



Assessment of Estuarine Water Quality at Cape Hatteras and Cape Lookout National Seashores

2015 Data Summary

Natural Resource Data Series NPS/SECN/NRDS—2016/1056



ON THE COVER

Low salt marsh on Shackleford Banks. View is looking eastward across Back Sound to South Core Banks.
Photo courtesy of Jason Gardner—Southeast Coast Network.

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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Contents

	Page
Figures	iv
Tables	v
Summary and Key Findings	vi
Introduction	1
Study Area	2
Cape Lookout National Seashore	2
Cape Hatteras National Seashore	3
Methods	8
Water-Quality Data Collection	8
Water-Quality Assessment Criteria	8
Results	9
Parameter-Based Condition Assessments	9
Water-Quality Data	16
Literature Cited	17

Figures

	Page
Figure 1. Map of Cape Hatteras National Seashore in 2015, showing the location of the SECN fixed water-quality monitoring station.	4
Figure 2. Map of Cape Lookout National Seashore in 2015, showing the location of the SECN fixed water-quality monitoring stations.	5
Figure 3. Map showing the location of coastal assessment sites sampled in July 2015 in the vicinity of Cape Hatteras and Cape Lookout National Seashores.	7
Figure 4. Turbidity measurements and quartiles measured in the vicinity of Cape Hatteras and Cape Lookout National Seashores in July 2015.	10
Figure 5. Chlorophyll <i>a</i> concentrations at sampling sites in the vicinity of Cape Hatteras and Cape Lookout National Seashores in July 2015.	11
Figure 6. Dissolved inorganic nitrogen concentrations at sampling sites in the vicinity of Cape Hatteras and Cape Lookout National Seashores in July 2015.	12
Figure 7. Dissolved inorganic phosphorus concentrations at sampling sites in the vicinity of Cape Hatteras and Cape Lookout National Seashores in July 2015.	13
Figure 8. Dissolved oxygen concentrations at sampling sites in the vicinity of Cape Hatteras and Cape Lookout National Seashores in July 2015.	14
Figure 9. Water-quality index rating at sampling sites in the vicinity of Cape Hatteras and Cape Lookout National Seashores in July 2015.	15

Tables

Page

Table 1. Map ID, waterbody names and locations, depth, coordinates, and chemical and physical attributes of sampling sites in the vicinity of Cape Hatteras and Cape Lookout National Seashores, July 2015.	6
Table 2. Coastal water-quality monitoring condition criteria for water-quality parameters collected by the Southeast Coast Network.	8
Table 3. Condition criteria used for water-quality assessment summaries at individual sampling sites and parks.	9
Table 4. Water-quality parameter values and assessment conditions for sampling sites in the vicinity of Cape Hatteras and Cape Lookout National Seashores in July 2015.	16

Summary and Key Findings

In July 2015 the Southeast Coast Network conducted an assessment of water quality in the vicinity of Cape Hatteras and Cape Lookout National Seashores as part of the National Park Service Vital Signs Monitoring Program.

Monitoring was conducted following methods developed by the Environmental Protection Agency (EPA) as part of the National Coastal Assessment Program (EPA 2009). Laboratory analysis measured chlorophyll *a* and total and dissolved concentrations of nitrogen and phosphorous. Field measurements included water temperature, pH, dissolved oxygen, and salinity. Water clarity, which requires a Secchi depth measurement, was calculated when possible. Because waters were often too shallow to effectively obtain an accurate Secchi depth measurement, turbidity measurements are also presented. All measured parameters were rated as good, fair, or poor based on thresholds set by the EPA (2012).

- Water clarity was not calculated at all sites due to the shallow depth of the seashore waters. Turbidity measurements ranged from 2.7 to 10.9 Formazin Nephelometric Units (FNU), and are good according to North Carolina state standards..
- Chlorophyll *a* concentrations were rated good at 24 sites (80%). Six sites (20%) sampled in 2015 were rated fair.
- Dissolved nutrient concentrations were good across the assessed area with dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) concentrations rated good at all 30 sites.
- Dissolved oxygen levels were rated good at 97% of sites (29 of 30 sites) and fair at 3% (one site).
- A water-quality condition summary index was calculated for each site sampled in Cape Hatteras and Cape Lookout National Seashores based on the categorical assessments of chlorophyll *a*, DIN and DIP concentrations, and dissolved oxygen. This summary index indicated good water-quality conditions at 93% of sites (28 of 30) and fair conditions at two sites (7%).
- Although water-quality conditions were rated as good at most sites, two sites near Manteo exhibited fair but degrading conditions, with elevated total nitrogen, and chlorophyll *a* concentrations, and low water-clarity conditions.

Introduction

Water resources are important to park management from ecological, regulatory, and visitor experience perspectives; therefore, estuarine water quality in and around parks was selected as one of several vital signs to be monitored by the National Park Service (NPS) Inventory and Monitoring (I&M) Program (DeVivo et al. 2008). Data collected as a part of this effort are intended to foster a better understanding of water resources in and around parks and contribute to a better understanding of park ecological processes and physical systems (Gregory et al. 2013).

To effectively monitor a diverse and dynamic set of estuarine water resources, the NPS Southeast Coast I&M Network (SECN) implemented a two-pronged monitoring approach, which consists of collecting periodic discrete and continuously recorded data from fixed stations located in each park combined with periodic synoptic assessments of water quality at a larger spatial scale in the waters surrounding park areas (Gregory et al. 2013). When implemented together, these approaches give a more complete picture of physical processes, diurnal and seasonal variations, and spatial patterns during critical portions of the year.

The network identified four specific monitoring objectives for which data are collected and analyzed as part of this effort (Gregory et al. 2013):

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

This report summarizes coastal water-quality monitoring data collected during a synoptic assessment to address objective 3 at Cape Hatteras and Cape Lookout National Seashores. Data was gathered from 24 July to 29 July 2015. The purpose of this document is to report the most recently collected data from within the seashores as part of an ongoing long-term water-quality monitoring program. This report was designed to provide water-quality monitoring data to managers as a concise summary in the context of applicable federal standards developed by the EPA. A previous synoptic assessment of water-quality conditions at Cape Hatteras and Cape Lookout National Seashores was conducted in July 2010 as part of I&M monitoring efforts (Gregory and Smith 2011).

Study Area

Estuaries are semi-enclosed coastal water bodies with free connection to the open sea, wherein sea water and fresh water mix. As a key defining feature, estuaries are at the interface of sea water and fresh water, which come together in a dynamic relationship created by ocean tides. Estuaries contain critical habitat for a variety of fish and wildlife species. They serve as nursery habitats for fish, crustaceans, and shellfish and foraging habitat for birds and mammals, while providing a multitude of recreational opportunities such as boating, fishing, and bird watching.

Estuarine ecosystems are vulnerable to impacts from various sources, including urban and industrial development. Severe impacts include: alterations to hydrodynamic processes; exposure to levels of chemical contaminants that cause mortality, altered growth, and reduced reproduction; and exposure to more frequent and severe hypoxia (Lerberg et al. 2000). Some nutrient inputs to coastal waters are natural and necessary for a healthy, functioning estuarine ecosystem; however, when nutrients from various sources—such as sewage and fertilizers—are introduced into an estuary, the concentration of available nutrients will increase beyond natural background levels. This increase in the rate of supply of organic matter may result in undesirable water-quality conditions, including increased chlorophyll, decreased water clarity, and lower concentrations of dissolved oxygen. In addition, macrobenthic communities in impacted areas are often characterized by low diversity, low numbers of rare and pollution-sensitive species, and low abundances (Lerberg et al. 2000). In areas with increased impervious cover, stormwater runoff is flashier and occurs in greater volumes than in undeveloped areas. This unnatural runoff is often polluted with a wide variety of low-level contaminants that are released into estuaries and can accumulate in sediment (Holland et al. 2004).

