Assessment of Coastal Water Resources and Watershed Conditions in Cape Lookout National Seashore North Carolina

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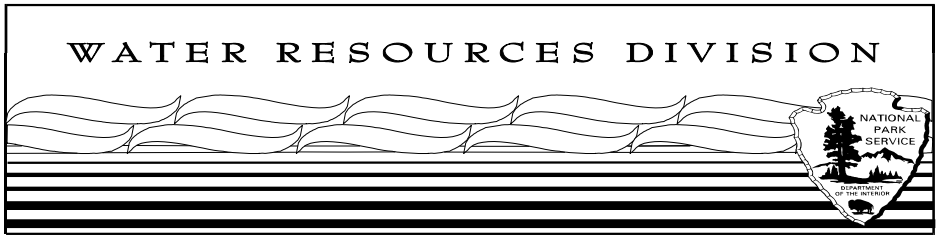

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EXECUTIVE SUMMARY

The purpose of this report was to 1) locate and examine existing water resources-related information pertaining to the water quality in and around Cape Lookout National Seashore; 2) provide a preliminary assessment of the existing condition of the water-related coastal marine resources; 3) identify current stressors or threats that may affect the future condition of these resources; and 4) to identify and make recommendations to fill in existing information gaps. Habitat issues, potential for invasive species, water quality, and trends in Park resource usage are addressed.

Cape Lookout National Seashore consists of a set of narrow microtidal transgressive barrier islands known as Core Banks aligned in a general north-south orientation, and a regressive barrier island called Shackleford Banks aligned in an east-west orientation. During hurricanes and nor'easters Core Banks is subject to overwash, inlet formation, migration, and closure and subsequently supports scant maritime forest. Shackleford Banks is protected by Cape Lookout, has sustained a significant maritime forest, and has a resident horse herd. There are no freshwater rivers or lakes in the park but a number of freshwater ponds are present, mostly on northern Core Banks and western Shackleford Banks. All areas of the Park presently have little human development and have no permanent residents. Privately owned structures within the Park are presently coming under park ownership.

There are no point sources of pollutants in the park, no agriculture and no urban sources of pollutant runoff. Any pollutants affecting Park waters must be brought in by currents from the mainland, deposited by rainfall, or leached from present or former septic systems or storage tanks on the islands. The North Carolina Division of Water Quality has three ambient monitoring sites in Back and Core Sounds, all at least five km from the Park. Data from 1994-2002 show no unusual nutrient or chlorophyll concentrations, and there are no TMDLs (pollutant total maximum daily loads) assigned for waters near the park. Fecal coliform bacteria data from the North Carolina Shellfish Sanitation Branch shows that all areas within five km of the Park are open for shellfishing and there are no park beaches closed by elevated enterococcus counts. There have been no harmful algal blooms reported in Park waters for the past 15 years, and fish populations in Core Sound are productive and physiologically healthy.

In 1998-2001 Park personnel commissioned a water quality survey of wells, dock areas, and tidal creeks in the Park (10 locations). Fecal coliform bacteria counts were generally low in all areas sampled. Median values for nutrients at surface water sites were generally low, but unusually high ammonium, nitrate, total nitrogen and total phosphorus concentrations occurred on rare occasions at certain dock and creek sites. Certain wells demonstrated high nutrient concentrations, including excessive nitrate, on several occasions, probably a result of septic system leachate.

The park is clearly doing a good job of minimizing future water pollution by the purchase of private structures on Core Banks and maintaining the Park habitat in as natural state as possible. It is recommended that the locations of the freshwater ponds be documented and put into a Geographic Information System, and basic water quality information be collected from a selection of these ponds. Additionally, some of the surface water locations that showed periodic high nutrient concentrations should be re-sampled for nutrients and chlorophyll in conjunction with the ponds. Since septic tank leachate is a likely source of nutrient contamination of surface and well waters, dye tracer studies of selected septic systems should be performed to assess performance and pathways of contamination. Soil

and groundwater contamination by petrochemicals and/or metals has been found in areas near former above ground storage tank incinerator sites, so follow up studies on extent of contamination and an assessment of background (control) concentrations should be continued.

Park management may also wish to survey beach waters in high use areas (such as the western end of Shackleford Banks) just prior to, during, and following a summer holiday weekend to assess fecal coliform and enterococcus abundance during a maximum potential pollution and human exposure period.

Because of periodic high nutrient levels and the possibility of exotic species inputs, an annual survey of estuarine park waters for the presence of *Pfiesteria* and other harmful algae should be commissioned as well. There is a paucity of benthic macroinvertebrate information from marine waters in and near the Park, thus a survey of benthos with special attention to the presence of exotic species is also recommended. Since the invasive species nutria is present on Core Banks, it is recommended that a small mammal survey be performed, along with an assessment of potential ecosystem damage by nutria. Finally, a survey of horse usage of the Shackleford Banks ecosystem in terms of grazing and physical impacts would be useful.

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PARK DESCRIPTION

Background

Location, size, and boundaries

Cape Lookout National Seashore consists of a series of barrier islands known as Core Banks and Shackleford Banks, located along the coast of North Carolina. This National Seashore is under the jurisdiction of the U.S. National Park Service and Park operations are directed from the Park Service headquarters on Harker's Island (www.nps.gov/calo). Core Banks runs approximately 76 km (47 miles) from northeast to southwest (Fig. 1); the northern boundary of Core Banks is Portsmouth Village (coordinates N 35 03.85, W 75 02.30) and the southernmost point of Core Banks is Cape Lookout (N 34 35.20, W 75 32.20). The widest portion of Core Banks is Portsmouth Island, approximately 3.2 km (2 miles) across (Schoenbaum 1982), while most of Core Banks is only 100-200 m wide (Pilkey 2003). Shackleford Banks is an island about 15 km (9 miles) long and less than one mile wide, running from Cape Lookout Bight east to west, terminating at Beaufort Inlet (Fig. 1). Its eastern end coordinates are N 34 37.70, W 76 31.80 and is western end coordinates are N 34 41.50, W 76 39.85. The Park boundary extends approximately 50 m (150 ft) beyond mean low tide into the ocean and includes approximately 24,500 acres of land (Dolan and Lins 1986).

Geological history

A common theory is that during the Pleistocene glacial period the shoreline was approximately 80 km seaward of its present position, with a dune ridge formed by wind and wave action. As the glaciers retreated during the Holocene marine transgression, sea level rose, broke through the dune ridge, and formed lagoons and sounds. The shoreline and associated dunes migrated shoreward with the rising sea level until sea level rise slowed greatly about 4,000 years ago, and wind, waves, and currents formed the basic Outer Banks configuration (Dolan and Lins 1986, and references within; Leatherman 1988). Core Banks continues to retreat shoreward slowly, according to historic charts and physical evidence (Dolan et al. 1973; Dolan and Lins 1986, and references within; Pilkey 2003). Core Banks is considered to be a chain of transgressive barrier islands, which are islands that have a sand deficiency and a propensity for shoreline retreat, while Shackleford Banks is a regressive barrier island, which is an island that demonstrates sand accretion, and contains multiple dune ridges (Leatherman 1988). Outer Banks islands that are unaltered by man are subject to periodic inlet formation, migration, and closure, and seawater overwash during hurricanes and nor'easters. The overwash process carries sediments from the beach side into the inland facing waters of the island where these sediments become the substrata for the biologically rich marshes in the sounds and lagoons (Dolan et al. 1973; Dolan and Lins 1986). During Hurricane Dennis in 1999 there was overwash so extensive that Core Banks migrated approximately one foot inland (Pilkey 2003). Overwash is a common process along the Outer Banks because of the low (microtidal) tidal range and small sediment supply (Dolan and Lin 1986, Leatherman 1988). Inlet formation creates flood tide deltas, which are sandy shoals that develop in the sound, providing substrata for new salt marshes, particularly when the inlet closes or migrates (Leatherman 1988).


