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ASSESSMENT OF COASTAL WATER RESOURCES AND WATERSHED CONDITIONS AT CAPE HATTERAS NATIONAL SEASHORE, NORTH CAROLINA

Michael A. Mallin, Matthew R. McIver, and Virginia L. Johnson

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Cover photos:

Top Left: Cape Hatteras Lighthouse, NPS photo
Top Right: Bodie Island drainage ditch, Michael Mallin
Bottom Right: Cape Hatteras Beach, NPS photo
Bottom Left: Okracoke ephemeral pond, Michael Mallin

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHIC PLATES

Acknowledgements

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Commonly used abbreviations

BOD - biochemical oxygen demand
CAFO - concentrated animal feeding operation
CAHA - Cape Hatteras National Seashore
CFU - colony-forming units
CHWA - Cape Hatteras Water Association
DO - dissolved oxygen
EPA - United States Environmental Protection Agency
GPD - gallons per day
MGD – million gallons per day
m - meter
mg/L - milligrams per liter (= parts per million)
NC - North Carolina
NCDEH - North Carolina Department of Environmental Health
NCDENR - North Carolina Department of Environment and Natural Resources
NCDWQ - North Carolina Division of Water Quality
N - nitrogen
NOAA - National Oceanic and Atmospheric Administration
NPS - National Park Service
NTU - Nephelometric turbidity units
P - phosphorus
Park - Cape Hatteras National Seashore
PAH - polycyclic aromatic hydrocarbons
psu - practical salinity units
ORV - off-road vehicle
SAV - submersed aquatic vegetation
UWL - Unique Wetland

EXECUTIVE SUMMARY

The purpose of this report was to locate and examine existing information pertaining to the water quality in and around Cape Hatteras National Seashore, assess the present and likely future water conditions of the park, and make recommendations to fill in existing information gaps. Water quality and quantity, habitat issues, potential for invasive species, and trends in Park resource usage are addressed. This report does not address issues pertaining to the Wright Brothers National monument or Fort Raleigh National Historic Site.

Cape Hatteras National Seashore includes a set of north-south aligned narrow microtidal transgressive barrier islands known as Bodie and Hatteras Islands, with Pea Island in between them (operated by the U.S. Fish and Wildlife Service). The Park also includes the southern portion of Hatteras Island, along with Ocracoke Island, aligned in a northeast to southwest orientation. During hurricanes and nor'easters some areas of the Park are subject to overwash, inlet formation, migration, and closure. There are wider and higher portions of the islands that support maritime forests on Hatteras Island (Buxton Woods) and Ocracoke Island (mainly near Ocracoke Village). Extensive brackish and freshwater wetlands are found on Bodie, Hatteras and Ocracoke Islands, and many freshwater swales, or sedges, are found among the dunes in Buxton Woods. Tidal creeks are important features on Ocracoke and Hatteras Islands, and manmade drainage ditches are important in terms of water distribution and quality on Bodie and Hatteras Islands. Temporary pools are also found throughout the Park.

An important demographic factor impacting the Park as well as the nearby communities is the large increase in human population that has steadily occurred on the islands over the past three decades. There is also a seasonal flux in population, with summer populations tripling those of winter populations due to vacationers and seasonal users. This is important in terms of nutrient and fecal bacterial loads on groundwater, because all sewage on the islands is treated by septic systems.

Bodie Island

Previous research has demonstrated that portions of the Park on south Bodie Island are receiving nutrient and microbial pathogen inputs from the highly developed Town of Nags Head, adjoining the Park, especially during the summer tourist seasons. Some of these inputs (septic leachate) impact drainage ditches between Nags Head and Roanoke Sound. Microbial pathogens also likely move readily through the sandy, saturated soils from groundwater into drainage ditches on Park property. Some of the ditches show the impacts of nutrient loading with algal blooms evident. Most of the ditches convey their contents westward through the wetlands toward Roanoke Sound. These ditches may also harbor elevated PAH concentrations due to heavy traffic crossing the ditches. Sedges and swales in the wetlands between Nags Head and Roanoke Sound receive some of the nutrient and pathogen inputs from the drainage ditches and surface runoff from Nags Head Village, but concentrations are considerably less than in the ditches.

One large drainage ditch conveys its contents to an ocean beach located on Park property at Ramp 1. However, there is presently low potential of nutrient loading and algal bloom formation in beach waters. This is simply because there are massive amounts of nuisance algae and macrophytes in the drainage ditch along Old Oregon Inlet Road that absorb the nutrients. If the ditch vegetation is eradicated, however, nutrient loading to the beach water at Ramp 1 could cause algal blooms during periods of calm weather. The ditch does convey elevated quantities of fecal bacteria to National Park Service (NPS) beach water at Ramp 1 at present, necessitating beach warning signs.

The Sound shore of lower Bodie Island is understudied in terms of nutrients and algal bloom potential, but an EMAP study in the mid 1990s found some minor toxicity problems with benthos at sites in the area. The tidal creeks in the area do not appear to be extensive, and are presently understudied. They would receive inputs from the wetlands in the interior of Bodie Island.

Hatteras Island

There are a number of major drainage ditches on Hatteras Island (south beach discharge, Peter's Ditch) that contain Park areas within their watersheds, and enter either the beach or Sound waters. The quality of these runoff waters is presently unknown, and information is needed to assess receiving water impacts and the effects of drainage manipulations. Additionally, the water quality of the creeks and marshes on Pea Island does not appear to have been studied.

The ocean beach on Hatteras Island does not appear to be in danger of receiving excessive nutrients from inside the Park and thus is at low risk for nuisance or toxic algal blooms. However, N.C. Shellfish Sanitation has documented high enterococcus counts along the beach in the vicinity of the south beach discharge from the wetlands, which has necessitated beach closures. Various beach areas are at risk from habitat disruption (nesting birds and sea turtles) from ORV traffic. The Sound shore of Hatteras Island is mainly adjoining municipal areas rather than Park areas. There is a potential (presently untested) for nutrient and bacterial pathogen loading, and algal blooms, in Sound waters that receive inputs from inland drainage systems such as Peter's Ditch. Toxins may be a moderate possibility in some areas based on EMAP sampling. The water quality of the tidal creeks draining the west side of Hatteras Island is unknown, but based on tidal creek data in nearby regions they could at times harbor algal blooms or bacterial pathogens from anthropogenic loading from local communities.

Some of the Park's groundwater resources that adjoin populated areas may be receiving nutrient inputs from septic leachate, based on at least one study. Based on that same study groundwater withdrawals in wellfield areas will cause habitat disruption in terms of limiting plant species richness and diversity in nearby swales. The ditches on Hatteras Island are unstudied, but the authors of this report observed an algal bloom in Peter's Ditch and assume this ditch collects runoff and septic leachate of nutrients and bacterial pathogens from populated areas.

Buxton Woods, on Hatteras Island, contains many freshwater swales, or sedges, that serve as important wildlife habitat and groundwater recharge areas. Swales well within the Park are insulated from anthropogenic impacts, but some swales near populated areas may be receiving inputs of nutrients and possibly pathogens from septic leachate or overland runoff. There are also extensive permanent and temporary wetlands on Hatteras Island (and the other islands within the Park) that are important habitat for many species of birds, including those with Threatened or Endangered status. Drainage of wetlands will likely cause some habitat disruption for native flora and fauna.

Ocracoke Island

Ocracoke Island has significant fresh and brackish water resources. These include seven tidal creeks intersecting Highway 12, a vast brackish marsh near South Point Road, a freshwater marsh near the northern end of the island in the vicinity of the ferry terminal, and temporary ponds along Highway 12 that are likely important local ecosystems. However, there is no published water quality information available on any of these ecosystems.

The ocean beach of Ocracoke Island is not presently at risk from algal blooms, either benign, nuisance or toxic. There are no local or offshore sources of nutrients, particularly of nitrate. There are no ocean discharges to provide a fecal bacteria risk either. Toxic compounds are not presently a risk but will be if oil exploration occurs offshore. The lionfish is an invasive species from the Gulf Stream; there may be others that appear from time to time.

The sound shore, at least in Park areas, is remote from local and mainland nutrient sources and is not likely to host algal blooms. However, there is an area 400 ft. offshore that receives effluent from the reverse osmosis drinking water plan, effluent that has nitrogen concentrations exceeding 5 mg/L. This nitrogen input into nutrient-limited Pamlico Sound has the potential to cause localized algal blooms. The Sound Shores - Oyster Creek development (outside of the Park) along the soundside of Ocracoke Village has canals that appear to have poor water quality and may host algal blooms at times. The nearby areas are closed to shellfishing; thus, there is fecal bacterial pollution along the Sound in non-Park areas. The Park areas are not likely to have significant habitat disruption along the Sound. Systematic data for invasive species is lacking, and EMAP results show little toxicity in nearby Sound waters.

The tidal creeks on Ocracoke appear to be unstudied in terms of nutrients, algae, bacteria, toxic compounds or species composition. The creek habitats do not appear to be at risk from physical disruption, however the constant automobile traffic crossing the creeks may cause elevated PAH (polycyclic aromatic hydrocarbon) loading to the creeks and their sediments. Automobiles are major sources of PAHs. Groundwater has not been systematically studied but septic contamination of drinking water is not a possibility due to the depth (620 ft.) of the wells. The brackish to oligohaline marsh on Ocracoke Island along South Point Road does not appear to be near any significant anthropogenic nutrient sources, but hosts dense periphytic algal blooms nonetheless, as well as an active microbial/planktonic food web. The presence of fecal bacteria, metals, and other toxic compounds appears to be unstudied in this marsh. The northern freshwater marsh and pond has dense periphyton and SAV beds, and the northern edge may receive inputs from a septic drainfield near the ferry terminal, so there is a potential for nutrient loading and algal blooms in this marsh pond. The invasive species *Phragmites* is a major presence in the southern marsh. Habitat disruption at present does not seem to be problematic in either marsh, as human use is confined to areas along the beach or road. The fresh-to-brackish water ponds along Highway 12, most of which appear to be temporary, are in Park areas remote from human pollution and are not at risk from anthropogenic loading, but some do host dense periphyton mats. There are no data on metals, other contaminants or invasive species, but habitat disruption may occur from ORV usage. Except for fish consumption advisories for selected freshwater and marine species based on mercury, there are no metals data available for the aquatic habitats of Ocracoke Island (or Hatteras and Bodie Islands!).

Recommendations

A high priority item would be to perform a resampling of the drainage ditches on south Bodie Island in the northern area of the park. The last sampling effort occurred ten years ago, and was only for nitrogen. Population has increased in the area and impacts to the Park's water resources are likely to have increased as well. These ditches include those carrying surface and shallow groundwater from east to west through the Park, and the ditch draining Nags Head surface water into the ocean at the beach at Ramp 1. We recommend that these systems be sampled for standard water quality parameters (water temperature, dissolved oxygen, pH, salinity, turbidity, fecal coliform bacteria or enterococcus bacteria, total nitrogen, ammonium, nitrate, total phosphorus, orthophosphate, BOD5 and chlorophyll *a*) on at least six occasions within a year's time. Less than six occasions would not be sufficient to capture seasonal effects impacting water quality parameters (more than six would certainly be better). Since these ditches are exposed to seasonally high traffic, it would also be prudent to sample them for toxic compounds that characterize automobile byproducts and urban runoff, such as polycyclic aromatic hydrocarbons (PAHs) and EPA priority pollutant metals. Additionally, an septic system survey should be redone to define present pollutant loading to the ditches and marshes.

Selected drainage ditches on Hatteras Island (south beach discharge, Peter's Ditch) contain Park areas in their watersheds, and enter either the beach or Sound waters. The quality of these runoff waters is presently unknown, and information is needed to assess receiving water impacts and the effects of drainage manipulations. We recommend that these ditches be sampled for standard water quality parameters (water temperature, dissolved oxygen, pH, salinity, turbidity, fecal coliform bacteria, enterococcus bacteria, total nitrogen, ammonium, nitrate, total phosphorus, orthophosphate, BOD5 and chlorophyll *a*) on at least six occasions within a year's time.

A major gap in the existing information regarding Cape Hatteras National Seashore water quality is the complete lack of information on the quality of Ocracoke Island's fresh and brackish water resources. These include the seven tidal creeks intersecting Highway 12, the vast brackish marsh near South Point Road, the freshwater marsh near the northern end of the island in the vicinity of the ferry terminal, and the temporary ponds that are likely important local ecosystems. We recommend that these systems be sampled for standard water quality parameters (water temperature, dissolved oxygen, pH, salinity, turbidity, fecal coliform bacteria, total nitrogen, ammonium, nitrate, total phosphorus, orthophosphate, BOD5 and chlorophyll *a*) on at least six occasions within a year's time. While the water quality of the sounds to the west of the Park are not currently being monitored by the North Carolina Division of Water Quality, we feel that it would be most productive for the Park to sample the tidal creeks, since that is where any Park-derived pollutants would be most concentrated.

Overall, there is a lack of good quality, up-to-date maps that show the key aquatic features including fresh and brackish wetlands, tidal creeks, ponds and major ditches on all of the Park's islands. Clearly, a high priority for the Park should be to produce a series of such maps (that can be electronically transferred) for Ocracoke, Hatteras, Pea and Bodie Islands. To do so will likely necessitate additional wetlands / hydrological delineations on-site, and possibly aerial photography specific toward that purpose. This can be encompassed under a "wetlands management survey".

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, southward drift from the Chesapeake Bay region or as invasive species from ship ballast water discharged near the Port of Morehead City. A much more possible scenario is the formation of blooms of the native toxic dinoflagellates *Pfiesteria piscicida* or *P. shumwayii* in estuarine areas that receive nutrients from the developed areas north of the park on Bodie Island or near the villages adjacent to the Park on Hatteras and Ocracoke Islands. Thus, we recommend that Cape Hatteras National Seashore contract with the Center for Applied Aquatic Ecology at North Carolina State University to conduct at the least an annual summer 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, including tidal creeks. 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.

Phragmites is a non-native marsh plant becoming abundant in some Park areas. A survey of its presence and potential for its spread would be a useful endeavor. This task could also be encompassed under a “wetlands management survey”.

PARK DESCRIPTION

Background

Location, size, and boundaries: Cape Hatteras National Seashore contains 14,337 ha (35,400 acres) of land, has 119 km (74 miles) of beach (NPS 2000a) and includes a series of barrier islands known as Bodie Island, Hatteras Island, and Ocracoke Island, located along the coast of North Carolina (Fig. 1). This National Seashore is under the jurisdiction of the U.S. National Park Service and Park operations are directed from the Park Service headquarters in Manteo (www.nps.gov/caha). The Park begins at Whalebone Junction on Bodie Island near Nags Head (coordinates N 35 54.30, W 75 36.00) and the southernmost point of the park is Ocracoke Inlet (N 34 04.00, W 76 01.30). Hatteras Island is approximately 84 km (52 miles) long and its width varies from less than 300 m (984 ft.) to a maximum of 6 km (3.7 miles) at Cape Hatteras (Fig. 1)). The Cape Hatteras area (N 35 13.00, W 75 31.50) contains Buxton Woods, the largest example of maritime forest in North Carolina (Cole and Bratton 1995). Across Hatteras Inlet (N 35 11.45, W 75 45.45) is Ocracoke Island, stretching for 25 km (15.5 miles) to Ocracoke Inlet (Fig. 1). Ocracoke Island is part of the Park except for 314 ha (775 acres) of Ocracoke Village. Pea Island, between Bodie Island and Hatteras Island, is owned by the NPS but managed by the Pea Island National Wildlife Refuge. The Park boundary on the ocean side is mean low tide, and on the sound side extends 150 ft. (50 m) from shore into the water.

Geological history: A variety of theories have been proposed to explain the origin of the Outer Banks. The most recent theory, based on corehole and seismic reflection data, is that the Banks formed above an ancient Pleistocene shoreline, called a headland (Riggs et al. 1995; Anderson et al. 2000). This headland eroded landward during glacial retreat and consequent sea level rise, until sea level rise slowed. Then progradation occurred via beach ridge growth of non-Pleistocene sediments, creating the Outer Banks. The sediment layers (stratigraphy) vary according to location of the coast, source of materials and time of deposition (Riggs et al. 1995). The rate of sea level rise in this region is approximately 3.7 mm/yr (Pendleton et al. 2004).

The North Carolina Outer Banks have retreated shoreward slowly, according to historic charts and physical evidence (Dolan et al. 1973; Dolan and Lins 1986, and references within). An analysis of shoreline movement of unaltered Core Banks during the 40-year period 1960-2001 shows an average shoreline erosion rate of 1.2 m (4 ft.) per year (Riggs and Ames 2005). Hurricane-rich periods showed severe erosion, while periods of low hurricane activity showed moderate beach accretion (Riggs and Ames 2005). The Outer Banks are considered to be a chain of transgressive barrier islands, which are islands that have a limited sand supply and a propensity for shoreline retreat. However, while the north face of Cape Hatteras is narrow and subject to overwash the southern flank features multiple dune ridges produced by accretion (Leatherman 1988). Outer Banks islands are subject to periodic inlet formation, migration, and closure, and seawater overwash during severe storms. 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). Overwash is a common process along unaltered Outer Banks islands because of the low (microtidal) tidal range and small sediment supply (Dolan and Lins 1986, Leatherman 1988). Overwash during moderately stormy periods tends to increase island elevation and enhance growth of vegetation both on dunes and in the back marsh (Riggs and Ames 2005). Overwash areas resulting from Hurricanes Isabel and Alex are clearly visible on Ocracoke Island along Highway 12 between Ocracoke Village and the Ocracoke-Hatteras Ferry, with obvious sand accretion on the sound side of the road and red cedars dead from salinity exposure (Plate 1).

Historically, inlets along the Outer Banks have opened and closed during major storms. Inlets have served both to isolate stretches of the Outer Banks (and their residents) and open new areas to shipping and commerce. Inlets are created when overwashed storm waters and accumulated rainfall in the sound flow outward through narrow, low elevation portions of the barrier near the end of the storm (Leatherman 1988). This process was dramatically brought into the focus of residents, Park personnel, and North Carolina State officials in September 2003, when Hurricane Isabel cut an inlet through Hatteras Island between the villages of Hatteras and Frisco, washing out 1,700 feet of Highway 12. However, the N.C. Department of Transportation repaired that breach and the road within a matter of weeks. Inlets are also instrumental in creating new marine habitat in the sounds. Inlets develop 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).

