies in the literature. The diagram includes biodiversity feedback loops, but not interconnections between energy availability, exotic species establishment, land transformation and socio-economic factors. From Luck (2007), with permission.

Regardless of these complexities, we felt it important to represent adjacent human population density (HPD) and human population growth (HPG) as indicators of natural resource health in Cape Lookout National Seashore. In addition, it generally can be stated with confidence that human population growth results in increasing land changes and exotic species introductions; and that land protected for conservation is often greatly reduced near human population centers (Luck 2007). As Luck (2007) wrote, "Protected areas close to human settlements suffer from 'double jeopardy (sensu Harcourt et al. 2001): they are small, which makes them susceptible to external impacts, and they are surrounded by high HPD potentially undermining their capacity to afford adequate protection to their associated ecosystems."

Our evaluation system for the two human population indicators considered the following information:

- National growth: Over the past decade (2001–2010), the national average was a 9.71% increase in HPG (1% per year), and the average HPD was 31.3 people per km^2 (81.3 people per $mile^2$). The 1% per year value was used in developing the evaluation system for HPG; we centered the middle category, fair, around this value (0.8 to 1.2% per yr).
- State growth: North Carolina has an overall population density of 75.7 people per km^2 (196.1 people per $mile^2$) as of 2010 (USCB 2015b) (Figure 79). The state grew 18.5% from 2000 to 2010 (from 8,049,310 people to 9,535,483 people; CensusViewer 2012), or 1.7%/yr.
- Local growth: As of 2010, Carteret County had 50.7 people per km^2 (131.3 people per $mile^2$), and the population growth rate was +1.0% per year over the period from 2000 to 2013 (13.9% total over that period).
- As an historic "reference" condition, about 500 years ago the HPD was 0.9 people per km^2 (2.3 people per $mile^2$) in the southeast region (from Burkett et al. 2001; Fagan 1995, Smith 2000).
- Analysis of 24 present-day wilderness areas revealed that all had population densities of ≤ 5 people per km^2 (12.8 people per $mile^2$) (Mittermeier et al. 2003). It would be expected that present-day conditions, even in areas considered somewhat "remote," would have substantially higher human population density than did the southeastern United States about 500 years ago.

As this seashore is widely regarded as among the most important havens for sensitive natural resources in the nation, and because Shackleford Banks is recognized by the National Park Service as a proposed wilderness area, we set the good category cutoff at less than or equal to five people per square kilometer (13 people per mi^2), comparable to conditions near wilderness areas as described above. Fair was set to the high end of the range of the average for North Carolina excluding major population centers (Figure 79; 19.2–38.4 people per km^2 [50–100 people per mi^2]). We also considered the poverty level in Carteret County (14% of the population).

The evaluation of the three selected human population indicators in relation to Cape Lookout NS is shown in Table 51b. Two of the three indicators yielded a fair evaluation and one was poor; thus, the overall evaluation of adjacent human population impact condition affecting the seashore is fair. It merits mention that the populations used Carteret County was for year-round permanent residents. Carteret County population increases significantly during the summer tourist season, so our analysis is for "best case" (i.e., lowest population) conditions. Human population impact condition would be much worse if the summer season populations had been considered here. We chose not to do so because we felt that the summer population impacts were more appropriately considered under Section 4.1.2, visitation.

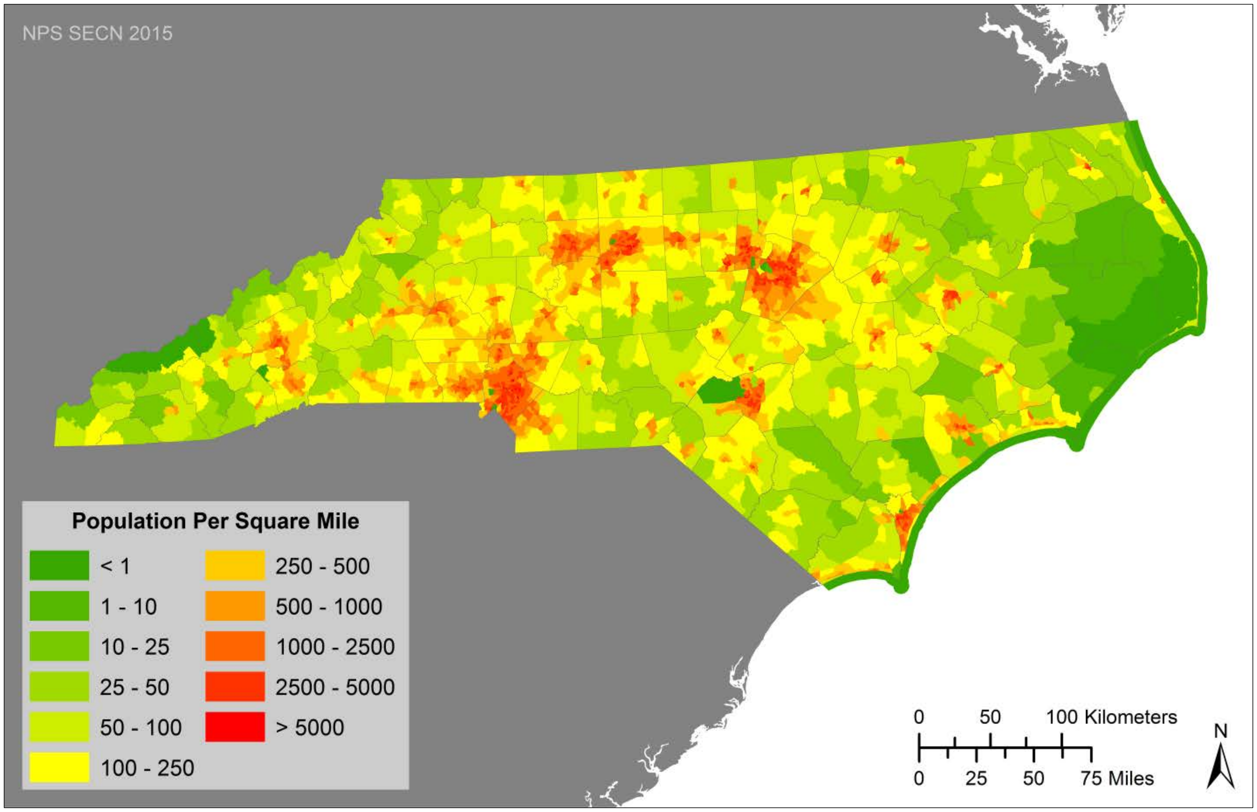

Figure 79. Human population distribution in N.C. Note that the Cape Lookout area is green (1–10 people per square mile), whereas left of the seashore along the western Outer Banks the population density is 250–1,000 people per square mile.

Table 51a. Present status of adjacent population condition affecting Cape Lookout. Note that for this condition, good indicates minimal adverse impact, whereas poor indicates maximal adverse impact. The three indicators are based only on year-round population data.

Indicator	Good	Fair	Poor
HPG_{COUNTY}	< 0.8%/year	> 0.8 to 1.2%/year	> 1.2%/year
HPD_{COUNTY}	< 5 people/km^2 (13/mile^2)	> 5 to 40/km^2 (50 to 100/mile^2)	> 40/km^2 (> 100/mile^2)
POV	< 5% of the population below poverty level	5–10%	> 10%

Table 51b. Present status of adjacent population condition in affecting Cape Lookout. Note that for this condition, good indicates minimal adverse impact, whereas poor indicates maximal adverse impact. The three indicators are based only on year-round population data.

Population Impact Indicators	CALO	Rating
Human Population Growth in the County (HPG_{COUNTY})	Increase of > 1.0%/year (2000–2010); the population has increased overall by 13.9% from 2000 to 2013.	Fair
Human Population Density (HPD_{COUNTY})	Carteret County: 50.7 people/km^2 (131.3 people / mile^2).	Fair
Poverty in the general area (POV)	Carteret County: 14% of population below the poverty level.	Poor

Table 51c. Present status of Adjacent Population Condition affecting CALO. Note that for this condition, *good* indicates minimal adverse impact, whereas *poor* indicates maximal adverse impact. The three indicators are based only on year-round population data. Evaluation (decadal basis—four indicators)

Good	Fair	Poor	CALO
< 2 good, < 1 fair, 0 poor	> 2 fair, < 1 poor	> 2 poor	Fair

4.1.2. Visitation

Issue: Although the NPS mission is partly centered on excellence in service for park visitors, visitors have been shown to negatively impact another key portion of the agency's mission, to protect natural and cultural resources. The conflict between the two parts of the NPS mission is apparent at Cape Lookout because this narrow seashore receives high visitation of about half a million people per year.

Visitors' impacts are identified by the National Park Service as among the top ten Issues for National Parks (National Geographic 2015; also see Buckley 2003). The two central portions of the NPS mission statement are in conflict especially when visitor pressure is high, and Cape Lookout exemplifies this implicit conflict. Some areas show signs of very high visitation pressure. Cape Lookout hosts from 480,000 to 600,000 visitors per year. Although visitation since the Great Recession began in 2008 has declined in comparison to visitation from 2001–2007 (maximum 860,602 in 2007) (Figure 4), visitation is expected to increase from 600,000 to 800,000 as the nation and the region continue to recover from this economic hardship. An ongoing, increasing and related problem is the trash discarded by a portion of the visitors. Neither the trash nor the number of trash incidents has been quantified.

The high levels of visitor use of Cape Lookout beaches that are important sea turtle and shorebird habitats have been an increasing concern for park staff. The ORV violations noted in Tables 38 and 41 involved vehicles that drove between posts (of sea turtle or piping plover closures) and the ocean at low tides, or (one can only assume, deliberately) drove through posts and rope, or (clearly deliberately) pulled up posts and drove through closures (see the NPS annual reports referenced in the table legends). The National Park Service (2008a) reported that in proposed wilderness area

Shackleford Banks, sea turtle "nest #111 was urinated and defecated on with paper left on site." The ORV Management Plan, when finalized, will hopefully improve this situation, but ORV violations/citations and warnings have numbered more than 200 in some recent years (Table 38).

Our index for visitor use is based on three indicators, outlined in Table 52a. The annual visitor number per area was estimated by dividing the number of visitors by the total park area. This approach tacitly assumes that visitors use all areas of the seashore equally, unrealistic because many visitors concentrate in certain areas such as trails. Therefore, the approach underestimates visitor pressure in the highly used areas, but it enables a straight-forward calculation of visitor pressure for the seashore. The final indicator, visitor pressure on trails, is more realistic than visitor number per area because people do concentrate in trail areas. There are two connected trails in the park on Harkers Island, the sound side Loop Trail (1.3 kilometers [0.8 mi] in length) and the Willow Pond Trail (0.5 kilometers [0.33 mi]) (NPS 2015h). In addition, although there are no actual trails on the barrier islands, many people hike the islands along the beach which is 91 kilometers (57.5 mi) long. Thus, we used a total "trail" length of 92.8 kilometers (58.6 mi) in developing this indicator.

A similar approach was followed as for visitor number per area, using trail length rather than area. The good, fair, and poor categories considered the easily eroded, sandy soils of Cape Lookout. In addition, we considered the information used to develop indicators for surrounding population condition. Based on the three indicators, the overall assessment of visitor condition in Cape Lookout is fair (Table 52c). By comparison the State of the Park report for Cape Lookout evaluated the number of visitors as good (which corresponds to our VIS indicator), but with decreasing trend/status considering that the number of visitors in 2012 was 19% less than the five-year average for 2007–2011. Notably, the report indicated low confidence in the assessment (NPS 2014e).

Table 52a. The three indicators used to evaluate visitation conditions in Cape Lookout*.

Indicator	Good	Fair	Poor
VIS (trend in number of visitors/year)	VIS trend decreasing or no change	VIS trend decreasing	VIS trend increasing or no change
$VP\text{-}A_{DAY}$ (visitor pressure per unit area in tourist season; visitors/km2/day)	< 5	≥ 5 to 25	> 25
$VP\text{-}T_{DAY}$ (visitor pressure on trails in tourist season; visitors/km of trail/day)	< 10	≥ 10 to ≤ 25	> 25

* Indicators are evaluated during the period of April–November.

Table 52b. The present visitation conditions in Cape Lookout, evaluated by the indicators in Table 52a.

Indicator	Cape Lookout evaluation	Rating
VIS	Cape Lookout has a median of 566,068 visitors/year (past 16 years). 2014 visitation (405,213) was less than the median and was the lowest annual visitation since 2000.	good
VP-A_{DAY}	Total park area is 114.3 km^2 (44.1 mi^2). In 2013, 89% of visitors (392,154 people) came to the seashore in April–November. Thus, Cape Lookout had an average of 3,434 visitors/km^2 in the busy period (244 days), or 13 visitors/km^2/day (34 visitors/$mile^2$/day).	fair
VP-T_{DAY}	Cape Lookout has 92.8 kilometers (58.6 mi) of trails and hiked (rustic) beach length. In April–November, assuming conservatively that 1/3 of visitors use the trails/beach length, the seashore has 4,561 visitors/km of trail in the busiest season (244 days), or 12 visitors/km of trail/day (4,561 visitors/mile of trail, or 19 visitors/mile of trail/day).	fair

Table 52c. The overall evaluation of the present visitation conditions in Cape Lookout, based on the three indicators in Table 52b.

Rating	Criteria	Overall rating
Good	≥ 2 indicators good, 0 poor	fair
Fair	≥ 2 indicators fair or good; 1 indicator is poor	
Poor	≥ 2 indicators poor	

It should be noted that this overall visitation condition is intended to serve as a "place holder" until park staff can develop a targeted recreational carrying capacity for Cape Lookout considering optimal protection of its natural resources, trails etc. This target could be developed, for example, following Cole and Carlson (2010). It would also be helpful for park staff to collect data on trail damage and trash left in the park to strengthen the Visitation Condition index.

4.2. Land Use/Land Cover—Shackleford Banks

Issue: Cape Lookout is somewhat buffered (separated) from the mainland by two narrow sounds, and the park historically contained very little development albeit with some agricultural use. The former villages have been abandoned. The proposed wilderness area, Shackleford Banks, is characterized by contiguous land cover; there is a small, unpaved trail, and the island has no connecting roads to the mainland.

Surrounding land use/land cover has been shown to strongly affect the habitat quality and integrity of terrestrial and aquatic communities within national parks. Cape Lookout is buffered from the mainland (e.g., distance from the Beaufort population center to the northern shore of Shackleford Banks) by 3.2 kilometers (2 mi) of Back Sound water. The pressures on this seashore from the mainland population and development are accounted for by our population condition indicators and surface water-quality condition indicators (below).

Within the park, human alteration of Core and Shackleford Banks has been evaluated as unlikely to intensify (Rasmussen et al. 2009). Therefore, we felt that it was inappropriate to develop surrounding land use/land cover indicators for Cape Lookout.

Within the park, however, an indicator was developed for wilderness character. The NPS (2014e) evaluated the wilderness character of Shackleford Banks overall as “condition is unchanging and warrants moderate concern,” based on four wilderness qualities:

- *Natural*—There are no roads or bridges to the proposed Shackleford Banks wilderness area, and the island remains a rare haven of diversity and complexity on the North Carolina coast. Natural processes are central to the visitor experience, and the natural qualities of the island also serve as a natural laboratory to study barrier island dynamics, climate change, and ecological changes over time.
- *Undeveloped*—Except for a dock on the island, a horse pen, two small comfort stations, and an equipment shed, Shackleford Banks is undeveloped. The contrast of extremely limited development within the proposed wilderness compared to neighboring islands and much of the North Carolina mainland exemplifies the undeveloped quality of the area. Visitors are lured by the almost entirely unobstructed views and natural sounds on the ocean side of the island. Shackelford Banks was assessed by the National Park Service (2014e) as “resource is in good condition and the condition is unchanging.”
- *Untrammeled*—Shackleford Banks is characterized by sections of sparsely visited beaches, dunes, and dense pockets of maritime forest in the island interior that very few humans visit. The majority of the island is untrammeled. Monitoring indicates that the dredging of Beaufort Inlet for navigation is causing some impacts to the natural geologic processes; in addition, the western side of the island has rock jetties on the sound side, and a breakwater in the dunes. (Coburn et al. 2010, NPS 2014e).
- *Solitude or Primitive and Unconfined Recreation Opportunity*—The outstanding opportunity for solitude and recreation remains a fundamental characteristic of the proposed Shackleford Banks wilderness. Vast views of endless sky and distant ocean horizons elicit a liberating isolation from

the urban world. The number of people visiting the beaches on the western end may diminish the opportunity for some visitors to fully experience the island's solitude, especially in summer.

After considering these qualities, we suggest three indicators for Wilderness Condition of the proposed Shackleford Banks wilderness area—natural character ($WILD_{NATURAL}$), developed condition ($WILD_{DEVELOP}$), and solitude and quiet ($WILD_{QUIET}$). Based on the evaluation approach shown in Tables 53a–53c, the overall Wilderness Condition of Shackleford Banks is good.

Table 53a. The three indicators used to evaluate wilderness conditions on Shackleford Banks (proposed wilderness) in Cape Lookout.

Indicator	Good	Fair	Poor
$WILD_{NATURAL}$ (natural character)	No connecting roads or bridges	One connecting unpaved road	> One connecting paved road
$WILD_{DEVELOP}$ (developed condition)	No development present or planned	One small village (< 50 people)	> One development with > 50 people
$WILD_{QUIET}$ (solitude and quiet)	Few visitors over most of the area	Relatively high visitation in one area not centralized	Relatively high visitation in > two areas

Table 53b. The present wilderness conditions of Shackleford Banks (proposed wilderness) in Cape Lookout, evaluated by the indicators in Table 53a.

Indicator	Cape Lookout evaluation	Rating
$WILD_{NATURAL}$	Shackleford Banks is isolated from the mainland, not connected by roads or bridges, and remains a rare haven of diversity and complexity.	good
$WILD_{DEVELOP}$	The island is undeveloped except for one dock, one horse pen, two small comfort stations, and one equipment shed. Development is prohibited.	good
$WILD_{QUIET}$	The island has outstanding opportunities for solitude, except for beaches on the the western end which have relatively high visitation.	fair

Table 53c. The overall evaluation of the present wilderness conditions of Shackleford Banks (proposed wilderness) in Cape Lookout, based on the three indicators in Table 53b.

Rating	Criteria	Overall rating
Good	> 2 indicators good, 0 poor	good
Fair	> 2 indicators fair or good, 1 poor	
Poor	> 2 indicators poor	

4.3. Air Quality

Issue: Air pollution is an ongoing, serious problem from urban and agricultural areas west of Cape Lookout NS, and is expected to be adversely impact the natural resources of the seashore.

In general, animals are exposed to air pollutants by inhaling gases or small particles, ingesting particles suspended in food or water, or absorbing gases through the skin (soft-bodied invertebrates, amphibians with thin, moist skin etc.) (Schreiber and Newman 1988; Brimblecombe et al. 2007; Mehaffey et al. 2009; Greaver et al. 2012). Ozone, SO_2, and NOx mostly affect the respiratory system, and animals with higher respiratory rates (e.g., many birds) are likely to be more adversely affected by gaseous pollutant injury. Metals such as mercury in air pollution can affect the circulatory, respiratory, gastro-intestinal, and central nervous systems. Often organs such as the kidney, liver, and brain are targeted, and entire populations can be adversely affected with damage extending subsequent generations.

The many impacts of acid deposition on terrestrial and freshwater ecosystems is the subject of an exhaustive literature (Tomlinson and Tomlinson 1990, Charles and Christie 1991, Brimblecombe et al. 2007, and references therein). In terrestrial ecosystems species that typically grow in nutrient-poor conditions, which characterizes the soils of Cape Lookout, are especially sensitive to the elevated nitrate enrichment that results in the soils, and their growth and survival are depressed (Aber 1992). Leaves affected by acid deposition are damaged, especially the chlorophyll pigment that is vital to photosynthesis. Like many other pollutants, acid deposition depresses terrestrial biodiversity as sensitive species are eliminated and more acid-tolerant species can survive. Acidification effects in freshwaters depend on the surrounding geology and soils, which determine the capacity of the water to neutralize acids. Most susceptible are freshwaters in areas without calcium, such as in Cape Lookout. Recently, a large body of literature has shown that even the calcium carbonate-rich oceans are acidifying from rapidly increasing carbon dioxide due to human-related activities, with impacts beginning to occur for estuarine and coastal marine ecosystems, and projected to increase (Caldeira and Wickett 2003, Fabry et al. 2008, Roberts et al. 2012).

The effects of decreasing pH on aquatic invertebrates and fish have been summarized in National Acid Precipitation Assessment Program (NAPAP) reports (e.g., NAPAP 2005) and similar documents from Scandinavia where acidification impacts have been extreme: In early stages of acidification, acid-sensitive species are replaced by acid-tolerant ones. As the pH continues to decline, toxic metals become more bioavailable, and more species are lost until even the microbial consortium of decomposers is adversely affected. The worst problems with acid deposition result from acid spates, wherein a “slug” or high amount of acid moves into a waterbody in the early phases of a storm. Larval stages of amphibians and fish, for example, are eliminated by acid spates over a short period (hours to a few days).

Considering the entire Southeast region, the National Park Service evaluates 10-year trends in air quality for parks with on-site or nearby monitoring. Maps show trends in ozone, deposition, and visibility that can be used to discern regional trends. For the period 1996–2005, ozone concentrations and nitrogen and sulfur deposition in the Southeast appear to be decreasing, while visibility is relatively unchanged.

More specific to Cape Lookout NS, the National Park Service (NPS 2011b) has developed guidance for assessing the air quality conditions within its parks, focusing on five key indicators among the myriad of air pollutants potentially affecting the seashore. These indicators include ozone (with two sub-indicators: human health, and seashore flora), N deposition, S deposition, visibility, and acidification (with five sub-indicators: pollutant exposure, ecosystem sensitivity, park protection, and overall summary risk). For ozone, the National Park Service included consideration of vegetation sensitivity as well as human health because science has shown that some plant species are more sensitive to ozone than humans. Thus, use of an ozone standard for humans would not be sufficiently protective of those species.

The National Park Service has developed management targets or "thresholds" for these five indicators, summarized in Table 54. The information and supporting science are given in several agency reports, especially NPS (2011b) and Sullivan et al. (2011a,b) where the conditions in Cape Lookout are also described. All five of the NPS-selected air quality indicators are not possible for park staff to control. Following the NPS guidance and stoplight system, one of the five indicators, ozone, is moderate concern (fair rating in the stop light approach); the other four indicators are of significant concern (poor rating in the stop light approach). The EPA AQI is good, and the overall park condition considering the potential for acidification is fair (moderate risk). Therefore, the present overall air-quality condition at Cape Lookout is evaluated as fair.

This evaluation differs from that in the State of the Park report by the National Park Service (2014e), which was based on a smaller set of indicators that included ozone (annual 4th-highest 8-hr concentration, fair), sulfur wet deposition (poor), nitrogen wet deposition (poor), and visibility (haze index, poor), as in Figures 10a–10d. As shown in Table 54, we considered those indicators as well as several others contained in reports, and also included the EPA AQI (AirNow 2015a). The broader set of indicators led to our overall fair evaluation for the seashore.

Table 54a. The eleven indicators used to evaluate air quality conditions in Cape Lookout.

Indicator	Good	Fair	Poor
AQI (EPA air quality index for Beaufort N.C.)	0–50 for ≥ 90% of days	≤ 100 for ≥ 90% of days	101–500 for > 10% of days
OZONE: human health (5 year impact)	≤ 60 ppb	61–75 ppb	≥ 76
OZONE W126 (impact on flora over the growing season)	< 7 ppm-hour	7–13 ppm-hour,	> 12 ppm-hour
OZONE SUM06 (cumulative ozone impact on flora)	< 8 ppm-hour	8–15 ppm-hour	> 15 ppm-hour
N-DEP (nitrogen deposition)	< 1 kg/ha/year	1–3 kg/ha/year	> 3 kg/ha/year
S-DEP (sulfur deposition)	< 1 kg/ha/year	1–3 kg/ha/year	> 3 kg/ha/year
VIS (visibility in deciviews(dv))	< 2 dv	2–8 dv	> 8 dv
ACID (pollutant exposure)	rank <13	≥ 13 to 23	> 23 to 35
ACID (ecosystem sensitivity)	rank <15	≥ 15 to 20	> 20 to 35
ACID (park protection)	rank <15	≥ 15 to < 23	≥ 23 to 35
ACID (summary risk index)	rank ≤ 2.5	> 2.5 to 3.4	> 3.4 to 5

Table 54b. The present eleven air quality conditions in Cape Lookout, evaluated by the indicators in Table 54a.

Indicator	Cape Lookout evaluation	Rating
AQI	1999–2009: In Beaufort, N.C. (134.4 kilometers [83.5 mi] from Hatteras Village) average AQI was below 50 throughout.	good
OZONE: human health	61–75 ppb for the 8-hour averaging time, 4^{th} maximal value	fair
OZONE W126	7–13 ppm-hour	fair
OZONE SUM06	8–15 ppm-hour	fair
N-DEP	> 3 kg/ha/year	poor
S-DEP	> 3 kg/ha/year	poor
VIS	> 8 dv	poor
ACID (pollutant exposure)	rank > 23 (high)	fair
ACID (ecosystem sensitivity)	rank < 9 (very low)	good
ACID (park protection)	rank ≥ 15 to < 23 (moderate)	fair
ACID (summary risk index)	rank 2.7–3.4 (moderate)	fair

Table 54c. The overall evaluation of the air quality conditions in Cape Lookout, based on the eleven indicators in Table 54b.

Rating	Criteria	Overall rating
Good	AQI good; ≥ 5 of 7 good, ≤ 2 fair (Moderate Concern), 0 poor (Significant Concern)	fair
Fair	AQI good or fair; ≥ 3 fair, ≤ 3 poor	
Poor	AQI unhealthy to hazardous; ≥ 4 poor	

4.4. Soundscape

Issue: Noise pollution can adversely affect the physiology, behavior, and survival of fauna communities. Noise pollution at Cape Lookout could be a concern on Shackleford Banks from the mainland (Beaufort population center) and ocean side from ORVs during the April–November period of high visitation.

The draft ORV Management Plan (NPS 2014a) summarized the soundscape/ acoustic environment at Cape Lookout, including the noise level of various human activities at the park. The assessment of soundscape/acoustic condition in the ORV management plan concluded that, "because of the nature of the seashore environment, the constant, dynamic sounds of wind and surf create a high level of ambient noise" especially on the ocean side of the seashore. Thus, the predominant sound along the ocean side is the surf, although ORVs can contribute to ocean side sounds on Core Banks. Noise sources at Cape Lookout are nearly all ≤ 24 dB(A) above ocean/wind sounds, and ocean/wind sounds generally characterize the seashore soundscape. The overall soundscape condition at this seashore is good (Table 55c).

Table 55a. The three indicators used to evaluate soundscape conditions in Cape Lookout.

Indicator	Good	Fair	Poor
$SOUND_{POP}$ (proximity to population center)	closest population center with ≥ 500 people is ≥ 16 kilometers (10 mi) away	One–two population centers (≥ 500 people) are within 16 kilometers (10 mi) of the seashore.	> 2 population centers (> 500 people) are within 16 kilometers (10 mi) of the seashore.
$SOUND_{TRAV}$ (proximity to a major mode of travel)	nearest federal or state highway or railroad is ≥ 8 kilometers (5 mi) distant..	One major road or railroad is in or near the seashore.	> 2 major roads and/or railroads are < 8 kilometers (5 mi) from the seashore.
$SOUND_{DATA/OBS}$ (data available for the park or park staff observations)	noise ≤ 24 dB(A) above ocean sounds during max. human activity; or, data n.a.; park staff seldom notice recreational noise levels that disturb SSCs..	noise > 24 to 55 dB(A) above ocean sounds; or, data n.a.; park staff occasionally notice noise levels that disturb SSCs.	noise > 55 dB(A) above wave sounds; or data n.a.; park staff commonly notice noise levels that disturb SSCs in periods of max. human activity.

Table 55b. The present soundscape conditions in Cape Lookout, evaluated by the indicators in Table 55a.

Indicator	Cape Lookout evaluation	Rating
$SOUND_{POP}$	Shackleford Banks is closest to a human population center (Beaufort, 3.2 kilometers [2 mi] distant), separated by the waters of Back Sound. Impacts from that potential noise source are muted sound side, and negligible ocean side.	fair
$SOUND_{TRAV}$	CALO (Shackleford Banks) is not close to a major federal or state highway or other travel artery.	good
$SOUND_{DATA/OBS}$	Data on sound levels at CALO: 130–140 dBA from gun blasts related to hunting on Core Banks; 100 dBA from planes flying overhead and boat congestion (Barden Inlet, Memorial Day weekend); 90 dBA from standing near a passing ORV ocean side; 80 dBA at the beach on a windy day; and 30–70 dBA during activities ranging from sitting in a tent sound side on North Core Banks after sundown, to walking along the ocean at Cape Lookout (NPA 2014a, p.234).	good

Table 55c. The overall evaluation of the present soundscape conditions in Cape Lookout, based on the three indicators in Table 55b.

Rating	Criteria	Overall rating
Good	$SOUND_{DATA/OBS}$ good, 1 other indicator good or fair and no indicator is poor	good
Fair	$SOUND_{DATA/OBS}$ fair, > 1 other indicator is good or fair	
Poor	$SOUND_{DATA/OBS}$ poor, or > 2 indicators are poor	

4.5. Lightscape

Issue: Light pollution from the mainland and, occasionally from the lighthouse, or camping areas at Cape Lookout can adversely affect the physiology, behavior, and survival of naturally occurring beneficial fauna such as sea turtle SSCs.

Cape Lookout is ranked by the NPS Night Sky Program, along with Cape Hatteras National Seashore, as the ninth best national park system unit to view the night sky because of very low to negligible artificial light (NPS 2014a). Light pollution at Cape Lookout adversely affects sea turtle hatchlings occasionally; since 1990, hatchlings from 32 different nests have become disoriented by artificial light and have crawled inland away from the ocean (NPS 2014a) although in a few of those instances confusion with topography may also have been a factor (NPS 2014a, Chapter 3, p.212). The NPS Night Sky Team performed night sky measurements at this seashore in 2012 (NPS 2014e), but as of November 2014 their findings are not yet available. A similar analysis of the lightscape at Cape Hatteras National Seashore concluded that that seashore has better night quality than most other national parks east of the Mississippi River. Considering the fact that Cape Hatteras National Seashore is immediately adjacent to nine population centers which can be substantial during the maximal tourism period (250,000 people per day), it is expected that Cape Lookout has even better night sky conditions (NPS 2014e). Nevertheless, the recently modeled ALR for Cape Lookout is 0.36 (lightscape fair, that is, of moderate concern). Based on the evaluation system shown in Table 56a, the overall lightscape condition at Cape Lookout is good based on the fact that much of the park still has an excellent, natural night sky (NPS 2014a). Sound side locations at Shackleford Banks, nearest the Beaufort population center, would be expected to have fair conditions, whereas more remote locations on Core Banks generally have a lightscape evaluated as good.

Table 56a. The two indicators used to evaluate lightscape conditions in Cape Lookout.

Indicator	Good	Fair	Poor
$LITE_{ARTIF}$ (Bortle Dark Sky Scale)	Classes 1 to 2 excellent, truly dark skies; or typical, truly dark skies.	Classes 3 to 4 rural sky: ground objects vaguely apparent; or rural/ suburban transition: sky noticeably brighter than the terrain, ground objects still fairly obscure.	≥ Class 5 suburban sky: ground objects partly lit, to inner city sky.
ALR (Average anthropogenic all-sky luminance/average natural all-sky luminance)	ALR < 0.33 (<26 nL average anthropogenic light in the sky; low concern)	ALR ≥ 0.33 to 2.00 (26–156 nL average anthropogenic light; moderate concern)	ALR > 2.00 (> 156 nL average anthropogenic light; high concern)

Table 56b. The present lightscape conditions in Cape Lookout, evaluated by the indicators in Table 56a.

Indicator	Cape Lookout evaluation	Rating
$LITE_{ARTIF}$	CALO is considered to have the least night sky pollution of most if not all national parks east of the Mississippi River, with Bortle Dark Sky Scale values of 1 to 2 (excellent to typical, truly dark skies).	good
ALR	Nevertheless, the modeled ALR for CALO is 0.36 (fair, moderate concern).	good

4.6. Geology

Issue: Cape Lookout, as part of the Outer Banks of North Carolina, is widely considered a national treasure, largely due to the geologic features and behavior of its barrier islands. However, the seashore is in an interglacial geologic period characterized by rising sea levels along with increasing frequency of major storms, and increased erosion as the barrier islands migrate landward. Human-imposed beach stabilization structures along the ocean side length of the seashore exacerbate erosion and impede the function of the barrier islands to protect the mainland from storm surges.

The data and forecasts regarding the geologic features of Cape Lookout's barrier islands all point in the same general direction of accelerated sea-level rise, increased frequency of major storms, increased flooding duration, and increased major erosion.The soils of Cape Lookout NS mostly consist of various sands, which are highly erodible. More than one-third of the land area has soils that are flooded, frequently flooded, or very frequently flooded.

- High erosion (recession) rates (-) of the ocean shoreline at Cape Lookout have been reported over time (Table 57):
- The North Carolina coast is sustaining the highest rates of relative sea-level rise along the entire U.S. Atlantic seaboard, 40.6 to 45.7 centimeters (16 to 18 inches, or 1.3 to 1.5 ft) per century (Zervas 2004, Kemp et al. 2008, U.S. Department of Transportation et al. 2008), along with severely eroding conditions (> 1.5 meters or 4.9 ft per yr, the worst-case category) based on Bernd-Cohen and Gordon (1998). Based on annual beach profile data collected at Shackleford Banks (2008–2012), annual loss of beach sediments has dramatically increased, from 4.26 m^3 per meter (1.7 $yards^3$per ft) to 23.83 m^3 per meter (9.5 $yards^3$ per ft), coupled with 1.4 meters (4.6 ft) of inland migration of shoreline position at the mean high water datum (NPS 2014e).
- The rate of sea-level rise at the City of Beaufort is 3.71 ± 0.64 mm/year (0.15 ± 0.03 inch/yr (Zervas 2001), while major areas of the park are only 30.5 to 61.0 centimeters (1–2 ft) above present MSL. The rate of relative sea-level rise for Cape Lookout has been evaluated as very high (5), about twice as high as the global average, based on water elevation data at Beaufort. As a moderate condition, other modeling work estimated that sea level in the Beaufort area would rise 0.55 meters (1.8 ft) by 2100 (USACE in Caffrey 2013).
- Marsh elevation—On the other hand, a recent study of fringing marsh vegetation in Carteret County, which included two sites at Cape Lookout, suggested that under the present rate of sea-level rise (3 mm/yr [0.12 in/yr]), fringing marshes would be able to maintain marsh biomass and surface elevation—if they receive sufficient sediment supply, which is an important consideration since Cape Lookout tends to be "sediment-deprived" (data from C. Currin, NOAA, in NPS 2014e).
- Mean significant wave heights at Cape Lookout were modeled to be between 1.2 and 1.3 meters (3.9 and 4.3 ft), categorized as high vulnerability and very high vulnerability, respectively.
- All of Cape Lookout was assessed as having very high vulnerability (> 1 meter) with respect to tidal range.

- Most of Cape Lookout has been evaluated as having very high vulnerability (CVI > 42.0) to inundation from a direct-hit hurricane (Thieler and Hammar-Klose 1999, Saunders et al. 2012). The seashore was in the top tier of vulnerability among the seven national seashores on the U.S. Atlantic Coast. About 11% of the CALO ocean side coastline was assessed as vulnerable to inundation from a category 1 storm, versus more than 91% vulnerable during a category 5 storm. A category 5 storm striking at high tide was estimated to cause a 4.9-m (16.0-ft) storm surge at the south end of Core Banks (Caffrey 2013).

Table 57. Erosion (recession) rates (-) of the ocean shoreline at CALO, also showing an accretion rate (+) in the Cape Lookout area.

Period (Source)	Location/Condition	Average per Year (Long-Term, > 2 yr)	Storm-Dominated Period (S) Erosion per Year
1940–1975 (34 yr)	Core Banks	-0.46 meters (-1.5 ft)	----
1943–1976 (32 yr)[a]	Shackleford Banks	-0.47 meters (-1.5 ft)	----
1960–2001	North Core Banks	-2.44 meters (-8.0 ft)	----
1960–2001	South Core Banks	-0.91 meters (-3.0 ft)	----
1960–1962[b]	Overall Net Average	-1.52 meters (-5.0 ft),	----
1960–1962[b]	(S) North Core Banks	----	-15.85 m (-52.0 ft)
1960–1962[b]	(S) South Core Banks	----	-6.40 m (-21.0 ft)
Sept. 1997–Oct. 2005 (8 yr), away from inlets[c]	Overall	-1.4 meters (-4.6 ft)	----
	near Cape Lookout	+2.55 meters (+8.4 ft)	----
	sw of Old Drum Inlet	-11.0 meters (-36.1 ft)	----
2008–2012 (5 yr)	Shackleford Banks—loss of beach sediments	-4.26 m[c]/m (-1.7 yards[c]/ ft)	----

[a] Dolan and Haywood 1977

[b] Riggs and Ames 2007)

[c] Stockdon and Thompson 2007

[d] NPS 2014e

The five geologic indicators recommended for Cape Lookout for barrier island change are shown in Table 58a.

There has been minimal installation of “stabilizing” structures at the seashore. Nevertheless, based on the five indicators in total, the geology and soils condition of Cape Lookout NS was evaluated as poor (Table 58c).

Table 58a. The five indicators used to evaluate geology and soil conditions in Cape Lookout.

Indicator	Good	Fair	Poor
$SOILS_{EROD}$	< 10% of the soils on an areal basis are highly erodible and commonly subject to flooding	10–25% of the soils are highly erodible and commonly subject to flooding	> 25% of the soils are highly erodible and subject to flooding
$GEOL_{EROD}$	minimal erosion < 30 centimeters (1 ft) per year (Bernd-Cohen and Gordon 1999)	moderate erosion 30–90 centimeters (1–3 ft) per year	severely eroding > 90 centimeters (3 ft) per year
$GEOL_{SEA\text{-}RISE}$	low rate ≤ 18 centimeters (7.1 in) per 100 years (condition 100 years ago—Riggs et al. 2008)	moderate rate > 18 to 30 centimeters (> 7.1 to 11.9 inches) per 100 years	high rate > 30 centimeters (11.9 in) per 100 years
$GEOL_{CVI}$	Low Vulnerability to Inundation from Future Storms (CVI < 32.0)	Moderate Vulnerabilty (CVI = 32.0 to 36.0)	High to Very High Vulnerability (CVI > 36.0)
$GEOL_{ARTIFICIAL}$	Stabilizing dunes, other human-constructed structures occur on ≤ 10% of the seashore length; most of the park is not affected by dredging activities, and "beach nourishment" is not used	Human-constructed structures occur on 10–20% of the seashore length; dredging activities have altered sand movement and currents in ≤ 2 key sensitive areas, and/or "beach nourishment" is being used on 1 of the barrier islands	Human-constructed structures occur on > 20% of the seashore length; and/or dredging activities have altered sand movement and currents in ≥ 3 key sensitive areas, and/or "beach nourishment" is being used on ≥ 2 of the barrier islands

Table 58b. The present geology and soils conditions in Cape Lookout, evaluated by the indicators in Table 58a.

Indicator	Cape Lookout evaluation	Rating
$SOILS_{EROD}$	CALO soils mostly consist of highly erodible sands.	poor
$GEOL_{EROD}$	CALO is sustaining, as an overall average, 1.4 meters (4.6 ft) of erosion per year (Stockdon and Thompson 2007), considered to be a severely eroding condition (Bernd-Cohen and Gordon 1998).	poor
$GEOL_{SEA\text{-}RISE}$	The rate of relative sea-level rise at the City of Beaufort, very near to Shackleford Banks, is 37 centimeters (14.6 in) per 100 years (Zervas 2001). As a moderate condition, other modeling work has estimated that sea level in the Beaufort area will rise 0.55 meters (1.8 ft) by 2100 (USACE in Caffrey 2013). The rate of relative sea-level rise for CALO has been evaluated as very high, about twice as high as the global average, based on water elevation data at Beaufort.	poor
$GEOL_{CVI}$	The CVI for CALO indicates that much of the park has very high vulnerability to long-term inundation by future major storms (CVI > 42.0) (Stockdon and Thompson 2007). About 11% of the ocean side shoreline was assessed as vulnerable to inundation by a Category 1 hurricane, vs. > 91% of the ocean side coastline if hit by a Category 5 storm. CALO was in the top tier of vulnerability among the seven national seashores on the U.S. Atlantic Coast.	poor
$GEOL_{ARTIFICIAL}$	CALO has been minimally altered with human-constructed "stabilizing" structures; for example, the western side of Shackleford Banks has a rock jetty. Dredging of Beaufort Inlet for navigation is adversely affecting natural geologic processes (e.g., sand movement) along Shackleford Banks. "Beach nourishment" practices have not been used.	good

Table 58c. The overall evaluation of the present geology and soils conditions in Cape Lookout, based on the five indicators in Table 58b.

Rating	Criteria	Overall rating
Good	CVI is 1–2 for ≥ 75% of the shoreline; $GEOL_{SEA\text{-}RISE}$ is good or fair, and the other 3 indicators are good.	poor
Fair	CVI is 3 for ≥ 50% of the shoreline, and at least 25% of the remainder is good (1–2); ≥ 2 of the other indicators are good or fair.	
Poor	CVI is ≥ 4 for ≥ 25% of the shoreline, and ≥ 1 other indicator is poor.	

4.7. Surface Water

Issues: There are few fresh surface water resources at Cape Lookout; mostly they occur as freshwater wetlands. The available information indicates that the natural hydrology has been maintained. The major surface water issue affecting this seashore is water quality. Shackleford Banks, in particular, is in close proximity to mainland pollution sources and various degraded surface waters in the Beaufort/Morehead City area (Figure 47). Within the park the sandy, thin soil layer over the shallow water table is thought to be inadequate to treat human wastes—a problem which is exacerbated on Shackleford Banks due to wastes from the wild horse herd—but data are generally lacking to enable assessment.

4.7.1. Surface Water Quality

Assessments provided in various SECN publications describe good surface water quality for Cape Lookout, based on limited sampling for most parameters. The assessments were made using EPA (2008b, 2012b) protocols (Tables 24a and 26a), and some of the quantitative ranges assigned to "good" and "fair" conditions are problematic because they could allow relatively pristine waters to substantially degrade. Recommended modifications to the EPA protocols are discussed at length in Section 6.3.1. Surface water-quality conditions were assessed using modified criteria which were stricter than criteria currently in use by the Southeast Coast Network. Tables 59a–c reflect this assessment with modified criteria.

Table 59a. The six indicators used to evaluate surface water quality conditions in Cape Lookout.

Indicator	Good	Fair	Poor
SWQ_{DO} (dissolved oxygen; mg/L)	> 5	3–5	< 3
SWQ_{TURB} (water clarity; turbidity assessed at 1 m depth)	Naturally high: < 2.30 Normal: < 1.61 Naturally low: < 0.92	Naturally high: 2.30–2.99 Normal: 1.61–2.30 Naturally low: 0.92–1.61	Naturally high > 2.30 Normal > 1.61 Naturally low > 0.92
SWQ_{DIP} (dissolved inorganic phosphorus; µg/L)	< 10	10–20	> 20
SWQ_{DIN} (dissolved inorganic nitrogen, µg/L)	< 80	80–120	> 120
SWQ_{CHL} (suspended microalgal chlorophyll *a* (corrected for pheopigments); µg/L)	< 3	3–10	> 10
SWQ_{FECAL} (*Enterococcus* bacteria; cfu/100 ml)	< 10% in violation	> 10% to 30% in violation	> 30% in violation

Table 59b. The surface water quality conditions in Cape Lookout, evaluated by the indicators in Table 59a.

Indicator	Cape Lookout evaluation	Rating
SWQ_{DO}	Sound side: Pamlico: 21 good Core: 20 Good Back: 22 Good (n = 63; 100% good; sampled mid-day)	good
SWQ_{TURB}	N.A.	N.A.
SWQ_{DIP}	Sound side: Pamlico: 4 good (50%), 4 Fair (50%) Core: 3 Good (27%), 8 fair (73%) Back: 5 Good (45%), 3 fair (55%) Total (n = 27): 44% good, 56% Fair.	fair
SWQ_{DIN}	Sound side: Pamlico: 4 good (100%) Core: 4 Good (67%), 2 fair (33%) Total (n = 10): 80% good, 20% fair, but sparse samples; inadequate for evaluation.	N.A.
SWQ_{CHL}	Sound side: Pamlico: 10 good (83%), 2 fair (17%) Core: 20 good (100%) Back: 18 good (100%)	good
SWQ_{FECAL}	Sound side: Core: 184 of 188 samples in compliance (98%, 2 stations) Back: 635 of 648 samples in compliance (98%, 4 stations) ocean side: 829 of 847 samples in compliance (98%; 3 stations)	good

Table 59c. The overall evaluation of the present surface water quality conditions at Cape Lookout based on the six indicators in Table 59b.