Figure 1. Cape Lookout National Seashore
OCRACOKE
Ocracoke Lighthouse
Cape Hatteras National Seashore
HYDE COUNTY
CARTERET COUNTY
North Rock
Beacon I
Shell Castle
Life-Saving Service Station (Historic)
Casey I
Ferry landing (Passenger)
Community Cemetery
Schoolhouse
CG CREEK
DOCTORS CREEK
PV-1
PORTSMOUTH VILLAGE
Sheep Island
Natural areas within Cape Lookout N.S.
Maritime Forest
Beach and grassland
Marshland
Tidal flat
Water depths
0 to 2 meters
Over 2 meters
One meter equals approximately 3.3 feet
Toll ferry
0 1 kilometer 5
0 1 mile 5
North
PAMLICO SOUND
PORTSMOUTH FLATS
Tidal flats may flood quickly at highside—depending upon winds and seasons.
PAMLICO COUNTY
CARTERET COUNTY
STATE VEHICLE FERRY LANDING
Pilotary Islands
Wainwright I
Shell Island
Harbor Island
Chain Shot Island
Cricket Island
Hog Island
Point of Grass
Cedar Island
Roe
Lola
Refuge Headquarters
Long Pt
WEST BAY
Cedar Island
CEDAR ISLAND
National Wildlife Refuge
Lookout Pt
THOROFARE BAY
Hall Pt
CORE SOUND
NORTH CORE BANKS
LONG POINT FERRY LANDING
LP 1
LP 2
LP FERRY
VEHICLE FERRY
ATLANTIC
Sheep Pt
Sealevel
Mill Pt
Masontown
Stacy
NELSON BAY
RALEIGH BAY
OCEAN
ATLANTIC
VEHICLE FERRY
DAVIS
Fortin I
Great I
Williston
GREAT ISLAND FERRY LANDING
GI-NPS DOCK
GI-1
GI-2
GI-FERRY DOCK
Shingle Pt
Goose I
Guthrie Hammock
Davis I
JARRETT BAY
SOUTH CORE BANKS
SCB CHAPEL
Smyrna
Otway
Bells Island
Cowpen I
Core Creek
North River Corner
Marshallberg
Codds Creek
Gloucester
Straits
Browns Island
Park Headquarters
HARKERS ISLAND
Shell Pt
BACK BAY
Morgan I
Bottle Run Pt
Jades I
Cedar Hammock
BEAUFORT
KQ FERRY DOCK
KQ
Ferry landing (passenger)
Cape Lookout Lighthouse
MOREHEAD CITY
Morehead City to New Bern 51 km, 32 mi
Fort Macon
Fort Macon State Park
SHACKLEFORD BANKS
LS-DOCK
CAPE LOOKOUT
U.S. Coast Guard Station (Historic)
ONSLOW BAY
Jetty
SCB-DY
SCB-LG
Cape Pt
ATLANTIC BEACH
BANKS
BOGUE

Human utilization and land use

The active geology and hydrology of the Outer Banks has historically determined use of the Outer Banks for settlement and commerce. The first permanent European settlements were established between Currituck and Roanoke Inlets on the sound side of the northern Outer Banks (Dolan and Lins 1986), usually in the maritime forest, which is the highest and safest place to be on the islands (Leatherman 1988). However, Roanoke Inlet shoaled in and finally closed in 1811, and Currituck Inlet closed in 1828, so shipping traffic moved south to Ocracoke Inlet (Dolan and Lins 1986). Portsmouth Village was established in 1753 by the North Carolina Assembly, and served as a point where goods were offloaded from larger vessels and then transferred by smaller boat to the mainland (Schoenbaum 1982; NPS 2000). This town thrived for several decades and once supported a population of 1,000 (NPS 2000). However, in 1846 a storm created Oregon and Hatteras Inlets, leading to a withdrawal of shipping traffic from Ocracoke Inlet (Dolan and Lins 1986). Most of the residents fled to the mainland in advance of occupying Union troops during the Civil War and many did not return after the war (Schoenbaum 1982). Portsmouth Village steadily declined, and the last resident left the village in 1971 (Schoenbaum 1982). At the southern end of Core Banks a lighthouse was built in 1812; its replacement, the Cape Lookout Lighthouse was completed in 1859. Cape Lookout Bight provided fishermen, merchants and pirates with a protected harbor. During the 19th century small communities of whalers and fishermen resided near the lighthouse at Cape Lookout and on Shackleford Banks. Following a devastating hurricane in 1899 most people left Shackleford Banks and moved to Harker's Island or Bogue Banks (Schoenbaum 1982). Cattle, sheep, horses and hogs had been introduced to the Outer Banks in the 1660's (Dolan and Lins 1986), but all livestock except horses had been removed by the early 1960s (Dolan et al. 1973).

Cape Lookout National Seashore was authorized in 1966 and transferred to the National Park Service in 1976 (Dolan and Lins 1986). At the time of the seashore authorization there were approximately 340 structures on these islands (Schoenbaum 1982); according to park personnel there are approximately 80 structures currently within Cape Lookout National Seashore. In the vicinity of the lighthouse and to the south toward Cape Point there is a former U.S. Coast Guard Station and a number of private dwellings. Under an agreement with the Park Service these dwelling have been purchased and are becoming Federal property.

Presently both Core Banks and Shackleford Banks are used solely for recreational purposes. Shackleford Banks has no vehicle traffic and human use of the island consists of sport fishing, swimming, surfing, hiking, camping, and nature study. Core Banks supports these same activities, but vehicle traffic is permitted along the beaches and there are some dirt roads in the interior of the island(s). Thus, during some periods there is a significant amount of surf fishing activity along the beaches and as many as 150 vehicles will be utilizing the beaches. Park personnel note that there is very little swimming along the beach of most of Core Banks, except for a swimming and surfing area from the lighthouse around to Power Squadron Spit facing Shackleford Banks. Hunting is also permitted in the Park except within the Portsmouth Village and Cape Lookout Village historic districts. Hunting is primarily for waterfowl, although there is a pheasant population on Core Banks that is hunted as well. In the middle and northern portions of Core Banks there are a number of cabins available for rent. Access to these areas is by privately operated ferry services from the towns of Davis and Atlantic (Fig. 1). Access to Portsmouth Village is by ferry from Ocracoke Island, to

the north across Ocracoke Inlet. Public access to southern Core Banks and Shackleford Banks is by commercial ferry from Beaufort, or private boat.

The nearby coastal ocean and sound waters are heavily utilized by commercial fishermen as well as sport fishermen (Table 1). Recreational fishermen employ both angling from boats and surf fishing along this seashore. Commercial fishermen utilize pound nets to target flounder, and trawl for shrimp and finfish. Menhaden are collected by seine haul off the ocean beach and sometimes in the sounds. Two kinds of mechanical harvest of shellfishing occur in or near Core Sound. One utilized by some shellfishermen is clam kicking, where outboard motor propellers are used to flush clams into a net in shallow water. Another is a hydraulic dredge, used by larger vessels. Intense mechanical harvesting has been shown to significantly reduce seagrass biomass and increase turbidity, but statistically significant reductions in bay scallop recruitment or pink shrimp abundance have not been documented in areas open to mechanical harvest (Freeman 1988). Core Sound is a productive commercial fishing area. Average annual total finfish landings from 2001-2003 were 2,276,159 lbs valued at $1,115,625, and average annual total shellfish landings for Core Sound from 2001-2003 were 1,669,913 lbs valued at $2,549,345 (NC Division of Marine Fisheries data).

Table 1. Commercially and/or recreationally fished species near Cape Lookout National Seashore.

Finfish	Shellfish
Leiostomus xanthurus (spot)	*Callinectes sapidus* (blue crab)
Paralicthys spp. (flounder)	*Mercenaria mercenaria* (hard clam)
Cynoscion nebulosis (speckled trout)	*Argopectens irradians* (scallop)
Cynoscion reaglis (gray trout)	*Crassostrea virginica* (oyster)
Sciaenops ocellatus (red drum)	*Penaeus* spp. (shrimp)
Pomatomus saltatrix (bluefish)	
Micropogonias undulates (croaker)	
Mugil spp. (mullet)	
Brevoortia tyrannus (Atlantic menhaden)	
Thunnus thynnus (bluefin tuna)	

Hydrologic information

Oceanographic setting

Cape Lookout is bordered to the east and south by fully marine waters of the Atlantic Ocean. The waters to the east of Core Banks are called Raleigh Bay, and waters to the south of Shackleford Banks are considered to be in northern Onslow Bay (Mallin et al. 2000). To the north and west of the park are the waters of Ocracoke Inlet, Pamlico Sound, Core Sound, and Back Sound (Fig. 1), which are polyhaline to marine in terms of salinity. Some of the coves and tidal creeks on the sound side of the park may be of variable estuarine salinities, depending on local rainfall. The east-west

orientation of Shackleford Banks and its location eastward of Cape Lookout offers this island some protection from major storm events.

Hydrology affecting the Park - marine and freshwater

As mentioned, Core Banks consists of a series of long, narrow islands. All of the ocean side 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. The sound side of the islands is a mixture of shallow bays, tidal creeks, salt marshes, abbreviated beaches and sparse low lying forest. Shoreline salinities are marine, and tides are semidiurnal with an average range of 1.1 m (Dolan and Lins 1986). Freshwater rivers and lakes do not exist on Core Banks. However, numerous freshwater ponds exist on Core Banks, particularly in the northern section called Portsmouth Island (Schwartz 1982). These ponds vary widely in size, vegetation composition, pH, and water color (Schwartz 1982). A number of freshwater ponds are also found on Shackleford Banks, principally on the west end. Another water resource noted by the authors of this report was located on the seaward beach of Cape Lookout about 1 km from the Coast Guard station (coordinates N 34 59.452, W 76 53.760). This was a large (about 5,000 m^2) brackish water pool about 10 cm deep that contained an extensive benthic algal mat. Park personnel stated that the pool appeared during the three-year period prior to this report.