Plate 1. Overwash and sand accretion on Ocracoke Island caused by Hurricane Isabel (photo M. Mallin).

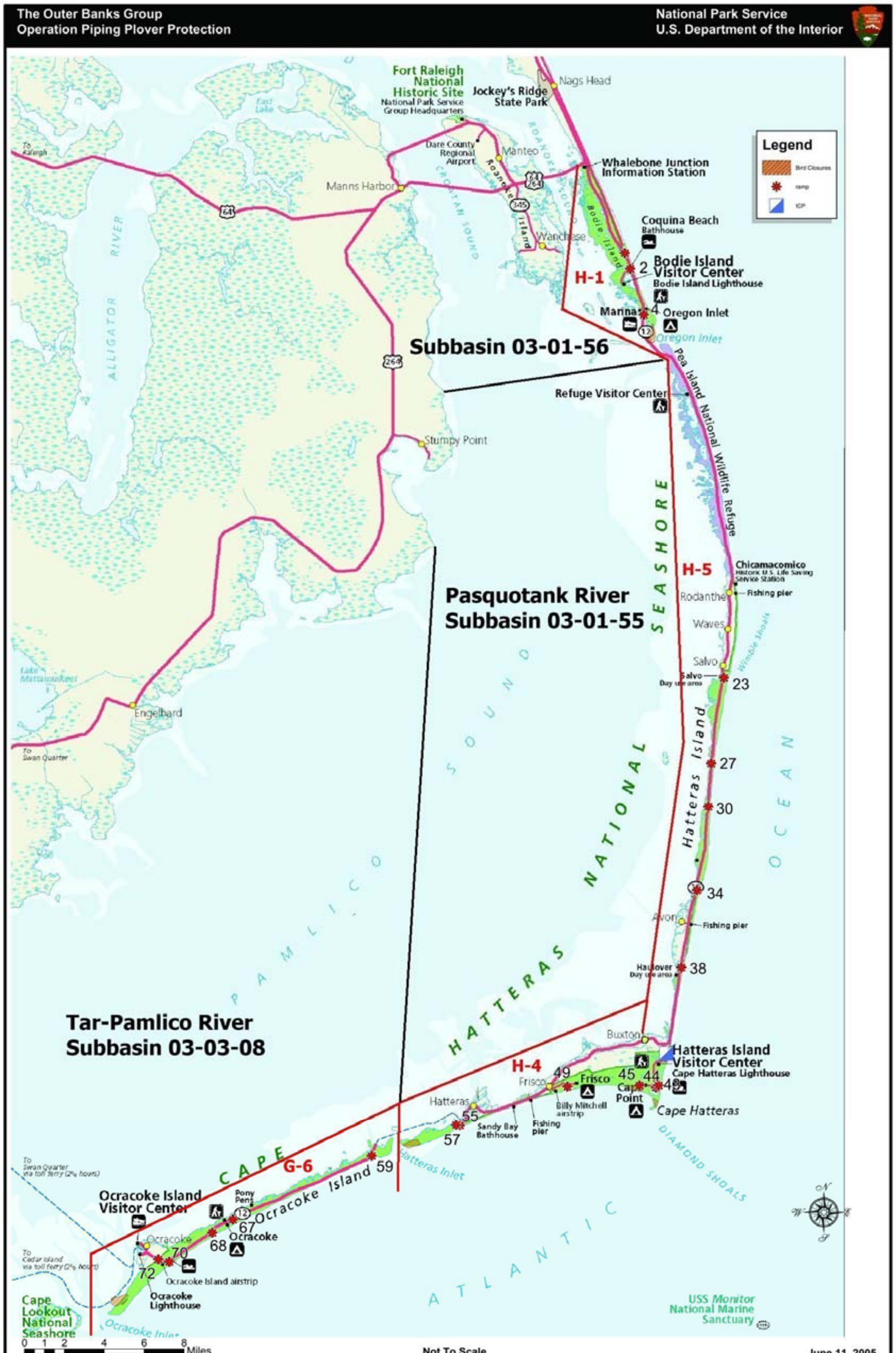


Figure 1. Map of Cape Hatteras National Seashore showing classified shellfish harvest waters and numbered beach access ramps.

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. An Algonkian speaking American Indian tribe lived in a town called Croatoan on Hatteras Island, arriving approximately 1000 AD. By the mid 1700s most had been driven from the Outer Banks by colonists or had succumbed to diseases brought from overseas (Shelton-Roberts and Roberts 2003). The first permanent European settlements were established around the mid 1600s 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 on North Core Banks 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). This town thrived for several decades and once supported a population of 1,000. However, in 1846 a storm created Oregon and Hatteras Inlets, leading to a withdrawal of shipping traffic from Ocracoke Inlet (Dolan and Lins 1986). At the start of the Civil War Confederate forts were established at Ocracoke and Oregon Inlets, but these fell to Union forces in 1861. Following the Civil War a series of livesaving stations and lighthouses were established along the Outer Banks to protect ships and their crews from shipwrecks caused by shoals and storms, which were responsible for the loss of numerous vessels (NPS 2000b).

The establishment of Cape Hatteras National Seashore was authorized in 1937 and was officially designated a National Seashore in 1953 (Schoenbaum 1982). Highway 12 is the principal north-south road, stretching from Whalebone Junction to Ocracoke Village, crossing Oregon Inlet over the Bonner Bridge. From Oregon Inlet south for 13 miles on upper Hatteras Island is the Pea Island National Wildlife refuge, managed by the U.S. Fish and Wildlife Service. This serves as a wintering and resting ground for geese, swans, 25 species of duck and various shorebirds, gulls and terns (Schoenbaum 1982). South of this reserve are the Villages of Rodanthe, Waves and Salvo. Rodanthe existed for many years as Chicamacomico but was renamed by the U.S. Postal Service in 1874. To the south of Salvo lies Avon, formerly a shipbuilding area when it was forested in colonial times (Schoenbaum 1982). The island narrows south of Avon, then expands to its widest point at Cape Hatteras, where the island turns to the southwest. The towns of Buxton and Frisco lie on either end of the cape, with the maritime forest of Buxton Woods in between. Buxton Woods (Plate 2) is one of the largest remaining examples of maritime forest along the East Coast, approximately 1,000 acres of which lie within the Park boundaries and about 800 acres are under state protection (NPS 2000a). This forest contains a variety of habitats supporting a diverse animal assemblage, and serves as an important aquifer recharge area (NPS 2000a). The Buxton area was one of the few places on the Outer Banks inhabited by the aforementioned Indians, which were called the Croatan and later Hatteras Indians in early colonial times (Schoenbaum 1982). The Banks narrow to a few hundred meters west of Frisco, then widen to a forested area where Hatteras Village lies. From here a ferry crosses Hatteras Inlet to and from Ocracoke Island. Presently, the towns adjacent to the Park receive heavy seasonal usage by vacationers utilizing hotels, campgrounds, and rental homes, and there are numerous second homes owned by out of town and out of state users.

Plate 2. Buxton Woods, Hatteras Island, Cape Hatteras National Seashore (photo M. Mallin).

The nearby coastal ocean and sound waters are heavily utilized by commercial fishermen as well as sport fishermen (Table 1). The juncture of estuarine and marine waters, routes for anadromous fish, and rapid (one hour) access to the Gulf Stream allow for the exploitation of many species. Recreational fishermen employ angling from boats and surf fishing along this seashore. Sport fishing boats put out from Oregon and Hatteras Inlets for Gulf Stream waters, where trophy fish such as white marlin, blue marlin, sailfish and bluefin tuna are caught, along with the more commonly caught yellowfin tuna and dolphin. 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. Commercial catch data are discussed later in this report under Biological Resources.

Although finfishing, particularly sport fishing, is a major industry in this region, shellfishing is less successful. Oyster production is considered to be poor and clam production is considered to be fair in the Hatteras Island area, with overall shellfishing commercial value rated as poor (Shellfish Sanitation Section 2002b). Around Ocracoke Island clam and oyster production, as well as commercial value, are rated as fair (Shellfish Sanitation Section 2002b). Landings of shellfish in Pamlico and Roanoke Sounds are discussed later in this report under Biological Resources.

Table 1. Species that are commonly fished either commercially and/or recreationally near Cape Hatteras National Seashore (compiled from various sources).

Finfish	Shellfish
nearshore and estuarine	
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)	
Morone saxatilis (striped bass)	
Scomberomorus cavalla (King mackerel)	
Scomberomorus maculates (Spanish mackerel)	
offshore	
Thunnus thynnus (bluefin tuna)	
Thunnus albacares (yellowfin tuna)	
Coryphaena hippurus (dolphin)	
Makaira nigricanus (blue marlin)	
Tetrapturus albidus (white marlin)	
Istiophorus platypterus (sailfish)	
Epinephelus spp. (grouper)	

Hydrologic information

Oceanographic setting: Cape Hatteras National Seashore is bordered to the east and south by fully marine waters of the Atlantic Ocean. The waters to the southeast of Ocracoke Island are called Raleigh Bay (Mallin et al. 2000), while that nearshore portion of the ocean in general to the east of the park is considered to be the Middle Atlantic Bight. Seaward from the barrier islands the continental shelf gradually deepens to about 5-60 m at the shelf break. From the shelf break seaward the ocean rapidly deepens (between about 50 to 100 km offshore). The Gulf Stream approximates the shelf break, but this current is very dynamic. Frictional forcing by the Gulf Stream drives the predominantly counterclockwise circulation in Raleigh Bay (Mallin et al. 2000). Filaments of the Gulf Stream sometimes flow landward up onto the shelf, bringing nitrogen-enriched water toward shore. On rare occasions these filaments can come as close as 10 km offshore. Mean wave height on Cape Hatteras is between 1.2 and 1.3 m, and tidal range is < 1.0 m (Pendleton et al. 2004).

West of Bodie Island are the waters of Roanoke Sound and to the west of the rest of the park lie the waters of Pamlico Sound (Fig. 1), which are of polyhaline (18-29 psu) salinities (Burkholder et al.

2004). Some of the coves and tidal creeks on the sound side of the park may be of variable estuarine salinities, depending on local rainfall. Rainfall on Hatteras Island averages about 143 cm/year (Anderson et al. 2000).

Hydrology affecting the Park - marine and freshwater: Cape Hatteras National Seashore consists of a series of long, narrow islands. The ocean side of these islands is sandy beach, generally leading up to 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, except for a few well developed maritime forests such as Nags Head Woods and Buxton Woods. Ocean shoreline salinities are marine, and tides are semidiurnal with an average range of 1.1 m (Dolan and Lins 1986). The most recent estimates of Pamlico Sound show that it contains 16.9 x 10^9 m^3 of water, with an annual turnover of 1.7 (Burkholder et al. 2004). Pamlico Sound is connected to the Atlantic Ocean by Hatteras Inlet between Hatteras and Ocracoke Islands, and Ocracoke Inlet, between Ocracoke and Portsmouth Island (Fig. 1). Roanoke Sound is connected to the ocean by Oregon Inlet, between Bodie and Hatteras Islands (Fig. 1).

Surface water resources: Freshwater rivers and large lakes do not exist in the park. On Bodie Island south of Whalebone Junction there are a number of wetland areas. The Village of Nags Head stretches south along the ocean beach and supports two roads running parallel to the beach, beyond and to the west of which is NPS land. Surface drainage from Nags Head enters a ditch along Old Oregon Inlet Road and empties into the ocean through an outfall pipe at NPS Ramp1. Groundwater drains west of Nags Head into five ditches perpendicular to Old Oregon Inlet Road toward Pamlico Sound (Plate 3). There are wetlands among the ditches on both sides of Highway 12 as well.

Plate 3. Ditch draining groundwater from Nags Head Village toward Pamlico Sound (photo M. Mallin).

The Cape Hatteras area has abundant freshwater wetlands, locally termed sedges (Plate 4). Most of these are interdunal areas that are in contact with the water table, also termed swales (Anderson and Mew 1995). Jennette Sedge, at 240 ha is the largest freshwater wetland area on Hatteras Island and is located in northern Buxton Woods (Fig. 2). There is a large east-west trending dune ridge that forms a natural divide regarding the direction of surface drainage flow. A number of surface drainages have been constructed to control flooding and mosquito populations from the Hatteras wetlands. Peters Ditch drains the northern area of Buxton Woods into Pamlico Sound at Frisco (Fig. 2). Two culverts that drain Jennette Sedge carry water to the north into Pamlico Sound, one of which (as measured by USGS) has a maximum drainage of 9,460 m^3/d (2.5 MGD). There are several tidal creeks on southern Hatteras Island (not associated with the Park) that discharge into Pamlico Sound. These include Joe Saur Creek, Brooks Creek, Cape Creek and others, which also carry drainage from inland areas.

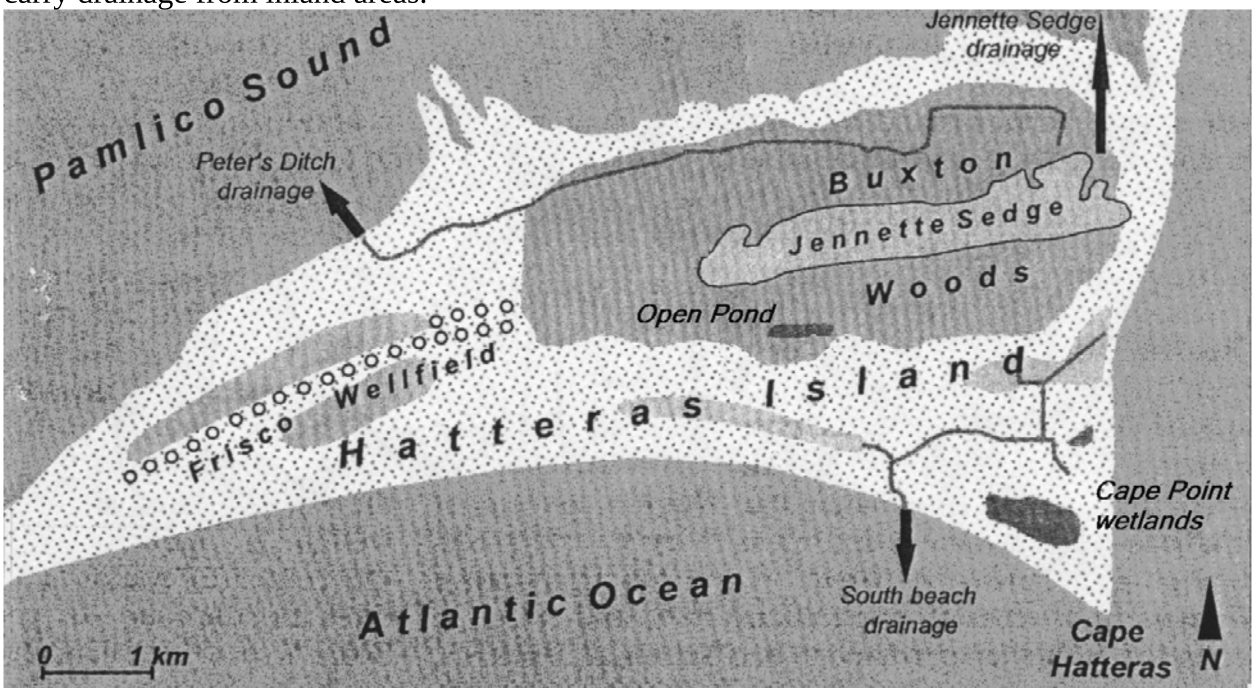


Figure 2. Hatteras Island maritime forest, wetlands, wellfields, and drainage system (revised from Anderson et al. 2000).

The southern portion of Buxton Woods hosts a large pond approximately 300 m long by 100 m wide called Open Pond (Plate 5). There are also extensive wetlands south of Buxton Woods in the Cape Point area (Fig. 1). Some are drained through a large pond area into the ocean, while some of the wetlands on the south side of the island are drained through a gated culvert (Plate 6) operated by the NPS, with a range of 0-37,800 m^3/d (0-10 MGD) (Anderson et al. 2000). Extensive rainfall causes flooding of the wetlands, the nearby NPS-operated Cape Point Campground and some of the roads and ramps (Plate 7). The Park's personnel note that conflict exists between ORV users and others who prefer greater drainage of the area, and Park needs to maintain the wetlands in Buxton Woods in as natural a state as possible (J. Ebert, NPS, personal communication). Another wetland resource presently exists on southern Hatteras Island near the Ocracoke Ferry terminal. It is a brackish pond and marsh that formed during recent hurricanes at the terminus of what was known as Pole Road, a dirt track used by ORVs.

Plate 4. Wetlands in Buxton Woods, Cape Hatteras National Seashore (photo M. Mallin).

Plate 5. Open Pond, southern Buxton Woods, Cape Hatteras National Seashore (photo M. Mallin).

Plate 6. Gated culvert operated by NPS that drains southern Hatteras Island wetlands into the Atlantic Ocean (photo M. Mallin).

Plate 7. Dirt road area near Cape Point Campground flooded by wetland runoff from southern Hatteras Island (photo M. Mallin).