Cape Lookout and Cape Hatteras National Seashores are adjacently located and separately maintained park units along the Outer Banks of the North Carolina coast, stretching from Beaufort Inlet on the south to Bodie Island on the north. Together these parks encompass over 59,000 acres of beaches, upland maritime forests, tidal creeks and salt marshes. Cape Lookout and Cape Hatteras National Seashores share a common geological history and are composed of a chain of transgressive and regressive barrier islands, formed during the Pleistocene glacial period from a large dune ridge which was located east of the Outer Bank's current location. The dune ridge gradually

migrated westward during the Holocene as sea levels rose until approximately 4000 years ago when wind, waves, and currents formed the present configuration of islands. All of these islands are subject to periodic inlet formation, migration, closure, and seawater overwash during severe storms (Mallin et al. 2004).

Cape Lookout National Seashore

Cape Lookout National Seashore includes approximately 24,500 acres of land and is composed of two main islands—Core Banks and Shackleford Banks (Figure 2). Cape Lookout National Seashore was authorized in 1966 and transferred to the National Park Service in 1976. Presently, its two main islands are solely used for recreational purposes. Shackleford Banks has no vehicle traffic and human use of the island consists of sport fishing, swimming, surfing, hiking, camping, and nature study. Core Banks supports these same activities, but vehicle traffic is permitted along the beaches, and there are some dirt roads in the interior of the islands.

Cape Lookout is bordered to the east and south by marine waters of the Atlantic Ocean. To the north and west of the seashore are the waters of Ocracoke Inlet, Pamlico Sound, Core Sound, and Back Sound. Some of the coves and tidal creeks on the sound side of the park may be of variable estuarine salinities, depending on local rainfall. Hunting, primarily for waterfowl, is also permitted in the park, except within the Portsmouth Village and Cape Lookout Village historic districts (Mallin et al. 2004).

The nearby coastal ocean and sound waters are heavily utilized by commercial fishermen as well as sport fishermen. Recreational fishermen employ both angling from boats and surf fishing along this seashore. Commercial fishermen utilize pound nets to target flounder, and trawl for shrimp and finfish. Menhaden are harvested by seines off the ocean beach and sometimes in the sounds.

Clam kicking (using outboard motors) and hydraulic dredging methods are occasionally used to harvest shellfish in the sound and have been shown to significantly reduce seagrass biomass and increase turbidity, although statistically significant reductions in bay scallop recruitment or pink shrimp abundance have not been documented in areas open to these types of mechanical harvest (Freeman 1988).

Major potential threats to water quality near Core and Shackleford Banks include two facilities discharging approximately 4.5 mgd of treated effluent into Taylors Creek (Mallin et al. 2004) located several kilometers from the seashore. Nonpoint pollution is not thought to be a problem due to the lack of large urban areas or concentrated livestock. Previous data collected from the western portion of Back and Core Sounds show waters that contain low average nitrate-N and moderate total phosphorus (TP) concentrations (Mallin et al. 2004).

Cape Hatteras National Seashore

Cape Hatteras National Seashore contains 35,400 acres of land, and includes a series of barrier islands known as Bodie Island, Hatteras Island, and Ocracoke Island (Figure 1). The establishment of Cape Hatteras National Seashore was authorized in 1937 and was officially designated a national seashore in 1953. Presently, the towns adjacent to the seashore 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. 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 bacteria loads on groundwater, because all sewage on the islands is treated by septic systems (Mallin et al. 2004).

Sport fishing boats launch from Oregon and Hatteras Inlets and travel to 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 harvested by haul seine off the ocean beach and sometimes in the sounds. 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 (Mallin et al. 2004).

Previous research has documented potential nutrient and pathogen problems in waters near Bodie Island near Nags Head. The waters of Pamlico Sound near Hatteras Island and adjoining municipal areas that drain into the sound are potential areas for nutrient and bacterial pathogen loading and algal blooms (Mallin et al. 2004). At Ocracoke Island, the waters of Pamlico Sound—at least in areas remote from local and mainland nutrient sources—are not considered likely to have algal blooms.

Cape Hatteras National Seashore Significant Waters Map

Southeast Coast Network
National Park Service
U.S. Department of the Interior

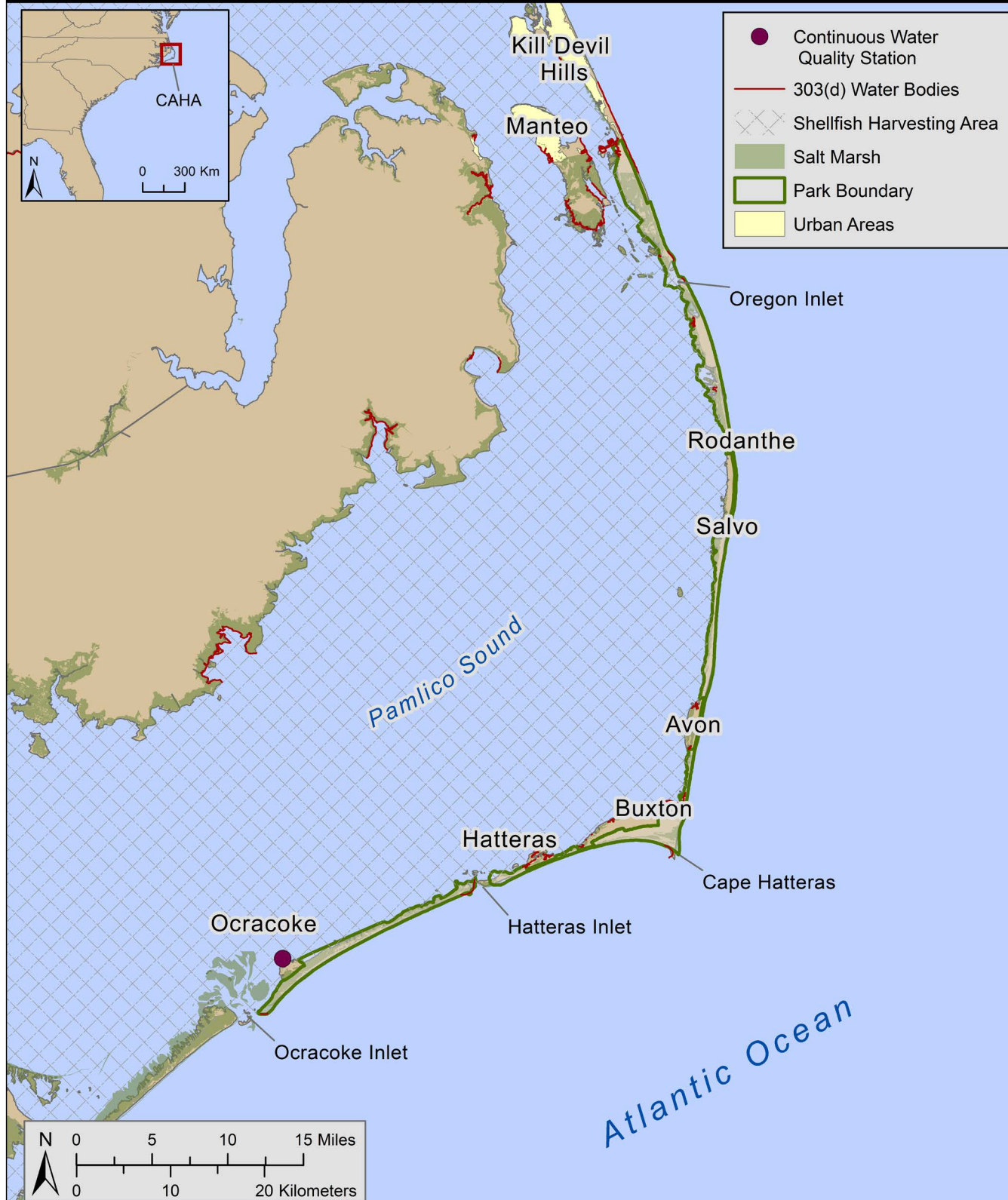


Figure 1. Map of Cape Hatteras National Seashore in 2015, showing the location of the SECN fixed water-quality monitoring station. The map also indicates areas of salt marsh (USFWS 2016), urbanization (US Census Bureau 2016), 303(d) listed water bodies (EPA 2016), and areas designated as having special uses or restrictions (NC OneMap 2016).