Groundwater resources

Barrier islands contain a lens of fresh water floating on salt water underneath the surface of the island (Leatherman 1988). 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 origination. Rainy periods expand the ponds and droughts reduce them. In contrast, Mullet Pond on the west end of Shackleford Banks was once part of Back Sound, and was formed by the closing of a former bay or lagoon (Schoenbaum 1982; Leatherman 1988).

Biological resources

Marine phytoplankton

The open ocean waters near the Park are not regularly monitored in terms of phytoplankton composition or biomass. A number of cruises over the continental shelf waters east of Core Banks has provided taxonomic information of common species and distribution (Marshall 1971; Marshall 1976). The shelf waters contained 43 species of coccolithophores, with the most abundant being *Coccolithus huxleyi*, *Syracosphaera mediterranea* and *S. pulchra*; 86 diatom species were recorded with the most abundant being *Skeletonema costatum*, *Rhizosolenia alata*, *Navicula* sp., *Chaetoceros decipiens* and *Asterionella japonica*; 42 pyrrhophyceans were found with the most abundant being *Exuviaella* sp., *Peridinium* sp., and *Prorocentrum* sp; and silicoflagellates were rarely seen, with *Dictyocha fibula* being the most common (Marshall 1971). Diatoms have been described as the predominant group in neritic (nearshore waters within 50 miles of the shoreline), with some taxa (*Melosira distans*, *M. islandica* and others) believed to be freshwater species transported seaward by river currents (Marshall 1976).

Subtidal and intertidal vegetation

The subtidal and intertidal waters of the eastern side of Core Sound provide abundant habitat for three seagrass species: the temperate species *Zostera marina* (eelgrass), the tropical species *Halodule wrightii* (shoalgrass) and widespread *Ruppia maritima* (widgeon grass), which is also found in fresh water (Ferguson et al. 1988). Southern Core Sound maintained 11,844 acres of seagrass habitat as of the Ferguson et al. (1988) survey (Fig. 2). Seagrass beds are excellent habitat for many species of finfish and shellfish. The salt marshes along the sound side of the Banks are vegetated primarily by *Spartina alterniflora* (salt marsh cordgrass), *Salicornia virginica* (glasswort), *Sueda linearis* (sea blite) and *Iva imbricata* (sea elder).

Upland vegetation

Due to the low topography and propensity for overwash the maritime forest is not developed on Core Banks, with the exception of some scattered trees. The dune field behind the beach berm contains *Spartina patens* (salt meadow hay) and *Uniola paniculata* (sea oats), around which dunes develop through sand accumulation (Dolan et al. 1973). Flat overwash terraces, formed by storms, are located behind the dunes and support S*olidago* (goldenrod) and *Spartina patens*, blending back into thickets of *Baccharius halimifolia* (groundsel-tree), *Myrica cerifera* (wax myrtle) and *Iva frutescens* (marsh elder). In well-protected areas shrub thickets contain *Ilex vomitoria* (yaupon), *Juniperus virginiana* (red cedar), and *Quercus virginiana* (live oak) (Dolan et al. 1973). Shackleford Banks contains a sandy beach facing the Atlantic Ocean to the southeast, which rises to a dune field that stretches from 100 to 300 m inland to maritime forest. The southwest end of the island is characterized by forest containing a number of freshwater ponds and marshes ranging from the extensive Mullet Pond to small ponds less than 100 m^2 in area. Principal vegetation in this area includes *Juniperus virginiana*, *Quercus virginiana*, *Myrica cerifera*, and *Sabal palmetto* (cabbage palm), *Yucca aloifolia* (Spanish bayonet), and *Smilax* spp. (catbriar).

Along the soundside of the island there is a narrow beach rising rapidly to vegetated dunes, becoming forested hammocks within 50 m of the sound. The freshwater Mullet Pond is largely overgrown with *Typha latifolia* (cattail). Some of the freshwater ponds contain thick algal mats; others contain various macrophytes including *Hydrocotyle* spp. (pennywort). Moving toward the center of the island the soundside beach becomes cut by a number of tidal creeks draining salt marshes. The local salt marsh vegetation is dominated by *Juncus roemerianus* (black needlerush), *Spartina alterniflora*, *Borrichia frutescens* (sea oxeye) and *Salicornia*. The eastern end of Shackleford Banks differs from the western end as it has few freshwater ponds; rather, the soundside and much of the central part of the island contain extensive salt marshes and mud flats dominated by *Juncus*. Some of the mud flats contain benthic algal mats dominated by the blue-green alga *Microcoleus lyngbyaceus* as well as numerous species of pennate diatoms (Plate 1). Upland areas on the eastern end of Shackleford Banks are vegetated by *Myria cerifera*, cacti, *Juniperus virginiana* and *Baccharis halimifoli*. *Hydrocotyle* spp. is ubiquitous and found in aquatic and terrestrial environments on Shackleford Banks. The protection offered by the east-west orientation and the large dune field of Shackleford Banks allows existence of 280 plant species, while the low, narrow and exposed Core Banks host only 35 plant species (Pilkey 2003).

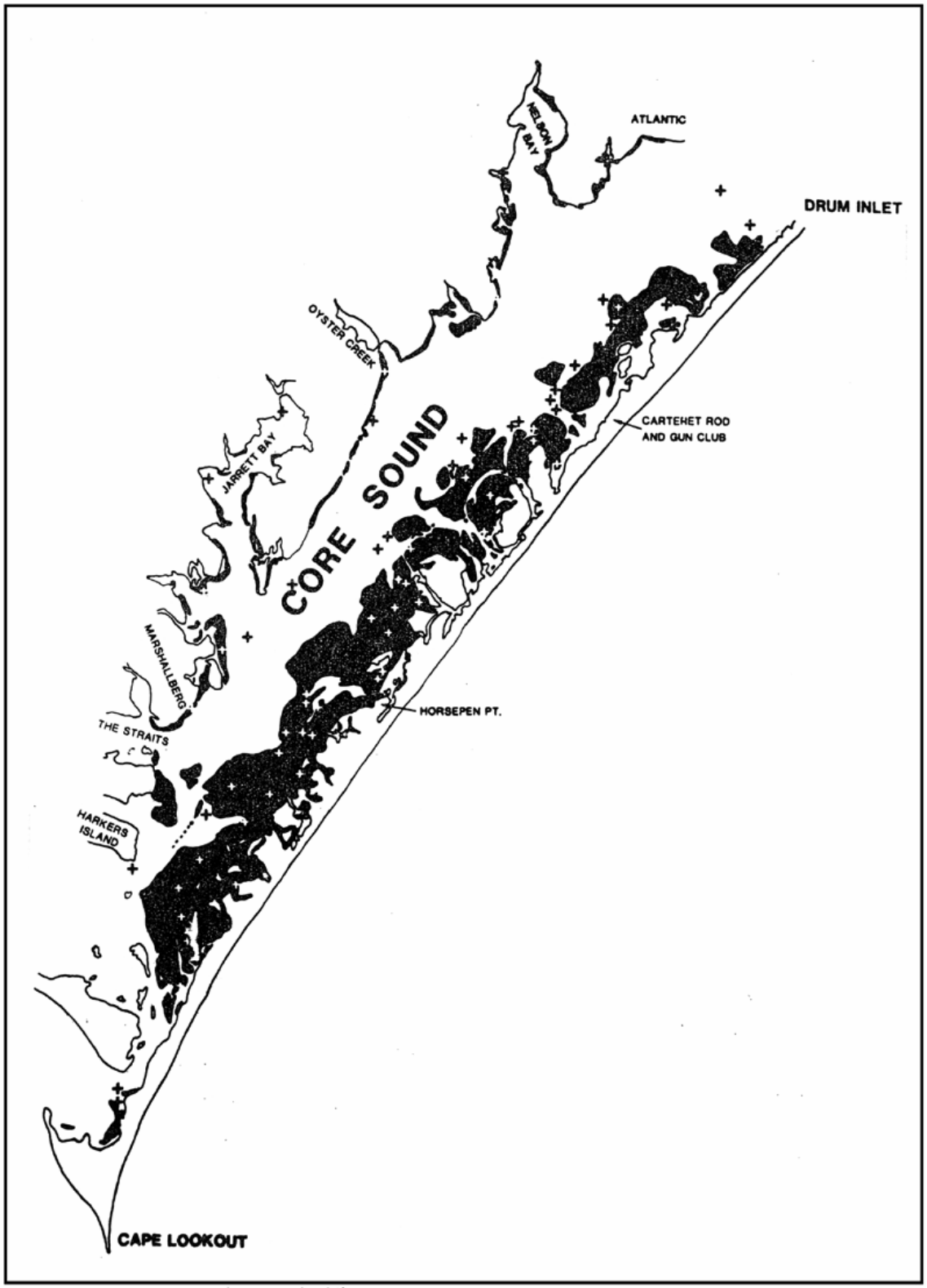

Figure 2. Principal seagrass distribution along Core Banks (From Ferguson et al. 1988).