Rating	Criteria	Overall rating
Good	Site: ≤ 1 indicator is fair, 0 indicators are poor Seashore: ≤ 5% of sites are in poor condition, ≤ 20% of sites are in fair condition	good
Fair	Site: 1 indicator is poor or > 2 indicators are fair Seashore: >20% of sites are in fair condition and < 20% of sites are in poor condition	
Poor	Site: ≥ 2 indicators are poor Seashore: > 20% of sites are in poor condition	

Table 59d. The evaluation of the present surface water quality conditions at sites at Cape Lookout based on the six indicators in Table 59b.

Pamlico Sound	Core Sound	Back Sound	Total
4 sites: 3 good, 1 fair	11 sites: 8 good, 3 fair	4 sites: 4 good	N=19 sites; 15 good (79%), 4 fair (21%)

4.7.3. Surficial Sediment Quality

Issue: Surficial sediments accumulate many chemical contaminants, including a wide array of toxic substances. The data available for Cape Lookout indicate overall good surficial sediment quality, and provide a baseline to help protect the water resources of this seashore long-term.

Surficial sediments (top 2–3 centimeters [1 in]) are the repository of many chemical contaminants, from various forms of nitrogen and phosphorus to toxic substances (Day et al. 1988; Long 2000; EPA 1981, 2004b). The resulting toxic habitat can cause recruitment failure, disease, and death of organisms that depend on that habitat for growth and survival, such as bottom feeding finfish and sessile shellfish (Long 2000).

The National Park Service and partners have surveyed the quality of surficial sediments in and around the seashore, and have found generally good sediment quality based on relatively sparse data, using the assessment criteria in Tables 24 and 25. Recommended modifications to existing protocols are discussed in Section 6.3.2. At present, based on the available data, sediment quality condition at the seashore is good (Table 61c).

Table 60a. Indices developed by the EPA to evaluate sediment quality, based on the effects range for nine metals (EPA 2008b, 2012b). Site condition is rated as good if the contaminant concentration is less than the ERL, fair if it is between the ERL and ERM, and poor if it is greater than or equal to the ERM [Conc.—concentration; LMW—low-molecular-weight; HMW—high-molecular-weight].

Metals (µg/g or ppm)[a]	< ERL (good)	ERL < Conc. < ERM (fair)	≥ ERM (poor)
Arsenic (As)	< 8.2	8.2–< 70	≥ 70
Cadmium (Cd)	< 1.2	1.2–< 9.6	≥ 9.6
Chromium (Cr)	< 81	81–< 370	≥ 370
Copper (Cu)	< 34	34–< 270	≥ 270
Lead (Pb)	< 46.7	46.7–< 218	≥ 218
Mercury (Hg)	< 0.15	0.15–< 0.71	≥ 0.71
Nickel (Ni)	< 20.9	20.9–< 51.6	≥ 51.6
Silver (Ag)	< 1	1–< 3.7	≥ 3.7
Zinc (Zn)	< 150	150–< 410	≥ 410

Table 60b. Indices developed by the EPA to evaluate sediment quality, based on the effects range for 19 organic substances (EPA 2008b, 2012b). Site condition is rated as good if the contaminant concentration is less than the ERL, fair if it is between the ERL and ERM, and poor if it is greater than the ERM [Conc.—concentration; LMW—low-molecular-weight; HMW—high-molecular-weight].

Organics (ng/g or ppb)	< ERL (good)	ERL < Conc. < ERM (fair)	≥ ERM (poor)
Acenaphthene	< 16	16– < 500	≥ 500
Acenaphthylene	< 44	44– < 640	≥ 640
Anthracene	< 85.3	85.3– < 1,100	≥ 1,100
Fluorene	< 19	19– < 540	≥40
2-Methylnaphthalene	< 70	70– < 670	≥ 670
Naphthalene	< 162	162– < 2,100	≥ 2,100
Phenanthrene	< 240	240– < 1,500	≥ 1,500
Benz(a)anthracene	< 261	261– < 1,600	≥ 1,600
Benzo(a)pyrene[b]	< 430	430– < 1,600	≥ 1,600
Chrysene	< 384	384– < 2,800	≥ 2,800
Dibenzo(a,h)anthracene	< 63.4	63.4– < 260	≥ 260
Fluoranthene	< 600	600– < 5,100	≥ 5,100
Pyrene	< 665	665– < 2,600	≥ 2,600
LMW PAHs	< 552	552– < 3,160	≥ 3,160
HMW PAHs	< 1,700	1,700– < 9,600	≥ 9,600
-tal PAHs	< 4,020	4,020– < 44,800	≥ 44,800
4"4 DDE	< 2.2	2.2– < 27	≥ 27
DDT	< 1.6	1.6– < 46.1	≥ 46.1
PCBs	< 22.7	22.7– < 180	≥ 180

[a] The ERL (effects range low) and ERM (effects range median) are the 10th and 50th percentiles, respectively, on an ordered list of concentrations in sedmient found in the literature that co-occur with a biological effect of interest (Long and Morgan 1990; O'Connor 2004). Neither value is actually a threshold of any chemical concentration in sediment at which the probability of toxicity shows an abrupt increase (O'Connor 2004).

[b] Benzo(a)pyrene does not have a non-cancer range (EPA 2008b).

Table 61a. Surficial Sediment Quality Condition for TOC at Cape Lookout, based on three indicators developed from 21 chemical parameters (DDE and DDT were considered together, and all PAHs were considered collectively). Management targets are based on EPA 2012 recommendations (EPA 2008, 2012).

TOC Content	EPA (2012) recommendation	CALO conditions
TOC Content (as percent dry weight of sediment)	< 2 % weight Good 2–5 % Fair > 5% Poor)	• TOC content was good for 100% of samples taken during 2000–2009 (n = 25; Parman 2012). • TOC content was good in 100% of samples taken in 2010 (13 stations) (Gregory and Smith 2011). • TOC content was good in 19 samples from QA/QC'd STORET data (2000–2014).

Table 61b. Surficial sediment quality conditions for nine metals in Cape Lookout. Management targets are based on EPA 2012 recommendations (EPA 2008, 2012)*.

Metals Concentrations	EPA (2012) recommendation	CALO Conditions
Arsenic (As) As_{SED}	< 8.2 µg/g (ppm)	• Data available from 2000–2009 (Parman et al. 2012) at 25 sites for As, Cu, and Hg; 100% within EPA recommendations • Data available from a 2010 survey (Gregory and Smith 2011); n = 13 sites; 100% within EPA recommendations. • QA/QC'd STORET data (2000–2014) from 19 stations for 8–9 of the indicators; 100% were within EPA recommendations. • Total number of samples, 57
Cadmium (Cd) Cd_{SED}	< 1.2 µg/g	
Chromium (Cr) Cr_{SED}	< 81 µg/g	
Copper (Cu) Cu_{SED}	< 34 µg/g	
Lead (Pb) Pb_{SED}	< 46.7 µg/g	
Mercury (Hg) Hg_{SED}	< 0.15 µg/g	
Nickel (Ni) Ni_{SED}	< 20.9 µg/g	
Silver (Ag) Ag_{SED}	< 1 µg/g	
Zinc (Zn) Zn_{SED}	< 150 µg/g	

*each Less Than Effects Range (ERL) Concentration

Table 61c. Surficial sediment quality conditions for organic toxic chemicals in Cape Lookout. Management targets are based on EPA 2012 recommendations (EPA 2008, 2012).*

Organic Toxic Chemicals (19):	EPA (2012) recommendation	CALO Conditions
2-methylnaphthalene (2-MNT) 2-MNT$_{SED}$	< 70 ng/g (ppb)	• Data available from Parman et al. (2012) for 11 parameters at 25 sites; 100% were within EPA recommendations • Data available from Gregory and Smith (2011) for 17 parameters at 12 sites; 100% were within EPA recommendations. • QA/QC'd STORET data (2000–2014) from 18 stations for PCBs, and for 2 stations for 7–11 other organic contaminants; 100% were within EPA recommendations. • Total number of samples for some indicators, 57 • Data available from Parman et al. (2012) for 11 parameters at 25 sites; 100% were within EPA recommendations • Data available from Gregory and Smith (2011) for 17 parameters at 12 sites; 100% were within EPA recommendations. • QA/QC'd STORET data (2000–2014) from 18 stations for PCBs, and for 2 stations for 7–11 other organic contaminants; 100% were within EPA recommendations. • Total number of samples for some indicators, 57
4"4 DDE (DDE) DDE$_{SED}$	< 1.6 ng/g	
Acenaphthene (ANT) ANT$_{SED}$	< 16 ng/g	
Acenaphthylene (ANTL)ANTL$_{SED}$	< 44 ng/g	
Anthracene (ATC) ATC$_{SED}$	< 85.3 ng/g	
Benz(a)anthracene BATC) BATC$_{SED}$	< 261 ng/g	
Benzo(a)pyrene (BPYR) BPYR$_{SED}$	< 430 ng/g	
Chrysene (CHR) CHR$_{SED}$	< 384 ng/g	
Dibenz(a,h)anthracene (DBATC) DBATC$_{SED}$	< 261 ng/g	
Fluoranthene (FLAT) FLAT$_{SED}$	< 600 ng/g	
Fluorine (FL) FL$_{SED}$	< 19 ng/g	
Naphthalene (NTL) NTL$_{SED}$	< 162 ng/g	
Phenanthrene (PAT) PAT$_{SED}$	< 240 ng/ga	
Pyrene (PYR) PYR$_{SED}$	< 665 ng/g	
Total DDT (DDT)DDT$_{SED}$	< 1.6 ng/g	
Total PAHs (TPAH) TPAH$_{SED}$	< 4,020 ng/g	
LMW PAHs (LPAH) LPAH$_{SED}$	< 552 ng/g	
HMW PAHs (HPAH) HPAH$_{SED}$	< 1,700 ng/g	
Total PCBs (PCB) PCB$_{SED}$	< 22.7 ng/g	

*each Less Than Effects Range (ERL) Concentration

Table 61d. The overall evaluation Surficial Sediment Quality Condition at Cape Lookout.

Rating	Criteria	Overall rating
Good	Overall site criteria: ≥ 90% of the indicators are good condition Overall seashore criteria: ≤ 5% of sites are in poor condition, ≤ 20% of sites are in fair condition	Good
Fair	Overall site criteria: ≥ 80% of the indicators are good or fair, ≤ 20% poor Overall seashore criteria > 20% of sites are in fair condition and < 20% of sites are in poor condition	
Poor	Overall site criteria: ≥ 20% of the indicators are poor O Overall seashore criteria: ≥ 20% of sites are in poor condition	

4.7.5. Fish Tissue Quality

Issue: Fish concentrate (bioaccumulate) many toxic contaminants from water and sediments depending on their feeding habits. Fish tissue quality at Cape Lookout is a major concern for three reasons: First, 100% of the sparse data (only seven tissue samples) were high in arsenic and about 40% were high in PAHs (Tables 26a–26c). Second, the whole fish body collectively was analyzed to produce the fish tissue quality data, rather than emphasizing the main organs that are known to accumulate toxic substances such as gill, brain, liver, and kidney. Third, fish tissue quality for arsenic and PAHs was worse within park waters than in surrounding waters. As mentioned, the high PAH, arsenic, and mercury concentrations that have been found in fish from Cape Lookout may reflect contamination from an aboveground storage tank, incinerator, and refueling pad on the island (Mallin et al. 2004). A more in-depth baseline of fish tissue quality is greatly needed for Cape Lookout to resolve whether these few samples are representative of fish tissue quality at this seashore, and the source(s) of arsenic and PAHs.

Fish tissue contamination by toxic pollutants is considered to be an integrator of overall ecosystem health that integrates water and sediment quality (EPA 2000b). Fish bioaccumulate many toxic substances by direct uptake from polluted water, consumption of polluted sediments, or consumption of contaminated organisms used for food (Parman et al. 2012, and references therein). A major proportion of these substances are very slowly biodegraded, which means that they tend to accumulate in exposed organisms over time, biomagnify at higher trophic levels such as fish, and pose a threat to human health from consumption of contaminated fish and other seafood.

The EPA (2000b) developed risk-based advisory guidance values for consumption of fish fillets (muscle) by recreational fishers. This approach may be the most protective from the perspective of human health, but not for fish health because toxic substances tend to accumulate in organs such as the gill, kidney, and liver, not in muscle tissue (Hodson 1988, Heath 1995, Dórea 2008). Thus, the levels recommended as good by the EPA (2008b, 2012b—see Table 25 of this report) are likely not protective of the health of sensitive fish species and life history stages.

Very sparse data on fish muscle tissue were available, insufficient for adequate analysis (only seven samples are available in 2000–2014). Therefore, here we suggest three “place holder” indicators for fish tissue condition at Cape Lookout, including arsenic ($FISH_{ARSENIC}$), PAHs ($FISH_{PAHS}$), and PCBs ($FISH_{PCBS}$) (Table 62), and we also suggest re-analysis of fish tissue quality as soon as more data become available. From the perspective of protecting the natural resources of Cape Lookout, the re-analysis should include fish tissues other than, or in addition to, muscle (e.g., tissues from the brain, gill, liver, and kidney) because data for those tissues will strengthen insights about impacts of toxic substances on fish health.

Table 62. The three indicators used to evaluate fish tissue quality conditions based on EPA recommended criteria. Sufficient data were not available for evaluation at Cape Lookout.

Indicator	Good	Fair	Poor
$FISH_{ARSENIC}$ (Arsenic content)	< 0.35 µg/g (ppm	0.35–0.70	> 0.70
$FISH_{PAHS}$ (Contamination by PAHs)	< 0.0016 µg/g	0.0016–0.0032	> 0.0032
$FISH_{PCBS}$ (Contamination by PCBs)	< 0.023 µg/g	0.023–0.040	> 0.040

4.8. Groundwater

Issue: Groundwater supplies are the only potable freshwater source in the park. The available data indicate that Groundwater Supply Condition at Cape Lookout is good. However, data (taken about 15 years ago) indicate that groundwater quality is impaired in three of seven wells by high nitrate (in violation of the EPA standard and the state's drinking water standard), and also by high ammonium and phosphorus suggesting contamination by septic system leachate.

4.8.1. Groundwater Supply

Demands for groundwater supplies on the mainland near Cape Lookout have significantly increased since the mid-1980s, reflected in the decrease in groundwater level in a USGS long-term monitoring well (Figure 52). In contrast, groundwater consumption at this seashore has been stable over time and is not expected to increase; moreover, shortages are not anticipated (Rasmussen et al. 2009). Based on this information, assessment using two suggested indicators led to an overall evaluation of fair groundwater supply condition at Cape Lookout (Table 63c).

Table 63a. The two indicators used to evaluate groundwater supply conditions in Cape Lookout.

Indicator	Good	Fair	Poor
$GRW_{OUTSIDE}$ (groundwater level in the long-term USGS monitoring well nearest CALO on the mainland)	increasing trend ($P < 0.05$)	no change	decreasing trend
GRW_{CALO} (annual water consumption in CALO, most recent year versus average of four previous years)	less than the average of the four previous years	equal to or less than 10% greater than the average of the four previous years	> 10% greater than the average of the four previous years

Table 63b. The present groundwater supply conditions in Cape Lookout, evaluated by the indicators in Table 66a.

Indicator	Cape Lookout evaluation	Rating
$GRW_{OUTSIDE}$	Groundwater level has significantly decreased ($P < 0.01$) over the period of record in the USGS long-term monitoring well (1986–) nearest the seashore.	poor
GRW_{CALO}	2008-2012: annual water consumption at CALO: 1.29 million L to 1.51 million L (0.34 to 0.40 million gallons) per year; 2012 (most recent year of available data): annual water consumption was 5% lower than the 4-year average for 2008–2011.	good

Table 63c. The overall evaluation of the present groundwater supply conditions in Cape Lookout, based on the two indicators in Table 66b.

Rating	Criteria	Overall rating
Good	Both indicators are good	fair
Fair	GRW_{CALO} is good or fair	
Poor	GRW_{CALO} is poor	

4.8.3. Groundwater Quality

The dated study summarized in Table 30 indicates groundwater quality impairment due to excessive nutrients (nitrate, ammonium, phosphate). The highly porous soils at the seashore make the aquifers vulnerable to contamination by pollution sources such as septic systems and fecal matter from the wild horse herd on Shackleford Banks. Saltwater intrusion also historically has been reported following major storms. Unfortunately, the only data available for the park are too old for use in assessing present groundwater quality condition. Therefore, four indicators for groundwater quality condition at Cape Lookout are recommended in Table 64 for use when recent and present-day information becomes available for the seashore.

Table 64. Five indicators recommended for assessment of groundwater quality condition at Cape Lookout when sufficient information becomes available for wells in the seashore.

Indicator	Good	Fair	Poor
GRW_{SALT} (saltwater intrusion into CUIS wells)	Median Cl^- in CALO wells is generally within natural background (30–50 mg/L); occasional saltwater intrusion occurs due to natural processes.	Median Cl^- exceeds natural background due to increased use demands, but Cl^- is below the EPA secondary drinking water standard (< 250 mg/L).	Average well-water Cl- exceeds the standard.
GTW_{TDS} (groundwater quality due to TDS)	Median CALO well water TDS levels are much less than 500 mg/L, the EPA secondary drinking water standard.	Median well-water TDS levels are at or approaching the EPA standard.	Median well-water TDS levels exceed the standard.
$GRW_{NO3\text{-}POTABLE}$ (groundwater quality due to nitrate for drinking water)*	Median CALO well-water nitrate levels are much less than 10 mg/L, the EPA/N.C. drinking water standard.	Median well-water nitrate levels are at or approaching the standard.	Median well-water nitrate levels exceed the standard.
$GRW_{NO3\text{-}FAUNA}$ (groundwater quality due to nitrate for fauna)*	Median CALO well-water nitrate levels are < 5 mg/L to protect sensitive stages of aquatic animals (Johansson et al. 2001; Camargo and Alanso 2005).	Median well-water nitrate is < 10 mg/L.	Median well-water nitrate is > 10 mg/L.
GRW_{FECAL} (groundwater quality due to fecal coliform bacteria)	Fecal coliform bacteria (or *Escherichia coli*) are not detected in well water.	Fecal coliforms (or *E. coli*) are detected at only one of the seven CALO wells, which can be blocked from use until the problem is rectified.	Fecal coliforms (or *E. coli*) are detected at > 2 wells.

* Two indicators for nitrate concentration are given for consideration by the National Park Service. Nitrate in shallow groundwater is very low in the general area unless affected by pollution sources (Spruill et al. 1996, Tesoriero et al. 2004). Of the two indicators for nitrate suggested here, obviously the second indicator, targeting protection of sensitive life history stages of aquatic animals such as some common amphibians, is more protective than the federal/state drinking water standard.

4.9. Biological Resources

Issue: An overall NPS goal is to manage native species in the park to restore and maintain natural community composition, structure, and diversity. The southeastern United States is among the highest in biodiversity nationwide and included many endemic species. Watershed development has led to species extinctions at a rate unrivaled elsewhere across the U.S. mainland. Various species are now threatened, endangered, or locally extirpated. Cape Lookout barrier islands and adjacent waters are one of few remaining havens in the Southeast for many SSCs. This seashore and Cape Hatteras National Seashore to the north also contain nearly all of the remaining critical seagrass habitat in North Carolina. The sensitive flora and fauna of Cape Lookout are threatened by many pressures that are not possible for the National Park Service to control.

4.9.1. Vascular Plant Communities

Indicators for this large, important group were developed considering terrestrial and wetland/ aquatic habitats separately. For each of the two general habitats, the indicators were based on the proportion of exotic taxa and total number of exotic taxa as outlined in Table 45, and on the proportion of invasive taxa. Thus, we considered vascular plant communities within the context of alteration by exotic plant species.

Exotic/invasive plants represent 19.3% of the terrestrial plant taxa in this park, and 3.7% of the wetland flora. Among the terrestrial taxa are 12 highly invasive species (three category R1 species, including two on the NPS Top Ten List for the southeastern United States; two category R2 taxa, four category R3, two WL-A, and one WL-B). The seashore wetland/aquatic habitats include only one highly invasive species, which is also on the NPS Top Ten List. In contrast, there are 13 taxa of vascular plant SSCs presently at the seashore, or 2% of the total vascular plant taxa. Within the past decade, the seashore could have potentially lost the federally endangered seabeach amaranth, although it can be re-established through natural means or with assistance from NPS staff.

Based on the indicators and evaluation format shown in Table 65a, considering the exotic/invasive plants and SSCs represented in the vegetation communities of Cape Lookout NS, the overall vascular plant flora condition in the seashore is poor. This evaluation mainly reflects the condition of terrestrial vascular plant communities in the seashore, notably the high proportion (nearly 20%, 46 species) of exotic terrestrial taxa including 12 highly invasive species.

Table 65a. The five indicators used to evaluate vascular plant community conditions in Cape Lookout.

Indicator	Good	Fair	Poor
$TERR_{EX}$ (proportion of exotic terrestrial taxa to total)	< 5% of the terrestrial taxa are exotic/invasive	≥ 5–15% are exotic/invasive	> 15% are exotic/invasive
$TERR_{CAT}$ (number of highly invasive taxa)	no category R1–R3 taxa, no NPS Top Ten List taxa	≤ 2 Category R1 taxa, ≤ 1 NPS Top Ten List taxon	3 or more R1 taxa, > 1 NPS Top Ten List taxa
WET_{EX} (proportion of exotic wetland/aquatic taxa)	< 5% of the wetland taxa are exotic/invasive	≥ 5–15% are exotic/invasive	> 15% are exotic/invasive
WET_{CAT} (number of highly invasive wetland/aquatic taxa)	no Category R1 taxa, ≤ 2 R2–R3 taxa, no NPS Top Ten List taxa	≤ 2 R1 taxa, ≤ 1 NPS Top Ten List taxon, or ≥ 4 Category R2–R3 taxa	Three or more R1 taxa
SSC_{PLANT} (number of SSCs)	SSC taxa are > 2% of the total vascular plant taxa	SSCs are 1–2% of the total vascular plant taxa	SSCs are < 1% of the total vascular plant taxa

Table 65b. The present vascular plant community conditions in Cape Lookout, evaluated by the indicators in Table 65a.

Indicator	Cape Lookout evaluation	Rating
$TERR_{EX}$	238 terrestrial vascular plant taxa in the park, including 46 exotic/ invasive taxa (19.3%).	poor
$TERR_{CAT}$	Three Category R1 species (two also on the NPS Top Ten List); two Category R2, four Category R3, two WL-A, one WL-B = 12 total.	poor
WET_{EX}	355 wetland + seven aquatic vascular plant taxa (362 total), including 13 exotic/invasive (3.7%).	good
WET_{CAT}	One Category R1 species (also on the NPS Top Ten List) (0.3% of total).	fair
SSC_{PLANTS}	There are 13 vascular plant SSCs in CALO, 2.2% of the total vascular plant taxa (600). Within the past decade the seashore lost the federally endangered plant (sea beach amaranth).	good

Table 65c. The overall evaluation of the vascular plant community conditions in Cape Lookout, based on the five indicators in Table 65b.

Rating	Criteria	Overall rating
Good	≥ 3 indicators good, ≤ 1 indicator fair, no indicators poor	poor
Fair	≥ 2 indicators fair, ≤ 1 indicator poor	
Poor	≥ 2 indicators poor	

4.9.3. Estuarine Benthic Macroinvertebrates

Based on application of the southeast coast benthic index (Tables 31and 32) to data collected at Cape Lookout by the National Park Service in July 2010, the overall benthic macroinvertebrate community condition was evaluated as good (healthy benthos), with only one of the ten sites having an overall rating of fair (some stress).

In addition to the information gained by applying the EPA southeast coast benthic index, we suggest another indicator of benthic macroinvertebrate community condition, based on the status of the seven commercially important species (Table 34). According to the NCDMF, three species are viable, three are ranked as “of concern,” and one species is “status unknown.” Oyster and clam production are poor and fair, respectively, in the Cape Lookout area. Based on the two indicators suggested in Table 66a, the overall benthic macroinvertebrate community condition at the seashore is fair (Table 66c).

Table 66a. The two indicators used to evaluate estuarine benthic macroinvertebrate conditions in Cape Lookout.

Indicator	Good	Fair	Poor
$\mathrm{INVERT}_{\mathrm{SECOAST}}$ (Southeast coast benthic index for the estuarine and marine macroinvertebrate community)	≥ 80% of sites have an index of 3.0–5.0 (healthy benthos; (annual average, 4–5 yr period)	≥ 60% of sites have an index of ≥ 2.0–2.5 (some stress), and ≤ 20% are poor (Unhealthy, index 1.0–1.5)	> 20% of sites have an index of 1.0–1.5 (unhealthy)
$\mathrm{INVERT}_{\mathrm{VIABLE}}$ (viability of commercially/ recreationally important benthic estuarine and marine macroinvertebrates)	≥ 80% of commercially important species are viable (NC DMF), and production is good	≥ 60% of these species are viable, and production is fair to good	< 60% of these species are viable, and production is fair to poor

Table 66b. The present estuarine/marine benthic macroinvertebrate conditions in Cape Lookout, evaluated by the indicators in Table 66a.

Indicator	Cape Lookout evaluation	Rating
$\mathrm{INVERT}_{\mathrm{SECOAST}}$	July 2010 survey of 10 sites in CALO habitats: 9 of the 10 sites were evaluated as good (healthy benthos); one site was evaluated as fair (some stress).	
$\mathrm{INVERT}_{\mathrm{VIABLE}}$	Of the seven commercially or recreationally important macroinvertebrate species, three are viable (43%), three are "of concern" (43%), and one is unknown status. Oyster production is generally poor; clam production is fair.	

Table 66c. The overall evaluation of the present estuarine benthic macroinvertebrate conditions in Cape Lookout, based on the two indicators in Table 66b.

Rating	Criteria	Overall rating
Good	Both indicators good	fair
Fair	≥ 1 indicator is good or fair	
Poor	both indicators poor	

4.9.5. Fish

Estuarine/marine fish species richness in and surrounding the seashore is very high, with at least 294 species (four freshwater taxa) reported to occur there. This species richness is comparable to that in Cape Hatteras National Seashore (with 295 species), which is expected since both parks are in the mixing area where the southernmost extension of the Labrador Current meets the warm waters of the Gulf Stream (Carpenter 2002a–c).

The high species richness of this seashore includes 46 species (16%) that are commercially and/or recreationally valuable. Unfortunately, however, these populations are generally stressed: only seven species (15%) are viable (healthy); three species (7%) are recovering; five species (11%) are depleted; and six species (13%) are status unknown. The remaining 25 species (54%) are of concern.

Based on this information, we recommend two indicators for fish community condition at Cape Lookout (Table 67b), and evaluate the overall condition as fair (Table 67c).

Table 67a. The two indicators used to evaluate fish community conditions in Cape Lookout.

Indicator	Good	Fair	Poor
$FISH_{SPP}$ (estuarine/marine fish species richness)	≥ 100 species present	75–99 species present	< 75 species present
$FISH_{VIABLE}$	≥ 80% of commercially important species are viable (NCDMF)	≥ 60% to 79% of these species are viable	< 60% of these species are viable

Table 67b. The present fish community conditions in Cape Lookout, evaluated by the indicators in Table 67a.

Indicator	Cape Lookout evaluation	Rating
$FISH_{SPP}$	Cape Lookout lies in the area where the Labrador Current southernmost extension mixes with the warm waters of the Gulf Stream, and thus has very high fish species richness (294 species).	good
$FISH_{VIABLE}$	Of the 46 commercially and/or recreationally important fish species, seven (15%) are viable, three (15%) are recovering, five (11%) are depleted, and six (13%) are unknown status.	fair

Table 67c. The overall evaluation of the present fish community conditions in Cape Lookout, based on the two indicators in Table 67b.

Rating	Criteria	Overall rating
Good	both indicators good	fair
Fair	≥ 1 indicator is good or fair	
Poor	both indicators poor	

4.9.6. Herpetofauna

Although the recent surveys of herpetofauna in the seashore have yielded interesting and helpful information, abundance data for the species found are not yet available so that classic species diversity indices such as the Shannon Weaver cannot be developed (Peet 1974; Magurran 1988, 2004). Therefore, we developed an index for herpetofauna using herpetofauna species richness. We based the index on the relationship published by Tuberville et al. (2005) between land use and species richness, excluding exotic/invasive taxa, among 16 parks of the Southeast Coast Network including Cape Lookout. At the time of the Tuberville et al. study, Cape Lookout NS had 35 total herpetofauna taxa, which was intermediate species richness (versus 42 species as of 2013, based on NPSpecies [NPS 2013c]). Species richness tends to be positively related to park area, but amphibian fauna are generally depauperate in barrier island habitats. The saline conditions at the seashore can account for why herpetofauna species richness is only borderline high. Therefore, based on the Tuberville et al. (2005) analysis, the herpetofauna species richness indicator in Cape Lookout NS was evaluated as good. It should be noted, however, that there is no information on the historic species richness of herpetofauna in the seashore. An assumption used in developing this indicator was that the highest species richness for the parks in the Southeast that were assessed by Tuberville et al. (2005) represents a good herpetofauna condition. Considering the known high diversity of herpetofauna in this region together with the high habitat degradation/loss and other negative impacts from watershed development, herpetofauna diversity likely was potentially higher historically.

Two other indicators are suggested for herpetofauna condition. One considers the number of SSC herpetofauna in the seashore (13), relative to the total number of SSC herpetofauna that recently were reported to occur in the area (23; Table 65) (LeGrand et al. 2013). Thus, Cape Lookout has 57% (13 of 23 species) of the herpetofauna SSCs reported to occur in the general area. This is comparable to the percentage of herpetofauna SSCs at Cape Hatteras National Seashore (50%, 13 of 26 species), but higher than other SECN park units which have fewer herpetofauna SSCs (e.g., Cumberland Island National Seashore, nine herpetofauna SSCs; Timucuan Ecological and Historic Preserve, seven SSCs—NPS 2013c). Moreover, despite the higher salinity, which tends to depress amphibian species numbers, the seashore has two amphibian SSCs. Note that sea turtle SSCs are separately considered in Section 4.9.7.3 below.

The third recommended indicator is based on the visual encounter survey (VES) data, beginning with findings from the 2010 survey, which we have set as a good condition for herpetofauna in the seashore. We suggest that trends the data from VESs should be tracked over time, beginning with the 2010 baseline. Our evaluation procedure using these three indicators is shown in Tables 69a–69c, and overall herpetofauna condition in the seashore was assessed as good.

Table 68. The 23 herpetofauna species of special concern reported to occur in the southeastern Coastal Plain/Carteret County of North Carolina[a] and the nine herpetofauna SSCs reported to occur in Cape Lookout[b,c].

Class	Species	Common Name	Present at CALO
Amphibians	*Ambystoma mabeei*	Mabee's salamander	X
	Bufo quercicus	Oak toad	X
	Pseudacris nigrita	Southern chorus frog	--
	Rana capito	Carolina gopher frog	--
Reptiles	*Alligator mississippiensis*	American alligator	--
	Caretta caretta	Loggerhead seaturtle	X
	Chelonia mydas	Green seaturtle	X
	Crotalus adamanteus	Eastern diamondback rattlesnake	--
	Crotalus horridus	Timber rattlesnake	--
	Deirochelys reticularia	Chicken turtle	--
	Dermochelys coriacea	Leatherback seaturtle	X
	Eretmochelys imbricata	Hawksbill seaturtle	X
	Farancia erytrogramma	Rainbow snake	--
	Heterodon simus	Southern hognose snake	--
	Lampropeltis getula sticticeps	Outer Banks kingsnake	X
	Lepidochelys kempii	Kemp's Ridley seaturtle	X
	Malaclemys terrapin	Diamondback terrapin	X
	Masticophis flagellum	Coachwhip	--
	Nerodia sipedon williamengelsi	Carolina watersnake	X
	Ophisaurus mimicus	Mimic glass lizard	--
	Regina rigida	Glossy crayfish snake	--
	Seminatrix pygaea	Black swamp snake	--
	Sistrurus miliarius	Pygmy rattlesnake	X

[a] SSCs in Coastal Plain/Carteret County reported by the North Carolina Natural Heritage Program (LeGrand et al. 2013).

[b] SSCs reported to occur in Cape Lookout from NPS (2013c).

[c] Two other reptiles, *Clemmys guttata* (spotted turtle—N.C. Status W1, N.C. Rank S3, Global Rank G5) and *Rhadinaea flavilata*.(pine woods snake—N.C. Status W2, N.C. Rank S3, Global Rank G4), both reported to occur at Cape Lookout, are on the state's watch list. The spotted turtle is also listed as endangered in the IUCN Red List (International Union for Conservation of Nature and Natural Resources (van Dijk 2013).

Table 69a. The three indicators used to evaluate herpetofauna community conditions in Cape Lookout.

Indicator	Good	Fair	Poor
$HERP_{SPP}$ (herpetofauna species richness wherein # amphibians ≥ # reptiles (evaluated at 5- to 10-year intervals)	≥ 47 native species	25–46 native species	≤ 24 native species
$HERP_{SSC}$ (herpetofauna SSCs versus SSCs reported in the area	≥ 8 SSCs detected (1/3 of the total number of 23 reported for the general region)	6–7 detected (as low as 1/4)	≤ 5 SSCs detected
$HERP_{VES}$ (# of species from VES, using consistent procedure, same timing/sites)	≥ 10 herpetofauna taxa (25% of the total reported (Appendix 3)	8–9 taxa (20% of the total reported)	< 13 taxa

Table 69b. The present herpetofauna community conditions in Cape Lookout, evaluated by the indicators in Table 69a.

Indicator	Cape Lookout evaluation	Rating
$HERP_{SPP}$	2001–2003: CALO was reported to contain 35 native species of herpetofauna, evaluated as moderate species richness reflecting diverse habitats (note that the NPS Certified Species List now includes 42 species—NPS 2013c).	fair
$HERP_{SSC}$	2013: 9 SSCs (2 amphibians, 11 reptiles) are reported to exist in CALO (NPS Certified Species List—NPS 2013c), whereas 23 SSCs are reported to exist in the general region (LeGrand 2013). CALO has 39% of the total number of SSCs reported for the general area. The seashore also has 2 species on the state's Watch List of SSCs reported for the general area.	good
$HERP_{VES}$	May and July 2010: 3 amphibian and 7 reptilian species were found in a short survey of the seashore.	good

Table 69c. The overall evaluation of the present herpetofauna community conditions in Cape Lookout, based on the five indicators in Table 69b.

Rating	Criteria	Overall rating
Good	$HERP_{SPP}$ good, ≥ 1 other indicator good, ≤ 1 other indicator fair	fair
Fair	≤ 2 other indicators good or fair, ≤ 1 other indicator poor	
Poor	≤ 2 indicators poor	

4.9.7. Birds

Cape Lookout is a Globally Important Bird Area, as it provides prime natural migration stopover areas for many neotropical migrants, and vitally important breeding habitats for colonial waterbirds. A total of 276 bird species have been reported to occur seasonally or year-round at Cape Lookout, including 51 SSCs (18.5% of the bird fauna). The Byrne et al. (2011b) landbird survey described the seashore as having medium to high bird fauna diversity based on species richness. Abundance data are lacking for bird species in the seashore, preventing calculation of Shannon Weaver or other widely accepted diversity indices for bird diversity. Thus, at present we have based indicators for Bird Fauna Condition at Cape Lookout on species richness, the 2011 landbird survey, the North American Breeding Bird Survey (BBS), and on the baseline survey conducted by Byrne et al. (2011b).

Bird species richness at Cape Lookout is moderate among the SECN parks, and lower than that of other coastal parks—as examples, the number of native bird taxa at other Globally Important Bird Areas include 208 at Kennesaw Mountain National Battlefield Park, 366 at Cape Hatteras National Seashore, 323 at Cumberland Island National Seashore, and 312 at Timucuan Ecological and Historic Preserve (NPS Certified Species List—NPS 2013c). Cape Lookout is a haven for SSCs; of the above four other SECN parks, Kennesaw Mountain National Battlefield Park and Timucuan Ecological and Historic Preserve are within large urban metropolitan areas and, as would be expected, they have a lower number of bird SSCs (3 and 13 [17], respectively). Cape Hatteras National Seashore and Cumberland Island National Seashore have 66 SSCs and 33 SSCs, respectively.

The BBS was developed by the USFWS in response to the need for a continental monitoring program following the widespread use of DDT (dichloro-diphenyl- trichloroethane) and other chlorinated hydrocarbon pesticides, and anecdotal reports about related increased mortality of songbirds (Robbins et al. 1986). The program presently represents a cooperative effort between the United States (USGS), Environment Canada—Canadian Wildlife Service, and the Comisión Nacionale para el Conocimiento Uso de la Biodiversidad (CONARIO). The BBS presently includes 3,400 randomly located permanent survey routes established along secondary roads. Each route is 39.4 kilometers (24.5 mi) long and consists of 50 stops spaced at 0.8-kilometer (0.5-mi) intervals. The routes are surveyed once each year during the peak of the breeding season. Volunteers experienced in identifying birds by sight and sound record all birds detected within 0.4 kilometers (0.25 mi) of each stop during a three-minute observation period (Robbins et al. 1986; Sauer et al. 2003). As a limitation, the annual surveys yield what might be more accurately described as a relative abundance index because they do not produce a complete counting of the breeding bird populations. In addition, differences in experience among volunteers can sometimes cause inconsistencies in the results. Nevertheless, these annual surveys have proven valuable in assessments of bird population trends (Link and Sauer 1998; Sauer et al. 2003).

BBS summaries of the data by year allow a rapid, user-friendly analysis of trends in the number of individuals and the number of species detected over time at a station of interest (Pardieck et al. 2015). The data are also presented by individual species. For BBS Route 63002 (Merrimon, on the North Carolina mainland), which is the route closest to Cape Lookout, from 2000–2013, the average number of species over 4- to 5-year intervals (77–89), and the number of individuals (989–1,702 individuals; mean 1,144; median 1,092) appear to have remained comparable, given the scatter in the data, over the past 14 years (Table 70, Figure 80). For 2000–2004 the five-year average was 84 species and 1,256 individuals; for 2005–2008 the four-year average was 87 species and 1,067 individuals; and for 2009–2013 the five year average was 83 species and 1,093 individuals.

Table 70. Breeding Bird Survey results for BBS Route 63002—Merrimon, N.C. near Cape Lookout. From the USGS (Pardieck et al. 2015).

Parameter	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Number of Species	78	87	88	83	84	86	83	89	89	84	77	83	87	82
Number of Individuals	998	1,702	1,170	1,124	1,287	1,115	1,073	1,092	989	1,092	1,067	1,074	1,199	1,032

Figure 80. Map showing the location of the Breeding Bird Survey Route 63002 at Merrimon, N.C., 7.2 kilometers (4.5 mi) north of Harkers Island (seashore headquarters) and 8 kilometers (5 mi) west of Cape Lookout on the mainland at its closest point (see Pardieck 2015).

Two other indicators suggested here for bird fauna condition in Cape Lookout were developed from the survey of landbirds conducted in 2010 by the Southeast Coast Network (Byrne 2011b). They include the observed number of species ($BIRD_{OBS\ SPP}$) and total bird abundance ($BIRD_{ABUND}$, number of individuals) in the seashore. Based on these five suggested indicators, the present bird fauna condition at Cape Lookout is good (Table 71c).

Table 71a. The five indicators used to evaluate bird fauna conditions in Cape Lookout.

Indicator	Good	Fair	Poor
$BIRD_{SPP}$ (bird species richness)	≥ 300 native species	275–299 native species	< 275 native species
$BIRD_{SSC}$ (Bird Species of Special Concern, assessed at 10-year intervals in "best" locations)	≥ 15 SSCs observed	10–14 SSCs observed	≤ 9 SSCs observed
$BIRD_{BBS}$ (breeding birds; annual; routinely conducted by volunteers for the USGS; assess at 10-year intervals)	≥ 75 native species, and number of individuals constant or increasing	60–74 native species, and number of individuals constant or increasing	< 60 native species, or number of individuals much lower over time
$LANDBIRD_{OBS\ SPP}$ (number of landbird species observed in NPS survey; assessed at 10-year intervals; same timing/sites as in 2010)	≥ 60 native species	46–59 native species	≤ 45 native species
$LANDBIRD_{ABUND}$ (abundance of landbirds observed in NPS; # individuals, same assessment)	≥ 600 individuals in total	501–599 individuals	≤ 500 individuals

Table 71b. The present bird fauna conditions in Cape Lookout, evaluated by the indicators in Table 71a.

Indicator	Cape Lookout evaluation	Rating
$BIRD_{SPP}$	CALO has moderate bird species richness relative to other SECN parks; 276 species have been reported to occur there seasonally or year-round (NPS 2013c).	fair
$BIRD_{SSC}$	2013 (NPS Certified Species List)—52 SSCs have been reported at CALO. SSCs represent 18.5% of the total bird species at the seashore.	good
$BIRD_{BBS}$	North American BBS in the seashore area (means): 2000–2004: 84 species, 1,256 individuals 2005–2008: 87 species, 1,067 individuals 2009–2013: 83 species, 1,093 individuals Grand mean: 84 species, 1,161 individuals Median: 84 species, 1,093 individuals.	good
$LANDBIRD_{OBS\ SPP}$	April–May 2010: 65 native species were detected at 30 established sites; in addition, 1 exotic species, the ring-necked pheasant, was found at 13% (4 of 30) of sampling sites.	good
$LANDBIRD_{ABUND}$	April–May 2010: 646 individuals were detected at 30 established sites.	good

Table 71c. The overall evaluation of the present bird fauna conditions in Cape Lookout, based on the five indicators in Table 71b.

Rating	Criteria	Overall rating
Good	$BIRD_{BBS}$ or $BIRD_{OBSSPP}$ good, ≥ 2 other indicators good, ≤ 1 other indicator fair, no indicator poor	good
Fair	$BIRD_{SPP}$ or $BIRD_{OBSSPP}$ fair; ≤ 2 other indicators fair, ≤ 1 other indicator poor	
Poor	≥ 2 indicators poor	

4.9.9. Mammals

Of the 21 mammalian species documented at Cape Lookout, 38% (8 species) are exotic/invasive taxa, including five species—coyotes, feral dogs, feral cats, nutria, and Norway rats—that are predators of shorebird and sea turtle SSCs. Coyotes are recent invaders. Based on this information, the mammalian fauna condition at the seashore is evaluated as poor (Table 72c).

Table 72a. The two indicators used to evaluate mammalian fauna conditions in Cape Lookout.

Indicator	Good	Fair	Poor
MAM_{INV} (proportion of exotic/invasive species; assess every 10 years)	< 10%, none common	10–20%	>20%
MAM_{PREDS} (mammalian exotic/invasive species that are predators of sea turtle and shorebird SSCs)	1–2 species, no recent	3–4 species, with ≥ 1 recent	≥ 5 species, with ≥ 1 recent

Table 72b. The present mammalian fauna conditions in Cape Lookout, evaluated by the indicators in Table 72a.

Indicator	Cape Lookout evaluation	Rating
MAM_{INV}	36% of the mammalian species in the park (8 of 22) are exotic/invasive taxa.	poor
MAM_{PREDS}	Of the eight exotic/invasive species, six (feral dog, feral cat, nutria, Norway rat, red fox, and coyote) are predators of sea turtle and shorebird SSCs, including the coyote as a recent invader.	poor

Table 72c. The overall evaluation of the present mammalian fauna conditions in Cape Lookout, based on the two indicators in Table 72b.

Rating	Criteria	Overall rating
Good	Both indicators good	poor
Fair	≥ 1 indicators fair, neither indicator poor	
Poor	≥ 1 indicator poor	

4.9.11. Species of Special Concern

<u>The American Oystercatcher as the Main Sentinel Species for Cape Lookout:</u>
The Cape Lookout draft ORV Management Plan (NPS 2014a) describes an Adaptive Management Strategy as integral to Alternatives B–D, wherein evaluation of species disturbance of the American oystercatcher would guide management alterations. The American oystercatcher was selected as the best indicator of SSC disturbance because this species is a solitary nester and is known to be among the most sensitive species at the seashore to human disturbance (NPS 2014a). In addition, this species is considered to be highly sensitive to climate change because sea-level rise is expected to reduce its habitat.

