



Assessment of Estuarine Water and Sediment Quality at Cape Hatteras National Seashore and Cape Lookout National Seashore *2021 Data Summary*

Natural Resource Data Series NPS/SECN/NRDS—2022/1373





ON THE COVER

Looking south into Pamlico Sound from site CAHA18_2021. NPS photo / SECN staff.

ON THIS PAGE

Preparing the boat for sampling. NPS photo / SECN staff.

Assessment of Estuarine Water and Sediment Quality at Cape Hatteras National Seashore and Cape Lookout National Seashore

2021 Data Summary

Natural Resource Data Series NPS/SECN/NRDS—2022/1373

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Summary and Key Findings

In July 2021 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 2010). 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 obtained when possible. All measured parameters were rated as good, fair, or poor based on thresholds set by the EPA (2012). 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 water in the sound. Of the sites where water clarity could be assessed (5 sites), four measured good and one fair. Sites that were too shallow to measure water clarity had water column conditions that did not preclude light from penetrating to the bottom of the water body so no ecological effects would be expected. Turbidity measurements ranged from 1.0 to 8.0 FNU (Formazin Nephelometric Units) and are good (i.e. < 25 NTU [Nephelometric Turbidity Units]) according to North Carolina Standards (NC Administrative Code 2019). Note that turbidity units of FNU and NTU are roughly equivalent.

- Chlorophyll *a* concentration was rated good at 29 sites (97%), and fair at one site (3%).
- Dissolved inorganic nitrogen (DIN) concentration was good at all 30 sites (100%).
- Dissolved inorganic phosphorus (DIP) concentration was good at all 30 sites (100%).
- Dissolved oxygen concentration (bottom) was rated good at all 30 sites (100%).
- A water-quality condition summary index was calculated for each site sampled at Cape Hatteras and Cape Lookout National Seashores based on the categorical assessments of chlorophyll *a*, DIN and DIP concentrations, dissolved oxygen, and water clarity. This summary index indicated good water-quality conditions at all thirty sites (100%).
- Based on the summary water-quality index rating, overall water-quality conditions at Cape Hatteras and Cape Lookout National Seashores during sampling in 2021 were good.
- For sediment, ecological condition was ranked as good at 30 sites (100%). As a result, no adverse impacts to benthic organisms due to sediment contamination are anticipated at any of the sampled sites. This ranking was assigned according to the 2010 Environmental Protection Agency, National Coastal Condition Assessment (NCCA) thresholds for sediment chemistry.



Site CAHA02_2021 at Pamlico Sound. NPS photo / SECN staff.

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 10 years.

This report summarizes coastal water-quality monitoring data collected during a synoptic assessment to address objectives 3 and 4 at Cape Hatteras and Cape Lookout National Seashores. Data were gathered from July 13–July 21, 2021. The purpose of this document is to report the most recently collected data from 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. Previous synoptic assessments of water-quality conditions at Cape Hatteras and Cape Lookout National Seashores were conducted in July 2010 and 2015 as part of I&M monitoring efforts (Gregory and Smith. 2011; Wright 2016).

Study Area

Cape Hatteras and Cape Lookout 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 (23,876 hectares [ha]) of beaches, upland maritime forests, tidal creeks and salt marshes. Cape Hatteras and Cape Lookout 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 4,000 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 Hatteras National Seashore

Cape Hatteras National Seashore contains 35,400 acres (14,326 ha) 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). 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 Lookout National Seashore

Cape Lookout National Seashore includes approximately 24,500 acres (9,915 ha) of land and is composed of two main islands— Core Banks and Shackleford Banks (Figures 2 and 3). 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.

Major threats to water quality near Core and Shackleford Banks include two facilities discharging approximately 4.5 mgd (millions of gallons per day) 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 Significant Waters Map

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

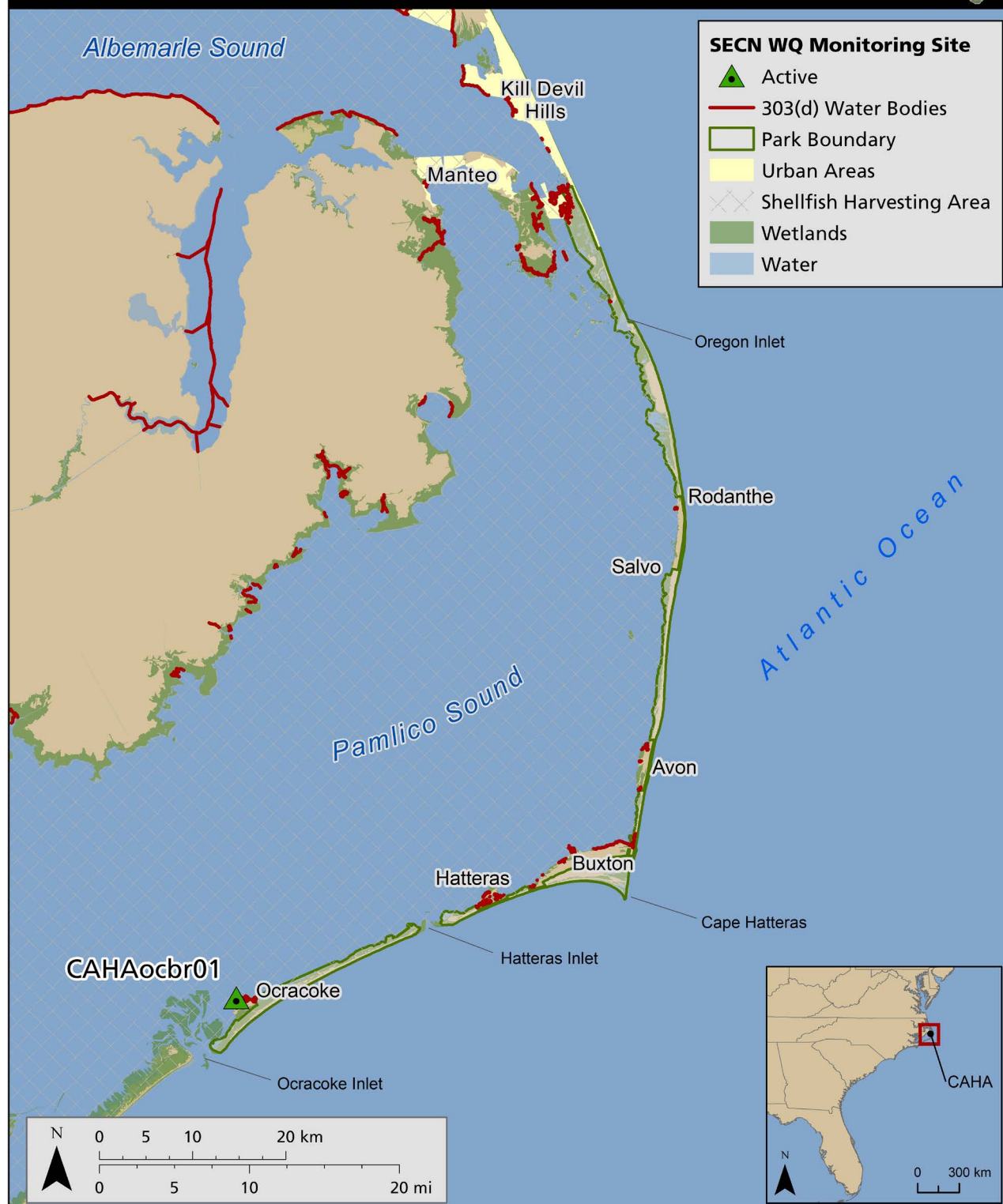


Figure 1. Map of fixed stations monitored by the Southeast Coast Network in Pamlico Sound, and significant waters in the vicinity of Cape Hatteras National Seashore, in 2021. Indicated are areas of salt marsh (FWS 2022), urbanized area (USCB 2022), 303(d) listed water bodies (EPA 2022), and areas designated as having special uses or restrictions such as shellfish harvest areas (NC DENR DEH-SSRWQS 2011).