Plate 1. Benthic microalgal mat on edge of tidal marsh on Shackleford Banks, NC.

Marine fauna

As noted earlier (Table 1) the marine waters near Core and Shackleford Banks host abundant and diverse marine fauna that are exploited by area commercial fishermen and area and visiting sport fishermen. The fish of Core Sound are healthy in comparison to those of the eutrophic lower Neuse Estuary/western Pamlico Sound junction, as determined by a comparison of multiple condition indicators between fish collected at both locations (Adams et al. 2003). From Cape Hatteras south to the North-South Carolina border and between 3 and 40 miles offshore is a Federal Flynet Closure Area, which was designated in 1997 to reduce bycatch of undersized weakfish, spot and croaker. Cape Lookout National Seashore and nearby waters are regularly utilized for mating and nesting by sea turtles, mainly *Caretta caretta* (Loggerhead) and *Chelonis mydas* (Green) sea turtles. Species seen rarely in the area are *Lepidochelys kempi* (Kemp's Ridley) and *Dermocheyls coriacea* (Leatherback) sea turtles (NPS undated). When spotted by Park staff, sea turtle nests on the beaches are roped off and protected. The Loggerhead turtle is considered to be Threatened and the Leatherback turtle is considered to be Endangered by both State and Federal regulators (NCDENR 2001). Park Service personnel also report that dead sea turtles and dead marine mammals periodically wash up on the shore. Between 2000 and 2003, 210 dead and 12 live sea turtles were found washed up on Core Banks, and 77 dead and one live sea turtle was found washed up on Shackleford Banks. Marine mammals in the area are studied by various scientific groups located at the NOAA Piver's Island facility in Beaufort and the Center for Marine Science at the University of North Carolina at Wilmington. Between 2000 and 2003, 14 dead dolphins were found washed up on

Shackleford Banks. During that period 46 dead dolphins, four dead whales, one dead harbor porpoise and five dead seals were found on Core Banks, along with one live seal. The dolphins were primarily bottlenose dolphins. The marine and estuarine benthic infauna and epibenthos within Park waters do not appear to have been systematically studied.

Freshwater fauna

There are no freshwater rivers, major streams, or lakes within Cape Lookout National Seashore, but there are many freshwater ponds on Shackleford and parts of Core Banks. Schwartz (1982) conducted a finfish seine survey of 92 of these ponds on both Shackleford and Core Banks, finding a number of species of small or young fish present in 52% of the ponds sampled (Table 2). The most abundant species were *Cyprinodon variegates* and *Gambusia affinis*, comprising approximately 39% and 22% of the individuals, respectively (Schwartz 1982). Assessments of the benthic fauna and zooplankton of these ponds have not been reported in the literature. While the ponds, particularly on Core Banks, are subject to beach water overwash during major storms, freshwater algae will survive via cyst and resting cell banks in the sediments, and freshwater zooplankton can produce resting eggs that will survive salt water conditions for short periods.

Table 2. Fish species found in freshwater ponds on Shackleford and Core Banks, in order of numerical abundance (from Schwartz 1982).

Species	Total number	Samples containing the species
Cyprinodon variegates (variegated minnow)	4362	48
Gambusia affinis (mosquitofish)	2431	41
Mugil cephalus (striped mullet)	1669	14
Fundulus heteroclitus (mummichog)	1018	34
Lucania parva (rainwater fish)	999	32
Leiostomus xanthurus (spot)	564	5
Fundulus confluentus (marsh killifish)	26	7
Fundulus majalis (striped killifish)	21	6
Fundulus luciae (spotfin killifish)	13	5
Menida menida (Atlantic silversides)	13	9
Brevoortia tyrannus (Atlantic menhaden)	12	1
Elops saurus (ladyfish)	2	1
Anguilla rostrata (American eel)	1	1

Upland fauna

Historically, sheep, goats, cows and pigs were grazed on Core Banks and Shackleford Banks, but have since been removed. The only remaining livestock include a population of now wild horses on Shackleford Banks. Other fauna on Core and Shackleford Banks include raccoons, river otters, rabbits and rice rats (NPS 2000). Along with the other small mammals nutria, non-native organisms, are reported to be common and utilize the freshwater ponds and marsh areas of Core Banks

(Schwartz 1982; Dr. T. Lankford, UNCW Biology Department, personal observation). Nutria have replaced native muskrat in some areas in Gulf States and can cause considerable physical damage to the marsh, but nothing is published regarding their environmental impact on Cape Lookout National Seashore. Numerous species of birds can be seen on Cape Lookout National Seashore (NPS 2002). Various tern species, egrets, herons, and shorebirds nest in the Park during summer (NPS 2000), and efforts are made by Park personnel to protect the nesting areas from human disturbance.

The most obvious component of Shackleford Bank's large fauna is the herd of approximately 125 wild horses. Horses have been living on the Outer Banks for centuries, and roam the entire length of Shackleford Banks. The herd is under some management to maintain a genetically diverse population at a healthy level through immunocontraception and periodic adoption of excess individuals (NPS 2002). Fresh drinking water sources for the horses are abundant on the western end of the island. On the eastern end the water resources are primarily salt marsh. However, two of this report's authors observed a small group of horses dig a well on the east end and drink from it while keeping the two researchers away from it (Plate 2). The researchers returned two hours later when the dig was deserted and measured the salinity of the well, which was only 0.5 ppt in an area dominated by salt marshes. Potentially relevant to the quality of the water resources on Shackleford Banks are the very abundant horse manure piles especially concentrated in the maritime forest. These manure piles are sources of concentrated nutrients and fecal bacteria.

Plate 2. Horses digging freshwater drinking hole near salt marsh, Shackleford Banks, N.C.

ASSESSMENT

Sources of pollutants

The North Carolina Division of Water Quality, a unit within the N.C. Department of Environment and Natural Resources, uses basinwide management plans for water quality and habitat analyses, pollution assessment and enforcement, and management efforts. Northern Core Banks is within Subbasin 03-04-14 of the Neuse River basin (NCDENR 2002). Shackleford Banks and southern Core Sound are within Subbasin 03-01-56 of the White Oak River basin (NCDENR 2001).

Point source pollution

There are no NPDES dischargers on Core or Shackleford Banks (NCDENR 2001; NCDENR 2002). Point source discharges on the mainland are considered to be minor except for the Beaufort WWTP (1.5 MGD) and Beaufort Fisheries, Inc. (3 MGD). These two facilities discharge into Taylor's Creek in Beaufort, located several km across marine waters from the Park. However, the data do not indicate a current land-based threat to park waters from nutrients or algal blooms. Most nutrients are utilized in the upper creek stations and the remainder is diluted by marine waters. Thus, dilution from marine waters would significantly reduce nutrient inputs from the source areas across Core Sound such as Beaufort, Harker's Island, the North River, and the tidal creeks and small communities on the mainland.

Non-point source pollution

There are no registered concentrated animal feeding operations (CAFOs) on Core or Shackleford Banks; thus, concentrated livestock waste runoff is not an issue. Manure piles from the resident horse population on Shackleford Banks may be a local source of pollution to the freshwater ponds and some marsh areas. Likewise, there are no traditional farms for row crops, and no attendant fertilizer runoff. Impervious surface coverage, which concentrates pollutants and increases stormwater runoff pollution, is very low and is not a factor on Core and Shackleford Banks. There are septic systems in use in a number of areas on North and South Core Banks that are potential (even likely) sources of nutrients to nearby wells and surface waters. Septic systems are not in use on Shackleford Banks.

There are no major non-point source runoff areas located on the mainland that affect northern Core Banks (NCDENR 2002). Potential runoff areas on the mainland that could impact southern Core Banks are the small communities along Core Sound and runoff from Open Grounds Farm, a major agricultural operation in Carteret County. However, there is no evidence that runoff from any of these sources is currently impacting southern Core Banks. Potential runoff areas that could impact Shackleford Banks include the small communities on Harker's Island, across Back Sound, and the Town of Beaufort, across the Beaufort Channel. There is no evidence that runoff from either of these sources is currently impacting Shackleford Banks. Atmospheric deposition of nitrogen can cause increases in coastal phytoplankton biomass (Paerl et al. 1990), and ammonia from CAFOs located as far as 80 km upwind can be deposited in estuarine and coastal waters (Walker et al. 2000). However, data on such deposition is lacking for Shackleford and Core Banks so such contributions are presently unknown.

Undefined sources of water pollution

Located on Core Banks are two areas of concern where former aboveground storage tanks, a former incinerator, and an active refueling pad have leaked some amount of pollutants (petroleum hydrocarbons, polynuclear aromatic hydrocarbons (PAHs), and metals) into soils and groundwater in the immediate vicinity of the sites (Bhate Environmental Associates 2004). This is presently under investigation, but a brief summary of preliminary results is presented following the well water discussion below.