The National Park Service developed four species indicators for American oystercatchers and a two-step adaptive management protocol (Table 73, Table 74a). The indicators and targets will be applied to the American oystercatcher population at Cape Lookout after imposing increased protection as follows. At present the National Park Service has not imposed a buffer area for courtship or mating birds; there is a 0.93 square-meter (10 square-foot) buffer for nesting birds in dunes, and a 91.4-meter (300-ft) buffer on either side of nests on beaches (that is, a 182.9-meter [600-ft] pass-through area). Full ramp-to-ramp closure to ORVs occurs when chicks are present on the beach, based on the availability of a backroad. The National Park Service (2014a, Alternative C) plans to increase the buffer area for American oystercatcher nests on beaches to 274.3 meters (900 ft) as a pass-through area. Full ramp-to-ramp closure to ORVs when chicks are present will still apply. In addition, an education certificate following completion of a free ORV driver education program will be required of drivers.

Table 73. The evaluation procedure recommended by the National Park Service (2014a) for American oystercatchers as a sentinel species at Cape Lookout NS.

Step	Evaluation
Step 1	Where two of the four indicators have reached moderate impacts (poor designation) for two consecutive years (evaluating the previous three year running average), one or more management actions will be implemented (e.g., increased education/testing, focused enforcement, trash management and fish scrap disposal, predator control, route restrictions, and increased buffers).
Step 2	If the indicators continue to be triggered for two more consecutive years after implementing Step 1, various actions will be taken to help reduce impacts to this species, such as reducing the number of long-term (annual) and/or short-term (10-day) vehicle permits; managing the size of parking lots; and increasing species protection buffer widths.

American oystercatchers have had very low reproductive success at Cape Lookout (except for 2004, which was the highest in the years 2000–2015) since surveying began in 1995 (NPS 2014a). On average, only 24% of all nests have produced hatchlings and very low numbers of chicks (Table 41). The information needed to assess the first three indicators in Table 74a is straightforward. Regarding the fourth indicator, however, more than 47% of nest losses per year have been due to undetermined causes, making loss of nests from mammalian predators difficult to assess accurately. The following information likely represents underestimates, since a portion of the “unknown causes” likely resulted from predation: In 2011, predation clearly caused at least 54% (46 of 85) of nest failures. In 2012, predation caused at least 38% of nest failures (26 of 68; NPS 2013f, 2014a). In 2013, of the 72 nest failures, at least 29% were known to have been due to predation while 64% were due to unknown causes (NPS 2013f).

Based on the evaluation format suggested by the National Park Service (2014a; Table 73), the above information, and the information contained in Table 41, the overall American oystercatcher condition at the seashore was good in the two consecutive years of 2012 and 2013 (Table 74c).

Table 74a. The four indicators used to evaluate American oystercatcher conditions as the main sentinel SSC in Cape Lookout NS (two consecutive years; three-year running average).

Indicator	Good	Fair	Poor
$AMOY_{BREED\text{-}PRS}$ (breeding population size)	≥ 60 breeding pairs (at least 55)	51–54 breeding pairs	≤ 50 breeding pairs
$AMOY_{NESTS}$ (nest survival)	> 30% of nests produce ≥ 1 chick	25–30% of nests produce ≥ 1 chick	< 25% of nests produce ≥ 1 chick
$AMOY_{FLEDG}$ (fledge rate)	> 0.40 chick per pair	0.30–0.40 chick per pair	< 0.30 chick per pair
$AMOY_{PRED}$ (mammal predation)	< 20% mortality for nests and chicks	20–25% mortality	> 25% mortality

Table 74b. The present American oystercatcher conditions in Cape Lookout NS, evaluated by the indicators in Table 74a.

Indicator	Cape Lookout evaluation	Rating
$AMOY_{BREED\text{-}PRS}$	2011: 62 breeding pairs. 2012: 58 breeding pairs. 2013: 63 breeding pairs. 3-year running average; 61 breeding pairs per year.	good
$AMOY_{NESTS}$	2011: 25% of nests produced > 1 chick. 2012–2013: 31% of nests/year produced > 1 chick. 3-year running average; 29% of nests per year.	fair
$AMOY_{FLEDG}$	2011: 0.60 chick per pair. 2012: 0.72 chick per pair. 2013: 0.40 chick per pair. 3-year running average; 0.57 chick per pair per year.	good
$AMOY_{PRED}$	2011: mammalian predation caused 54% of the nest losses. 2012: mammalian predation caused 38%; 2013: mammalian predation caused 29%. 3-year running average; 40% of nest losses were caused by predation.	poor

Table 74c. The overall evaluation of the present American oystercatcher conditions in Cape Lookout, based on the four indicators in Table 74b.

Rating	Criteria	Overall rating
Good	≥ 2 indicators good and ≤ 1 indicator poor	good
Fair	≥ 2 indicators fair, ≤ 1 indicator good, ≤ 1 indicator poor	
Poor	≥ 2 indicators poor	

Although the American oystercatcher is the sentinel species considered for general SSC protection at Cape Lookout in NPS (2014a), the seashore has considerable data for the piping plover and sea turtles as well. Therefore, based on performance measures that have been developed by the National Park Service in partnership with the U. S. Fish and Wildlife Service, indicators and assessments for those SSCs are as follows.

Piping Plover

The year 2013 marked the highest productivity of piping plovers ever recorded at Cape Lookout, and the first time that the fledge success rate at this seashore exceeded 1.0 (NPS 2014a). At present, the National Park Service closes historical and potential nesting areas for piping plovers at Cape Lookout on 1 April each year. A 45.7-meter (150-ft) buffer closed to ORVs is established for courtship/mating birds and nests. The buffer is expanded to 182.9 meters (600-ft) for chicks on the beaches. In addition, on the north end of South Core Banks, 2.0 kilometers (1.25 mi) of beach length is closed to ORVs when chicks are hatched. The National Park Service (NPS 2014a, Alternative C) plans to increase protection of piping plovers during nesting season by expanding full recreational closures to provide for a 45.7-meter (150-ft) buffer in areas of territorial, courtship, or mating behavior occurring outside existing closures.).

Performance measures for three indicators of piping plover condition at Cape Lookout are outlined in the Fish and Wildlife Service recovery plan (USFWS 1996a; Table 75). Based on that information, the overall piping plover condition at Cape Lookout is presently assessed as fair (Table 76c).

Table 75. Desired future conditions for the piping plover SSC at Cape Lookout, developed by the National Park Service in partnership with the USFWS (see USFWS 1996a)*.

Indicator	Target (Performance Measure)
Number of breeding pairs per year	≥ 25
Number of nests per breeding pair per year	≥ 1
Fledge rate per breeding pair per year	≥ 1.5 chick fledged

* Note that if one or more performance measures are not met, Cape Lookout will reinitiate consultation with the USFWS as part of the annual review process identified in the USFWS amended biological opinion (USFWS 2007b), unless there is mutual agreement that the failure to meet the goal was caused by factors not possible for the National Park Service to control.

Table 76a. The three indicators used to evaluate piping plover condition in CALO, developed from performance measures contributed by the National Park Service in partnership with the U. S. Fish & Wildlife Service (NPS 2014a, USFWS 1996a).

Indicator	Good	Fair	Poor
$PPL_{BREED\text{-}PRS}$ (number of breeding pairs; 5-year average)	≥ 25 breeding pairs	15–24 breeding pairs	< 15 breeding pairs
$PPL_{NESTS/PR}$ (number of nests per breeding pair; 5-year average)	≥ 1 nest per breeding pair per year	0.80–0.99 nest per breeding pair per year	< 0.80 nest per breeding pair per year
PPL_{FLEDG} (fledge rate; 5-year average)	≥ 1.5 chick per breeding pair	0.1.0–1.5 chick per breeding pair	≤ 1.0 chick per breeding pair

Table 76b. The present piping plover conditions in Cape Lookout, evaluated by the indicators in Table 76a.

Indicator	Cape Lookout evaluation	Rating
$PPL_{BREED\text{-}PRS}$	2009–2013: $PPL_{BREED\text{-}PRS}$ averaged 43 per year range: 36–51; median: 43	good
$PPL_{NESTS/PR}$	2009–2013: $PPL_{NESTS/PR}$ averaged 1.24 nests per breeding pair per year range: 1.15–1; median: 1.25	good
PPL_{FLEDG}	2009–2013: PPL_{FLEDG} averaged 0.82 chicks per breeding pair per year range: 0.57–1.04; median: 0.83	poor

Table 76c. The overall evaluation of the present piping plover conditions in Cape Lookout, based on the three indicators in Table 76b.

Rating	Criteria	Overall rating
Good	PPL_{FLEDG} good, ≥1 other indicator good, no indicator poor	
Fair	PPL_{FLEDG} fair, ≤ 1 other indicator good, ≤ 1 other indicator poor	fair
Poor	PPL_{FLEDG} poor	

Sea Turtles

The federal recovery plan for loggerheads, the major sea turtle species in Cape Lookout, identifies coastal development, commercial fisheries, and pollution threats to the loggerhead population (NMFS and USFWS 1991, 2008). The recovery plan lists six actions needed to achieve recovery: (i) provide long-term protection to important nesting beaches such as national seashores, (ii) ensure at least 60% hatch success on major nesting beaches, (iii) implement effective lighting ordinances or lighting plans on all major nesting beaches within each state, (iv) determine distribution and seasonal movements for all life stages in a marine environment, (v) minimize mortality from commercial fisheries, and (vi) reduce the threat from marine pollution.

At present, Cape Lookout National Seashore establishes three ramp-to-ramp turtle relocation areas on North Core Banks and on South Core Banks during turtle nesting season. The nests are marked and

ORV closures (9.1 meters [30 ft] at the nest and 27.4 meters [90 ft] at the high tide line) are established beginning 50 days after the nest is established. The National Park Service (NPS 2014a, Alternative C) plans to increase the buffer area for sea turtle nests to 9.1 meters (30 ft) at nests and 45.7 meters (150 ft) at the high tide line.

Performance measures for two indicators of sea turtle condition at Cape Lookout were identified by the National Park Service in partnership with the U.S. Fish and Wildlife Service (Table 79). Based on that information together with consideration of the data summaries, the overall sea turtle condition at Cape Lookout NS is presently assessed as good (Table 78c).

Table 77. Desired future conditions for sea turtles at Cape Lookout NS [a,b].

Indicator	Target (Performance Measure)	Source
Ratio of False Crawls to Nests (annual)	< 1:1	Adapted from the 2008 Loggerhead Recovery Plan goal (NMFS and USFWS 2008)
Percentage of North Carolina total sea turtle nests (five-year average)	≥ 20% of the North Carolina total (five-year average)	From the Biological Opinion (USFWS 2007b)

[a] From NPS (2014a), in consultation with the USFWS for the CALO Interim Protected Species Management Plan/Environmental Assessment (NPS 2006a), the associated Biological Opinion (USFWS 2006a), the Amended Biological Opinion (USFWS 2007b), and NPS (2006c).

[b] Note that if one or more performance measures are not met, CALO will reinitiate consultation with the USFWS as part of the annual review process identified in the USFWS Amended Biological Opinion (USFWS 2007b), unless there is mutual agreement that the failure to meet the goal was caused by factors not possible for the National Park Service to control.

Table 78a. The two indicators (developed from performance measures identified by the National Park Service in partnership with the USFWS) used to evaluate sea turtle conditions in Cape Lookout.

Indicator	Good	Fair	Poor
$STURTL_{\%NESTS}$ (percentage of state sea turtle nests; five-year average)	≥ 10% of state total/year at CALO	5% to < 10% of state total/year at CALO	< 5% of state total/year at CALO
$STURTL_{RATIO}$ (ratio of false crawls/nests per year; five-year average)	< 1:1	1:1 to 1.3:1	> 1.3:1

Table 78b. The present sea turtle conditions in Cape Lookout, evaluated by the indicators in Table 78a.

Indicator	Cape Lookout evaluation	Rating
$STURTL_{\%NESTS}$	2009–2013: CALO averaged 21.6% (range 20–27%, median 20%) of the state total.	good
$STURTL_{RATIO}$	2009–2013: the annual ratio averaged 0.86 (range 0.85 to 1.11; median 0.98). Two years (2009 and 2011) had a ratio > 1.	good

Table 78c. The overall evaluation of the present sea turtle conditions in Cape Lookout, based on the two indicators in Table 78b.

Rating	Criteria	Overall rating
Good	Both indicators good	good
Fair	≤1 indicator fair, no indicator poor	
Poor	≥1 indicator poor	

4.9.13. Special Management Issue—the Feral Horse Population

The population size of the feral horses at Cape Lookout has a generally decreasing trend line over time from the highs in the early- to mid-management years. The congressionally legislated range is 120–130 horses (See the Cape Lookout Horse Management Plan, NPS 2007).

Two indicators are suggested for wild horse population at the seashore, and were used to evaluate the present wild horse population condition as good (Table 79c). The number of horses has been less than the high of the target population (120–130 animals) since 2004, and no horses have been removed for population reasons since 2009.

Table 79a. The two indicators used to evaluate feral horse population conditions in Cape Lookout.

Indicator	Good	Fair	Poor
$HORSES_{NUMBER}$ (total abundance)	maximum target is ≤130	131–140	> 140
$HORSES_{REMOVE}$ (removal of horses)	no horses removed (annual)	< 5 horses removed (annual)	≥ 5 horses removed (annual)

Table 79b. The present feral horse population conditions in Cape Lookout, evaluated by the indicators in Table 79a.

Indicator	Cape Lookout evaluation	Rating
$HORSES_{NUMBER}$	The maximum number of horses in the feral herd on Shackleford Banks has been less than 130 animals since 2003.	good
$HORSES_{REMOVE}$	No horses have been removed to balance the size of the herd since 2009.	good

Table 79c. The overall evaluation of the present feral horse population conditions in Cape Lookout, based on the two indicators in Table 79b.

Rating	Criteria	Overall rating
Good	Both indicators good	good
Fair	≤1 indicator fair, neither indicator poor	
Poor	≥1 indicator poor	

5. Climate and Climate Change

5.1. Climate

Climate is considered here as the short-term and long-term patterns and processes of weather events for a given location (Paz et al. 2008). Natural patterns and processes of weather events characterized the Earth ecosystem prior to alterations imposed by various human activities. As part of the Earth's ecosystem, climate provides the fundamental background conditions for natural resources, and it is among the most significant influences on natural resources anywhere on Earth: Weather and climate are key drivers for ecosystem patterns and processes, affecting both biotic and abiotic components alike. Understanding the role of climate as a forcing agent for other vital signs (e.g., plant and animal communities) is a critical component of SECN monitoring…Continuous weather monitoring is [also] a key factor in separating the effects of climate from the effects of human-induced disturbance on plant and animal community and population dynamics (Wright 2012a).

Climatological data are recorded by five sources including Ocracoke Village (Ocracoke), 6.4 kilometers (4 mi) from Cape Lookout; the Morehead City 2WNW weather station, 7.7 kilometers (4.8 mi) from the park; the City of Beaufort tide station (temperature only), 2.9 kilometers (1.8 mi) distant; the CLKN7 station in the park (temperature only); and the Croatan station (relative humidity [RH] only), 21.1 kilometers (13.1 mi) distant (Table 80). Of the five stations, two are in the Cooperative Observer Program (COOP); one is in the National Ocean Service (NOS, of the National Oceanic and Atmospheric Administration, NOAA) national network; one is in the National Buoy Data Center (NBDC); and one is a Remote Automated Weather Station (RAWS) (see Wright 2012a for further information).

Summary climate data for Cape Lookout are presented in annual reports published by the Southeast Coast Network (prior to 2010), and are available online in the National Park Service Integrated Resource Management (IRMA) portal (NPS 2015e). Currently, climate data for National Park Service units is compiled and disseminated by the NPS Climate Change Response program.

The seashore has a humid, subtropical climate with temperatures modified by the Atlantic Ocean; winters are usually mild, spring lasts from late February to early May, and the humid summer season averages 32.2°C (90°F). Heat indices seldom break 38°C (100°F) because of the moderating effects of the Atlantic Ocean, and the average July temperature is 31.1°C (88°F). Winters typically are mild, with January lows at 1–3°C (low to mid-30s°F), and snowfall averaging 4.8 centimeters (1.9 in) in the years when it occurs. Total annual precipitation averages 145 centimeters (57.1 in) (Thornberry-Ehrlich 2006), and about 60% of it falls from April through September. The area averages 117 precipitation days per year. On average there are 211 sunny days per year (Carteret County Health Department 2014). The area is also hurricane-prone—tropical storms occur during late summer/early fall about one in 1.37 years as of 2013, and Cape Hatteras, North Carolina—just north of the seashore—was ranked the number one area most affected by hurricanes from 1871 to the present (104 times; last updated in March 2014; Williams 2015).

Table 80. Weather stations in or near Cape Lookout (Wright 2012b).

Distance (km [mi])	Station Name	National Network	Station ID	Latitude (dd)	Longitude (dd)	County	Elevation (m [ft])	Start Date
6.4 [4.0]	Ocracoke	COOP	316349	35.1	-75.983	Hyde	1.2 [3.9]	5/1/1957
7.7 [4.8]	Morehead City 2 WNW	COOP	315830	34.7333	-76.733	Carteret	3.0 [9.8]	9/1/1948
2.9 [1.8]	Beaufort*	NOS	8656483	34.7167	-76.667	Carteret	Not listed	6/10/1990
In CALO	CLKN7*	NBDC	CLKN7	34.622	-76.525	Carteret	4.6 [15.1]	11/7/1984
21.1 [13.1]	Croatan (RH only)	RAWS	319602	34.7833	-76.867	Carteret	6.1 [20]	Feb. 2003

5.1.1. Temperature

Climatic conditions can vary substantially depending on the location in the park (Covington et al. 2009). Therefore, we used Climate Division 7, the Central Coastal Plain, for this analysis (Figure 81) rather than a specific location such as Cape Lookout NS. The National Weather Service of the National Oceanic and Atmospheric Administration (NOAA NWS) has records for this area covering the period from 1895 to the present. This analysis considered the 112-year record from 1900 through 2012 (see NCEI 2016a). We also separately analyzed the period from 1930 through 2012, but the trend results were very similar using the two different starting years. The mean annual temperature across the 112-year record was 16.2°C (61.1°F). There was an increasing trend in both average annual temperature and average summer temperature (June through August) over time (Figures 82 and 83). In the past 45 years (1967-2012), however, mean annual temperature increased more substantially, by 0.22°C (0.4°F) per decade (Figure 82), and mean summer temperature (June–August) showed an increase of 0.22°C (0.5°F) (Figure 83).

It should be noted that at least five years of monthly data are required for monotonic trend analysis (continuous rate of change, increasing or decreasing), and for a step trend (abrupt shift up or down), at least two years of monthly data before and after the shift are required (e.g. Lettenmaier et al. 1982, Hirsch 1988). Thus, the decadal data, taken daily, are sufficient for conducting statistical trend analysis.

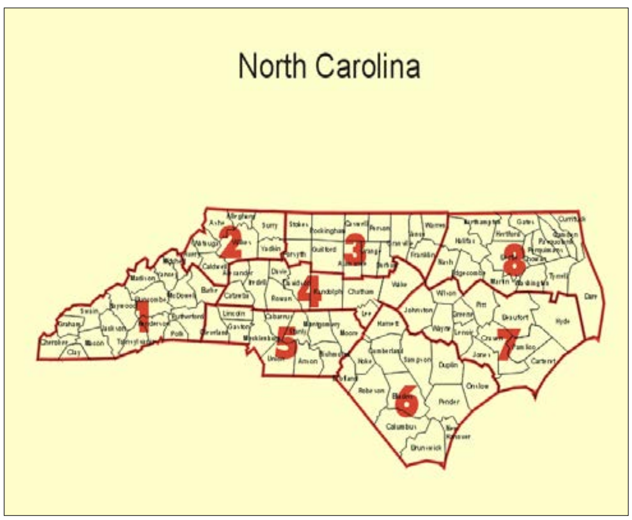

Figure 81. The NOAA NWS climatic divisions in North Carolina. From NOAA NWS.

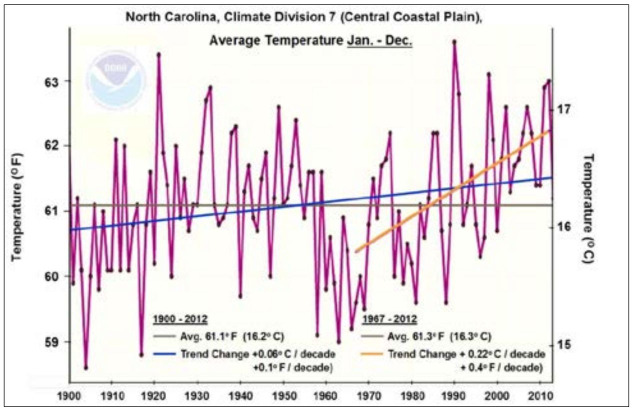

Figure 82. Mean annual temperature in N.C. Climate Division 7, including Cape Lookout NS (1900–2012 and 1967–2012), showing an increasing trend (NCEI 2016a).

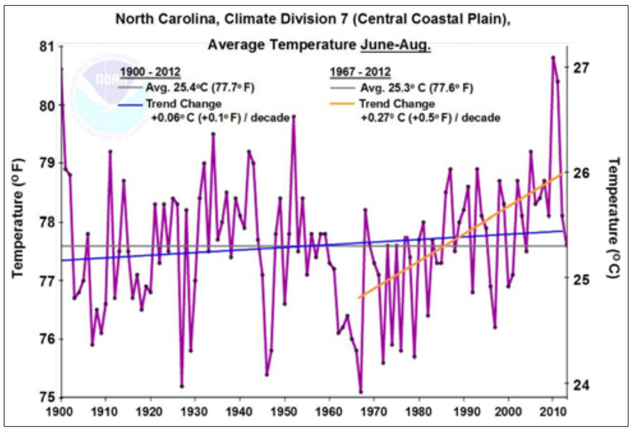

Figure 83. Mean summer temperature (June–August) in N.C. Climate Division 7, including Cape Lookout NS (1900–2012), showing an increasing trend (NCEI 2016a).

5.1.2. Precipitation

Similar analyses were conducted for precipitation falling in the Climate Division 7 area over time. Average annual precipitation from 1900 to 2012 varied greatly, but showed a very slight decreasing trend (0.08 centimeters [0.03 in]) per decade (Figure 84). The overall mean was 128.8 centimeters (50.72 in) over the 112-year period. Average summer (June–August) precipitation decreased by 0.64 centimeters (0.25 in) over the 112-year period (Figure 85*).* The mean summer precipitation was 43.8 centimeters (17.24 in). Overall, annual and summer temperatures have increased, while annual and summer precipitation have decreased. The trend of increasing temperature has been more pronounced in the past 45 years. Collectively, the data suggest that increasing temperatures and decreasing precipitation (hotter, drier summer conditions) could lead to a decrease in available water and an increase in drying which may, in turn, promote more frequent and/or frequent and/or severe drought conditions.

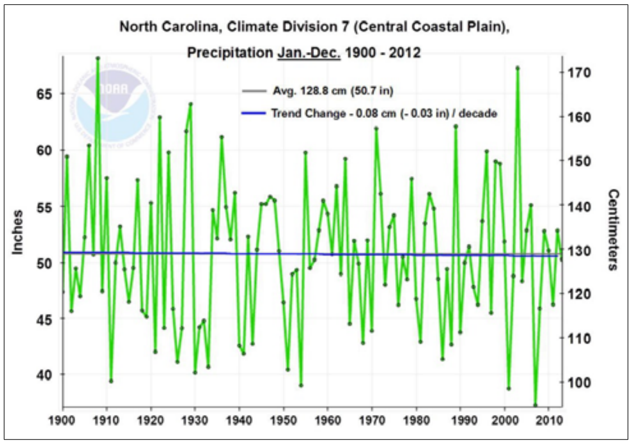

Figure 84. Mean annual precipitation in the N.C. Climate Division 7 area from 1900 through 2012, showing a slight decrease (by 0.08 centimeters [0.03 in]) per decade and an overall mean of 128.8 centimeters (50.72 in). The trend is not statistically significant, as indicated by the flat trend line (no change) (NCEI 2016a).

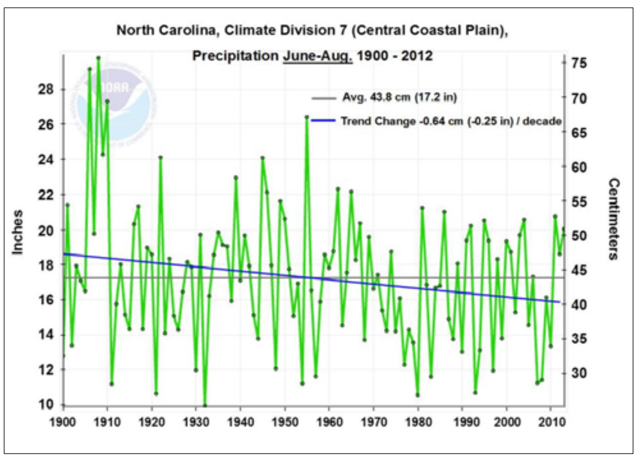

Figure 85. Mean summer precipitation (June–August) in the N.C. Climate Division 7 area from 1900 through 2012, showing a decrease (by 0.64 centimeters [0.25 in]) per decade. The mean summer precipitation was 43.8 centimeters (17.24 in) over that period (NCEI 2016a).

5.1.3. Moisture

Drought severity was assessed (1896 or 1920 through 2012) using the Palmer Drought Severity Index (PDSI, a scale ranging from -5 to +5), which assesses the duration and intensity of long-term drought-inducing circulation patterns (Dai et al. 2004, Dai 2011a,b). PDSI values rank the severity of a given drought (Table 81). Drought severity during the summer season (June–August) was highly variable over time, but the data show a strong increase in the proportion of months that were in the slightly dry/favorably moist, abnormally dry, and excessively dry classes since 1967 (Figure 86). In addition, severely dry conditions have increased since 1995.

In Climate Division 7, including the seashore, droughts have worsened. The data also show that abnormally wet and wet conditions have increased since 2003. Collectively the data suggest that extremes of abnormally wet and abnormally dry conditions have characterized the area since the late

1960s to mid-1970s. Such climatic extremes have been predicted to accompany the overall warming trend in climate change (Kundzewicz et al. 2007; Brekke et al. 2009; Karl et al. 2009).

Table 81. The Palmer Drought Severity Index (PDSI) scale. From Dai et al. (2004) Note: scale ranges from -5 to +5).

Scale Interval	Class Description
-3 or less	Severely dry
-2 to less than -3	Excessively dry
-1 to less than -2	Abnormally dry
-1 to less than 1	Slightly dry / favorably moist
1 to less than 2	Abnormally wet
2 to less than 3	Wet
3 or greater	Excessively wet

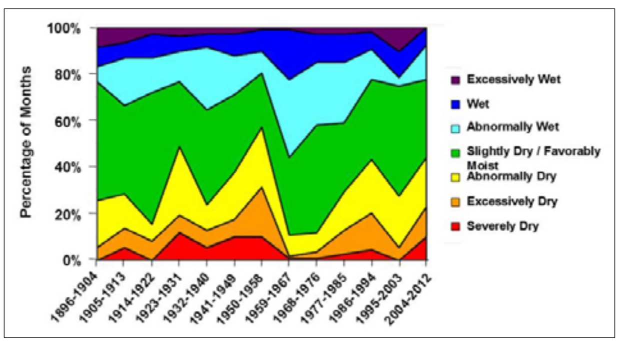

Figure 86. PDSI values in N.C. Climate Division 7, including Cape Lookout NS, over nine-year periods from 1896 through 2012, showing a large percentage in the “excessively dry” class over the past four decades. Data from the Southeast Regional Climate Center (SERCC).

5.1.4. Phenology (Growing Degree Days)

Phenology is the study of the effects of changes in the seasonal variation of temperature and precipitation on biological processes, reflected in the timing of reproduction, flowering, and the length of the growing season. We assessed changes in phenology as growing degree days (GDDs), defined as the total amount of time in an annual cycle when the temperature is above 4.4°C (40°F), roughly equivalent to the growing season when non-evergreen plants are able to photosynthesize. The monthly mean temperature for Climate Division 7 over time (1930–2012) was used to estimate the approximate number of GDDs per month:

$$GDD = (Tm - 40)\ Dm$$

Here Tm = monthly mean temperature, and Dm = number of days in month. The GDDs for each month were added to estimate the GDDs per year, and these values were plotted over time to assess long-term changes in the numbers of GDDs in the area. Using the approach of Dorr et al. (2009), we also considered phenology within the context of a calendar year by selecting an arbitrary GDD threshold of 1200 and then estimating the date at which that number of GDDs was reached. This would be similar to estimating the specific date when a phenologic event such as cherry tree flowering in March or April. The total monthly accumulated GDD through 31 March was calculated by multiplying the mean daily temperature by the number of days in a month, and the difference from 1200 was determined.

It should be noted that the dataset used for this analysis, from Morehead City, North Carolina, was selected because it had the most data near the seashore. Nevertheless, the dataset had frequent missing data, and three years (1965, 1969, 2009) each had an entire month with missing data. The annual GDD should have been higher for those years. The missing month in 2009 was September, which typically has substantial GDDs; the "true" GDD value for 2009 should have, at a minimum, been between the GDD values of 2008 and 2010. With exception of 2009, the annual GDD has steadily increased since 2000 (Figure 87).

The number of days required to reach the 1,200 GDD was estimated as the slope of the line for the approximate month. If the difference was positive, the exact date where 1200 was achieved was estimated as the slope of the line between the total GDD for March and the total for April. If the difference was negative, the same procedure was used between February and March. In this way, the calendar date when the 1200 GDD was achieved was calculated for each year (Figure 88). The data show that the annual GDD in the Morehead City, North Carolina area has decreased from 1949 (first available data) through 2012.

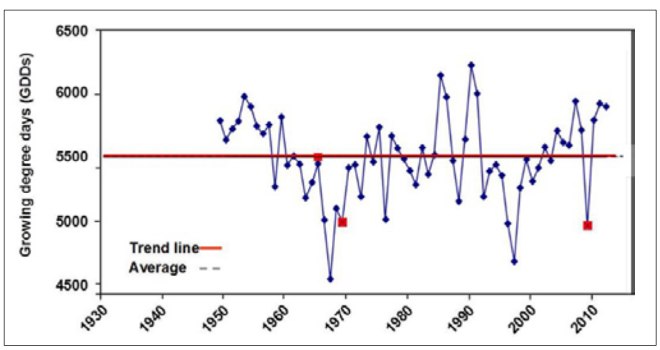

Figure 87. The total GDDs per year at Morehead City, N.C., for which the most data were available at a site or area near the seashore. Data are shown from 1949 (data first available) through 2012. This dataset contained substantial missing data. Three years, 1965, 1969, and 2009 (red squares) had one entire month with no data; thus the annual GDD should have been higher for those years, especially 2009 wherein September was the missing month. Based on the available data, the long-term mean annual GDD total is 5,504 (dashed line). The trend line (red) indicates that there has been no apparent change in the total GDDs per year during the 63-year period. Data from the SERCC.

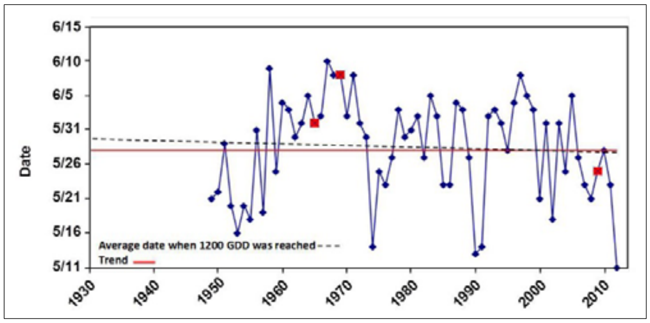

Figure 88. The approximate date when 1200 GDD was reached for each year in the Morehead City, N.C. area during the period from 1949 (data first available) through 2012. The date has decreased over this 63-year period. Three years, 1965, 1969, and 2009 (red squares) had one entire month with no data. Data from the SERCC.

5.1.5. Extreme Weather Events

The North Carolina coast is prone to hurricanes—tropical storms occur during late summer/ early fall about one in 1.75 years as of 2013 (Wilmington, North Carolina area, last updated in March 2014; see Williams 2015). It is also prone to extra-tropical late fall-early spring “nor’easters,” major storms named for the continuously strong northeasterly wind that blows in from the Atlantic Ocean when the storm moves near the coastline (SCONC 2016b). Their wind gusts can reach hurricane force, up to about 119 kilometers (74 mi) per hour, and they can cause heavy precipitation and large waves resulting in significant coastal erosion.

The Saffir/Simpson Hurricane Scale (SSHS; Table 82) rates and categorizes hurricanes on a scale of 1 to 5 based on wind speeds (Blake et al. 2007), and a major hurricane is rated as a 3, 4, or 5 on the SSHS. Storm tracks within a 161-kilometer (100-mi) radius of Cape Lookout NS, North Carolina, were acquired from 1851 through 2013 from the State Climate Office of North Carolina (Table 83). Each storm was rated as a tropical depression (TD), a tropical storm (TS), and category 1-5 hurricanes. Storms categorized as tropical depressions have maximum sustained winds of about 61 kilometer/hour (38 mph) or less. Tropical storms have maximum sustained winds of about 63 to 117 kilometers per hour (39–73 mph) (U.S. Department of Commerce 2013). Storms that occurred on successive days were combined into one storm event, and the event was assigned the most severe storm rating that it received). The data were considered by month and by nine-year intervals (Figures 89 and 90).

Of the 168 storms that occurred from 1851–2013, 70% were tropical depressions and tropical storms; 25% were Category 1 and Category 2 hurricanes, 5% were Category 3 hurricanes, and there was one Category 4 hurricane (Table 83, Figure 91. Most storms have occurred during June–October, known as hurricane season in North Carolina (Figure 91). The total number has increased from the 1930s to the present (Figure 90).

Table 82. The Saffir/Simpson Hurricane Scale (Blake et al. 2007), with typical characteristics of hurricanes by category.

Scale Number (Category)	Wind Speed (mph)	Millibars	Inches	Surge (ft)	Damage
1	74–95	> 979	> 28.91	4 to 5	Minimal
2	96–110	965–979	28.50–28.91	6 to 8	Moderate
3	111–130	945–964	27.91–28.47	9 to 12	Extensive
4	131–155	920–944	27.17–27.88	13 to 18	Extreme
5	> 155	< 920	< 27.17	> 18	Catastropic

Table 83. The total numbers of lows, extratropical storms, tropical depressions, subtropical storms, tropical storms, and hurricanes that affected a 161-kilometer (100-mi) radius from Cape Lookout NS, N.C. during the period1851–2013; data available through 2013. Data from SCONC 2015.

Classification	# of Storms	% of Storms
Category 5	0	0.00%
Category 4	1	0.58%
Category 3	8	4.62%
Category 2	17	9.83%
Category 1	26	15.03%
Tropical Storm	71	41.04%
Subtropical Storm	2	1.16%
Tropical Depression	19	10.98%
Subtropical Depression	3	1.73%
Extratropical Storm	24	13.87%
Low	2	1.16%
Total	*168*	*100%*

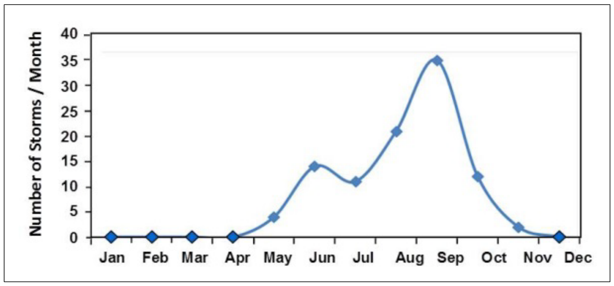

Figure 89. The total number of major and minor storms by month (1930–2013) that occurred within 161 kilometers (100 mi) of Cape Lookout NS (SCONC 2015).

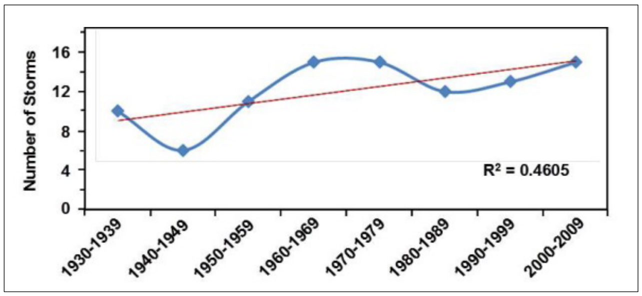

Figure 90. The total number of major and minor storms per decade (1930–2009, the latest year for which a complete decade of data are available) that occurred within 161 kilometers (100 mi) of Cape Lookout NS (SCONC 2015). The total number was 97.

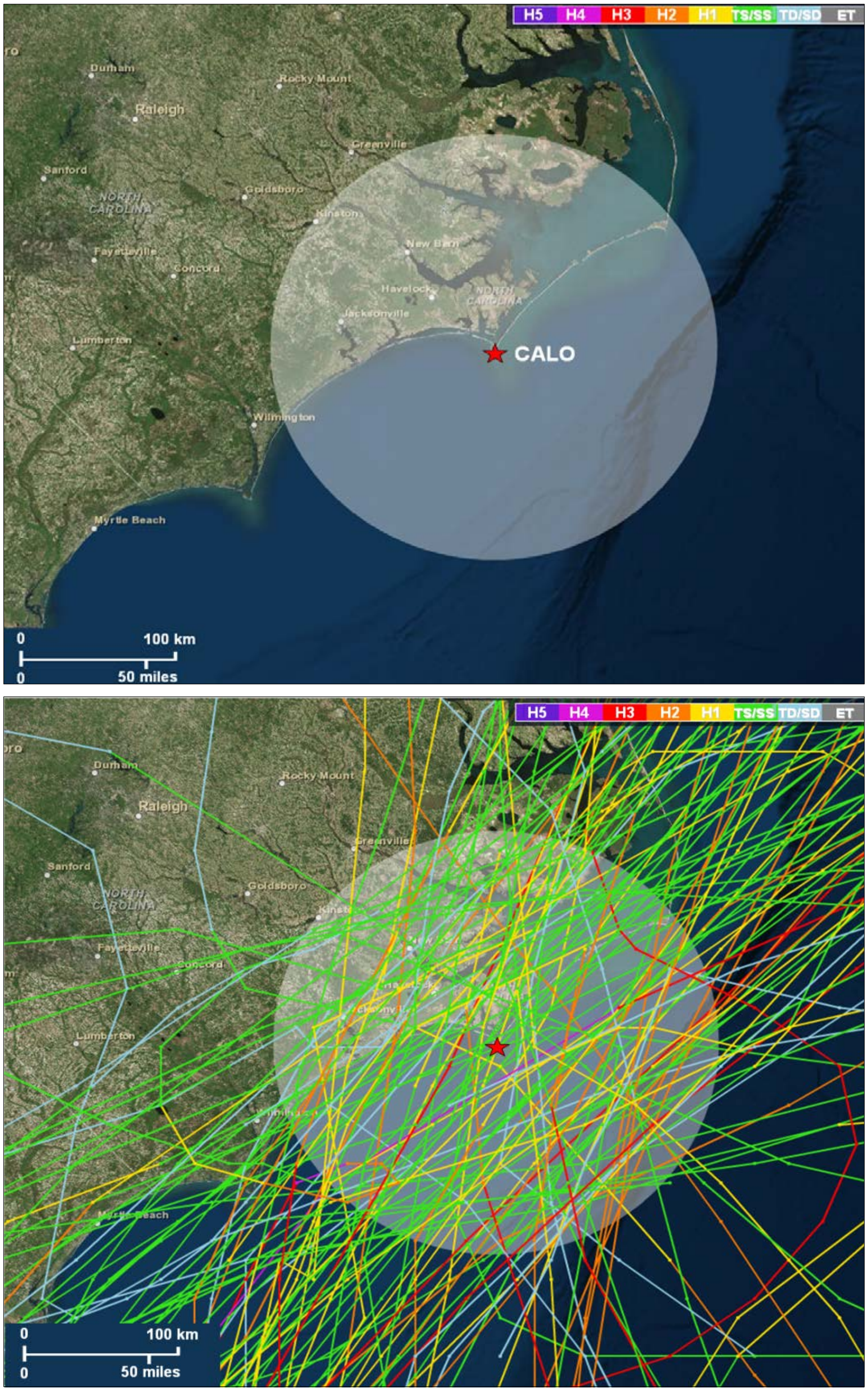

Figure 91. Hurricane level 1–5 storms, tropical/subtropical storms, and tropical/subtropical depressions during 1851 through 2013 within a 161-kilometer (100-mile) radius of Cape Lookout NS (star: 35.2546° N, 75.5200°W). From NOAA 2016b [H1, H2, H3, H4, H5—hurricane storm level; TS/SS—tropical/subtropical storms; TD/SD—tropical/subtropical depressions].

5.1.6. Sea-Level Rise

> *Sea level does not just gently rise and oceanic waters flood quietly across the land. Because storms are frequent and significant high energy events, they become the drivers that erode the shorelines, move the barrier islands, and cause ecosystems to migrate upward and landward.*
>
> *—Riggs et al. (2008)*

Consensus Forecasts

Scientists have reached consensus worldwide, as reflected by the International Panel on Climate Change (IPCC 2014), on the following statement: There is more than 95% certainty that 100% of the warming that is occurring now and projected, as well as the warming that was documented over the past 60 years, is being or has been caused by human actions.

The southeastern United States is already sustaining impacts of global warming, especially increasing trends in air temperatures, rising sea levels, acidification of waterbodies (fresh and brackish/marine), changing weather patterns, shifting species ranges, and rising ocean temperatures (NPS 2007a). An increasing trend in ocean temperature has been linked to an increased number of category 4–5 hurricanes (Webster et al. 2005; Emanuel 2005; Elsner et al. 2008). Between 1980 and 2007, North Carolina shared the impacts of 26–30 individual climate and weather-related disasters, the majority of them storms, that each caused over one billion dollars in total damages (NOAA 2007). A severe storm would have a devastating impact of the coastal land, waters, ecosystems, and the built environment of northeastern North Carolina. The Outer Banks are regarded as especially vulnerable to damage from major storms (ECU 2008).

Late fall/winter nor’easters, hurricanes, and less intense tropical storms, and the characteristic shallow shoals near Cape Hatteras and Cape Lookout National Seashores, have led to the area being called the Graveyard of the Atlantic, as historians have estimated that more than 1,000 shipwrecks have occurred in that area since the 1600s (Pendleton et al. 2004; and see NWS undated). Sea-level rise that has been directly related to global warming is occurring worldwide (IPCC 2014), but the North Carolina coast is sustaining the highest rates of relative sea-level rise along the entire U.S. Atlantic seaboard, 40.6–45.7 centimeters (16–18 in) per century based on tide gauge records and marsh peat analyses (Zervas 2004; Kemp et al. 2008). Tide gauge and historical data show that relative sea-level rise 100 years ago was 17.8 centimeters (7 in) per century; 200 years ago it was only 7.6 centimeters (3 in) per century (Riggs et al. 2008) (Figure 92).

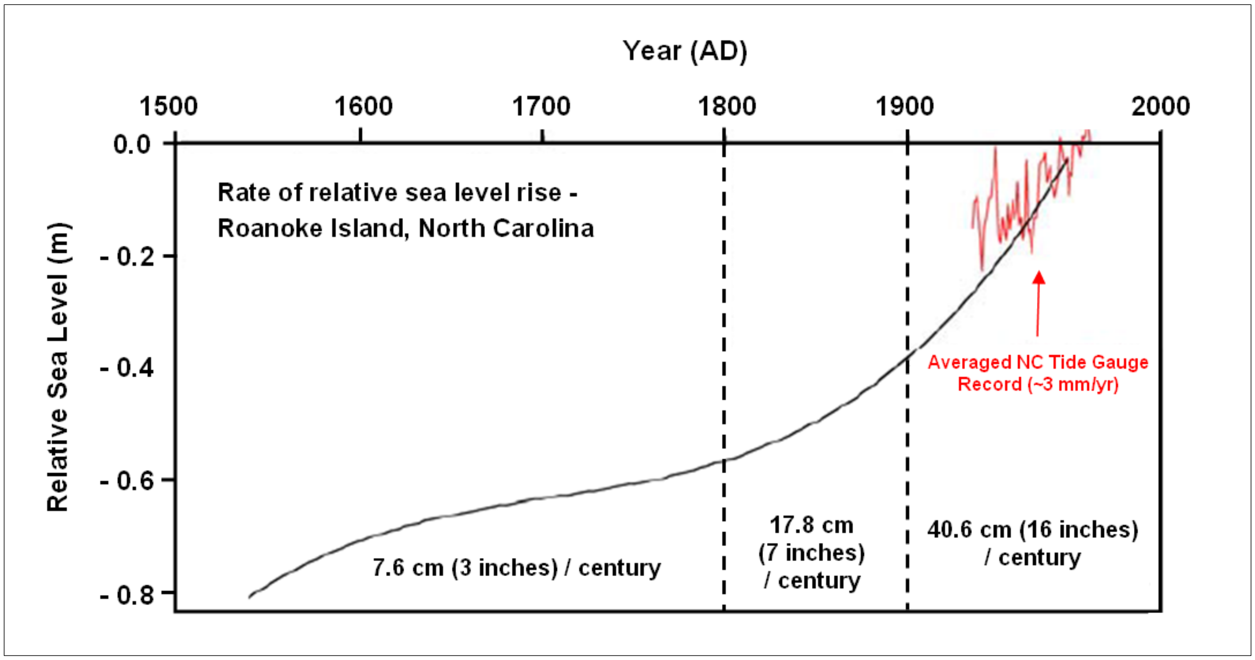

Figure 92. Generalized relative sea level at Roanoke Island in the northern Outer Banks since 1500 AD, based on salt marsh microfossils (foraminifera) from Sand Point. The analysis indicates that the present rate of sea-level rise at Roanoke Island is 0.42 centimeters (0.17 in) per year (42 centimeters [16.5 in] per century). Modified from ECU (2008).

