



Fixed-Station Water Quality Monitoring at Cape Lookout National Seashore, Shackleford Banks Site

2008-2009 Data Summary

Natural Resource Data Series NPS/SECN/NRDS—2014/693



ON THE COVER

Shackleford Banks overlooking Onslow Bay.
Photograph by: Briana Smrekar, SECN staff.

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Summary and Key Findings

In 2007, the National Park Service (NPS) Southeast Coast Network (SECN) Inventory and Monitoring Program began a partnership with the North Carolina National Estuarine Research Reserve (NCNERR) to collect water quality data in the estuarine waters near Cape Lookout National Seashore (CALO). Two continuous monitoring stations have been operational since 2008 in the Shackleford Banks Dock and in the Middle Marshes area. Shackleford Banks (CALOshak) data are summarized in this report. For more information on Cape Lookout water quality, see the separate data summary report for the Middle Marshes fixed-station site. Methods used are adapted from the water quality monitoring program established by the National Estuarine Research Reserve Program (Wenner and Geist 2001). The Cape Lookout National Seashore fixed-station water quality monitoring sites are part of the SECN estuarine water quality monitoring program, which routinely collects data in the vicinity of seven coastal parks along the southeastern U.S. coast (DeVivo et al. 2008, Gregory et al. 2013). Highlights from the 2008-2009 data record are summarized below.

- Water temperature, dissolved oxygen, salinity, pH, depth, turbidity, and specific conductance data were collected continuously at CALOshak. Monthly measurements of water clarity conditions were also made. Additionally, grab samples were collected monthly and analyzed for chlorophyll *a* levels, dissolved inorganic nitrogen, dissolved inorganic phosphorus, total dissolved nitrogen, and total dissolved phosphorus.
- Discrete water quality samples collected monthly indicated a range of water clarity conditions with three *fair* ratings, one *poor* rating, and the balance of the samples rated *good*. Chlorophyll *a* was generally *good*, with three *fair* ratings in the summer and early fall. Dissolved oxygen, dissolved inorganic nitrogen, and dissolved inorganic phosphorus were *good* across the period of record.
- Dissolved oxygen was generally lower in warmer months and higher in cooler months, with mean monthly dissolved oxygen levels ranging from 6.50 mg/L in August 2008 to 8.70 mg/L in February 2009. Data from December and January 2009 were too sparse to compute monthly means. Individual readings ranged from 3.96 mg/L to 12.15 mg/L.
- Salinity concentrations generally declined after periods of high rainfall and runoff. Mean monthly salinity levels ranged from 31.70 ppt in December 2009 to 38.80 ppt in July 2009. Individual readings ranged from a low of 23.05 ppt to a high of 39.58 ppt.
- The percentage of total expected continuous data used in statistical analysis varied across parameters with 81% of water temperature data being used, 67% for dissolved oxygen, 83% for salinity, 71% for pH, 80% for depth, and 68% for turbidity. Missing data were most commonly caused by battery failure or poor mount design which resulted in the sonde coming out of the water.

Introduction

Because of the importance of water resources to park management from ecological, regulatory, and visitor experience perspectives, estuarine water quality in and around parks was selected as one of several Vital Signs to be monitored by the Southeast Coast Network (SECN) Inventory and Monitoring 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 an increased awareness of park ecological processes and physical systems (Gregory et al. 2013).

To effectively monitor the diverse and dynamic set of estuarine water resources, the SECN has implemented a two-pronged monitoring approach consisting of collecting data from continuously recording fixed stations located in each park and collecting monthly discrete water samples for nutrient analysis. When combined, these two approaches give a more complete picture of physical processes, diurnal and seasonal variations, and spatial patterns during critical portions of the year than either could if implemented singularly.

The SECN has identified four specific monitoring objectives for which data are collected and analyzed as part of this effort. Objectives 1 and 2 below are addressed in this report (Gregory et al. 2013):

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

In 2007, the SECN began a cooperative effort with the North Carolina National Estuarine Research Reserve (NCNERR) to collect continuous water quality and monthly nutrient data in the waters around Cape Lookout National Seashore (CALO) in order to assess water quality conditions and examine trends in temporal variability. This report provides a summary of data collected at the Shackleford Banks site (Figure 1; Table 1) during 2008-2009 and presents a snapshot of conditions to park managers as well as information on short-term variability and seasonal trends of conditions in waters in the vicinity of CALO.

Cape Lookout National Seashore

Cape Lookout National Seashore is along the southern end of the Outer Banks and is largely undeveloped and accessible only by boat. Cape Lookout is made up of three barrier islands covering 56 miles of the central coast of North Carolina. Most of the Seashore consists of North and South Core Banks, a 44-mile long barrier system oriented in a southwest to northeast direction and separated New Drum Inlet (Figure 1).

Instead of exhibiting the typical barrier island zonation of a wide berm, low dunes, grasslands, shrub thickets, and salt marsh, the northern end of Portsmouth Island is characterized by vast tidal sand flats (averaging 0.6 miles in width) located between the berm and the dunes of a series of marsh-fringed islands. At triangularly shaped Cape Lookout, continuous dunes similar to those on Shackleford Banks can be found on the southwest side, with several small freshwater marshes present in depressions between the dunes. High dunes have significantly reduced overwash, allowing thickets to further stabilize the flats of the Cape's interior. A long spit extends from the western tip of Cape Lookout and has encouraged accretion in this direction.

Specific issues of concern to CALO include off-road vehicle use and the associated effects on dunes, threatened and endangered species, commercial fishing, military over-flights, and non-native species. Additionally, the Back Sound north of Shackleford Banks at CALO drains the populated areas of Morehead City and Beaufort. Numerous water bodies in the vicinity of CALO have been 303(d) listed for water quality violations (Figure 1). For example, the marine waters both north and south of Cape Lookout—as well as those off Cape Lookout itself—have been listed for elevated levels of mercury in fish and elevated aquatic bacteria levels. Areas in the Core and Bogue Sounds have also been listed for elevated aquatic pathogen levels which have caused shellfishing areas to be closed or only conditionally approved (USEPA 2013).



Figure 1. Location of continuous water quality monitoring stations at Cape Lookout National Seashore in 2008-2009. The data presented in this summary are from the CALOshak site only. Map shows estuarine and marine water resources in the vicinity of Cape Lookout National Seashore in North Carolina. Depicted are areas of salt marsh (USFWS 2013), urbanization (U. S. Census Bureau 2013), 303(d) listed water bodies (USEPA 2013), and areas designated as having special uses or restrictions (NCDENR 2013).

Methods

Data collection at the Cape Lookout fixed stations is modeled after an ongoing coastal water quality monitoring program using methods established by the National Estuarine Research Reserve Program (Wenner and Geist 2001). Detailed field and lab standard operating procedures and methods have been reported for the continuously collected data in (Gregory et al. 2013). Methods are briefly summarized in the following sections.

Sampling Location at Shackleford Banks

The sampling location is located at one of the areas of most concentrated use on Shackleford Banks, approximately 1/2 mile from Beaufort Inlet at the Cape Lookout National Seashore dock. A boat is required to access the island and boat traffic is heavy in this area. Tides in this area range 2-3 feet. The site was selected by NCNERR staff because of its proximity to a previous water quality monitoring site. The exact sampling location is described in Table 1 below.

Table 1. Location of the CALOshak continuous water quality monitoring site at Cape Lookout National Seashore during 2008-2009.