Assessment of biological resources with respect to water quality (both surface and groundwater)

Water quality standards

The State of North Carolina has ambient water quality standards (NCDENR 1999) for common water quality parameters including dissolved oxygen (5 mg/L), turbidity (50 NTU for freshwater, 25 NTU for brackish and salt water), and chlorophyll *a* (40 μg/L). Microbiological water quality standards are discussed in a subsequent section. North Carolina also has standards for metals and various toxic compounds (NCDENR 1999). No North Carolina Division of Water Quality (NCDWQ) ambient water quality monitoring stations are located within the park boundaries, and NCDWQ does not monitor water quality in oceanside waters of the Outer Banks.

Water Quality in Back and Core Sounds

NCDWQ considers northern Core Banks part of Subbasin 03-04-14 of the Neuse River basin (NCDENR 2002). NC DWQ has historically or is currently operating three sites in Subbasin 03-04-14 (Fig. 3). Station J9930000 is located 15 miles (24 km) away from Core Banks by water at the mouth of the Neuse River. Station J9938000 is located in west Thorofare Bay, through the canal and 6.5 water miles (10.5 km) from Core Banks. Station J9940000 is located off the Highway 12 bridge over Thorofare Canal, four water miles (6.5 km) away from Core Banks (NCDENR 2002). The locations of these three sites preclude their usefulness in a water quality assessment of Cape Lookout National Seashore. NC DWQ considers Shackleford Banks and southern Core Sound to be part of the White Oak River Subbasin 03-01-56, (NCDENR 2001). NCDWQ has or is operating three ambient water quality stations in the general vicinity of southern Cape Lookout Park (Fig. 3). Station P9720000 is located near Harker's Island in Back Sound, about three miles (5 km) by water from Shackleford Banks; Station P9730000 is located at the mouth of Jarrett Bay three water miles from southern Core Banks, and Station P9740000 is located at the mouth of Nelson Bay, three water miles from southern Core Banks. An assessment of key water quality data collected since 1994 at those three locations is summarized in Table 3.

The NCDWQ data from the western portion of Back and Core Sounds show waters that on average contain low nitrate-N and moderate total phosphorus (TP) concentrations (Table 3). Maximum TP concentrations can reach relatively high levels, but maximum nitrate concentrations from 1994-2002 never exceeded 0.5 mg/L, a moderate level (Table 3). More telling is the summary chlorophyll *a* data, a response variable to nutrient loading. Mean concentrations at all three NCDWQ sites can be

Figure 3. Locations of NCDWQ and NC Shellfish Sanitation sampling sites near CALO.

considered low to moderate (Bricker et al. 1999; Mallin et al. 2000), with maximum concentrations not reaching half of what NCDWQ considers indicative of eutrophic waters (NCDENR 1999). Thus, at present we feel that concentrations of mainland-derived nutrients, and probably other pollutants, are too low to impact Cape Lookout National Seashore waters.

Table 3. Summary water quality statistics for NC DWQ ambient monitoring stations located within 5 km of Cape Lookout National Seashore (1994-2002). Data are presented as mean ± standard deviation / range / median, fecal coliform data as geometric mean / range.

Station	Nitrate-N (mg/L)	TP (mg/L)	Chlorophyll *a* (μg/L)	Fecal col. (CFU/100 mL)
P9720000	0.026±0.063	0.032±0.058	3.7 ± 2.9	7
	0.010-0.500	0.010-0.500	1.0-12.0	1-18
	0.010	0.020	2.5	
P9730000	0.021±0.029	0.039±0.120	4.2±4.1	7
	0.010-0.150	0.010-1.000	1.0-19.0	1-10
	0.010	0.020	2.5	
P9740000	0.023±0.033	0.033±0.027	4.7±4.3	8
	0.010-0.150	0.010-0.200	1.0-15.0	1-160
	0.010	0.020	4.0	

Water quality within Cape Lookout National Seashore

Dr. Michael Rikard of the National Park Service at Cape Lookout commissioned a water quality survey for eight well water sites and eight surface water locations between December 1998 and June 2001 (Fig. 1). The sites were sampled on ten occasions for salinity, conductivity, pH, fecal coliform bacteria, ammonium-N, nitrate-N, total Kjeldahl nitrogen (TKN), total nitrogen and total phosphorus (Tables 4 and 5).

There is an Environmental Protection Agency standard of 10 mg/L for nitrate-N for drinking water, to protect infants from potentially fatal methemoglobinemia (blue-baby syndrome). This illness occurs when excessive nitrate in the body is reduced to nitrite, which converts hemoglobin to methemoglobin, rendering red blood cells unable to carry oxygen. This EPA standard was exceeded during the survey in the Great Island well #2 (GI-2), and was approached in GI-1 and Portsmouth Village well #1 (PV-1, Table 4). High concentrations of ammonium were also found at GI-2 and PV-1 (Table 4). Thus, there is a source of nitrogen to local groundwaters at these locations.

The high ammonium and phosphorus concentrations in some of the Cape Lookout wells were comparable to concentrations found in wells located near barrier island experimental septic systems that had drainfields close (30 cm) to the water table, where saturated and anoxic conditions prevailed (Cogger et al. 1988). Under drier conditions with drainfields well above the water table, nitrate concentrations exceeding 10 mg/L were detected as far as 3 meters from drainfield trenches in the Cogger et al. (1988) experimental trenches. The other Cape Lookout wells tested were not potentially problematic in terms of nitrate and human health. Phosphorus concentrations were high at GI-2 and PV-1 as well (Table 4). The nutrient source to the wells is likely septic system leachate (M. Rikard, personal comm.), which can be problematic in sandy soils of barrier islands if the water table is high (Cogger et al. 1988).

As mentioned above, two locations are experiencing some soil and groundwater contamination from toxicants. One area is the Gun Club site on south Core Banks, where former aboveground storage tanks (ASTs) were located. At this location petroleum hydrocarbons have contaminated the soils and groundwater beneath the sites, with the extent of the contamination presently unknown; also at the Gun Club there was petroleum hydrocarbon contamination in the soil and groundwater beneath the Generator Pad (Bhate Environmental Associates 2004). In a second area of concern, Portsmouth Village, an area behind the Coast Guard Maintenance Building where three ASTs were once located showed extensive soil and groundwater petroleum hydrocarbon contamination. There was minor contamination in an area near a cabin where an AST once stood. At an incinerator site the groundwater showed levels of arsenic, chromium and lead that exceed N.C. groundwater standards. The authors of the report recommended further analysis of the extent of contamination and intensive mapping of the areas of concern (Bhate Environmental Associates 2004).

Nutrient concentrations in some of the surface water sites sampled during the survey were surprisingly high at times (Table 5). The GI-NPS-Dock, LS-Dock, and CG Creek and Doctor's Creek at Portsmouth Village (Fig.1) all showed maxima that are unusually high for tidal creeks and coves located away from upland nutrient sources (McMillan et al. 1992; Lewitus et al. 1998; White et al. 2004; Mallin et al. 2004). Mean total phosphorus concentrations at all surface sites can be considered moderate to high, with maxima at some stations unusually high (Table 5).

The source of these elevated nutrients is unclear, although leachate from former and present septic systems may be a factor. Chlorophyll *a* data are not available to measure the biotic response to these elevated nutrients. We emphasize that incidents of high nutrients are rare, with median nutrient concentrations (Table 5) generally much lower than mean concentrations and well within ranges seen in other tidal creek systems (McMillan et al. 1992; Lewitus et al. 1998; Mallin et al. 2004).

Ecosystem effects

Ecosystem effects may be considered changes to the habitat, food web, or health of plant or animal communities. Water quality issues that could affect the flora or fauna of Park waters include excessive nutrient loading leading to eutrophic conditions, and consequent nuisance or toxic algal blooms. Toxic compounds in the surface or groundwaters could affect plant or animal survival or growth. With minimal human habitation on the islands since early 1900, and no industry, there would be very limited local sources of pesticides and herbicides. However, as mentioned earlier a recent study (Bhat Environmental Associates 2004) showed soil and groundwater contamination

Table 4. Cape Lookout well water quality, December 1998 – June 2001 (n = 10). Data presented as mean ± standard deviation / range / median, except for fecal coliform bacteria: geometric mean/range.