Cape Lookout National Seashore Significant Waters Map

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

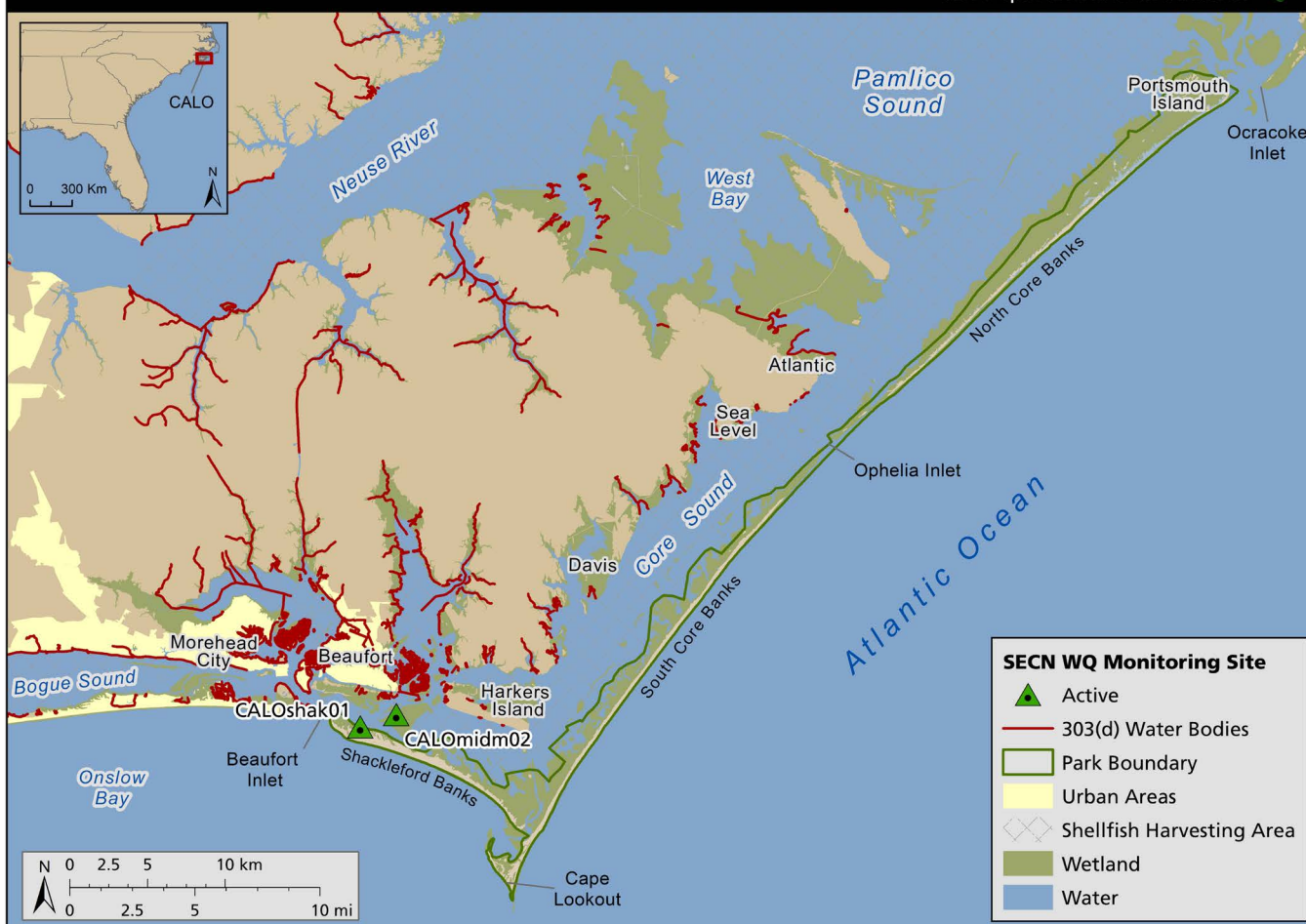


Figure 2. Map of fixed stations monitored by the Southeast Coast Network in Core Sound, and significant waters in the vicinity of Cape Lookout National Seashore, in 2021. Indicated are areas of salt marsh (FWS 2022), urbanized area (USCB 2022), 303(d) listed water bodies (EPA 2022), and areas designated as having special uses or restrictions such as shellfish harvest areas (NC DENR DEH-SSRWQS 2011).

Cape Hatteras and Cape Lookout National Seashores 2021 Parkwide Assessment Sites

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Figure 3. Map showing the location of coastal assessment sites sampled in July 2021 at Cape Hatteras and Cape Lookout National Seashores. See Table 1 for more information about each site.

Table 1. Site name, waterbody name and location, depth, coordinates, and chemical and physical attributes of sampling sites at Cape Hatteras and Cape Lookout National Seashores, July 13–21, 2021. All coordinates are in NAD83 Datum, in UTM zone 18. Salinity, pH, and water temperature measured at a depth of 0.5 meters unless water depth was too shallow, then it was measured at 0.1 meters. [SAV—sub-aquatic vegetation; m—meters; °C—Celsius; PSU—practical salinity units; FNU—Formazin Nephelometric Units].

Site Name	Water Body	UTMX	UTMY	SAV	Debris	Site Depth (m)	Sample Depth (m)	Water Temperature (°C)	pH	Salinity (PSU)	Turbidity (FNU)
CAHA01_2021	Pamlico Sound	454103	3946612	Yes	No	0.6	0.5	27.42	8.68	20.75	1.1
CAHA02_2021	Pamlico Sound	454532	3915626	Yes	No	0.9	0.5	29.32	8.34	22.48	1.4
CAHA06_2021	Roanoke Sound	446410	3965862	No	No	1.0	0.5	30.61	8.24	10.80	4.9
CAHA09_2021	Pamlico Sound	412399	3887256	No	No	1.5	0.5	29.25	8.20	27.05	2.2
CAHA10_2021	Pamlico Sound	441494	3899128	Yes	No	0.8	0.5	29.97	8.35	25.25	1.4
CAHA13_2021	Roanoke Sound	446990	3963392	Yes	No	0.6	0.1	31.06	8.59	14.88	8.2
CAHA14_2021	Pamlico Sound	452042	3907404	Yes	No	0.7	0.5	30.46	8.46	27.36	2.0
CAHA16_2021	Pamlico Sound	455242	3925163	Yes	No	1.1	0.5	28.10	8.34	21.74	1.2
CAHA17_2021	Pamlico Sound	455309	3929265	No	No	0.9	0.5	27.68	8.29	21.29	1.3
CAHA18_2021	Pamlico Sound	454793	3917731	Yes	No	0.6	0.1	28.63	8.33	21.68	1.2
CAHA22_2021	Pamlico Sound	456407	3940111	Yes	No	1.4	0.5	28.35	8.33	21.32	0.9
CAHA25_2021	Pamlico Sound	411772	3887587	No	No	2.5	0.5	28.86	8.17	26.63	2.9
CAHA26_2021	Hatteras Inlet	433698	3896347	No	No	0.5	0.1	28.49	8.17	34.90	2.1
CAHA29_2021	Pamlico Sound	455296	3944603	Yes	No	0.4	0.1	27.32	8.45	21.10	1.4
CAHA30_2021	Pamlico Sound	439636	3898597	Yes	No	0.4	0.1	29.74	8.25	26.47	3.3
CALO03_2021	Core Sound	361576	3839122	No	No	1.8	0.5	26.82	8.14	35.49	1.7
CALO04_2021	Core Sound	390564	3870184	Yes	No	0.9	0.5	28.05	8.30	33.46	1.6
CALO05_2021	Back Sound	351697	3839669	No	No	0.9	0.5	28.40	8.14	35.66	1.1
CALO07_2021	Back Sound	356932	3837768	No	No	1.7	0.5	27.42	8.10	35.35	3.3
CALO08_2021	Core Sound	387328	3865811	Yes	No	0.7	0.1	27.74	8.25	36.53	2.0
CALO11_2021	Core Sound	370011	3849595	Yes	No	0.8	0.5	27.10	8.19	35.70	1.4
CALO12_2021	Pamlico Sound	400090	3879116	Yes	No	0.7	0.1	28.59	8.30	26.62	1.9
CALO15_2021	Core Sound	362954	3840559	No	No	0.8	0.5	26.78	8.15	35.63	1.4
CALO19_2021	Back Sound	359818	3836986	Yes	No	0.6	0.1	28.25	8.20	35.16	1.9
CALO20_2021	Core Sound	393086	3872989	Yes	No	0.8	0.1	28.78	8.32	25.32	1.6
CALO21_2021	Back Sound	352157	3838448	No	No	2.5	0.5	28.05	8.15	35.29	1.8
CALO23_2021	Back Sound	355650	3839189	No	No	2.3	0.5	27.79	8.08	35.73	6.4
CALO24_2021	Core Sound	388573	3867411	Yes	No	0.4	0.1	29.24	8.23	23.66	1.7
CALO27_2021	Core Sound	373923	3854061	Yes	No	1.3	0.5	27.10	8.30	36.21	1.6
CALO28_2021	Pamlico Sound	400263	3879935	Yes	No	0.6	0.1	28.53	8.26	24.58	1.9

Methods

The water-quality assessment was conducted in estuarine waters of Pamlico, Core and Back Sounds, following the methods developed by the Environmental Protection Agency (EPA) National Coastal Assessment Program (EPA 2010). 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.