Freshwater ponds are found throughout Cape Hatteras National Seashore (Schwartz 1983). Some of these ponds are interdunal areas, also called swales or sedges; and some are in more open, flat wetland areas. The ponds vary in size, substrate composition, pH, vegetation, and water color (Schwartz 1983). Samples collected from five dune ponds in Nags Head Woods north of and outside of the Park demonstrated that the water chemistry of those ponds was similar to that of local groundwater (Kling 1986). Additionally there are a number of fresh and brackish temporary ponds (some interdunal and others not associated with dunes), also known as ephemeral ponds or pools, in which the water may be present for anywhere from a few weeks to years. These temporary ponds are sometimes called vernal pools, but strictly speaking that term should be applied only to ponds that fill in the spring and dry in summer (Colburn 2004). Some examples of ephemeral ponds are located on northern Ocracoke Island on the west side of Highway 12, a few km south of the Hatteras-Ocracoke ferry dock (Fig. 3). These ponds were roughly 100 m^2 and about 0.5 m mean depth (Plate 8). A visit to three of these ponds in August 2004 by the authors found water temperatures ranging from 31-33^{o}C, salinities from 5-14 psu, and dissolved oxygen concentrations from 5.3-10.5 mg/L (72-140% saturation). The ponds had abundant periphyton, predominantly diatoms, gymnodinoid dinoflagellates, and filamentous and coccoid blue-green algae. There were no apparent fish in two ponds, but *Gambusia*, other fish, and crabs were present in the third pond, and raccoon tracks were identified on shore. Temporary ponds are important ecologically as breeding habitat for amphibians and reptiles and areas of high biodiversity for many taxa groups, including vertebrates, crustaceans, insects, mollusks, annelids, rotifers and others (Colburn 2004). Other temporary pools in the Park exist briefly in low areas on the dirt roads that are numbered as ramps leading from Highway 12 to the sound side of Hatteras Island.

Plate 8. Temporary pond, northern Ocracoke Island, Cape Hatteras National Seashore (photo M. McIver).

Ocracoke Island hosts an extensive oligohaline to mesohaline marsh just outside the town and behind the airport (Fig. 3). This marsh is transected by 1.8 miles of road (South Point Road) that leads to the ocean beach. The beach is used recreationally for swimming, surfing, and surf fishing, and toward and along the inlet surf fishermen use it extensively. Behind the beach is a short dune ridge, then the terrain slopes into the marsh. There are deep (1 m) drainage ditches on either side of the road through the marsh, often with flowing water. The marsh drains into Ocracoke Inlet through an extensive swash zone. Samples taken in May 2005 by the authors at a number of roadside locations yielded salinities ranging from 2 – 17 psu, with dissolved oxygen concentrations from 5.8-7.5 mg/L (53-78% saturation). Salinities were lowest near the swimming beach (there is no direct connection between the swimming beach and marsh) and near the back of the marsh closest to Highway 12, and highest salinities were found in mid-marsh where ditches drain toward the inlet.

Seven tidal creeks bisect Highway 12, between Ocracoke Village and the Hatteras Ferry, all on Park property (Fig. 3). The first two encountered north of Ocracoke Village appeared to have at most only a tenuous connection with Pamlico Sound. Island Creek was fresh and blackwater at the Highway, drained an area including the NPS Ocracoke Campground, and had a nature trail crossing the creek west of the highway. The second creek (Shad Hole) was very shallow in August 2005, with 95% freshwater plant coverage and small open patches of blackwater. The remaining five creeks were clearly tidal creeks (Table 2). The creek banks contained obvious periphyton mats (consisting mainly of filamentous blue-green algae and diatoms); with salt marsh vegetation creekside toward the sound (Plate 9), and some woody vegetation (such as red cedar) near the bridges (Plate 10).

Plate 9. Tidal creek and marsh, Ocracoke Island, Cape Hatteras National Seashore (photo M. Mallin).

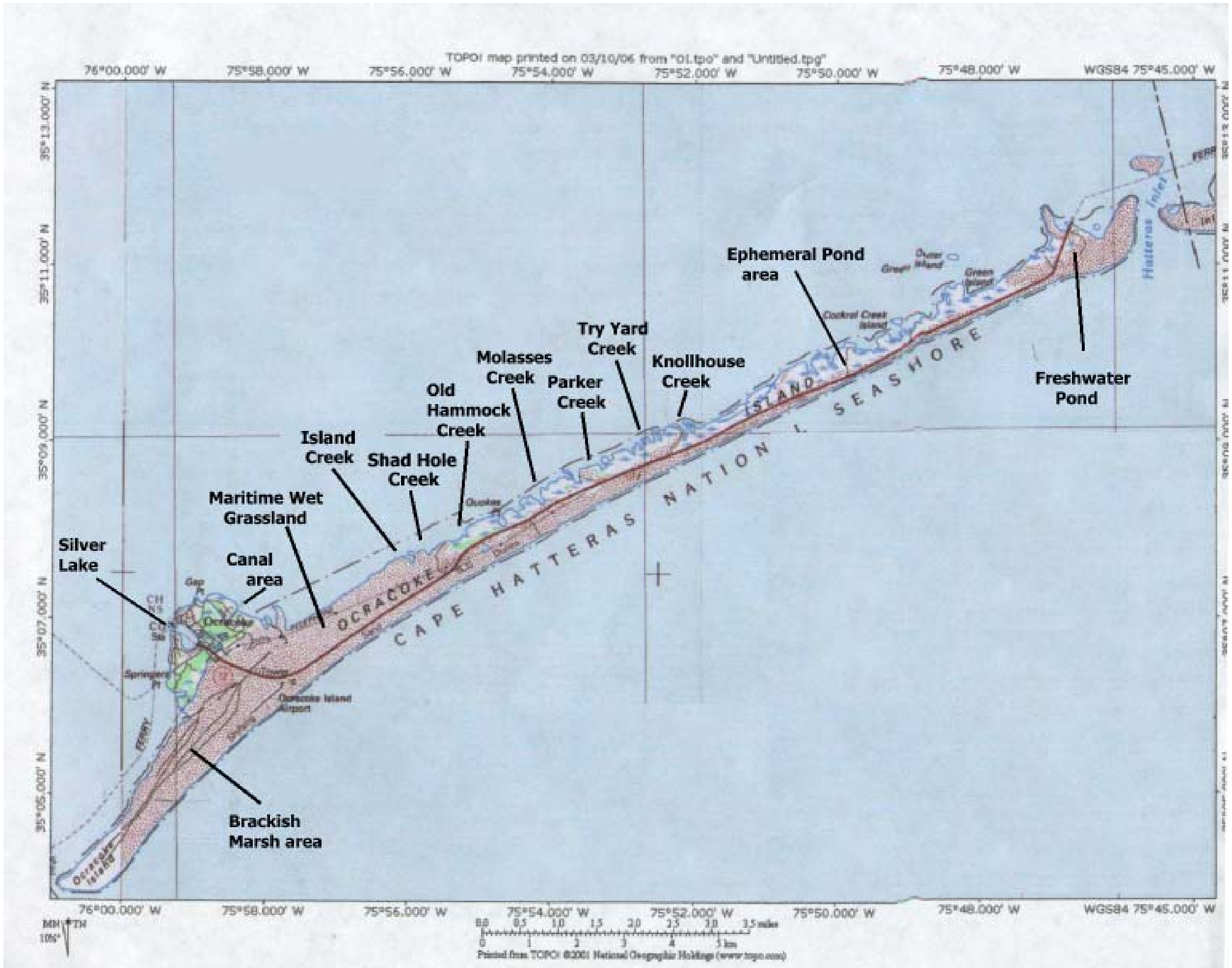


Figure 3. Brackish and freshwater resources on Ocracoke Island, Cape Hatteras National Seashore.

Plate 10. Woody vegetation, tidal creek inland Ocracoke Island (photo M. Mallin).

North along Highway 12 past the tidal creeks and near the Hatteras Ferry terminal there is a large open pond (Fig. 3) approximately 150 m long by 40 m wide (located at N 33.18692, W 77.78051). It is about 0.5 m deep, and in May 2005 salinity was essentially fresh (0.6 psu) with dissolved oxygen concentrations of 11.1 mg/L (123% saturation).

Table 2. Creeks on NPS property crossing Highway 12 on Ocracoke Island, from south to north leaving Ocracoke Village, sampled August 2005.

Name	GPS location	Salinity	Dissolved oxygen
Island Creek	N35.12679, W75.92154	0.1 psu	3.9 mg/L (52% sat.)
Shad Hole Creek	N35.13149, W75.91567	NA	NA
Old Hammock Creek	N35.13401, W75.90826	17.8 psu	4.1 mg/L (61% sat.)
Molasses Creek	N35.13687, W75.90129	12.2 psu	3.7 mg/L (48% sat.)
Parkers Creek	N35.14025, W75.89357	9.6 psu	3.1 mg/L (42% sat.)
Try Yard Creek	N35.14301, W75.88625	12.3 psu	5.0 mg/L (71% sat.)
Knollhouse Creek	N35.14598, W75.87758	11.2 psu	2.7 mg/L (37% sat.)

Ground water resources: On Hatteras Island there is a water table aquifer extending from the land surface to confining silt and clay layers below, with two permeable units each 10 m thick below and between the semi-confining silt and clay layer, all underlain by another semi-permeable confining layer (Bolyard et al. 1979; Anderson 2002). Swales, also called sedges or slacks, are areas of low elevation between dunes, likely formed originally by wind blowouts, which are in contact with the upper water table (Leatherman 1988). Some of the ponds on Cape Hatteras National Seashore appear to have this origination. Rainy periods expand the ponds and droughts reduce them. The soils of the island are very porous and rainfall infiltrates directly into the upper aquifer (Bolyard et al. 1979). Saltwater overwash during storm surges can recharge the water table aquifers with brackish water. Anderson (2002) found that salty floodwaters from Hurricane Emily in 1993 caused chloride levels in the Buxton Woods Aquifer to rise from 40 to 280 mg/L, remaining above 100 mg/L for eight months.

The Buxton Woods Aquifer is an historically important source of drinking water for the residents of southern Hatteras Island. The aquifer consists of three units: an upper permeable layer 12 m thick, with a semiconfining layer of silts and fine sands below it, and a lower aquifer which is a 12-24 m thick layer of shell and shell hash, underlain by a 13 m thick confining layer of silty to clayey sand (Anderson et al. 2000). The Cape Hatteras Water Association (CHWA) is a private company that supplies water to local communities from the Frisco Wellfield (Fig. 2), a set of 22 vertical wells spaced 150 m apart. The CHWA was incorporated in 1965 to supply water to Buxton, Frisco, Hatteras and later Avon. Previously, residents used individual wells and rainwater cisterns for water (Anderson and Mew 1995). The aquifer still supplies a portion of the local drinking water, although presently deep wells (70 m) collect brackish water that is treated by reverse osmosis for most freshwater demands (Anderson 2002).

Losses, or sinks to the aquifer are residential use, evapotranspiration from the surface and vegetation, and surface drainage from wetlands. Sources to the aquifer are groundwater recharge through rainfall and overwash during major storms. Jennette Sedge (Fig. 2) may serve as a freshwater storage reservoir for the upper aquifer by filling under wet conditions and supplying recharge to the aquifer under dry or high-use conditions (Anderson et al. 2000).

The vast majority of drinking water on Ocracoke Island comes from an aquifer 620 ft. deep. The water is brackish (approximately 2200 mg/L chloride content) with very low turbidity (1-2 NTU) and is purified through a reverse osmosis treatment system, located on Park property in Ocracoke Village. About 65% of the water pumped up ends up as potable; the remaining 35% is waste effluent (L. Burrus, Ocracoke Sanitary District, personal communication). Water use varies seasonally on the island. In winter months it is approximately 3,000,000 gallons per month rising to a maximum of about 9,000,000 gallons per month in summer tourist season (Ocracoke Sanitary District records). The waste effluent from the purification process is discharged 400 feet offshore into Pamlico Sound. Salinity of the effluent is about 10 ppt (chloride content about 4800 mg/L) with virtually no fecal coliform bacteria (the discharge area is open to shellfishing). Total nitrogen of the effluent is 5-6 mg/L, which is mostly as ammonium (Ocracoke Sanitary District records); thus there is a potential problem for localized algal blooms to occur. However, there are no data or anecdotal evidence that this is a problem.

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: Seagrass beds are known to be excellent habitat for many species of finfish and shellfish. Ferguson et al. (1988) performed a survey of submersed aquatic vegetation habitat from Back Sound to Currituck Sound. The authors sampled 120 stations between Ocracoke and Oregon Inlets and found 69% of them vegetated, at water depth less than 2 m. The subtidal and intertidal waters of the eastern shore of Pamlico and Roanoke Sounds provided habitat for three seagrass species. The two dominant taxa were the temperate species *Zostera marina* (eelgrass) and the tropical species *Halodule wrightii* (shoalgrass), with lesser abundances of *Ruppia maritima* (widgeon grass), which is also found in fresh water (Ferguson et al. 1988). There is no more recent information on seagrass in this area. At this writing, Ms. Elizabeth Noble of Elizabeth City State University is leading a seagrass mapping project of Currituck Sound and nearby environs.

The salt marshes along the sound side of the Outer Banks are vegetated primarily by *Spartina alterniflora* (salt marsh cordgrass), *Salicornia virginica* (glasswort), *Sueda linearis* (sea blite) and

Iva imbricata (sea elder). In marsh areas not regularly flooded by salt water *Juncus roemerianus* (black needlerush) may dominate the system. The marsh along Ocracoke's South Point Road hosts a diverse vegetation community. The drainage ditches contain abundant periphyton, particularly during warmer months. A sample taken by the authors in August 2005 showed that the periphyton consisted largely of floating mats of the blue-green alga *Microcoleus lyngbyaceus*, intermixed with pennate diatoms. Harpacticoid copepods, rotifers, protozoans and nematodes graze on the smaller algae and bacteria in the mat (Plate 11). We suspect that these ditches are loci of intense microbial food web interactions, and may be important resources to small or young fish utilizing the marsh. The marsh macrophyte vegetation includes *Phragmites* sp. (common cane, an invasive species), *Spartina patens* (salt meadow hay), *Scirpus robustus* (salt marsh bulrush), *Borrichia* sp. (sea oxeye), *Hydrocotyle* sp. (pennywort), *Eleocharis* spp.(spike rush), patches of *Juncus* and mixed grasses. The marsh also contains raised areas (hammocks) supporting *Juniperus virginiana* (red cedar), *Iva frutescens* (marsh elder), *Myrica cerifera* (wax myrtle), *Persea borbonia* (red bay) and a variety of other plants (Plate 12). The authors of this report observed abundant birdlife utilizing the marsh including ducks, white ibis, redwing blackbirds, and others. This marsh area, along with the marsh located on the west side of Highway 12 a few km north of Ocracoke Village (Fig. 3), are known as maritime wet grasslands and are listed as Unique Wetland (UWL) sites by the North Carolina Division of Water Quality and the Natural Heritage Program (Schwartzman 2004). The large pond at the north end of Ocracoke Island near the ferry terminal (Fig. 3) contains extensive periphyton and submersed aquatic vegetation (mainly *Potamogeton pectinalis* (Sago pondweed)). The fresh-oligohaline marsh surrounding it consists primarily of *Typha* sp. (cattail) with some *Juncus* patches (Plate 13), with visible wading bird usage. A septic leachfield is near the north end of the pond, serving bathrooms and showers.

Plate 11. Micrograph of periphyton mat community in Ocracoke Island brackish marsh drainage ditch, with harpacticoid copepod, a nauplius, and a rotifer (lower right) grazing within (photo M. Mallin and M. McIver).

Plate 12. Hammock in brackish marsh (Maritime Wet Grassland), southern Ocracoke Island, Cape Hatteras National Seashore (photo M. Mallin).

Plate 13. Freshwater pond and marsh, northern Ocracoke Island near ferry landing (photo M. Mallin).

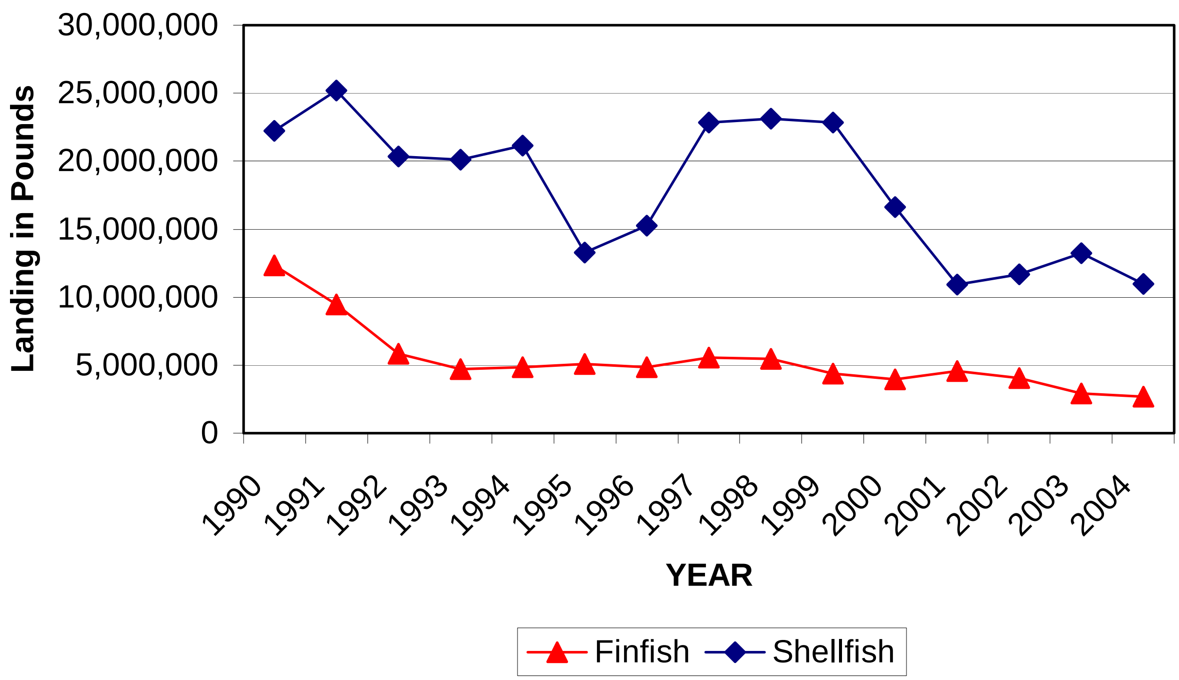
Upland vegetation: The oceanfront from Bodie Island south through Ocracoke Island no longer has a natural barrier island vegetation pattern, such as what is seen on Core Banks (Mallin et al. 2004b). In the 1930's the primary dune was fertilized and seeded, and later maintained as a protective barrier to prevent storm-driven overwash and road washout (Dolan et al. 1973). Grasses, primarily *Ammophilia breviligulata* (American beach grass) and to a lesser extent *Uniola paniculata* (sea oats) covered the dunes, along with other plants including *Cakile* sp. (sea rocket), *Croton punctatus* (Croton), *Iva imbricata* (sea elder). However, shoreline retreat has created large gaps in the artificial dune and natural hurricane processes such as overwash and inlet formation are again impacting Ocracoke, Hatteras and Bodie Islands (Young et al. 1999). As mentioned, overwash areas on Ocracoke Island are visible along Highway 12. In some areas after large storms dunes are rebuilt and seeded with vegetation.