Well	Salinity ppt	FC CFU/100mL	Nitrate mg N/L	Ammonium mg N/L	Total N mg N/L	Total P mg P/L
GI-1	0.4±0.5 0.0-1.4 0.2	1 1-1	0.74±2.23 0.01-7.10 0.05	0.18±0.26 0.05-0.82 0.05	3.14±4.54 0.25-14.10 0.94	0.40±0.67 0.04-1.70 0.06
GI-2	0.9±0.7 0.1-2.0 0.6	1 1-36	1.30±3.44 0.01-11.00 0.05	4.05±7.00 0.05-21.40 0.75	9.13±9.49 1.19-25.51 5.35	2.02±4.65 0.02-15.00 0.07
KQ	0.1±0.1 0.0-0.3 0.1	1 1-145	0.30±0.79 0.01-1.90 0.05	0.11±0.13 0.05-1.41 0.05	1.37±1.51 0.18-4.70 0.50	0.55±0.65 0.03-2.86 0.05
SCB-DY	0.3±0.4 0.0-0.7 0.3	2 1-145	0.23±0.59 0.01-1.90 0.05	0.20±0.43 0.05-1.41 0.05	1.39±1.48 0.25-5.10 0.80	0.49±0.76 0.03-2.12 0.13
SCB-LG	4.2±1.5 1.7-6.6 4.0	1 1-5	0.27±0.68 0.01-2.20 0.05	0.32±0.42 0.05-1.43 0.17	1.56±1.80 0.25-6.20 0.89	0.51±0.59 0.05-1.88 0.30
PV-1	5.3±4.0 1.2-14.9 4.8	3 1-478	1.06±2.31 0.01-7.00 0.05	1.73±2.34 0.20-7.89 0.82	4.02±3.12 0.50-9.75 2.93	1.36±1.29 0.05-3.63 0.97
LP-1	0.4±0.3 0.0-0.9 0.3	1 1-52	0.30±0.74 0.01-2.40 0.05	0.14±0.14 0.05-0.46 0.05	1.63±2.66 0.25-9.10 0.69	0.34±0.52 0.04-1.72 0.12
LP-2	1.4±2.0 0.1-5.4 0.5	2 1-190	0.04±0.02 0.01-0.06 0.05	0.13±0.18 0.05-0.62 0.05	0.82±0.59 0.25-2.10 0.54	0.98±1.31 0.05-3.86 0.31

GI = Great Island; KQ = Keeper's Quarters; SCB = South Core Banks; DY = David Yeoman; LG = Long Cabin; PV = Portsmouth Village; LP = Long Point.

Table 5. Cape Lookout surface water quality, December 1998 – June 2001 (n = 10). Data presented as mean ± standard deviation / range / median, except for fecal coliform bacteria: geometric mean/range.

Well	Salinity ppt	FC CFU/100mL	Nitrate mg N/L	Ammonium mg N/L	Total N mg N/L	Total P mg P/L
GI-NPS Dock	26.4±4.9 15.6-33.9 26.7	10 1-453	0.20±0.53 0.01-1.70 0.05	0.28±0.55 0.05-1.80 0.05	1.34±1.40 0.25-4.60 0.61	0.53±0.84 0.03-2.37 0.07
GI-Ferry Dock	26.9±4.7 16.0-33.4 26.9	8 1-160	0.04±0.02 0.01-0.05 0.05	0.17±0.21 0.05-0.66 0.05	1.86±3.96 0.25-13.10 0.50	0.39±0.53 0.05-1.64 0.08
SCB-Chapel	27.3±4.7 17.0-34.0 27.4	3 1-53	0.41±1.19 0.01-3.80 0.05	0.16±0.22 0.05-0.75 0.05	1.81±2.64 0.21-8.50 0.70	0.50±0.57 0.03-1.32 0.19
KQ-Ferry Dock	32.3±1.1 30.5-33.6 32.6	3 1-23	0.18±0.43 0.01-1.40 0.05	0.11±0.16 0.05-0.57 0.05	0.88±0.52 0.25-1.60 0.80	0.67±0.88 0.03-2.30 0.20
LS-Dock	31.8±2.3 26.3-33.7 32.4	1 1-4	0.76±2.26 0.01-7.20 0.05	0.13±0.19 0.05-0.67 0.05	2.06±2.90 0.25-7.60 0.68	0.47±0.75 0.04-1.95 0.10
CG-Creek	21.3±6.1 12.0-30.2 21.3	4 1-115	2.51±6.60 0.01-21.00 0.05	0.25±0.36 0.05-1.10 0.05	3.70±6.87 0.50-22.60 0.74	0.67±0.68 0.10-1.90 0.30
Doctors Creek	22.5±6.2 12.7-29.9 23.1	22 1-430	0.47±1.31 0.01-4.20 0.05	0.26±0.54 0.05-1.80 0.05	1.40±1.55 0.25-5.40 0.86	0.70±0.90 0.05-2.34 0.28
LP-Ferry	26.1±6.1 16.3-35.3 25.1	2 1-59	0.04±0.02 0.01-0.05 0.05	0.20±0.31 0.05-1.05 0.05	1.17±1.40 0.25-4.91 0.62	0.71±1.11 0.04-3.26 0.10

GI = Great Island; KQ = Keeper's Quarters; LS = Les & Sally; SCB = South Core Banks; LP = Long Point; CG = Coast Guard

from ASTs and an incinerator in two Park areas. NCDWQ does not routinely sample for complex compounds, so there are no data for NCDWQ stations within the two relevant subbasins. As a wholistic measure of ecosystem health it is worth mentioning once again that the fish of Core Sound are healthy in comparison to those of the eutrophic lower Neuse Estuary/western Pamlico Sound junction, as determined by a comparison of multiple condition indicators between fish collected at both locations (Adams et al. 2003). Below are some specific indications of ecosystem effects.

Hypoxia and anoxia

Incidents of marine or estuarine hypoxia (low dissolved oxygen, or DO) or anoxia (no dissolved oxygen) can occur in waters impacted by elevated biochemical oxygen demand (BOD), combined with vertical stratification to prevent mixing. These conditions occur most frequently in summer when elevated water temperatures hold less dissolved oxygen. Incidents where DO drops below 2 mg/L are capable of causing death to sessile marine organisms and displacement of mobile species (Diaz and Rosenberg 1995). The waters in the immediate vicinity of Cape Lookout National Seashore are generally well mixed by wind and tides, have generally low nutrient concentrations, and are unlikely to host algal blooms. Park Service personnel have not seen evidence of algal blooms in the Park's water resources. Thus, marine finfish and shellfish kills caused by hypoxia or anoxia have not been reported in the vicinity of Cape Lookout National Seashore. Following Hurricane Floyd, there was bottom water hypoxia in western Pamlico Sound (DO 2.0-4.0 mg/L) for about two weeks, although the upper 5 m of the water column maintained DO in excess of 5 mg/L during this period (Paerl et al. 2001; Burkholder et al. 2004). Reports of massive benthos mortality and loss of the future fishery (Paerl et al 2001) later proved to be unfounded as no evidence of kills was documented, and later data showed long-term resilience in the fisheries, with the exception of the blue crab fishery (Burkholder et al. 2004). In contrast to the Sound waters, the freshwater ponds in the park are generally small, enclosed bodies of water, which may be impacted by organic BOD loading from decaying aquatic vegetation and manure from the wild horse population (on Shackleford Banks). A preliminary survey by the authors in October 2003 found a few ponds on Shackleford Banks that had hypoxic waters (dissolved oxygen < 4.0 mg/L). It is likely that during summer more ponds are afflicted with hypoxia. This could stress the resident fish populations known to inhabit these ponds (Schwartz 1982).

Toxic algal blooms

Toxic algal blooms have the capacity to severely disrupt aquatic ecosystems through fish kills and food web changes (Burkholder 1998). The only recorded toxic bloom that affected Cape Lookout waters was caused by a large and persistent bloom of the dinoflagellate *Karenia brevis* (formerly *Ptychodiscus brevis*), which was generated off the Florida coast, carried into local waters by a Gulf Stream meander and maintained there by wind patterns from November 1987 through February 1988. This bloom impacted the coastal area from Hatteras Inlet to Cape Fear, forcing closure of the shellfishery and leading to considerable economic loss, affecting shellfish reproduction, and causing 48 cases of neurological shellfish poisoning (Summerson and Peterson 1990; Tester et al. 1991). No further incidents of this organism affecting Cape Lookout waters have been recorded. The toxic dinoflagellates *Pfiesteria piscicida* and *P. shumwayae* have caused fish kills in the Neuse, Pamlico, and New River Estuaries, but the closest *Pfiesteria*-caused fish kill occurred in Taylor's Creek near Beaufort in December 1991 (Glasgow et al. 2001). Surveys in selected areas of the Outer Banks have only found low concentrations of *Pfiesteria* spp. (see Section 2C). As *Pfiesteria* spp. prefer nutrient enriched waters and more estuarine conditions, blooms of *Pfiesteria* in Cape Lookout waters

are likely to be rare. However, we note that the 1999-2002 survey did detect periodic incidences of high nutrients at some estuarine creek and dock sites, so the possibility of potentially harmful algal blooms cannot be discounted.

Human health issues

Water borne factors potentially influencing human health can be assessed by several metrics. These metrics include shellfish safety in terms of microbial contamination, water contact safety in terms of either fecal coliform bacterial or enterococci counts, and water contact or aerosol safety in terms of toxic algal blooms. Human contact with toxic or otherwise dangerous chemicals in surface or groundwaters is another potential issue.