In 2021, 30 sites in Pamlico, Core and Back Sounds 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 (1.6–3.3 feet [ft]) intervals at each site, to measure temperature, pH, dissolved oxygen, and salinity. Chlorophyll *a* and total dissolved nutrient samples were collected from 0.5 meters (1.6 ft) 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 determine light extinction depths, which were converted

to light attenuation coefficients (*k*) using the equation: $K = c / \text{Secchi depth (in meters)}$ where “*c*” is a constant that corresponds to the water body’s naturally occurring clarity conditions (i.e., *c* = 1.0 for naturally turbid conditions, *c* = 1.4 for normal turbidity conditions, or *c* = 1.7 for waters supporting submerged aquatic vegetation (SAV) restoration [Smith et al. 2006; EPA 2016]). Cape Hatteras and Cape Lookout National Seashores use a coefficient of 1.4 because the area experiences “normal turbidity” (EPA 2016). This method of estimating water-clarity condition is generally used when information on light transmission in the water column is missing. The Southeast Coast Network is reporting derived values to maintain data consistency across other network parks. Water clarity was not assessed at sites with excessive current or when they were too shallow to ascertain an accurate Secchi depth measurement. When sites were too shallow to access by boat, or when they were in heavily trafficked channels, alternate sites were used.

Water-Quality Assessment Criteria

The categorical assessments (e.g., good, fair, poor) use measurements of chlorophyll *a*, nutrients, bottom 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 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.

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) [$\mu\text{g/L}$ —micrograms per liter; mg/L —milligrams per liter].

Rating	Water Clarity (<i>k</i>) ¹	Chlorophyll <i>a</i> ($\mu\text{g/L}$)	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

¹Light attenuation coefficients (*k*) were used to assess water-clarity conditions using criteria categories in Smith et al. (2006) which are comparable to the EPA (2012) criteria for the assessed water bodies.

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.

Sediment Data Collection

Sediment samples were collected by taking multiple grabs at each site using a 6.8-kilogram (kg; 24-pound [lbs]) Ponar Sampler with a sample area of 152 × 152 millimeter (mm; 6 × 6 inches [in]). The top 2 centimeters (0.79 inches) from each sample were composited and split into three separate samples that were analyzed for organic contaminants, metals, total organic carbon (TOC), and grain size. Samples were stored on wet ice or in a refrigerator until completion of analysis by the contracted laboratory.

Sediment Assessment Criteria

The Southeast Coast Network uses Environmental Protection

Agency (EPA) National Coastal Condition Assessment (NCCA) sediment quality guidelines (SQG) for estuarine waters to assess the degree of sediment contamination. These SQGs include the mean Effects-Range Median Quotient (mERM-Q) and Logistic Regression Model (LRM). Together, the mERM-Q and LRM provide a holistic interpretation of sediment chemistry and its potential effects on benthic organisms.

The mERM-Q approach assesses the relative degree of sediment contamination and estimates the probability of toxicity to benthic organisms from sediment contaminants (EPA 2016). Calculation of mERM-Q relies upon the Effects Range Low (ERL) and Effects Range Median (ERM) values shown in Table 4. Effects Range Median is the median concentration of a contaminant observed to have adverse biological effects in the literature studies examined. While ERL is the 10th percentile concentration of a contaminant represented by studies demonstrating adverse biological effects in the literature. Ecological effects are not likely to occur at contaminate concentrations below the ERL criterion.

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

Rating	Site Water Quality Index Rating ¹	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 more than 50% of sites are in good 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 50% or less of sites are in good 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

¹Park and site water-quality index ratings are adapted from ratings established by the EPA (2012).

Table 4. Thresholds for sediment chemistry used to determine ecological condition by site (EPA 2010) [mERM-Q— mean Effects-Range Median Quotient; LRM— Logistic Regression Model; Pmax—maximum probability].

Rank	Threshold
Good	mERM-Q < 0.1 and LRM Pmax ≤ 0.5
Fair	mERM-Q ≥ 0.1 – ≤ 0.5 or LRM Pmax > 0.5 – < 0.75
Poor	mERM-Q > 0.5 or LRM Pmax ≥ 0.75

The LRM approach calculates the probability of observing a toxic effect based on individual contaminant concentrations and the maximum probability (Pmax) of observing toxicity from all contaminants in a sample (EPA 2016). Values used in the LRM-Pmax calculation (B0 and B1) are in Table 5.

Previous park-wide assessments conducted by the network and the EPA used % Total Organic Carbon (TOC) as a rating

factor for sediment quality. However, in 2010, the EPA updated its methods to reflect current practices and %TOC is no longer a component of the sediment quality index. As a result, %TOC has been reported below for comparison with past reports, but was not used in determination of ecological condition by site.

Table 5. Sediment quality guideline values used to calculate mERM-Q and LRM-Pmax (EPA 2016) [ERL=Effects Low Range; ERM=Effects Range Median; mERM-Q— mean Effects-Range Median Quotient; LRM— Logistic Regression Model; Pmax— maximum probability].

Sediment Chemicals Analyzed	Units	ERL	ERM	Used to calculate mERM-Q	B0	B1	Used to calculate LRM-Pmax
Antimony	µg/g	–	–	–	-0.9005	2.411	X
Arsenic	µg/g	8.2	70	X	-4.1407	3.1674	X
Cadmium	µg/g	1.2	9.6	X	-0.34	2.5073	X
Chromium	µg/g	81	370	X	-6.4395	2.9952	X
Copper	µg/g	34	270	X	-5.7878	2.9325	X
Lead	µg/g	46.7	218	X	-5.4523	2.7662	X
Mercury	µg/g	0.15	0.71	X	0.8041	2.5461	X
Nickel	µg/g	20.9	51.6	–	-4.6119	2.7658	X
Silver	µg/g	1	3.7	X	-0.1117	1.9684	X
Zinc	µg/g	150	410	X	-7.9834	3.342	X
Acenaphthene	ng/g	16	500	X	-3.6165	1.7532	X
Acenaphthylene	ng/g	44	640	X	-2.962	1.3797	X
Anthracene	ng/g	85.3	1100	X	-3.6574	1.4854	X
Fluorene	ng/g	19	540	X	-3.7146	1.8071	X
2-methylnapthalene	ng/g	70	670	X	-3.7579	1.7833	X
Napthalene	ng/g	160	2100	X	-3.7753	1.6152	X
Phenanthrene	ng/g	240	1500	X	-4.4576	1.6768	X
Benz(a)anthracene	ng/g	261	1600	X	-4.2013	1.5747	X
Benzo(a)pyrene	ng/g	430	1600	X	-4.3005	1.5832	X
Chrysene	ng/g	384	2800	X	-4.3241	1.5372	X
Dibenz(a,h)anthracene	ng/g	63.4	260	X	-3.6308	1.7692	X
Fluoranthene	ng/g	600	5100	X	-4.4574	1.4787	X
Pyrene	ng/g	665	2600	X	-4.708	1.5854	X
Total DDT	ng/g	1.6	46.1	X	–	–	–
Total PCB congeners	ng/g	22.7	180	X	-3.4613	1.3488	X
Total PAHs	ng/g	4020	44800	–	–	–	–

Results

Parameter-Based Water Condition Assessments

Figures 4–8 illustrate the spatial distribution of sampling sites and the corresponding ratings for water clarity, chlorophyll *a*, dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), and bottom-reading 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 Cape Hatteras and Cape Lookout National Seashores water quality. Site-specific water-quality data for each parameter are also presented in Table 6.

Water clarity was not calculated at all sites due to the shallow depth of the water in the sound. Of the sites where water clarity could be assessed (5 sites), four measured good and one fair. Sites that were too shallow to measure water clarity had water column conditions that did not preclude light from penetrating to the bottom of the water body so no ecological effects would be expected. Turbidity measurements ranged from 1.0 to 8.0 FNU (Formazin Nephelometric Units) and are good (i.e. < 25 NTU) according to North Carolina Standards (NC Administrative Code 2019 (Table 1). Note that turbidity units of FNU and NTU (Nephelometric Turbidity Units) are roughly equivalent.

Chlorophyll *a* concentration was rated good at 29 sites (97%), and fair at one site (3%).

Dissolved inorganic nitrogen (DIN) concentration was good at all 30 sites (100%).

Dissolved inorganic phosphorus (DIP) concentration was good at all 30 sites (100%).

Dissolved oxygen concentration (bottom) was rated good at all 30 sites (100%).

A water-quality condition summary index was calculated for each site sampled at Cape Hatteras and Cape Lookout National Seashores based on the categorical assessments of chlorophyll *a*, DIN and DIP concentrations, dissolved oxygen, and water clarity. This summary index indicated good water-quality conditions at all thirty sites (100%).

Based on the summary water-quality index rating, overall water-quality conditions at Cape Hatteras and Cape Lookout National Seashores during sampling in 2021 were good.

Sediment Condition Assessments

Metal and organic contaminant concentration data is provided in Tables 7, 8a, and 8b. Figure 10 is a map which shows the spatial distribution of sampling sites and the corresponding ratings for ecological condition based on sediment chemistry. The inset graph shows the percentage of sites in each ecological condition rating category (good, fair, poor). Data used to make the map and graph are shown in Table 9. Ecological condition was ranked as good at 30 sites (100%). As a result, no adverse impacts to benthic organisms due to sediment contamination are anticipated at any of the sampled sites. These rankings were assigned according to the 2010 Environmental Protection Agency, National Coastal Condition Assessment (NCCA) thresholds for sediment chemistry.