Differences in predictions about impacts of accelerated global warming have arisen, at least in part, because of the spatial complexity of sea level trends (Rossby et al. 2013). Nevertheless, there is strong agreement that models are forecasting an average global temperature increase over this century of 1.7–5.6°C (3.3–10.1°F), and temperatures appear to be tracking at the higher end of that range (NPS 2007a). Specialists predict, as a conservative estimate, that sea-level rise will accelerate to 0.9 meters (3 ft) above present sea level by the year 2100 in direct response to global warming (IPCC 2014). A coastal flooding model (Zervas 2004) combined a hydrodynamic tide model of Pamlico, Albemarle, Core, and Bogue sounds and adjacent estuarine and coastal waters with the high-resolution, topographic/bathymetric digital elevation map based on the LiDAR topographic and bathymetric data. The model forecasted the extent of inundation in Pamlico and Bogue sounds and the Neuse River as a function of a 0.9-meter (3-ft) rise in sea level (Figure 93). As the figure shows, most of Core Banks as well as some areas of Shackleford Banks would be inundated long-term by the end of this century.

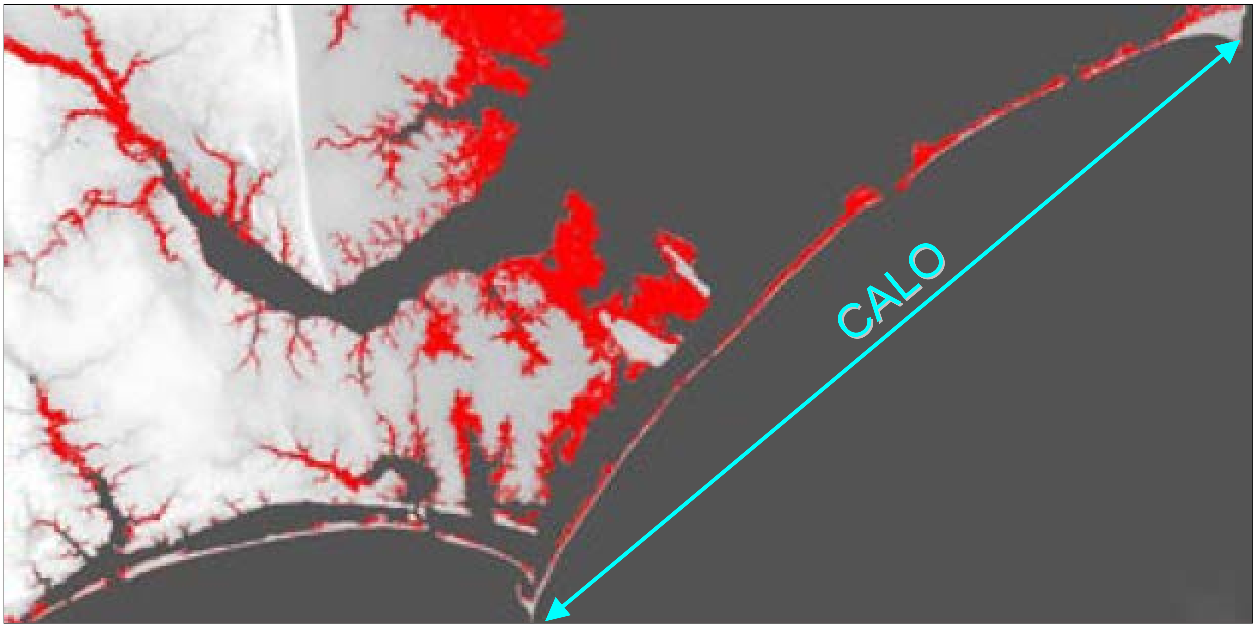

Figure 93. Modeled areas in red, including nearly all of CALO, are areas that were projected to be inundated by a 0.9-meter (3-ft) rise in sea level (Zervas 2004).Some models predict sea level will rise at least that much by the year 2100 (IPCC 2014).

Some researchers additionally have reported that the U.S. Atlantic Coast from the Gulf of Maine to Florida is a "hotspot" for accelerated flooding (Ezer and Atkinson, 2014). They point out that extreme surge events (which they define as 0.9 meters [3 ft] above mean higher high water, MHHW)— usually associated with hurricanes or intense storms—are relatively rare in comparison to minor tidal flooding (defined as 0.3 meters [1 ft] above MHHW). Their analysis shows that the duration of minor tidal flooding has accelerated in the past 25 years in most coastal locations examined on the U.S. Atlantic Coast. The average increase in annual minor flooding duration was 20 hours in 1970 versus 1971 to 1990, and 50 hours from 1971–1990 to 1991–2013. Moreover, the spatial variations in acceleration of flooding resembled the spatial variations of acceleration in sea level reported by Sallenger et al. (2012). The increase in minor flooding could be predicted fairly well from sea-level rise and tidal range, whereas the frequency of extreme storm surge flooding events was found to be less predictable and influenced by the North Atlantic Oscillations. As Ezer and Atkinson (2014) noted, with higher seas there are also more flooding events that are not related to storm surges. For example, assuming that Hurricane Sandy (August 2012) and a comparable storm 100 years ago struck land at the same tidal stage, Hurricane Sandy would have caused more floods than the comparable storm because sea level was lower 100 years ago.

Sea-level rise has already had a major adverse impact on the coastlines of North Carolina (Pilkey et al. 1998). From 1975 to 2000, the state lost nearly 120.5 square kilometers (46.5 mi^2) of coastal area, about 60% of the wetlands in the northeastern portion of the state (Riggs 2001). As sea level rises, the shoreline recedes and one ecosystem class can be transformed into another, substantially changing the function of coastal areas (EPA 2008a). Rates of shoreline recession vary greatly depending on the shoreline geology, type, geometry, and composition; the geographic location; the size and shape of associated coastal waterbodies; coastal vegetation; water level; and storm frequency/intensity (EPA 2008a). Regardless, North Carolina is in the top three states considered (along with Florida and Louisiana) to be most vulnerable to the consequences of sea-level rise (East Carolina University [ECU] 2008). The Outer Banks are the most vulnerable area of the state to inundation from sea-level rise and recession of the eastern shore (i.e., displacement inland)—although, fortunately, Shackleford Banks is not as vulnerable as most of the Outer Banks as explained above. Burroughs and Tebbens (2008) compared the change in position of the shoreline at Core Banks, Ocracoke and lower Hatteras Island, and upper Hatteras Island in September of 1997 and 1998 (the latter year, just after the passage of Hurricane Bonnie). The shoreline position retreat was least along Core Banks (7.54 ± 0.25 meters [24.7 ± 0.82 ft]), maximal along Ocracoke/lower Hatteras Island (13.4 ± 0.08 meters [44.0 ± 0.26 ft]), and intermediate at upper Hatteras Island (9.26 ± 0.26 m [30.4 ± 0.85 ft]).

The combination of increased sea-level rise and increased storm surge, by exacerbating shoreline erosion, could adversely impact beach nesting species at the seashore such as the American oystercatcher, piping plover, and loggerhead sea turtles (NPS 2014e).

5.2. Climate Change

Issue: Climate change is rapidly advancing in the Southeast, manifested through warming temperatures, altered patterns and amounts of precipitation (droughts, floods), and the storm frequency. Cape Lookout NS, consisting of narrow islands of sand at the ocean's edge very near MSL, is extremely vulnerable to climate change impacts and predicted changes, if realized, will dramatically impact the natural resources of this seashore.

Baron et al. (2008) described climate change as already redefining U.S. national parks, and advised park managers to begin to include climate change considerations into all activities and plans. Not surprisingly, species richness, extirpations, and introductions in national parks in other nations, as well as the U.S., have been found to be strongly related to climate, more so than to any other factor (Rivard et al. 2000). To increase the resilience of the natural biota to the many changes resulting from climate change, Baron et al. (2008) recommended reducing habitat loss and fragmentation, invasive species, and pollution; protecting important ecosystem and physical features; restoring damaged systems and natural processes; and reducing the risks of catastrophic loss through establishing refugia, relocating valued species, replicating populations and habitats, and attempting to maintain representative examples of beneficial species populations.

The Intergovernmental Panel on Climate Change (IPCC 2014) has projected that temperature in the Southeast will increase 2.2 to 5.0°C (4 to 9°F) by 2080, and that sea levels will rise more than 0.9 meters (3 ft) by 2100. Since 1970, average annual temperatures in the Cape Lookout region have increased (Fisichelli 2013; Kunkel et al. 2013; Figure 94), and winters in particular are warming: The average number of freezing days has declined by four to seven days per year (Karl et al. 2009). The Southeast has been described as a difficult area to predict for some climate change impacts (Ingram et al. 2013). Extreme daily high temperatures are also increasing (Kunkel et al. 2013). Most areas are also becoming wetter, especially in the autumn; in contrast, during the spring and summer seasons, areas affected by moderate to severe droughts have increased (Karl et al. 2009). It is uncertain whether precipitation will increase or decrease, but models suggest that there will be heavier downpours interspersed with increased droughts between storm events. Thus, both the risk of flooding and the risk of drought are expected to increase. Coastal areas are expected to sustain stronger hurricanes, accelerated sea-level rise, and larger storm surges (Karl et al. 2009). The Southeast has been described as a difficult area to predict for some climate change impacts (Ingram et al. 2013).

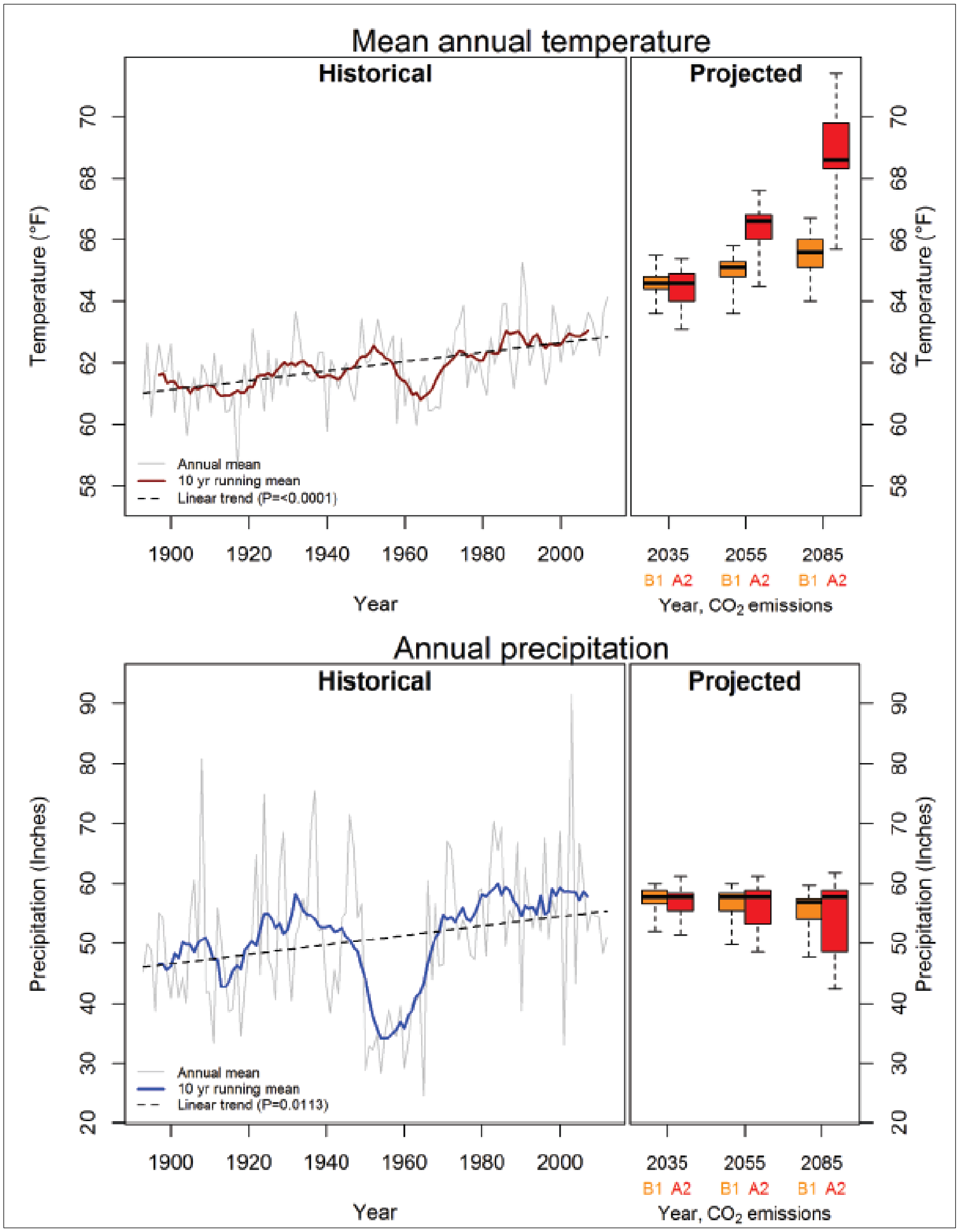

Figure 94. Historical and projected mean annual temperature and annual precipitation for CALO. Historical data (1893–2012) are from the Morehead City, N.C. weather station (cdiac.ornl.gov).Projected climate change (30-year means) for the region including the seashore are for three future time periods centered on 2035 (2021–2050), 2055 (2041–2070), and 2085 (2070–2099). Two greenhouse gas emissions scenarios are presented, the low (B1) and high (A2) scenarios (IPCC 2007). Projected climate boxplots indicate the variability in future projections among 14–15 CMIP3 climate models. Values for the area including CALO are based on projected changes from individual climate models averaged across the southeast region: the bold horizontal black line represents the mean among all models, the upper and lower bounds of the boxes indicate the 25th and 75th percentile model output values and the whiskers show the minimum and maximum change averaged across the region. From Fisichelli (2013), also included in NPS (2014e).

Supporting Baron et al.'s (2008) findings and our analysis, in the State of the Park report for Cape Lookout NS the National Park Service (2014e) wrote:

> *The park is very vulnerable to being impacted by the effects of climate change…. The park is in a region already at the extreme warm end of its historical climate…and sea level has risen almost 17.8 centimeters (7 inches) in the past 60 years (Caffrey 2013)…Expected reduction in habitat for juvenile estuarine finfish and crustacean shellfish may decrease fisheries production. Changes in temperature, ocean pH, local acidification, sea-level rise, and saltwater intrusion could impact molluscan shellfish and change their distribution. Warmer water may contribute to more harmful algal blooms and increases in pathogens in shellfish that affect humans when they are consumed (Ingram et al. 2013)…Saltwater intrusion into coastal freshwater systems will increase [and] this could impact marsh and terrestrial ecosystems.*

We worked through some complexities in manipulating the longer datasets needed to produce some of the summary graphics for (1) determining the date when the 1200 GDD threshold is reached, and (2) using the PDSI data to rank the severity of drought over seven "moisture classes" ranging from excessively wet to severely dry (Table 81). The first program uses GDD data to calculate the date where the 1200 GDD threshold is reached. The computation involves finding the calendar date when the 1200 GDD threshold is reached for each year in the dataset, by summing the monthly values until the sum is greater than 1200 and then calculating the slope of the line between that month and the month preceding to determine the exact date on which the 1200 would occur. Typically, the value 1200 is achieved between April and May, but occasionally between March and April, or May and June, depending on the temperature. The second program uses the PDSI data to rank the severity of drought over the seven moisture classes. The computation involves calculating the proportion of the number of monthly observations in each drought class for every nine-year period.

For the seashore, the rapidly rising summer temperatures over the past decade, and the decreasing trend in precipitation and moisture concomitant with an increase in the proportion of "dry" months are undesirable trends from the perspective of attempting to maintain, insofar as possible, a natural, healthy ecosystem at Cape Lookout NS. A recent analysis of climate change trends for the southern Outer Banks by the NPS Climate Change Response Program similarly predicted increasing temperatures and decreasing precipitation for the area (Fisichelli 2013) (Figure 94). The GDD (since 2000, except for 2009) and extreme weather events are both increasing, and the number of days required to reach the 1200 GDD in the area has decreased. All of these conditions are undesirable.

The Southeast Coast Network has worked to develop a climate science strategy in an attempt to prepare for and mitigate the adverse impacts of global warming on all of the national parks in the region (DeVivo et al. 2011). The National Park Service (2014e) noted that attempting to manage for climate change based on an historic natural range of variation will be "increasingly futile in many locations," because reference conditions and/or judgments about resource condition or trend likely will need to change as the rate of climate change accelerates and the National Park Service must respond to novel and even unprecedented conditions.

The NPS Climate Change Response Program has set 1 meter (3.3 ft) of relative sea-level rise in the next 100–150 years as a “standard benchmark for use across all parks” (Peek et al. 2015). Clearly, such careful preparation is merited. As of 2010, the state of North Carolina had officially accepted the findings of a special report on projected climate change impacts—most notably, that sea level would rise 0.99 meters (3.25 ft) per century by 2100 (North 8 Carolina Coastal Resources Commission [CRC] 2010).

The new sea-level rise report by the NCCRC was published in 2015. At the Beaufort tidal gauge, relative sea level by 2045 was projected to rise by an average of 8.1 centimeters (3.2 in) (range, 7.1–9.1 centimeters or 2.8–3.6 inches). This finding was compared to ICCP predictions for relative sea-level rise in the region assuming the lowest versus the highest greenhouse gas emission scenarios, combined with vertical land movement. At the lowest ICCP greenhouse gas emission, sea level was predicted to rise 16.5 centimeters (6.5 in; range, 27.2–56.1 centimeters or 10.7–22.1 in) by 2045. At the highest ICCP greenhouse gas emission scenario, sea level was predicted to rise 19.1 centimeters (7.5 in, range 12.7–25.4 centimeters or 5.0-10.0 in) by 2045 (NCCRC Panel 2015).

6. Discussion

6.1. Summary of Natural Resource Conditions in Cape Lookout National Seashore

This in-depth analysis of the natural resources of Cape Lookout NS considered available information for all natural resource categories ranging from climate to SMIs (Tables 84 and 85). In total, 66 indicators were used to evaluate the 20 categories of natural resources for which sufficient information was available to allow some level of assessment. The overall condition of ten categories was rated as good; six were in fair condition; and four were in poor condition. Nearly all of the fair and poor conditions were strongly influenced or controlled by external forces that are not possible for the National Park Service to control.

This report card can function as a valuable resource for Cape Lookout staff and the Southeast Coast Network by enabling rapid communication to concerned citizens, policymakers in local, state, and federal governments, industries etc. about the pressing need to improve protection of the natural resources at this seashore, which is a major natural wonder of this nation. It is our hope that the many people who enjoy the wealth of natural resources at Cape Lookout, including the millions of people across the nation who use the seashore for recreation—and who expect to continue to enjoy it—will respond to this report card by contributing more stewardship toward the goal of improving the status and protection of its natural resource conditions.

Table 84. Report Card for Natural Resource Conditions in Cape Lookout as of 2014.

NATURAL RESOURCE CATEGORY	Indicators	CALO
Adjacent human population impact	3	Fair
Visitation—Human Population in the seashore	3	Fair
Wilderness condition (Shackleford Banks)	3	Good
Air quality	8	Fair
Soundscape	3	Good
Lightscape	2	Good
Geology and soils, including sea-level rise	5	Poor
Surface water quality	4	Good
Surficial sediment quality	3	Good
Groundwater supply	2	Fair
Vascular flora	5	Poor
Benthic estuarine/marine macroinvertebrates	2	Fair
Fish	2	Fair
Herpetofauna	3	Fair
Birds	5	Good
Mammals	2	Poor
American oystercatcher sentinel ssc	4	Good
Piping plover ssc	3	Fair
Sea Turtle sscs	2	Good
Feral horse population	2	Good

Table 85. Summary of Natural Resource Conditions in Cape Lookout, including 20 separate categories that were evaluated using the 68 listed indicators.

Category	Indicators	Present status in Cape Lookout NS	Condition	Overall
Physical/Chemical				
Human population in the general area	HPG_{COUNTY}—human population density in Carteret County	*Population increasing 1.0% per year (average, 2000–2013)	Fair	Fair
	HPD_{COUNTY}—human population density in Carteret County	*50.7 people per km^2 (181.3 people/$mile^2$);	Fair	
	POV—poverty in the general area	*14% of the Carteret county population, respectively, below the poverty level.	Poor	
Visitation—human population in park	VIS—# visitors/year (trend)	*405,213 visitors per year (median, past 16 years); 2014 visitation 405,213, the lowest annual visitation since 2000.	Good	Fair
	$VP\text{-}A_{DAY}$—visitor pressure/area, tourist season	*Avg. of 14 visitors/km^2/day (36/mi^2/day).	Fair	
	$VP\text{-}T_{DAY}$—visitor pressure on trails, tourist season	*Avg. of 12 visitors per km of trail per day (19 visitors/mi/day)	Fair	
Wilderness land use	$WILD_{NATURAL}$—natural character	* Shackleford Banks is isolated from the mainland and remains a rare haven of diversity and complexity.	Good	Good
	$WILD_{DEVELOP}$—developed condition	* The island is undeveloped except for very minimal features, and development is prohibited.	Good	
	$WILD_{QUIET}$—solitude and quiet	* The island has outstanding opportunities for solitude, except for beaches on the western end with somewhat high visitation.	Fair	
Air quality	AQI_{USEPA}—Air Quality Index	* 1999–2009 (Beaufort, N.C.): average was <50 throughout.	Good	Fair
	AQ_{OZONE}—O_3 ; and	* 61–75 ppb ozone (8-hour average time, fourth maximum value)	Fair	
	$AQ_{OZ\text{-}W126}$—humans	*W126 =7–13 ppm	Fair	
	$AQ_{OZ\text{-}SUM06}$—plants	*SUM06 = 8–15 ppm-hr.	Fair	
	$AQ_{N\text{-}DEP}$—nitrogen deposition	* 2005–2009: N-DEP > 3 kg/ha/yr.	Poor	

Table 85 (continued). Summary of Natural Resource Conditions in Cape Lookout, including 20 separate categories that were evaluated using the 68 listed indicators.

Category	Indicators	Present status in Cape Lookout NS	Condition	Overall
Physical/Chemical (continued)				
Air quality (continued)	$AQ_{S\text{-}DEP}$—sulfur deposition	* 2005–2009: S-DEP > 3 kg/ha/yr.	Poor	Fair
	AQ_{VIS}—visibility	* 2005–2009: VIS > 8 dv.	Poor	
	AQ_{ACID}—acidification	* Pollutant exposure high, ecosystem sensitivity very low, seashore protection moderate; overall moderate risk from acidic pollution.	Fair	
Soundscape	$SOUND_{POP}$—proximity to pop. center	* Shackleford Banks is closest to a human population center (Beaufort, 3.2 km [2 mi] distant), separated by Back Sound. Impacts muted sound side and negligible concern.	Fair/good	Good
	$SOUND_{TRAV}$—proximity to major transportation source	* CALO is not close to a major travel artery.	Good	
	$SOUND_{DATA/OBS}$—noise pollution data and/or park staff observations	* Data overall indicate *good* conditions at this seashore; highest noise pollution from gun blasts (hunting, Core Banks) and military flyovers (130–140 dBA and 11 dBA, respectively).	Good	
Lightscape	$LITE_{ARTIF}$—Bortle Dark Sky Scale	* CALO is considered to have the least night sky pollution of most if not all national parks east of the Mississippi River; $LITE_{ARTIF}$ is 1–2 (Excellent to Typical, Truly Dark Skies).	Good	Good
	ALR = $\frac{\text{average anthropogenic all-sky luminance}}{\text{average natural all-sky luminance}}$	* Nevertheless, the modeled ALR for CALO is 0.36 (= *fair*; moderate concern)	Fair	
Geology and soils	$Soils_{EROD}$—soil erodability	* CALO soils are mostly highly erodible sands.	Poor	Poor
	$GEOL_{CEAN\text{-}EROD}$—eroding conditions ocean side	* CALO is sustaining 1.4 meters (>4.6 ft) of erosion per year, which is considered “severely eroding.”	Poor	
	$GEOL_{SEA\text{-}RISE}$—relative sea-level rise	* Relative sea-level rise at Beaufort is 37 centimeters (14.6 in) per 100 years, evaluated as a very high rate. As a moderate prediction, by 2100 sea level there will rise 0.55 meters (1.8 ft).	Poor	

Table 85 (continued). Summary of Natural Resource Conditions in Cape Lookout, including 20 separate categories that were evaluated using the 68 listed indicators.

Category	Indicators	Present status in Cape Lookout NS	Condition	Overall
Physical/Chemical (continued)				
Geology and soils (continued)	$GEOL_{CVI}$—Coastal Vulnerability Index specifically for CALO	* The CVI for CALO (>42.0) indicates that much of the seashore has very high vulnerability to long-term inundation by future major storms.	Poor	Poor
	$GEOL_{ARTIFICIAL}$—human-constructed structures along the shorelines	* CALO has been altered minimally with human-constructed “stabilizing” structures.	Good	
Surface water quality	SWQ_{DO} ≥ 5 mg/L	* Previous analyses—DO data mostly *good*; 2000–2014 data *good*.	Good	Good
	SWQ_{TURB} (water clarity) <0.92	* Previous analyses and 2000–2014 —few turbidity data	N.A.	
	SWQ_{DIP} (phosphate) <10 µg/L (summer)	* Few DIP data for previous analyses; 2000–2014 data *fair*.	Fair	
	SWQ_{DIN} (nitrate + ammonium) <80 µg/L	* Few DIN data for previous analyses or for 2000–2014.	N.A.	
	SWQ_{CHL} (corrected) <3 µg/L	* Previous Chlorophyll *a*—*good* (but concentration range too high; 2000–2014 data *good*).	Good	
	SWQ_{FECAL} <200 CFU/100mL (May–Oct), <1000 (Nov–Apr); OR <400 (all year)	* 2000–2014 data *good* both sound side and ocean side.	Good	
Sediment quality	$SEDQUAL_{TOC}$—<2% dry weight of sediment	* Previous analyses and analysis of 2000–2014 data *good*.	Good	Good
	$SEDQUAL_{METALS}$—9 chemical parameters	* Previous analyses and analysis of 2000–2014 data *good*	Good	
	$SEDQUAL_{ORG}$—18 chemical parameters	* Previous analyses and analysis of 2000–2014 data *good*	Good	
Ground-water supply	$GRW_{OUTSIDE}$ —change in groundwater level over time in the long-term USGS monitoring well nearest CALO	* Groundwater level has significantly decreased (P<0.01) over the period of record (1986–) in the USGS long-term monitoring well nearest the seashore.	Poor	Fair
	GRW_{CALO}—annual water consumption at CALO (most recent year versus average of the previous four years)	* Annual water consumption at CALO was 1.29 to 1.51 million liters (0.34 to 0.40 million gallons) per year in 2008–2012 (most recent data); water consumption was 5% lower in 2012 than the yearly average for 2008–2011.	Good	

Table 85 (continued). Summary of Natural Resource Conditions in Cape Lookout, including 20 separate categories that were evaluated using the 68 listed indicators.

Category	Indicators	Present status in Cape Lookout NS	Condition	Overall
Biological—General Groupings (as of 2013)				
Vascular flora	$TERR_{EX}$— # of Exotics/Total	* Terrestrial: 46 exotic taxa, 238 total taxa (19.3%).	Poor	Poor
	$TERR_{CAT}$— # of highly invasive taxa	* Terrestrial: 12 highly invasive taxa.	Poor	
	WET_{EX}— # of Exotics/Total	* Wetland/aquatic: 13 exotic taxa, 363 total taxa (3.7%).	Good	
	WET_{CAT}— # of highly invasive taxa	* Wetland/aquatic: 1 highly invasive species.	Fair	
	SSC_{PLANTS}—# of SSCs	* 13 vascular plant SSCs in CALO, 2.2% of the total taxa; 1 species apparently extirpated within the past decade.	Good	
Estuarine/marine benthic macro-invertebrates	$INVERT_{SECOAST}$—Southeast Coast Benthic Index for the community	* July 2010 survey—9 of 10 sites *good* (healthy benthos), 1 site *fair* (some stress).	Good	Fair
	$INVERT_{SECOAST}$—Viability of commercially/recreationally important species	* 3 of 7 species are viable (43%), 3 are “of concern” (43%), and 1 is Unknown status.	Poor	
Fish	$FISH_{SPP}$—fish species richness (#)	* CALO lies at the intersection of the southernmost Labrador Current and the warm waters of the Gulf Stream—has very high species richness (294 species).	Good	Fair
	$FISH_{VIABLE}$—Viability of commercially/recreationally important species	* Seven of 46 species (15%) are viable, three (7%) are recovering, five (11%) are Depleted, and six (13%) are unknown status.Twenty-five species are considered to be species of concern.	Poor	
Herpeto-fauna	$HERP_{SPP}$—species richness (#)	* 2001–2003—CALO had 35 native species, evaluated as moderate species richness reflecting diverse habitats (now has 42 reported species).	Fair	Fair
	$HERP_{SSC}$—SSCs in CALO versus SSCs reported for the general area	* 2013—13 SSCs (1 amphibian, 12 reptiles) found in CALO, set as baseline for *good*.	Good	
	$HERP_{VES}$—# species detected with VES	* 2010—10 species (3 amphibians, 7 reptiles) detected with VES in a short survey of CALO, set as baseline for *good*.	Good	

Table 85 (continued). Summary of Natural Resource Conditions in Cape Lookout, including 20 separate categories that were evaluated using the 68 listed indicators.

Category	Indicators	Present status in Cape Lookout NS	Condition	Overall
Biological—General Groupings (as of 2013—continued)				
Birds	$BIRD_{SPP}$—# of native species	* NPS Certified Species List (2013)—CALO has moderate bird species richness (276 species).	Fair	Good
	$BIRD_{SSC}$—# of SSCs	* NPS Certified Species List (2013)—52 SSCs reported at CALO (18.5% of the total number of bird species).	Good	
	$BIRD_{BBS}$—# of species and # of individuals (Breeding Bird Surveys)	* BBS near the seashore (2000–2013): ≥75 species, and the # of individuals has remained roughly constant.	Good	
	$LANDBIRD_{OBS\ SPP}$—number of landbird species found in NPS survey	* April–May 2010—65 native species and 1 exotic species detected at CALO.	Good	
	$LANDBIRD_{ABUND}$—abundance of landbirds	* April–May 2010—646 individuals detected at CALO.	Good	
Mammals	MAM_{INV}—proportion of exotic/invasive species	* 38% of the mammalian species in the seashore (8 of 21) are exotic/invasive taxa.	Poor	Poor
	MAM_{PREDS}—# of mammalian exotic/invasive species preying upon sea turtle and shorebird SSCs	* 5 of the 8 exotic/invasive mammalian species are predators of sea turtle and shorebird SSCs, including the coyote as a recent invader.	Poor	
Species of Concern (3 Selected SSCs) and 1 Special Management Issue				
American oyster-catcher	$AMOY_{BREED\text{-}PRS}$—# of breeding pairs per year (5-year average)	* 2011—62 pairs; 2012–58 pairs; 2013–63 pairs; 3-year running average—61 breeding pairs per year.	Good	Good
	$AMOY_{NESTS}$—nest survival per year	* 2011—25% of nests produced ≥1 chick; 2012–2013—31% of nests per year produced ≥1 chick; 3-year running average—29% of nests per year produced ≥1 chick.	Good	
	$AMOY_{FLEDG}$—fledge rate per year	* 2011—0.6 chicks per pair; 2012—0.72 chicks per pair; 2013—0.40 chicks per pair; 3-year running average—0.57 chicks per pair per year.	Good	
	$AMOY_{PRED}$—mammalian predation per year	* 2011–2013—mammalian predation caused 54%, 38%, and 40% of nest losses, respectively; 3-year running average—40% of nest losses were caused by mammalian predation.	Good	

Table 85 (continued). Summary of Natural Resource Conditions in Cape Lookout, including 20 separate categories that were evaluated using the 68 listed indicators.

Category	Indicators	Present status in Cape Lookout NS	Condition	Overall
Species of Concern (3 Selected SSCs) and 1 Special Management Issue (continued)				
Piping plover	$\text{PPL}_{\text{BREED-PRS}}$—# of breeding pairs per year (5-year average)	* 2009–2013—# of breeding pairs has averaged 43 per year (range, 36–51 breeding pairs per year; median, 43).	Good	Fair
	$\text{PPL}_{\text{NESTS/PR}}$—# of nests per breeding pair per year (5-year average)	* 2009–2013—average of 1.24 nests per breeding pair (range, 1.15–1.35 nests).	Good	
	$\text{PPL}_{\text{FLEDG}}$—fledge rate (5-year average)	* 2009–2013—fledge rate averaged 0.82 chicks per pair (range, 0.57–1.04 chicks per pair; median, 0.83 chicks).	Poor	
Sea turtles	$\text{STURTL}_{\text{\%NESTS}}$—percentage of the total # of sea turtle nests in N.C. per year (5-year average)	* 2009–2013—CALO averaged 21.6% (range, 20–27%; median, 20%) of the state total.	Good	Good
	$\text{STURTL}_{\text{RATIO}}$—ratio of false crawls-to-nests per year (5- to 7-year average)	* 2009–2013—the annual ratio averaged 0.86 (range, 0.85 to 1.11; median, 0.98). Two years (2009 and 2011) had a ratio exceeding 1.	Good	
Feral horse herd	$\text{HORSES}_{\text{NUMBER}}$—total abundance per year	* 2004–2013—the maximum number of horses in the feral herd has been between 110 and 130 except in 2012–2013 when the horse herd declined, likely due to disease that was not possible for the NPS to control.	Good	Good
	$\text{HORSES}_{\text{REMOVE}}$—removal per year		Good	

6.2. Remaining Major Knowledge Gaps and Next Steps

Major knowledge gaps prevented or seriously restricted evaluation of the present condition of fish tissue quality and groundwater quality in the seashore, as well as several other natural resource categories. These gaps and efforts needed to fill them include:

- *Visitation*—The seashore would benefit from a targeted recreational carrying capacity for visitation based on optimal protection of natural resources and trails. In addition, data on trash left in the seashore, and improved quantification of violations of seashore regulations by pedestrians, ORVs etc. would strengthen assessment of visitation condition.
- *Air Quality*—It would be helpful for the National Park Service to install at least one air quality monitor at this seashore, which would greatly facilitate tracking air quality changes over time. In addition, eight plant species at Cape Lookout have been identified as especially sensitive to ozone, including sweetgum, yellow poplar, Virginia creeper, loblolly pine, black cherry, sassafras, smooth cordgrass, and northern fox grape (Porter 2003). The National Park Service should consider tracking selected populations of these species, or a subset (including saltmarsh cordgrass since it is the dominant saltmarsh species), over time as sentinels of potentially harmful ozone levels.
- *Surface Water Quality*— In addition to the current continuous monitoring being conducted at two sites, the synoptic (coastal assessment) sites surveyed in recent NPS efforts (Gregory and Smith 2011, Wright 2016) should be sampled at least monthly every other year to better characterize surface water quality. It would be helpful to include measurement of water temperature, salinity, pH, dissolved oxygen, water clarity, fecal coliform bacteria (more samples sound side are needed), total nitrogen, total phosphorus, ammonium, nitrate, orthophosphate, and suspended microalgal biomass as chlorophyll *a*.
- *Groundwater Supply*—Groundwater recharge/discharge areas in and around Cape Lookout should be re-mapped and quantified so that this critically important resource can be more accurately evaluated over time.
- *Groundwater Quality*—Only sparse information on groundwater quality, at few locations, is available for Cape Lookout. Monthly sampling at least every other year is needed to characterize pH, salinity, conductivity, chloride, and concentrations of potential pollutants known to contaminate groundwater from septic effluent leachate, especially nitrate+nitrite, total phosphorus, soluble reactive phosphate, and fecal bacteria. Contamination of ground-water as well as soil from known sources should be characterized to determine the nature, extent, and persistence of hazardous substances.
- *Vascular Plant Communities*—A thorough, vouchered plant survey should be conducted at Cape Lookout to update and scientifically verify the NPS Certified Species List for the seashore.
- *Seagrass Meadows*—Seagrass meadows have gone unmentioned in nearly all recent NPS reports about the natural resources of Cape Lookout, yet the seagrass meadows along the sound side of this park are vitally important to the ecology and commercial/recreational fishing activities of the entire U.S. Atlantic Coast. Moreover, nearly all of the remaining seagrass habitat in North Carolina—which is formally designated as “critical habitat” for various commercially important

finfish and shellfish—lies on the sound side of Cape Lookout and the national park to the south, Cape Hatteras National Seashore. Seagrasses are excellent integrators of environmental stress from nutrient pollution, increasing turbidity, and other factors (Burkholder et al. 2007b). The seagrass *Zostera marina* (marine eelgrass) in particular is highly sensitive to increasing temperature (Touchette and Burkholder 2002, and references therein), and therefore it is also an excellent indicator of rising temperatures from global warming in climate change. In fact, marine eelgrass is considered an excellent indicator of the health of the overall shallow sound side ecosystems (Burkholder et al. 2007b). Seagrass habitats, and the abundance/distribution of *Zostera marina* in sound side park waters, should be tracked over time by the National Park Service and agency partners at decadal intervals.

- *Benthic Estuarine Macroinvertebrates*—Benthic macroinvertebrate fauna are routinely used nationwide to indicate aquatic ecosystem health. A complete, validated list of present-day taxa in this important community is needed for Cape Lookout. Benthic estuarine macroinvertebrates should be surveyed at five-year intervals (the generally recommended frequency—e.g., Van Dolah et al. 2004, Jutte et al. 2005), in mid-summer (June–August) when water quality variables such as dissolved oxygen are most likely to stress the biota (Van Dolah et al. 2004). Ideally, the surveys should be paired with surveys of surficial sediment quality (Van Dolah et al. 2004). Shannon-Weaver Indices should be determined for the benthic macroinvertebrate communities, as in Hymel (2009), so that diversity can be tracked over time.
- *Fish*—Fish muscle tissue data for Cape Lookout, while sparse, are a concern because they suggest that fish health is being compromised from high contamination by toxic substances such as arsenic and polycyclic aromatic hydrocarbons. Fish tissues such as brain, gill, kidney and liver should be assessed for toxic substance content at multiple stations sound side and ocean side to evaluate the status of fish tissue quality more rigorously, and to assist in tracking contaminant sources that are in or near the seashore. A second issue of concern for fish communities is the extent to which highly invasive lionfish may be altering fish communities. Cape Lookout should take advantage of the NPS Lionfish Response Plan to assist in tracking this species and its impacts the seashore marine coastal community.
- *Feral Horse Herd*—The seashore has a strong monitoring program for feral horses, and should consider additional indicators of horse health such as nutrition and disease which could be tracked over time.
- *A Predator Management Plan*—Cape Lookout would benefit from a formal predator management plan. The predator management plan (including ghost crabs as well as mammals) would yield long-term benefits by strengthening predator control.
- *Analysis Over Time of the Cumulative and Synergistic Effects of Pressures from Climatic, Adjacent Population, and Exotic/Invasive Species Changes*—The rate of climate warming in this century is projected to be from 2.5- to 5.8-fold higher than the rate measured during the 1900s (Hansen et al. 2014, and references therein). Temperatures are expected to increase by 2.58°C to 4.58°C. Watershed development is expected to accelerate; for example, an average 255% increase in housing density is projected by 2100 in lands surrounding national parks throughout the nation (Hansen et al. 2014). Exotic/invasive species generally are favored by disturbances

such as these (Ferriter et al. 2007). The cumulative, synergistic effects of such changes are expected to dramatically impact ecosystem function and biodiversity in national parks (Parks and Harcourt 2002; Radeloff et al. 2010; Hansen et al. 2014). In fact, it has been estimated that 30% of the parklands may lose their present biomes by as early as 2030 (Hansen et al. 2014). We have recommended various additional efforts by the Southeast Coast Network which, together with the present and planned I&M Program actions, will strengthen understanding about how each of these pressures affects Cape Lookout natural resources. The resulting databases will make it possible for the Southeast Coast Network to consider climatic, population, land use, and exotic/invasive species changes more realistically—through integrative rather than separate analyses of cumulative/synergistic impacts over time (e.g., Goetz et al. 2014). Ultimately, that approach offers the best hope of restoring and protecting the natural resources of Cape Lookout.

6.3. Surface Water Quality

6.3.1. Surface Water-Quality Criteria recommendations

Assessments provided in various SECN publications describe good surface water quality for Cape Lookout, based on limited sampling for most parameters. The assessments were made using EPA (2008b, 2012b) protocols (Tables 28 and 29), and some of the quantitative ranges assigned to "good" and "fair" conditions are problematic because they could allow relatively pristine waters to substantially degrade. We question these quantitative ranges because of serious limitations in the approach, as follows:

- The DO criteria, with fair as low as 2 mg/L, is a concentration indicating severe hypoxia, known to cause physiological stress for many aquatic biota and death for sensitive life history stages (Diaz and Rosenberg 1995, Diaz 2001, and references therein) (Figure 95). The rationale as explained by Parman et al. (2012) is that, although DO provides a general indicator of coastal health that integrates many symptoms of degraded water quality, low DO can also occur naturally, such as in bottom waters of salinity-stratified estuaries). Such an approach fails to protect relatively pristine waters such as the CALO area from substantial water quality degradation related to pollution.

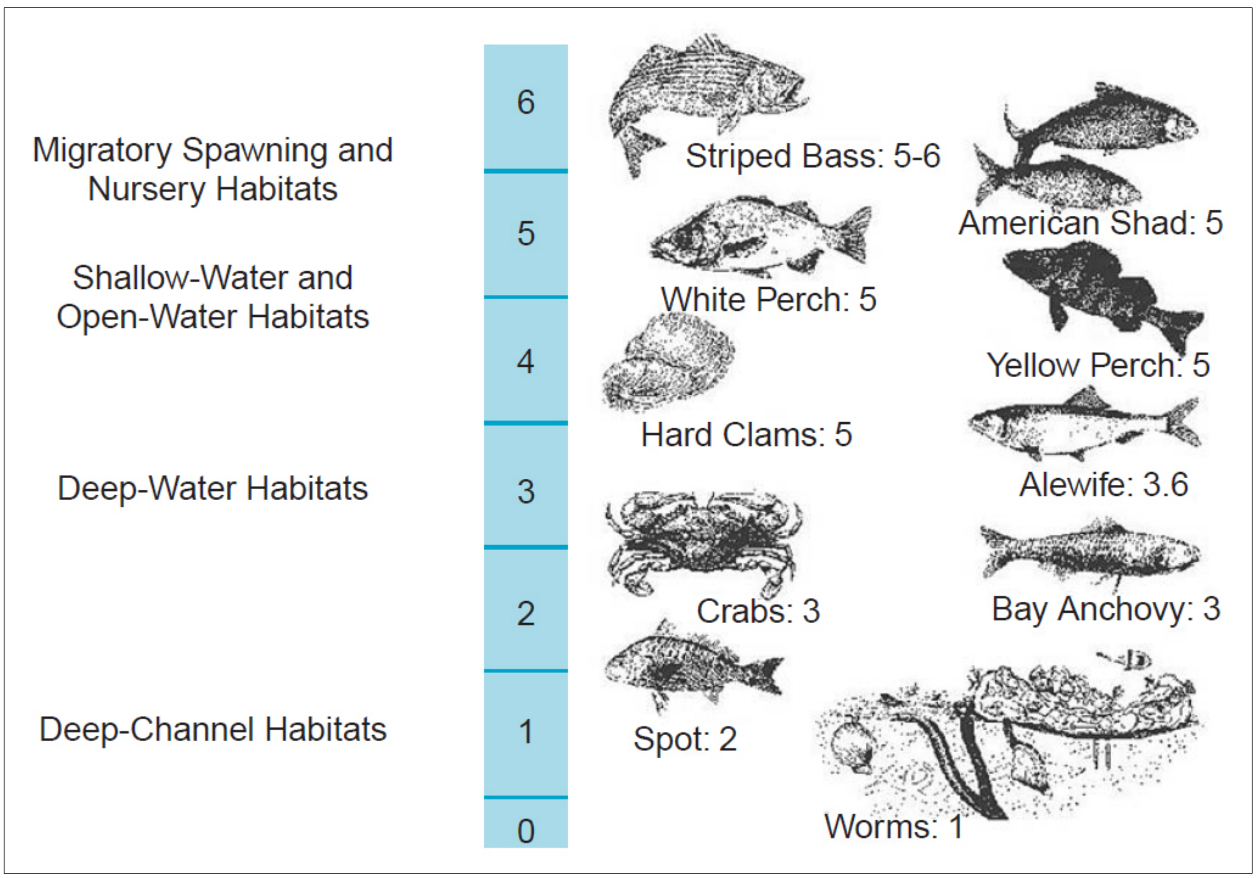

Figure 95. DO levels commonly regarded as essential for sensitive stages of various estuarine/marine coastal aquatic animals. From CBP (2012).