Name	Location Description	Location (lat/long)	Period of Record
CALOshak	Shackleford Banks Dock	34.68692/-76.64364	09/2007 – Present

Continuous Data

Continuously collected data include water temperature, dissolved oxygen, salinity, pH, depth, turbidity, and specific conductance (Gregory et al. 2013). Readings for these parameters are collected at 15-minute intervals using YSI data sondes (Model 6600) which are deployed in 3-5 week intervals depending on routine instrument maintenance schedules. The data collection platform at CALOshak consists of a 4-inch diameter PVC tube attached vertically to a piling on the Shackleford Banks Dock with the sonde suspended within and approximately one meter from the bottom. Water is allowed to freely circulate via openings cut into the PVC housing. A carriage bolt is inserted through the housing at the submerged end to prevent instrument loss should the attachment hardware fail. Anti-fouling paint is used on the PVC tube to extend deployment intervals which are sometimes shortened due to excessive biofouling. The sonde probe guard is covered with plastic mesh to prevent fish, crabs, and detritus from entering the sensor area which could skew measurements or damage the instrument's probes. Figure 2 shows a photo of the station and additional details on site selection and installation procedures are reported by Gregory et al. (2013).

Prior to deployment, the data sonde is calibrated according to YSI recommendations (YSI 2011) for dissolved oxygen, specific conductance (for salinity measurements), pH (two-point calibration), depth, and turbidity (two-point calibration) with additional instructions provided in Gregory et al. (2013). After instrument retrieval, data sondes are returned to the laboratory where post-deployment readings are made using calibration standards to evaluate the accuracy and validity of the data collected for that deployment period. All pre-deployment and post-retrieval calibration information is recorded on calibration data sheets that are archived at SECN office locations. After post-retrieval processing is complete, the sonde is cleaned, reconditioned, and readied for redeployment with methods outlined by YSI (2011). Performance specifications of the YSI 6600 are shown in Table 2.

Data generated during the deployment period are reviewed and certified by SECN staff prior to being made available to park staff. During the data review process data may be flagged (marked as suspect) for a variety of reasons including: the presence of heavy fouling on equipment, lack of post-calibration data, readings outside of equipment specifications, calibration errors, and extended deployment times. All flagged data remain in the data set, but are excluded from analyses and reports. Water quality data are not corrected, however missing periods of data may result from problems such as probe failures that cause complete loss of data. A daily mean is not calculated when the percentage of flagged or missing data exceeds 25% of the total expected data for the day.



Figure 2. Photo of continuous data collection station at Shackleford Banks Dock (CALOshak) at Cape Lookout National Seashore. Photo by John Fear, NCNERR staff.

Table 2. Performance specifications of YSI 6600 EDS data loggers deployed at the continuous monitoring site (YSI 2011).

Parameter	Range	Resolution	Accuracy
Temperature	-5–50 °C	0.01 °C	+/- 0.15°C
Dissolved Oxygen (% saturation)	0–500%	0.1%	0 to 200%: +/- 2% of reading or 2% air saturation, whichever is greater
Dissolved Oxygen (mg/L)	0–50 mg/L	0.01 mg/L	0 to 20 mg/L: +/- 2% of reading or 0.2 mg/L whichever is greater
Salinity	0–70 ppt	0.01 ppt	+/- 1% of reading or 0.1 ppt, whichever is greater
Conductivity	0–100 mS/cm	0.001 to 0.1 mS/cm; range dependent	+/- 0.5% of reading + 0.001 mS/cm
pH	0 to 14 units	0.01 units	+/- 0.2
Depth	0–9 m (0–30 ft)	0.001m (0.001ft)	+/- 0.018m (+/- 0.06 ft.)
Turbidity	0–1000 NTU	0.1 NTU	+/- 2% of reading or 0.3 NTU, whichever is greater

Discrete Data

Water sample collection for this project is conducted by NCNERR staff, usually at the time of routine station maintenance. Secchi depth is measured using standard equipment; an 8-inch diameter black and white Secchi disk. Water samples are collected as grabs in clean, field-rinsed sample containers. Samples are filtered using a 0.45-micron filter prior to preservation. Water samples and chlorophyll *a* filters are shipped to water quality analysis labs on wet ice. Quality Control procedures include the collection of both field blanks and duplicates. Original chain of custody paperwork accompanies all samples to the laboratory. Data collection standard operating procedures are further documented in (Gregory et al. 2013). Samples were analyzed by Chesapeake Biological Laboratory in Solomons, Maryland.

Water clarity scores and water clarity conditions were derived from estimated light attenuation coefficients (k) using the equation: $k = a / Z_{\text{Secchi}}$, where Z is Secchi depth, in meters and a is assigned to one of three values depending on the water body's naturally occurring clarity conditions ($a = 1.0$ for naturally turbid conditions, $a = 1.4$ for moderately turbid conditions, or $a = 1.7$ for clear water estuaries). Constants used for CALO are 1.4 (Lisa Smith 2009, USEPA personal communication) and were estimated for each water clarity class based on values reported by Smith et al. (2006). This method of estimating water clarity condition is generally used when information on water column light transmission is missing; the SECN is reporting derived values for data consistency among other Network parks and recently collected datasets where water column light transmission information was not collected.

Assessment Criteria

Water quality was assessed for each of the parameters following the East/Gulf Coast site criteria in USEPA's National Coastal Assessment IV Report (Table 3) using data from the monthly samples. The categorical assessments (i.e., *good*, *fair*, and *poor*) use measurements of water clarity, chlorophyll *a*, dissolved oxygen and nutrients and are intended to highlight a range of conditions including acutely degraded water quality conditions. Light attenuation coefficients (k) were used to assess water clarity conditions using criteria categories in Smith et al. (2006) which are equivalent to the USEPA criteria for the assessed water bodies (USEPA 2012).

Table 3. USEPA (2012) coastal water quality monitoring condition criteria for water quality parameters collected by the Southeast Coast Network.

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

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 USEPA (2012) criteria for the assessed water bodies.

Results

Continuous Data

Daily averages for individual parameters are shown in Figures 3-8. Key findings summarized by month include:

- Monthly mean water temperatures at CALOshak ranged from 8.5°C in January 2009 to 27.7°C in August 2009. Individual readings ranged from 4.5°C to 32.1°C overall.
- Mean monthly dissolved oxygen levels ranged from 6.50 mg/L in August 2008 to 8.70 mg/L in February 2009, with December and January 2009 not having enough data to compute monthly means. Individual readings ranged from 3.96 mg/L to 12.15 mg/L.
- Mean monthly salinity levels ranged from 31.70 ppt in December 2009 to 38.80 ppt in July 2009. Individual readings ranged from a low of 23.05 ppt to a high of 39.58 ppt.
- Mean monthly pH levels ranged from 7.87 to 8.20, with an individual low of 7.73 and did not exceed 8.33 across the entire data record.
- Turbidity ranged from 1.9 NTU in August 2009 to a high of 17.3 NTU in November 2008, with August of 2008 not having enough data to compute a monthly average. Individual readings ranged from 0.0 to 218.4.
- For each parameter, monthly minimum and maximum values with mean and standard deviation are given in Table 4 below. No data were collected in February, September, or December 2008. Percentage of expected count indicates the level of completeness of the monthly data sets used for calculating mean, maximum, and minimum statistics and equals the number of data points collected (i.e., not missing or flagged) divided by the total number of expected points for a complete month of data. For months where all of the data were either missing and/or flagged, the percentage of values is 0% and no statistics (mean, maximum, or minimum) are presented. When the percentage values are low, the statistics (mean, maximum, and minimum) may be less informative than for months where all or nearly all of the data were used in the calculation of summary statistics. For daily averages, days containing less than 75% of all possible data points do not have a daily average computed.