Cape Hatteras and Cape Lookout National Seashores Water Clarity (k)

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

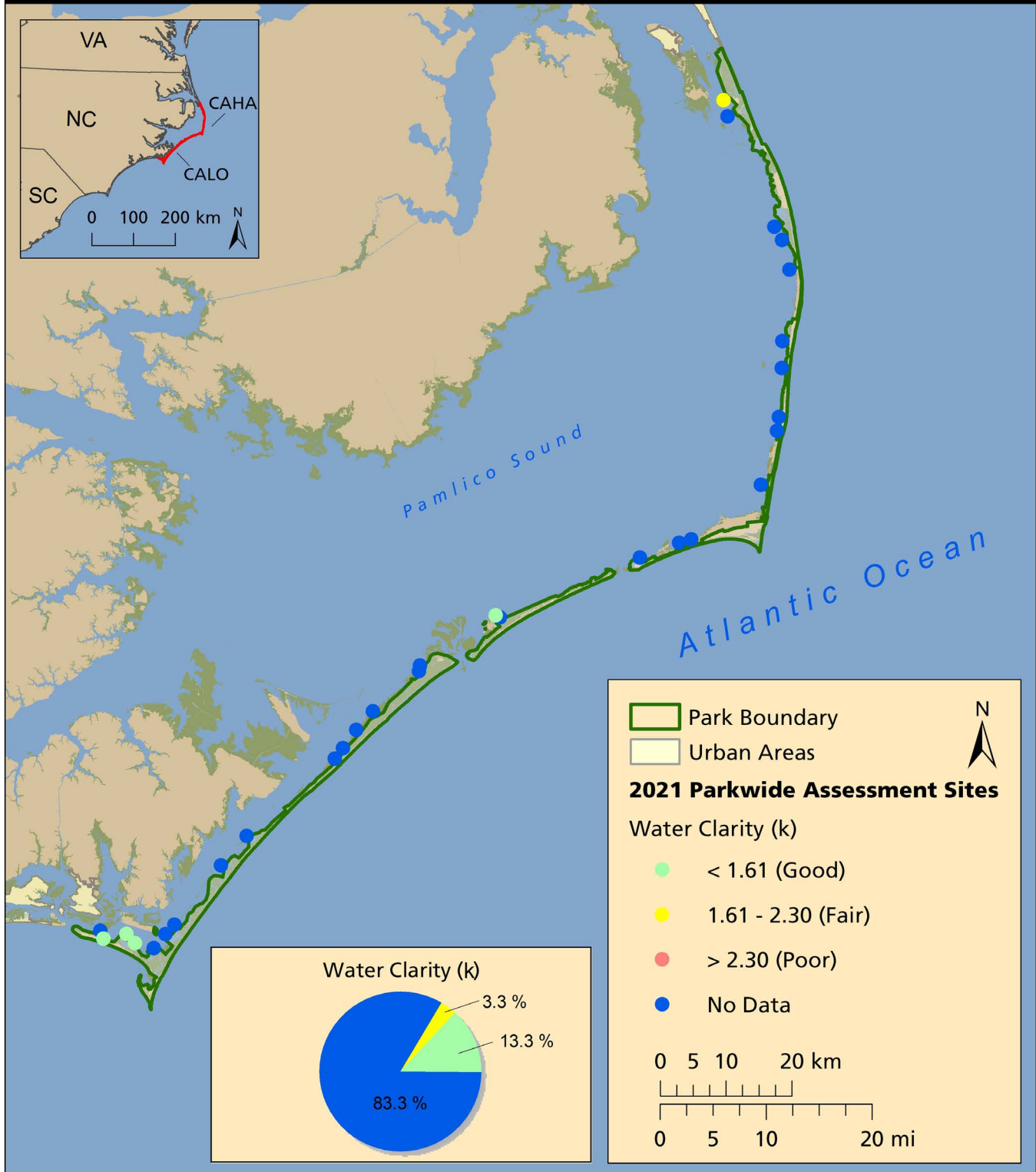


Figure 4. Water clarity ratings at sampling sites at Cape Hatteras and Cape Lookout National Seashores in July 2021. Inset graph shows the percent of sites in each condition category [green—good; yellow—fair; blue—n/a].

Cape Hatteras and Cape Lookout National Seashores Chlorophyll a

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

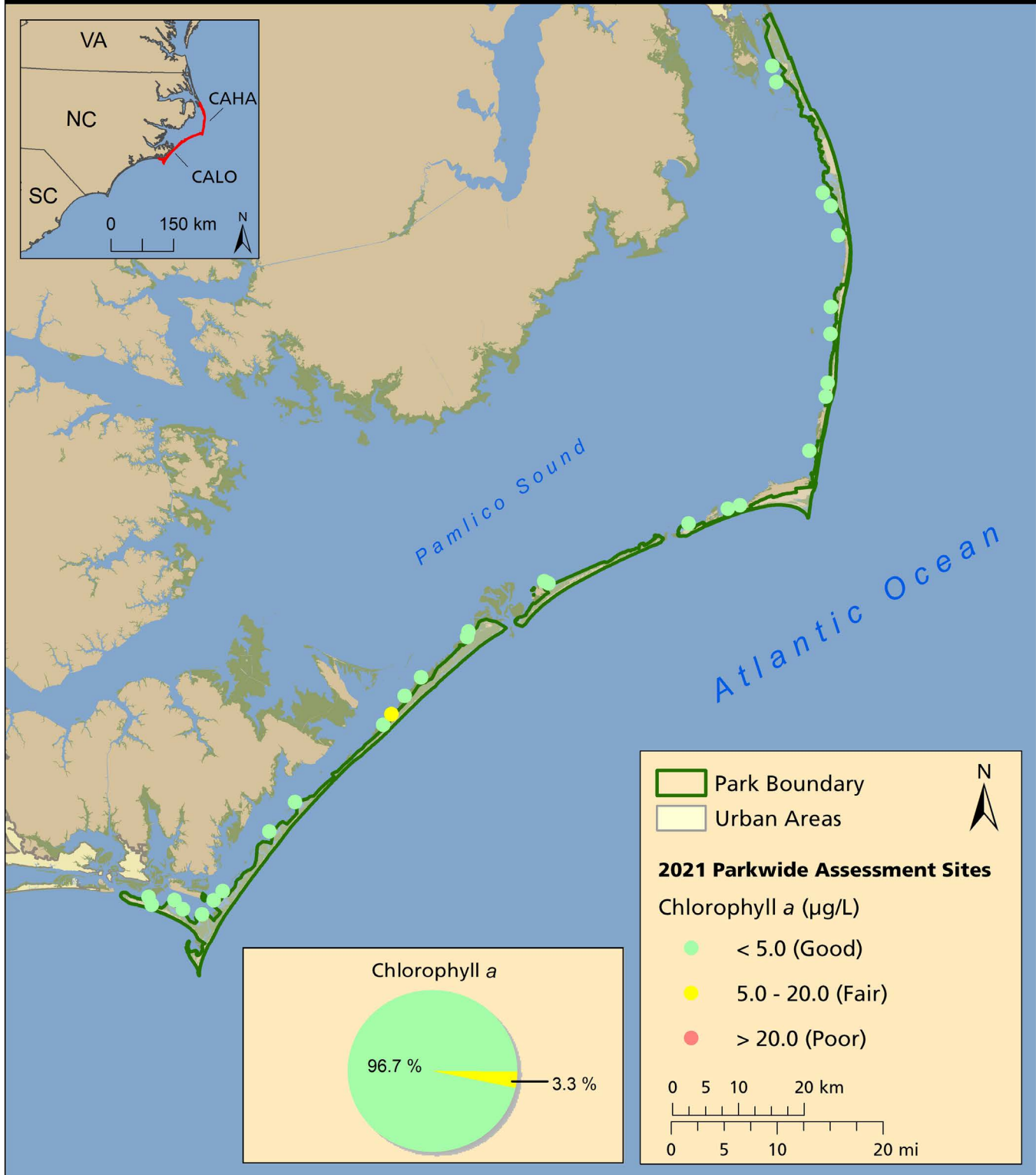


Figure 5. Chlorophyll a concentrations Cape Hatteras and Cape Lookout National Seashores in July 2021. Inset graph shows the percent of sites in each condition category [green—good; yellow—fair].