- Elevated chl*a* concentrations are used as an indicator of nutrient pollution. Natural chl*a* levels are much less than 5 µg/L, the upper end of the good range in these assessment criteria, in most coastal ocean waters, sound waters, and high-quality freshwaters unless they have been degraded by nutrient pollution (Raymont 1963; Day et al. 1989; Wetzel 2001). A system such as Cape Lookout would be allowed to "degrade up" to the upper limit of the good range and still be considered "highly acceptable." The upper boundary of the fair range reflects consideration of all sampling sites and then taking a "middle" concentration range. Such an approach, again, would fail to protect many relatively pristine waters such as Cape Lookout from substantial water quality degradation.
- Nitrogen (N) and phosphorus (P) generally are the nutrients that are most limiting to plant and algal growth in coastal waters. The ratio of these two nutrients, that is, the nutrient stoichiometry, is also very important in controlling plant and algal growth. Among various forms of N and P, these primary producers directly consume the inorganic forms (ammonium and nitrate, NH_4^+ and NO_3^-) and P (orthophosphate, PO_4^{-c}). Ammonium + nitrate (along with nitrite, usually negligible or very low even in polluted systems) are the two forms of N in DIN. A DIN concentration .01 mg/L is considered the threshold for nutrient enrichment that supports harmful algal blooms (Mallin 2000b and references therein). The good ranking in the EPA (2008b) assessment criteria for DIN therefore allows no margin of safety to protect aquatic ecosystems from seriously worsening effects of nutrient pollution. The upper edge of the range for the fair ranking is half a milligram per liter of inorganic N. Such conditions indicate excessive pollution to surface waters; 0.5 mg DIN/L would indicate a source such as partially diluted septic effluent leachate (Burkholder et al. 2007 and references therein; Eddy 2005; Camargo and Alonso 2005).
- Orthophosphate is the major form of DIP. In relatively pristine waters, this ion is negligible; because the phosphate ion is so "potent" in stimulating noxious algal growth, pristine waters begin to change into moderately nutrient-enriched at a concentration of only 0.01 mg/L (Wetzel 2001, and references therein). While the good range for this parameter in the EPA (2008b) assessment criteria is science based, it affords no margin of error to protect pristine systems from water quality degradation. An orthophosphate concentration up to 0.05 µg/L would be evaluated as indicating fair conditions. When orthophosphate levels are that high, it means that a major pollution source such as synthetic fertilizers, sewage, or animal wastes have contaminated the system—which would translate into major water quality problems for much of Cape Lookout.

There is a more fundamental problem with the DIN and DIP data reported in some NPS reports (e.g., Parman et al. 2012, p.37)—they are not actual data:

> *Because SECN probabilistic surveys measured TDN and TDP and did not break them down into the inorganic portions, DIN and DIP values were determined based on the ratio of fixed site DIN:TDN and DIP:TDP. This ratio was applied to probabilistic TDN and TDP to determine summertime DIN and DIP. Thus, it is important that reported values are not measured DIN and DIP inside the parks, but it is the best that can be accomplished with available data.*
> *—Parman et al. 2012*

Unfortunately, such ratios can significantly change within the timeframe of a week, or even a few days (e.g., Hubertz and Cahoon 1999; Verity 2002; Gardner and Kjerfve 2006). There is *substantial* (daily, weekly, site-by-site etc.) variation in the relative proportions of organic and inorganic N and P in the total dissolved pool (Ormaza-González and Statham 1991; Boynton et al. 1995; Seitzinger and Sanders 1997; Stedmon et al. 2006). Use of one seasonal value for the ratio of TDN: DIN and of TDP: DIP to estimate the actual concentrations of DIN and DIP from actual measurements only of TDN and TDP is not supported by estuarine/coastal marine science. Such an approach should not be used without a strong, supporting dataset. Until such data can be gathered, DIN and DIP should not be estimated across a given season based on one measurement of both parameters. Actual measurements of DIN and DIP are needed in order to apply criteria involving those parameters.

Given these considerations, we recommend modifications of the EPA (2008b, 2012b) evaluation protocols and their application by the Southeast Coast Network as shown in Table 86). Using that altered assessment protocol, we evaluated water quality data collected in 2000–2014 from stations within 8 kilometers (5 mi) of Cape Lookout. Overall surface-water quality at Cape Lookout is still good, based on that more protective assessment (Table 67).

Table 86. Suggested alterations of the protocol ranges used by EPA for evaluation of surface water quality condition at Cape Lookout. (EPA 2008b, 2012b).

Parameter Water Quality[a]	Good	Fair	Poor
Dissolved oxygen (DO) (mg/L)[b]	> 5	3–5	< 3
Chlorophyll *a* (chl*a*) (µg/L)[c]	< 3	3–15	> 15
Dissolved inorganic nitrogen (DIN), summer (mg/L)[d]	< 0.08	0.08–0.2	> 0.2
Dissolved inorganic phosphorus (DIP), summer (mg/L)[d]	< 0.01	0.01–0.02	> 0.02

[a] The sampling frequency is recommended as every 2 years rather than every 5 years because a 5-year sampling interval would miss many important events influencing surface water quality.

[b] DO ranges: prolonged exposure to < 3 mg/L causes death to sensitive marine life (Diaz and Rosenberg 1995, Diaz 2001 and references therein; and see Figure 89).

[c] Chlorophyll *a* ranges: modifications are based on information from Raymont (1963), Day et al. (1989), and Dennison et al. (1993).

[d] DIN and DIP ranges: modifications are based on Mallin (2000a) and references therein.

However, we question the quantitative ranges for these criteria because of serious limitations in the approach, and also have reservations about the approach because it inadvertently would allow relatively pristine waters to substantially degrade and still be considered good or fair. Thus, the good category, and certainly the fair category (which is regarded as generally acceptable by state agencies such as NCDENR), could easily fail to protect relatively pristine ecosystems such as Cape Lookout from substantial water quality degradation. We recognize the value of the EPA assessment criteria (2008b) as an important "first step" in evaluating a given aquatic ecosystem. Nevertheless, these criteria, based on an "average" concentration range for the many stations that were considered in creating it, fail to protect relatively pristine ecosystems from serious degradation.

6.3.2. Sediment Sampling Recommendations

The National Park Service and partners have surveyed the quality of surficial sediments in and around the seashore, and have found generally good sediment quality based on relatively sparse data, using the assessment criteria in Tables 24 and 25. We strongly recommend one modification (Table 68), to sample at least selected stations every two years rather than every 10 years because the 10-year frequency is inadequate to reliably characterize sediment quality over time, according to the published scientific literature (Schropp et al. 1989; Mudroch and Azcue 1995; Reynoldson and Rodriguez 1999). If a two-year frequency is cost-prohibitive, we recommend two-year sampling of at least a subset of three to four sites near population centers, along with two to three control sites for comparison.

It should be mentioned that for adequate assessment of sediment contaminants, quarterly to annual sampling (warmest season) is recommended (Schropp et al. 1989; Mudroch and Azcue 1995; Reynoldson and Rodriguez 1999).

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Appendix A. GIS Information

Table A-1. Geographic Information System data layers for the Cape Lookout National Seashore extent [proj—projection].

File name	Layer name	Category	Description	Source	Scale	Proj	Datum	Metadata
nc_nerrs.shp	National Estuarine Research Reserve System (Section 315 of the Coastal Zone Management Act) in the Southeast U.S. - 1998 - Cape Hatteras and Cape Lookout National Seashore	Boundary	This dataset contains Ocean Planning Information System (OPIS) vector polygon data. OPIS was developed to provide coastal and ocean resource managers in the Southeast with access to regional digital geographic mapping information and technologies to facilitate coordinated decision making within and across the multi-layered U.S. ocean management framework. Specific areas of interest within vicinity of CAHA and CALO were selected manually.	NOAA CSC	unknown	UTM Zone 18N	NAD 83	Yes
caha_calo_nwr.shp	National Wildlife Refuge Boundaries for the Southeast U.S. - 1998 - Cape Hatteras and Cape Lookout National Seashore	Boundary	This dataset contains Ocean Planning Information System (OPIS) vector polygon data. OPIS was developed to provide coastal and ocean resource managers in the Southeast with access to regional digital geographic mapping information and technologies to facilitate coordinated decision making within and across the multi-layered U.S. ocean management framework. These data were submitted by the U.S. Fish and Wildlife Service to the National Marine Protected Areas Inventory. Specific areas of interest within vicinity of CAHA/CALO were merged to county boundaries or a specified extent enclosing the park(s).	NOAA CSC	unknown	UTM Zone 18N	NAD 83	Yes
calo.shp	Alternate Admininistrative Boundary for Cape Lookout National Seashore (from park data holdings)	Boundary	Vector polygon shapefile representing the park version of the administrative boundary for CALO. The boundary came directly from the park GIS holdings.	Park GIS Library	1:10 million	UTM Zone 18N	NAD 83	Yes
calo_admin_harkers_isl.shp	Alternate NPS Admininistrative Boundary for Cape Lookout National Seashore (Unofficial Boundary That Includes Harkers Island/Visitor Center Section)	Boundary	This boundary is a hybrid version of the current NPS administrative boundary described below and an unofficial, digitized depiction of the Harkers Island section of the park. This version of the boundary was necessary because the official NPS boundary has never included the Harkers Island section. Please use as an unofficial boundary only due to the fact that the boundary contains areas that were digitized by network personnel.	NPS	1:10 million	UTM Zone 18N	NAD 83	Yes

File name	Layer name	Category	Description	Source	Scale	Proj	Datum	Metadata
calo_administrative.shp	Current NPS Admininistrative Boundary for Cape Lookout National Seashore (Official Boundary That Excludes Harkers Island/Visitor Center Section)	Boundary	Vector polygon shapefile representing the NPS administrative boundary for CALO. This boundary was originally part of a larger NPS regional dataset and is intended for use at the regional level. This boundary is also found in the state_regional_gis directory and it may need to be updated as the NPS national administrative boundary dataset is updated. Please note that this version of the boundary does not include the Harkers Island/Visitor Center section of the park.	NPS	1:10 million	UTM Zone 18N	NAD 83	Yes
nc_cities.shp	Cities and Towns of the United States	Cities	This point vector dataset contains cities that were collected from the 1970 National Atlas of the United States. This is a revised version of the December 2003 map layer. Specific areas of interest within vicinity of CAHA/CALO were merged to county boundaries or a specified extent enclosing the park(s).	National Atlas of the United States	1: 2,000, 000	UTM Zone 18N	NAD 83	Yes
dem (dem_ft, mtr)	7.5 Minute Digital Elevation Model (DEM)	Elevation	Digital raster dataset representing terrain elevation data in feet, meters, and the original download format. Blocks cover the extent of CALO.	USGS/ I & M	30m	UTM Zone 18N	NAD 83	No
coast_dem.img	National Elevation Dataset (DEM)	Elevation	The U.S. Geological Survey has developed a National Elevation Dataset (NED). The NED is a seamless mosaic of best-available elevation data. The 7.5-minute elevation data for the conterminous United States are the primary initial source data. NED has been clipped to CAHA/CALO surrounding extent.	USGS	30m	UTM Zone 18N	NAD 83	Yes
hydro	Large-scale Digital Line Graph - Hydrography	Hydrography	Vector polyline shapefiles representing hydrography DLGs in 7.5 minute blocks for the extent of CALO.	USGS	1: 24,000	UTM Zone 18N	NAD 83	Yes
hypso	Large-scale Digital Line Graph - Hypsography	Hypsography	Vector polyline shapefiles representing hypsography DLGs in 7.5 minute blocks for the extent of CALO.	USGS	1: 24,000	UTM Zone 18N	NAD 83	Yes
5, 10, 20 ft contours (directories); caha_contours.shp	5, 10, and 15 ft. contours for CALO (by county and entire park extent)	Hypsography	These datasets contain 5, 10, and 20 ft. contour lines that cover Carteret county and thus the extent of CALO. The data was derived from LIDAR floodplain maps created by the North Carolina floodplain mapping program.	NCDOT GIS Branch	unknown	UTM Zone 18N	NAD 83	Yes
nwi (directory)	National Wetlands Inventory	NWI	Vectory polyline and polygon shapefiles representing national wetlands inventory in 7.5 minute blocks for the extent of CALO.	USFWS	1: 24,000	UTM Zone 18N	NAD 83	Yes

File name	Layer name	Category	Description	Source	Scale	Proj	Datum	Metadata
calo_nwi_2010 (directory)	National Wetlands Inventory - Cape Lookout National Seashore (2010)	NWI	Vectory polyline and polygon shapefiles representing national wetlands inventory in 7.5 minute blocks for the extent of CALO. The directory also contains a merged quad dataset. The data is essentially the same as that found above except that it has been updated to the most current version (2010).	USFWS	1: 24,000	UTM Zone 18N	NAD 83	Yes
pipetran	Large-scale Digital Line Graph - Pipelines	Transportation	Vector polyline shapefiles representing pipeline DLGs in 7.5 minute blocks for a portion of CALO.	USGS	1: 24,000	UTM Zone 18N	NAD 83	Yes
BEAUFORR.shp	Large-scale Digital Line Graph - Railroads	Transportation	Vector polyline shapefiles representing railroad DLGs in 7.5 minute blocks for a portion of CALO.	USGS	1: 24,000	UTM Zone 18N	NAD 83	Yes
roadtrail (dlg_roads)	Large-scale Digital Line Graph - Roads	Transportation	Vector polyline shapefiles representing road DLGs in 7.5 minute blocks for a portion of CALO.	USGS	1: 24,000	UTM Zone 18N	NAD 83	Yes
calo_roads.shp	Bureau of Transportation Statistics U.S. Road Networks	Transportation	This data set portrays a Bureau of Transportation Statistics overview of the road networks for all fifty States, the District of Columbia, and Puerto Rico. An extent containing CALO was extracted from the original dataset.	BTS	1: 100,000	UTM Zone 18N	NAD 83	Yes
calo_ports.shp	U.S. Army Corps of Engineers Ports	Transportation	Vector point shapefile representing US. Army Corps of Engineeer ports.	BTS	1: 100,000	UTM Zone 18N	NAD 83	Yes
caloveg	Cape Lookout NS Vegetation and Fuel Model Data	Fire	Vector polygon ArcInfo coverage representing vegetation cover types and fire fuel model data for Cape Lookout National Seashore. Also contains a shapefile version in the projection specified.	NC State	1: 24,000	UTM Zone 18N	NAD 83	Yes - text file only
calo_aquifer.shp	Principal Aquifers of the 48 Conterminous United States, Hawaii, Puerto Rico, and the U.S. Virgin Islands	Geology	Vector polygon shapefile representing principal aquifers of the U.S.—clipped to CALO extent.	USGS	1: 2,500,000	UTM Zone 18N	NAD 83	Yes
calo_artreefs.shp	North Carolina Artifical Reefs	Geology	Vector point shapefile representing locations of artifical reefs around CALO.	NOAA	un-known	UTM Zone 18N	NAD 83	Yes

File name	Layer name	Category	Description	Source	Scale	Proj	Datum	Metadata
calo_gre (directory)	NPS Geologic Resources Evaluation (GRE) for CALO	Geology	This directory contains geomorphic units, contacts and ridge lines (where applicable) found in CALO as a result of the GRE study. The main directory contains a number of subdirectories that cover individual portions of the park at a detailed level (portions of the park are excluded) as well as larger park sections in general overviews (entire park is covered).	NPS GRE Program	1: 24,000	UTM Zone 18N	NAD 83	Yes
nc_geology.shp	Geologic map of North Carolina	Geology	This dataset represents the digital equivalent of the official State Geology map (1:500,000-scale), but was digitized from (1:250,000-scale) base maps. The geologic formation id is the only attribute present. An id key was sought but none was found.	NC DEHNR-Division of Land Resources, NC Geological Survey	1: 250,000	UTM Zone 18N	NAD 83	Yes
nc_npdes.shp	National Pollution Discharge Elimination System sites for North Carolina	Monitoring	This dataset contains the locations of EPA National Pollutant Discharge Elimination System sites for the areas near or in CALO and CAHA.	EPA	unknown	UTM Zone 18N	NAD 83	Yes
ssurgo - carteret (directory)	Soil Survey Geographic (SSURGO) database for Carteret County, North Carolina	Soils	This data set is a digital soil survey and generally is the most detailed lever of soil geographic data.	USDA - NRCS	unknown	UTM Zone 18N	NAD 83	Yes
ssurgo_nps (directory)	National Park Service - Soil Survey Geographic (SSURGO) database for Cape Lookout National Seashore, North Carolina	Soils	This data set is a digital soil survey and generally is the most detailed lever of soil geographic data. Specifically, the data set is identical to the one listed above except that it has undergone some additional processing by NPS personnel such as clipping the set to the park extent and adding the musym names to the attribute table.	NPS - GRD -SIMP	unknown	UTM Zone 18N	NAD 83	Yes

File name	Layer name	Category	Description	Source	Scale	Proj	Datum	Metadata
statsgo - gsmsoil_nc (directory)	State Soil Geographic (STATSGO) data base for North Carolina	Soils	This data set is a digital general soil association map developed by the National Cooperative Soil Survey. It consists of a broad based inventory of soils and nonsoil areas that occur in a repeatable pattern on the landscape and that can be cartographically shown at the scale mapped. The soil maps for STATSGO are compiled by generalizing more detailed soil survey maps. The data is in shapefile format in both NAD 83 and UTM 18 NAD 83 and is accompanied by a large amount of descriptive tabular data.	CALO	statsgo-gsmsoil_nc (dir-ectory)	State Soil Geographic (STATSGO) data base for North Carolina	Soils	
herps (directory)	Herpetofaunal Species Locations	Species	This directory contains the locations of herpetofauna found in Cape Lookout National Seashore (CALO) during a study performed by Tuberville, Willson, Dorcas, and Gibbons in conjunction with the Savannah River Ecology Laboratory (SREL) between May 2001 and October 2003.	CALO	herps (dir-ectory)	Herpetofaunal Species Locations	Species	
nc_bs92.shp	Submerged Aquatic Vegetation of Bogue Sound, NC 1992	Veg	Polygon vector shapefile representing submerged aquatic vegetation in Coastal N.C. from 1992 aerial photography	NOAA	1: 20,000	UTM Zone 18N	NAD 83	Yes
calo_veg	Cape Lookout NS Vegetation and Fuel Model Data	Veg	Vector polygon ArcInfo coverage representing vegetation cover types and fire fuel model data for Cape Lookout National Seashore. Also contains a shapefile version in the projection specified.	NC State	1: 24,000	UTM Zone 18N	NAD 83	Yes - text file only
nc_huc14.shp	Hydrologic Units - North Carolina	Watershed	The USDA-Natural Resources Conservation Service, Raleigh Office in cooperation with the NC Center for Geographic Information & Analysis, and the NC Dept. of Environment, Health and Natural Resources, Division of Water Quality developed the Hydrologic Units-North Carolina digital data to track resource and conservation activities in the state's river basins and subbasins. Using the 14-digit hyrologic unit code the regional, subregional, accounting, cataloging, NRCS sub-unit, and NRCS reporting unit boundaries id's are recorded. The area attributes allow the user to see hydrologic unit, river basin and subbasin levels of geography.	CALO	nc_huc14.shp	Hydrologic Units - North Carolina	Watershed	

File name	Layer name	Category	Description	Source	Scale	Proj	Datum	Metadata
se_huc8.shp	8-Digit HUC Hydrologic Units 1:250,000	Watershed	This dataset was compiled originally to provide the National Water Quality Assessment (NAWQA) study units with an intermediate-scale river basin boundary for extracting other GIS data layers. The data can also be used for illustration purposes at intermediate or small scales (1:250K to 1:2M). The dataset covers the extent of the entire south atlantic gulf region and includes descriptions at the basin and subbasin level.	CALO	se_huc8.shp	8-Digit HUC Hydrologic Units 1:250,000	Watershed	
carteret_co_wetlands.shp; hyde_co_wetlands.shp	Wetland Types - North Carolina Coastal Area	Wetlands	Polygon vector shapefile representing National Wetlands Inventory (NWI), county soils (DSL), and classified land use/land cover from TM satellite imagery.	NC DNR	1: 24,000	UTM Zone 18N	NAD 83	Yes
wqgis	Cape Lookout National Seashore Small-Scale Base GIS Data	WQ GIS	The data are comprised of small-scale base GIS data layers, including roads, hydrography, political boundaries,trails and other layers as available and appropriate, compiled for the purpose of displaying the locations of point-based hydrologic features (water quality monitoring stations, stream gages, industrial discharges, drinking intakes, and water impoundments) proximate to national park units.	NPS WRD	1: 100,000	UTM Zone 18N	NAD 83	Yes
drg_nad83	Digital Raster Graphics	DRGs	1:24,000 DRGs in .tif format; NAD83; collars removed. Covers the extent of CALO. Directory also includes a mosaic and 1:100,000 DRG of area (Morehead City).	USGS	1: 24,000	UTM Zone 18N	NAD 83	No
coast_landsat.img	WEBMAP.LANDSAT_L277 (Landsat Orthoimagery Mosaic)	Image	The Landsat Mosaic orthoimagery database contains Landsat Thematic Mapper imagery for the conterminous United States. The more than 700 Landsat scenes have been resampled to a 1-arc-second (approximately 30-meter) sample interval in a geographic coordinate system using the North American Horizontal Datum of 1983.	USGS	1: 100,000	UTM Zone 18N	NAD 83	Yes
NAIP_2005_INC (directory)	NAIP Digital Georectified Image(s)	Image	This directory contains true color digital ortho quarter quad imagery from the National Agricultural Imagery Program (NAIP) in GeoTIFF format. NAIP acquires digital ortho imagery during the agricultural growing seasons in the continental U.S. Specifically, the directory contains 2005 NAIP imagery for the extent of CALO (incomplete).	USDA-FSA-APFO Aerial Photography Field Office	1 and 2 Meter	UTM Zone 18N	NAD 83	Yes

File name	Layer name	Category	Description	Source	Scale	Proj	Datum	Metadata
coast_nlcd.img	Outer Banks, NC Landcover Dataset	Image	The National Land Cover Dataset was compiled from Landsat satellite TM imagery (circa 1992) with a spatial resolution of 30 meters and supplemented by various ancillary data (where available).	USGS	30 meter	UTM Zone 18N	NAD 83	Yes
coast_nlcd01.img	National Land Cover Database Zone 58 Land Cover Layer	Image	This dataset (NLCD 2001) is an update of the 1992 NLCD described above. The extent covers coastal NC from WRBR to CALO. Note: there are 2 metadata files associated with this dataset due to it's spanning of 2 land use zones (58, 60); both files are provided in the dataset file folder.	USGS	30 meter	UTM Zone 18N	NAD 83	Yes
post_isabel	Post Isabel Hurricane Aerial Photos	Image	Aerial imagery in . tif format of CALO immediately post Hurricane Isabel.	Kucera Intl.	1 meter	SPCS Meters	NAD 83	No
usgs_imagery_2009 (directory)	Carolina National Parks - CIR Orthophotos	Image	This directory contains high resolution color infrared aerial orthophoto imagery taken in May of 2009 that covers the extent of the park. The directory also contains a vector imagery index grid as well as an ASCII file that appears to be a DEM that covers both Cape Lookout and Cape Hatteras.	USGS	.3 meter	UTM Zone 18N	NAD 83	Yes
park_data	Multiple layers - CALO GIS	Park Data	This directory contains a variety of datasets from the CALO GIS library. Data are in multiple coordinate systems and projections (SPCS, UTM, and LAT/LONG). Some metadata exist in the form of tables or readme text files. Use these data at your own risk.	Park Library	NA	Other	Other	Yes

Appendix B. Water Quality

All values reported as less than the level of detection (nd) or less than the reporting limit (brl) were replaced with 1/2 the value, following Ellis and Gilbert (1980) and Zirschky et al. (1985). The selected parameters shown are those most commonly considered in water and sediment quality assessment.

More than 50% of the samples were below detection or below the reporting limit with the analytical technique used; thus, statistical interpretation was not attempted. Selected parameters included those most commonly considered in water quality assessment; most of those that were not included here also had been sampled infrequently (once or on few dates).

Table B-1. Water quality and sediment quality monitoring site information for waters in or near CALO (within 4.8 km or 3 miles) proceeding from north to south.

Site Name	Agency	Location	County	Latitude	Longitude
NPS CALO 2010 ALT05	NPS	Pamlico Sound	Hyde	35.0717	-76.0284
EPA EMAP NC04-0012	EPA	Pamlico Sound	Hyde	35.08	-76.041
EPA EMAP NC01-0035	EPA	Pamlico Sound	Carteret	34.99	-76.1671
NPS CALO 2010 03	NPS	Pamlico Sound	Carteret	34.9899	-76.173
NPS CALO 2010 ALT17	NPS	Core Sound	Carteret	34.9426	-76.2226
EPA EMAP NC00-0018	EPA	Core Sound	Carteret	34.9388	-76.2376
NPS CALO 2010 ALT12	NPS	Core Sound	Carteret	34.9218	-76.2337
EPA EMAP NC04-0031	EPA	Core Sound	Carteret	34.91	-76.261
NPS CALO 2010 ALT28	NPS	Core Sound	Carteret	34.9048	-76.2693
NPS CALO 2010 26	NPS	Core Sound	Carteret	34.8727	-76.3133
NC Recreational Water Quality Program C75	NCRWQP	Core Sound	Carteret	34.8591	-76.3197
EPA EMAP NC01-0020	EPA	Core Sound	Carteret	34.8315	-76.3608
NPS CALO 2010 ALT10	NPS	Core Sound	Carteret	34.8235	-76.3845
NPS CALO 2010 12	NPS	Core Sound	Carteret	34.7956	-76.4074
NC Recreational Water Quality Program C75A	NCRWQP	Core Sound	Carteret	34.7614	-76.4131

Table B-1 (continued). Water quality and sediment quality monitoring site information for waters in or near CALO (within 4.8 km or 3 miles) proceeding from north to south.

Site Name	Agency	Location	County	Latitude	Longitude
EPA EMAP NC00-0020	EPA	Core Sound	Carteret	34.7752	-76.4284
EPA EMAP NC03-0019	EPA	Core Sound	Carteret	34.71	-76.483
NC Recreational Water Quality Program C58	NCRWQP	Back Sound	Carteret	34.6872	-76.6441
NC Recreational Water Quality Program C59A	NCRWQP	Back Sound	Carteret	34.6794	-76.6191
NC Recreational Water Quality Program C66	NCRWQP	Back Sound	Carteret	34.6847	-76.5288
NC Recreational Water Quality Program C68	NCRWQP	Back Sound	Carteret	34.6558	-76.5185
NPS CALO 2010 ALT02	NPS	Back Sound	Carteret	34.6830	-76.5727
NPS CALO 2010 04	NPS	Back Sound	Carteret	34.6623	-76.5565
NPS CALO 2010 ALT06	NPS	Back Sound	Carteret	34.6519	-76.5243
NPS CALO 2010 08	NPS	Back Sound	Carteret	34.6698	-76.5112
NPS CALO 2010 20	NPS	Back Sound	Carteret	34.6655	-76.5287
NC Recreational Water Quality Program C69A	NCRWQP	Lookout Bight (sound side)	Carteret	34.6239	-76.5252
NC Recreational Water Quality Program C69B	NCRWQP	Lookout Bight (sound side)	Carteret	34.6137	-76.5382
NC Recreational Water Quality Program C69C	NCRWQP	Lookout Bight (ocean side)	Carteret	34.6213	-76.5208

Table B-2. Water quality and sediment quality data for monitoring site NPS CALO 2010 ALT05 in Pamlico Sound [brl—below reporting limit; nd—not detected].

Parameter	Date	n	Mean (range)	Median
Temperature (ºC)	7/7/2010	14	26.8 (26.7–27.0)	26.8
Salinity (ppt)	7/7/2010	14	28.0 (26.9–29.9)	27.9
DO (mg/L)[a]	7/7/2010	14	6.6 (6.43–6.78)[d]	6.6
pH	7/7/2010	14	8.1 (8.11–8.14)	8.1
Nitrogen (µg/L)[a]	7/7/2010	6	234 (217–255)	227
Phosphate (DIP) (µg/L)[a]	7/7/2010	3	16 (14–17)[e]	16
Chlorophyll *a* (µg/L)[a]	7/7/2010	6	3.5 (2.8–4.4)[d]	3.4
TOC (mg/kg, sediment)	7/7/2010	1	260	----
Aluminum, total (mg/kg, sediment)	7/7/2010	1	5,710	----
Antimony, total (mg/kg, sediment)	7/7/2010	1	brl	----
Arsenic, total (mg/kg, sediment)[b]	7/7/2010	1	nd[d]	----
Cadmium, total (mg/kg, sediment)[b]	7/7/2010	1	brl[d]	----
Chromium, total (mg/kg, sediment)[b]	7/7/2010	1	3.4[d]	----
Iron, total (mg/kg, sediment)	7/7/2010	1	1,920	----
Lead, total (mg/kg, sediment)[b]	7/7/2010	1	nd[d]	----
Manganese, total (mg/kg, sediment)	7/7/2010	1	47.3	----
Mercury, total (mg/kg, sediment)[b]	7/7/2010	1	brl[d]	----
Nickel, total (mg/kg, sediment)[b]	7/7/2010	1	brl[d]	----
Selenium, total (mg/kg, sediment)	7/7/2010	1	2.9	----
Silver, total (mg/kg, sediment)[b]	7/7/2010	1	nd[d]	----
Tin, total (mg/kg, sediment)	7/7/2010	1	brl	----
Zinc, total (mg/kg, sediment)[b]	7/7/2010	1	brl[d]	----
All other chemical compounds, PCBs[c]	7/7/2010		nd[d]	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-3. Water quality and sediment quality data for monitoring site EPA EMAP NC01-0035 in Pamlico Sound. There were no range or median values for any parameters at this site.

Parameter	Date	n	Mean
$NO_3^-N + NO_2^-N$ (µg/L)[a]	8/7/2001	1	22[d]
NH_4^+N (µg/L)[a]	8/7/2001	1	11[d]
Phosphate (DIP) (µg/L)	8/7/2001	1	nd[d]
Chlorophyll *a* (µg/L)[a]	8/7/2001	1	6.13[e]
TSS (mg/L)	8/7/2001	1	21
TOC (%, sediment)	8/7/2001	1	0.33%
Aluminum, total (µg/g, sediment)	8/7/2001	1	nd
Antimony, total (µg/g, sediment)	8/7/2001	1	nd
Arsenic, total (µg/g, sediment)[b]	8/7/2001	1	nd[d]
Cadmium, total (µg/g, sediment)[b]	8/7/2001	1	nd[d]
Chromium, total (µg/g, sediment)[b]	8/7/2001	1	nd[d]
Copper, total (µg/g, sediment)[b]	8/7/2001	1	nd[d]
Iron, total (µg/g, sediment)	8/7/2001	1	nd
Lead, total (µg/g, sediment)[b]	8/7/2001	1	nd[d]
Manganese, total (µg/g, sediment)	8/7/2001	1	nd
Mercury, total (µg/g, sediment)[b]	8/7/2001	1	nd[d]
Nickel, total (µg/g, sediment)[b]	8/7/2001	1	nd[d]
Selenium, total (µg/g, sediment)	8/7/2001	1	nd
Silver, total (µg/g, sediment)[b]	8/7/2001	1	nd[d]
Tin, total (µg/g, sediment)	8/7/2001	1	10.74
Zinc, total (µg/g, sediment)[b]	8/7/2001	1	nd[d]
Fluoranthene, total (ng/g, sediment)	8/7/2001	1	5
All other chemical compounds, PCBs[c]	8/7/2001	1	nd[d]

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-3 (continued). Water quality and sediment quality data for monitoring site EPA EMAP NC01-0035 in Pamlico Sound. There were no range or median values for any parameters at this site.

Parameter	Date	n	Mean
Acteocina canaliculata	8/7/2001	1	7
Bittiolum varium	8/7/2001	1	3
Branchiomaldane vicenti	8/7/2001	1	1
Capitella capitata	8/7/2001	1	18
Crepidula fornicata	8/7/2001	1	5
Cyathura polita	8/7/2001	1	2
Cymadusa compta	8/7/2001	1	15
Erichsonella attenuata	8/7/2001	1	9
Gemma gemma	8/7/2001	1	16
Haplocytheridea setipunctata	8/7/2001	1	4
Heteromastus filiformis	8/7/2001	1	26
Laeonereis culveri	8/7/2001	1	1
Leptosynapta	8/7/2001	1	1
Mediomastus	8/7/2001	1	3
Odostomia	8/7/2001	1	2
Phyllodocidae	8/7/2001	1	1
Prionospio	8/7/2001	1	38
Prionospio heterobranchia	8/7/2001	1	179
Scoloplos robustus	8/7/2001	1	2
Streptosyllis arenae	8/7/2001	1	3
Syllidae	8/7/2001	1	1
Tubificidae	8/7/2001	1	34

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-4. Water quality and sediment quality data for monitoring site NPS CALO 2010 03 in Pamlico Sound.

Parameter	Date	n	Mean (range)	Median
Temperature (ºC)	7/7/2010	2	34 (34–34)	34
Salinity (ppt)	7/7/2010	2	25.5 (25.53–25.53)	25.5
DO (mg/L)[a]	7/7/2010	2	9.6 (9.55–9.55)[d]	9.6
pH	7/7/2010	2	9.0 (9.04–9.04)	9
Nitrogen (µg/L)[a]	7/7/2010	2	618 (611–624)	618
Phosphate (µg/L)[a]	7/7/2010	1	12[e]	----
Chlorophyll *a* (µg/L)[a]	7/7/2010	2	7.1 (7.01–7.22)[e]	7.1

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-5. Water quality and sediment quality data for monitoring site NPS CALO 2010 ALT17 in Core Sound.

Parameter	Date	n	Mean (range)	Median
Temperature (ºC)	7/7/2010	2	31.0 (31–31.02)	31
Salinity (ppt)	7/7/2010	2	28 (27.95–27.95)	28
DO (mg/L)[a]	7/7/2010	2	8.0 (8–8.09)[d]	8[d]
pH	7/7/2010	2	8.3 (8.32–8.32)	8.3
Nitrogen (µg/L)[a]	7/7/2010	2	408 (406–410)	408
Phosphate (DIP) (µg/L)[a]	7/7/2010	1	13[e]	----
Chlorophyll *a* (µg/L)[a]	7/7/2010	2	2.9 (2.87–2.96)[d]	2.9[d]
TOC (mg/kg, sediment)	7/7/2010	1	711	----
Aluminum, total (mg/kg, sediment)	7/7/2010	1	3,850	----
Antimony, total (mg/kg, sediment)	7/7/2010	1	brl	----
Arsenic, total (mg/kg, sediment)[b]	7/7/2010	1	nd[d]	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-5 (continued). Water quality and sediment quality data for monitoring site NPS CALO 2010 ALT17 in Core Sound.

Parameter	Date	n	Mean (range)	Median
Cadmium, total (mg/kg, sediment)[b]	7/7/2010	1	brl[d]	----
Chromium, total (mg/kg, sediment)[b]	7/7/2010	1	3.64[d]	----
Iron, total (mg/kg, sediment)	7/7/2010	1	1,700	----
Lead, total (mg/kg, sediment)[b]	7/7/2010	1	nd[d]	----
Manganese, total (mg/kg, sediment)	7/7/2010	1	28.1	----
Mercury, total (mg/kg, sediment)[b]	7/7/2010	1	nd[d]	----
Nickel, total (mg/kg, sediment)[b]	7/7/2010	1	brl[d]	----
Selenium, total (mg/kg, sediment)	7/7/2010	1	3.4	----
Silver, total (mg/kg, sediment)[b]	7/7/2010	1	nd[d]	----
Tin, total (mg/kg, sediment)	7/7/2010	1	brl	----
Zinc, total (mg/kg, sediment)[b]	7/7/2010	1	brl[d]	----
All other chemical compounds, PCBs[c]	7/7/2010	1	nd[d]	----

[a] Indicator parameters for water quality (purple text)
[b] Indicator metals for sediment quality (blue text)
[c] Indicator organic contaminants for sediment quality (red text)
[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)
[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)
[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-6. Water quality and sediment quality data for monitoring site EPA EMAP NC00-0018 in Core Sound.

Parameter	Date	n	Mean	Median
$NO_3^-N + NO_2^-N$ (µg/L)[a]	8/22/2000	1	55[e]	9
NH_4^+N (µg/L)[a]	8/22/2000	1	77[e]	----
TN (µg/L)	8/22/2000	1	255	----
TP (µg/L)	8/22/2000	1	nd	----
Chlorophyll *a* (µg/L)[a]	8/22/2000	1	3.02[d]	----
TSS (mg/L)	8/22/2000	1	18.24	----

[a] Indicator parameters for water quality (purple text)
[b] Indicator metals for sediment quality (blue text)
[c] Indicator organic contaminants for sediment quality (red text)
[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)
[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)
[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-6 (continued). Water quality and sediment quality data for monitoring site EPA EMAP NC00-0018 in Core Sound.

Parameter	Date	n	Mean	Median
TOC (%, sediment)	8/22/2000	1	0.02%	----
Aluminum, total (µg/g, sediment)	8/22/2000	1	7,860	----
Antimony, total (µg/g, sediment)	8/22/2000	1	0.1	----
Arsenic, total (µg/g, sediment)[b]	8/22/2000	1	nd[d]	----
Cadmium, total (µg/g, sediment)[b]	8/22/2000	1	0.03[d]	----
Chromium, total (µg/g, sediment)[b]	8/22/2000	1	9[d]	----
Copper, total (µg/g, sediment)[b]	8/22/2000	1	3[d]	----
Iron, total (µg/g, sediment)	8/22/2000	1	8,190	----
Lead, total (µg/g, sediment)[b]	8/22/2000	1	4.8[d]	----
Manganese, total (µg/g, sediment)	8/22/2000	1	274	----
Mercury, total (µg/g, sediment)[b]	8/22/2000	1	nd[d]	----
Nickel, total (µg/g, sediment)[b]	8/22/2000	1	2[d]	----
Selenium, total (µg/g, sediment)	8/22/2000	1	nd	----
Silver, total (µg/g, sediment)[b]	8/22/2000	1	0.1[d]	----
Tin, total (µg/g, sediment)	8/22/2000	1	0.5	----
Zinc, total (µg/g, sediment)[b]	8/22/2000	1	18[d]	----
1-Methylnaphthalene (ng/g, sediment)	8/22/2000	1	0.14	----
2-Methylnaphthalene (ng/g, sediment)	8/22/2000	1	0.22	----
Benzo[ghi]perylene (ng/g, sediment)	8/22/2000	1	0.058	----
Biphenyl (ng/g, sediment)	8/22/2000	1	0.057	----
DDT,o,p'- (ng/g, sediment)	8/22/2000	1	0.009	----
Fluoroanthene (ng/g, sediment)[c]	8/22/2000	1	0.074[d]	----
Fluorene (ng/g, sediment)[c]	8/22/2000	1	0.076[d]	----
Naphthalene (ng/g, sediment)[c]	8/22/2000	1	0.34[d]	----
p,p'-DDE (ng/g, sediment)	8/22/2000	1	0.006	----
PCB-028 (ng/g, sediment)[c]	8/22/2000	1	0.017[d]	----

[a] Indicator parameters for water quality (purple text)
[b] Indicator metals for sediment quality (blue text)
[c] Indicator organic contaminants for sediment quality (red text)
[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)
[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)
[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-6 (continued). Water quality and sediment quality data for monitoring site EPA EMAP NC00-0018 in Core Sound.

Parameter	Date	n	Mean	Median
PCB-101 (ng/g, sediment)[c]	8/22/2000	1	0.01[d]	----
PCB-153 (ng/g, sediment)[c]	8/22/2000	1	0.006[d]	----
Pyrene (ng/g, sediment)[c]	8/22/2000	1	0.06[d]	----
All other chemical compounds, PCBs[c]	8/22/2000	1	nd[d]	----
Acanthohaustorius millsi	8/22/2000	1	1	----
Acteocina canaliculata	8/22/2000	1	4	----
Capitella capitata	8/22/2000	1	2	----
Gemma gemma	8/22/2000	1	34	----
Glycinde solitaria	8/22/2000	1	1	----
Haplocytheridea setipunctata	8/22/2000	1	2	----
Heteromastus filiformis	8/22/2000	1	1	----
Idotea	8/22/2000	1	1	----
Lucina radians	8/22/2000	1	1	----
Mediomastus	8/22/2000	1	2	----
Nereis	8/22/2000	1	1	----
Paraonis fulgens	8/22/2000	1	15	----
Prionospio heterobranchia	8/22/2000	1	4	----
Scolelepis squamata	8/22/2000	1	4	----
Spionidae	8/22/2000	1	1	----
Spiophanes bombyx	8/22/2000	1	1	----
Streblospio benedicti	8/22/2000	1	1	----
Streptosyllis varians	8/22/2000	1	1	----
Syllidae	8/22/2000	1	1	----
Tellina agilis	8/22/2000	1	1	----
Tellinidae	8/22/2000	1	2	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-7. Water quality and sediment quality data for monitoring site NPS CALO 2010 ALT12 in Core Sound.

Parameter	Date	n	Mean (range)	Median
Temperature (ºC)	7/7/2010	2	33.5 (33.51–33.52)	33.5
Salinity (ppt)	7/7/2010	2	29.5 (29.5–29.58)	29.5
DO (mg/L)[a]	7/7/2010	2	9.2 (9.08–9.23)[d]	9.2[d]
pH	7/7/2010	2	8.7 (8.74–8.74)	8.7
Nitrogen (µg/L)[a]	7/7/2010	2	443 (442.8–443.1)	443
Phosphate (DIP) (µg/L)[a]	7/7/2010	1	11[e]	----
Chlorophyll *a* (µg/L)[a]	7/7/2010	2	3.2 (2.92–3.54)[d]	3.2[d]
TOC (mg/kg, sediment)	7/7/2010	1	792	----
Aluminum, total (mg/kg, sediment)	7/7/2010	1	5,010	----
Antimony, total (mg/kg, sediment)	7/7/2010	1	3.56	----
Arsenic, total (mg/kg, sediment)[b]	7/7/2010	1	nd[d]	----
Cadmium, total (mg/kg, sediment)[b]	7/7/2010	1	brl[d]	----
Chromium, total (mg/kg, sediment)[b]	7/7/2010	1	6.71[d]	----
Iron, total (mg/kg, sediment)	7/7/2010	1	8,230	----
Lead, total (mg/kg, sediment)[b]	7/7/2010	1	nd[d]	----
Manganese, total (mg/kg, sediment)	7/7/2010	1	298	----
Mercury, total (mg/kg, sediment)[b]	7/7/2010	1	nd[d]	----
Nickel, total (mg/kg, sediment)[b]	7/7/2010	1	1.16[d]	----
Selenium, total (mg/kg, sediment)	7/7/2010	1	brl	----
Silver, total (mg/kg, sediment)[b]	7/7/2010	1	nd[d]	----
Tin, total (mg/kg, sediment)	7/7/2010	1	nd	----
Zinc, total (mg/kg, sediment)[b]	7/7/2010	1	10.6[d]	----
All other chemical compounds, PCBs[c]	7/7/2010	1	nd[d]	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-8. Water quality and sediment quality data for monitoring site EPA EMAP NC04-0031 in Core Sound.