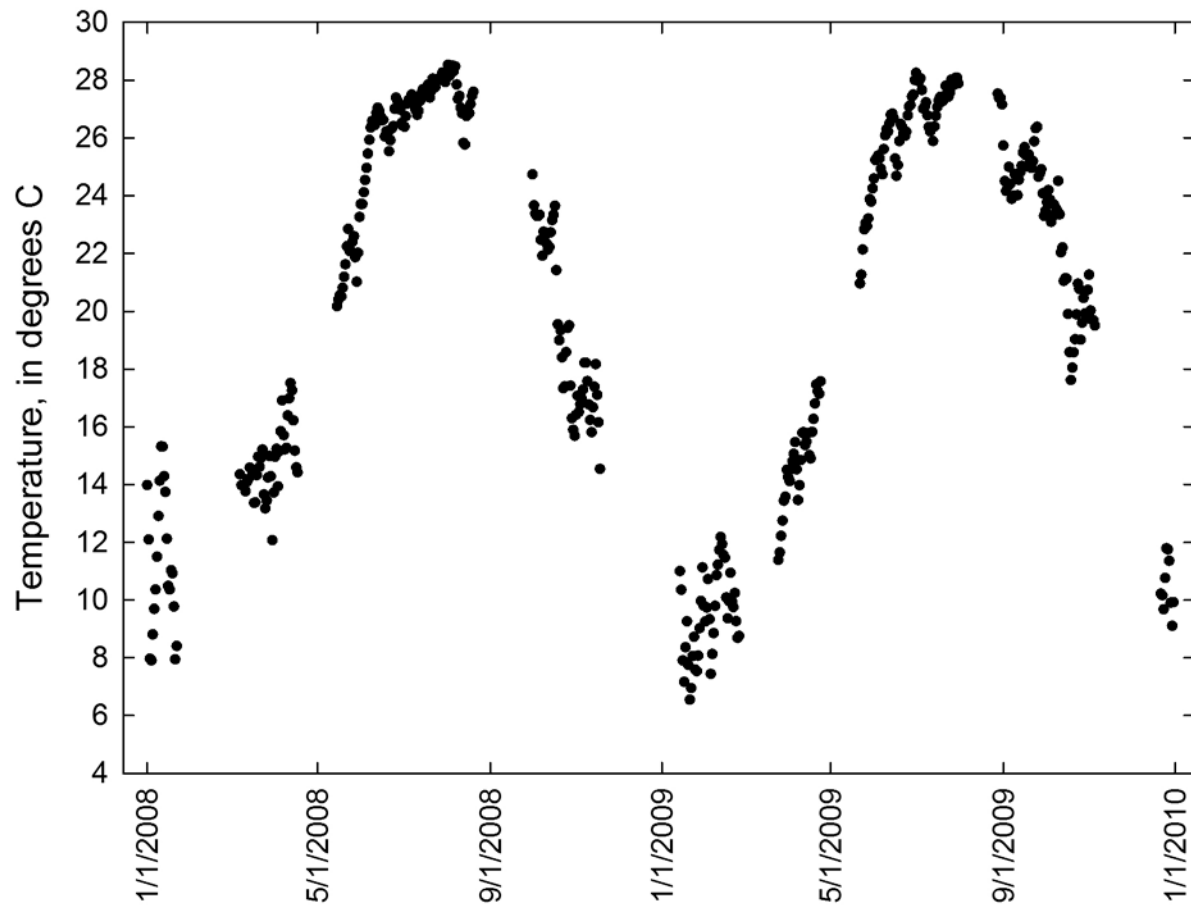


Figure 3. Mean daily values for water temperature at Shackleford Banks (CALOshak) at Cape Lookout National Seashore during 2008-2009. Breaks in the data record indicate missing or flagged data.

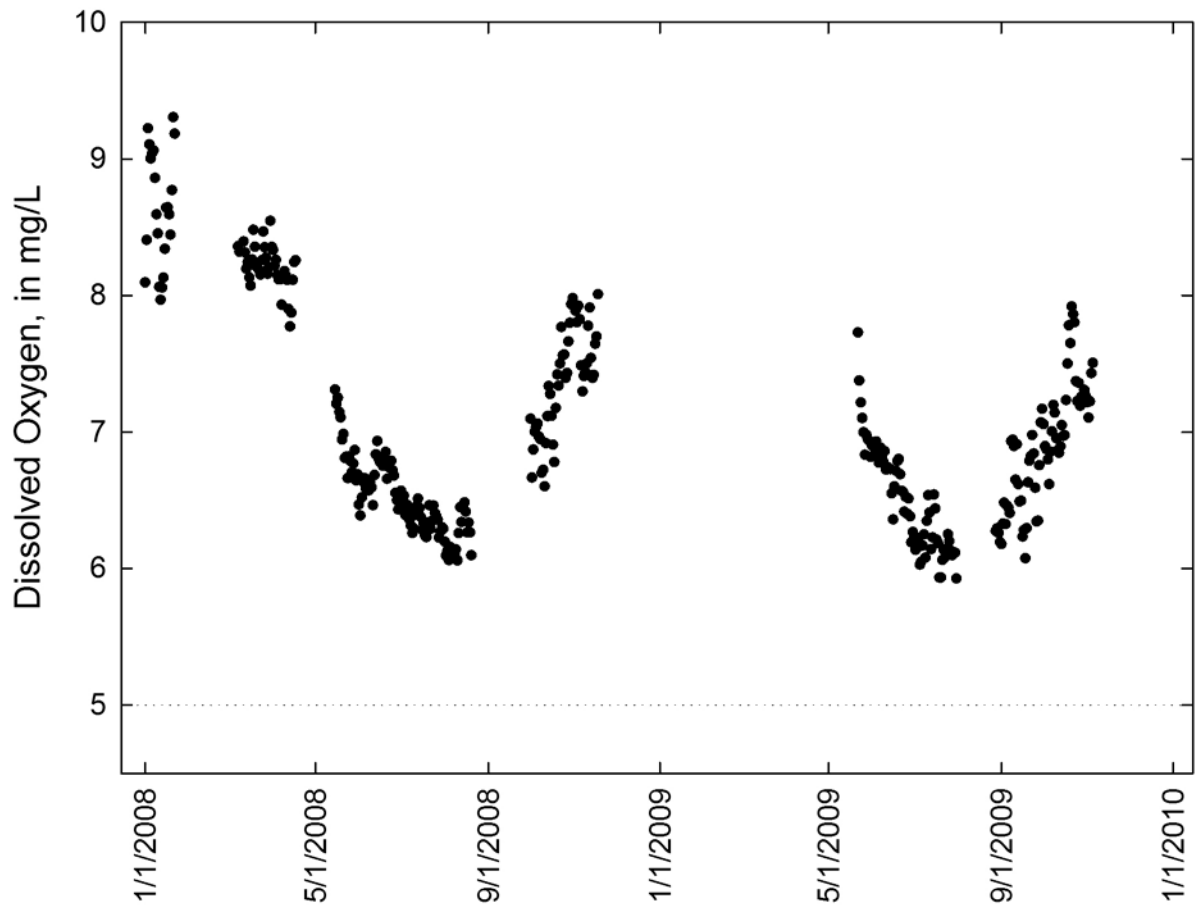


Figure 4. Mean daily values for dissolved oxygen at Shackleford Banks (CALOshak) at Cape Lookout National Seashore during 2008-2009. Breaks in the data record indicate missing or flagged data. Concentrations above 5 mg/L are considered *good* based on EPA National Coastal Assessment Criteria.