Cape Hatteras and Cape Lookout National Seashores Dissolved Inorganic Nitrogen

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

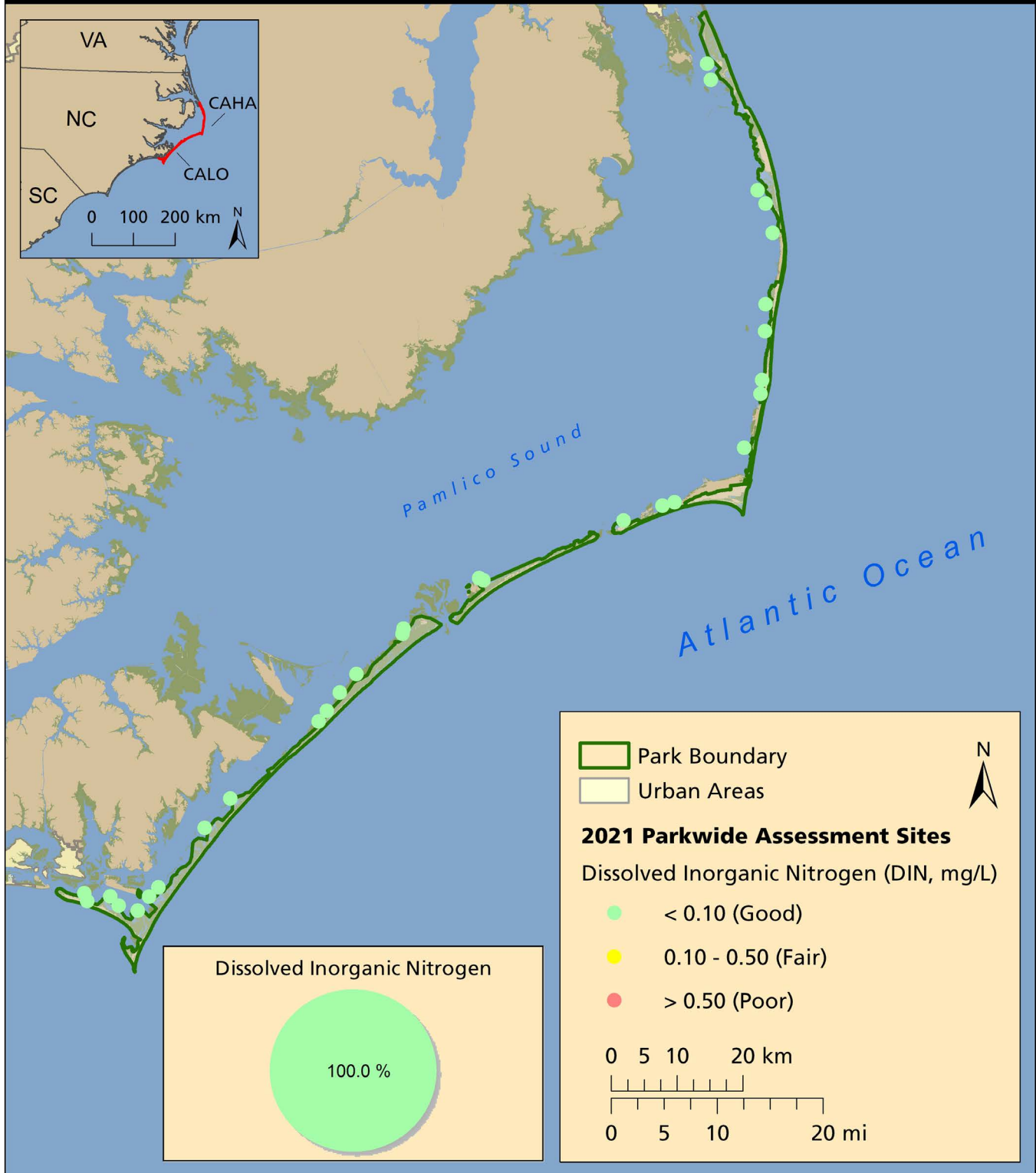


Figure 6. Dissolved inorganic nitrogen concentrations at sampling sites at Cape Hatteras and Cape Lookout National Seashores in July 2021. Inset graph shows the percent of sites in each condition category [green—good].

Cape Hatteras and Cape Lookout National Seashores Dissolved Inorganic Phosphorus

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

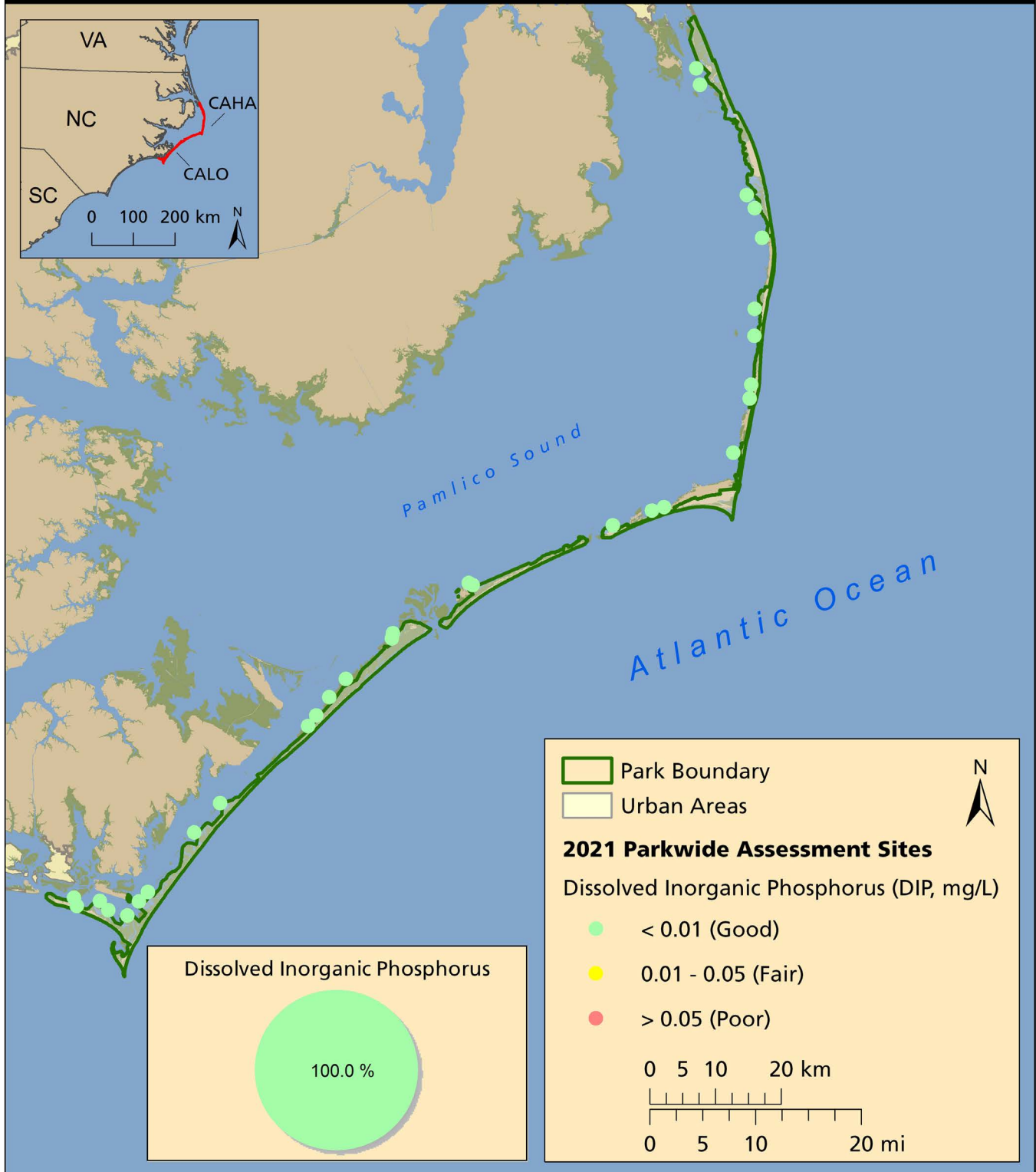


Figure 7. Dissolved inorganic phosphorus concentrations at sampling sites at Cape Hatteras and Cape Lookout National Seashores in July 2021. Inset graph shows the percent of sites in each condition category [green—good].