Cape Lookout National Seashore Significant Waters Map

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National Park Service
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Figure 2. Map of Cape Lookout National Seashore in 2015, showing the location of the SECN fixed water–quality monitoring stations. The map also indicates areas of salt marsh (USFWS 2016), urbanization (US Census Bureau 2016), 303(d) listed water bodies (EPA 2016), and areas designated as having special uses or restrictions (NC OneMap 2016).

Table 1. Map ID, waterbody name and location, depth, coordinates, and chemical and physical attributes of sampling sites in the vicinity of Cape Hatteras and Cape Lookout National Seashores, July 2015. The table cross-references official site names and Map ID numbers used to present data in this report (Figure 3). All coordinates are in NAD83 Datum, in UTM zone 18. Salinity, pH, water temperature, and dissolved oxygen were measured at a depth of 0.5 meters [DO—dissolved oxygen; SAV—sub-aquatic vegetation].

ID	Water Body	Site Depth (m)	UTMX	UTMY	Site Name	Water Temp (°C)	SAV	Debris	pH	DO (mg/L)	Salinity (ppt)
01	Pamlico Sound	0.98	445010	3969262	CALOCAHA-44	26.8	Y	N	8.80	9.7	7.3
02	Pamlico Sound	0.66	445845	3966711	CALOCAHA-58	26.6	N	N	8.76	10.2	8.1
03	Pamlico Sound	0.68	452587	3955841	CALOCAHA-51	27.3	Y	N	8.03	7.3	30.7
04	Pamlico Sound	0.75	452969	3954893	CALOCAHA-56	26.8	Y	N	8.15	8.1	27.1
05	Pamlico Sound	0.71	453817	3951400	CALOCAHA-42	26.7	Y	N	8.97	13.2	22.0
06	Pamlico Sound	0.30	455902	3946367	CALOCAHA-47	28.2	Y	N	8.56	10.8	23.0
07	Pamlico Sound	0.46	456152	3944021	CALOCAHA-36	27.3	Y	N	8.62	10.1	25.1
08	Pamlico Sound	1.20	452436	3909335	CALOCAHA-48	26.9	Y	N	8.14	7.4	26.2
09	Pamlico Sound	0.98	452511	3905897	CALOCAHA-39	28.6	Y	N	8.22	7.9	27.1
10	Pamlico Sound	0.46	452875	3904421	CALOCAHA-59	27.1	Y	N	8.06	7.0	26.9
11	Pamlico Sound	0.74	440061	3898967	CALOCAHA-54	25.7	N	N	8.16	6.3	28.2
12	Pamlico Sound	0.61	432422	3895650	CALOCAHA-34	26.3	N	N	8.09	6.4	34.8
13	Pamlico Sound	0.60	419166	3889927	CALOCAHA-40	26.8	Y	N	8.26	9.7	27.7
14	Pamlico Sound	0.40	417753	3889802	CALOCAHA-55	26.6	Y	N	8.23	9.1	25.6
15	Pamlico Sound	0.42	415536	3888691	CALOCAHA-32	20.4	Y	Y	8.12	7.2	27.5
16	Core Sound near Ocracoke Inlet	0.53	401165	3881548	CALOCAHA-35	27.9	Y	N	8.03	6.7	32.8
17	Core Sound	0.51	398727	3878206	CALOCAHA-60	27.8	Y	N	8.19	8.3	29.1
18	Core Sound	0.36	399423	3877829	CALOCAHA-46	28.2	Y	N	8.17	9.0	30.7
19	Core Sound	0.43	394423	3872798	CALOCAHA-49	27.9	Y	N	8.25	8.3	32.8
20	Core Sound	0.46	392330	3871524	CALOCAHA-33	27.5	Y	N	8.31	8.3	31.5
21	Core Sound	0.36	387776	3865887	CALOCAHA-53	27.7	Y	N	7.90	4.8	32.3
22	Core Sound	0.49	382665	3862057	CALOCAHA-38	28.2	Y	N	8.22	8.4	34.9
23	Core Sound	0.39	374559	3854600	CALOCAHA-41	28.2	Y	N	8.21	8.9	26.6
24	Core Sound near Hoise Island	0.17	374228	3853164	CALOCAHA-45	28.4	Y	N	7.98	10.0	38.9
25	Core Sound	0.58	368109	3847642	CALOCAHA-57	27.9	Y	Y	8.00	6.9	37.9
26	Core Sound	0.61	367529	3845050	CALOCAHA-43	28.2	Y	N	8.00	6.1	37.4
27	Back Sound near Middle Marshes	1.54	348428	3840726	CALOCAHA-50	27.4	N	N	8.08	6.6	36.3
28	Back Sound	1.68	358368	3836479	CALOCAHA-52	27.4	Y	N	8.06	6.1	36.8
29	Back Sound	0.87	359748	3836170	CALOCAHA-37	27.5	Y	N	8.03	6.1	36.8
30	Back Sound	0.61	358676	3835489	CALOCAHA-31	27.4	Y	N	8.04	6.7	36.8

Cape Hatteras and Cape Lookout National Seashores 2015 Coastal Assessment Sampling Sites