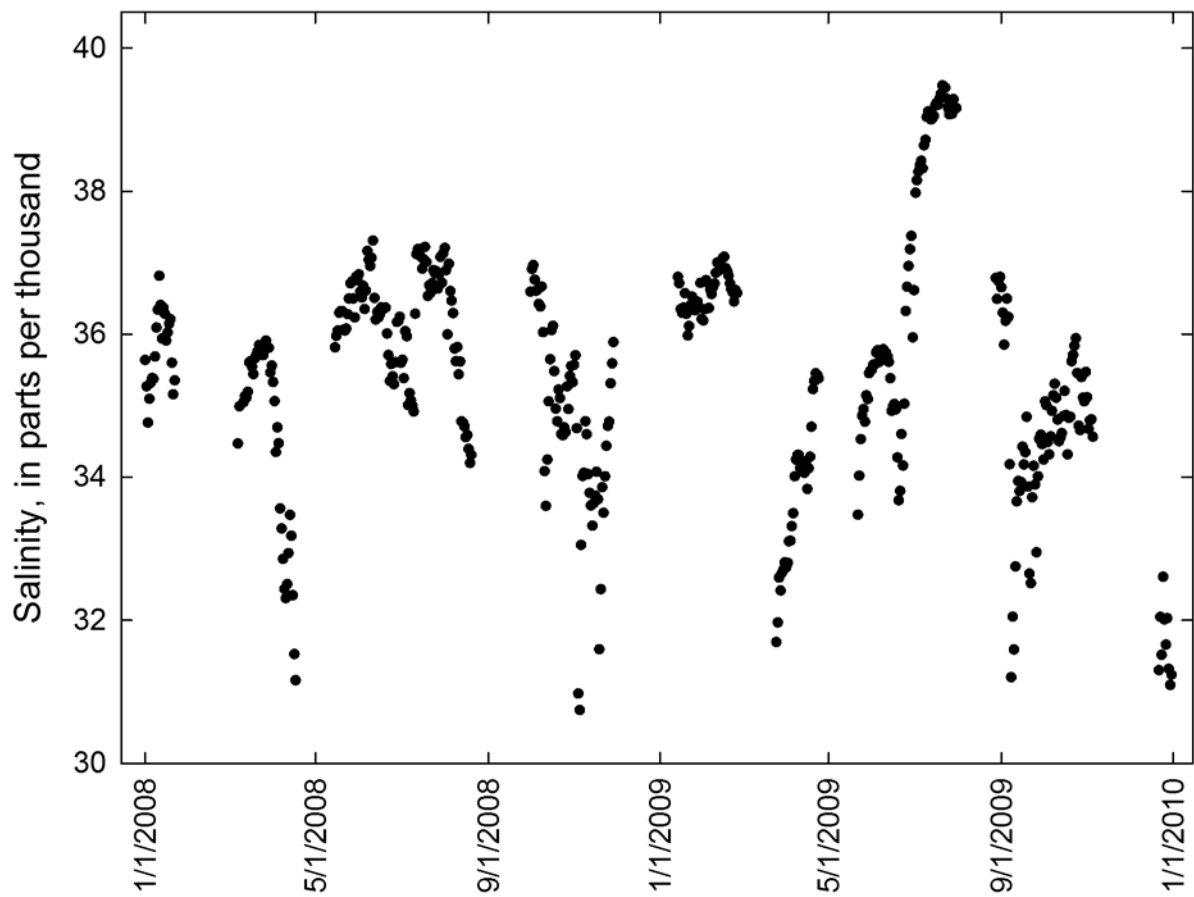


Figure 5. Mean daily values for salinity at Shackleford Banks (CALOshak) at Cape Lookout National Seashore during 2008-2009. Breaks in the data record indicate missing or flagged data.

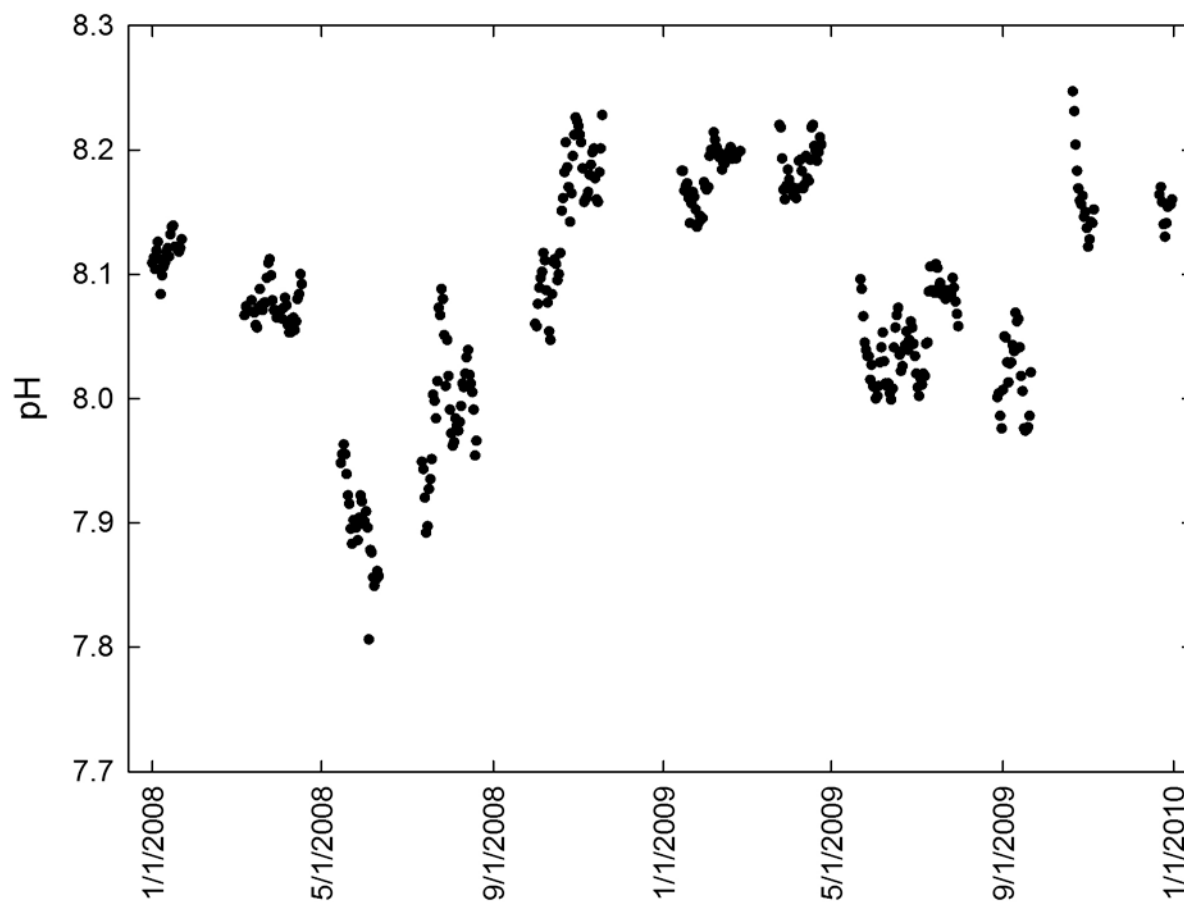


Figure 6. Mean daily values for pH at Shackleford Banks (CALOshak) at Cape Lookout National Seashore during 2008-2009. Breaks in the data record indicate missing or flagged data.