Parameter	Date	n	Mean (range)	Median
Temperature (°C)	9/23/2004	2	22.6 (22.6–22.6)	22.6
Salinity (ppt)	9/23/2004	2	20.3 (20.3–20.3)	20.3
DO (mg/L)[a]	9/23/2004	2	9.4 (9.43–9.43)[d]	9.4[d]
pH	9/23/2004	2	8.2 (8.2–8.2)	8.2
$NO_3^-N + NO_2^-N$ (µg/L)[a]	9/23/2004	1	4.9[d]	----
NH_4^+N (µg/L)[a]	9/23/2004	1	5.1[d]	----
TN (µg/L)	9/23/2004	1	360.5	----
TP (µg/L)	9/23/2004	1	49.7	----
Phosphate (DIP) (µg/L)[a]	9/23/2004	1	12.1[e]	----
Chlorophyll *a* (µg/L)[a]	9/23/2004	1	4.6[d]	----
TOC (%, sediment)	9/23/2004	1	0.00563 %	----
Aluminum, total (µg/g, sediment)	9/23/2004	1	6,490	----
Antimony, total (µg/g, sediment)	9/23/2004	1	nd	----
Arsenic, total (µg/g, sediment)[b]	9/23/2004	1	1.4[d]	----
Cadmium, total (µg/g, sediment)[b]	9/23/2004	1	nd[d]	----
Chromium, total (µg/g, sediment)[b]	9/23/2004	1	6.9[d]	----
Copper, total (µg/g, sediment)[b]	9/23/2004	1	0.17[d]	----
Iron, total (µg/g, sediment)	9/23/2004	1	3,900	----
Lead, total (µg/g, sediment)[b]	9/23/2004	1	4.5[d]	----
Manganese, total (µg/g, sediment)	9/23/2004	1	127	----
Mercury, total (µg/g, sediment)[b]	9/23/2004	1	nd[d]	----
Nickel, total (µg/g, sediment)[b]	9/23/2004	1	1.4[d]	----
Selenium, total (µg/g, sediment)	9/23/2004	1	nd	----
Silver, total (µg/g, sediment)[b]	9/23/2004	1	0.023[d]	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-8 (continued). Water quality and sediment quality data for monitoring site EPA EMAP NC04-0031 in Core Sound.

Parameter	Date	n	Mean (range)	Median
Tin, total (µg/g, sediment)	9/23/2004	1	3	----
Zinc, total (µg/g, sediment)[b]	9/23/2004	1	6.8[d]	----
All other chemical compounds, PCBs[c]	9/23/2004	1	nd[d]	----
Bivalvia	9/23/2004	1	1	----
Callinectes sapidus	9/23/2004	1	1	----
Gemma gemma	9/23/2004	1	42	----
Haplocytheridea setipunctata	9/23/2004	1	1	----
Lagodon rhomboides	9/23/2004	1	21	----
Leitoscoloplos	9/23/2004	1	2	----
Mulinia lateralis	9/23/2004	1	2	----
Mysidae	9/23/2004	1	2	----
Nassarius vibex	9/23/2004	1	1	----
Orthopristis chrysoptera	9/23/2004	1	1	----
Paralichthys dentatus	9/23/2004	1	1	----
Paraonis fulgens	9/23/2004	1	5	----
Prionospio pygmaea	9/23/2004	1	1	----
Scolelepis texana	9/23/2004	1	3	----
Streblospio benedicti	9/23/2004	1	6	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-9. Water quality and sediment quality data for monitoring site NPS CALO 2010 ALT28 in Core Sound.

Parameter	Date	n	Mean (range)	Median
Temperature (ºC)	7/7/2010	4	29.4 (29.41–29.41)	29.4
Salinity (ppt)	7/7/2010	4	32.3 (32.27–32.27)	32.3
DO (mg/L)[a]	7/7/2010	4	7.3 (7.09–7.4)[d]	7.3[d]
pH	7/7/2010	4	8.2 (8.15–8.16)	8.2
Nitrogen (µg/L)[a]	7/7/2010	2	194 (192–196)	194
Phosphate (µg/L)[a]	7/7/2010	1	12[e]	----
Chlorophyll *a* (µg/L)[a]	7/7/2010	2	1.9 (1.25–2.49)[d]	1.9[d]
TOC (mg/kg, sediment)	7/7/2010	1	847	----
Aluminum, total (mg/kg, sediment)	7/7/2010	1	13,100	----
Antimony, total (mg/kg, sediment)	7/7/2010	1	2.95	----
Arsenic, total (mg/kg, sediment)[b]	7/7/2010	1	nd[d]	----
Cadmium, total (mg/kg, sediment)[b]	7/7/2010	1	brl[d]	----
Chromium, total (mg/kg, sediment)[b]	7/7/2010	1	7.81[d]	----
Iron, total (mg/kg, sediment)	7/7/2010	1	6,090	----
Lead, total (mg/kg, sediment)[b]	7/7/2010	1	nd[d]	----
Manganese, total (mg/kg, sediment)	7/7/2010	1	193	----
Mercury, total (mg/kg, sediment)[b]	7/7/2010	1	nd[d]	----
Nickel, total (mg/kg, sediment)[b]	7/7/2010	1	1.64[d]	----
Selenium, total (mg/kg, sediment)	7/7/2010	1	brl	----
Silver, total (mg/kg, sediment)[b]	7/7/2010	1	nd[d]	----
Tin, total (mg/kg, sediment)	7/7/2010	1	nd	----
Zinc, total (mg/kg, sediment)[b]	7/7/2010	1	10.6[d]	----
All other chemical compounds, PCBs[c]	7/7/2010	1	nd[d]	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-10. Water quality and sediment quality data for monitoring site NPS CALO 2010 26 in Core Sound.

Parameter	Date	n	Mean (range)	Median
Temperature (ºC)	7/6/2010	2	24.6 (24.61–24.62)	24.6
Salinity (ppt)	7/6/2010	2	32.7 (32.7–32.78)	32.7
DO (mg/L)[a]	7/6/2010	2	5.1 (5.13–5.15)[d]	5.1[d]
pH	7/6/2010	2	8 (7.94–8)	8
Nitrogen (µg/L)[a]	7/6/2010	2	191 (190–191)	191
Phosphate (DIP) (µg/L)[a]	7/6/2010	1	11[e]	----
Chlorophyll *a* (µg/L)[a]	7/6/2010	2	2.9 (2.6–3.17)[d]	2.9[d]
TOC (mg/kg, sediment)	7/6/2010	1	760	----
Aluminum, total (mg/kg, sediment)	7/6/2010	1	11,900	----
Antimony, total (mg/kg, sediment)	7/6/2010	1	brl	----
Arsenic, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Cadmium, total (mg/kg, sediment)[b]	7/6/2010	1	brl[d]	----
Chromium, total (mg/kg, sediment)[b]	7/6/2010	1	5.94[d]	----
Iron, total (mg/kg, sediment)	7/6/2010	1	2,870	----
Lead, total (mg/kg, sediment)[b]	7/6/2010	1	nd	----
Manganese, total (mg/kg, sediment)	7/6/2010	1	94.7	----
Mercury, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Nickel, total (mg/kg, sediment)[b]	7/6/2010	1	1.34[d]	----
Selenium, total (mg/kg, sediment)	7/6/2010	1	brl	----
Silver, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Tin, total (mg/kg, sediment)	7/6/2010	1	nd	----
Zinc, total (mg/kg, sediment)[b]	7/6/2010	1	7.1[d]	----
All other chemical compounds, PCBs[c]	7/6/2010	1	nd[d]	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-11. Water quality and sediment quality data for monitoring site NC Recreational Water Quality Program C75 in Core Sound.

Parameter	Date	n	Mean (range)
Enterococcus (mpn or CFU/100 mL)	Feb 2003–Dec 2006	77	(brl–31)

Table B-12. Water quality and sediment quality data for monitoring site EPA EMAP NC01-0020 in Core Sound.

Parameter	Date	n	Mean (range)
$NO_3^-N + NO_2^-N$ (µg/L)[a]	8/8/2001	1	23[d]
NH_4^+N (µg/L)[a]	8/8/2001	1	13[d]
Phosphate (DIP) (µg/L)[a]	8/8/2001	1	44[e]
Chlorophyll *a* (µg/L)[a]	8/8/2001	1	1.89[d]
TSS (mg/L)	8/8/2001	1	10
TOC (%, sediment)	8/8/2001	1	0.085%
Aluminum, total (µg/g, sediment)	8/8/2001	1	71,900
Antimony, total (µg/g, sediment)	8/8/2001	1	nd
Arsenic, total (µg/g, sediment)[b]	8/8/2001	1	16.071[d]
Cadmium, total (µg/g, sediment)[b]	8/8/2001	1	0.691[d]
Chromium, total (µg/g, sediment)[b]	8/8/2001	1	57.139[d]
Copper, total (µg/g, sediment)[b]	8/8/2001	1	29.491[d]
Iron, total (µg/g, sediment)	8/8/2001	1	48,700
Lead, total (µg/g, sediment)[b]	8/8/2001	1	41.165[d]
Manganese, total (µg/g, sediment)	8/8/2001	1	880
Mercury, total (µg/g, sediment)[b]	8/8/2001	1	0.152[d]
Nickel, total (µg/g, sediment)[b]	8/8/2001	1	32.563[d]

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-12 (continued). Water quality and sediment quality data for monitoring site EPA EMAP NC01-0020 in Core Sound.

Parameter	Date	n	Mean (range)
Selenium, total (µg/g, sediment)	8/8/2001	1	0.973
Silver, total (µg/g, sediment)[b]	8/8/2001	1	0.293[d]
Tin, total (µg/g, sediment)	8/8/2001	1	18.09
Zinc, total (µg/g, sediment)[b]	8/8/2001	1	155.442[d]
All other chemical compounds, PCBs[c]	8/8/2001	1	nd[d]
Acteocina canaliculata	8/8/2001	1	11
Ampelisca verrilli	8/8/2001	1	6
Cirratulidae	8/8/2001	1	4
Eusarsiella	8/8/2001	1	2
Gemma gemma	8/8/2001	1	34
Glycinde solitaria	8/8/2001	1	1
Haminoea solitaria	8/8/2001	1	1
Haplocytheridea setipunctata	8/8/2001	1	14
Hydrozoa	8/8/2001	1	1
Leitoscoloplos	8/8/2001	1	1
Leitoscoloplos fragilis	8/8/2001	1	3
Leptosynapta tenuis	8/8/2001	1	2
Listriella barnardi	8/8/2001	1	9
Mactridae	8/8/2001	1	1
Maldanidae	8/8/2001	1	1
Nemertea	8/8/2001	1	2
Nereiphylla fragilis	8/8/2001	1	2
Odostomia teres	8/8/2001	1	1
Orbinia riseri	8/8/2001	1	1
Prionospio heterobranchia	8/8/2001	1	17
Scolelepis texana	8/8/2001	1	2

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-12 (continued). Water quality and sediment quality data for monitoring site EPA EMAP NC01-0020 in Core Sound.

Parameter	Date	n	Mean (range)
Scoloplos robustus	8/8/2001	1	2
Semelidae	8/8/2001	1	1
Streptosyllis arenae	8/8/2001	1	1
Tellina agilis	8/8/2001	1	2
Tellinidae	8/8/2001	1	3
Terebra	8/8/2001	1	8
Terebra dislocata	8/8/2001	1	1
Tharyx acutus	8/8/2001	1	5

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-13. Water quality and sediment quality data for monitoring site NPS CALO 2010 ALT10 in Core Sound.

Parameter	Date	n	Mean (range)	Median
Temperature (°C)	7/6/2010	4	27.7 (27.6–27.79)	27.6
Salinity (ppt)	7/6/2010	4	35.2 (35.16–35.23)	35.2
DO (mg/L)[a]	7/6/2010	4	5.7 (5.62–5.74)[d]	5.7[d]
pH	7/6/2010	4	8.3 (8.26–8.33)	8.3
Nitrogen (µg/L)[a]	7/6/2010	4	267 (245–290)	266
Phosphate (DIP) (µg/L)[a]	7/6/2010	2	11 (10–11)[e]	11[e]
Chlorophyll *a* (µg/L)[a]	7/6/2010	4	2.9 (2.6–3.17)[d]	2.9[d]
TOC (mg/kg, sediment)	7/6/2010	1	747	----
Aluminum, total (mg/kg, sediment)	7/6/2010	1	11,900	----
Antimony, total (mg/kg, sediment)	7/6/2010	1	brl	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-13 (continued). Water quality and sediment quality data for monitoring site NPS CALO 2010 ALT10 in Core Sound.

Parameter	Date	n	Mean (range)	Median
Arsenic, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Cadmium, total (mg/kg, sediment)[b]	7/6/2010	1	brl[d]	----
Chromium, total (mg/kg, sediment)[b]	7/6/2010	1	5.64[d]	----
Iron, total (mg/kg, sediment)	7/6/2010	1	2,870	----
Lead, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Manganese, total (mg/kg, sediment)	7/6/2010	1	60	----
Mercury, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Nickel, total (mg/kg, sediment)[b]	7/6/2010	1	1.42[d]	----
Selenium, total (mg/kg, sediment)	7/6/2010	1	brl	----
Silver, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Tin, total (mg/kg, sediment)	7/6/2010	1	brl	----
Zinc, total (mg/kg, sediment)[b]	7/6/2010	1	7.2[d]	----
All other chemical compounds, PCBs[c]	7/6/2010	1	nd[d]	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-14. Water quality and sediment quality data for monitoring site NPS CALO 2010 12 in Core Sound.

Parameter	Date	n	Mean (range)	Median
Temperature (ºC)	7/6/2010	2	27.9 (27.78–28)	27.9
Salinity (ppt)	7/6/2010	2	35.7 (35.68–35.69)	35.7
DO (mg/L)[a]	7/6/2010	2	4.4 (4.41–4.41)[e]	4.4[e]
pH	7/6/2010	2	8.3 (8.31–8.33)	8.3
Nitrogen (µg/L)[a]	7/6/2010	2	259 (232–285)	259

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-14 (continued). Water quality and sediment quality data for monitoring site NPS CALO 2010 12 in Core Sound.

Parameter	Date	n	Mean (range)	Median
Phosphate (DIP) (µg/L)[a]	7/6/2010	1	8[d]	----
Chlorophyll *a* (µg/L)[a]	7/6/2010	2	1.2 (0.6–1.7)[d]	1.2[d]
TOC (mg/kg, sediment)	7/6/2010	1	722	----
Aluminum, total (mg/kg, sediment)	7/6/2010	1	7,920	----
Antimony, total (mg/kg, sediment)	7/6/2010	1	brl	----
Arsenic, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Cadmium, total (mg/kg, sediment)[b]	7/6/2010	1	brl[d]	----
Chromium, total (mg/kg, sediment)[b]	7/6/2010	1	4.41[d]	----
Iron, total (mg/kg, sediment)	7/6/2010	1	2,080	----
Lead, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Manganese, total (mg/kg, sediment)	7/6/2010	1	39.6	----
Mercury, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Nickel, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Selenium, total (mg/kg, sediment)	7/6/2010	1	3.07	----
Silver, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Tin, total (mg/kg, sediment)	7/6/2010	1	brl	----
Zinc, total (mg/kg, sediment)[b]	7/6/2010	1	5.6[d]	----
All other chemical compounds, PCBs[c]	7/6/2010	1	nd[d]	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-15. Water quality and sediment quality data for monitoring site NC Recreational Water Quality Program C75A in Core Sound.

Parameter	Date	n	Mean (range)
Enterococcus (mpn or CFU/100 mL)	Feb 07–Dec 10	111	(brl–164)

Table B-16. Water quality and sediment quality data for monitoring site EPA EMAP NC00-0020 in Core Sound.

Parameter	Date	n	Mean	Median
$NO_3^-N + NO_2^-N$ (µg/L)[a]	8/19/2000	1	85[e]	9
NH_4^+N (µg/L)[a]	8/19/2000	1	59[e]	----
TN (µg/L)	8/19/2000	1	735	----
TP (µg/L)	8/19/2000	1	42	----
Chlorophyll *a* (µg/L)[a]	8/19/2000	1	2.9[d]	----
TSS (mg/L)	8/19/2000	1	6.8	----
TOC (%, sediment)	8/19/2000	1	0.06%	----
Aluminum, total (µg/g, sediment)	8/19/2000	1	14,100	----
Antimony, total (µg/g, sediment)	8/19/2000	1	0.1	----
Arsenic, total (µg/g, sediment)[b]	8/19/2000	1	1[d]	----
Cadmium, total (µg/g, sediment)[b]	8/19/2000	1	nd[d]	----
Chromium, total (µg/g, sediment)[b]	8/19/2000	1	9[d]	----
Copper, total (µg/g, sediment)[b]	8/19/2000	1	2[d]	----
Iron, total (µg/g, sediment)	8/19/2000	1	5,630	----
Lead, total (µg/g, sediment)[b]	8/19/2000	1	5.9[d]	----
Manganese, total (µg/g, sediment)	8/19/2000	1	131	----
Mercury, total (µg/g, sediment)[b]	8/19/2000	1	nd[d]	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-16 (continued). Water quality and sediment quality data for monitoring site EPA EMAP NC00-0020 in Core Sound.

Parameter	Date	n	Mean	Median
Nickel, total (µg/g, sediment)[b]	8/19/2000	1	2[d]	----
Selenium, total (µg/g, sediment)	8/19/2000	1	nd	----
Silver, total (µg/g, sediment)[b]	8/19/2000	1	0.1[d]	----
Tin, total (µg/g, sediment)	8/19/2000	1	0.3	----
Zinc, total (µg/g, sediment)[b]	8/19/2000	1	14[d]	----
1-Methylnaphthalene (ng/g, sediment)	8/19/2000	1	0.23	----
2-Methylnaphthalene (ng/g, sediment)	8/19/2000	1	0.49	----
Benzo[ghi]perylene (ng/g, sediment)[c]	8/19/2000	1	0.26[d]	----
Endosulfan sulfate (ng/g, sediment)	8/19/2000	1	0.016	----
Fluoranthene (ng/g, sediment)[c]	8/19/2000	1	0.22[d]	----
Naphthalene (ng/g, sediment)[c]	8/19/2000	1	0.54[d]	----
PCB-028 (ng/g, sediment)[c]	8/19/2000	1	0.72[d]	----
PCB-052 (ng/g, sediment)[c]	8/19/2000	1	0.025[d]	----
PCB-101 (ng/g, sediment)[c]	8/19/2000	1	0.029[d]	----
PCB-105 (ng/g, sediment)[c]	8/19/2000	1	0.013[d]	----
PCB-153 (ng/g, sediment)[c]	8/19/2000	1	0.04[d]	----
PCB-180 (ng/g, sediment)[c]	8/19/2000	1	0.012[d]	----
PCB-209 (ng/g, sediment)[c]	8/19/2000	1	0.006[d]	----
Pyrene (ng/g, sediment)[c]	8/19/2000	1	0.2[d]	----
All other chemical compounds, PCBs[c]	8/19/2000	1	nd[d]	----
Acteocina canaliculata	8/19/2000	1	48	----
Americhelidium americanum	8/19/2000	1	1	----
Ampelisca sp.	8/19/2000	1	5	----
Ampelisca verrilli	8/19/2000	1	5	----
Gemma gemma	8/19/2000	1	5	----
Glycera dibranchiata	8/19/2000	1	1	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-16 (continued). Water quality and sediment quality data for monitoring site EPA EMAP NC00-0020 in Core Sound.

Parameter	Date	n	Mean	Median
Glycinde solitaria	8/19/2000	1	3	----
Haplocytheridea setipunctata	8/19/2000	1	4	----
Lucina radians	8/19/2000	1	2	----
Ophelina cylindricaudata	8/19/2000	1	1	----
Paraprionospio pinnata	8/19/2000	1	1	----
Prionospio sp.	8/19/2000	1	1	----
Pyramidellidae	8/19/2000	1	1	----
Scolelepis squamata	8/19/2000	1	1	----
Scoloplos robustus	8/19/2000	1	2	----
Scoloplos rubra	8/19/2000	1	1	----
Spiophanes bombyx	8/19/2000	1	1	----
Tellinidae	8/19/2000	1	3	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-17. Water quality and sediment quality data for monitoring site EPA EMAP NC03-0019 in Core Sound.

Parameter	Date	n	Mean (range)	Median
Temperature (°C)	7/9/2003	2	30.25 (30.2–30.3)	30.25
Salinity (ppt)	7/9/2003	2	34 (34–34)	34
DO (mg/L)[a]	7/9/2003	2	7.8 (7.75–7.8)[d]	7.8[d]
pH	7/9/2003	2	(8.1–8.1)	8.1
$NO_3^-N + NO_2^-N$ (µg/L)[a]	7/9/2003	2	9 (8–10)[d]	9[d]
NH_4^+N (µg/L)[a]	7/9/2003	2	4 (2–6)[d]	4[d]

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-17 (continued). Water quality and sediment quality data for monitoring site EPA EMAP NC03-0019 in Core Sound.

Parameter	Date	n	Mean (range)	Median
TN (µg/L)	7/9/2003	2	238 (226–249)	238
TP (µg/L)	7/9/2003	2	27 (23–31)	27
Phosphate (DIP) (µg/L)[a]	7/9/2003	2	8 (6.6–8.8)[d]	8[d]
Chlorophyll *a* (µg/L)[a]	7/9/2003	2	0.93 (0.88–0.98)[d]	0.93[d]
TSS (mg/L)	7/9/2003	2	29.4 (26.8–32.1)	29.4
TOC (%, sediment)	7/9/2003	1	0.06%	----
Aluminum, total (µg/g, sediment)	7/9/2003	1	14,900	----
Antimony, total (µg/g, sediment)	7/9/2003	1	0.26	----
Arsenic, total (µg/g, sediment)[b]	7/9/2003	1	1.6[d]	----
Cadmium, total (µg/g, sediment)[b]	7/9/2003	1	nd[d]	----
Chromium, total (µg/g, sediment)[b]	7/9/2003	1	8.9[d]	----
Copper, total (µg/g, sediment)[b]	7/9/2003	1	1.8[d]	----
Iron, total (µg/g, sediment)	7/9/2003	1	5,260	----
Lead, total (µg/g, sediment)[b]	7/9/2003	1	7.5[d]	----
Manganese, total (µg/g, sediment)	7/9/2003	1	136	----
Mercury, total (µg/g, sediment)[b]	7/9/2003	1	nd[d]	----
Nickel, total (µg/g, sediment)[b]	7/9/2003	1	2[d]	----
Selenium, total (µg/g, sediment)	7/9/2003	1	nd	----
Silver, total (µg/g, sediment)[b]	7/9/2003	1	0.4[d]	----
Tin, total (µg/g, sediment)	7/9/2003	1	3.3	----
Zinc, total (µg/g, sediment)[b]	7/9/2003	1	10.6[d]	----
All other chemical compounds, PCBs[c]	7/9/2003	1	nd[d]	----
Acteocina canaliculata	7/9/2003	1	82	----
Americhelidium americanum	7/9/2003	1	1	----
Ampelisca	7/9/2003	1	1	----
Ampelisca verrilli	7/9/2003	1	2	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-17 (continued). Water quality and sediment quality data for monitoring site EPA EMAP NC03-0019 in Core Sound.

Parameter	Date	n	Mean (range)	Median
Bivalvia	7/9/2003	1	3	----
Caecum pulchellum	7/9/2003	1	1	----
Eusarsiella disparalis	7/9/2003	1	1	----
Gammarus	7/9/2003	1	1	----
Gemma gemma	7/9/2003	1	18	----
Glycinde solitaria	7/9/2003	1	1	----
Haminoea solitaria	7/9/2003	1	4	----
Haplocytheridea setipunctata	7/9/2003	1	21	----
Hypleurochilus geminatus	7/9/2003	1	1	----
Laevicardium	7/9/2003	1	2	----
Lagodon rhomboides	7/9/2003	1	93	----
Leiostomus xanthurus	7/9/2003	1	30	----
Leptosynapta tenuis	7/9/2003	1	20	----
Mediomastus	7/9/2003	1	6	----
Mediomastus ambiseta	7/9/2003	1	1	----
Mulinia lateralis	7/9/2003	1	1	----
Orthopristis chrysoptera	7/9/2003	1	18	----
Paralichthys dentatus	7/9/2003	1	1	----
Podocopida	7/9/2003	1	2	----
Polydora	7/9/2003	1	1	----
Prionospio	7/9/2003	1	1	----
Pyramidella crenulata	7/9/2003	1	1	----
Pyramidellidae	7/9/2003	1	1	----
Rhepoxynius hudsoni	7/9/2003	1	22	----
Rictaxis punctostriatus	7/9/2003	1	1	----

Table B-17 (continued). Water quality and sediment quality data for monitoring site EPA EMAP NC03-0019 in Core Sound.

Parameter	Date	n	Mean (range)	Median
Tagelus divisus	7/9/2003	1	1	----
Tellina agilis	7/9/2003	1	2	----
Tellinidae	7/9/2003	1	2	----
Terebra	7/9/2003	1	1	----

Table B-18. Water quality and sediment quality data for monitoring site NC Recreational Water Quality Program C58 in Back Sound.

Parameter	Date	n	Mean (range)
Enterococcus (mpn or CFU/100 mL)	Jan 03–Dec 12	171	(brl–75)

Table B-19. Water quality and sediment quality data for monitoring site NC Recreational Water Quality Program C59A in Back Sound.

Parameter	Date	n	Mean (range)
Enterococcus (mpn or CFU/100 mL)	Jan 03–Dec 12	172	(brl–20)

Table B-20. Water quality and sediment quality data for monitoring site NC Recreational Water Quality Program C66 in Back Sound.

Parameter	Date	n	Mean (range)	Number Unacceptable
Enterococcus (mpn or CFU/100 mL)	Jan 03–Dec 12	172	(brl–560)	3 (2% > 104)

Table B-21. Water quality and sediment quality data for monitoring site NC Recreational Water Quality Program C68 in Back Sound.

Parameter	Date	n	Mean (range)
Enterococcus (mpn or CFU/100 mL)	Jan 03–Dec 10	133	(brl–42)

Table B-22. Water quality and sediment quality data for monitoring site NPS CALO 2010 ALT02 in Back Sound.

Parameter	Date	n	Mean (range)	Median
Temperature (ºC)	7/6/2010	8	27.6 (27.49–27.98)	27.6
Salinity (ppt)	7/6/2010	8	35.1 (35.0–35.08)	35.1
DO (mg/L)[a]	7/6/2010	8	6.7 (6.57–6.8)[d]	6.7[d]
pH	7/6/2010	8	8.1 (8.09–8.11)	8.1
Nitrogen (µg/L)[a]	7/6/2010	6	168 (156–177)	167
Phosphate (µg/L)[a]	7/6/2010	3	9 (8–9)[d]	9
Chlorophyll *a* (µg/L)[a]	7/6/2010	6	1.1 (0.07–1.9)[d]	1.2[d]
TOC (mg/kg, sediment)	7/6/2010	1	1,440	----
Aluminum, total (mg/kg, sediment)	7/6/2010	1	17,400	----
Antimony, total (mg/kg, sediment)	7/6/2010	1	brl	----
Arsenic, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Cadmium, total (mg/kg, sediment)[b]	7/6/2010	1	brl[d]	----
Chromium, total (mg/kg, sediment)[b]	7/6/2010	1	10.7[d]	----
Iron, total (mg/kg, sediment)	7/6/2010	1	7,480	----
Lead, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Manganese, total (mg/kg, sediment)	7/6/2010	1	127	----
Mercury, total (mg/kg, sediment)[b]	7/6/2010	1	brl	----
Nickel, total (mg/kg, sediment)[b]	7/6/2010	1	brl	----
Selenium, total (mg/kg, sediment)	7/6/2010	1	nd[d]	----
Silver, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Tin, total (mg/kg, sediment)	7/6/2010	1	nd[d]	----
Zinc, total (mg/kg, sediment)[b]	7/6/2010	1	14.7	----
All other chemical compounds, PCBs[c]	7/6/2010	1	nd[d]	----

[a] Indicator parameters for water quality (purple text)
[b] Indicator metals for sediment quality (blue text)
[c] Indicator organic contaminants for sediment quality (red text)
[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)
[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)
[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-23. Water quality and sediment quality data for monitoring site NPS CALO 2010 04 in Back Sound.

Parameter	Date	n	Mean (range)	Median
Temperature (ºC)	7/6/2010	4	29.5 (29.13–29.98)	29.5
Salinity (ppt)	7/6/2010	4	35.3 (35.25–35.28)	35.3
DO (mg/L)[a]	7/6/2010	4	6.4 (6.25–6.52)[d]	6.4[d]
pH	7/6/2010	4	8.1 (8.14–8.15)	8.1
Nitrogen (µg/L)[a]	7/6/2010	2	159 (156–161)	159
Phosphate (DIP) (µg/L)[a]	7/6/2010	1	12[e]	----
Chlorophyll *a* (µg/L)[a]	7/6/2010	2	1.4 (1.28–1.46)[d]	1.4[d]
TOC (mg/kg, sediment)	7/6/2010	1	835	----
Aluminum, total (mg/kg, sediment)	7/6/2010	1	6,300	----
Antimony, total (mg/kg, sediment)	7/6/2010	1	brl	----
Arsenic, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Cadmium, total (mg/kg, sediment)[b]	7/6/2010	1	brl[d]	----
Chromium, total (mg/kg, sediment)[b]	7/6/2010	1	4.2[d]	----
Iron, total (mg/kg, sediment)	7/6/2010	1	2,330	----
Lead, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Manganese, total (mg/kg, sediment)	7/6/2010	1	47.9	----
Mercury, total (mg/kg, sediment)[b]	7/6/2010	1	brl[d]	----
Nickel, total (mg/kg, sediment)[b]	7/6/2010	1	brl[d]	----
Selenium, total (mg/kg, sediment)	7/6/2010	1	3.6	----
Silver, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Tin, total (mg/kg, sediment)	7/6/2010	1	brl	----
Zinc, total (mg/kg, sediment)[b]	7/6/2010	1	5.47[d]	----
All other chemical compounds, PCBs[c]	7/6/2010	1	nd[d]	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-24. Water quality and sediment quality data for monitoring site NPS CALO 2010 ALT06 in Back Sound.

Parameter	Date	n	Mean (range)	Median
Temperature (ºC)	7/6/2010	2	27.0 (27.02–27.02)	27
Salinity (ppt)	7/6/2010	2	35.3 (35.34–35.34)	35.3
DO (mg/L)[a]	7/6/2010	2	6.1 (6.06–6.1)[d]	6.1[d]
pH	7/6/2010	2	8.0 (8.04–8.05)	8
Nitrogen (µg/L)[a]	7/6/2010	2	139 (138–140)	139
Phosphate (DIP) (µg/L)[a]	7/6/2010	1	7[d]	----
Chlorophyll *a* (µg/L)[a]	7/6/2010	2	0.6 (0.30–0.87)[d]	0.6[d]
TOC (mg/kg, sediment)	7/6/2010	1	823	----
Aluminum, total (mg/kg, sediment)	7/6/2010	1	5,350	----
Antimony, total (mg/kg, sediment)	7/6/2010	1	brl	----
Arsenic, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Cadmium, total (mg/kg, sediment)[b]	7/6/2010	1	brl[d]	----
Chromium, total (mg/kg, sediment)[b]	7/6/2010	1	4.5[d]	----
Iron, total (mg/kg, sediment)	7/6/2010	1	2,900	----
Lead, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Manganese, total (mg/kg, sediment)	7/6/2010	1	79.5	----
Mercury, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Nickel, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Selenium, total (mg/kg, sediment)	7/6/2010	1	brl	----
Silver, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Tin, total (mg/kg, sediment)	7/6/2010	1	nd	----
Zinc, total (mg/kg, sediment)[b]	7/6/2010	1	5.72[d]	----
All other chemical compounds, PCBs[c]	7/6/2010	1	nd[d]	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-25. Water quality and sediment quality data for monitoring site NPS CALO 2010 08 in Back Sound.

Parameter	Date	n	Mean (range)	Median
Temperature (ºC)	7/6/2010	4	29.1 (29.11–29.13)	29.1
Salinity (ppt)	7/6/2010	4	35.6 (35.6–35.68)	35.6
DO (mg/L)[a]	7/6/2010	4	7.1 (6.86–7.22)[d]	7.2[d]
pH	7/6/2010	4	8.1 (8.09–8.14)	8.1
Nitrogen (µg/L)[a]	7/6/2010	4	255 (195–317)	255
Phosphate (DIP) (µg/L)[a]	7/6/2010	2	10.5 (10–11)[e]	10.5[e]
Chlorophyll *a* (µg/L)[a]	7/6/2010	4	0.85 (0.35–1.35)[d]	0.85[d]
TOC (mg/kg, sediment)	7/6/2010	1	1,430	----
Aluminum, total (mg/kg, sediment)	7/6/2010	1	2,310	----
Antimony, total (mg/kg, sediment)	7/6/2010	1	2.06	----
Arsenic, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Cadmium, total (mg/kg, sediment)[b]	7/6/2010	1	brl[d]	----
Chromium, total (mg/kg, sediment)[b]	7/6/2010	1	6[d]	----
Iron, total (mg/kg, sediment)	7/6/2010	1	4,160	----
Lead, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Manganese, total (mg/kg, sediment)	7/6/2010	1	121	----
Mercury, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Nickel, total (mg/kg, sediment)[b]	7/6/2010	1	brl[d]	----
Selenium, total (mg/kg, sediment)	7/6/2010	1	nd	----
Silver, total (mg/kg, sediment)[b]	7/6/2010	1	nd[d]	----
Tin, total (mg/kg, sediment)	7/6/2010	1	nd	----
Zinc, total (mg/kg, sediment)[b]	7/6/2010	1	7.78[d]	----
All other chemical compounds, PCBs[c]	7/6/2010	1	nd[d]	----

[a] Indicator parameters for water quality (purple text)

[b] Indicator metals for sediment quality (blue text)

[c] Indicator organic contaminants for sediment quality (red text)

[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)

[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)

[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-26. Water quality and sediment quality data for monitoring site NPS CALO 2010 20 in Back Sound.

Parameter	Date	n	Mean (range)	Median
Temperature (ºC)	7/6/2010	4	29.4 (29.35–29.49)	29.4
Salinity (ppt)	7/6/2010	4	35.5 (35.54–35.55)	35.5
DO (mg/L)[a]	7/6/2010	4	6.7 (6.68–6.74)[d]	6.7[d]
pH	7/6/2010	4	8.1 (8.09–8.1)	8.1
Nitrogen (µg/L)[a]	7/6/2010	4	160 (158–161)	160
Phosphate (DIP) (µg/L)[a]	7/6/2010	1	9[d]	----
Chlorophyll *a* (µg/L)[a]	7/6/2010	4	0.6 (0.32–0.83)[d]	0.6[d]
TOC (mg/kg, sediment)	7/6/2010	1	1,130	----
Aluminum, total (mg/kg, sediment)	7/6/2010		19,700	----
Antimony, total (mg/kg, sediment)	7/6/2010		brl	----
Arsenic, total (mg/kg, sediment)[b]	7/6/2010		nd[d]	----
Cadmium, total (mg/kg, sediment)[b]	7/6/2010		brl[d]	----
Chromium, total (mg/kg, sediment)[b]	7/6/2010		9.45[d]	----
Iron, total (mg/kg, sediment)	7/6/2010		4,780	----
Lead, total (mg/kg, sediment)[b]	7/6/2010		nd[d]	----
Manganese, total (mg/kg, sediment)	7/6/2010		100	----
Mercury, total (mg/kg, sediment)[b]	7/6/2010		nd[d]	----
Nickel, total (mg/kg, sediment)[b]	7/6/2010		brl[d]	----
Selenium, total (mg/kg, sediment)	7/6/2010		brl	----
Silver, total (mg/kg, sediment)[b]	7/6/2010		nd[d]	----
Tin, total (mg/kg, sediment)	7/6/2010		brl	----
Zinc, total (mg/kg, sediment)[b]	7/6/2010		10.8[d]	----
All other chemical compounds, PCBs[c]	7/6/2010		nd[d]	----

[a] Indicator parameters for water quality (purple text)
[b] Indicator metals for sediment quality (blue text)
[c] Indicator organic contaminants for sediment quality (red text)
[d] Good evaluation category for indicators of surface water quality at the seashore (green shading)
[e] Fair evaluation category for indicators of surface water quality at the seashore (yellow shading)
[f] Poor evaluation category for indicators of surface water quality at the seashore (red shading)

Table B-27. Water quality and sediment quality data for monitoring site NC Recreational Water Quality Program C69A in Lookout Bight.

Parameter	Date	n	Mean (range)	Number Unacceptable
Enterococcus (mpn or CFU/100 mL)	Jan 03–Dec 12	363	(brl–1,652)	14 (4% > 104)

Table B-28. Water quality and sediment quality data for monitoring site NC Recreational Water Quality Program C69B in Lookout Bight.

Parameter	Date	n	Mean (range)	Number Unacceptable
Enterococcus (mpn or CFU/100 mL)	Jan 03–Dec 12	172	(brl–75)	----

Table B-29. Water quality and sediment quality data for monitoring site NC Recreational Water Quality Program C69C in Lookout Bight.

Parameter	Date	n	Mean (range)	Number Unacceptable
Enterococcus (mpn or CFU/100 mL)	Feb 07–Dec 12	312	(brl–782)	4 (1% > 104)

Appendix C. Vascular Plant Information

Table C-1. Terrestrial vascular plants reported to occur in CALO according to the NPS Certified Species List (NPS 2013c), with information on species of concern from the North Carolina Conservation Board (2010; NCDA—Protected Plant List, http://www.ncagr.gov/plantindustry/plant/plantconserve/plist.htm), the Natural Heritage Program of NC DENR (Buchanan and Finnegan 2010), and the U.S. Fish and Wildlife Service (http://www.fws.gov/raleigh/species/cntylist/carteret.html, last accessed in August 2014). Information on exotic species was taken from Smith (2008); new taxa indicated are from Byrne et al. (2012—survey conducted in 2010).

Scientific Name	Common Name(s)	Notes
Acalypha gracilens	Slender copperleaf, slender threeseed mercury	--
Achillea millefolium	Bloodwort, carpenter's weed, common yarrow	--
Achillea millefolium var. *occidentalis*	Western yarrow	*Achillea millefolium* var. *occidentalis* is given as *Achillea millefolium* ssp. *lanulosa* in NPSpecies.
Acorus americanus	Sweetflag	--
Ageratina aromatica var. *aromatica*	Lesser snakeroot	*Ageratina aromatica* var. *aromatica* is given as *Eupatorium aromaticum* in NPSpecies.
Ailanthus altissima	Ailanthus, copal tree, tree of heaven, tree-of-heaven	Exotic/invasive
Allium canadense	Canada garlic, meadow garlic, meadow onion, wild onion	--
Allium vineale	Wild garlic	Exotic/invasive
Amaranthus hybridus	Green pigweed, slim amaranth, smooth amaranth	--
Ambrosia artemisiifolia	Annual ragweed, common ragweed, low ragweed	--
Ammophila breviligulata	American beachgrass	--
Ampelaster carolinianus	Climbing aster	--
Andropogon glomeratus	Bushy bluestem	--
Andropogon glomeratus var. *glomeratus*	Bushy bluestem	New
Arthraxon hispidus	Small carpgrass	Exotic/invasive; *Arthraxon hispidus* is given as *Arthraxon hispidus* var. *cryptatherus* in NPSpecies.