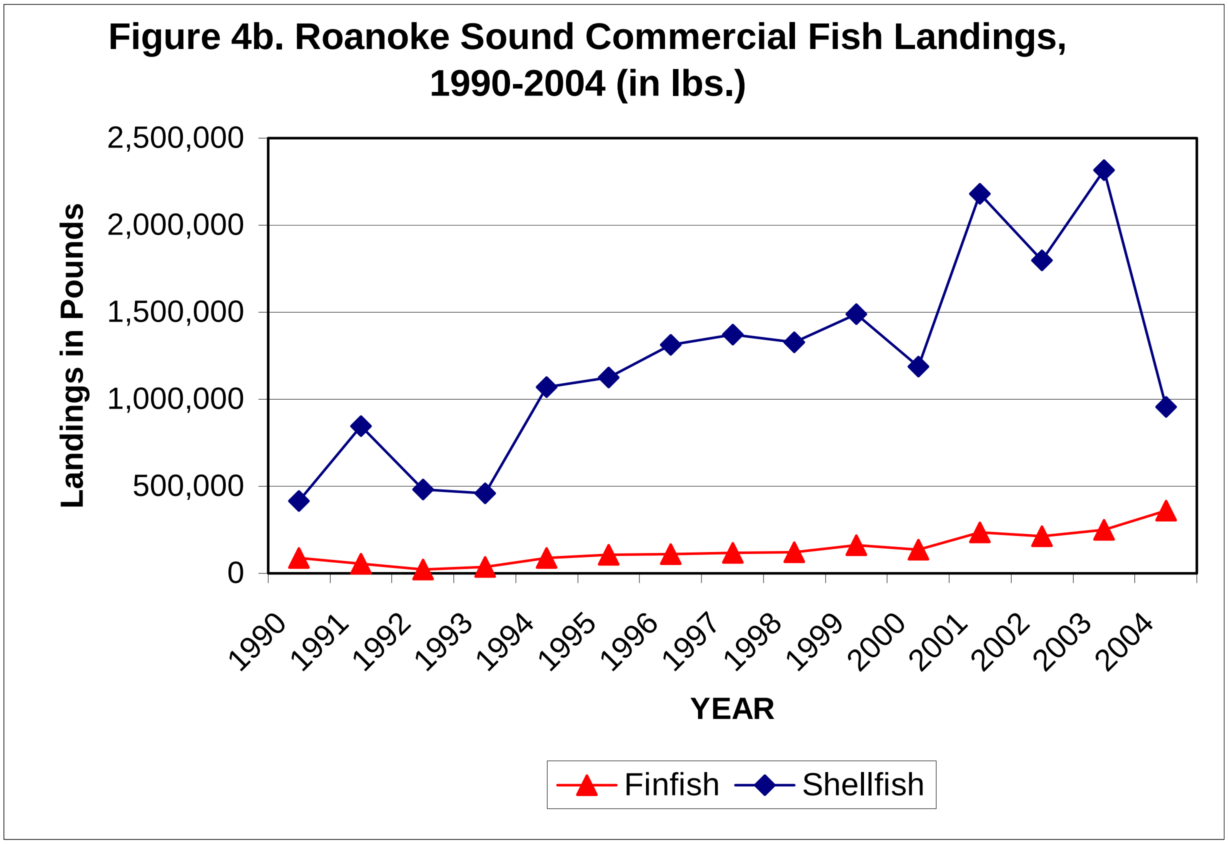
Maritime forest is found in wider areas of the Cape Hatteras National Seashore, including Nags Head, Avon, Buxton, Frisco and Ocracoke Village. This forest, particularly Buxton Woods (Plate 2), supports a wide diversity of species. The overstory on the ridges contain *Quercus virginiana* (live oak), *Pinus taeda* (loblolly pine), *Juniperus virginiana* (red cedar), *Q. laurifolia* (laurel oak), hornbeam and holly trees (Plate 14), while dogwoods, *Myrica cerifera* (wax myrtle), *Ilex vomitoria* (yaupon), *Callicarpa americana* (beauty-berry) and various *Vitis* and *Smilax* spp. characterize the understory (Schoenbaum 1982; Ehrenfield and Oskarsson 1991). The swales between ridges are wetlands that are dominated by *Cladium jamaicensis* (sawgrass), *Typha latifolia* (cattail), *Saggitaria latifolia* (duck-potato), *Hydrocotyle umbellate* (marsh pennywort), and *Polygonum punctatum* (water smartweed) (Ehrenfield and Oskarsson 1991; Cole and Bratton 1995). The aforementioned Jennette Sedge within Buxton Woods is listed as a UWL (as interdune pond) by the NC DWQ and the Natural Heritage Program, and the Cape Point wetland area is listed as a UWL as maritime wet grassland.

Plate 14. Forested dune area, mid-Ocracoke Island, Cape Hatteras National Seashore (photo M. Mallin).

Marine fauna: As noted earlier (Table 1) the marine waters near Cape Hatteras National Seashore host abundant and diverse marine fauna that are exploited by area commercial fishermen and area and visiting sport fishermen. Pamlico Sound is an important commercial fishing area for the region (Fig. 4a). Over the past several years there has been a decrease in shellfish landing, mainly due to decreases in the crab landings. The blue crab fishery had been fished at or above sustainable levels from 1996 on; following Hurricane Floyd (as a result of floodwaters) crabs were hyperaggregated into the Sound where they encountered high fishing pressure (Burkholder et al. 2004). The finfishery has declined to a lesser extent, mainly due to lower grey trout landings (R. Carpenter, NC DMF, personal communication). In contrast, the Roanoke Sound commercial fishery has increased its landings recently (Fig. 4b). This has resulted from increased crab landings in the Sound, as well the recovery of the striped bass population and a subsequent increase in its quotas (R. Carpenter, NC DMF, personal communication).

Figure 4a. Pamlico Sound Commercial Fish Landings,1990-2004 (in lbs.)

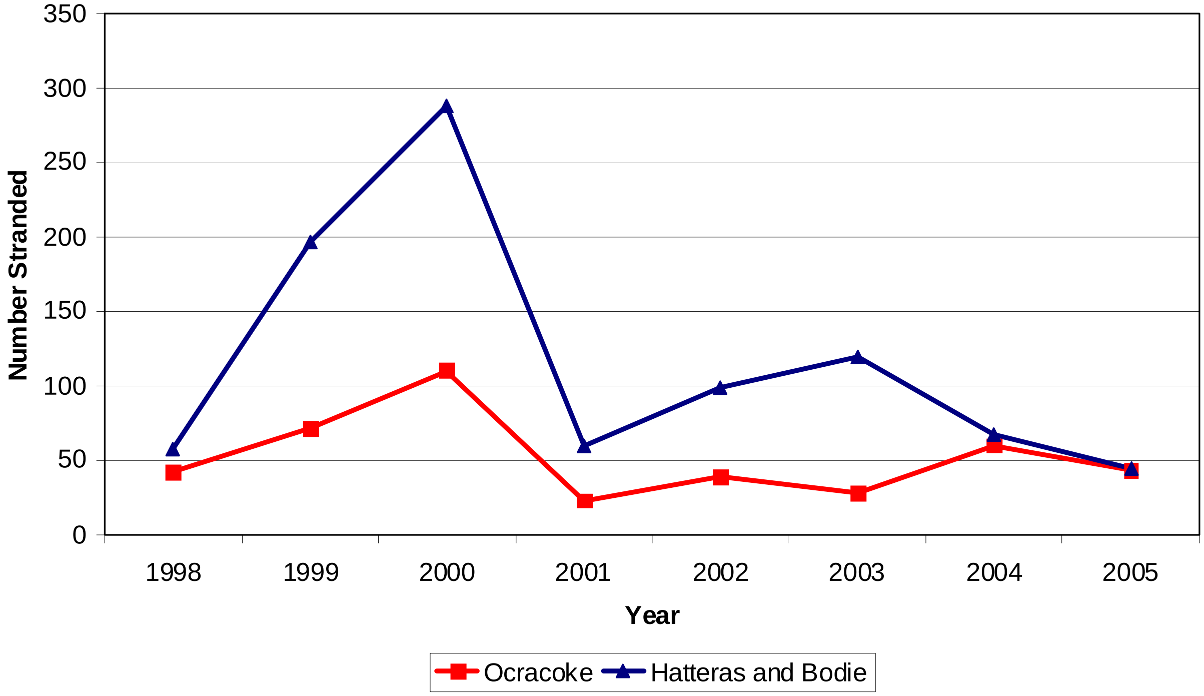




Cape Hatteras National Seashore and nearby waters are regularly utilized for mating and nesting by sea turtles, mainly *Caretta caretta* (Loggerhead) and *Chelonis mydas* (Green) sea turtles. Species less seen in the area are *Lepidochelys kempi* (Kemp's Ridley) and *Dermocheyls coriacea* (Leatherback) sea turtles (Webster 1984). 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 (NCDWQ 2002; 2004). Sea turtle strandings are more abundant on Hatteras and Bodie Islands than Ocracoke Island, with peak strandings in 2000 and minimal strandings in 1998 and 2005 (Fig. 5). Sea turtle strandings by species for this period include *C. caretta* (841), *C. mydas* (255), *L. kempi* (203), *D. coriacea* (21) and others (26).

An annual average of 75 sea turtle nests have been found on Park lands from 1992-2004. In 2002 there was a record high of 101, in 2003 there were 89, and in 2004 the number of nests dropped to 50. Of the 50 nests, 46 were Loggerhead nests, three were Green sea turtle nests, and one was a Leatherback nest. Of the 50 nests, 39 were on Hatteras Island, 10 on Ocracoke Island and one was on Bodie Island. Regarding the low number of nests, breeding activity was low throughout the southeastern U.S. and Caribbean in 2004, and hatching success was poor due to the impact of hurricanes (Lyons 2005).

Figure 5. Sea turtle strandings on Ocracoke and Hattteras and Bodie Islands, Cape Hatteras National Seashore.



A diverse community of marine mammals utilize the area waters. These include *Trichechus mantus* (manatees), *Phoca vitulina* (harbor seals), *Phocoena phocoena* (harbor porpoises), *Delphinus* spp. (common dolphins), *Tursiops truncates* (bottlenose dolphins), *Stenella frontalis* (spotted dolphins) and several species of whales (Webster 1984). 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 Wilmington. Marine mammal strandings (live and dead) are dominated by various dolphins, with porpoises a distant second (Fig. 6). Whales and seals are occasionally stranded. Hatteras Island receives the majority of stranding, followed by Ocracoke and Pea Islands (Fig. 6), with occasional strandings reported from the Park area on Bodie Island.

The marine and estuarine benthic infauna and epibenthos within Park waters do not appear to have been systematically studied, although a few sites in sound waters near the Park have been assayed for benthos as part of the EMAP program and follow-up efforts (see Ecosystem effects section). The nearby marine zooplankton communities have not been systematically studied.

<u>Rare and Threatened Aquatic Species</u>: Besides the sea turtles listed above, *Malaclemys terrapin terrapin*, the estuarine Northern Diamondback Terrapin, is found in the area (the authors of this report saw this species in Molasses and Parkers Creeks on Ocracoke Island in August 2005). *Acipenser brevirostrum*, the anadromous shortnose sturgeon utilizes nearby waters during

migrations, and the Endangered *Trichechus manatus* (manatee) is on occasion spotted in this region (NCDWQ 2002; 2004).

Freshwater flora: A single collection from five dune ponds outside of the Park in Nags Head Woods showed that their benthic microflora consisted of freshwater diatoms (Kling 1986). There were at least 20 species of aquatic macrophytes associated with these ponds, 18 of which were freshwater species (Kling 1986).

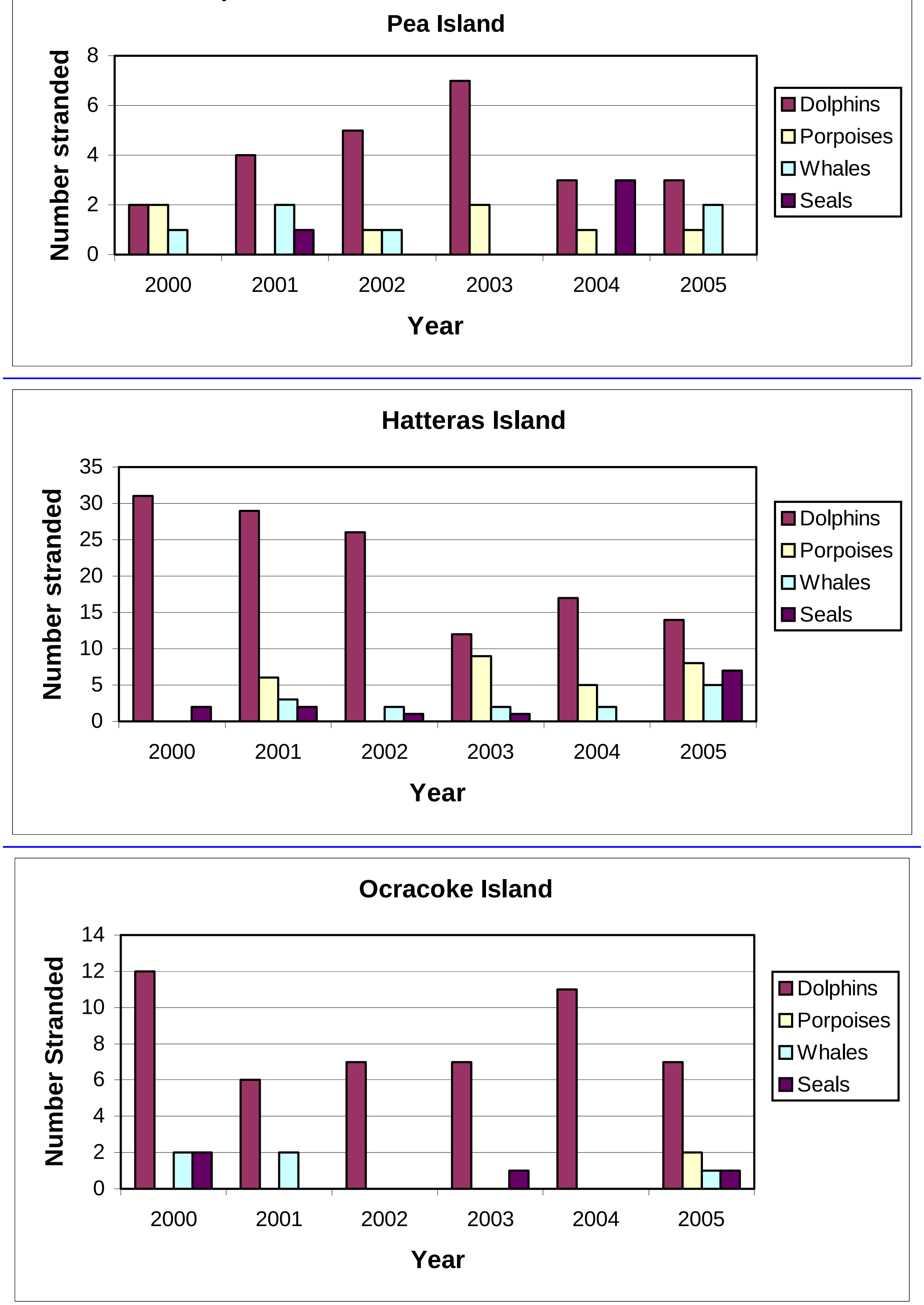
Freshwater fauna: There are no freshwater rivers, major streams, or large lakes within Cape Hatteras National Seashore, but as indicated, there are a number of freshwater ponds on these islands. Schwartz (1983) conducted a finfish seine survey of 96 ponds both within the Park and in Outer Banks locations north of the Park to the Virginia State Line. The survey documented 25 species from 14 families of fishes, some of which apparently entered the upper Outer Banks as a result of overwash from the freshwater Currituck Sound, and others that were stocked (Table 3). During the survey twelve ponds on Hatteras Island and two ponds on Ocracoke Island were sampled; seven species were found on Hatteras Island and seven on Ocracoke Island. Schwartz (1983) used an index of relative importance to rank these species (Table 3).

Table 3. Fish species found in freshwater ponds on Hatteras and Ocracoke Islands ranked in order of the index of relative importance (modified from Schwartz 1983).

Hatteras (12 ponds)	Ocracoke (2 ponds)
Lepomis gibbosus (pumpkinseed)	*Cyprinodon variegates* (variegated minnow)
Gambusia a. holbrooki (mosquitofish)	*Fundulus confluentus* (marsh killifish)
Micropterus salmoides (largemouth bass)	*Lucania parva* (rainwater killifish)
Anguilla rostrata (American eel)	*Gambusia a. holbrooki* (mosquitofish)
Lucania parva (rainwater killifish)	*Fundulus heteroclitus* (mummichog)
Lepomus machrochirus (bluegill)	*Anguilla rostrata* (American eel)
Cyprinus carpio (carp)	*Menida beryllina* (inland silversides)

The benthic fauna of fresh and brackish ponds within the Park have not been reported in the literature. A one-time net haul collection from five dune ponds in Nags Head Woods, outside of the Park, found at least 18 species of zooplankton (Kling 1986). The species found (including *Mesocyclops edax, Tropocyclops prasinus, Bosmina longirostris, Daphnia ambigua* and others) are freshwater taxa that are very common in mainland North Carolina reservoirs (Mallin 1986). While Outer Banks ponds, particularly in lower lying areas, 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. In areas where the dunes are higher the local ponds may be shielded from saltwater inputs and overwash for many years.