Cape Hatteras and Cape Lookout National Seashores Dissolved Oxygen

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

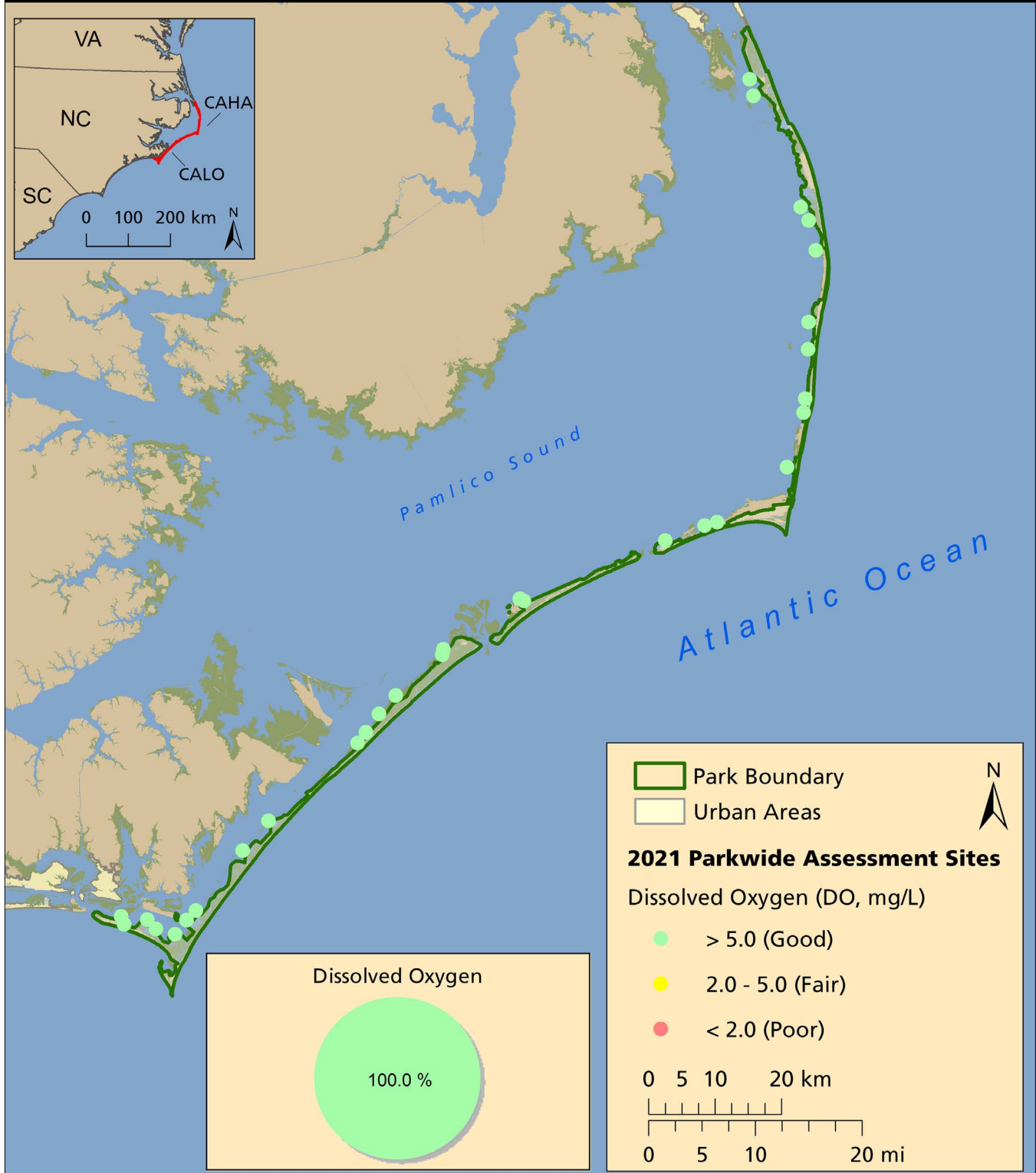


Figure 8. Dissolved oxygen concentrations at sampling sites at Cape Hatteras and Cape Lookout National Seashores in July 2021. Inset graph shows the proportion of sites in each condition category [green—good].

Cape Hatteras and Cape Lookout National Seashores Site Water Quality Index Rating

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

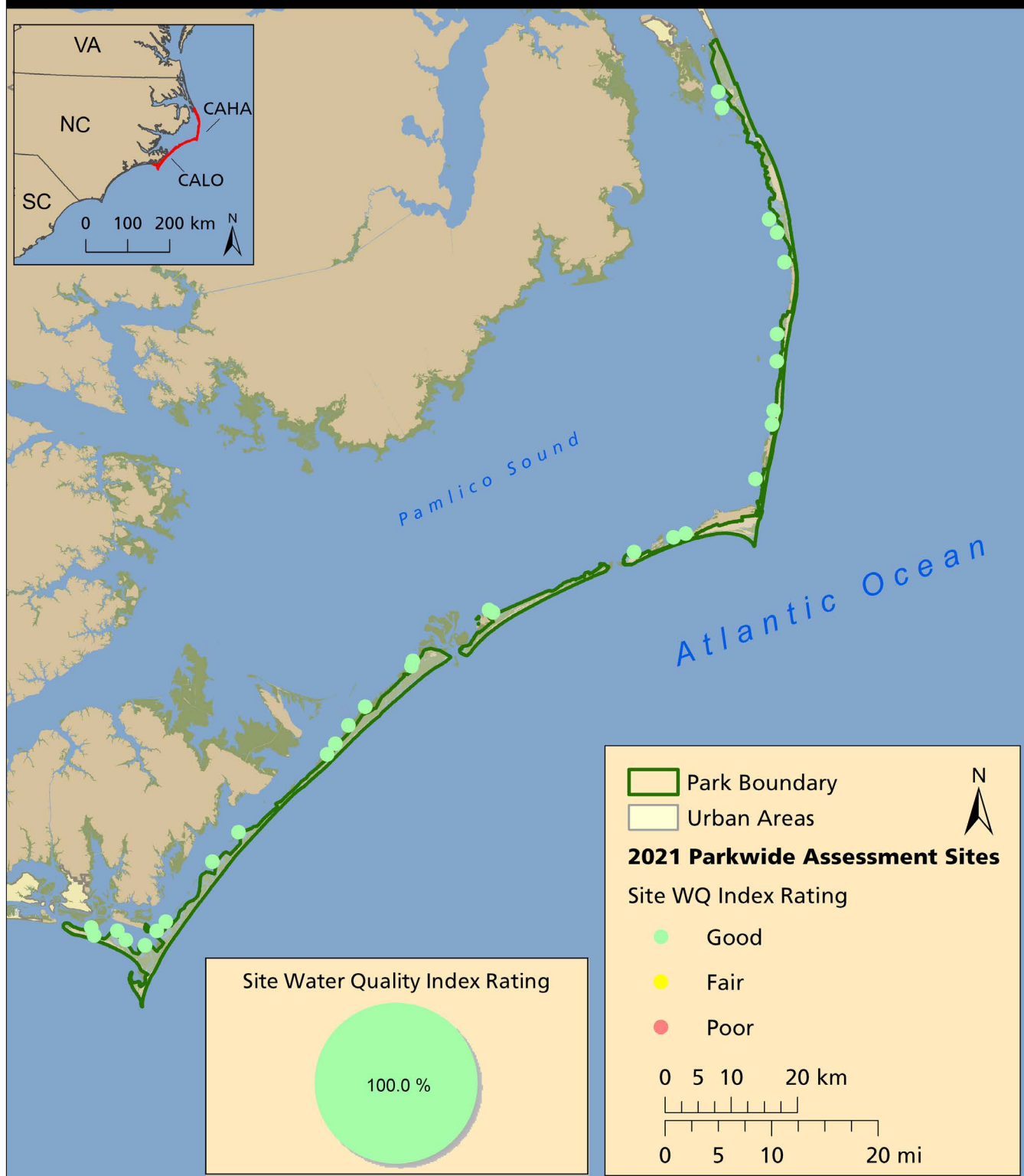


Figure 9. Water-quality index rating at sampling sites in the vicinity of Cape Hatteras and Cape Lookout National Seashores in July 2021. Inset graph shows the proportion of sites in each condition category [green—good].