Scientific Name	Common Name(s)	Notes
Asimina parviflora	Smallflower pawpaw	--
Asplenium platyneuron	Ebony spleenwort	--
Asplenium x *ebenoides*	Scott's spleenwort	--
Atriplex subspicata	Saline saltbush	*Atriplex subspicata* is given as *Atriplex patula* spp. *hastata* in NPSpecies.
Aureolaria flava	Smooth yellow false foxglove	--
Aureolaria laevigata	Entireleaf yellow false foxglove	--
Axonopus fissifolius	Carpetgrass, common carpetgrass, Louisiana grass	--
Bidens bipinnata	Spanish needles, spanish-needles	Exotic/invasive
Bromus japonicus	Japanese brome, Japanese bromegrass, Japanese chess	Exotic/invasive
Bromus rigidus	Ripgut brome	--
Callicarpa americana	American beautyberry, French mulberry	--
Cassia chamaecrista	Partridge pea	--
Chamaecrista nictitans ssp. *nictitans* var. *nictitans*	Sensitive partridge pea	*Chamaecrista nictitans* ssp. *nictitans* var. *nictitans* is given as *Cassia nictitans* in NPSpecies.
Celtis occidentalis	Common hackberry, hackberry, western hackberry	--
Cenchrus longispinus	Burgrass, field sandbur, innocent-weed	--
Cenchrus spinifex	Coastal sandbur	--
Cenchrus tribuloides	Sanddune sandbur	--
Centrosema virginianum	Spurred butterfly pean	New
Cerastium glomeratum	Sticky chickweed	Exotic/invasive
Chenopodium ambrosioides	Mexican tea, Mexican-tea	Exotic/invasive

Scientific Name	Common Name(s)	Notes
Chenopodium botrys	Jerusalem oak, Jerusalem oak goosefoot	Exotic/invasive
Chenopodium opulifolium	Seaport goosefoot	--
Clitoria mariana	Atlantic pigeonwings, pidgeonwings	--
Cnidoscolus stimulosus	Spurge nettle, finger rot	--
Commelina erecta	Erect dayflower, whitemouth dayflower	--
Conyza canadensis	Canada horseweed, horseweed fleabane, mares tail	--
Conyza canadensis var. *canadensis*	Canadian horseweed	--
Conyza canadensis var. *pusilla*	Canadian horseweed, fleabane	*Conyza canadensis* var. *pusilla* is given as *Erigeron pusillus* in NPSpecies.
Coreopsis lanceolata	Lance coreopsis, lanceleaf tickseed	--
Cornus florida	Flowering dogwood	--
Crotalaria rotundifolia	Rabbitbells	--
Croton glandulosus	Vente conmigo	--
Croton glandulosus var. *septentrionalis*	Vente conmigo	--
Croton punctatus	Croton, Gulf croton	--
Cucurbita pepo	Field pumpkin, vegetable marrow	--
Cuscuta pentagona var. *pentagona*	Fiveangled dodder	*Cuscuta pentagona* var. *pentagona* is given as *Cuscuta arvensis* in NPSpecies.
Cynodon dactylon	Bermudagrass	Exotic/invasive
Cyperus ovatus	Ovateleaf flatsedge	--
Datura stramonium	Jamestown weed, jimsonweed, mad apple	--
Desmodium paniculatum	Narrow-leaf tick-trefoil, panicled tickclover	--
Desmodium perplexum	Perplexed ticktrefoil	--

Scientific Name	Common Name(s)	Notes
Desmodium strictum	Pinebarren ticktrefoil	--
Dichanthelium acuminatum var*. acuminatum*	Tapered rosette grass	*Dichanthelium acuminatum* var*. acuminatum* is given as *Panicum acuminatum* in NPSpecies.
Dichanthelium commutatum	Variable panicgrass	--
Dichanthelium latifolium	Broadleaf rosette grass	--
Dichanthelium sabulorum var*. patulum*	Hemlock rosette grass	--
Dichanthelium scabriusculum	Woolly rosette grass	--
Dichanthelium scoparium	Velvet panicum	--
Dichanthelium sphaerocarpon var*. sphaerocarpon*	Roundseed panicgrass	Exotic/invasive; *Dichanthelium sphaerocarpon* var. *sphaerocarpon* is given as *Panicum sphaerocarpon* in NPSpecies.
Dichanthelium spretum	Eaton's rosette grass	--
Digitaria filiformis	Slender crabgrass	--
Digitaria sanguinalis	Crabgrass, hairy crab grass	Exotic/invasive
Eclipta prostrata	Eclipta, false daisy, yerba de tago, yerba de tajo	Exotic/invasive
Elephantopus tomentosus	Devil's grandmother, hairy elephantfoot	--
Eleusine indica	Crowsfoot grass, goose grass	Exotic/invasive
Eragrostis curvula	Weeping lovegrass	--
Eragrostis pilosa	India lovegrass, Indian lovegrass	Exotic/invasive
Eremochloa ophiuroides	Centipede grass	Exotic/invasive
Erigeron annuus	Annual fleabane, eastern daisy fleabane	--
Erigeron quercifolius	Oakleaf fleabane	--
Euonymus patens	Spindle tree	--
Eupatorium hyssopifolium var*. laciniatum*	Hyssopleaf thoroughwort	--

Scientific Name	Common Name(s)	Notes
Eustachys petraea	Finger grass, pinewoods fingergrass	--
Festuca rubra	Ravine fescue, red fescue	--
Ficus carica	Common fig, edible fig, fiku, piku	Exotic/invasive
Gaillardia pulchella	Firewheel, Indian blanket, rose-ring gaillardia	--
Galactia volubilis	Downy milkpea	--
Galium hispidulum	Coastal bedstraw	--
Galium pilosum	Hairy bedstraw	--
Galium pilosum var. *puncticulosum*	Hairy bedstraw	--
Gamochaeta pennsylvanica	Pennsylvania everlasting	*Gamochaeta pennsylvanica* is given as *Gnaphalium purpureum* var. *spathulatum* in NPSpecies.
Gamochaeta purpurea	Spoon-leaf purple everlasting	--
Gaura angustifolia	Southern beeblossom	--
Gaura biennis	Biennial beeblossom	--
Gaura mollis	Velvetweed	--
Geranium carolinianum	Carolina crane's-bill, Carolina geranium	--
Gladiolus x gandavensis	Gladiolus	Exotic/invasive
Gnaphalium purpureum var. *americanum*	Catfoot, chafe weed, everlasting, purple cudweed	--
Helianthemum corymbosum	Pinebarren frostweed	--
Helianthemum georgianum	Georgia frostweed	--
Heterotheca subaxillaris	Camphorweed, golden aster	--
Hieracium gronovii	Hawkweed	--
Holosteum umbellatum	Jagged chickweed	--
Hordeum pusillum	Little barley, little wildbarley	--

Scientific Name	Common Name(s)	Notes
Hypericum gentianoides	Orangegrass, pinweed St. Johnswort	--
Hypericum perforatum	Common St. Johnswort, Klamath weed	Exotic/invasive
Hypoxis hirsuta	Common goldstar, eastern yellow star-grass	--
Ipomoea batatas	Sweet potato	--
Juniperus virginiana	Eastern redcedar, eastern red-cedar, red cedar juniper	--
Kummerowia striata	Common lespedeza, Japanese clover	Exotic/invasive
Lactuca canadensis	Canada lettuce, Florida blue lettuce, wild lettuce	--
Lactuca graminifolia	Grass-leaf lettuce, grassleaf lettuce	--
Lagenaria siceraria	Bottle gourd	--
Lamium amplexicaule	Common henbit, giraffehead, henbit, henbit deadnettle	Exotic/invasive
Lantana camara	Lantana, largeleaf lantana	Exotic/invasive
Lechea mucronata	Hairy pinweed	--
Lechea pulchella var*. pulchella*	Leggett's pinweed	*Lechea pulchella* var. *pulchella* is given as *Lechea leggettii* in NPSpecies.
Lepidium virginicum	Poor man's pepper grass, poorman pepperweed, poorman's pepper	--
Lespedeza cuneata	Chinese lespedeza, sericea lespedeza	Exotic/invasive
Lespedeza virginica	Slender lespedeza	--
Leucanthemum vulgare	Ox-eye daisy, oxeye daisy, oxeye-daisy, oxeyedaisy	--
Liatris pilosa	Shaggy blazing star	*Liatris pilosa* is given as *Liatris graminifolia* in NPSpecies.
Lolium multiflorum	Annual ryegrass, Italian ryegrass	--

Scientific Name	Common Name(s)	Notes
Lolium perenne	Italian ryegrass, perennial rye grass, perennial ryegrass	--
Lolium pratense	Meadow fescue, meadow ryegrass	--
Maclura pomifera	Bois d'arc, osage orange, osage-orange, osageorange	Exotic/invasive
Marrubium vulgare	Horehound, white horehound	--
Melia azedarach	Chinaberry, chinaberry tree	Exotic/invasive
Melica mutica	Oniongrass, twoflower melic, twoflower melicgrass	--
Mimosa microphylla	Littleleaf sensitive-briar, sensitive brier	--
Monarda punctata	Spotted beebalm	--
Morella caroliniensis	Evergreen bayberry, southern bayberry	--
Morella cerifera	Small wax myrtle, waxmyrtle	--
Nothoscordum bivalve	Crowpoison	--
Nuttallanthus canadensis	Canada toadflax	--
Oenothera biennis	Common evening primrose	--
Oenothera fruticosa	Narrowleaf evening-primrose, sundrops	--
Oenothera fruticose ssp. *Fruticosa*	Narrowleaf evening primrose	*Oenothera fruticosa* ssp. *fruticosa* is given as *Kneiffia arenicola* in NPSpecies.
Oenothera humifusa	Seabeach evening-primrose, seabeach evening primrose	--
Oenothera laciniata	Cut-leaf evening-primrose	--
Oenothera parviflora	Northern evening-primrose	--
Oplismenus hirtellus	Bristle basketgrass	--
Opuntia ficus-indica	Indian fig, Indian-fig, tuna cactus	Exotic/invasive

Scientific Name	Common Name(s)	Notes
Opuntia humifusa	Devil's-tongue, pricklypear	--
Opuntia pusilla	Cockspur pricklypear	--
Osmanthus americanus	Devilwood, wild olive	--
Oxalis rubra	Oxalis rubra, windowbox woodsorrel	Exotic/invasive
Oxalis stricta	Common yellow oxalis, erect woodsorrel, sheep sorrel, sourgrass	--
Oxalis violacea	Purple woodsorrel, violet wood-sorrel, violet woodsorrel	--
Panicum lancearium	Fall panic, fall panicgrass, fall panicum, western witchgrass	--
Paronychia baldwinii ssp*. Baldwinii*	Baldwin's nailwort	*Paronychia baldwinii* ssp. *baldwinii* is given as *Anychiastrum baldwinii* in NPSpecies.
Paronychia baldwinii ssp*. Riparia*	Baldwin's nailwort	*Paronychia baldwinii* ssp. *riparia* is given as *Paronychia riparia* in NPSpecies.
Passiflora incarnata	Purple passionflower, maypop	--
Passiflora lutea	Passionflower, yellow passionflower	--
Petunia x *atkinsiana [axillaris* x *integrifolia]*	Garden petunia	Exotic/invasive; *Petunia* x *atkinsiana* [*axillaris* x *integrifolia*] is given as *Petunia* x *atkinsiana* in NPSpecies.
Phleum pratense	Common timothy, timothy	--
Phlox drummondii	Annual phlox, drummond phlox	Exotic/invasive
Phoradendron leucarpum	Oak mistletoe	--
Physalis pubescens	Groundcherry, husk tomato, husk-tomato	--
Physalis viscosa	Grape groundcherry, groundcherry, starhair groundcherry	--
Physalis walterq	Walter's groundcherry	*Physalis vicosa* ssp. *maritima*, included in NPSpecies, is now a synonym of *Physalis walteri*.

Scientific Name	Common Name(s)	Notes
Phytolacca americana var. *americana*	American pokeweed	*Phytolacca americana* var. *americana* is given as *Phytolacca decandra* in NPSpecies.
Pinus taeda	Loblolly pine	--
Piptochaetium avenaceum	Blackseed needlegrass, blackseed speargrass	--
Pityopsis graminifolia var. *graminifolia*	Silkgrass, narrowleaf silkgrass	SSC; *Pityopsis graminifolia* var. *graminifolia* is given as *Chrysopsis graminifolia* in NPSpecies.
Plantago virginica	Paleseed indianwheat, Virginia plantain	--
Pleopeltis polypodioides ssp. *Polypodioides*	Resurrection fern	Fern; *Pleopeltis polypodiodes* ssp. *polypodioides* is given as *Polypodium polypodioides* in NPSpecies.
Pluchea carolinensis	Cure for all	--
Poa pratensis	Kentucky bluegrass	Exotic/invasive
Polygala verticillata	Whorled milkwort	--
Polygonum glaucum	Seaside knotweed	SSC
Polystichum acrostichoides	Christmas fern	New; Fern
Populus alba	White poplar	Exotic/invasive
Potentilla canadensis	Dwarf cinquefoil	New
Prunus angustifolia	Chickasaw plum	--
Prunus caroliniana	Carolina laurelcherry	--
Prunus serotina	Black cherry, black chokecherry	--
Pseudognaphalium obtusifolium ssp. *Obtusifolium*	Rabbit-tobacco	*Pseudognaphalium obtusifolium* ssp. *obtusifolium* is given as *Gnaphalium obtusifolium* in NPSpecies.
Pteridium aquilinum	Bracken, bracken fern, northern bracken fern, western brackenfern	Fern
Pterocaulon virgatum	Wand blackroot	--
Pyrrhopappus carolinianus	Carolina desert chicory, Carolina false-dandelion	--

Scientific Name	Common Name(s)	Notes
Quercus falcata	Southern red oak	--
Quercus stellata	Post oak	--
Raphanus raphanistrum	Wild radish	--
Rhus copallina	Dwarf sumac, shining sumac	--
Rhus copallinum	Winged sumac, flameleaf sumac	--
Ricinus communis	Castor bean, castorbean	--
Robinia pseudoacacia	Black locust, false acacia, yellow locust	--
Rosa carolina	Carolina rose	--
Rosa multiflora	Multiflora rose	Exotic/invasive; New
Rubus allegheniensis	Allegheny blackberry	--
Rubus cuneifolius	Sand blackberry	New
Rubus persistens	Persistent blackberry	--
Rudbeckia hirta	Blackeyed susan	--
Saccharum giganteum	Sugarcane plumegrass	--
Salicornia maritima	Slender glasswort, slender grasswort	--
Salsola kali	Prickly Russian thistle, Russian thistle, tumbleweed	Exotic/invasive
Sanicula canadensis	Canada sanicle, Canadian blacksnakeroot	--
Sarcocornia perennis	Chickenclaws	--
Sassafras albidum	Sassafras	--
Senecio vulgaris	Common groundsel, old-man-in-the-Spring	Exotic/invasive
Sida rhombifolia	Arrowleaf sida, cuban jute, Cuban-jute	Exotic/invasive
Sideroxylon lycioides	Buckthorn bully	--

Scientific Name	Common Name(s)	Notes
Sideroxylon tenax	Tough bumelia	--
Silene antirrhina	Catchfly, sleepy campion, sleepy catchfly	--
Solanum carolinense	Apple of Sodom, bull nettle, Carolina horsenettle, devil's tomato, horsenettle, sand briar	--
Solanum gracilius	Slender nightshade	--
Solanum pseudogracile	Glowing nightshade	--
Solidago odora	Anise scented goldenrod, fragrant goldenrod	--
Sonchus asper	Perennial sowthistle, prickly sowthistle, spiny sowthistle	Exotic/invasive
Sonchus oleraceus	Annual sowthistle, common sow-thistle	Exotic/invasive
Sorghastrum elliottii	Slender Indiangrass	--
Specularia perfoliata	Clasping Venus' looking-glass	--
Spergularia salina	Salt sandspurry	--
Stellaria media	Chickweed, common chickweed, nodding chickweed	Exotic/invasive
Stenotaphrum secundatum	St. Augustine grass	Exotic/invasive
Symphyotrichum racemosum	Smooth white oldfield aster	--
Taraxacum officinale	Blowball, common dandelion, dandelion, faceclock	--
Tillandsia usneoides	Spanish moss	--
Toxicodendron pubescens	Atlantic poison oak, poison oak	--
Trichostema dichotomum	Blue curls, forked bluecurls	--
Tridens flavus	Purpletop, purpletop tridens	--
Trifolium aureum	Golden clover	Exotic/invasive
Trifolium dubium	Hop clover, smallhop clover, suckling clover	Exotic/invasive

Scientific Name	Common Name(s)	Notes
Trifolium repens	Dutch clover, ladino clover, white clover	Exotic/invasive
Triodanis perfoliata	Clasping bellwort, clasping Venus' looking-glass	--
Triplasis purpurea	Purple sand grass, purple sandgrass	--
Uniola paniculata	Seaoats	--
Vaccinium arboreum	Farkleberry, tree sparkleberry, tree-huckleberry	--
Vaccinium corymbosum	Highbush blueberry	--
Vaccinium fuscatum	Black highbush blueberry	--
Vaccinium stamineum	Deerberry	--
Vaccinium tenellum	Small black blueberry	--
Vaccinium virgatum	Smallflower blueberry	--
Valerianella radiata	Beaked cornsalad	--
Verbascum thapsus	Big taper, common mullein, flannel mullein	Exotic/invasive
Verbena polystachya	Verbena	--
Verbena scabra	Sandpaper vervain	--
Veronica arvensis	Speedwell	Exotic/invasive
Vulpia myuros	Foxtail fescue, rat-tail fescue, rat-tailed fescue, rattail fescue	Exotic/invasive
Vulpia sciurea	Squirreltail fescue	--
Yucca aloifolia	Aloe yucca	--
Yucca gloriosa	Moundlily yucca	--

Table C-2. Wetland plants reported to occur in CALO according to the NPS Certified Species List (NPS 2013c), with information on species of concern from the North Carolina Conservation Board (2010; NCDA Protected Plant List, http://www.ncagr.gov/plantindustry/plant/plantconserve/plist.htm), the Natural Heritage Program of NC DENR (Buchanan and Finnegan 2010), and the U.S. Fish and Wildlife Service (http://www.fws.gov/raleigh/species/cntylist/carteret.html, last accessed in August 2014). Information on exotic species was taken from Smith (2008); new taxa indicated are from Byrne et al. (2012—survey conducted in 2010).

Scientific Name	**Common Name(s)**	**Notes**
Acer rubrum	Red maple	--
Agalinis maritima	Saltmarsh false foxglove, seaside gerardia	--
Agalinis purpurea	Purple false foxglove	--
Agrostis stolonifera	Carpet bentgrass, creeping bent, creeping bentgrass	--
Amaranthus cannabinus	Tidalmarsh amaranth	--
Amaranthus pumilus	Seabeach amaranth, seaside amaranth	SSC
Amelanchier canadensis	Canadian serviceberry	--
Amelanchier obovalis	Coastal serviceberry	--
Ammannia coccinea	Purple ammannia, valley redstem	--
Ammannia latifolia	Pink redstem	--
Ampelopsis arborea	Peppervine	--
Andropogon glaucopsis	Purple bluestem	*Andropogon glaucopsis* is given in NPSpecies as *Andropogon virginicus* var. *glaucopsis*.
Andropogon virginicus	Broomsedge, broomsedge bluestem, yellow bluestem	--
Andropogon virginicus var. *virginicus*	Broomsedge bluestem	--
Apios americana	Apios americana, groundnut, potatobean	--
Apocynum cannabinum	Indianhemp, common dogbane, dogbane, hemp dogbane	--
Aralia spinosa	Angelicatree, devil's walkingstick	--
Arenaria lanuginosa	Spreading sandwort	SSC
Arenaria serpyllifolia	Thymeleaf sandwort	Exotic/invasive
Asclepias lanceolata	Fewflower milkweed	--
Aster subulatus var. *subulatus*	Eastern annual saltmarsh aster	--
Atriplex cristata	Crested saltbush	--
Atriplex patula	Halberd-leaf orache, spear saltbush, spear saltweed	--

Scientific Name	Common Name(s)	Notes
Atriplex prostrata	Triangle orache	*Atriplex postrata* is given in NPSpecies as *Atriplex platula* var. *hastate.*
Baccharis angustifolia	Saltwater false willow	--
Baccharis halimifolia	Eastern baccharis, silverling	Exotic/invasive
Bacopa monnieri	Coastal waterhyssop, herb of grace, herb-of-grace	--
Berchemia scandens	Rattan-vine, Alabama supplejack	--
Bidens laevis	Burmarigold, smooth beggartick, smooth beggarticks	--
Boehmeria cylindrica	Small-spike false nettle	--
Borrichia frutescens	Bushy seaoxeye, bushy seaside tansy	--
Briza minor	Little quakinggrass	--
Buchnera americana	American bluehearts, bupleurum	--
Bulbostylis capillaris	Densetuft hairsedge, threadleaf beakseed	--
Bulbostylis ciliatifolia	Capillary hairsedge	--
Bulbostylis stenophylla	Sandy field hairsedge	--
Cakile edentula	American searocket	--
Cakile edentula ssp. *harperi*	Harper's searocket	*Cakile edentula* ssp. *harperi* is given in NPSpecies as *Cakile harperi.*
Calystegia sepium	Bearbind, devil's guts, hedge bindweed	--
Campsis radicans	Trumpet creeper	New
Canna x *generalis*	Canna lily	--
Cardamine hirsuta	Hairy bittercress	Exotic/invasive
Carex alata	Broadwing sedge	--
Carex albolutescens	Greenwhite sedge	--
Carex floridana	Florida sedge	*Carex floridana* is given in NPSpecies as *Carex nigromarginata* var. *floridana*.
Carex nigromarginata	Black edge sedge	--
Carpinus caroliniana	American hornbeam	--
Carya glabra	Pignut hickory	--

Scientific Name	Common Name(s)	Notes
Catalpa bignonioides	Southern catalpa	--
Centella asiatica	Spadeleaf	Exotic/invasive
Centella erecta	Erect centella	--
Chamaesyce maculata	Spotted sandmat	--
Chamaesyce nutans	Eyebane, nodding spurge, spotted sandmat, spotted spurge	--
Chamaesyce polygonifolia	Seaside sandmat, seaside spurge	--
Chasmanthium laxum	Slender woodoats, spike uniola	--
Chenopodium glaucum	Oak-leaf goosefoot, oakleaf goosefoot	--
Cicuta maculata	Common water hemlock, poison parsnip	--
Cicuta maculata var*. maculata*	Spotted water hemlock	*Cicuta maculata* var. *maculata* is given in NPSpecies as *Cicuta curtissii.*
Cirsium horridulum	Yellow thistle	--
Cirsium horridulum var*. horridulum*	Yellow thistle	*Cirsium horridulum* var. *horridulum* is given in NPSpecies as *Cirsium spinosissimum*.
Cladium mariscus ssp*. jamaicense*	Jamaica swamp sawgrass, saw grass	Exotic/invasive; *Cladium mariscus* ssp. *jamaicense* is given in NPSpecies as *Cladium jamaicense*.
Clematis catesbyana	Satincurls, coastal virgin's-bower	SSC
Clematis ligusticifolia	Virgin's bower, virgins bower, virginsbower, western white clematis	--
Commelina erecta	Erect dayflower, whitemouth dayflower	--
Commelina erecta var*. angustifolia*	Whitemouth dayflower	*Commelina erecta* var. *angustifolia* is given in NPSpecies as *Commelina angustifolia*.
Corallorrhiza wisteriana	Coralroot, spring coralroot	SSC

Scientific Name	Common Name(s)	Notes
Coreopsis gladiata	Coastal plain tickseed	--
Cornus foemina	Stiff dogwood	--
Cuphea carthagenensis	Colombian waxweed	Exotic/invasive
Cuscuta gronovii	Scaldweed	--
Cynanchum angustifolium	Gulf coast swallow-wort, climbing milkweed	--
Cyperus bipartitus	Brook flatsedge, shining flat sedge, slender flatsedge	--
Cyperus croceus	Baldwin's flatsedge	--
Cyperus filicinus	Fern flatsedge	--
Cyperus flavescens	Pale flatsedge, yellow flatsedge	--
Cyperus haspan	Haspan flatsedge	--
Cyperus odoratus	Fragrant flatsedge, rusty flat sedge	--
Cyperus polystachyos	Manyspike flatsedge	--
Cyperus polystachyos var*. texensis*	Texan flatsedge	--
Cyperus retrofractus	Rough flatsedge	--
Cyperus retrorsus	Pine barren flatsedge	--
Cyperus retrorsus var*. retrorsus*	Pine barren flatsedge	Exotic/invasive; *Cyperus retrorsus* var. *retrorsus* is given in NPSpecies as *Cyperus cylindricus.*
Cyperus strigosus	Strawcolored flatsedge, strawcolor flatsedge, strawcolor nutgrass	--
Cyperus tetragonus	Fourangle flatsedge	SSC
Dactylus glomerata	Cock's-foot or orchard grass	--
Decodon verticillatus	Swamp loosestrife	--
Dichanthelium aciculare	Needleleaf rosette grass	--
Dichanthelium acuminatum var. *fasciculatum*	Huachuca panic, tapered rosette grass, western panicgrass	--
Dichanthelium dichotomum var. *dichotomum*	Cypress panicgrass	--
Dichanthelium laxiflorum	Openflower rosette grass	--

Scientific Name	Common Name(s)	Notes
Dichanthelium sabulorum var. *thinium*	Hemlock rosette grass	*Dichanthelium sabulorum* var. *thinium* is given in NPSpecies as *Panicum portoricense* var. *portoricense*.
Dichondra carolinensis	Carolina ponysfoot, grass ponyfoot	--
Diodia teres	Poor joe, poorjoe, rough buttonweed	--
Diodia virginiana	Virginia buttonweed	--
Diospyros virginiana	Common persimmon, eastern persimmon, persimmon	--
Distichlis spicata	Saltgrass, desert saltgrass, inland saltgrass, marsh spikegrass	--
Dulichium arundinaceum	Threeway sedge	--
Echinochloa crus-galli	Barnyard grass, cockspur, Japanese millet	Exotic/invasive
Echinochloa walteri	Coast cockspur, coast cockspur grass, walter's barnyard grass	--
Eleocharis albida	White spikerush	--
Eleocharis fallax	Creeping spikerush	--
Eleocharis flavescens	Yellow spikerush	*Eleocharis flavescens* is given in the NPSpecies as *Eleocharis ochreata.*
Eleocharis microcarpa	Smallfruit spikerush	--
Eleocharis montevidensis	Sand spikerush	--
Eleocharis olivacea	Bright green spikerush	--
Eleocharis robbinsii	Robbins spikerush, Robbins' spikerush	SSC
Eleocharis rostellata	Beaked spike-rush, beaked spikesedge	--
Elephantopus carolinianus	Carolina elephantsfoot, leafy elephantfoot	--
Elephantopus nudatus	Naked elephantfoot, smooth elephantsfoot	--
Elymus virginicus	Virginia wild rye, Virginia wildrye	--
Elymus virginicus	Virginia wildrye	--
Eragrostis elliottii	Field lovegrass	--
Eragrostis pectinacea	Purple love grass, purple lovegrass	--
Eragrostis refracta	Coastal lovegrass	--
Eragrostis spectabilis	Petticoat-climber, purple lovegrass	--

Scientific Name	Common Name(s)	Notes
Erechtites hieraciifolia	Burnweed	--
Eupatorium anomalum	Florida thoroughwort	--
Eupatorium capillifolium	Dogfennel	--
Eupatorium dubium	Coastalplain joepyeweed	--
Eupatorium leucolepis	Justiceweed	--
Eupatorium mohrii	Mohr's thoroughwort	--
Eupatorium pilosum	Rough boneset	--
Eupatorium serotinum	Lateflowering thoroughwort	--
Euthamia caroliniana	Slender goldentop	Exotic/invasive; *Euthamia minor*, *Euthamia tenuifolia*, and *Solidago microcephala*, included in NPSpecies, are all synonyms of *Euthamia caroliniana*.
Festuca octoflora	Sixweeks fescue	--
Fimbristylis autumnalis	Slender fimbry	--
Fimbristylis caroliniana	Carolina fimbry	--
Fimbristylis castanea	Marsh fimbry, saltmarsh fimbristylis	--
Fimbristylis dichotoma	Forked fimbry	--
Fimbristylis thermalis	Hot springs fimbry, hotspring fimbry, hotsprings fimbry	--
Fraxinus caroliniana	Carolina ash	New
Fuirena breviseta	Saltmarsh umbrella-sedge, saltmarsh umbrellasedge	--
Fuirena squarrosa	Hairy umbrella-sedge, hairy umbrellasedge	--
Galium obtusum	Blunt-leaf bedstraw, bluntleaf bedstraw, bristly bedstraw	--
Galium obtusum ssp. *obtusum*	Bluntleaf bedstraw	--
Galium tinctorium	Stiff marsh bedstraw	New
Gaylussacia dumosa	Dwarf huckleberry	New
Gelsemium sempervirens	Carolina jessamine, evening trumpetflower	--
Gerardia maritima	Saltmarsh false foxglove	--
Glyceria acutiflora	Creeping mannagrass	--
Gratiola virginiana	Roundfruit hedgehyssop, Virginia hedgehyssop	--

Scientific Name	Common Name(s)	Notes
Hamamelis virginiana	American witchhazel, witch-hazel, witchhazel	--
Heliotropium curassavicum	Quail plant, salt heliotrope, seaside heliotrope	--
Hibiscus moscheutos	Crimsoneyed rosemallow, swamp rosemallow	--
Hydrocotyle bonariensis	Largeleaf pennywort	--
Hydrocotyle umbellata	Manyflower marshpennywort, umbrella pennyroyal	--
Hydrocotyle verticillata	Whorled marsh pennywort, whorled pennyroyal	--
Hypericum crux-andreae	Atlantic st. peter's-wort, St. Peterswort	--
Hypericum hypericoides	St. Andrew's cross, St. Andrews cross	--
Hypericum mutilum	Dwarf St. Johnswort	--
Ilex cassine	Dahoon	--
Ilex glabra	Inkberry	--
Ilex opaca	American holly	--
Ilex vomitoria	Yaupon	--
Ipomoea lacunosa	Pitted morningglory, white morninglory, whitestar	--
Ipomoea pandurata	Bigroot morningglory, bigroot morninglory, man of the earth	--
Ipomoea sagittata	Saltmarsh morning-glory, saltmarsh morningglory	--
Iresine rhizomatosa	Juda's bush, rootstock bloodleaf	--
Iva frutescens	Gronovis hawkweed, queendevil	--
Iva imbricata	Marshelder, seacoast marshelder, seashore elder	--
Juncus biflorus	Bog rush	--
Juncus bufonius	Toad rush	--
Juncus canadensis	Canadian rush	--
Juncus coriaceus	Leathery rush	--
Juncus dichotomus	Forked rush	--
Juncus effusus	Common rush, lamp rush	--
Juncus marginatus	Grassleaf rush	--
Juncus megacephalus	Bighead rush	--
Juncus roemerianus	Black needlerush, needlegrass rush	--
Juncus scirpoides	Needlepod rush	--
Juncus tenuis	Field rush, path rush, poverty rush, slender rush	--

Scientific Name	Common Name(s)	Notes
Juniperus virginiana var. *silicicola*	Southern redcedar	*Juniperus virginiana* var. *silicola* is given in NPSpecies as *Juniperus silicicola.*
Kosteletzkya virginica	Virginia saltmarsh mallow, Virginia saltmarsh willow	--
Krigia virginica	Virginia dwarfdandelion	--
Lilaeopsis chinensis	Eastern grasswort	--
Limonium carolinianum	Carolina sea-lavender, Carolina sealavender	--
Linum floridanum var. floridanum	Florida yellow flax	--
Linum medium	Stiff yellow flax	--
Linum medium var. *medium*	Stiff yellow flax	--
Linum virginianum	Woodland flax	--
Lonicera japonica	Chinese honeysuckle, Japanese honeysuckle	Exotic/invasive
Lonicera sempervirens	Trumpet honeysuckle	--
Ludwigia alata	Winged primrose-willow	--
Ludwigia maritima	Seaside primrose-willow	--
Ludwigia microcarpa	Smallfruit primrose-willow	--
Ludwigia palustris	Marsh primrose-willow, marsh seedbox	--
Ludwigia repens	Creeping primrose-willow, creeping waterpurslane	--
Ludwigia virgata	Savannah primrose-willow	--
Lycopus virginicus	Virginia bugleweed, virginia bugleweed, Virginia water horehound	--
Lyonia lucida	Fetterbush lyonia	--
Lythrum lineare	Wand lythrum, loosestrife	--
Magnolia grandiflora	Southern magnolia	New
Magnolia virginiana	Sweetbay	--
Matelea gonocarpos[n]	Angular-fruit milkvine	--
Melothria pendula	Drooping melonnettle, Guadeloupe cucumber	--
Mikania scandens	Climbing hempvine, climbing hempweed	--
Mitchella repens	Partridgeberry	--
Mitreola petiolata	Lax hornpod	--
Mollugo verticillata	Carpetweed, green carpetweed	Exotic/invasive

Scientific Name	Common Name(s)	Notes
Morus rubra	Red mulberry	--
Muhlenbergia capillaris	Hairawn muhly	--
Muhlenbergia capillaris var. *filipe*	Gulf hairawn muhly, gulf muhly	*Muhlenbergia capillaris* var. *filipes* is given in NPSpecies as *Muhlenbergia capillaris* var. *filipes.*
Myosurus minimus	Tiny mousetail	--
Myrica gale	Sweetgale	SSC
Nyssa ogeche	Ogeechee tupelo	--
Nyssa sylvatica	Black gum, black tupelo, blackgum	--
Nyssa sylvatica var. *biflora*	Swamp tupelo	--
Oldenlandia uniflora	Clustered mille graines, oneflower oldenlandia	--
Onoclea sensibilis	Sensitive fern	Fern
Ophioglossum petiolatum	Longstem adderstongue	--
Osmunda regalis	Royal fern	Fern
Osmunda regalis var. *spectabilis*	Royal fern	Fern
Panicum anceps	Beaked panicgrass, beaked panicum	--
Panicum amarum	Bitter panicgrass, bitter panicum	--
Panicum dichotomiflorum	Fall panicgrass	--
Panicum rigidulum var. *pubescens*	Redtop panicgrass, redtop panicum	*Panicum rigidulum* var. *pubescens* is given in NPSpecies as *Panicum longifolium*.
Panicum rigidulum var. *rigidulum*	Redtop panicgrass, redtop panicum	--
Panicum verrucosum	Warty panicgrass	--
Panicum virgatum	Old switch panic grass, switchgrass	--
Panicum virgatum var. *virgatum*	Switchgrass	--
Parapholis incurva	Curved sicklegrass	--
Parietaria floridana	Florida pellitory, pellitory	--
Parietaria praetermissa	Large-seed pellitory, clustered pellitory	SSC
Parthenocissus quinquefolia	Virginia creeper	--

Scientific Name	Common Name(s)	Notes
Paspalum distichum	Knotgrass, knotroot paspalum	--
Paspalum floridanum	Florida paspalum	--
Paspalum laeve	Field paspalum	--
Paspalum notatum	Bahia grass, bahiagrass	Exotic/invasive
Paspalum setaceum	Fringeleaf paspalum, sand paspalum, slender crown grass	--
Paspalum urvillei	Vasey grass, Vasey's grass, vaseygrass	Exotic/invasive
Paspalum vaginatum	Seashore paspalum	--
Persea borbonia	Redbay	--
Persea palustris	Swamp bay	--
Phalaris caroliniana	Carolina canarygrass	--
Phragmites australis	Common reed	New
Phyla nodiflora	Turkey tangle fogfruit, frogbit	--
Phytolacca americana	American pokeweed, common pokeweed, inkberry, pigeonberry	--
Pilea fontana	Lesser clearweed	--
Pilea pumila	Canada clearweed, Canadian clearweed	--
Plantago heterophylla	Slender plantain	--
Plantago lanceolata	Buckhorn plantain, English plantain, lanceleaf Indianwheat	Exotic/invasive
Pluchea camphorata	Camphor pluchea, camphor weed	--
Pluchea foetida	Stinking camphorweed	--
Pluchea odorata var. *odorata*	Sweetscent	*Pluchea odorata* var. *odorata* is given in NPSpecies as *Pluchea purpurascens.*
Pluchea rosea	Rosy camphorweed	--
Poa annua	Annual blue grass, annual bluegrass, walkgrass	--
Polygala lutea	Orange milkwort	--
Polygonum lapathifolium	Curltop ladysthumb, dock-leaf smartweed, nodding smartweed	--
Polygonum persicaria	Ladysthumb, ladysthumb smartweed, smartweed	--
Polygonum punctatum	Dotted smartweed	--

Scientific Name	Common Name(s)	Notes
Polygonum punctatum var. *confertiflorum*	Dotted smartweed	--
Polygonum setaceum	Bog smartweed	--
Polypogon monspeliensis	Annual rabbit's-foot grass, annual rabbitsfoot grass	--
Polypremum procumbens	Juniper leaf	--
Portulaca oleracea	Common purslane, duckweed, garden purslane	--
Proserpinaca pectinata	Combleaf mermaidweed, mermaidweed	--
Ptilimnium capillaceum	Herbwilliam, threadleaf mockbishopweed	--
Quercus laurifolia	Laurel oak	--
Quercus nigra	Water oak	--
Quercus phellos	Willow oak	--
Quercus virginiana	Live oak	--
Ranunculus sceleratus	Celeryleaf buttercup, cursed buttercup	--
Rhexia mariana	Maryland meadowbeauty	--
Rhynchospora caduca	Anglestem beaksedge	--
Rhynchospora colorata	Starrush whitetop	--
Rhynchospora glomerata	Clustered beaksedge	--
Rhynchospora latifolia	Sandswamp whitetop	--
Rhynchospora odorata	Fragrant beaksedge	SSC
Rosa palustris	Swamp rose	--
Rubus trivialis	Southern dewberry	--
Rumex crispus	Curley dock, narrowleaf dock, sour dock, yellow dock	--
Rumex hastatulus	Heartwing dock, heartwing sorrel	--
Sabal minor	Dwarf palmetto	--
Sabatia campanulata	Slender rose gentian	New
Sabatia calycina	Coastal rose gentian	New
Sabatia stellaris	Rose of Plymouth, sea-pink	--
Sacciolepis striata	American cupscale	--
Sagina decumbens	Beach pearlwort, trailing pearlwort	--

Scientific Name	Common Name(s)	Notes
Sagittaria lancifolia	Bulltongue, bulltongue arrowhead, scythefruit arrowhead	*Sagittaria falcata*, included in NPSpecies, is now within the species *Sagittaria lancifolia*.
Sagittaria latifolia	Broadleaf arrowhead, common arrowhead	--
Salicornia bigelovii	Dwarf saltwort	--
Salicornia virginica	Virginia glasswort	--
Salix caroliniana	Salix, willow, willow species	--
Samolus valerandi ssp. *parviflorus*	Seaside brookweed	*Samolus valerandi* ssp. *parviflorus* is given in NPSpecies as *Samolus floribundus*.
Samolus parviflorus	Water-pimpernel	--
Saururus cernuus	Lizard's tail, lizards tail	--
Schizachyrium littorale	Shore little bluestem, seacoast bluestem	*Schizachyrium littorale* is given in NPSpecies as *Andropogon scoparius* var. *littoralis*.
Schizachyrium scoparium var. *scoparium*	Little bluestem, broomsedge	*Schizachyrium scoparium* var. *scoparium* is given in NPSpecies as *Andropogon scoparius*.
Schoenoplectus americanus	American bulrush, chairmaker's bulrush	*Schoenoplectus americanus*, included in NPSpecies, is also given as *Scirpus americanus* (synonym) in that List.
Schoenoplectus robustus	Sturdy bulrush, saltmarsh bulrush	--
Schoenoplectus tabernaemontani	Great bulrush, soft-stem bulrush, softstem bulrush	--
Scirpus acutus	Hardstem bulrush	--
Scleria triglomerata	Whip nutrush	--

Scientific Name	Common Name(s)	Notes
Scleria verticillata	Low nutrush	--
Scutellaria integrifolia	Helmet flower	--
Sesbania punicea	Rattelbox, rattlebox	--
Sesuvium maritimum	Slender seapurslane	--
Sesuvium portulacastrum	Shoreline seapurslane	--
Setaria magna	Giant bristlegrass	--
Setaria parviflora	Marsh bristlegrass, knotroot bristlegrass, yellow bristlegrass, foxtail grass	--
Setaria pumila ssp. pumila	Yellow foxtail	*Setaria pumila* ssp. *pumila* is given in NPSpecies as *Setaria glauca*.
Sisyrinchium atlanticum	Eastern blue-eyed grass, eastern blueeyed grass	*Sisyrinchium mucronatum* var. *atlanticum*, included in NPSpecies is a synonym of *Sisyrinchium atlanticum*.
Sisyrinchium mucronatum	Needle-tip blue-eyed-grass, needletip blue-eyed grass	--
Sisyrinchium rosulatum	Annual blue-eyed grass, annual blueeyed grass	Exotic/invasive
Smilax auriculata	Earleaf greenbrier	--
Smilax bona-nox	Saw greenbrier	--
Smilax glauca	Cat greenbrier	--
Smilax laurifolia	Laurel greenbrier	--
Smilax rotundifolia	Bullbriar, common catbriar, common greenbrier	--
Smilax tamnoides	Bristly greenbrier	--
Solidago fistulosa	Pinebarren goldenrod	--
Solidago sempervirens	Seaside goldenrod	--
Sparganium androcladum	Branched bur-reed, branched burreed, branching bur-reed	--
Spartina alterniflora	Smooth cordgrass, Atlantic cordgrass, saltmarsh cordgrass	--
Spartina cynosuroides	Big cordgrass	--
Spartina patens	Salt meadow cordgrass, marshhay cordgrass	--
Spermolepis divaricata	Forked scaleseed, roughfruit scaleseed	--

Scientific Name	Common Name(s)	Notes
Sphenopholis obtusata	Prairie wedgegrass, prairie wedgescale	--
Sphenopholis pensylvanica	Swamp wedgescale	--
Spiranthes lacera var. *gracilis*	Northern slender lady's tresses	*Spiranthes lacera* var. *gracilis* is given in NPSpecies as *Spiranthes gracilis.*
Spiranthes laciniata	Lacelip-ladies'-tresses, lacelip ladiestresses	SSC
Spiranthes ovalis	October ladies'-tresses	--
Spiranthes vernalis	Spring lady's tresses, upland ladiestresses, nodding ladies tresses	--
Sporobolus indicus	Rattail smutgrass, smut grass, smutgrass	--
Sporobolus indicus var. *indicus*	Smut grass	*Sporobolus indicus* var. *indicus* is given in NPSpecies as *Sporobolus poiretii*.
Sporobolus virginicus	Seashore dropseed, saltmarsh dropseed	SSC
Strophostyles helvola	Amberique-bean, trailing fuzzybean, trailing wildbean, wild bean	--
Strophostyles umbellata	Pink fuzzybean, perennial wildbean	--
Suaeda linearis	Annual seepweed	--
Symphyotrichum subulatum	Eastern annual saltmarsh aster	The taxon *Aster subulatus* var. *subulatus*, included in NPSpecies, is not mentioned in the USDA Plants database, but *Aster subulatus* is given as a synonym of *Symphyotrichum subulatum*.
Symphyotrichum tenuifolium	Perennial saltmarsh aster	--
Tamarix gallica	French tamarisk, saltcedar, tamarisk, tamarix	--
Taxodium distichum	Bald cypress, baldcypress	Exotic/invasive
Teucrium canadense	American germander, Canada germander	--
Thelypteris palustris[ee]	Eastern marsh fern, marsh fern, meadow fern	Fern

Scientific Name	Common Name(s)	Notes
Thelypteris palustris var*. pubescens*	Eastern marsh fern, marsh fern, meadow fern	Fern; *Thelypteris palustris* var. *pubescens* is given in NPSpecies as *Dryopteris thelypteris*.
Tilia americana var*. heterophylla*	American basswood	*Tilia americana* var. *heterophylla* is given in NPSpecies as *Tilia michauxii*.
Toxicodendron radicans	Eastern poison ivy, poison ivy, poisonivy	--
Tradescantia ohiensis	Bluejacket, Ohio spiderwort	--
Triadenum virginicum	Marsh St. john's wort, Virginia marsh St. Johnswort	--
Triglochin striata	Three-rib arrowgrass	--
Typha angustifolia	Narrow-leaf cat-tail, narrowleaf cattail	Exotic/invasive
Typha domingensis	Southern cattail, southern cat-tail	--
Typha latifolia	Broadleaf cattail, cattail, cattail (common), common cattail	--
Vaccinium myrsinites	Shiny blueberry	--
Veronica peregrina	Common speedwell, corn speedwell, rock speedwell	--
Viola x *primulifolia (*pro sp.*) [lanceolata* x *macloskeyi]*	Primrose-leaved violet	*Viola* x *primulifolia* L. (pro sp.) [*lanceolata* x *macloskeyi*] is given in NPSpecies as *Viola primulifolia*.
Vitis aestivalis	Summer grape	--
Vitis labrusca	Fox grape	--
Vitis rotundifolia	Muscadine, muscadine grape	--
Vulpia octoflora	Eight-flower six-weeks grass, pullout grass, sixweeks fescue	--
Woodwardia virginica	Virginia chainfern, virginia chainfern	Fern
Xanthium strumarium	Cocklebur, cockleburr, common cocklebur	--
Xyris caroliniana	Carolina yelloweyed grass	--
Zanthoxylum clava-herculis	Hercules' club, Hercules'-club, Hercules-club pricklyash	--

Table C-3. Aquatic Plants reported to occur in CALO according to the NPS Certified Species List (NPS 2013c).

ScientificName	Common Name(s)	Notes
Ceratophyllum demersum	Common hornwort, coon's tail, coon's-tail, coontail, hornwort	freshwater
Myriophyllum verticillatum	Whorl-leaf watermilfoil, whorled water-milfoil	freshwater
Proserpinaca palustris	Marsh mermaid-weed, marsh mermaidweed	freshwater
Ruppia maritima	Widgeongrass	estuarine/marine
Utricularia purpurea	Eastern purple bladderwort, purple bladderwort	freshwater
Utricularia subulata	Zigzag bladderwort	freshwater
Zostera marina	Marine eelgrass, seawrack	marine

Table C-4. Fish reported to occur in CALO according to the NPS Certified Species List (NPS 2013c). Note that species are estuarine/marine unless otherwise noted. In this table, the notes regarding commercial and/or recreational importance are from the North Carolina Division of Marine Fisheries within NC DENR (NC DMF 2011—see http://www.ncfisheries.net/stocks/index.html, last accessed in August 2014). An additional species, the invasive lionfish (*Pterois volitans*) was added by the authors of this report to reflect recently published information.