Figure 6. Marine mammal strandings (live and dead) on Cape Hatteras National Seashore, 2000-2005.



Upland fauna: Historically, sheep, goats, cows and pigs were grazed on the Outer Banks, but have since been removed. On Ocracoke Island there is a herd of approximately 30 semi-wild horses in a penned area about seven miles north of Ocracoke Village. The herd is managed by the Park Service to maintain the population at a healthy level (Shelton-Roberts and Roberts 2003). There is a also a small horse pen off of State Road 1242 in Frisco (Shellfish Sanitation Section 2002b)

Terrestrial mammals are abundant in Cape Hatteras National Seashore, especially in the maritime forest areas, with approximately 24 species represented from Nags Head south to Ocracoke (Webster 1988). Mammals utilizing fresh and salt marshes as habitat include the *Cryptotis parva parva* (Least shrew), *Sylvilagus palustris palustris* (Marsh rabbit), *Oryzomys palustris palustris* (Marsh rice rat), *Microtus pennsylvanicus nigrans* (Meadow vole), *Ondatra zibethicus macrudon*, (Muskrat), *Myocastor coypus bonariensis* (Nutria, an invasive species), *Mustela vison mink* (Mink), and *Lutra Canadensis lataxina*.(River otter). Mammals utilizing freshwater ponds include muskrats, otter, *Procyon lotor lotor* (Raccoon), and *Odocoilus virginianus virginianus* (White-tailed deer) (Webster 1988). Ocracoke Island has much lower mammalian diversity than Hatteras Island, with only six species represented (Webster and Reese 1992). This has been attributed to lack of maritime forest, fewer freshwater wetlands, and frequent overwash from hurricanes and nor'easters (Webster and Reese 1992). Park personnel note that an occasional feral pig is seen on NPS property.

Cape Hatteras National Seashore is very important for neotropical migrant landbirds, waterbirds, waterfowl, shorebirds, and marshbirds throughout the year. General concerns for birds related to water quality include threats to prey species and habitats that support prey species. Habitats include submersed aquatic vegetation, marsh, inshore ocean and sound waters, brackish ponds, and freshwater ponds. Prey species include nearly all estuarine fishes, shrimp, crabs, insects and many other invertebrates. Basically, any water quality issues or concerns that would threaten either habitats for birds or their prey species, have the potential to impact birds (Walker Golder, North Carolina Audubon Society, personnel communication). The Piping Plover is of great concern to the NPS, and considerable efforts are made to keep ORV users and foot traffic well away from beach and dune nesting sites.

The ephemeral wet sand flats/ponds at Bodie Island spit on the north side of Oregon Inlet, the Hatteras Inlet spit at the end of Pole Road on north side of Hatteras Inlet (Plate 15), the Ocracoke Inlet spit (north side of Ocracoke Inlet), the wet sand flats associated with the permanently flooded pond at Cape Point (Fig. 2) and the ephemeral wet sand flats and ponds at Cape Point (Plate 16) support tens of thousands of shorebirds annually, representing at least 21 species. These areas are critical foraging sites for Piping Plovers breeding in the Park, as well as migrating and wintering Piping Plovers from the Atlantic Coast and Great Lakes populations, currently federally-listed as Threatened and Endangered, respectively. These shorebirds are attracted by the rich and abundant invertebrate prey and any threat to this prey base will likely negatively impact shorebirds using these habitats (Walker Golder, North Carolina Audubon Society, personnel communication).

Plate 15. Brackish wetland formed by hurricanes near Hatteras Inlet
(formerly end of Pole Rd.: photo M. Mallin).

Plate 16. Cape Point wetlands, Hatteras Island, Cape Hatteras National Seashore (photo M. Mallin).

ASSESSMENT OF PARK WATER RESOURCES

Sources of pollutants

Point source pollutants: There are no NPDES dischargers on Ocracoke Island (NCDWQ 2004). There are seven minor NPDES discharges in subbasin 03-03-08 (the sparsely populated western shore of Pamlico Sound) located on the mainland over 30 km across marine waters from the park. There are six minor NPDES dischargers in subbasin 03-01-55 (Fig. 1), which includes Hatteras Island and a small section of northeast Dare County (NCDWQ 2002). There is one NPDES minor discharger in subbasin 03-01-56 (Fig. 1), which is Bodie Island including the northern section of the Park, Nags Head, Kill Devil Hills, Kitty Hawk, and Southern Shores (NCDWQ 2002). That minor NPDES discharger is Villas Association, Inc., and uses an on-site land application method.

Non-point source pollution: There are no registered concentrated animal feeding operations (CAFOs) on Ocracoke, Hatteras, or lower Bodie Islands; thus, concentrated livestock waste runoff is not an issue. Manure piles from the resident horse population on Ocracoke Island may be a very localized source of pollution to the nearby marsh areas; after a rain event there is visible standing water in and near the pens. There are no traditional farms for row crops, and no attendant fertilizer runoff within the park. Impervious surface coverage, which concentrates pollutants and increases stormwater runoff pollution, is a problem in some areas near ferry landings, roads, and the limited commercial areas adjacent to the Park on all three islands (Shellfish Sanitation Section 2002a and 2002b). There are septic systems in use throughout the park and in the adjacent municipalities that are sources of nutrients to nearby wells and surface waters in some areas. There are no major non-point source runoff areas located on the mainland that are likely to affect Ocracoke or Hatteras Islands due to the distance from the mainland. However, the northern section of the Park on Bodie Island abuts densely developed areas and is receiving pollution via groundwater and surface water (see section B2 below for details).

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 are lacking for Cape Hatteras National Seashore so such contributions are presently unknown. All of the Outer Banks are located within 80 km of the mainland, but counties less than 80 km from the Park have low concentrations of swine (Mallin and Cahoon 2003) as well as cattle, turkeys and chickens (N.C. Department of Agriculture records). There are only four registered swine CAFOs in Hyde County with a combined total of 15,400 animals (NCDWQ 2004), not enough to impact atmospheric ammonia deposition across Pamlico Sound in the Park.

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 Roanoke and eastern Pamlico Sounds: NCDWQ considers Roanoke Sound to be part of the Pasquotank River subbasin 03-01-56 (Fig. 1), which includes Bodie Island (NCDWQ 2002). NCDWQ considers northeastern Pamlico Sound as part of subbasin 03-01-55 (Fig. 1), which includes Hatteras Island from Oregon to Hatteras Inlets. NCDWQ conducts no water quality or benthic macroinvertebrate, fish community or fish tissue analysis in those two subbasins (NCDWQ 2002). Ocracoke Island and part of eastern Pamlico Sound is included in subbasin 03-03-08 (Fig. 1) of the Tar-Pamlico River basin (NCDWQ 2004). There are no NCDWQ ambient water quality monitoring stations located in or near Ocracoke Island. Approximately 30 km of open Pamlico Sound water separates Ocracoke Island from the mainland. Thus, at present we feel that loading of mainland-derived nutrients, and probably other pollutants, are too low to impact Ocracoke Island. In a survey Pamlico Sound was considered to have moderate nitrogen loading and moderate phytoplankton biomass (Bricker et al. 1999).

Water quality within Cape Hatteras National Seashore: Over the past two decades a few water quality studies have taken place in the Park. Two occurred in lower Bodie Island and two in the Hatteras/Buxton Woods area.

Lower Bodie Island water quality: There are known surface and groundwater water quality problems on lower Bodie Island impacting NPS lands. Cole (1988) and Cole and Bratton (1995) studied seven drainage ditch and six marsh sites from 1988-1991 to determine if pollutants from Nags Head Village were impacting park waters (Fig. 7). These authors found that several parameters had significantly higher concentrations in the drainage ditches than the marsh locations, including salinity, conductivity, copper, ammonium, phosphate and fecal coliform bacteria, while dissolved oxygen concentrations were significantly lower (see Fig. 8 for means and standard deviations, revised from Cole and Bratton, 1995). Nitrate concentrations were low in both types of habitat, while ammonium concentrations were relatively high compared with tidal creeks in the region (McMillan et al. 1992; Mallin et al. 2004a). Ammonium is a nutrient species characteristic of sewage, as well as natural organic decomposition. Phosphate concentrations in the marsh locations were comparable to regional tidal creeks, but phosphate concentrations in the ditches were somewhat higher (McMillan et al. 1992; Mallin et al. 2004a). Fecal coliform bacteria counts in particular were much higher in the ditches than in the marshes (Fig. 8). There is no reason to assume animal usage of ditches would be greater than usage of the marsh sites; thus the authors concluded that septic leachate from Nags Head was causing the elevated counts in the ditches. The authors also sampled for optical brighteners, a tracer of human detergent usage at the sites. Optical brighteners were found at all the sites, indicating that septic leachate was impacting both the drainage ditches and marshes within the Park. Thus, this study indicated that septic leachate was impacting drainage ditches on NPS land to a considerable degree and the marshes to a lower degree.

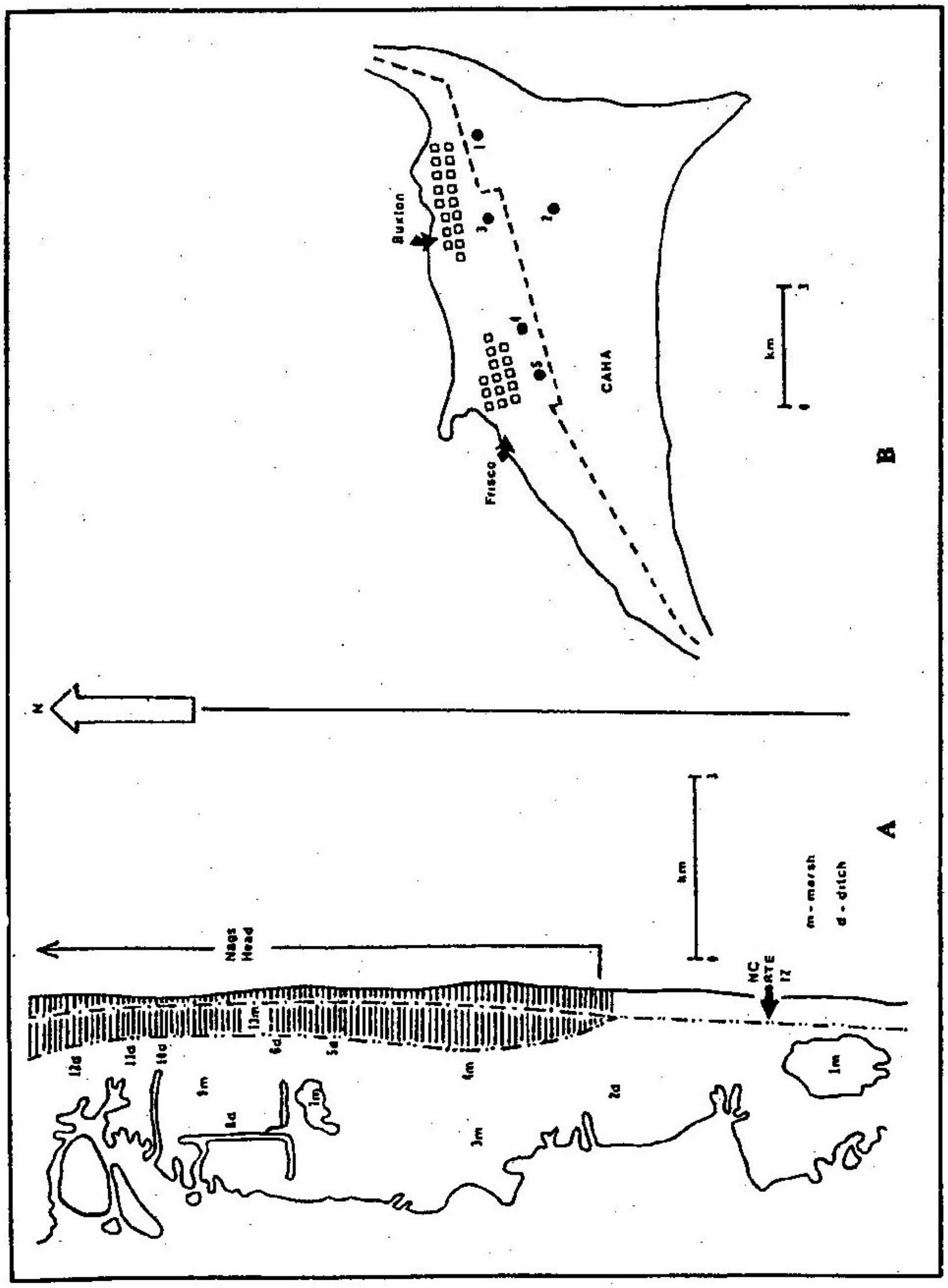
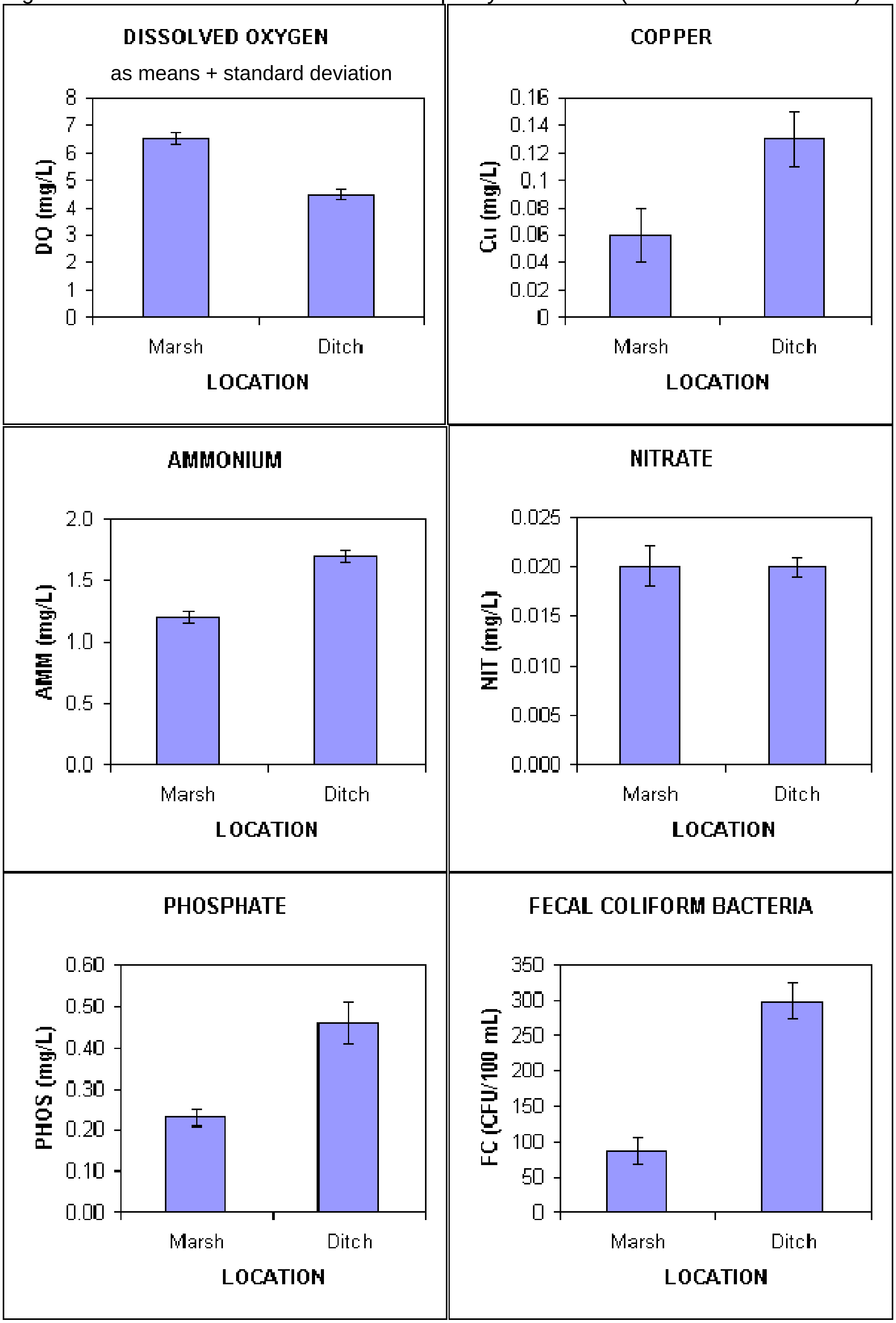


Figure 7. A. Location of ditch and marsh sampling sites on Bodie Island, and B. Location of swales sampling sites in Buxton Woods. Cape Hatteras (from Cole and Bratton 1995).

Fig. 8. Bodie Island ditch and marsh water quality 1988-1991 (Cole and Bratton 1995).



The second water quality study performed on southern Bodie Island was carried out in 1995-1996 (Evans and Houston 2000). The objectives were to better understand the flow of groundwater and assess the potential impact of septic system leachate on NPS waters. Nitrate and ammonium were sampled from a set of six wells (Fig. 9) and six ditches (Fig. 10) on NPS land near and away from development in Nags Head Village (Tables 4 and 5). A well cluster located near a septic drainfield associated with a hotel (Fig. 9) showed high nitrate concentrations (some exceeding 10 mg-N/L), indicating that septic leachate was entering groundwater beneath NPS land in that area (Table 4). Higher concentrations were found in summer, when the tourism population was highest. Wells located 600 ft. or more from developed areas did not show elevated nitrogen concentrations (Table 4). Ammonium concentrations were not excessive in any of the wells. Evans and Houston (2000) indicated that the drainage ditches were effective at capturing groundwater flow originating from the Nags Head area adjoining NPS land. Using the well data and subsequent modeling, the authors felt that septic leachate would be pushed in the direction of the sound rather than the ocean. In a related modeling effort on Australian barrier islands Nielson (1999) described how the interplay of tides and waves leads to mounding of groundwater near the beach, which would force groundwater in a landward (soundward) direction, carrying associated septic wastewater and other pollutants.