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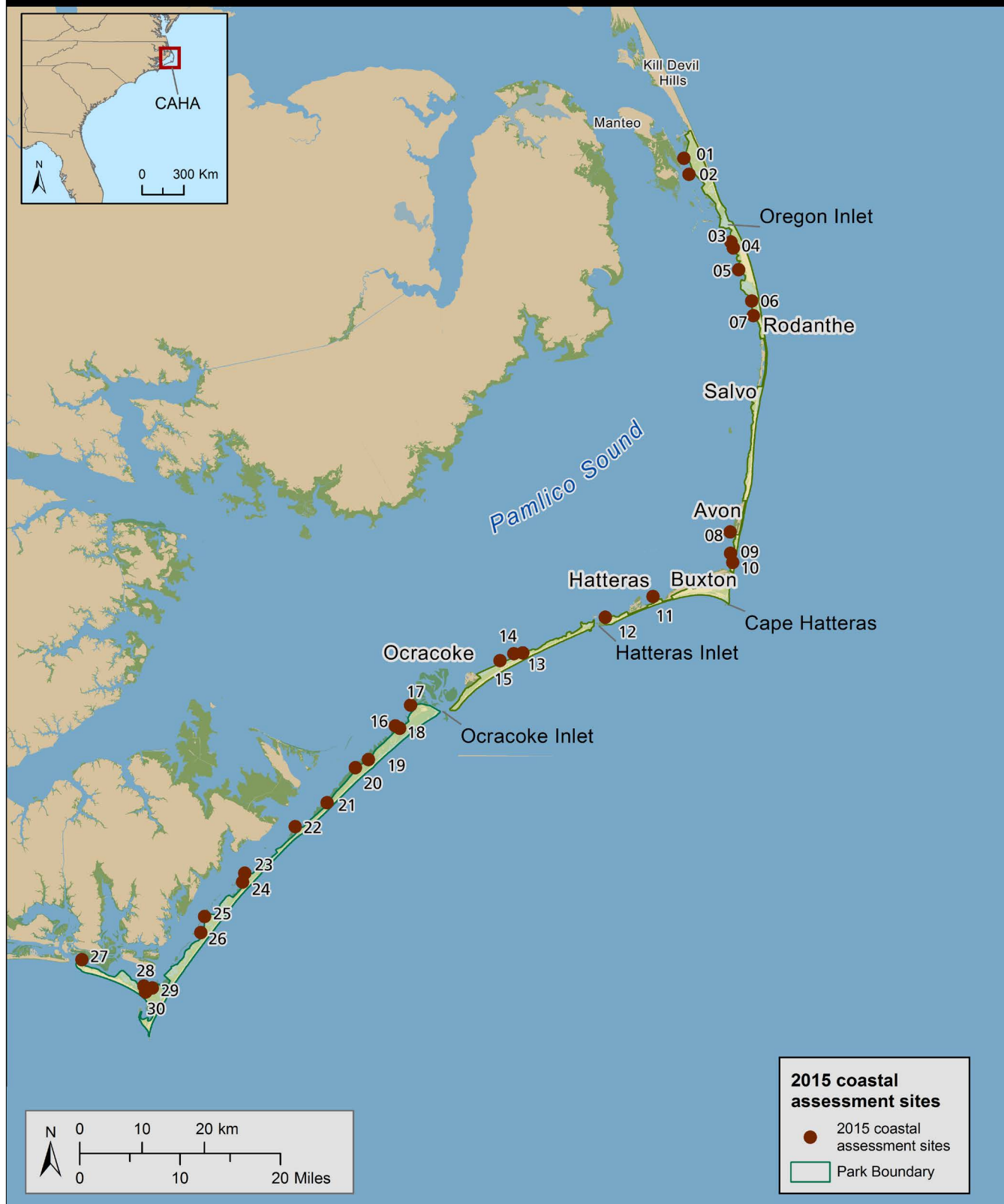


Figure 3. Map showing the location of coastal assessment sites sampled in July 2015 in the vicinity of Cape Hatteras and Cape Lookout National Seashores.

Methods

The water-quality assessment was conducted in estuarine and tidal creek waters in the vicinity of the seashores, following the methods developed by the Environmental Protection Agency (EPA) National Coastal Assessment Program (EPA 2009). Descriptions of the water-quality parameters and the assessment criteria are from the EPA National Coastal Assessment IV Report (EPA 2012). Methods used for these assessments were partially adapted and integrated into protocols tailored specifically to parks in the Southeast Coast Network (Gregory et al. 2013). Site selection and sampling methodology are briefly outlined in the following sections.

Thirty sites in the seashore’s waters were randomly selected for monitoring following methods developed by the EPA (Table 1, Figure 3) (Stevens 1997; Stevens and Olsen 1999; Stevens and Olsen 2004). A pool of alternate sites was selected in case any of the original sites were not accessible. This method of randomly selecting spatially balanced sites provides managers with a statistically valid estimate of the overall conditions of the assessed resource within or around the park.

Water-Quality Data Collection

The water-quality assessment conducted during this sampling period incorporated hydrographic profiles at 0.5–1.0 meter intervals at each site, to measure temperature, pH, dissolved oxygen, and salinity. Chlorophyll *a* levels were measured concurrently, and total and dissolved nutrient samples were collected from 0.5 meters below the surface. Chlorophyll *a* samples were processed using known volumes of water samples that were filtered onto glass-fiber filters

then refrigerated and submitted for laboratory analysis. Water clarity was estimated at each site using a Secchi disk to estimate light extinction depths, which were converted to light attenuation coefficients and corrected for naturally occurring turbidity conditions (Smith et al. 2006). Water clarity was not assessed at sites too shallow to ascertain an accurate Secchi depth measurement. When sites were too shallow to access by boat, alternate sites were used.

Water-Quality Assessment Criteria

The categorical assessments (e.g., good, fair, poor) use measurements of chlorophyll *a*, nutrients, dissolved oxygen, and water clarity (Table 2) and are intended to characterize acutely degraded water-quality conditions. The assessments do not consistently identify sites that experience occasional or infrequent hypoxia, nutrient enrichment, or decreased water clarity. Therefore, a rating of poor for the water-quality index means that the site likely exhibited consistently poor conditions before or after the assessment period. If a site is designated fair or good, the site did not experience poor conditions on the date of sampling; however, the site could be characterized by poor conditions for short time periods.

Site assessments were also made using an index that combines the ratings for each parameter into a site-specific water-quality index rating. This index allows for general comparisons between sites in a park (Table 3) and can be used to summarize overall conditions in the waters around a park. This rating also allows general comparisons between parks based on the percentage of sites that fall within the good, fair, or poor categories.

Table 2. Coastal water-quality monitoring condition criteria for water-quality parameters collected by the Southeast Coast Network. Based on thresholds set by the EPA (2012) [µg/L—micrograms per liter; mg/L—milligrams per liter].

Rating	Water Clarity (<i>k</i>) ¹	Chlorophyll <i>a</i> (µg/L)	Dissolved Inorganic Nitrogen (DIN) (mg/L)	Dissolved Inorganic Phosphorus (DIP) (mg/L)	Dissolved Oxygen (mg/L)
Good	<1.61	<5	<0.1	<0.01	>5
Fair	1.61–2.30	5–20	0.1–0.5	0.01–0.05	2–5
Poor	>2.30	>20	>0.5	>0.05	<2

¹ The sites assessed in the estuarine waters of Cape Hatteras and Cape Lookout National Seashores were too shallow to effectively measure Secchi depth; thus, water clarity was not calculated for this synoptic study.

Results

Parameter-Based Condition Assessments

Figures 4–8 illustrate the spatial distribution of sampling sites and the corresponding ratings for turbidity, chlorophyll *a*, dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), and dissolved oxygen (DO) based on each parameter's corresponding condition category. Inset graphs on Figures 4–8 show the proportion of sites in the assessed area that were placed in each rating category. The map and graph in Figure 9 summarize seashore-wide water quality. Site-specific water-quality data for each parameter are also presented in Table 4.

- Water clarity was not calculated at 26 sites due to the shallow depth of the seashore waters. Turbidity measurements ranged from 2.7 to 10.9 Formazin Nephelometric Units (FNU), and are considered good by North Carolina state water-quality standards.
- Chlorophyll *a* concentrations were rated good at 24 sites (80%). Six sites (20%) sampled in 2015 were rated fair.
- Dissolved nutrient concentrations were good across the assessed area with dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) concentrations rated good at all 30 sites.
- Dissolved oxygen concentrations were rated good at 97% of sites (29 of 30 sites) and fair at 3% (one site).
- A water-quality condition summary index was calculated for each site sampled in Cape Hatteras and Cape Lookout National Seashores based on the categorical assessments of chlorophyll *a*, DIN and DIP concentrations, and dissolved oxygen. This summary index indicated good water-quality conditions at 93% of sites (28 of 30) and fair conditions at two sites (7%).
- Based on the summary water-quality index rating for the seashore, overall water quality conditions in Cape Hatteras and Cape Lookout National Seashores in July 2015 were good.