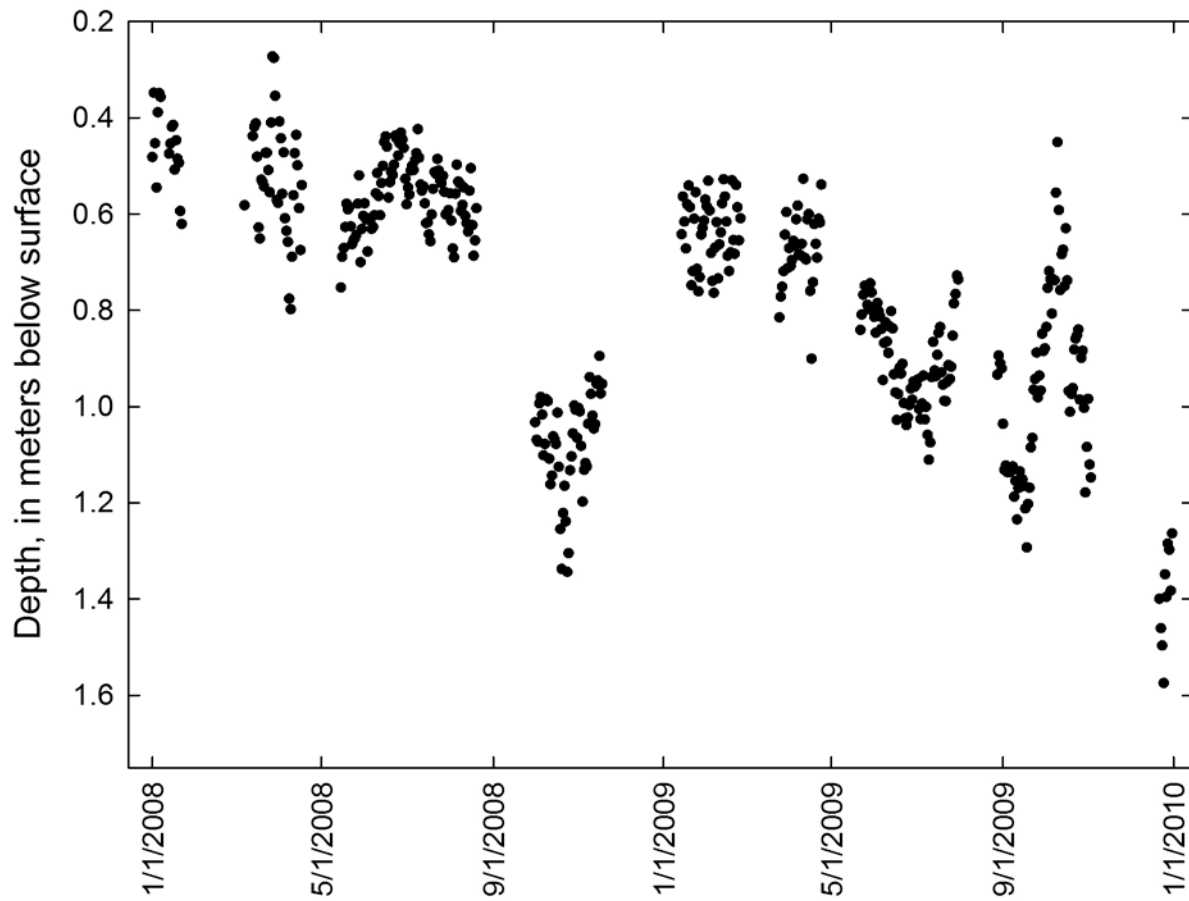


Figure 7. Mean daily values for depth at Shackleford Banks (CALOshak) at Cape Lookout National Seashore during 2008-2009. Breaks in the data record indicate missing or flagged data.

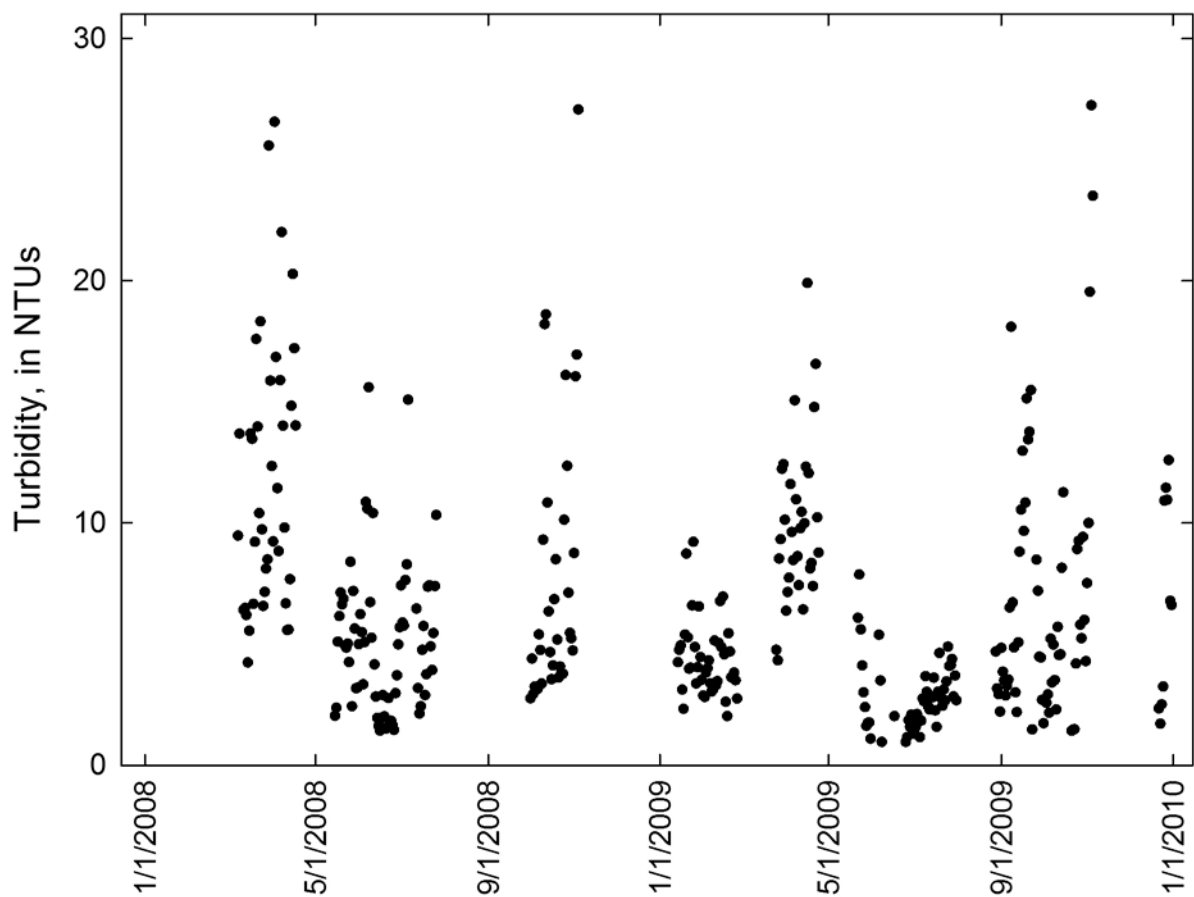


Figure 8. Mean daily values for turbidity at Shackleford Banks (CALOshak) at Cape Lookout National Seashore during 2008-2009. Breaks in the data record indicate missing or flagged data.

Table 4. Monthly minimum, maximum, and mean values for water quality parameters collected at Shackleford Banks Dock (CALOshak) at Cape Lookout National Seashore during 2008-2009. Standard deviations (stdev) are provided in parentheses. Percentage values for each month indicate the number of data points collected during one calendar month of data collection divided by the total number of expected points for a complete month of data. A dash “-” indicates no data.

	Temp (°C)	Dissolved Oxygen (mg/L)	Salinity (ppt)	pH	Depth (m)	Turbidity (NTU)
January 2008 (Expected count 2,976)						
Actual Count	1,970	1,970	1,969	1,969	1,694	166
Minimum	5.08	7.51	33.090	7.79	0.001	0.00
Mean (stdev)	11.4 (2.6)	8.6 (0.5)	35.8 (1.0)	8.12 (0.03)	0.5 (0.3)	8.6 (18.5)
Maximum	17.26	12.15	37.27	8.19	1.16	198.80
Percentage	66%	66%	66%	66%	57%	6%
February 2008 (No data collected)						
March 2008 (Expected count 2,976)						
Actual Count	2,225	2,225	2,225	2,225	2,079	2,225
Minimum	11.02	7.31	33.380	7.99	0.001	2.80
Mean (stdev)	14.0 (1.0)	8.3 (0.2)	35.5 (0.5)	8.08 (0.02)	0.5 (0.3)	11.2 (8.3)
Maximum	18.00	9.29	36.42	8.18	1.22	96.00
Percentage	75%	75%	75%	75%	70%	75%
April 2008 (Expected count 2,880)						
Actual Count	2,863	2,849	2,863	2,863	2,819	2,862
Minimum	12.30	6.60	26.640	7.83	0.001	1.80
Mean (stdev)	17.0 (2.1)	7.9 (0.4)	32.9 (1.6)	8.03 (0.05)	0.5 (0.3)	10.7 (11.1)
Maximum	23.92	9.17	35.81	8.16	1.50	218.40
Percentage	99%	99%	99%	99%	98%	99%
May 2008 (Expected count 2,976)						
Actual Count	2,970	2,970	2,970	2,970	2,812	2,947
Minimum	16.95	5.15	32.190	7.73	0.004	0.90
Mean (stdev)	21.0 (1.5)	7.1 (0.4)	35.1 (1.3)	7.94 (0.04)	0.6 (0.3)	7.1 (12.9)
Maximum	25.51	8.03	37.44	8.05	1.33	210.00
Percentage	100%	100%	100%	100%	94%	99%
June 2008 (Expected count 2,880)						
Actual Count	2,828	2,828	2,824	1,051	2,803	2,822
Minimum	21.94	4.86	27.330	7.73	0.001	0.30
Mean (stdev)	26.2 (1.2)	6.7 (0.4)	36.3 (0.7)	7.87 (0.03)	0.5 (0.3)	4.4 (7.0)
Maximum	29.17	8.52	38.27	7.98	1.34	175.50
Percentage	98%	98%	98%	36%	97%	98%

Table 4. Continued.