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 1995-1996 survey at two of the wells on Bodie Island that were closest to the hotel, HT 3 and HT 4 (Table 4). Thus, there is a septic system source of nitrogen from nearby developed areas to nearby park groundwaters at these locations. Evans and Houston (2000) noted that septic leachate is likely to enter the groundwater table at times because the seasonal water table is less than 30 inches in most of the area; thus the wastewater entering the subsurface may not encounter sufficient unsaturated soil to provide proper aerobic treatment.

Table 4. Lower Bodie Island well water quality, June 1995 – March 1996 (n ranges from 3 to 5). Data as mean ± standard deviation / range / median (summarized from Evans and Houston 2000)

Well	HT 2	HT 3	HT 4	FH 2	FH 3	CP
Nitrate-N mg/L	0.67±0.69 0.1-1.44 0.10	5.73±6.31 0.1-11.30 5.77	4.86±5.43 0.14-10.60 0.05	0.14±0.17 0.01-0.33 0.10	0.12±0.10 0.01-0.21 0.94	0.09±0.07 0.01-0.18 0.01
Ammonium-N mg/L	0.92±0.66 0.29-1.60 0.88	0.15±0.14 0.01-0.32 0.07	0.27±0.32 0.27-0.64 0.08	0.29±0.33 0.10-0.67 0.11	0.13±0.06 0.10-0.20 0.10	0.18±0.10 0.10-0.29 0.16

HT 2, HT 3, HT 4 = well cluster adjacent to hotel septic system; FH 2, FH 3 = well cluster 600 ft from nearest septic system; CP = control well 0.5 miles from any development

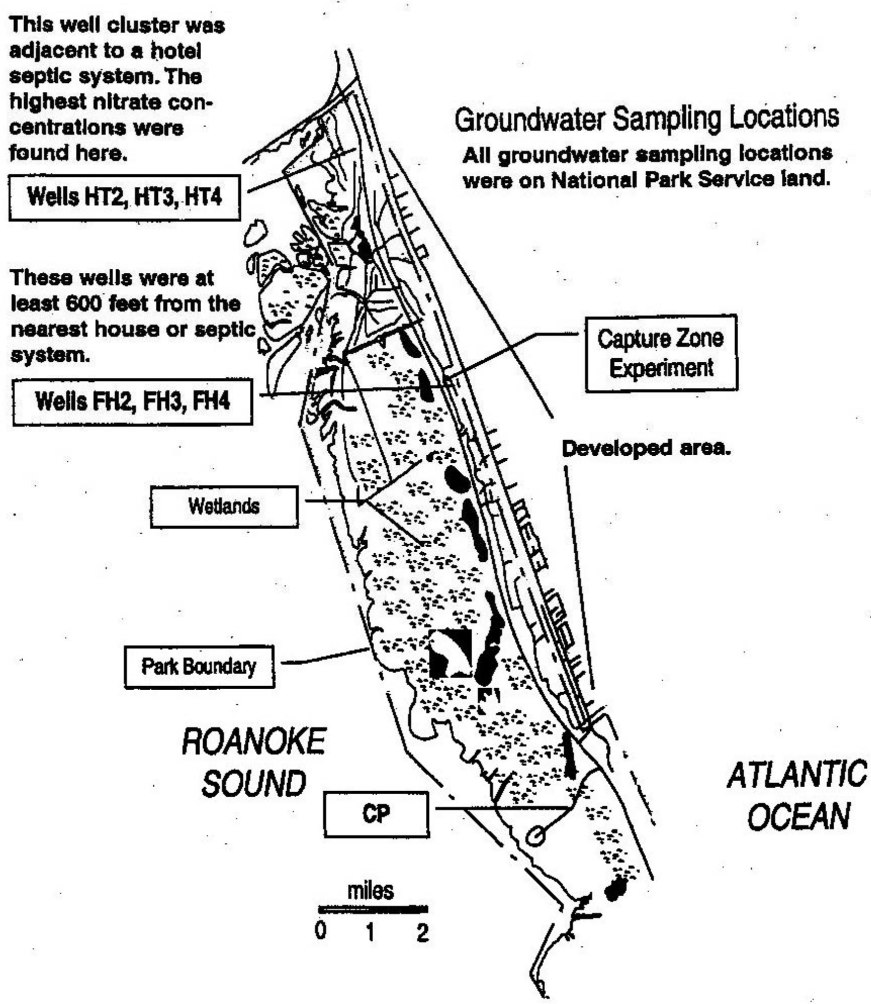


Figure 9. Groundwater wells sampled on Bodie Island by Evans and Houston (2000).

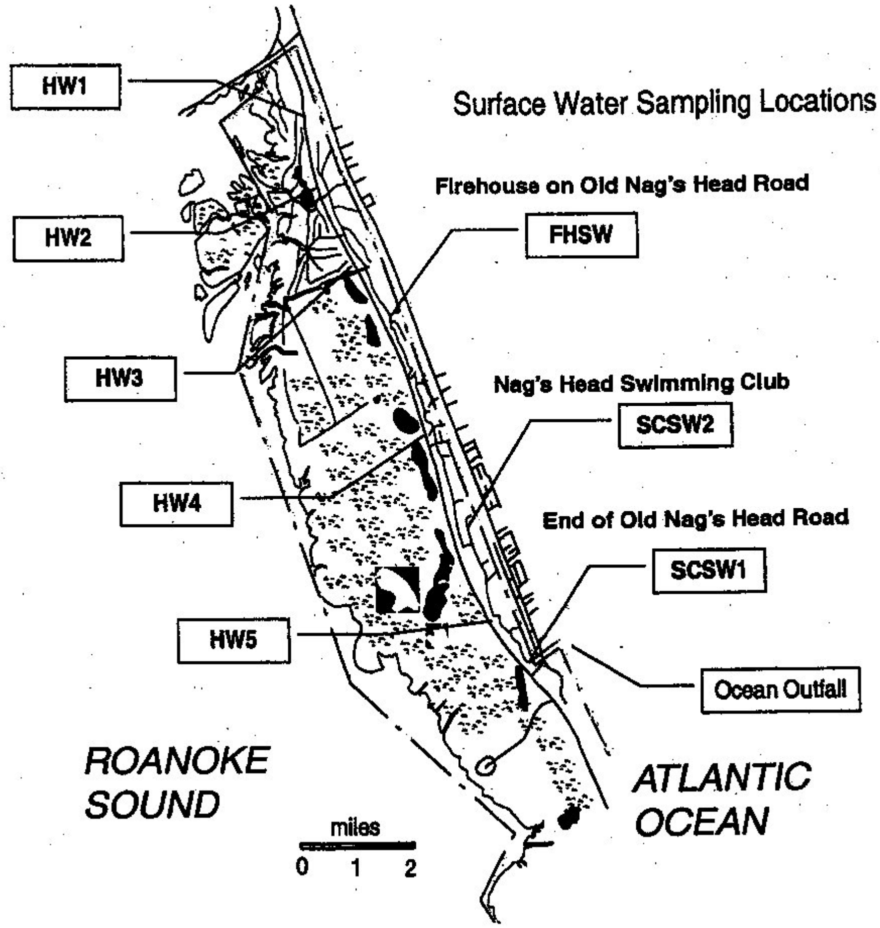


Figure 10. Surface water ditch sites sampled on Bodie Island by Evans and Houston (2000).

Inorganic nitrogen concentrations in the Bodie Island ditches ranged from low to moderate (Table 5). The authors indicated that the water quality along the length of the ditches was well mixed; thus sampling at one location per ditch on the outgoing tide was recommended to obtain representative nitrogen concentrations. Chlorophyll *a*, BOD, or dissolved oxygen concentrations were not sampled; thus the fate of inorganic nitrogen (and impact on water quality) in the ditches was not discussed in that report. Evans and Houston (2000) sampled nitrogen concentrations in the ditch that drains south Nags Head Village into the ocean at the beach at the Park border (Fig. 10). Inorganic nitrogen levels were low to moderate; however, the authors of the present report observed that this ditch is extremely eutrophic, and covered with algal and macrophyte blooms ((Plate 17). Thus, the nitrogen from Nags Head surface runoff is rapidly being taken up and is stimulating nuisance algal and macrophyte growth.

Table 5. Lower Bodie Island drainage ditch water quality, June 1995 – March 1996 (n = 4). Data presented as mean $\pm$ standard deviation / range / median (summarized from Evans and Houston 2000)

Ditch	HW1	HW2	HW3	HW4	SC1	SC2	FHSW
Nitrate-N mg/L	0.14$\pm$0.19 0.01-0.41 0.08	0.13$\pm$0.12 0.01-0.27 0.12	0.08$\pm$0.11 0.01-0.23 0.05	0.09$\pm$0.10 0.01-0.33 0.09	0.16$\pm$0.18 0.01-0.40 0.11	0.11$\pm$0.07 0.01-0.33 0.05	0.66$\pm$0.18 0.49+0.91 0.61
Amm.-N mg/L	0.20$\pm$0.09 0.14-0.33 0.17	0.33$\pm$0.10 0.23-0.46 0.31	0.32$\pm$0.25 0.10-0.61 0.28	0.28$\pm$0.31 0.01-0.69 0.23	0.45$\pm$0.44 0.10-1.10 0.20	0.12$\pm$0.69 0.05-0.21 0.17	0.12$\pm$0.07 0.05+0.21 0.11

HW1, HW2, HW3, HW4 = drainage ditches crossing Highway 12 and discharging into the sound or freshwater wetlands in the park; SC1 = drainage ditch crossing Old Nags Head Rd. and discharging into ocean; SC2 = drainage ditch at Nags Head Swimming Club; FHSW = drainage ditch at the firehouse on Old Nags Head Rd.

<u>Cape Hatteras area water quality</u>: Cole and Bratton (1995) sampled five swales in Buxton Woods (1988-1991) to determine if septic leachate from nearby communities in Buxton or Frisco was entering the Park and impacting the water quality of the swales (Fig. 7). There was considerable variability in parameter concentrations among the five swales (Fig. 11). Nitrate concentrations were generally low, while ammonium concentrations were in the range of the marsh sites on Bodie Island but lower than the Bodie Island ditch sites (Figs. 8 and 11). Phosphate concentrations ranged between those of the ditch and marsh sites on Bodie Island (Figs. 8 and 11). Mean fecal coliform concentrations ranged broadly across the five sites, and some sites had mean concentrations exceeding the N.C. recreational water standard of 200 CFU/100 mL (Fig. 11). Optical brighteners were found at only one location, and only on two occasions, thus the authors concluded that septic leachate contamination was minimal to non-existent and the periodic elevated fecal coliform bacteria counts were likely due to wild animals congregating at the swale sites.

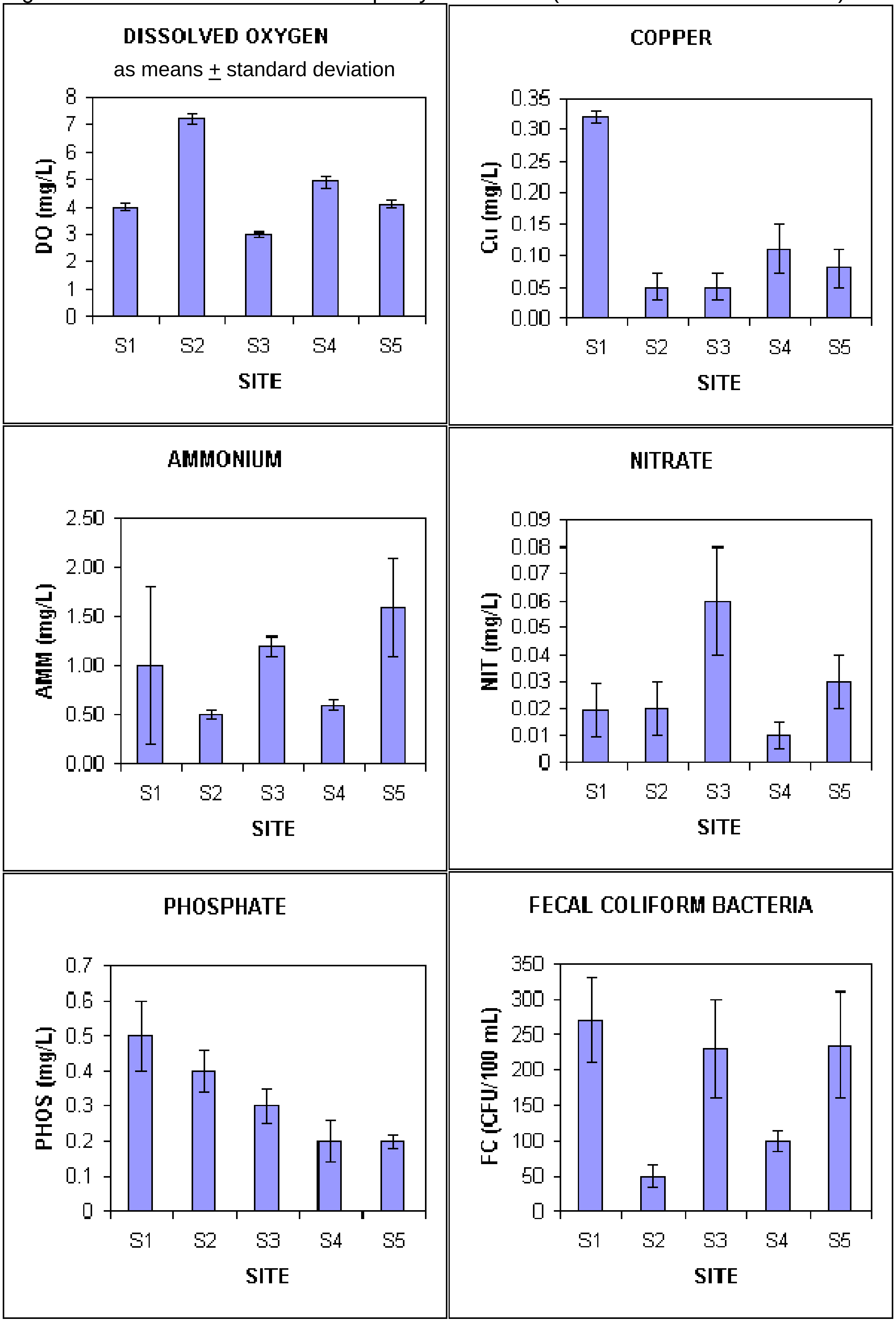
Plate 17. Eutrophic ditch with algal mats and macrophyte blooms, Old Oregon Inlet Rd. (photo M. Mallin).

Another, but very limited, set of water quality data within Buxton Woods swales was collected by Ehrenfield and Oskarsson (1991). Five swales in undisturbed park areas and five swales in disturbed private areas (housing areas and wellfields) were sampled on a single occasion in 1989 for several water quality parameters. Nutrient data showed that there was no difference in ammonium concentrations between disturbed and undisturbed sites, and ammonium was the principal inorganic nitrogen species in undisturbed areas. Nitrite and especially nitrate concentrations were much higher in the disturbed sites, and concentrations of these two oxidized inorganic nitrogen species were very low in the undisturbed swales. Orthophosphate in the disturbed sites was approximately double that of the undisturbed sites (Table 6). The authors suggested runoff of fertilizers from lawns and gardens and septic leachate may have contributed to this disparity. The authors found lower plant diversity and species richness in the impacted swales and noted that increases in limiting nutrients often leads to a reduction in diversity due to competitive advantages of certain species in the absence of nutrient deficiencies.

Table 6. Nutrient concentrations (mg/L) in protected versus disturbed swales in Buxton Woods as mean $\pm$ standard deviation, n = 5 sites, one sampling trip (from Ehrenfeld and Oskarsson 1991).

Area	Ammonium-N	Nitrate-N	Nitrite-N	Orthophosphate-P
Protected	0.790+0.261	0.008+0.008	0.001+0	0.122+0.076
Disturbed	0.810+0.152	1.020+0.637	0.034+0.024	0.264+0.360

Fig. 11. Buxton Woods swale water quality 1988-1991 (from Cole and Bratton 1991).



Ocracoke Island water quality: Presently no surface water quality data on Ocracoke Island exists in the literature. Thus, there is no baseline data against which to judge anthropogenic impacts and no data to assess the relative health of the Ocracoke Island water quality compared with other coastal waters. No surface water quality data appeared to be available for Pea Island, either.

Ecosystem effects: Water quality issues that could affect the flora of Park waters include excessive nutrient loading leading to eutrophic conditions and toxic compounds in the surface or groundwaters that could affect plant survival or growth. As previously indicated, Cape Hatteras National Seashore is separated by one to many km of water from the mainland, and mainland sources of nutrients and toxicants, thus pollution would most likely come from local sources.

Hypoxia and anoxia-open water: 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. Such incidents are capable of causing death of sessile marine organisms and displacement of mobile species (Diaz and Rosenberg 1995). The waters in the immediate vicinity of most of Cape Hatteras National Seashore are generally well mixed by wind and tides, have generally low nutrient concentrations, and are unlikely to host algal blooms. A survey of fish kill reports (1997-2003) assembled by NCDWQ showed that fish kills in general have occurred only rarely in waters near the Park (http://www.esb.enr.state.nc.us/Fishkill/fishkillmain.htm). A kill of 3,100 fish in 1998 in Roanoke Sound near Manteo was attributed to hypoxia, and a small kill in 2002 in Oregon Inlet was believed to be bycatch from trawlers. Marine finfish and shellfish kills caused by hypoxia or anoxia have not been reported along Cape Hatteras National Seashore proper in recent years.

Hypoxia and anoxia-inland water: In 1988-1991 Cole and Bratton (1995) found significantly lower dissolved oxygen concentrations in Bodie Island drainage ditches compared with marsh areas (Fig. 8). This may have been the result of septic system leachate creating a larger biochemical oxygen demand (BOD), either directly from labile organic matter or indirectly through stimulation of algal blooms that later died to become BOD. Dissolved oxygen measurements taken by Cole and Bratton (1995) at five swales in Buxton Woods showed high variability among sites, with at least one swale averaging rather low values (Fig. 11). Isolated swales might naturally yield low dissolved oxygen concentrations if macrophyte vegetation and periphyton growth is constrained by shade, and/or there is little wind driven mixing and organic-rich waters (Colburn 2004). There appears to be no published historical dissolved oxygen data from the freshwater resources on Ocracoke Island.