Table 3. Condition criteria used for water-quality assessment summaries at individual sampling sites and parks.

Rating	Site Water Quality Index Rating	Park Water Quality Index Rating
Good	A maximum of one indicator is rated fair, and no indicators are rated poor.	Less than 10% of sites are in poor condition, and less than 50% of sites are in combined poor and fair condition.
Fair	One indicator is rated poor, or two or more indicators are rated fair.	10% to 20% of sites are in poor condition, or more than 50% of sites are in combined poor and fair condition.
Poor	Two or more of the five indicators are rated poor.	More than 20% of sites are in poor condition.
Missing	Two components of the indicator are missing and the available indicators do not suggest a fair or poor rating.	NA

Cape Hatteras and Cape Lookout National Seashores Relative Turbidity

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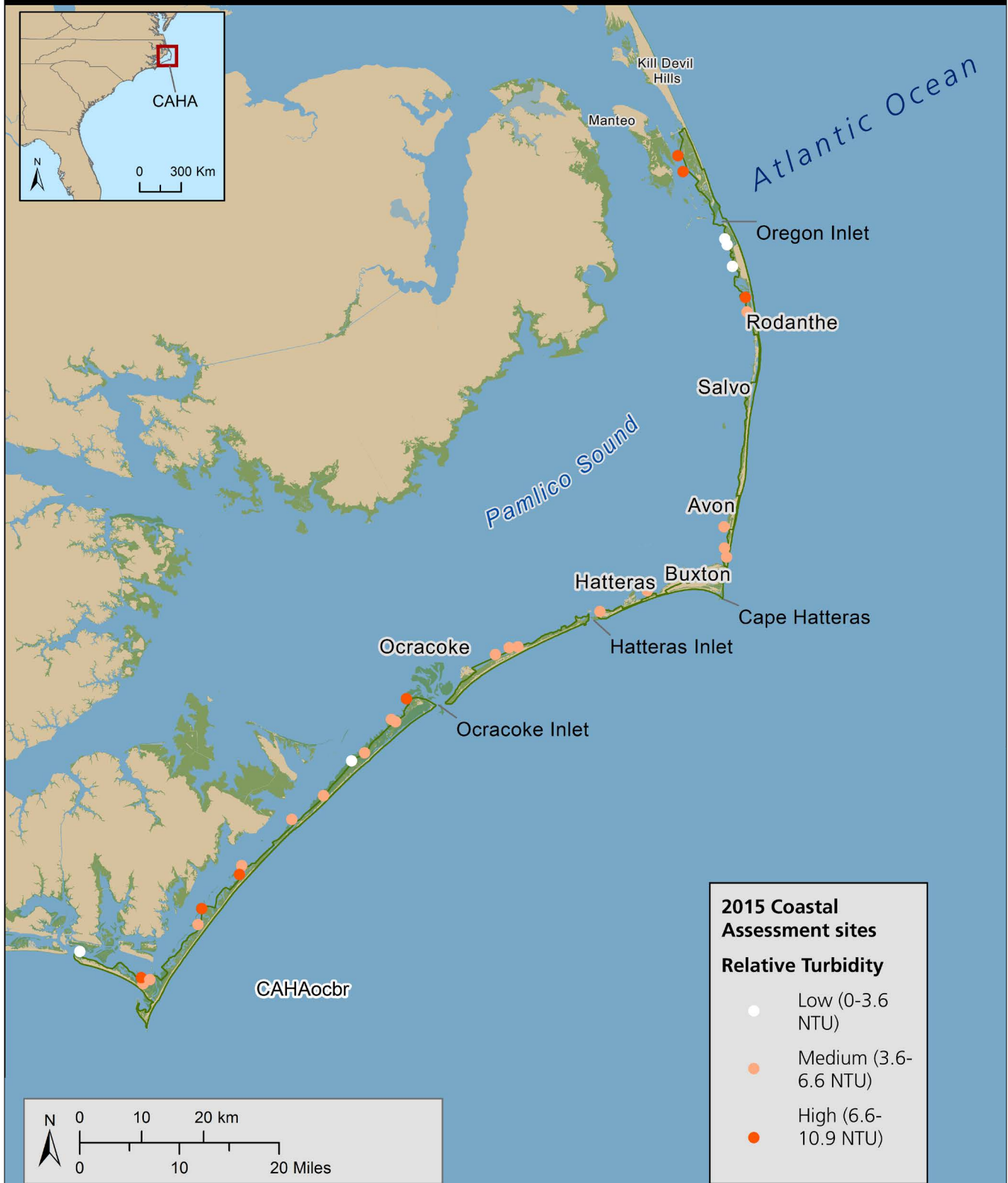


Figure 4. Relative turbidity measurements and quartiles measured in the vicinity of Cape Hatteras and Cape Lookout National Seashores in July 2015.

Cape Hatteras and Cape Lookout National Seashores Chlorophyll a

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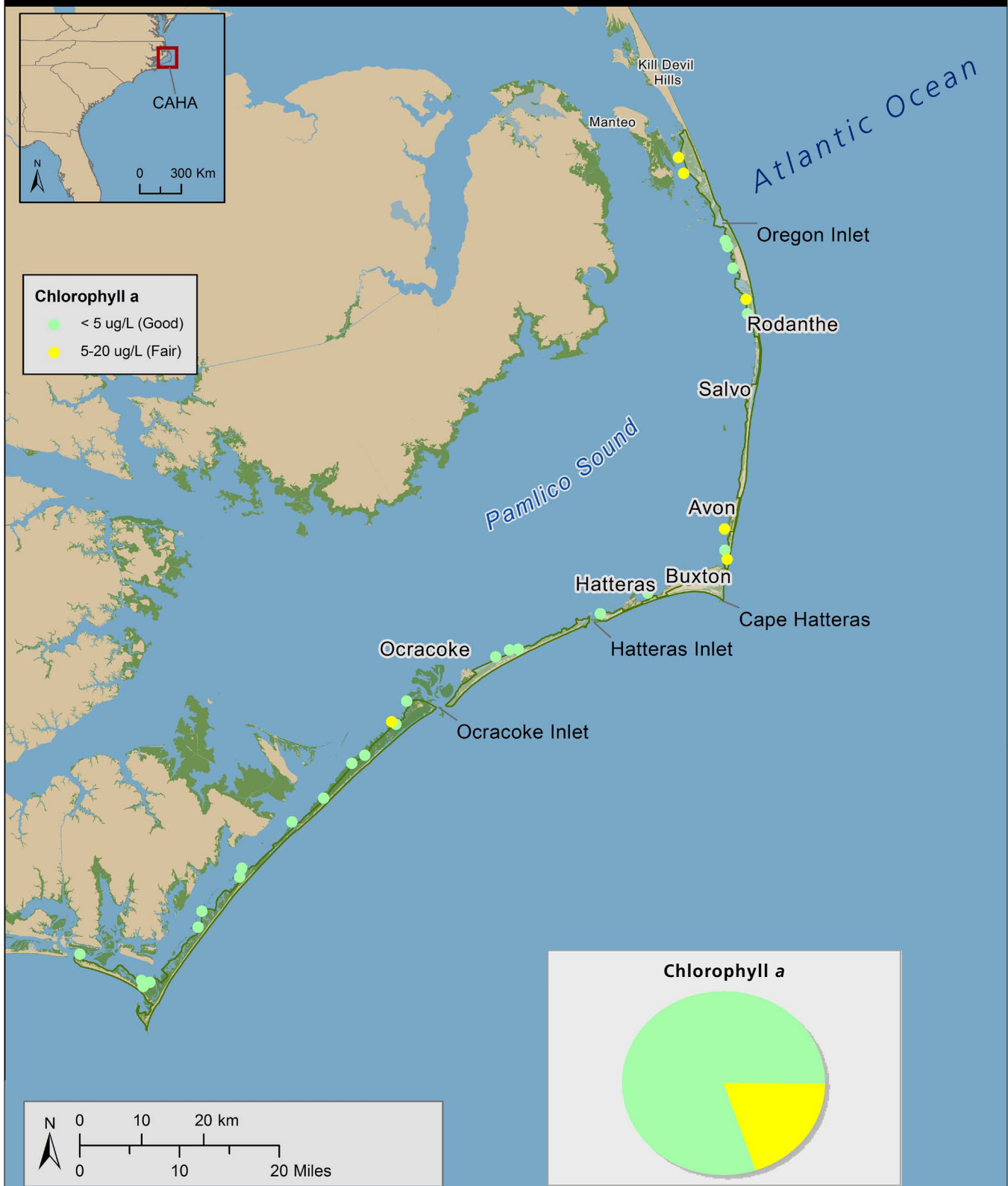