Scientific Name	Common Name(s)	Notes
Ablennes hians	Flat needlefish	--
Abudefduf saxatilis	Sergeant major	--
Abudefduf taurus	Night sergeant	--
Acanthocybium solandri	Wahoo	--
Acanthostracion quadricornis	Scrawled cowfish	--
Acanthurus bahianus	Ocean surgeon	--
Acanthurus chirurgus	Coctorfish	--
Acanthurus coeruleus	Blue tang	--
Acipenser oxyrinchus	Atlantic sturgeon, Gulf sturgeon	SSC; Commercially and recreationally important; Species of concern (NC DMF)
Aetobatus narinari	Bonnetray, spotted eagle ray	--
Albula vulpes	Bonefish	--
Alectis ciliaris	African pompano, threadfin	--
Alosa aestivalis	Blueback herring, blueback shad	--
Alosa mediocris	Bonejack, fall herring, freshwater taylor	--
Alosa pseudoharengus	Alewife, bigeye herring, branch herring	--
Alosa sapidissima	American shad, Atlantic shad, common shad, white shad	Commercially important; Species of concern (NC DMF)
Aluterus schoepfii	Orange filefish	--
Aluterus scriptus	Scrawled filefish, unicornfish	--

Scientific Name	Common Name(s)	Notes
Anchoa hepsetus	Broad-striped anchovy, striped anchovy	--
Anchoa lyolepis	Dusky anchovy, shortfinger anchovy	--
Anchoa mitchilli	Bay anchovy	--
Ancylopsetta ommata	Gulf of Mexico ocellated flounder	--
Anguilla rostrata	American eel	SSC; Commercially important; Depleted (NC DMF); Catadromous
Antennarius ocellatus	Ocellated frogfish	--
Apogon pseudomaculatus	Twospot cardinalfish	--
Archosargus probatocephalus	Sheepshead	Commercially important; Status unknown (NC DMF)
Ariomma regulus	Spotted driftfish	--
Ariopsis felis	Hardhead catfish	--
Astroscopus guttatus	Northern stargazer	--
Astroscopus y-graecum	Southern stargazer	--
Auxis rochei	Bullet mackerel, bullet tuna, long corseletted frigate mackerel	--
Auxis thazard	Frigate mackerel, frigate tuna	--
Bagre marinus	Gafftopsail catfish	--
Bairdiella chrysoura	Silver perch	--
Balistes capriscus	Gray triggerfish	--
Brevoortia tyrannus	Atlantic menhaden, bugfish, bunker	Commercially important; Species of concern (NC DMF)
Calamus leucosteus	Whitebone porgy	--
Cantherhines pullus	Orangespotted filefish	--
Carangoides bartholomaei	Yellow jack	--

Scientific Name	Common Name(s)	Notes
Carangoides ruber	Bar jack	--
Caranx crysos	Blue runner	--
Caranx hippos	Crevalle jack	--
Caranx latus	Horse-eye jack	--
Carcharhinus acronotus	Blacknose shark	Commercially and recreationally important; Species of concern (NC DMF)
Carcharhinus brevipinna	Spinner shark	Commercially and recreationally important; Species of concern (NC DMF)
Carcharhinus falciformis	Silky shark	Commercially and recreationally important; Species of concern (NC DMF)
Carcharhinus leucas	Bull shark	Commercially and recreationally important; Species of concern (NC DMF)
Carcharhinus limbatus	Blacktip shark	Commercially and recreationally important; Species of concern (NC DMF)
Carcharhinus obscurus	Dusky shark	Commercially and recreationally important; Species of concern (NC DMF)
Carcharhinus plumbeus	Sandbar shark	Commercially and recreationally important; Species of concern (NC DMF)
Carcharias taurus	Sand tiger, sand tiger shark	Commercially and recreationally important; Species of concern (NC DMF)
Carcharodon carcharias	Great white shark, white shark	Commercially and recreationally important; Species of concern (NC DMF)
Centropristis striata	Black sea bass	Commercially important; Recovering North of Cape Hatteras; Recovered south of the Cape
Centropristis philadelphica	Rock sea bass	--
Centropristis striata	Black sea bass	--
Cetorhinus maximus	Basking shark	Commercially and recreationally important; Species of concern (NC DMF)

Scientific Name	Common Name(s)	Notes
Chaetodipterus faber	Atlantic spadefish	--
Chaetodon capistratus	Foureye butterflyfish	--
Chaetodon ocellatus	Spotfin butterflyfish	--
Chaetodon striatus	Banded butterflyfish	--
Chasmodes bosquianus	Striped blenny	--
Cheilopogon heterurus	Atlantic flyingfish, blotchwing flyingfish	--
Chilomycterus antillarum	Web burrfish	--
Chilomycterus schoepfii	Burrfish, porcupinefish, striped burrfish	--
Chilomycterus spinosus	Striped burrfish	--
Chloroscombrus chrysurus	Atlantic bumper	--
Citharichthys macrops	Spotted whiff	--
Citharichthys spilopterus	Bay whiff	--
Conger oceanicus	Conger eel	--
Coryphaena equiselis	Pompano dolphin, pompano dolphinfish	--
Coryphaena hippurus	Dolphin, dolphinfish	Offshore viable (NC DMF)
Coryphopterus glaucofraenum	Bridled goby	--
Ctenogobius boleosoma	Darter goby	--
Ctenogobius shufeldti	Freshwater goby	Freshwater
Cynoscion nebulosus	Spotted seatrout	Commercially and recreationally important; Depleted (NC DMF)
Cynoscion nothus	Silver seatrout	--
Cynoscion regalis	Weakfish, gray trout, sea trout	Commercially and recreationally important; Depleted (NC DMF)
Cyprinodon variegatus	Sheepshead minnow, sheepshead pupfish	--

Scientific Name	Common Name(s)	Notes
Dasyatis americana	Southern stingray	--
Dasyatis centroura	Clam cracker, roughtail stingray, stingaree	--
Dasyatis hastata	Hawaiian stingray	--
Dasyatis sabina	Atlantic stingray	--
Dasyatis say	Bluntnose stingray	--
Decapterus macarellus	Mackerel scad	--
Decapterus punctatus	Round scad	--
Diapterus auratus	Irish pompano	--
Diodon holocanthus	Balloonfish, hairy porcupinefish	--
Diplectrum formosum	Sand perch	--
Diplodus holbrookii	Spottail pinfish	--
Dipturus laevis	Barndoor skate	--
Dorosoma cepedianum	Hickory shad, American gizzard shad, eastern gizzard shad	Commercially and recreationally important; Status unknown (NC DMF)
Dorosoma petenense	Threadfin shad	--
Echeneis naucrates	Sharksucker	--
Elagatis bipinnulata	Rainbow runner	--
Elops saurus	Ladyfish	--
Engraulis eurystole	Camiguana anchovy, silver anchovy	--
Epinephelus morio	Red grouper	Commercially and recreationally important; Species of concern (NC DMF)
Epinephelus nigritus	Warsaw grouper	Commercially and recreationally important; Species of concern (NC DMF)
Equetus lanceolatus	Jackknife fish, jackknife-fish	--

Scientific Name	Common Name(s)	Notes
Esox niger	Chain pickerel	Freshwater
Etropus crossotus	Fringed flounder	--
Etropus microstomus	Smallmouth flounder	--
Etrumeus teres	Atlantic red herring, Maray, red-eye round herring	--
Eucinostomus argenteus	Spotfin mojarra	--
Eucinostomus gula	Silver jenny	--
Euthynnus alletteratus	False albacore, little tuna, little tunny	--
Fistularia tabacaria	Bluespotted cornetfish, tobacco trumpetfish	--
Fundulus confluentus	Marsh killifish	SSC; Freshwater
Fundulus heteroclitus	Mummichog	--
Fundulus luciae	Spotfin killifish	SSC; Freshwater
Fundulus majalis	Striped killifish	--
Galeocerdo cuvier	Tiger shark	Commercially and recreationally important; Species of concern (NC DMF)
Gambusia affinis	Mosquitofish, western mosquitofish	Freshwater
Gambusia holbrooki	Eastern mosquitofish	Freshwater
Ginglymostoma cirratum	Nurse shark	Commercially and recreationally important; Species of concern (NC DMF)
Gobiesox strumosus	Skilletfish	--
Gobionellus oceanicus	Highfin goby, sharptail goby, slim goby	--
Gobiosoma bosc	Naked goby	--
Gobiosoma ginsburgi	Seaboard goby	--
Gymnachirus melas	Naked sole	--

Scientific Name	Common Name(s)	Notes
Gymnothorax nigromarginatus	Blackedge moray	--
Gymnura altavela	Spiny butterfly ray	--
Gymnura micrura	Smooth butterfly ray	--
Haemulon aurolineatum	Tomtate	--
Haemulon plumierii	White grunt	--
Halichoeres bivittatus	Slippery dick	--
Halichoeres caudalis	Painted wrasse	--
Halichoeres maculipinna	Clown wrasse	--
Harengula jaguana	Scaled herring, scaled sardine	--
Hemiramphus balao	Balao	--
Hemiramphus brasiliensis	Ballyhoo	--
Hippocampus erectus	Lined seahorse, spotted seahorse	--
Histrio histrio	Sargassum frogfish, sargassumfish	--
Holacanthus bermudensis	Blue angelfish	--
Hyperoglyphe perciformis	Barrelfish	--
Hypleurochilus geminatus	Crested blenny	--
Hyporhamphus meeki	American halfbeak, false silverstripe halfbeak	--
Hyporhamphus unifasciatus	Atlantic silverstripe halfbeak, silverstripe halfbeak	--
Hypsoblennius hentz	Feather blenny	--
Katsuwonus pelamis	Arctic bonito, mushmouth, oceanic bonito	--
Kyphosus sectator	Bermuda chub, rudderfish, sea chub	--

Scientific Name	Common Name(s)	Notes
Lactophrys trigonus	Trunkfish	--
Lagocephalus laevigatus	Smooth puffer	--
Lagodon rhomboides	Pinfish	--
Larimus fasciatus	Banded drum	--
Leiostomus xanthurus	Spot	Commercially and recreationally important; Species of concern (NC DMF)
Lepisosteus osseus	Longnose gar	--
Lobotes surinamensis	Atlantic tripletail, tripletail	--
Lophius americanus	Monkfish, goosefish	Commercially and recreationally important; Recovering (NC DMF)
Lucania parva	Rainwater killifish	--
Lutjanus analis	Mutton snapper	--
Lutjanus apodus	Schoolmaster, schoolmaster snapper	--
Lutjanus campechanus	Red snapper, northern red snapper	Commercially and recreationally important; Species of concern (NC DMF)
Lutjanus griseus	Gray snapper, grey snapper	--
Lutjanus synagris	Lane snapper	--
Lyosphaera globosa	Marblefish, marblefish	--
Manta birostris	Atlantic manta, giant manta, Pacific manta	--
Masturus lanceolatus	Sharptail mola, sharptail sunfish	--
Megalops atlanticus	Tarpon	--
Membras martinica	Rough silverside	--
Membras vagrans	Silverside	--
Menidia beryllina	Inland silverside, tidewater silverside	--

Scientific Name	Common Name(s)	Notes
Menidia menidia	Atlantic silverside	--
Menticirrhus americanus	Jewsharp drummer, southern kingfish	Commercially and recreationally important; Status unknown (NC DMF)
Menticirrhus littoralis	Gulf kingfish	Commercially and recreationally important; Status unknown (NC DMF)
Menticirrhus saxatilis	Gulf minkfish, northern kingfish	Commercially and recreationally important; Status unknown (NC DMF)
Merluccius bilinearis	Silver hake	--
Microgobius thalassinus	Green goby	--
Micropogonias undulatus	Atlantic croaker	Commercially and recreationally important; Species of concern (NC DMF)
Micropterus dolomieu	Smallmouth bass	--
Micropterus salmoides	Largemouth bass	--
Mobula hypostoma	Atlantic devil ray, devil ray	--
Mola mola	Ocean sunfish	--
Monacanthus ciliatus	Fringed filefish	--
Morone americana	White perch	--
Morone saxatilis	Striped bass	Commercially and recreationally important; Species of concern (NC DMF)
Mugil cephalus	Striped mullet, black mullet, gray mullet	Commercially and recreationally important; Viable (NC DMF)
Mugil curema	Silver mullet, white mullet	--
Mullus auratus	Red goatfish	--
Mustelus canis	Dusky smooth-hound, smooth dogfish	--
Mycteroperca bonaci	Black grouper	--
Mycteroperca microlepis	Charcoal belly, gag	--
Myliobatis freminvillii	Bullnose ray	--

Scientific Name	Common Name(s)	Notes
Myrichthys ocellatus	Goldspotted eel, palespotted eel	--
Myrophis punctatus	Speckled worm eel	--
Narcine brasiliensis	Lesser electric ray	--
Naucrates ductor	Pilotfish	--
Negaprion brevirostris	Lemon shark	Commercially and recreationally important; Species of concern (NC DMF)
Nicholsina usta	Emerald parrotfish	--
Nomeus gronovii	Man-of-war fish	--
Ocyurus chrysurus	Yellowtail snapper	--
Ogcocephalus nasutus	Shortnose batfish	--
Oligoplites saurus	Leatherjack, leatherjacket	--
Ophichthus gomesii	Shrimp eel	--
Ophidion josephi	Crested cusk-eel	--
Ophidion marginatum	Striped cusk-eel	--
Opisthonema oglinum	Atlantic thread herring	--
Opsanus tau	Oyster toadfish	--
Orthopristis chrysoptera	Pigfish	--
Parablennius marmoreus	Seaweed blenny	--
Paracanthurus hepatus	Common surgeon, doctorfish	--
Paralichthys albigutta	Gulf flounder	--
Paralichthys dentatus	Summer flounder, fluke	Commercially and recreationally important; Viable (NC DMF)
Paralichthys lethostigma	Southern flounder	Commercially and recreationally important; Depleted (NC DMF)
Paralichthys squamilentus	Broad flounder	--

Scientific Name	Common Name(s)	Notes
Pareques umbrosus	Cubbyu	--
Peprilus paru	Harvestfish, northern harvestfish, northern harvestfish	--
Peprilus triacanthus	Butterfish	--
Pogonias cromis	Black drum	Commercially and recreationally important; Status unknown (NC DMF)
Pollachius virens	Coalfish, pollock, saithe	--
Polydactylus octonemus	Atlantic threadfin	--
Pomatomus saltatrix	Bluefish	Commercially and recreationally important; Viable (NC DMF)
Porichthys porosissimus	Atlantic midshipman	--
Priacanthus arenatus	Bigeye	--
Prionotus carolinus	Common searobin, northern searobin	--
Prionotus evolans	Striped searobin	--
Prionotus rubio	Blackfin searobin, blackwing searobin	--
Prionotus scitulus	Leopard searobin	--
Prionotus tribulus	Bighead searobin	--
Pristigenys alta	Short bigeye	--
Pristis pectinata	Smalltooth sawfish, wide sawfish	--
Pseudupeneus maculatus	Spotted goatfish	--
Pterois volitans	Lionfish	Exotic/invasive
Rachycentron canadum	Cobia	--
Raja eglanteria	Clearnose skate	--
Rhincodon typus	Whale shark	Commercially and recreationally important; Species of concern (NC DMF)
Rhinobatos lentiginosus	Atlantic guitarfish	--

Scientific Name	Common Name(s)	Notes
Rhinoptera bonasus	Cownose ray	--
Rhizoprionodon terraenovae	Atlantic sharpnose shark	Commercially and recreationally important; Species of concern (NC DMF)
Rhomboplites aurorubens	Vermilion snapper	--
Rypticus maculatus	Whitespotted soapfish	--
Sarda sarda	Atlantic bonito, bloater, bone jack	--
Sardinella aurita	Round sardinella, Spanish sardine	--
Sciaenops ocellatus	Red drum	Commercially and recreationally important; Recovering (NC DMF)
Scomber scombrus	Atlantic mackerel	--
Scomberomorus cavalla	King mackerel	Commercially and recreationally important; Species of concern (NC DMF)
Scomberomorus maculatus	Atlantic Spanish mackerel, Spanish mackerel	Commercially and recreationally important; Viable (NC DMF)
Scomberomorus regalis	Cero, painted mackerel	--
Scophthalmus aquosus	Brill, sand dab, spotted flounder, windowpane	--
Scorpaena brasiliensis	Barbfish, goosehead scorpionfish	--
Scorpaena grandicornis	Plumed scorpionfish, poison grouper	--
Selar crumenophthalmus	Bigeye scad	--
Selene setapinnis	Atlantic moonfish	--
Selene vomer	Lookdown	--
Seriola dumerili	Greater amberjack	--
Seriola lalandi	Great amberjack, yellowtail, yellowtail jack	--
Seriola rivoliana	Almaco jack, Pacific amberjack	--
Seriola zonata	Banded rubberfish, banded rudderfish	--

Scientific Name	Common Name(s)	Notes
Serraniculus pumilio	Pygmy sea bass	--
Serranus subligarius	Belted sandfish	--
Sphoeroides dorsalis	Marbled puffer	--
Sphoeroides maculatus	Northern puffer	--
Sphoeroides spengleri	Bandtail puffer	--
Sphyraena barracuda	Great barracuda	--
Sphyraena borealis	Northern sennet	--
Sphyraena guachancho	Guaguanche	--
Sphyrna lewini	Scalloped hammerhead	--
Sphyrna mokarran	Great hammerhead	--
Sphyrna tiburo	Bonnethead, shovelhead	--
Sphyrna zygaena	Smooth hammerhead	--
Squalus acanthias	Spiny dogfish, grayfish, piked dogfish, dogfish, spurdog	Commercially and recreationally important; Viable (NC DMF)
Squatina dumeril	Atlantic angel shark, Atlantic angelshark, sand devil	Commercially and recreationally important; Species of concern (NC DMF)
Stegastes fuscus	Dusky damselfish	--
Stegastes partitus	Bicolor damselfish	--
Stegastes variabilis	Cocoa damselfish	--
Stellifer lanceolatus	Star drum	--
Stenotomus caprinus	Longspine porgy	--
Stenotomus chrysops	Scup, porgy	Commercially and recreationally important; Viable (NC DMF)
Stephanolepis hispida	Planehead filefish	--

Scientific Name	Common Name(s)	Notes
Stephanolepis setifer	Pygmy filefish	--
Strongylura marina	Atlantic needlefish, silver gar	--
Syacium papillosum	Dusky flounder	--
Symphurus plagiusa	Blackcheek tonguefish	--
Syngnathus floridae	Dusky pipefish	--
Syngnathus fuscus	Northern pipefish	--
Syngnathus louisianae	Chain pipefish	--
Syngnathus springeri	Bull pipefish	--
Synodus foetens	Inshore lizardfish	--
Tautoga onitis	Tautog	--
Tautogolabrus adspersus	Cunner	--
Thunnus alalunga	Albacore, longfinned albacore	--
Torpedo nobiliana	Atlantic torpedo	--
Trachinocephalus myops	Bluntnose lizardfish, snakefish	--
Trachinotus carolinus	Florida pompano	--
Trachinotus falcatus	Permit	--
Trachinotus goodei	Palometa	--
Trachurus lathami	Rough scad	--
Trichiurus lepturus	Atlantic cutlassfish, Australian hairtail, largehead hairtail	--
Trinectes maculatus	Hogchoker	--
Tylosurus acus acus	Agujon	--

Scientific Name	Common Name(s)	Notes
Tylosurus crocodilus crocodilus	Houndfish	--
Upeneus parvus	Dwarf goatfish	--
Urobatis jamaicensis	Yellow stingray	--
Urophycis earllii	Carolina hake	--
Urophycis floridana	Southern codling, southern hake	--
Urophycis regia	Spotted codling, spotted hake	--

Table C-5. Amphibian species reported to occur in CALO according to the NPS Certified Species List (NPS 2013c). Note that ** —SSC; new — from Smrekar et al. (2013).

ScientificName	Common Name(s)	New?
*Ambystoma mabeei***	Mabee's salamander	No
Anaxyrus terrestris	Southern toad	Yes
Bufo fowleri	Fowler's toad	No
*Bufo quercicus***	Oak toad	No
Gastrophryne carolinensis	Eastern narrow-mouthed toad	No
Hyla cinerea	Green tree frog, green treefrog	No
Hyla squirella	Squirrel treefrog	No
Lithobates catesbeianus	Bullfrog	Yes
Notophthalmus viridescens	Eastern newt	No
Pseudacris ocularis	Little grass frog	No
Rana sphenocephala	Florida leopard frog, southern leopard frog	No
Scaphiopus holbrookii	Eastern spadefoot	No

Table C-6. Reptiles reported to occur in CALO according to the NPS Certified Species List (NPS 2013c). Note that **— SSC; (**) — species is on the North Carolina Watch List for species of concern (LeGrand et al. 2013).

ScientificName	Common Name(s)
Agkistrodon contortrix	Copperhead
Anolis carolinensis	Green anole
*Caretta caretta***	Loggerhead, loggerhead sea turtle
*Chelonia mydas***	Common green sea turtle, green sea turtle
Chelydra serpentina	Common snapping turtle, snapping turtle
Clemmys guttata(**)	Spotted turtle
Cnemidophorus sexlineatus	Six-lined racerunner
Coluber constrictor	Eastern racer, racer
Coluber constrictor constrictor	Northern black racer
*Dermochelys coriacea***	Leatherback, leatherback sea turtle
Elaphe obsoleta	Eastern rat snake, rat snake, Texas ratsnake
*Eretmochelys imbricata***	Carey, hawksbill, hawksbill sea turtle
Eumeces inexpectatus	Southeastern five-lined skink
Heterodon platirhinos	Eastern hog-nosed snake, spreading adder

ScientificName	Common Name(s)
Kinosternon subrubrum	Common mud turtle, eastern mud turtle
Lampropeltis getula	Common kingsnake
*Lampropeltis getula sticticeps***	Outer Banks kingsnake
*Lepidochelys kempii***	Kemp's ridley, Atlantic ridley, Atlantic ridley sea turtle
*Malaclemys terrapin***	Diamondback terrapin
Nerodia fasciata	Banded water snake, routhern water snake
Nerodia fasciata fasciata	Banded water snake, southern water snake
Nerodia sipedon	Northern water snake
*Nerodia sipedon williamengelsi***	Carolina water snake
Opheodrys aestivus	Rough green snake, rough greensnake
Ophisaurus ventralis	Eastern glass lizard
Rhadinaea flavilata(**)	Pine woods snake
Scincella lateralis	Ground skink, Little brown skink
*Sistrurus miliarius***	Pigmy rattlesnake, pygmy rattlesnake
Terrapene carolina	Common box turtle, eastern box turtle
Thamnophis sauritus	Eastern ribbon snake

Table C-7. Birds reported to occur seasonally or year-round in CALO according to the NPS Certified Species List (NPS 2013c).

Scientific Name	Common Name(s)	Notes
Accipiter cooperii	Cooper's hawk	--
Accipiter striatus	Sharp-shinned hawk	SSC
Actitis macularia	Spotted sandpiper	Wetland/aquatic
Agelaius phoeniceus	Red-winged blackbird	Wetland/aquatic
Aix sponsa	Wood duck	Wetland/aquatic
Alca torda	Razorbill	Wetland/aquatic
Alle alle	Dovekie, little auk	Wetland/aquatic
Ammodramus caudacutus	Saltmarsh sharp-tailed sparrow, saltmarsh sparrow	SSC; Wetland/aquatic
Ammodramus maritimus	Seaside sparrow	Wetland/aquatic
Ammodramus savannarum	Grasshopper sparrow	SSC
Anas acuta	Northern pintail	Wetland/aquatic

Scientific Name	**Common Name(s)**	**Notes**
Anas americana	American wigeon	Wetland/aquatic
Anas clypeata	Northern shoveler	Wetland/aquatic
Anas crecca	Green-winged teal	Wetland/aquatic
Anas discors	Blue-winged teal	SSC; Wetland/aquatic
Anas platyrhynchos	Mallard	Wetland/aquatic
Anas rubripes	American black duck	Wetland/aquatic
Anas strepera	Gadwall	Wetland/aquatic
Anous stolidus	Brown noddy	Wetland/aquatic
Anthus rubescens	American pipit	--
Archilochus colubris	Ruby-throated hummingbird	--
Ardea alba	Great egret	Wetland/aquatic
Ardea herodias	Great blue heron	Wetland/aquatic
Arenaria interpres	Ruddy turnstone	Wetland/aquatic
Asio flammeus	Short-eared owl	SSC
Aythya affinis	Lesser scaup	Wetland/aquatic
Aythya americana	Redhead	Wetland/aquatic
Aythya collaris	Ring-necked duck	Wetland/aquatic
Aythya marila	Greater scaup	Wetland/aquatic
Aythya valisineria	Canvasback	Wetland/aquatic
Baeolophus bicolor	Tufted titmouse	*Baeolophus bicolor*, the tufted titmouse, is newly reported for CALO as of Byrne et al. (2001b).
Bartramia longicauda	Upland sandpiper	Wetland/aquatic
Bombycilla cedrorum	Cedar waxwing	--
Botaurus lentiginosus	American bittern	SSC; Wetland/aquatic
Branta bernicla	Brant	Wetland/aquatic
Branta canadensis	Canada goose	Exotic/invasive; Wetland/aquatic
Bubo virginianus	Great horned owl	--
Bubulcus ibis	Cattle egret	Exotic/invasive
Bucephala albeola	Bufflehead	Wetland/aquatic
Bucephala clangula	Common goldeneye	Wetland/aquatic
Buteo jamaicensis	Red-tailed hawk	--
Buteo lineatus	Red-shouldered hawk	--

Scientific Name	Common Name(s)	Notes
Buteo platypterus	Broad-winged hawk	--
Butorides virescens	Green heron	Wetland/aquatic
Calcarius lapponicus	Lapland longspur	--
Calidris alba	Sanderling	Wetland/aquatic
Calidris alpina	Dunlin	Wetland/aquatic
Calidris bairdii	Baird's sandpiper	Wetland/aquatic
Calidris canutus	Red knot	SSC; Wetland/aquatic
Calidris ferruginea	Curlew sandpiper	Wetland/aquatic
Calidris fuscicollis	White-rumped sandpiper	Wetland/aquatic
Calidris himantopus	Stilt sandpiper	Wetland/aquatic
Calidris maritima	Purple sandpiper	Wetland/aquatic
Calidris mauri	Western sandpiper	Wetland/aquatic
Calidris melanotos	Pectoral sandpiper	Wetland/aquatic
Calidris minutilla	Least sandpiper	Wetland/aquatic
Calidris pusilla	Semipalmated sandpiper	Wetland/aquatic
Calonectris diomedea	Cory's shearwater	Wetland/aquatic
Caprimulgus carolinensis	Chuck-will's-widow	--
Cardinalis cardinalis	Northern cardinal	--
Carduelis pinus	Pine siskin	--
Carduelis tristis	American goldfinch	--
Carpodacus mexicanus	House finch	Exotic/invasive
Carpodacus purpureus	Purple finch	--
Cathartes aura	Turkey vulture	--
Catharus fuscescens	Veery	--
Catharus guttatus	Hermit thrush	SSC
Catharus minimus	Gray-cheeked thrush	--
Catharus ustulatus	Swainson's thrush	SSC
Catoptrophorus semipalmatus	Willet	--
Certhia americana	Brown creeper	SSC
Ceryle alcyon	Belted kingfisher	Wetland/aquatic
Chaetura pelagica	Chimney swift	--

Scientific Name	Common Name(s)	Notes
Charadrius melodus	Piping plover	SSC; Wetland/aquatic
Charadrius semipalmatus	Semipalmated plover	Wetland/aquatic
Charadrius vociferus	Killdeer	--
Charadrius wilsonia	Wilson's plover	SSC; Wetland/aquatic
Chen caerulescens	Snow goose	Wetland/aquatic
Chlidonias niger	Black tern	Wetland/aquatic
Chondestes grammacus	Lark sparrow	SSC
Chordeiles minor	Common nighthawk	--
Circus cyaneus	Northern harrier	SSC
Cistothorus palustris	Marsh wren	Wetland/aquatic
Cistothorus platensis	Sedge wren	Wetland/aquatic
Clangula hyemalis	Oldsquaw	Wetland/aquatic
Coccothraustes vespertinus	Evening grosbeak	--
Coccyzus americanus	Yellow-billed cuckoo	--
Colaptes auratus	Northern flicker	--
Colinus virginianus	Northern bobwhite	--
Columba livia	Rock dove	Exotic/invasive
Contopus virens	Eastern wood-pewee	--
Coragyps atratus	Black vulture	--
Corvus ossifragus	Fish crow	Wetland/aquatic
Cyanocitta cristata	Blue jay	--
Cygnus columbianus	Tundra swan	Wetland/aquatic
Dendroica caerulescens	Black-throated blue warbler	--
Dendroica castanea	Bay-breasted warbler	--
Dendroica discolor	Prairie warbler	--
Dendroica dominica	Yellow-throated warbler	--
Dendroica fusca	Blackburnian warbler	--
Dendroica magnolia	Magnolia warbler	--
Dendroica palmarum	Palm warbler	--
Dendroica pensylvanica	Chestnut-sided warbler	--
Dendroica petechia	Yellow warbler	--

Scientific Name	Common Name(s)	Notes
Dendroica pinus	Pine warbler	--
Dendroica striata	Blackpoll warbler	--
Dendroica tigrina	Cape May warbler	--
Dolichonyx oryzivorus	Bobolink	SSC
Dumetella carolinensis	Gray catbird	--
Egretta caerulea	Little blue heron	SSC; Wetland/aquatic
Egretta rufescens	Reddish egret	Wetland/aquatic
Egretta thula	Snowy egret	SSC; Wetland/aquatic
Egretta tricolor	Tricolored heron	SSC; Wetland/aquatic
Elanoides forficatus	American swallow-tailed kite, swallow-tailed kite	SSC; Wetland/aquatic
Eudocimus albus	White ibis	SSC; Wetland/aquatic
Falco columbarius	Merlin	Wetland/aquatic
Falco peregrinus	Peregrine falcon	SSC
Falco sparverius	American kestrel	SSC
Fregata magnificens	Magnificent frigatebird	Wetland/aquatic
Fulica americana	American coot	Wetland/aquatic
Gallinago gallinago	Common snipe	Wetland/aquatic
Gallinula chloropus	Common moorhen	Wetland/aquatic
Gavia immer	Common loon	Wetland/aquatic
Gavia stellata	Red-throated loon	Wetland/aquatic
Gelochelidon nilotica	Gull-billed tern	SSC; Wetland/aquatic; *Gelochelidon nilotica*, the gull-billed tern, was given as the synonym *Sterna nilotica* in NPS (2013c).
Geothlypis trichas	Common yellowthroat	--
Guiraca caerulea	Blue grosbeak	--
Haematopus palliatus	Amerian oystercatcher	SSC; Wetland/aquatic
Haliaeetus leucocephalus	Bald eagle	SSC; Wetland/aquatic
Himantopus mexicanus	Black-necked stilt, Hawaiian stilt	SSC; Wetland/aquatic
Hirundo rustica	Barn swallow	--
Hydroprogne caspia	Caspian tern	SSC; Wetland/aquatic; *Hydroprogne caspia*, the Caspian tern, was given as the synonym *Sterna caspia* in NPS (2013c).

Scientific Name	Common Name(s)	Notes
Hylocichla mustelina	Wood thrush	--
Icteria virens	Yellow-breasted chat	--
Icterus galbula	Baltimore oriole, northern oriole	--
Icterus spurius	Orchard oriole	--
Ixobrychus exilis	Least bittern	SSC; Wetland/aquatic
Junco hyemalis	Dark-eyed junco	--
Larus argentatus	Herring gull	Wetland/aquatic
Larus atricilla	Laughing gull	Wetland/aquatic
Larus delawarensis	Ring-billed gull	Wetland/aquatic
Larus fuscus	Lesser Black-backed gull	Wetland/aquatic
Larus glaucoides	Iceland gull	Wetland/aquatic
Larus hyperboreus	Glaucous gull	Wetland/aquatic
Larus marinus	Great black-backed gull	Wetland/aquatic
Larus minutus	Little gull	Wetland/aquatic
Larus philadelphia	Bonaparte's gull	Wetland/aquatic
Laterallus jamaicensis	Black rail	SSC; Wetland/aquatic
Limnodromus griseus	Short-billed dowitcher	Wetland/aquatic
Limnodromus scolopaceus	Long-billed dowitcher	Wetland/aquatic
Limosa fedoa	Marbled godwit	Wetland/aquatic
Limosa haemastica	Hudsonian godwit	Wetland/aquatic
Lophodytes cucullatus	Hooded merganser	SSC; Wetland/aquatic
Melanerpes carolinus	Red-bellied woodpecker	--
Melanerpes erythrocephalus	Red-headed woodpecker	--
Melanitta fusca	White-winged scoter	Wetland/aquatic
Melanitta nigra	Black scoter	Wetland/aquatic
Melanitta perspicillata	Surf scoter	Wetland/aquatic
Melospiza georgiana	Swamp sparrow	--
Melospiza lincolnii	Lincoln's sparrow	--
Melospiza melodia	Song sparrow	--
Mergus serrator	Red-breasted merganser	Wetland/aquatic

Scientific Name	Common Name(s)	Notes
Mimus polyglottos	Northern mockingbird	--
Mniotilta varia	Black-and-white warbler	--
Molothrus ater	Brown-headed cowbird	--
Morus bassanus	Northern gannet	Wetland/aquatic
Myiarchus crinitus	Great crested flycatcher	--
Numenius americanus	Long-billed curlew	Wetland/aquatic
Numenius phaeopus	Whimbrel	Wetland/aquatic
Nyctanassa violacea	Yellow-crowned night-heron	SSC; Wetland/aquatic
Nycticorax nycticorax	Black-crowned night-heron	SSC; Wetland/aquatic
Oceanites oceanicus	Wilson's storm petrel, Wilson's storm-petrel	--
Onychoprion fuscatus	Sooty tern	Wetland/aquatic*; Onychoprion fuscatus*, the sooty tern, was given as the synonym *Sterna fuscatus* in NPS (2013c).
Oporornis agilis	Connecticut warbler	Wetland/aquatic
Oxyura jamaicensis	Ruddy duck	Wetland/aquatic
Pandion haliaetus	Osprey	Wetland/aquatic
Parula americana	Northern parula	--
Passerculus sandwichensis	Savannah sparrow	SSC
Passerella iliaca	Fox sparrow	--
Passerina ciris	Painted bunting	SSC
Passerina cyanea	Indigo bunting	--
Pelecanus erythrorhynchos	American white pelican	Wetland/aquatic
Pelecanus occidentalis	Brown pelican	SSC; Wetland/aquatic
Petrochelidon pyrrhonota	Cliff swallow	--
Phalacrocorax auritus	Double-crested cormorant	SSC; Wetland/aquatic
Phalacrocorax carbo	Great cormorant	Wetland/aquatic
Phalaropus fulicaria	Red phalarope	Wetland/aquatic
Phalaropus lobatus	Red-necked phalarope	Wetland/aquatic
Phalaropus tricolor	Wilson's phalarope	Wetland/aquatic
Phasianus colchicus	Common pheasant, ring-necked pheasant	Exotic/invasive

Scientific Name	Common Name(s)	Notes
Pheucticus ludovicianus	Rose-breasted grosbeak	--
Philomachus pugnax	Ruff	Wetland/aquatic
Picoides pubescens	Downy woodpecker	--
Pipilo erythrophthalmus	Eastern towhee, rufous-sided towhee	--
Piranga olivacea	Scarlet tanager	--
Piranga rubra	Summer tanager	--
Plectrophenax nivalis	Snow bunting	--
Plegadis falcinellus	Glossy ibis	SSC; Wetland/aquatic
Pluvialis dominica	American golden plover	Wetland/aquatic
Pluvialis squatarola	Black-bellied plover	Wetland/aquatic
Podiceps auritus	Horned grebe	Wetland/aquatic
Podiceps grisegena	Red-necked grebe	Wetland/aquatic
Podilymbus podiceps	Pied-billed grebe	SSC; Wetland/aquatic
Poecile carolinensis	Carolina chickadee	--
Polioptila caerulea	Blue-gray gnatcatcher	--
Porzana carolina	Sora	Wetland/aquatic
Progne subis	Purple martin	--
Protonotaria citrea	Prothonotary warbler	--
Puffinus gravis	Greater shearwater	Wetland/aquatic
Puffinus griseus	Sooty shearwater	Wetland/aquatic
Puffinus lherminieri	Audubon's shearwater	Wetland/aquatic
Quiscalus major	Boat-tailed grackle	--
Quiscalus quiscula	Common grackle	--
Rallus elegans	King rail	SSC; Wetland/aquatic
Rallus limicola	Virginia rail	SSC; Wetland/aquatic
Rallus longirostris	Clapper rail	Wetland/aquatic
Recurvirostra americana	American avocet	Wetland/aquatic
Regulus calendula	Ruby-crowned kinglet	--
Regulus satrapa	Golden-crowned kinglet	SSC
Riparia riparia	Bank swallow	SSC; Wetland/aquatic
Rissa tridactyla	Black-legged kittiwake	Wetland/aquatic

Scientific Name	Common Name(s)	Notes
Rynchops niger	Black skimmer	SSC; Wetland/aquatic
Sayornis phoebe	Eastern phoebe	--
Scolopax minor	American woodcock	--
Seiurus aurocapillus	Ovenbird	--
Seiurus noveboracensis	Northern waterthrush	Wetland/aquatic
Setophaga coronata	Yellow-rumped warbler	SSC; *Setophaga coronata* is listed as the synonym *Dendroica coronata* in the NPS Certified Species List (NPS 2013c).
Setophaga virens	Black-throated green warbler	SSC; *Setophaga virens* is given as the synonym *Dendroica virens* in the NPS Certified Species List (NPS 2013c).
Setophaga ruticilla	American redstart	--
Sialia sialis	Eastern bluebird	--
Sitta canadensis	Red-breasted nuthatch	SSC
Somateria mollissima	Common eider	Wetland/aquatic
Sphyrapicus varius	Yellow-bellied sapsucker	SSC
Spizella pallida	Clay-colored sparrow	--
Spizella passerina	Chipping sparrow	--
Spizella pusilla	Field sparrow	--
Stelgidopteryx serripennis	Northern rough-winged swallow	--
Stercorarius longicaudus	Long-tailed jaeger	Wetland/aquatic
Stercorarius parasiticus	Parasitic jaeger, arctic skua, parasitici skua	Wetland/aquatic
Stercorarius pomarinus	Pomarine jaeger	Wetland/aquatic
Sterna dougallii	Roseate tern	SSC; Wetland/aquatic
Sterna forsteri	Forster's tern	SSC; Wetland/aquatic
Sterna hirundo	Common tern	SSC; Wetland/aquatic
Sterna sandvicensis	Sandwich tern	Wetland/aquatic
Sternula antillarum	Least tern	Wetland/aquatic*; Sternula antillarum*, the least tern, was given as the synonym *Sternula antillarum* in NPS (2013c).
Sturnella magna	Eastern meadowlark	--
Sturnus vulgaris	European starling	Exotic/invasive
Tachycineta bicolor	Tree swallow	--

Scientific Name	Common Name(s)	Notes
Thalasseus maximum	Royal tern	Wetland/aquatic; *Thalasseus maximus*, the royal tern, was given as the synonym *Sterna maxima* in NPS (2013c).
Thalasseus sandvicensis	Sandwich tern	Wetland/aquatic; *Thalasseus sandvicensis*, the sandwich tern, was given as the synonym *Sterna sandvicensis* in NPS (2013c).
Thryothorus ludovicianus	Carolina wren	--
Toxostoma rufum	Brown thrasher	--
Tringa flavipes	Lesser yellowlegs	Wetland/aquatic
Tringa melanoleuca	Greater yellowlegs	Wetland/aquatic
Tringa solitaria	Solitary sandpiper	Wetland/aquatic
Troglodytes aedon	House wren	--
Troglodytes troglodytes	Winter wren	SSC
Tryngites subruficollis	Buff-breasted sandpiper	Wetland/aquatic
Turdus migratorius	American robin	--
Tyrannus dominicensis	Gray kingbird	--
Tyrannus tyrannus	Eastern kingbird	--
Tyrannus verticalis	Western kingbird	SSC
Tyto alba	Barn owl, common barn-owl	--
Vermivora celata	Orange-crowned warbler	--
Vermivora peregrina	Tennessee warbler	--
Vermivora pinus	Blue-winged warbler	SSC
Vermivora ruficapilla	Nashville warbler	--
Vireo griseus	White-eyed vireo	--
Vireo olivaceus	Red-eyed vireo	--
Vireo philadelphicus	Philadelphia vireo	--
Vireo solitarius	Blue-headed vireo, solitary vireo	--
Wilsonia canadensis	Canada warbler	--
Wilsonia citrina	Hooded warbler	--
Wilsonia pusilla	Wilson's warbler	--
Zenaida macroura	Mourning dove	--
Zonotrichia albicollis	White-throated sparrow	--
Zonotrichia leucophrys	White-crowned sparrow	--

Table C-8. Mammals from terrestrial and freshwater wetland habitats, reported to occur in CALO according to the NPS Certified Species List (NPS 2013c). We added information about likely habitats in CALO (not specified by Webster 2010).This table also indicates differences between the NPS Certified Species Lists (NPS 2013c) and Webster (2010).

Scientific Name	Common Name(s)	Barrier Island(s)	Dune & Overwash Fan	Maritime Forest & Shrub Thicket	Swale & Pond	Estuarine Marsh (Saltmarsh)	Disturbed Habitat
Canis latrans[a,1]	Coyote	all three main islands (NPS 2007c)	--	--	--	--	--
Canis lupus familiaris[1]	Feral dog	all three main islands	--	--	--	--	--
Cryptotis parva	Least shrew, bee shrew, little short-tailed shrew	North Core Banks	--	--	x	--	--
Equus caballus[b,1]	Feral horse	Shackleford Banks	x	--	x	x	--
Felis catus[1]	Feral cat	all three main islands	x	x	x		x
Lasiurus seminolus[c]	Seminole bat	unspecified	--	--	x	--	--
Lontra canadensis	Northern river otter, river otter	all three main islands	--	--	x	x	--
Mus musculus[1]	House mouse	North Core Banks, South Core Banks	x	--	--	--	x
Mustela vison	American mink, mink	all three main islands	--	--	x	x	--

[a] Not in Webster's list (had not yet been detected in CALO)

[b] Invasive, but considered desirable by the general public

[c] Webster (2010) included the silver-haired bat, hoary bat (*Lasiurus cinereus*), and evening bat (*Nycticeius humeralis*) as "probably present," and the eastern red bat (*Lasiurus borealis*) as "observed only" on North Shore Banks and Shackleford Banks. For all four bat species, he indicated that the habitat in CALO is swales and ponds.

[d] Not in Webster's list

[e] This taxon was not listed in the NPS Certified Species List (NPS 2013c), but mentioned elsewhere in NPS reports as present in the seashore.

[f] Webster: unconfirmed

[1] Exotic/invasive

Table C-8 (continued). Mammals from terrestrial and freshwater wetland habitats, reported to occur in CALO according to the NPS Certified Species List (NPS 2013c). We added information about likely habitats in CALO (not specified by Webster 2010).This table also indicates differences between the NPS Certified Species Lists (NPS 2013c) and Webster (2010).

Scientific Name	Common Name(s)	Barrier Island(s)	Dune & Overwash Fan	Maritime Forest & Shrub Thicket	Swale & Pond	Estuarine Marsh (Saltmarsh)	Disturbed Habitat
Myocastor coypus[1]	Nutria, coypu	all three main islands	x	--	x	x	--
Odocoileus virginianus[a]	White-tailed deer	all three main islands (NPS 2007c)	--	x	x	--	--
Ondatra zibethicus	Muskrat, common muskrat, muskbeaver	all three main islands	--	--	x	x	--
Oryzomys palustris	Marsh rice rat	all three main islands	--	--	x	x	--
Procyon lotor	Common raccoon, northern raccoon, raccoon	all three main islands	x	x	x	x	--
Rattus norvegicus[1]	Norway rat	North Core Banks	--	--	--	--	x
Scalopus aquaticus	Eastern mole, topos	Shackleford Banks		x	--	--	--
Sciurus carolinensis[d]	Eastern gray squirrel, gray squirrel	recent information not available	--	x	--	--	--
Sylvilagus floridanus	Eastern cottontail	all three main islands	x	--	x	--	--

[a] Not in Webster's list (had not yet been detected in CALO)

[b] Invasive, but considered desirable by the general public

[c] Webster (2010) included the silver-haired bat, hoary bat (*Lasiurus cinereus*), and evening bat (*Nycticeius humeralis*) as "probably present," and the eastern red bat (*Lasiurus borealis*) as "observed only" on North Shore Banks and Shackleford Banks. For all four bat species, he indicated that the habitat in CALO is swales and ponds.

[d] Not in Webster's list

[e] This taxon was not listed in the NPS Certified Species List (NPS 2013c), but mentioned elsewhere in NPS reports as present in the seashore.

[f] Webster: unconfirmed

[1] Exotic/invasive

Table C-8 (continued). Mammals from terrestrial and freshwater wetland habitats, reported to occur in CALO according to the NPS Certified Species List (NPS 2013c). We added information about likely habitats in CALO (not specified by Webster 2010).This table also indicates differences between the NPS Certified Species Lists (NPS 2013c) and Webster (2010).

Scientific Name	Common Name(s)	Barrier Island(s)	Dune & Overwash Fan	Maritime Forest & Shrub Thicket	Swale & Pond	Estuarine Marsh (Saltmarsh)	Disturbed Habitat
Sylvilagus palustris	Marsh rabbit	all three main islands	--	--	x	x	--
Urocyon cinereoargenteus[e]	Gray fox	--	--	--	--	--	--
Ursus americanus[f]	American black bear, black bear	--	--	--	--	--	--
Vulpes vulpes[f,1]	Red fox	--	--	--	--	--	--

[a] Not in Webster's list (had not yet been detected in CALO)

[b] Invasive, but considered desirable by the general public

[c] Webster (2010) included the silver-haired bat, hoary bat (*Lasiurus cinereus*), and evening bat (*Nycticeius humeralis*) as "probably present," and the eastern red bat (*Lasiurus borealis*) as "observed only" on North Shore Banks and Shackleford Banks. For all four bat species, he indicated that the habitat in CALO is swales and ponds.

[d] Not in Webster's list

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[f] Webster: unconfirmed

[1] Exotic/invasive

Table C-9. Marine mammals of CALO, based on marine mammal stranding records. See https://www.nps.gov/calo/learn/nature/loader.cfm?csModule=security/getfile&PageID=1112999 (last accessed in January 2017).

ScientificName	Common Name(s)
Balaena glacialis	Northern right whale
Balaenoptera physalus	Fin whale
Balaenoptera acutorostrata	Minke whale
Crystophora cristata	Hooded seal
Delphinus delphis	Common dolphin
Feresa attenuate	Pygmy killer whale
Globicephala macrorhynchus	Shortfinned pilot whale
Grampus griseus	Risso's dolphin
Kogia breviceps	Pygmy sperm whale
Kogia sima	Dwarf sperm whale
Lagenodelphis hosei	Fraser's dolphin
Lagenorhyncus acutus	Atlantic white-sided dolphin
Megaptera novaeangliae	Humpback whale
Mesoplodon europaeus	Gervais' beaked whale
Mesoplodon mirus	True's beaked whale
Phoca vitulina	Harbor seal
Phocoena phocoena	Harbor porpoise
Physeter macrocephalus	Sperm whale
Stenella coeruleoalba	Striped dolphin
Stenella frontalis	Atlantic spotted dolphin
Tursiops truncatus	Bottlenose dolphin

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