	Temp (°C)	Dissolved Oxygen (mg/L)	Salinity (ppt)	pH	Depth (m)	Turbidity (NTU)
July 2008 (Expected count 2,976)						
Actual Count	2,949	2,948	2,949	1,978	2,878	2,040
Minimum	25.52	3.96	27.410	7.75	0.001	1.00
Mean (stdev)	27.5 (0.8)	6.4 (0.4)	36.4 (0.9)	7.99 (0.07)	0.5 (0.3)	6.0 (6.8)
Maximum	30.84	7.55	37.44	8.17	1.22	128.70
Percentage	99%	99%	99%	66%	97%	69%
August 2008 (Expected count 2,976)						
Actual Count	1,887	1,887	1,887	1,887	1,871	0
Minimum	24.12	4.24	32.820	7.84	0.002	-
Mean (stdev)	27.5 (1.1)	6.2 (0.5)	35.6 (1.1)	7.99 (0.04)	0.6 (0.3)	-
Maximum	32.14	7.35	37.30	8.11	1.27	-
Percentage	63%	63%	63%	63%	63%	0%
September 2008 (No data collected)						
October 2008 (Expected count 2,976)						
Actual Count	2,914	2,913	2,914	2,914	2,914	2,912
Minimum	12.37	5.57	30.320	7.98	0.394	0.70
Mean (stdev)	20.8 (2.8)	7.2 (0.5)	35.5 (1.4)	8.1 (0.1)	1.1 (0.3)	6.7 (5.8)
Maximum	25.49	9.00	37.77	8.27	1.94	64.10
Percentage	98%	98%	98%	98%	98%	98%
November 2008 (Expected count 2,880)						
Actual Count	1,771	1,771	2,694	1,771	1,771	386
Minimum	9.80	6.05	23.050	8.11	0.093	1.70
Mean (stdev)	16.8 (1.4)	7.7 (0.4)	33.9 (1.6)	8.2 (0.0)	1.0 (0.3)	17.3 (16.6)
Maximum	19.40	8.80	36.56	8.26	1.80	159.40
Percentage	61%	61%	94%	61%	61%	13%
December 2008 (No data collected)						
January 2009 (Expected count 2,976)						
Actual Count	1,674	0	1,674	1,674	1,674	1,674
Minimum	4.45	-	34.910	8.09	0.031	1.40
Mean (stdev)	8.5 (1.6)	-	36.4 (0.5)	8.2 (0.0)	0.6 (0.3)	5.0 (3.0)
Maximum	13.25	-	37.75	8.22	1.33	26.30
Percentage	56%	0%	56%	56%	56%	56%
February 2009 (Expected count 2,688)						
Actual Count	2,688	328	2,688	2,688	2,657	2,688
Minimum	5.07	8.09	33.500	8.13	0.001	0.90
Mean (stdev)	10.1 (1.4)	8.7 (0.3)	36.7 (0.4)	8.2 (0.0)	0.7 (0.3)	3.8 (2.8)
Maximum	14.14	9.56	37.42	8.24	1.40	55.00
Percentage	100%	12%	100%	100%	99%	100%
March 2009 (Expected count 2,976)						

Table 4. Continued.

	Temp (°C)	Dissolved Oxygen (mg/L)	Salinity (ppt)	pH	Depth (m)	Turbidity (NTU)
Actual Count	2,972	2,339	2,972	2,972	2,972	2,971
Minimum	5.61	7.23	28.360	8.08	0.086	1.10
Mean (stdev)	11.7 (1.7)	8.6 (0.3)	34.2 (2.1)	8.2 (0.0)	0.9 (0.4)	5.2 (4.5)
Maximum	18.65	10.09	37.08	8.33	1.70	66.40
Percentage	100%	79%	100%	100%	100%	100%
April 2009 (Expected count 2,880)						
Actual Count	2,864	597	2,864	2,864	2,863	2,864
Minimum	11.41	6.72	31.760	8.12	0.001	0.90
Mean (stdev)	16.5 (2.4)	7.9 (0.4)	34.3 (0.9)	8.2 (0.0)	0.7 (0.3)	9.1 (5.3)
Maximum	23.80	8.43	36.19	8.28	1.51	58.90
Percentage	99%	21%	99%	99%	99%	99%
May 2009 (Expected count 2,976)						
Actual Count	2,975	2,969	2,975	2,975	2,975	2,894
Minimum	14.40	5.50	30.000	7.87	0.128	0.00
Mean (stdev)	21.6 (1.9)	7.3 (0.4)	35.4 (1.0)	8.1 (0.1)	0.8 (0.3)	4.9 (6.3)
Maximum	25.73	8.70	36.50	8.31	1.53	151.90
Percentage	100%	100%	100%	100%	100%	97%
June 2009 (Expected count 2,880)						
Actual Count	2,879	2,876	2,879	2,879	2,879	1,647
Minimum	22.45	4.15	32.770	7.88	0.248	0.00
Mean (stdev)	26.1 (1.1)	6.7 (0.5)	35.5 (0.9)	8.0 (0.0)	0.9 (0.3)	1.9 (2.3)
Maximum	29.26	7.71	37.60	8.17	1.77	38.10
Percentage	100%	100%	100%	100%	100%	57%
July 2009 (Expected count 2,976)						
Actual Count	2,974	2,915	2,974	2,915	2,974	2,964
Minimum	24.21	4.27	35.040	7.87	0.250	0.10
Mean (stdev)	27.4 (0.9)	6.2 (0.4)	38.8 (0.8)	8.1 (0.0)	0.9 (0.3)	2.9 (4.8)
Maximum	30.30	7.40	39.58	8.16	1.68	111.00
Percentage	100%	98%	100%	98%	100%	100%
August 2009 (Expected count 2,976)						
Actual Count	1,252	350	1,252	350	1,252	1,064
Minimum	26.07	5.31	33.900	7.94	0.322	0.00
Mean (stdev)	27.7 (0.6)	6.3 (0.2)	36.1 (0.4)	8.0 (0.0)	0.7 (0.2)	1.9 (4.3)
Maximum	29.53	6.67	37.17	8.07	1.36	128.70
Percentage	42%	12%	42%	12%	42%	36%

Table 4. Continued.