Figure 5. Chlorophyll a concentrations at sampling sites in the vicinity of Cape Hatteras and Cape Lookout National Seashores in July 2015. Inset graph shows the proportion of sites in each condition category [Green—good; yellow—fair; red—poor].

Cape Hatteras and Cape Lookout National Seashores Dissolved Inorganic Nitrogen

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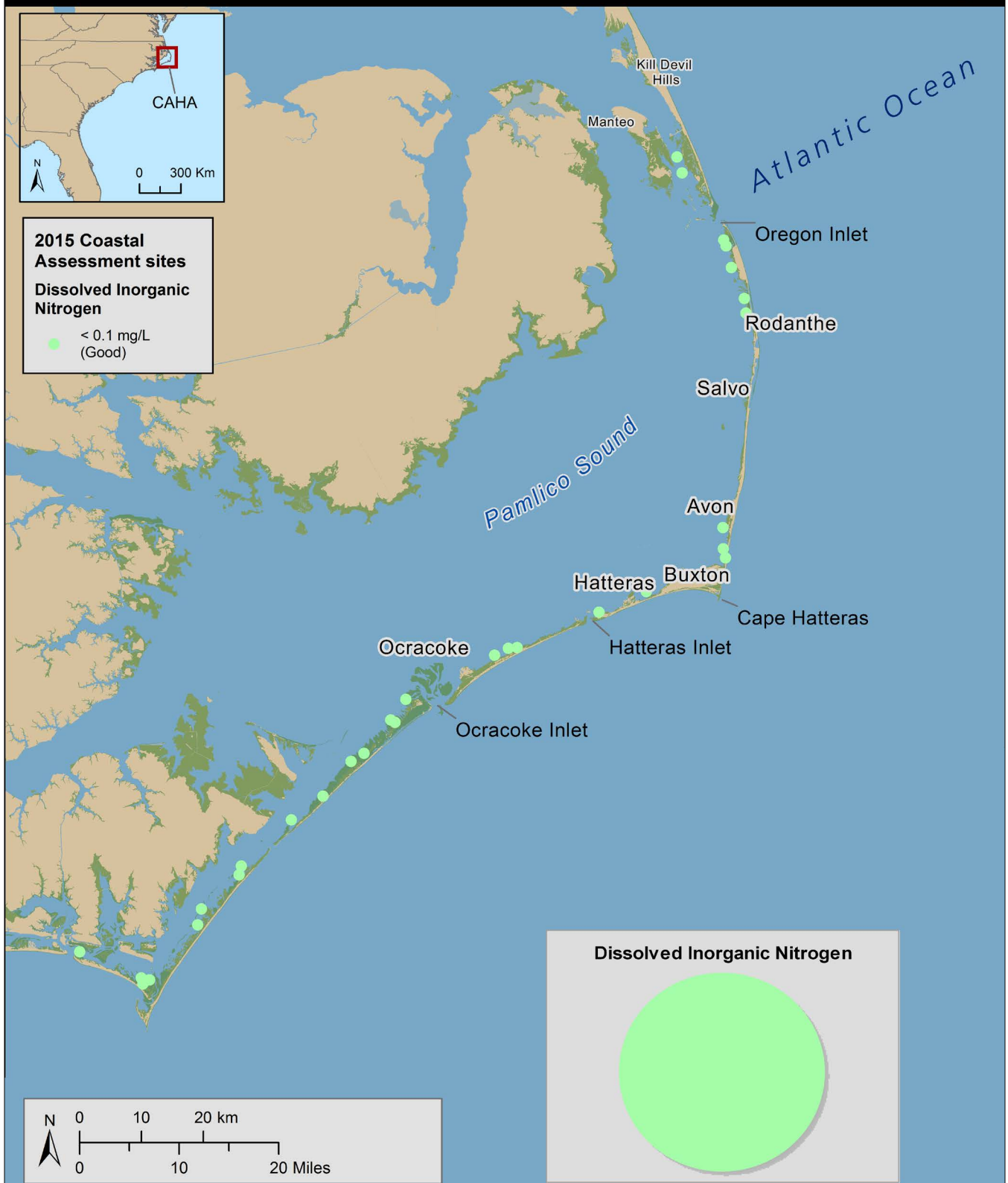


Figure 6. Dissolved inorganic nitrogen concentrations at sampling sites in the vicinity of Cape Hatteras and Cape Lookout National Seashores in July 2015. Inset graph shows the proportion of sites in each condition category [Green—good].