In August 2005 dissolved oxygen readings were taken by the authors of this report at mid-day in three of the five drainage ditches on lower Bodie Island. Concentrations ranged from 1.3-7.1 mg/L (19-109% saturation) during a period of high water temperatures (36.2-36.7 ^{o}C). In the ditch with lowest dissolved oxygen there were clumps of floating algal mats and *Gambusia* (mosquitofish) feeding amongst them (Plate 18). During that same period samples were taken in six Ocracoke Island tidal creeks (Table 2). Concentrations ranged from 2.7-5.0 mg/L (37-71% saturation) during what is seasonally the most stressful period for this parameter (water temperatures were 30-31 ^{o}C). Fish and turtles were using the creeks at this time and stressed organisms were not visible.

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 Hatteras 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 Hatteras 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 kills have occurred in the Pamlico River Estuary during 1991-1997 (Glasgow et al. 2001). Unpublished surveys in selected areas of the Outer Banks have only found low concentrations of *Pfiesteria* spp. As *Pfiesteria* spp. prefer nutrient enriched waters and more estuarine conditions, blooms of *Pfiesteria* near Cape Hatteras waters are likely to be rare. However, since septic systems in developed areas abutting the park clearly leach nutrients into Park waters, brackish marsh areas at risk from septic leachate may accumulate excess nutrients. Thus, the possibility of blooms cannot be discounted in those areas.

There is a potential for toxic blue-green algal blooms or nuisance algal blooms of those or other taxa groups to occur in freshwater areas of the Park. These could occur in nutrient-enriched Bodie Island drainage ditches (Plate 18), Hatteras Island swales that are impacted by runoff or septic system leachate, or tidal creeks, marshes and ponds on Ocracoke Island. There appears to be no published information on phytoplankton or attached algal biomass in any of these systems.

Plate 18. Ditch with algal mats and *Gambusia* draining Nags Head groundwater to Roanoke Sound (photo M. Mallin).

Sediment toxicity and quality: Exposure to toxicants such as metals, pesticides and other organic contaminants can cause toxicity to benthic organisms and adversely impact living habitat of invertebrates and fish. In 1994-1997 the EPA EMAP program analyzed estuarine sediments throughout North Carolina and quantified the condition of the benthic communities (Fig. 12). Overall, there were few degraded locations in the open waters of Pamlico Sound, though 64% of the sites sampled in Albemarle Sound were contaminated (Hackney et al. 1998; Hyland et al. 2000). Low dissolved oxygen problems were not found at sites close to Cape Hatteras National Seashore. Several sites (044, 059, 123, 206, 229) in Pamlico Sound within a few km of the Park (Fig. 12) showed at least one toxic response to bioassays (Hackney et al. 1998). Three sites (059, 206, 222) showed moderate sediment contamination (Hackney et al. 1998). The presence of groundwater toxicants does not appear to have been examined within Bodie, Hatteras or Ocracoke Islands. If such contamination exists, it is likely localized near small sources such as fuel storage areas within or near the Park (Mallin et al. 2004b).

<u>Human health issues</u>: Waterborne 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 Hatteras National Seashore 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; NCDHR 1987).

Area G-6 encompasses the Ocracoke Island littoral zone (Fig. 1). The majority of this region (13,300 acres) is open for shellfishing except for two areas totaling 135 acres (Shellfish Sanitation Section 2002a). Silver Lake (Fig. 3) is the enclosed harbor of Ocracoke Village and all of it is closed for shellfishing - this is a high use area with three marinas and a considerable amount of impervious surface area in the immediate vicinity (Shellfish Sanitation Section 2002a). The second closed area is a developed residential area cut by canals along the north side of the village (Fig. 3). Area H-4 contains 5,800 available acres and covers the area from Hatteras Village to the middle of Cape Hatteras, including Frisco (Fig. 1). A total of 225 acres are closed to shellfishing by bacterial contamination (Shellfish Sanitation Section 2002b). There are several closed areas in the Hatteras Village area, including all canals. There are nine marinas in H-4, and many of the septic systems are on sand or fill and may discharge into adjacent waters (Shellfish Sanitation Section 2002b). The only significant large animal populations are of dogs, ducks, and gulls. Area H-4 suffered a significant decline in bacteriological water quality between surveys in 1998 and 2002 (Shellfish Sanitation Section 2002b). Area H-5, upper Hatteras Island (Fig. 1), has several areas closed to shellfishing near Buxton, Avon and Salvo (Shellfish Sanitation Section 1999 records). Area H-1 contains portions of Roanoke Sound including the northern area of the Park (Fig. 1), and has <10% of its acreage closed to shellfish, with non-point source runoff from adjacent land uses cited as the principal contaminant source (NCDWQ 2002).

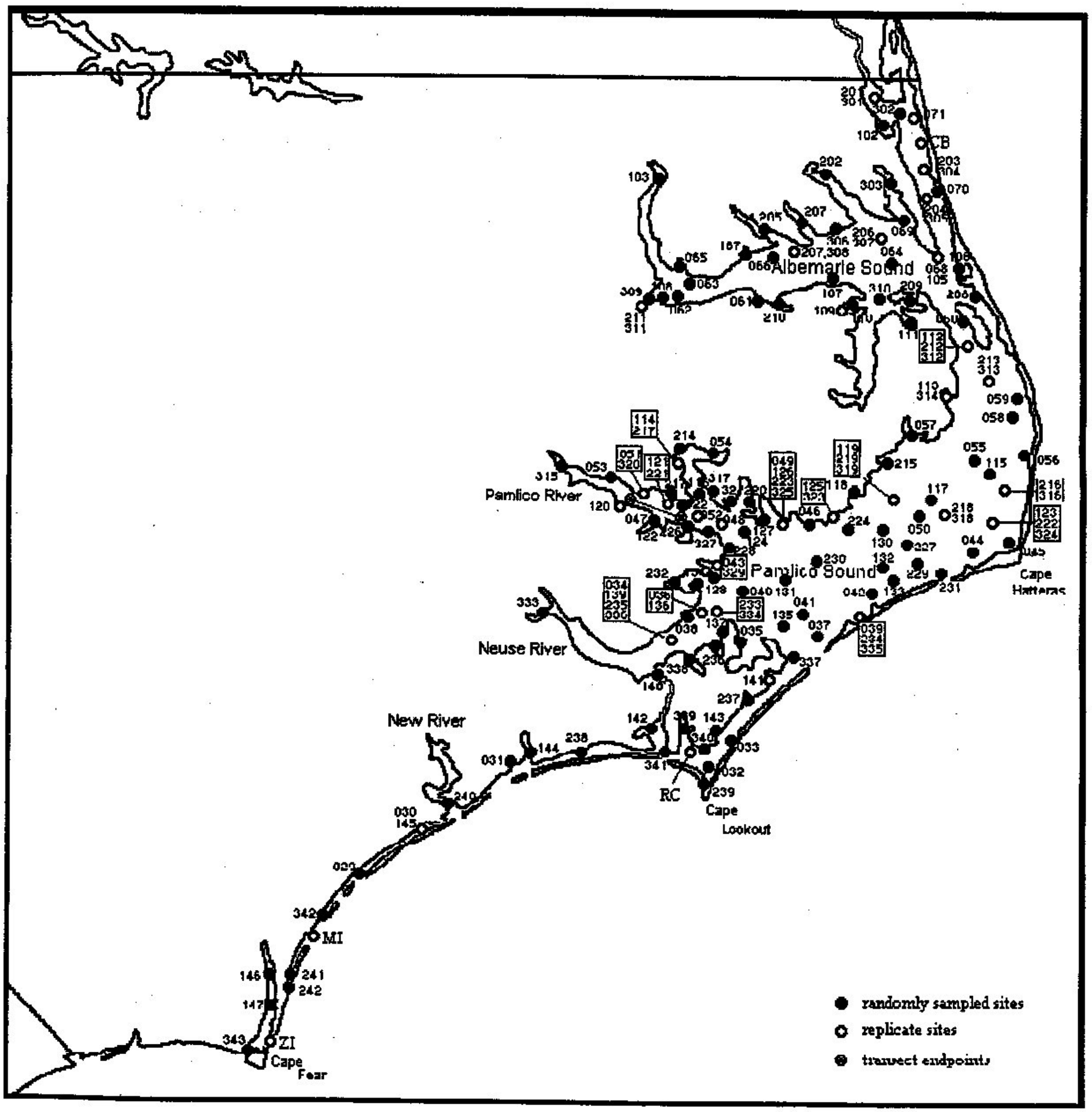


Figure 12. Eastern North Carolina estuarine sites sampled during the EMAP Program, 1994-1997 (map from Hackney et al. 1998).

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 and assigns identification numbers to each station sampled. Data obtained from the Shellfish Sanitation Section covering the period 1997-2003 indicates that there are several sampling stations in or adjacent to Cape Hatteras Seashore that show repeat violations of the fecal coliform or enterococcus standard. One area was Oregon Inlet (Stations 23 – coordinates N35.798665, W75.540362, and 24 – N35.794902, W75.548710), which had at least some violations in seven of seven years. In the Buxton area Station 33, at the Canadian Hole area (N35.298664, W75.514702) was impacted more than once in four of seven years. In Frisco repeat violations occurred at Stations 37 (ocean area at N35.232138, W75.604396) and 38 (sound area at N35.220190, W75.660750 - seven of seven years). Station 28 near Waves (N35.573558, W75.468716) had repeat violations in seven of seven years, and in Avon Station 31 (sound area at N35.372625, W75.502810) and 32 (at beach ramp 38, N35.321898, W75.506823) had several repeat violations. The beach at Ramp 1, at the northernmost edge of the Park at Nags Head is impacted by a beachfront discharge pipe that drains surface runoff from a densely populated residential area adjacent to the Park (Plate 19). High fecal microbe counts characterize the runoff from the pipe and necessitates permanent posting of the beach by N.C. Shellfish Sanitation (J.D. Potts, N.C. Shellfish Sanitation, personal communication). This is a case of a Park beach polluted from a nearby urban area. Thus, high-use areas in beaches and sounds near Outer Banks municipalities show potential for human microbial infections through water contact.

Plate 19. Stormwater outfall area at Ramp 1, northern Cape Hatteras National Seashore (photo M. Mallin).

Septic system contamination of freshwater resources in the park is a major concern to park officials (NPS 2000a) and has been studied by Cole and Bratton (1995) and Evans and Houston (2000). The 1988-1991 Bodie Island marsh and ditch water quality survey (Cole and Bratton 1995) found that median fecal coliform bacterial counts for marsh sites were 23 CFU/100 mL and for ditch sites was 170 CFU/100 mL. Average fecal coliform counts for the marshes and ditches were 87 and 298 CFU/100 mL, respectively. Thus, the drainage ditches on Bodie Island were often well above the NC human contact water standard of 200 CFU/100 mL and a potential human health problem, but the bacteria counts in the marshes were rarely a problem (Fig. 8). Data for the five marsh sites sampled in Buxton Woods (Fig. 11) showed average fecal coliform counts exceeding 200 CFU/100 ml at three locations, with the other two locations at 100 CFU/10 ml or less (Cole and Bratton 1995). These results, coupled with the presence of optical brighteners in ditch and marsh sites on Bodie Island led Cole and Bratton (1995) to cite improperly functioning septic systems as the coliform source on Bodie Island, and wildlife as the source in Buxton Woods. Since this survey occurred in 1988-1991 it is likely that increased human development in Nags Head and possibly Buxton and Frisco (see Section C1) has led to further deterioration of the bacteriological quality of drainage ditches and nearby freshwater wetlands.

Earlier it was noted that a ditch draining wetlands on the south side of Cape Hatteras (Plate 6) is gated and controlled by the NPS. The water quality of the drainage has not been systematically studied, and if it contains high concentrations of fecal microbes the drainage could impact beach water quality. Beach water samples taken by N.C. Shellfish Sanitation in spring and summer 2003 and summer 2004 (when drainage from the south beach discharge was entering the ocean) showed several excessive enterococcus counts (J.D. Potts, N.C. Shellfish Sanitation, personal communication). The excessive counts required beach closures in the area and the posting of signs warning swimmers of the discharge. Thus, this drainage (Fig. 2) is of concern to both the NPS and the N.C. Division of Water Quality.

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) conducts annual surveys along selected areas of the North Carolina Outer Banks for the presence of *Pfiesteria*. Unpublished 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, as mentioned, septic system nutrient leachate into estuarine areas near developed regions 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.

List of impairments (State and Federal listings)

Subbasin 03-01-55 (Fig. 1)has no impaired waters in terms of aquatic life/secondary recreation, or primary recreation; however, several areas near populated portions of Cape Hatteras are classified as non-supportive because they are closed to shellfishing (NCDWQ 2002). In subbasin 03-01-56 (Fig. 1) there is a portion of Roanoke Sound not far from the Park that is closed to primary recreation (swimming) near the outfall from Villas Association, Inc. (NCDWQ 2002). There are some very limited areas in Roanoke Sound near Park waters that are non-supportive for shellfish harvest; these are located in the populated areas near the bridge from Bodie Island to Manteo, and at a marina near Oregon Inlet (NCDWQ 2002). Subbasin 03-03-08 (Fig. 1) has no areas classified as impaired for aquatic life (NCDWQ 2004). Two areas along the shores of Ocracoke Island are considered impaired as they are closed to shellfish harvest (NCDWQ 2004); however, these are not in Park waters but are located in Silver Lake, the main harbor for Ocracoke Village and in and near the canal development in the northeast portion of Ocracoke Village (Fig. 3).

All of the marine waters in subbasins 03-01-55 and 03-01-56, and 03-03-08 are impaired by a fish consumption advisory for king mackerel, tilefish, shark, and swordfish based on mercury (NCDWQ 2002). The saltwater fish consumption advisory in coastal North Carolina waters is described in (http://www.schs.state.nc.us/epi/fish/contaminants.html).

List of water bodies with undocumented conditions/status

Few of the many freshwater ponds on parts of Ocracoke, Hatteras and Bodie Islands have official documented water quality conditions or status. There are a few records of various pond water parameters including temperature, pH, dissolved oxygen, and other constituents that were collected during a fisheries survey by Schwartz (1983) and Kling (1986-from Nags Head Woods outside of the Park). The tidal creeks on Ocracoke and Hatteras Islands appear to have not been studied at all. A 1988-1991 study by Cole and Bratton (1995) found poor water quality in ditches impacted by septic leachate from Nags Head (Plate 18) and better water quality in nearby marshes (Fig. 8). That same study found that several swales in Buxton Woods had somewhat elevated fecal coliform counts and ammonium levels (Fig. 11), but were considered relatively unimpacted by humans nonetheless.

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). There is currently very rapid growth on Bodie Island, in NCDWQ subbasin 03-01-56. From 1990-2000 the human population increased by 47% in Nags Head, and overall subbasin 03-01-56 population density increased from 41 per mile^2 in 1970 to 130 per mile^2 in 1980 to 305 per mile^2 in 1990 (NCDWQ 2002). Population is expected to continue to increase in the upper Outer Banks, and pollution of Park resources from the nearby burgeoning population is a serious concern to Cape Hatteras National Seashore personnel (J. Ebert, NPS, personnel communication).

In NCDWQ subbasin 03-01-55 (Hatteras Island) population density remains low because of the limited private land. Population density over time went from 18 per mile^2 in 1970 to 40 per mile^2 in 1980 to 36 per mile^2 in 1990 (NCDWQ 2002). Ocracoke Island is in Hyde County, which in general has a very low population density (NCDWQ 2004). However, there are large numbers of summer visitors to the villages adjacent to the Park on Ocracoke and Hatteras Islands. For instance, the permanent population of Ocracoke Village is 800, increasing to 4,500 in summer (Shellfish Sanitation Section 2002a). The permanent population of Hatteras Village is 1,700, which increases to 6,000 in summer, and the permanent population of Frisco is 700, which increases to 5,000 in summer (Shellfish Sanitation Section 2002b).

Land use: A concern to Park personnel is the conversion of nearby landscapes from natural landscapes to impervious surfaces, leading to increased runoff of pollutant containing stormwater into Park areas (NPS 2000a). Increases in impervious surface coverage in coastal areas are strongly correlated with increases in freshwater discharge, fecal coliform bacterial loading, shellfish area closures, and degradation of benthic biological communities (Mallin et al. 2001; Holland et al. 2004). The developed areas of Nags Head Village adjoining the Park exemplify this with the Village's surface runoff flowing through the ditch along Old Oregon Inlet Road (Plate 17) and then into the beach waters near Ramp 1 (Plate 18). Groundwater carrying septic leachate appears to flow landward from Nags Head and flow through the Park's ditches and wetlands in the direction of Roanoke Sound (Plate 19).

Presently all of the Cape Hatteras National Seashore and adjoining municipalities utilize septic systems to treat human sewage. On Bodie Island some of the septic leachate enters NPS groundwater and drainage ditches. On Hatteras Island septic leachate may impact some swales located near housing areas. On Ocracoke Island septic leachate impacts on NPS waters have not been examined, although the potential exists at least in Island Creek and the northern freshwater marsh. Within the Village of Ocracoke septic leachate is not a problem to residential drinking water, which largely comes from deep wells. A municipal wastewater treatment system in Ocracoke Village would likely have the very adverse effect of allowing much greater surface development and impervious surface coverage on non-NPS areas of the island and increased surface water pollution from stormwater runoff.

Surface and groundwater withdrawals: Surface waters are not utilized for drinking purposes. However, as mentioned earlier, the NPS has control of a drainage gate on Cape Point and is asked to drain the wet areas following rain events for the purposes of opening the nearby roads, ramps, and campground. Drawdown of the wetlands is an ecological concern in terms of altering the habitat for the local biota. Drawdown of the aquifer associated with excessive groundwater withdrawals has been cited as a concern to NPS officials (NPS 2000a). Anderson and Mew (1995) used CHWA records to estimate that on lower Hatteras Island water consumption rises from a winter minimum of 400,000 GPD to a summer maximum of 1,400,000 GPD, with an approximate water table elevation decrease of 2-3 ft. In a study of vegetation communities of swales in Buxton Woods, Ehrenfeld and Oskarsson (1991) found that areas experiencing rapid groundwater withdrawals and fluctuations (such as the wellfields) have lower plant diversity and species richness compared with unimpacted areas. They suggested that the water level fluctuations, along with higher nutrients, led to the lower species diversity in the wellfields. Deep well withdrawal such as on Ocracoke Island (from 620 ft.) triples in summer compared with winter (Ocracoke Sanitary District Water Department records), but there is no evidence that present withdrawals adversely affect that aquifer.