	Temp (°C)	Dissolved Oxygen (mg/L)	Salinity (ppt)	pH	Depth (m)	Turbidity (NTU)
September 2009 (Expected count 2,880)						
Actual Count	2,879	2,866	2,879	2,076	2,879	2,778
Minimum	22.03	4.76	25.120	7.79	0.512	0.00
Mean (stdev)	24.9 (1.0)	6.6 (0.5)	34.1 (2.1)	8.0 (0.0)	1.1 (0.3)	7.3 (9.2)
Maximum	27.70	8.09	37.30	8.12	1.84	199.00
Percentage	100%	100%	100%	72%	100%	96%
October 2009 (Expected count 2,976)						
Actual Count	2,975	2,975	2,975	1,093	2,975	2,408
Minimum	14.54	5.37	31.530	8.07	0.282	0.00
Mean (stdev)	21.3 (2.2)	7.2 (0.5)	35.0 (0.8)	8.2 (0.0)	0.8 (0.3)	4.7 (5.1)
Maximum	25.44	8.75	36.30	8.30	1.60	132.50
Percentage	100%	100%	100%	37%	100%	81%
November 2009 (Expected count 2,880)						
Actual Count	449	449	449	449	353	448
Minimum	18.15	6.42	32.740	8.04	0.480	2.30
Mean (stdev)	20.1 (0.9)	7.3 (0.4)	34.8 (0.9)	8.1 (0.0)	1.1 (0.4)	17.1 (11.9)
Maximum	22.27	8.37	35.95	8.18	1.83	110.40
Percentage	16%	16%	16%	16%	12%	16%
December 2009 (Expected count 2,976)						
Actual Count	896	0	896	896	896	896
Minimum	7.31	-	27.540	8.09	0.701	0.70
Mean (stdev)	10.5 (1.5)	-	31.7 (2.0)	8.2 (0.0)	1.4 (0.3)	7.2 (6.0)
Maximum	12.95	-	34.33	8.20	2.05	34.00
Percentage	30%	0%	30%	30%	30%	30%

Discrete Data

Monthly water quality data collected at Cape Lookout National Seashore during 2008-2009 are shown in Table 5. Condition categories of assessed parameters from USEPA (2012) except for water clarity which was assessed using light attenuation values (k) derived from Secchi depth readings using a constant for estuarine water with naturally turbid conditions (Smith et al. 2006). In cases when the Secchi disk hit bottom, an accurate (k) value cannot be computed. These values are presented as estimated values. Condition categories generally correspond to those used by USEPA in the National Coastal Condition Report IV (2012). Key findings include:

- Water clarity was *good* with the exception of three months that were *fair* (July and October of 2008 and May of 2009) and one month that was *poor* (March of 2008).
- Chlorophyll *a* levels were *good* for all months but three, which were rated *fair*. Chlorophyll *a* levels ranged from 1.18 μ g/L to 8.32 μ g/L.
- Dissolved oxygen levels were *good* for all months sampled in 2008 and 2009.
- Four samples were analyzed across the two year time span for dissolved inorganic nitrogen and dissolved inorganic phosphorus. The results for all four were *good*.
- Total dissolved nitrogen (TDN) ranged from 0.16 mg/L in March of 2008 to 0.43 mg/L in November of 2009. Total dissolved phosphorus (TDP) ranged from 0.009 mg/L in January of 2008 to 0.024 mg/L in July 2008. There are currently no EPA assessment categories for TDN and TDP.

Table 5. Monthly water quality data collected at Shackleford Banks Dock (CALOshak) at Cape Lookout National Seashore during 2008-2009. Water clarity was assessed using light attenuation values (k) using a constant for estuarine water with naturally turbid conditions (Smith et al. 2006) and assessment categories that correspond to USEPA (2012). Condition of other assessed parameters from USEPA (2012). [Green (■), *good*; yellow (■), *fair*; and red (■), *poor*; k , light attenuation coefficient; $\mu\text{g/L}$, micrograms per liter; mg/L , milligrams per liter; --, missing data or no calculation conducted; *, Secchi disk hit bottom, value estimated or not calculated; Chl, chlorophyll; DO, dissolved oxygen; DIN, dissolved inorganic nitrogen; DIP, dissolved inorganic phosphorus; TDN, total dissolved nitrogen; TDP, total dissolved phosphorus].

Date	Water Clarity (k)	Chl a ($\mu\text{g/L}$)	DO (mg/L)	DIN (mg/L)	DIP (mg/L)	TDN (mg/L)	TDP (mg/L)
1/22/2008	--	3.23	10.6	--	--	0.17	0.009
3/07/2008	2.33	3.91	8.4	--	--	0.16	0.011
4/17/2008	1.56	4.50	8.6	--	--	0.19	0.017
5/15/2008	0.93	2.84	7.3	--	--	0.19	0.012
6/12/2008	--	8.32	6.8	--	--	0.18	0.015
7/11/2008	1.87	4.06	6.2	--	--	0.27	0.024
8/20/2008	--	4.63	7.2	0.011	0.0024	0.31	0.020
10/01/2008	1.87	4.37	7.4	--	--	0.23	0.015
11/19/2008	1.40	5.80	8.7	0.017	0.0041	0.33	0.018
1/14/2009	0.80	3.67	7.4	--	--	0.18	0.010
2/25/2009	0.93	1.18	8.3	0.013	0.0031	0.24	0.013
3/25/2009	0.56	1.36	7.2	--	--	0.32	0.016
4/24/2009	0.88	1.60	8.4	--	--	0.17	0.010
5/22/2009	1.87	4.22	7.8	--	--	0.20	0.011
6/24/2009	0.70	1.88	7.0	--	--	0.23	0.014
7/31/2009	0.93	1.66	5.9	0.023	0.0030	0.26	0.015
8/28/2009	1.24	2.93	5.0	--	--	0.22	0.015
9/22/2009	1.08	6.75	7.1	--	--	0.17	0.013
10/20/2009	1.12	1.70	7.8	--	--	0.29	0.018
11/24/2009	0.70	2.97	--	--	--	0.43	0.016
12/22/2009	0.67	1.38	8.1	--	--	0.27	0.017

Anomalies and Missing Data

The period of data collection presented in this report is from January 1, 2008 at 00:00 through December 31, 2009 at 23:30. Missing or anomalous data during the reporting years may be due to several factors including equipment malfunction, calibration errors, excessive biofouling, or periods of time when the equipment was not deployed (e.g., during extreme storm events or routine equipment swaps). The percentage of total expected data used in analysis of the monthly minimum, maximum, and mean varied across parameters with 81% of water temperature data being used, 67% for dissolved oxygen, 83% for salinity, 71% for pH, 80% for depth, and 68% for turbidity. Missing data were most commonly caused by battery failure or the sonde coming out of the water. No corrections were applied to data as per data analysis procedures prescribed in Gregory et al. (2013). Anomalous and deleted data are shown in Table 6 below.

Table 6. Description of anomalous and deleted data and their associated periods of record for data collection at Shackleford Banks Dock (CALOshak) during 2008-2009.

Parameter	Description	Start Date & Time	End Date & Time
	MISSING DATA	1/22/2008 14:45	3/7/2008 11:00
		8/20/2008 15:45	10/1/2008 15:15
		11/29/2008 2:15	1/14/2009 13:15
		3/25/2009 8:45	3/25/2009 9:30
		5/22/2009 10:15	5/22/2009 10:15
		6/24/2009 14:15	6/24/2009 14:15
		7/31/2009 9:00	7/31/2009 9:00
		8/10/2009 9:30	8/28/2009 8:15
		10/20/2009 14:30	10/20/2009 14:30
		11/5/2009 16:15	12/22/2009 15:45
ALL	Intermittent data were deleted due to YSI 6600 data sonde being out of water. The salinity and dissolved oxygen readings indicated that the sonde was out of water.	1/2/2008 21:30	1/22/2008 14:30
		3/9/2008 2:00	3/23/2008 4:30
		4/2/2008 11:45	4/5/2008 14:30
		4/2/2008 12:45	4/2/2008 12:45
		5/8/2008 16:30	5/8/2008 16:30
		5/31/2008 10:30	6/6/2008 16:45
		6/28/2008 9:30	6/28/2008 9:30
		6/30/2008 11:00	6/30/2008 12:30
		7/1/2008 11:45	7/4/2008 16:00
		7/15/2009 15:45	7/15/2009 15:45
Battery	Data are suspect due to an unknown sonde malfunction.	11/19/2008 10:45	11/29/2008 2:00
	Data were deleted due to unknown sonde malfunction.	4/27/2009 2:15	4/27/2009 6:00
Temp	Data are suspect due to an unknown sonde malfunction.	11/19/2008 10:45	11/29/2008 2:00
	Data were deleted due to unknown sonde malfunction.	4/27/2009 2:15	4/27/2009 6:00
Dissolved Oxygen	Intermittent dissolved Oxygen (DO) readings are suspect because readings are above 120% saturation.	4/10/2008 16:30	4/10/2008 16:30
		4/10/2008 19:15	4/10/2008 20:15
		4/24/2008 14:00	4/24/2008 14:15

Table 6. Continued.