Cape Hatteras and Cape Lookout National Seashores Dissolved Inorganic Phosphorus

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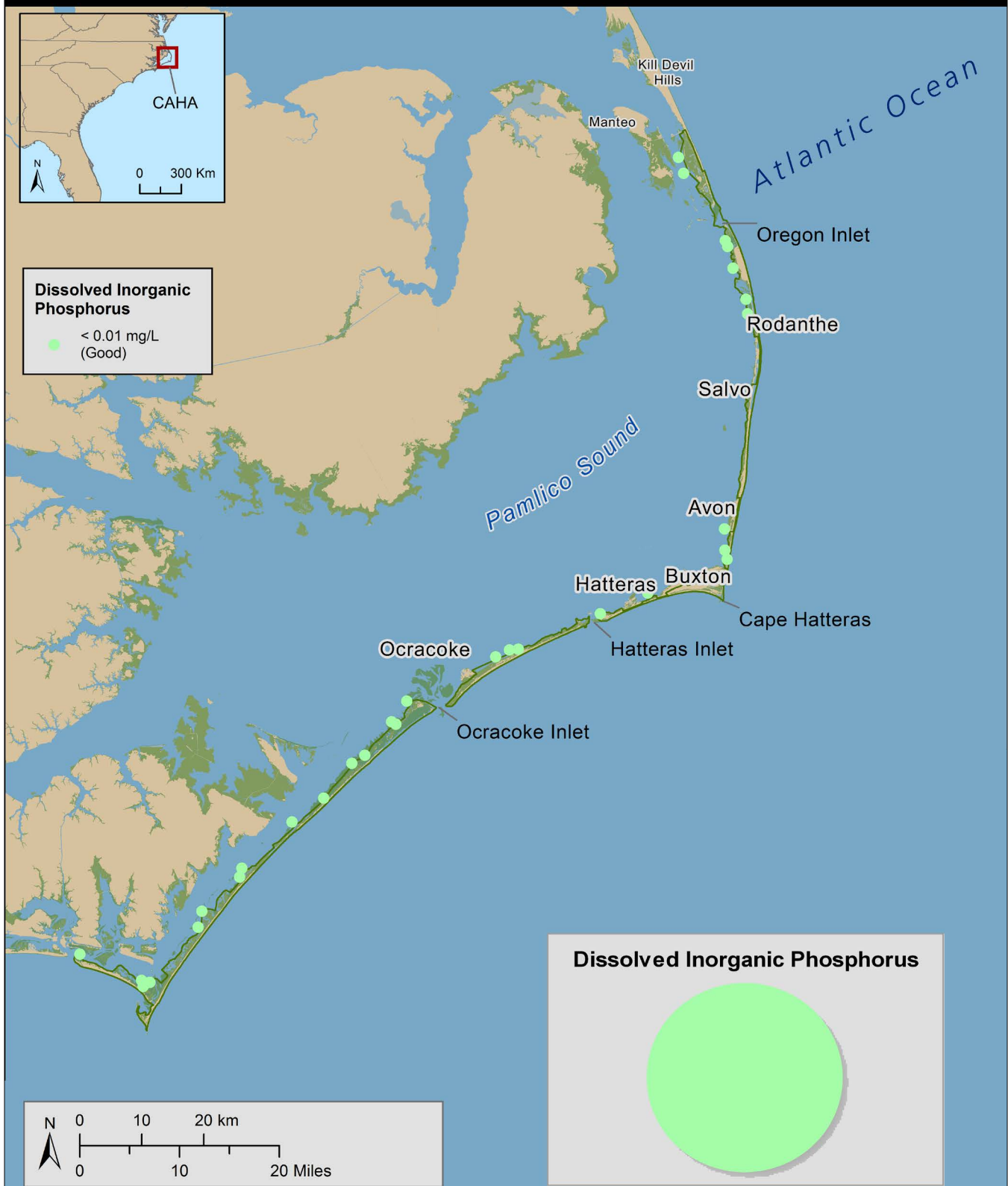


Figure 7. Dissolved inorganic phosphorus concentrations at sampling sites in the vicinity of Cape Hatteras and Cape Lookout National Seashores in July 2015. Inset graph shows the proportion of sites in each condition category [Green—good].

Cape Hatteras and Cape Lookout National Seashores Dissolved Oxygen

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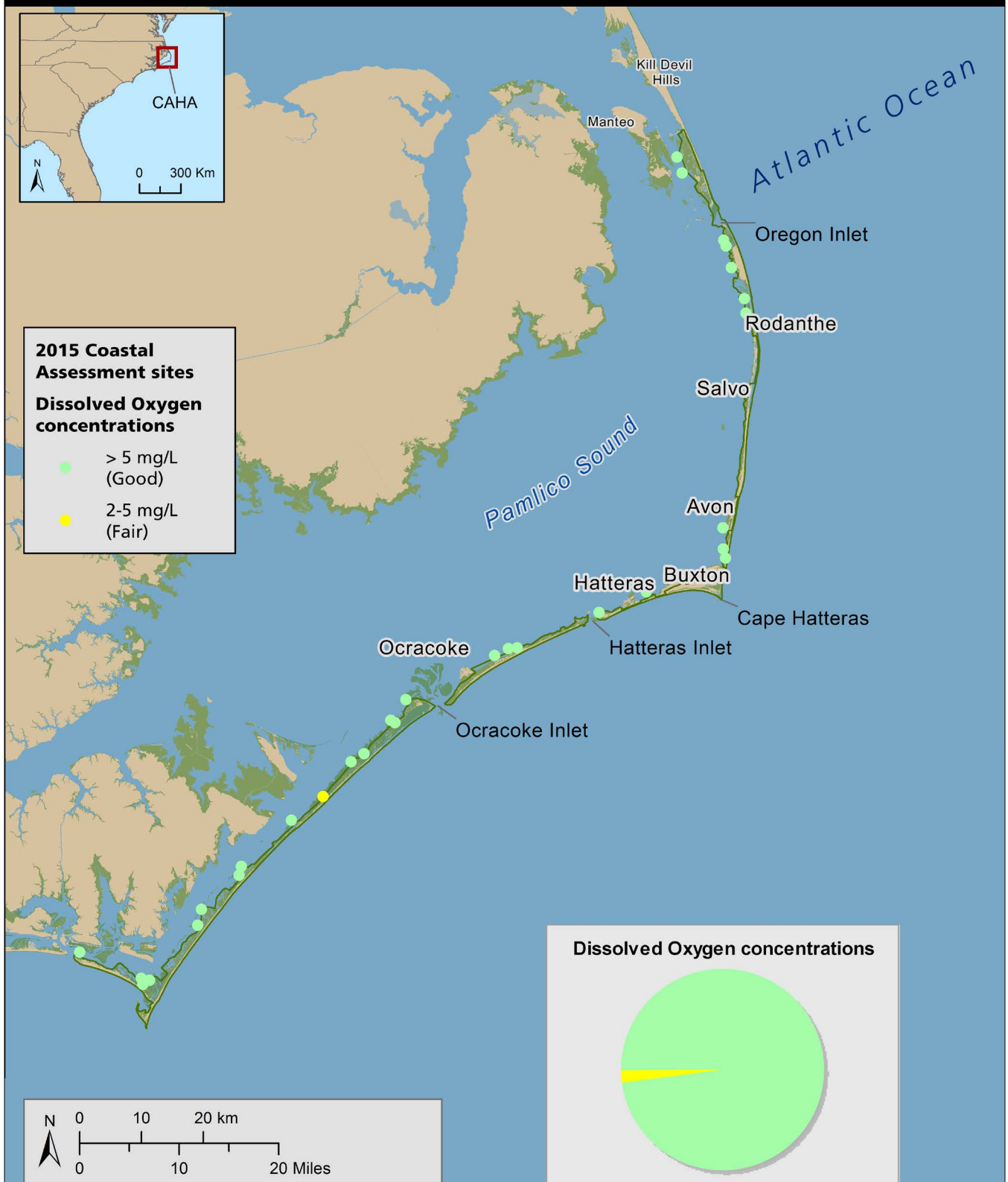


Figure 8. Dissolved oxygen concentrations at sampling sites in the vicinity of Cape Hatteras and Cape Lookout National Seashores in July 2015. Inset graph shows the proportion of sites in each condition category [Green—good; yellow—fair].