Nuisance and invasive species: The nearest major ocean traffic port is the Port of Morehead City, at nearly 100 km from Ocracoke Island. This port 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 Hatteras water resources have not been documented. The distance from this port makes such invasions of Park water unlikely at best. However, gradual movement of non-native species into the Park from other coastal areas is always a possibility.

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 flora and fauna are adapted to and are not in themselves considered by us to be detrimental to the environment. However, the beach erosion mentioned earlier in the report, which is exacerbated by these storms, has major impacts to human habitation near the Park. As Plate 20 shows, people continue to build beachfront dwellings in Nags Head and to the north of Nags Head. Over the long run a certain percentage of these dwellings will become uninhabitable due to natural erosion.

Driving is permitted on the beach in designated areas of Cape Hatteras National Seashore, and this can be a significant physical disturbance to the flora, fauna, and water resources if drivers ignore park regulations. Principally beach motor traffic is a threat to nesting bird and turtle nesting 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 these islands to selected areas and during selected periods (http://www.nps.gov/caha/bdriv.htm).

Free-ranging horse herds can severely damage wetland ecosystems through, trampling, overgrazing and defecation (Noon and Martin 2004). The horses on Ocracoke Island are in a penned area, which is a combination of two of the options presented by Noon and Martin (2004) for limiting wetland damage by a wild horse herd's activities.

Historically, the largest anthropogenic physical impact to Cape Hatteras National Seashore was the establishment, fertilization, and planting of a protective primary dune line along the beachfront by the Civilian Conservation Corps from 1936 to1940, later augmented by the NPS in the 1950s and 1960s (Dolan et al. 1973). This led to narrowing of the beach and subsequent dune erosion problems due to lack of overwash (Dolan et al. 1973). Presently the artificial dune line has large gaps in it due to shoreline retreat (Young et al. 1999), which has led to exposure of human developed areas to flooding, overwash, and inlet formation (as on south Hatteras Island during Hurricane Isabel in 2004).

Plate 20. Severe beach erosion and condemned beach house, Nags Head area (photo D. Webster).

Sea-Level Rise

The present rate of sea-level rise for the North Carolina shoreline is calculated to range from 1.0 to 1.5 feet per hundred years based upon data from tidal gauges along the Atlantic coast (Riggs and Ames, 2003). The rate of sea level rise in Beaufort, NC (about 75 km SW of Ocracoke Island) is approximately 1.2 feet per hundred years based upon 27 years of data. (Pendleton and others, 2004). Limited data for the period from 1980 to 2000 from Duck, NC suggest that sea level for the Albemarle Embayment region may be rising at the rate of 1.5 feet per hundred years. This rate of sea level rise for Cape Hatteras is approximately double that of the global sea level rise average of 7.1 inches for the past century (Douglas, 1997). The Intergovernmental Panel on Climate Change Report (IPCC, 2001) predicts an additional rise of (18.9 inches) by 2100 which is more than double the rate of rise for the 20th century. Potential impacts to the North Carolina coast, including Cape Hatteras, of increased rates of sea level rise include accelerated rates of shoreline erosion (Plate 20) and land loss, inundation of wetlands and estuaries saltwater intrusion into groundwater aquifers, and even future collapse of some barrier island segments (Riggs and Ames, 2003; Pendleton and others, 2004).

Inlet Migration and Dredging

Since Oregon Inlet opened in 1846, it has migrated southward a distance of just over 2 miles (3.2 km), at an average rate of approximately 23 m/yr (75 ft/yr). It also has undergone alternate periods of widening and narrowing, typically in response to severe storms. Bonner Bridge, which spans the inlet, is the only land transportation link between Bodie Island to the north and Hatteras Island and its villages to the south. The bridge was built in 1962, two years after the US Army Corps of Engineers began to maintain the authorized navigation channel through Oregon Inlet. During the 1980's, the navigation channel was maintained by hopper dredging, with the sediment disposed of off the northern end of Pea Island in water depths as much as 9 m (30 feet) (Dolan and others, 2006). This disposal worsened a downdrift sand deficit, and led to accelerated beach erosion along the north end of Pea Island. The accelerated erosion prompted the construction in 1989 of a revetment and terminal groin on the north end of Pea Island to protect the southern end of Bonner Bridge and the highway approaches. This stabilized the south side of Oregon Inlet, but the inlet continued its attempt to migrate southward with accretion of the Bodie Island spit on the north side of the inlet. To maintain the navigability of Oregon Inlet, maintenance dredging is necessary on a generally annual basis. Since 1989, dredged sand has been bypassed to the surf-zone and the subaerial beach along Pea Island National Wildlife Refuge south of the inlet. In total, 4.9 million cubic meters (6.5 million cubic feet) of sand has been bypassed to Pea Island, with 3.4 million cubic meters (4.5 million cubic feet) placed on the beach (Dolan and others, 2006).

Table 7. Current and potential stressors that are or may affect Cape Hatteras National Seashore habitats.

Ocracoke Island

Stressor	Ocean beach	Sound shore	Tidal creeks	GW	Marsh	FW ponds
Algal blooms	OK	PP	PP	OK	EP	OK
Toxic algae	OK	PP	PP	OK	PP	ND
Nutrient loading	OK	EP	PP	OK	PP	OK
Excessive nitrate	OK	OK	OK	ND	OK	OK
Fecal bacteria	OK	EP[1]	PP	ND	ND	OK
Metals contamination	EP (Hg)[2]	EP (Hg)[2]	PP (Hg)[2]	ND	ND	ND
Toxic compounds	ND	OK	PP (PAHs)	ND	ND	ND
Invasive species	PP (lionfish)	ND	ND	OK	EP[3]	ND
Habitat disruption	EP (ORV)	OK	OK	OK	OK	PP (ORV)

Hatteras Island

Stressor	Ocean beach	Sound shore	Tidal creeks	GW	Ditches	sedges/swales
Algal blooms	OK	PP	PP	OK	EP	OK
Toxic algae	OK	PP	PP	OK	PP	OK
Nutrient loading	OK	PP[4]	PP	EP	EP	EP
Excessive nitrate	OK	OK	OK	EP	EP	OK
Fecal bacteria	EP (drainage)	PP[5]	PP	EP	EP	EP
Metals contamination	EP (Hg)[2]	EP (Hg)[2]	PP (Hg)[2]	ND	ND	ND
Toxic compounds	ND	EP	ND	ND	ND-PP	ND
Invasive species	PP (lionfish)	ND	ND	OK	EP[3]	ND
Habitat disruption	EP (ORV)	MP (ORV)	OK	EP	EP	PP(drainage)

Bodie Island

Stressor	Ocean beach	Sound shore	Tidal creeks	GW	Ditches	sedges/swales
Algal blooms	OK-PP	PP	PP	OK	EP	EP
Toxic algae	OK	PP	PP	OK	PP	ND
Nutrient loading	OK-PP	PP	EP	EP	EP	EP
Excessive nitrate	OK	OK	OK	EP	EP	EP
Fecal bacteria	EP	PP[5]	OK	EP	EP	EP
Metals contamination	EP (Hg)[2]	EP (Hg)[2]	PP (Hg)[2]	ND	ND	ND
Toxic compounds	ND	EP	ND	ND	PP (PAH)	ND
Invasive species	PP (lionfish)	EP	PP	OK	EP[3]	ND
Habitat disruption	EP (ORV)	OK	OK	OK	OK	ND

Definitions: EP – existing problem, OK – low or no problem, PP – potential problem, ND – no data to make judgment

1 - Based on closed shellfishing area around developed canal community soundside

2 – Fish tissue consumption advisory by NC DWQ

3 - *Phragmites* is abundant in areas of the oligohaline marsh

SYNOPSIS OF STRESSORS TO CAPE HATTERAS NATIONAL SEASHORE WATER BODIES: EXPLANATION OF TABLE 7.

Ocracoke Island

The ocean beach of Ocracoke Island is not presently at risk from algal blooms, either benign, nuisance or toxic. There are no local or offshore sources of nutrients, particularly of nitrate. There are no ocean discharges to provide a fecal bacteria risk either. Toxic compounds are not presently a risk but will be if oil exploration occurs offshore. The lionfish is an invasive species from the Gulf Stream; there may be others that appear from time to time.

The sound shore, at least in Park areas, is remote from local and mainland nutrient sources and is not likely to host algal blooms. However, there is an area 400 ft. offshore that receives the effluent from the reverse osmosis plant, effluent that has nitrogen concentrations exceeding 5 mg/L. This nitrogen input into nutrient limited Pamlico Sound waters has the potential to cause localized algal blooms; thus the PP rating for nutrient loading and algal blooms. The Sound Shores - Oyster Creek development along the soundside of Ocracoke Village has canals that appear to have poor water quality and may host algal blooms at times. The nearby areas are closed to shellfishing; thus, there is an EP for fecal bacterial pollution along the Sound. The Park areas are not likely to have significant habitat disruption along the Sound. Systematic data for invasive species is lacking, and EMAP results show little toxicity in nearby Sound waters.

The tidal creeks on Ocracoke appear to be unstudied in terms of nutrients, algae, bacteria, toxic compounds or species composition. The creek habitats do not appear to be at risk from physical disruption, however the constant automobile traffic crossing the creeks may cause elevated PAH (polycyclic aromatic hydrocarbon) loading to the creeks and their sediments. Automobiles are major sources of PAHs. Groundwater has not been systematically studied but septic contamination of drinking water is not a possibility due to the depth (620 ft.) of the wells. The brackish to oligohaline marsh on Ocracoke Island along South Point Road does not appear to be near any significant anthropogenic nutrient sources, but hosts dense periphytic algal blooms nonetheless (Plate 11). The presence of fecal bacteria, metals, and other toxic compounds appears to be unstudied in this marsh. The northern freshwater marsh has dense periphyton and SAV beds, and the northern edge may receive inputs from a septic drainfield near the ferry terminal, there is a potential for nutrient loading and algal blooms. The invasive species *Phragmites* is a major presence in the southern marsh. Habitat disruption at present does not seem to be problematic in either marsh, as human use is confined to areas along the beach or road. The freshwater ponds, most of which appear to be temporary, are in Park areas remote from human pollution and are not at risk from anthropogenic loading, but some do host dense periphyton mats. There are no data on metals, other contaminants or invasive species, but habitat disruption may occur from ORV usage. Except for the fish consumption advisories for selected freshwater and marine species based on mercury, there are no metals data available for the aquatic habitats of Ocracoke Island (or Hatteras and Bodie Islands!).

Hatteras Island

The ocean beach on Hatteras Island does not appear to be in danger of receiving excessive nutrients from inside the Park and thus has a low risk for nuisance or toxic algal blooms. However, N.C. Shellfish Sanitation has documented high enterococcus counts along the beach in the vicinity of the south beach discharge from the wetlands (Plate 7), which has necessitated beach closures. Various beach areas are at risk from habitat disruption (nesting birds and sea turtles) from ORV traffic. The Sound shore of Hatteras Island is mainly adjoining municipal areas rather than Park areas. There is a potential (presently untested) for nutrient and bacterial pathogen loading, and algal blooms, in Sound waters that receive inputs from inland drainage systems such as Peter's Ditch. Toxins may be a moderate possibility in some areas based on EMAP sampling. The water quality of the tidal creeks draining the west side of Hatteras Island is unknown, but based on data elsewhere (Mallin et al. 2004a) they could at times harbor algal blooms or bacterial pathogens from anthropogenic loading from local communities.

Some of the Park's groundwater resources that adjoin populated areas may be receiving nutrient inputs from septic leachate, based on at least one study (Ehrenfeld and Oskarsson 1991). Based on that same study groundwater withdrawals in wellfield areas will cause habitat disruption in terms of limiting plant species richness and diversity in nearby swales. The ditches are unstudied on Hatteras Island, but the authors of this report observed an algal bloom in Peter's Ditch and assume this ditch collects runoff and septic leachate of nutrients and bacterial pathogens from populated areas. Bacterial pathogens are likely periodically abundant in the south beach discharge ditch, based on the enterococcus counts along the nearby beach. There is probably some input of nutrients and possibly pathogens into swales that adjoin populated (i.e. disturbed) areas, through septic leachate and possibly runoff. However, swales well within Buxton Woods are well protected from such inputs (Plate 4). Drainage of wetlands (Plate 6) will likely cause some habitat disruption for native flora and fauna.

Bodie Island

There is presently a low concern rating for the potential of nutrient loading and algal bloom formation in beach waters. This is simply because the massive amounts of nuisance algae and macrophytes in the drainage ditch along Old Oregon Inlet Road absorb the nutrients (Plate 17). If the ditch vegetation is eradicated, however, nutrient loading to the beach water at Ramp 1 could cause algal blooms. The ditch does drain bacteria-rich water onto the beach area at present, necessitating beach warning signs (Plate 19). The Sound shore of lower Bodie Island is understudied in terms of nutrients and algal bloom potential, but there were some minor toxicity problems with benthos at sites in the area. The tidal creeks in the area do not appear to be extensive, and are presently understudied. They would receive inputs from the wetlands in the interior of Bodie Island.

In selected areas (near developments) groundwater receives septic leachate with high nitrate concentrations, especially during the summer tourist seasons. Microbial pathogens also likely move readily through the sandy, saturated soils from groundwater into the drainage ditches on Park property. Some of the ditches show the impacts of nutrient loading with algal blooms evident (Plate 18). The ditches convey their contents westward through the wetlands toward Roanoke Sound (Plate 3). The ditches may also harbor elevated PAH concentrations due to heavy traffic crossing the ditches. The sedges and swales in the wetlands between Nags Head and Roanoke Sound receive some of the nutrient and pathogen inputs from the drainage ditches and surface runoff from Nags Head Village, but concentrations are considerably less than in the ditches.

RECOMMENDATIONS FOR ADDRESSING IMPAIRMENTS, POTENTIAL IMPACTS AND UNDOCUMENTED WATER BODIES

A major gap in the existing information regarding Cape Hatteras National Seashore water quality is the complete lack of information on the quality of Ocracoke Island's fresh and brackish water resources. These include the seven tidal creeks intersecting Highway 12, the vast brackish marsh near South Point Road, the freshwater marsh near the northern end of the island in the vicinity of the ferry terminal, and the temporary ponds that are likely important local ecosystems. We recommend that these systems be sampled for standard water quality parameters (water temperature, dissolved oxygen, pH, salinity, turbidity, fecal coliform bacteria, total nitrogen, ammonium, nitrate, total phosphorus, orthophosphate, BOD5 and chlorophyll *a*) on at least six occasions within a year's time. While the water quality of the sounds to the west of the Park are not currently being monitored by the North Carolina Division of Water Quality, we feel that it would be most productive for the Park to sample the tidal creeks, since that is where any Park-derived pollutants would be most concentrated.

Another high priority item would be to perform a resampling of the drainage ditches on south Bodie Island in the northern area of the park. The last sampling effort occurred ten years ago, and was only for nitrogen. Population has increased in the area and impacts to the Park's water resources are likely to have increased as well. These ditches include those carrying surface and shallow groundwater from east to west through the Park, and the ditch draining Nags Head surface water into the ocean at the beach at Ramp 1. We recommend that these systems be sampled for standard water quality parameters (water temperature, dissolved oxygen, pH, salinity, turbidity, fecal coliform bacteria or enterococcus bacteria, total nitrogen, ammonium, nitrate, total phosphorus, orthophosphate, BOD5 and chlorophyll *a*) on at least six occasions within a year's time. Less than six occasions would not be sufficient to capture seasonal effects impacting water quality parameters (more than six would certainly be better). Since these ditches are exposed to seasonally high traffic, it would also be prudent to sample them for toxic compounds that characterize automobile byproducts and urban runoff, such as polycyclic aromatic hydrocarbons (PAHs) and EPA priority pollutant metals. An updated septic system survey is needed to define present pollutant loadings into Park ditches and wetlands.

Selected drainage ditches on Hatteras Island (south beach discharge, Peter's Ditch) contain Park areas in their watersheds, and enter either the beach or Sound waters. The quality of these runoff waters is presently unknown, and information is needed to assess receiving water impacts and the effects of drainage manipulations. We recommend that these ditches be sampled for standard water quality parameters (water temperature, dissolved oxygen, pH, salinity, turbidity, fecal coliform bacteria, enterococcus bacteria, total nitrogen, ammonium, nitrate, total phosphorus, orthophosphate, BOD5 and chlorophyll *a*) on at least six occasions within a year's time.

Overall, we found a lack of good quality, up-to-date maps that show the key aquatic features including fresh and brackish wetlands, tidal creeks, ponds and major ditches on all of the Park's islands. Clearly, a high priority for the Park should be to produce a series of such maps (that can be electronically transferred) for Ocracoke, Hatteras, Pea and Bodie Islands. To do so will likely necessitate additional wetlands / hydrological delineations on-site, and possibly aerial photography specific toward that purpose. This can be accomplished under the umbrella of a "wetlands management survey".

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, southward drift from the Chesapeake Bay region or as invasive species from ship ballast water discharged near the Port of Morehead City. A much more possible scenario is the formation of the native toxic dinoflagellates *Pfiesteria piscicida* or *P. shumwayii* in estuarine areas that receive nutrients from the developed areas north of the park on Bodie Island or near the villages adjacent to the park on Hatteras and Ocracoke Islands. Thus, we recommend that Cape Hatteras 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, including tidal creeks. 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.

Phragmites is a non-native marsh plant becoming abundant in some Park areas. A survey of its presence and potential for its spread would be a useful endeavor. This can be undertaken as part of a wetlands management survey.

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As the nation’s principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the 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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