Cape Hatteras and Cape Lookout National Seashores Ecological Condition

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

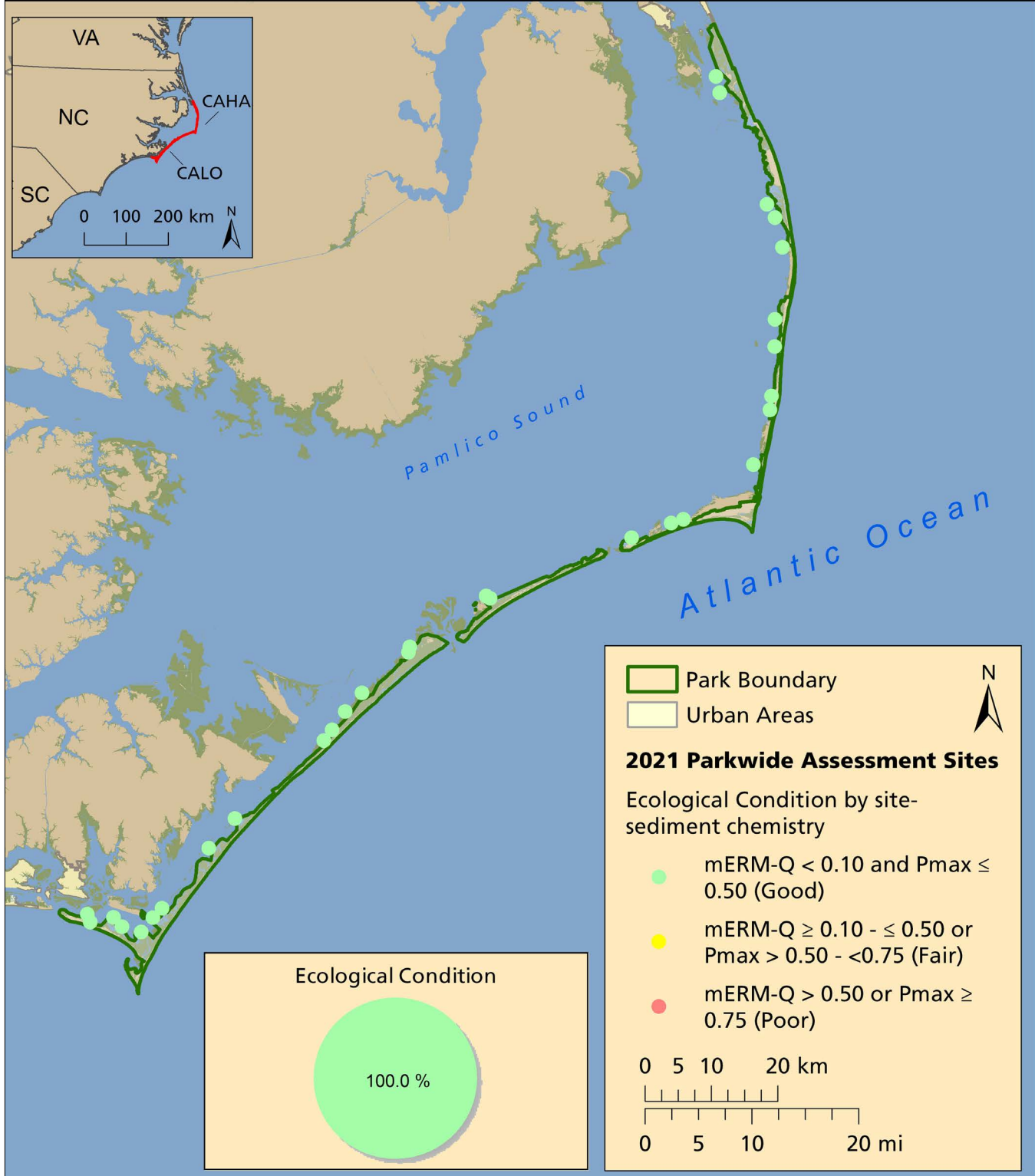


Figure 10. Spatial distribution of sampling sites and the corresponding ratings for ecological condition based on sediment chemistry at Cape Hatteras and Cape Lookout National Seashores in July 2021. Inset graph shows the proportion of sites in each condition category [green—good].

Water-Quality Data

Table 6. Water-quality parameter values and assessment conditions for sampling sites in the vicinity of Cape Hatteras and Cape Lookout National Seashores July 13–21, 2021. Water clarity was assessed using light attenuation values (k) using a constant (1.4) for estuarine waters experiencing “normal turbidity” (Smith et al. 2006) and assessment categories that correspond to EPA (2012). Condition of other assessed parameters based on EPA (2012) [Green^a—good; yellow^b—fair; red^c—poor; *result was less than or equal to the Method Detection Limit [MDL reported]; k—light attenuation coefficient; µg/L—micrograms per liter; N—Nitrogen; mg/L—milligrams per liter; P—Phosphorous; – — data not collected]. Dissolved oxygen concentrations are taken near the bottom (deepest reading).

Site Name	Water Clarity (k ⁻¹)	Chlorophyll a (µg/L)	Dissolved Oxygen (DO, mg/L)	Dissolved Inorganic N (DIN, mg/L)	Dissolved Inorganic P (DIP, mg/L)	Total Dissolved Nitrogen ² (mg/L)	Total Dissolved Phosphorus ² (mg/L)
CAHA01	–	1.16 ^a	6.2 ^a	0.011 ^{a*}	0.0037 ^a	0.39	0.014
CAHA02	–	1.29 ^a	7.3 ^a	0.011 ^{a*}	0.0035 ^a	0.27	0.014
CAHA06	2.0 ^b	4.54 ^a	8.5 ^a	0.013 ^{a*}	0.0077 ^a	0.33	0.023
CAHA09	–	3.17 ^a	7.1 ^a	0.011 ^{a*}	0.0055 ^a	0.23	0.021
CAHA10	–	1.82 ^a	8.4 ^a	0.011 ^{a*}	0.0045 ^a	0.28	0.018
CAHA13	–	4.98 ^a	11.7 ^a	0.011 ^{a*}	0.0056 ^a	0.33	0.017
CAHA14	–	1.99 ^a	8.2 ^a	0.011 ^{a*}	0.0036 ^a	0.22	0.014
CAHA16	–	1.48 ^a	6.5 ^a	0.014 ^a	0.0039 ^a	0.29	0.014
CAHA17	–	2.18 ^a	6.3 ^a	0.011 ^{a*}	0.0040 ^a	0.30	0.015
CAHA18	–	1.36 ^a	7.0 ^a	0.011 ^{a*}	0.0041 ^a	0.29	0.014
CAHA22	–	1.01 ^a	6.6 ^a	0.011 ^{a*}	0.0040 ^a	0.35	0.013
CAHA25	0.9 ^a	2.73 ^a	6.3 ^a	0.011 ^{a*}	0.0049 ^a	0.22	0.015
CAHA26	–	2.54 ^a	6.8 ^a	0.011 ^{a*}	0.0043 ^a	0.14	0.013
CAHA29	–	1.57 ^a	7.0 ^a	0.011 ^{a*}	0.0035 ^a	0.36	0.015
CAHA30	–	2.77 ^a	7.4 ^a	0.011 ^{a*}	0.0042 ^a	0.22	0.017
CALO03	–	2.79 ^a	6.2 ^a	0.011 ^{a*}	0.0049 ^a	0.16	0.026
CALO04	–	2.94 ^a	7.9 ^a	0.011 ^{a*}	0.0044 ^a	0.21	0.019
CALO05	–	2.05 ^a	6.5 ^a	0.011 ^{a*}	0.0043 ^a	0.13	0.014
CALO07	1.0 ^a	3.60 ^a	6.0 ^a	0.011 ^{a*}	0.0041 ^a	0.14	0.015
CALO08	–	3.12 ^a	7.9 ^a	0.011 ^{a*}	0.0034 ^{a*}	0.20	0.017
CALO11	–	1.34 ^a	6.5 ^a	0.011 ^{a*}	0.0048 ^a	0.20	0.022
CALO12	–	2.45 ^a	7.3 ^a	0.011 ^{a*}	0.0037 ^a	0.25	0.016
CALO15	–	2.41 ^a	6.3 ^a	0.011 ^{a*}	0.0037 ^a	0.13	0.015
CALO19	–	3.05 ^a	7.1 ^a	0.011 ^{a*}	0.0046 ^a	0.20	0.023
CALO20	–	3.28 ^a	8.6 ^a	0.011 ^{a*}	0.0044 ^a	0.29	0.018
CALO21	0.7 ^a	2.88 ^a	6.7 ^a	0.011 ^{a*}	0.0040 ^a	0.15	0.015
CALO23	1.2 ^a	3.12 ^a	5.9 ^a	0.011 ^{a*}	0.0042 ^a	0.16	0.015
CALO24	–	5.46 ^b	7.3 ^a	0.011 ^{a*}	0.0042 ^a	0.35	0.023
CALO27	–	1.88 ^a	5.9 ^a	0.011 ^{a*}	0.0053 ^a	0.26	0.027
CALO28	–	2.54 ^a	6.7 ^a	0.012 ^a	0.0042 ^a	0.27	0.019

¹ Light attenuation coefficients (k) were used to assess water-clarity conditions using criteria categories in Smith et al. (2006) which are comparable to the EPA (2012) criteria for the assessed water bodies.

² There are no EPA condition criteria for TDN and TDP.

Table 7. Concentrations of select metals for sites sampled at Cape Hatteras and Cape Lookout National Seashores July 13–21, 2021. All results are presented in mg/kg [*—result was greater than or equal to the Method Detection Limit (MDL) but below the Practical Quantitation Limit (PQL); **—result was less than the Method Detection Limit].