Cape Hatteras and Cape Lookout National Seashores Site Water Quality Rating

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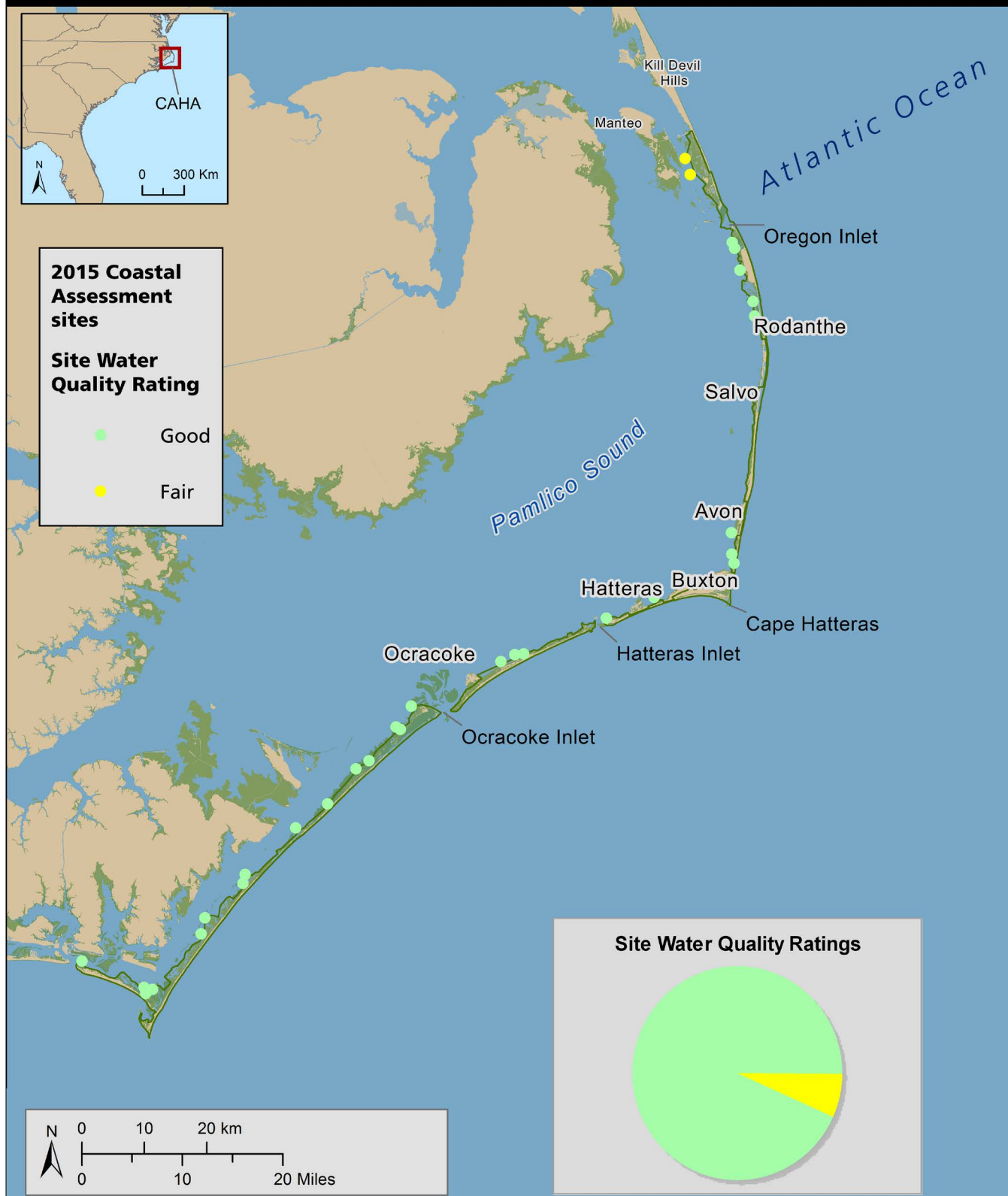


Figure 9. Water-quality index rating at sampling sites in the vicinity of Cape Hatteras and Cape Lookout National Seashores in July 2015. Inset graph shows the proportion of sites in each condition category [Green—good; yellow—fair].

Water-Quality Data

Table 4. Water-quality parameter values and assessment conditions for sampling sites in the vicinity of Cape Hatteras and Cape Lookout National Seashores in July 2015. Conditions of assessed parameters are from the EPA (2012) [Green^a—good; yellow^b—fair; red^c—poor; µg/L—micrograms per liter; N—Nitrogen; mg/L—milligrams per liter; P—Phosphorous].

Map ID	Water Clarity (k)	Turbidity ¹ (PPT)	Chlorophyll a (µg/L)	Dissolved Oxygen (DO, mg/L)	Dissolved Inorganic N (DIN, mg/L)	Dissolved Inorganic P (DIP, mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
01	2.33 ^c	8.39	17.8 ^b	9.7 ^a	0.011 ^a	0.0032 ^a	1.03	0.0388
02	2.80 ^c	8.70	20.0 ^b	10.2 ^a	0.012 ^a	0.0033 ^a	1.14	0.0513
03	--	2.82	1.5 ^a	7.3 ^a	0.007 ^a	0.0041 ^a	0.18	0.0196
04	--	3.59	4.0 ^a	8.1 ^a	0.011 ^a	0.0023 ^a	0.29	0.0253
05	--	3.26	1.8 ^a	13.2 ^a	0.011 ^a	0.0031 ^a	0.50	0.0229
06	--	10.86	7.1 ^b	10.8 ^a	0.030 ^a	0.0035 ^a	0.89	0.0573
07	--	6.00	2.7 ^a	10.1 ^a	0.014 ^a	0.0035 ^a	0.62	0.0297
08	1.27 ^a	4.36	5.5 ^b	7.4 ^a	0.013 ^a	0.0035 ^a	0.51	0.0366
09	--	4.06	4.2 ^a	7.9 ^a	0.009 ^a	0.0029 ^a	0.48	0.0284
10	--	4.91	8.3 ^b	7.0 ^a	0.007 ^a	0.0036 ^a	0.58	0.0521
11	--	4.01	3.9 ^a	6.3 ^a	0.007 ^a	0.0026 ^a	0.35	0.0294
12	--	5.83	2.3 ^a	6.4 ^a	0.009 ^a	0.0022 ^a	0.19	0.0199
13	--	3.88	2.4 ^a	9.7 ^a	0.011 ^a	0.0050 ^a	0.53	0.0189
14	--	3.93	3.3 ^a	9.1 ^a	0.009 ^a	0.0025 ^a	0.42	0.0236
15	--	5.93	3.9 ^a	7.2 ^a	0.010 ^a	0.0027 ^a	0.42	0.0247
16	--	9.18	3.5 ^a	6.7 ^a	0.027 ^a	0.0044 ^a	0.33	0.0371
17	--	5.72	5.1 ^a	8.3 ^a	0.006 ^a	0.0026 ^a	0.41	0.0394
18	--	6.06	3.6 ^a	9.0 ^a	0.014 ^a	0.0028 ^a	0.48	0.0351
19	--	5.45	3.2 ^a	8.3 ^a	0.011 ^a	0.0034 ^a	0.51	0.0373
20	--	3.6	2.3 ^a	8.3 ^a	0.010 ^a	0.0038 ^a	0.47	0.0251
21	--	3.91	3.2 ^a	4.8 ^b	0.018 ^a	0.0032 ^a	0.43	0.0298
22	--	6.04	3.9 ^a	8.4 ^a	0.012 ^a	0.0020 ^a	0.42	0.0393
23	--	5.17	2.0 ^a	8.9 ^a	0.010 ^a	0.0024 ^a	0.26	0.0254
24	--	7.56	3.0 ^a	10.0 ^a	0.012 ^a	0.0023 ^a	0.66	0.0581
25	--	7.21	2.1 ^a	6.9 ^a	0.017 ^a	0.0021 ^a	0.43	0.0285
26	--	6.56	2.4 ^a	6.1 ^a	0.013 ^a	0.0024 ^a	0.31	0.0264
27	--	2.68	1.3 ^a	6.6 ^a	0.007 ^a	0.0022 ^a	0.17	0.0167
28	1.12	7.34	2.6 ^a	6.1 ^a	0.007 ^a	0.0018 ^a	0.21	0.0246
29	--	5.41	2.9 ^a	6.1 ^a	0.006 ^a	0.0016 ^a	0.21	0.0220
30	--	5.97	2.1 ^a	6.7 ^a	0.024 ^a	0.0030 ^a	0.31	0.0322

Water clarity was not calculated at the majority of sites due to the shallow depth of the seashore waters. Turbidity measurements were used as a surrogate measurement at these sites.

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