Shellfish contamination

First, shellfish safety is a matter of concern through human consumption of microbially contaminated shellfish. The Shellfish Sanitation Branch of the North Carolina Division of Environmental Health monitors the waters on the sound side of Cape Lookout and Shackleford Banks and will advise the Division of Marine Fisheries to close waters for shellfish harvest if fecal coliform counts (as colony-forming units per 100 ml of water, or CFU/100 ml) exceed the United States standard. This standard is based on a minimum of 30 sets of samples, in which the geometric mean count cannot exceed 14 CFU/100 ml, and less than 10% of samples cannot exceed 43 CFU/100 ml (P. Fowler, NCDEH, personal communication; also NCDHR 1987).

Area E-5, the Taylor's Creek area, has two stations located within 1 km of the western portion of Shackleford Banks, Stations 22 and 23. Both of these stations had fecal coliform counts well below the standard and are open for shellfishing (Shellfish Sanitation Section 2002). Area E-7, the Back Sound area, has Stations 18, 20, 21, 22, 23 and 24 located within one km of eastern Shackleford Banks, southern Core Banks, or the islands associated with these locations. All six of these stations had fecal coliform counts well below standard and are open for shellfishing (Shellfish Sanitation Section 2000). At the NCDWQ ambient monitoring sites in Back and Core Sounds, geometric mean fecal coliform bacterial counts were below the NC shellfishing standard of 14 CFU/100 mL (NCDHR 1987) at all three sites, with few maxima exceeding the shellfishing standard (Table 3).

Microbial pathogens and human contact

Humans can contract illness through contact with microbially contaminated waters while swimming, surfing, sailing, etc., if pathogenic viruses, bacteria or protozoans enter the individual through the mouth, nose, eyes, or open wounds. The North Carolina freshwater standard for human contact is 200 CFU/100 ml of fecal coliform bacteria (NCDENR 1999). North Carolina currently uses the indicator organism enterococcus for its coastal recreational water standard (recommended by the Federal EPA) in which the geometric mean of five samples collected within 30 days must be no greater than 35 CFU/100 ml, and includes a single sample maximum below 104 CFU/100 ml (NCDEH 2004). The North Carolina Shellfish Sanitation Section conducts recreational beach surveys to assay for water safety. Data obtained from Shellfish Sanitation covering the period 1997-2003 indicates that there are no sampling stations in or adjacent to Cape Lookout Seashore that show repeat violations of the fecal coliform or enterococcus standard. Samples collected on September 11, 2001 showed elevated fecal coliform counts at the Cape Lookout Park Service dock (Station 69A) and in the Cape Lookout Hook (Station 69), with 350 and 540 CFU/100 ml, respectively. On

one other occasion, June 22, 1999, Station 69 had elevated enterococci of 42 CFU/100 ml, but very low fecal coliform counts.

The 1998-2001 well water survey found that geometric mean fecal coliform counts at the sampled wells ranged between 1-3 CFU 100 ml, with few maxima exceeding problematic levels (Table 4). Thus, it appears that septic system leachate of fecal coliform bacteria is not a problem near these wells. The 1998-2001 surface water survey utilized fecal coliform bacteria instead of enterococci. The results showed geometric mean fecal coliform counts well below the NC human contact water standard of 200 CFU/100 mL, with few maxima exceeding the standard (Table 5). Thus, the results of this survey support the above NC Shellfish Sanitation Section results indicating generally clean microbiological water quality in terms of human contact.

Exposure to toxic algae
Humans can also be adversely affected by skin contact with water containing toxic algae, or breathing aerosols containing toxins from such algae (Burkholder 1998). The only toxic algae known to affect humans that are commonly found in North Carolina estuarine and coastal waters are the dinoflagellates *Pfiesteria piscicida* and *P. shumwayae* (Burkholder and Glasgow 1997; Glasgow et al. 2001). Contact with these taxa in laboratory and bloom conditions in the field have caused mild to severe illness in humans, with symptoms including neurological impairment, immune system dysfunction, respiratory ailments, skin lesions, and memory loss (Glasgow et al. 1995; Grattan et al. 1998; Haselow et al. 2001). The Center for Applied Aquatic Ecology at North Carolina State University (www.ncsu.edu/wq) has conducted several surveys along selected areas of the North Carolina Outer Banks for the presence of *Pfiesteria*. Surveys performed from 1996-2003 have indicated very low concentrations of *Pfiesteria* spp. in these waters (Dr. J.M. Burkholder, NCSU, personnel communication). The high salinities and generally low nutrient concentrations in most of the local waters do not provide an environment conducive to *Pfiesteria* proliferation. However, the periodic high nutrient concentrations found at some of the dock sites may provide rare opportunities for *Pfiesteria* growth.

Algal toxins and shellfish consumption
Humans can also become ill or die from consumption of shellfish containing toxins concentrated by filtration of toxic dinoflagellates other than *Pfiesteria* (Burkholder 1998). However, those toxic species are not native to North Carolina waters, and with the exception of the one *K. brevis* episode, dinoflagellate shellfish poisoning has not been a problem in North Carolina.

Contamination of fish for human consumption
There is a mercury based fish consumption warning (see List of Impairments below for details) for four species of marine finfish that likely results from airborne Hg from distant fossil fuel power plants.

Toxicants in groundwater
As mentioned, a survey did find elevated concentrations of petroleum hydrocarbons in soil and groundwater in two Park areas where ASTs were located, and concentrations of some metals exceeding N.C. groundwater standards at an incinerator site. The extent of groundwater contamination and whether it impacts any wells is unknown.

List of impairments (State and Federal listings)

Along northern Core Banks (NCDENR Subbasin 03-04-14) all waters are described as supporting aquatic life and secondary recreation (NCDENR 2002). There are no beach water impairments and shellfishing is allowed near northern Core Banks; the nearest waters closed to shellfishing are located at the Cedar Island ferry landing, over 12 km away by water (NCDENR 2002). However, all of the local waters are impaired by a fish consumption advisory for king mackerel based on mercury (NCDENR 2002). Southern Core Banks and Shackleford Banks are part of NCDENR Subbasin 03-05-05. There are no shellfishing or beach water impairments (NCDENR 2001). Again, all of the local waters are impaired by a fish consumption advisory for king mackerel based on mercury, and tilefish, shark, and swordfish have also been included in the saltwater fish consumption advisory in coastal North Carolina waters (http://www.schs.state.nc.us/epi/fish/contaminants.html).

List of water bodies with undocumented conditions/status

The many freshwater ponds on parts of Core and Shackleford Banks have no official documented water quality conditions or status. The only records of pond water quality are temperature, pH, and dissolved oxygen measurements collected during a fisheries survey by Schwartz (1982) over two decades ago.

OTHER AREAS OF CONCERN

Coastal development trends

Population

Human population growth is rapid in the coastal zone of the United States, particularly in the southeast (Mallin et al. 2000). Along the North Carolina coast there is a strong statistical correlation between increased population and increased closures of shellfishing waters from elevated fecal bacterial counts (Mallin et al. 2001). From 1990-2000 the human population increased by 27.2% in Morehead City, near the westernmost end of Shackleford Banks. However, the population of nearby Atlantic Beach decreased by 8.1% during that period, and the population of Beaufort, across the sound from Shackleford Banks, decreased by 1% during that period (NCDENR 2001). The area from Beaufort north to Cedar Island along Highway 70 consists of small rural communities surrounded by extensive wetlands and lowlands, with limited buildable high ground. There are no beaches to attract vacationers, a lot of insect pests, and few convenient services. Extensive urbanization in this area does not appear to be an issue in the near future.

Neither Core Banks nor Shackleford Banks contains a resident human population, and with the purchase of the private residences by the Park Service there is expected to be none in the future. However, visitors to these seashores, especially the western end of Shackleford Banks, may increase in the future with general coastal population increases. Currently Park personnel estimate that as many as 300-400 boats visit Shackleford Banks on July 4th weekend. This can potentially lead to increased law enforcement activities by Park and Coast Guard personnel, overuse of the outhouse facilities on Shackleford Banks, increased fecal bacterial contamination of the local beach and shellfishing waters, and disruption of nesting bird habitat.

Land use

Human land use within Core and Shackleford Banks is unlikely to intensify. The Park Service has purchased most of the private dwellings on Core Banks and their fate has yet to be determined. Many of the structures are historic buildings and will not be demolished, but either used by the Park or leased to the public (M. Rikard, NPS, personal communication).

Surface and groundwater withdrawals

Well water is currently drawn from 90 ft down for use at the Core Banks fish camps and park facilities. Since the private dwellings on Core Banks are coming under the jurisdiction of the Park Service use of the groundwater is not likely to increase, and shortages are not likely to become an issue. Surface waters on Shackleford Banks are not used for human consumption, nor is there any groundwater withdrawal except for two non-potable wells used for washing.