Site	Antimony	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
CAHA-01	0.82**	0.95*	0.082**	4.7	1.50*	0.82**	0.0048*	3.00*	16.0**
CAHA-02	0.64**	0.64**	0.064**	1.6	0.64**	0.64**	0.0017**	0.64**	13.0**
CAHA-06	0.65**	0.65**	0.065**	1.3	0.65**	0.65**	0.0017**	0.65**	13.0**
CAHA-09	0.62**	0.62**	0.062**	2.0	0.62**	0.62**	0.0016**	0.62**	12.0**
CAHA-10	0.59**	0.60*	0.059**	1.7	0.59**	0.59**	0.0016**	0.59**	12.0**
CAHA-13	0.74**	0.81*	0.074**	3.3	1.10*	0.74**	0.0074	2.10*	15.0**
CAHA-14	0.66**	0.97*	0.066**	2.9	0.66*	0.66**	0.0028*	1.60*	13.0**
CAHA-16	0.67**	0.67**	0.067**	2.8	0.67**	0.67**	0.0028*	1.60*	13.0**
CAHA-17	0.64**	0.64**	0.064**	2.5	0.64**	0.64**	0.0017**	1.30*	13.0**
CAHA-18	0.64**	0.76*	0.064**	1.4	0.64**	0.66*	0.0016**	0.64**	13.0**
CAHA-22	0.74**	0.77*	0.074**	2.8	0.84*	0.74**	0.0019**	2.00*	15.0**
CAHA-25	0.66**	0.98*	0.066**	4.0	0.77*	0.66**	0.0019*	1.50*	13.0**
CAHA-26	0.63**	1.20*	0.063**	2.1	0.63**	0.63**	0.0016**	0.63**	13.0**
CAHA-29	0.67**	0.67**	0.067**	1.9	0.67**	0.67**	0.0017**	0.95*	13.0**
CAHA-30	0.86**	1.40*	0.086**	6.1	1.90*	0.86**	0.0022**	3.50	17.0**
CALO-03	0.63**	0.87*	0.063**	2.6	0.63**	1.40*	0.0016**	0.63**	13.0**
CALO-04	0.63**	0.63**	0.063**	2.6	0.63**	0.85*	0.0017**	0.63**	13.0**
CALO-05	0.65**	0.79*	0.065**	4.8	0.65**	1.20*	0.0017**	0.65**	13.0**
CALO-07	0.67**	1.30*	0.067**	4.7	0.67**	0.67**	0.0017**	1.30*	13.0**
CALO-08	0.68**	0.82*	0.068**	3.8	0.68**	1.0*	0.0017**	1.10*	14.0**
CALO-11	0.65**	0.84*	0.065**	3.1	0.65**	0.72*	0.0016**	0.68*	13.0**
CALO-12	0.66**	0.66*	0.066**	2.3	0.66**	0.66**	0.0016**	0.73*	13.0**
CALO-15	0.67**	1.50*	0.067**	3.6	0.67**	0.67**	0.0017*	0.67**	13.0**
CALO-19	0.65**	2.30*	0.065**	4.0	0.65**	0.65**	0.0017**	0.79*	13.0**
CALO-20	0.66**	0.66**	0.066**	3.0	0.66**	0.66**	0.0017**	0.89*	13.0**
CALO-21	0.62**	1.70*	0.062**	2.2	0.62**	0.62**	0.0016**	0.62**	12.0**
CALO-23	0.68**	1.20*	0.068**	5.3	0.68**	0.82*	0.0017**	1.20*	14.0**
CALO-24	0.63**	0.63**	0.063**	2.4	0.63**	0.63**	0.0016**	0.63**	13.0**
CALO-27	0.66**	1.10*	0.066**	3.4	0.66**	0.76*	0.0017**	0.74*	13.0**
CALO-28	0.65**	0.70*	0.065**	2.8	0.65**	0.65**	0.0017**	0.76*	13.0**

Table 8a. Organic contaminant concentrations (Acenaphthene–Chrysene) for sites sampled at Cape Hatteras and Cape Lookout National Seashores July 13–21, 2021. All results are presented in mg/kg.[*—result was greater than or equal to the Method Detection Limit (MDL) but below the Practical Quantitation Limit (PQL); **— result was less than the MDL].

[illegible]

Table 8b. Organic contaminant concentrations (Dibenz(A,H)Anthracene – Total PCBs) for sites sampled at Cape Hatteras and Cape Lookout National Seashores July 13–21, 2021. All results are presented in mg/kg. [*—result was greater than or equal to the Method Detection Limit (MDL) but below the Practical Quantitation Limit (PQL); **—result was less than the Method Detection Limit.

Site	Dibenz(A,H) Anthracene	Fluoranthene	Pyrene	Low Molecular Weight PAH	High Molecular Weight PAH	Total PAHs	P,P-Dichlorodiphenyl- dichloroethylene (DDE)	P,P-Dichlorodiphenyl- trichloroethane (DDT)	Total PCBs
CAHA-01	0.034**	0.034**	0.034**	0.238	0.204	0.612	0.0033**	0.0073**	0.20**
CAHA-02	0.027**	0.027**	0.027**	0.189	0.162	0.486	0.0026**	0.0058**	0.16**
CAHA-06	0.027**	0.027**	0.027**	0.189	0.162	0.486	0.0026**	0.0058**	0.16**
CAHA-09	0.027**	0.027**	0.027**	0.189	0.162	0.486	0.0025**	0.0055**	0.15**
CAHA-10	0.025**	0.025**	0.025**	0.175	0.150	0.450	0.0025**	0.0056**	0.15**
CAHA-13	0.030**	0.030**	0.030**	0.210	0.180	0.540	0.0030**	0.0065**	0.18**
CAHA-14	0.027**	0.027**	0.027**	0.189	0.162	0.486	0.0028**	0.0061**	0.17**
CAHA-16	0.028**	0.028**	0.028**	0.196	0.168	0.504	0.0028**	0.0062**	0.17**
CAHA-17	0.026**	0.026**	0.026**	0.182	0.156	0.468	0.0026	0.0058	0.16**
CAHA-18	0.025**	0.025**	0.025**	0.175	0.150	0.450	0.0026**	0.0058**	0.16**
CAHA-22	0.029**	0.029**	0.029**	0.203	0.174	0.522	0.0030**	0.0067**	0.18**
CAHA-25	0.028**	0.028**	0.028**	0.196	0.168	0.504	0.0027**	0.0060**	0.16**
CAHA-26	0.025**	0.025**	0.025**	0.175	0.150	0.450	0.0027**	0.0060**	0.16**
CAHA-29	0.028**	0.028**	0.028**	0.196	0.168	0.504	0.0027**	0.0061**	0.17**
CAHA-30	0.034**	0.034**	0.034**	0.238	0.204	0.612	0.0036**	0.0079**	0.22**
CALO-03	0.027**	0.027**	0.027**	0.189	0.162	0.486	0.0027**	0.0060**	0.15**
CALO-04	0.027**	0.027**	0.027**	0.189	0.162	0.486	0.0027**	0.0060**	0.15**
CALO-05	0.027**	0.027**	0.027**	0.189	0.162	0.486	0.0026**	0.0057**	0.16**
CALO-07	0.028**	0.028**	0.028**	0.196	0.168	0.504	0.0028**	0.0063**	0.17**
CALO-08	0.028**	0.028**	0.028**	0.196	0.168	0.504	0.0028**	0.0061**	0.17**
CALO-11	0.025**	0.025**	0.025**	0.175	0.150	0.450	0.0027**	0.0059**	0.16**
CALO-12	0.026**	0.026**	0.026**	0.182	0.156	0.468	0.0026**	0.0058**	0.16**
CALO-15	0.028**	0.028**	0.028**	0.196	0.168	0.504	0.0026**	0.0057**	0.17**
CALO-19	0.028**	0.028**	0.028**	0.196	0.168	0.504	0.0027**	0.0059**	0.16**
CALO-20	0.028**	0.028**	0.028**	0.196	0.168	0.504	0.0028**	0.0062**	0.17**
CALO-21	0.026**	0.026**	0.026**	0.182	0.156	0.468	0.0026**	0.0058**	0.16**
CALO-23	0.028**	0.028**	0.028**	0.196	0.168	0.504	0.0027**	0.006**	0.16**
CALO-24	0.027**	0.027**	0.027**	0.189	0.162	0.486	0.0026**	0.0057**	0.15**
CALO-27	0.028**	0.028**	0.028**	0.196	0.168	0.504	0.0029**	0.0063**	0.17**
CALO-28	0.027**	0.027**	0.027**	0.189	0.162	0.486	0.0027**	0.0059**	0.16**

Table 9. Ecological condition, based on sediment, for sites sampled at Cape Hatteras and Cape Lookout National Seashores in July 13–21, 2021. Ecological condition was determined using the thresholds for sediment chemistry in EPA NCCA 2010 [green^a—good]. Total Organic Carbon % was not used to determine site condition but is presented for comparison with previous parkwide assessments of sediment quality.

Site	Ecological Condition by Site	Total Organic Carbon %
CAHA-01	Good ^a	0.130
CAHA-02	Good ^a	0.024
CAHA-06	Good ^a	0.024
CAHA-09	Good ^a	0.024
CAHA-10	Good ^a	0.024
CAHA-13	Good ^a	0.078
CAHA-14	Good ^a	0.046
CAHA-16	Good ^a	0.051
CAHA-17	Good ^a	0.024
CAHA-18	Good ^a	0.024
CAHA-22	Good ^a	0.070
CAHA-25	Good ^a	0.041
CAHA-26	Good ^a	0.024
CAHA-29	Good ^a	0.026
CAHA-30	Good ^a	0.140
CALO-03	Good ^a	0.024
CALO-04	Good ^a	0.024
CALO-05	Good ^a	0.024
CALO-07	Good ^a	0.044
CALO-08	Good ^a	0.055
CALO-11	Good ^a	0.024
CALO-12	Good ^a	0.026
CALO-15	Good ^a	0.024
CALO-19	Good ^a	0.024
CALO-20	Good ^a	0.026
CALO-21	Good ^a	0.110
CALO-23	Good ^a	0.036
CALO-24	Good ^a	0.024
CALO-27	Good ^a	0.025
CALO-28	Good ^a	0.024

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