Nuisance and invasive species

The nearby Port of Morehead City presents a potential gestation place for alien marine organisms such as toxic dinoflagellates or nuisance bivalves, or other food web-altering organisms. This is because nonindigenous marine planktonic organisms have been dispersed into new and distant habitats through ballast water exchanges by ocean going vessels (Carlton and Geller 1993). While non-native species introductions have occurred in many North Carolina freshwater habitats, such invasions of the Cape Lookout water resources have not been documented. However, along the U.S. East Coast there is both northward and southward movement of various non-native invertebrates including the green crab (*Carcinus maenas*) and green mussel (*Perna viridis*) towards the Cape Lookout area. Unfortunately there is no synoptic survey data to verify the presence of such invasive species at this time. Offshore in shelf waters the non-native lionfish (*Pterois volitans*) has recently become established, and its effects on the offshore ecosystem are presently unknown.

Physical impacts

Physical changes to the landscape may impact fresh or brackish water quality. Disturbances such as hurricanes and nor'easters are natural phenomenon that the native flora and fauna are adapted to and will not be considered further here. As noted, there is presently minimal human development within Cape Lookout National Seashore, and any future building is likely to be minimal and Park related. The principal physical disturbances to Core Banks presently come from beach motor vehicle traffic. Beach motor traffic is principally a threat to nesting bird habitat and park personnel attempt to protect such habitats. Vehicle traffic through the dunes can increase the instability of such areas and increase the potential for dune migration (Leatherman 1988). In terms of water quality and aquatic resources vehicle traffic on tidal flats and salt marsh areas can have long term damage to resident vegetation, alter salinity, increase anoxia of sediments, and directly kill aquatic organisms (Leatherman 1988). To minimize such damage the National Park Service limits driving on Core Banks to the ocean side of dunes or officially marked trails, limits driving between dunes to marked routes, and prohibits driving on the Core Sound side of the islands and the sand flats on North Core Banks (http://www.nps.gov/calo/orv.htm). Shackleford Banks has no public use of motor vehicles but there is ATV use by park service personnel. Generally, human physical disturbances are limited to foot traffic and the potential of a human caused forest fire. Overgrazing and trampling by the horse herd on Shackleford Banks are physical disturbances that may negatively impact the salt marshes and reduce their primary nursery function (Pilkey 2003).

RECOMMENDATIONS FOR ADDRESSING IMPAIRMENTS, POTENTIAL IMPACTS AND UNDOCUMENTED WATER BODIES.

The National Park Service is clearly limiting the pollution of Cape Lookout National Seashore waters by limiting human development of these islands and maintaining the Park habitats in as natural state as possible. However, there are a number of present and potential stressors that are or may affect the Park ecosystem that should be considered further (Table 6).

The most significant freshwater resource on Cape Lookout National Seashore consists of the many small ponds that characterize parts of Core Banks and Shackleford Banks. These ponds are a resource at least for the wildlife that visit or inhabit this Park. As such, they also represent potential locations for future ecological studies that may be carried out or commissioned by the Park. Due to their isolation from the mainland these ponds may harbor rare or endemic plant or animal species. It would be worthwhile to have the locations of these ponds mapped and placed into a GIS layer. It would be of further use to have a selection of these ponds sampled for standard water quality parameters (water temperature, dissolved oxygen, pH, salinity, total nitrogen, ammonium, nitrate, total phosphorus, orthophosphate, dissolved organic carbon, chlorophyll *a*) on at least 2-4 occasions. On Shackleford Banks, the extensive horse manure may make it worthwhile to collect pond samples for fecal coliform bacteria as well. It is possible that campers might utilize these freshwater ponds for drinking or washing, and the potentiality of contracting an illness from fecal bacteria does exist.

We feel that there is currently low potential for eutrophic conditions to increase in nearby seawater due to the distance from the mainland. However, due to the elevated nutrient maxima at some of the Core Banks dock and tidal creek sites detected in the 1998-2001 survey, additional nutrient and chlorophyll *a* testing at selected sites should be performed in conjunction with the pond testing (Table 6).

Since high nitrate and other nutrients were found in selected wells and surface waters in the Park we recommend that dye studies be performed in suspect septic systems to determine if septic leachate can be the cause of elevated nutrients, and if further action should be undertaken to reduce this contamination.

We recommend that further studies of the petroleum hydocarbon and heavy metals soil and groundwater contamination be initiated. The extent and flow pathways of the contamination should be mapped, and samples should also be taken in control areas to measure background levels.

Because there are numerous visitors to Shackleford Banks and lower Core Banks on certain holiday weekends, especially July 4th and Labor Day, there is some possibility of unusually high fecal bacterial counts in the boat use areas during these periods. The Park Service may want to commission a fecal coliform and enterococcus survey of busy locations with sampling to occur just before, during, and after such a holiday. This information would provide the Park Service and State Shellfish Sanitation Branch personnel an idea of potential human health risks (if any) by swimming in these waters during maximum use periods.

Table 6. Current and potential stressors that are affecting or may affect Cape Lookout National Seashore environments.

Shackleford Banks

Stressor	Ocean beach	Sound shore	Tidal creeks	Wells	FW ponds
Algal blooms	LP	LP-PP	PP	LP	ND
Toxic algae	LP	LP-PP	PP	LP	ND
Nutrient loading	LP	LP-PP[1]	PP (horses)	ND	PP (horses)
Excessive nitrate	LP	LP	LP	ND	ND
Excessive fecal bacteria	LP	LP-PP[2]	PP (horses)	ND	PP (horses)
Metals contamination	HP (Hg)[3]	HP (Hg)[3]	PP (Hg)[3]	ND	ND
Toxic compounds	ND	ND	ND	ND	ND
Invasive species	PP (lionfish)	ND	LP	LP	ND
Habitat disruption	LP	PP (horses)	PP (horses)	LP	PP (horses)

Core Banks

Stressor	Ocean beach	Sound shore	Tidal creeks	Wells	FW ponds
Algal blooms	LP	LP-PP	PP	LP	ND
Toxic algae	LP	LP-PP	PP	LP	ND
Nutrient loading	LP	LP-PP[4]	MP	MP	ND
Excessive nitrate	LP	LP	MP	MP	ND
Excessive fecal bacteria	LP	LP-PP[5]	LP	LP	ND
Metals contamination	HP (Hg)[3]	HP (Hg)[3]	PP (Hg)[3]	ND	ND
Toxic compounds	ND	ND	ND	ND-PP	ND
Invasive species	PP (lionfish)	ND	LP	LP	ND
Habitat disruption	PP (vehicles)	LP	LP	LP	ND

Definitions: HP – high concern problem, MP – moderate concern problem, LP – low concern or no problem, PP – potential problem, ND – no data to make judgment

1 - based on several high nutrient measurements at docks on Core Banks NPS survey, and potential horse manure loading

2 - Based on holiday boater/swimmer use of the end sound/beach on western Shackleford Banks

3 – Fish tissue consumption advisory by NC DWQ

4 - based on several high nutrient readings at selected dock areas during NPS survey

5 – based on a few isolated incidents of elevated indicator bacteria during Shellfish Sanitation Recreational Water safety surveys

There is a slight possibility for toxic dinoflagellates or other toxic or potentially toxic algae to bloom in these coastal waters, seeded either by rare Gulf Stream meanders or as invasive species from ship ballast water discharged near the Port of Morehead City (Table 6). Thus, we recommend that Cape Lookout National Seashore contract with the Center for Applied Aquatic Ecology at North Carolina State University to conduct at the least an annual survey of Park waters for the presence of *Pfiesteria* spp. and other harmful algal species.

Regarding other potential exotic species, it is recommended that a benthic macroinvertebrate survey be performed in and near soundside Park waters. This would have the dual purpose of assessing the health of the present benthic community and surveying the area for the presence of exotic species moving into Park waters.

Nutria are a non-native species now established on Core Banks. A small mammal survey should be performed with the goals of population assessment as well as ecosystem impacts of this animal. It would also be useful for the Park Service to perform an assessment of the ecosystem impacts of the wild horse herd on Shackleford Banks. Grazing impacts on the vegetation and physical modification of the environment should be considered in this study. It would complement the above suggested water quality analysis of ponds on Shackleford Banks.

Mechanical harvesting of shellfish such as clam kicking or dredging is a potential threat to seagrass communities and water quality. Studies to investigate threats from shell fishing activities should be conducted to assess impacts on sea grass beds and the degradation of water quality from an increase in turbidity. Although past studies have not shown a significant reduction in bay scallop recruitment and pink shrimp abundance from harvesting, future studies should monitor the impact of commercial and recreational shell fishing activity on the population abundance of these species.

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As the nation's principal conservation agency, the Department of the Interior has responsibility fo
most of our nationally owned public lands and natural resources. This includes fostering sound us
of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving t
environmental and cultural values of our national parks and historical places; and providing for th
enjoyment of life through outdoor recreation. The department assesses our energy and mineral
resources and works to ensure that their development is in the best interests of all our people by
encouraging stewardship and citizen participation in their care. The department also has a major
responsibility for American Indian reservation communities and for people who live in island
territories under U.S. administration.

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