Parameter	Description	Start Date & Time	End Date & Time
Dissolved Oxygen	Intermittent dissolved Oxygen (DO) readings are suspect because readings are above 120% saturation.	4/24/2008 15:00	4/24/2008 16:15
		7/18/2008 13:00	7/18/2008 13:00
		10/14/2008 14:00	10/14/2008 14:00
		4/30/2009 15:45	4/30/2009 16:15
		4/30/2009 16:45	4/30/2009 16:45
		5/12/2009 13:45	5/12/2009 15:00
		6/10/2009 14:15	6/10/2009 14:15
		6/10/2009 15:00	6/10/2009 15:00
		6/10/2009 15:30	6/10/2009 15:30
		9/22/2009 15:15	9/22/2009 15:15
		9/22/2009 15:45	9/22/2009 16:45
		9/23/2009 15:15	9/23/2009 15:15
		9/23/2009 16:30	9/23/2009 16:45
		9/23/2009 17:30	9/23/2009 17:30
		9/23/2009 18:00	9/23/2009 18:30
	Dissolved Oxygen data were marked suspect due to unknown probe malfunction.	1/14/2009 13:30	2/25/2009 13:45
		3/25/2009 9:45	4/24/2009 13:30
		7/31/2009 9:15	8/10/2009 9:15
		12/22/2009 16:00	12/31/2009 0:00
	Data are suspect due to an unknown sonde malfunction.	11/19/2008 10:45	11/29/2008 2:00
	Data were deleted due to unknown sonde malfunction.	4/27/2009 2:15	4/27/2009 6:00
Salinity and Specific Conductance	Data are suspect due to an unknown sonde malfunction.	6/4/2008 13:30	6/4/2008 14:15
		11/19/2008 10:45	11/19/2008 11:15
	Data were deleted due to unknown sonde malfunction.	4/27/2009 2:15	4/27/2009 6:00
pH	pH data were deleted due to probe failure during deployment.	6/12/2008 10:30	6/28/2008 9:15
		6/28/2008 9:45	6/30/2008 10:45
		6/30/2008 12:45	7/1/2008 11:30
		7/1/2008 13:30	7/2/2008 12:30
		7/2/2008 14:30	7/3/2008 13:30
		7/3/2008 15:30	7/4/2008 14:30
		7/4/2008 16:15	7/11/2008 9:15
		10/11/2009 10:00	10/20/2009 14:15
	Data are suspect due to an unknown sonde malfunction.	11/19/2008 10:45	11/29/2008 2:00
		7/31/2009 9:15	8/10/2009 9:15
		9/22/2009 15:15	10/11/2009 9:45
		4/27/2009 2:15	4/27/2009 6:00
Depth	Intermittent depth readings were negative or zero.	1/1/2008 20:00	1/22/2008 14:15
		3/7/2008 13:45	3/28/2008 20:00
		4/4/2008 14:30	4/6/2008 15:30
		4/19/2008 13:15	4/20/2008 14:45
		5/2/2008 10:45	5/12/2008 22:00

Table 6. Continued.

Parameter	Description	Start Date & Time	End Date & Time
Depth		6/15/2008 11:30	6/17/2008 14:00
		6/30/2008 0:15	7/5/2008 17:15
		7/20/2008 16:00	7/20/2008 16:15
		7/23/2008 5:15	7/23/2008 6:00
		7/24/2008 6:00	7/24/2008 7:30
		7/27/2008 9:00	8/2/2008 15:45
		2/8/2009 12:30	2/12/2009 16:45
		4/11/2009 16:00	4/11/2009 16:00
	Data are suspect due to an unknown sonde malfunction.	11/19/2008 10:45	11/29/2008 2:00
	Data were deleted due to unknown sonde malfunction.	4/27/2009 2:15	4/27/2009 6:00
Turbidity	Data are marked suspect due to mount / equipment issues.	11/4/2009 16:15	11/5/2009 16:00
		7/7/2008 0:00	7/11/2008 9:15
		7/27/2008 0:45	8/15/2008 20:30
	Intermittent turbidity readings marked suspect due to heavy fouling on and around probes.	8/15/2008 21:00	8/18/2008 8:45
		8/18/2008 9:15	8/20/2008 15:30
		11/5/2008 0:30	11/19/2008 10:30
		10/15/2009 18:30	10/20/2009 14:15
		5/1/2008 6:15	5/6/2008 9:15
		7/6/2008 19:45	7/10/2008 21:45
		7/27/2008 0:30	8/18/2008 9:00
		11/6/2008 18:00	11/10/2008 14:45
		11/15/2008 1:00	11/15/2008 1:00
	Intermittent turbidity data marked suspect due to spikes of 1000 NTU or higher. Spiking turbidity data could be a result of direct interference from a foreign body and/or the EDS wiper parking over the optics.	11/18/2008 15:15	11/19/2008 7:00
		3/13/2009 20:45	3/13/2009 20:45
		5/22/2009 8:00	5/22/2009 8:00
		6/9/2009 6:45	6/9/2009 6:45
		6/22/2009 16:00	6/23/2009 15:00
		7/3/2009 2:45	7/3/2009 2:45
		7/10/2009 5:00	7/10/2009 5:00
		7/28/2009 4:00	7/28/2009 4:00
		10/29/2009 16:30	10/29/2009 16:30
		1/1/2008 0:00	1/22/2008 14:15
Turbidity		5/16/2009 14:00	5/17/2009 17:30
		5/28/2009 0:00	8/10/2009 9:15
		8/31/2009 5:30	8/31/2009 6:15
	Intermittent turbidity data are marked suspect due to calibration error. Small negative turbidity values indicated a calibration error.	9/5/2009 22:30	9/5/2009 22:45
		9/10/2009 0:00	9/10/2009 0:00
		9/12/2009 1:00	9/12/2009 3:30
		9/23/2009 0:30	9/25/2009 8:00
		9/30/2009 20:15	10/3/2009 2:15
		10/6/2009 23:15	10/6/2009 23:15
		10/8/2009 20:45	10/10/2009 3:15

Table 6. Continued.

Parameter	Description	Start Date & Time	End Date & Time
		10/13/2009 22:15	10/14/2009 4:45
		10/20/2009 11:45	10/20/2009 12:45
	Data are suspect due to an unknown sonde malfunction.	11/19/2008 10:45	11/29/2008 2:00
	Data were deleted due to unknown sonde malfunction.	4/27/2009 2:15	4/27/2009 6:00
		4/15/2008 13:15	4/15/2008 13:15
		5/1/2008 4:30	5/11/2008 4:30
		6/5/2008 13:45	6/5/2008 13:45
		6/8/2008 15:15	6/8/2008 15:15
	Intermittent turbidity data marked suspect due to lone spike, less than 1,000 but more than 200 from previous and following readings.	6/10/2008 23:00	6/11/2008 18:00
		6/18/2008 11:15	6/18/2008 11:15
		7/2/2008 6:00	7/3/2008 21:00
		7/6/2008 7:45	7/6/2008 13:45
		7/14/2008 6:30	7/14/2008 6:30
		10/14/2008 5:15	10/14/2008 5:15
		10/26/2008 23:45	10/26/2008 23:45
		5/11/2009 5:30	5/11/2009 5:30
		5/13/2009 6:45	5/13/2009 6:45
		5/19/2009 10:15	5/19/2009 10:15
		5/20/2009 22:15	5/20/2009 22:15
	Intermittent turbidity data marked suspect due to lone spike, less than 1,000 but more than 200 from previous and following readings.	7/5/2009 0:00	7/5/2009 0:00
		7/12/2009 21:30	7/12/2009 21:30
		7/28/2009 5:30	7/28/2009 5:30
		9/7/2009 2:30	9/7/2009 2:30
		9/19/2009 9:00	9/19/2009 9:00
		9/19/2009 14:00	9/19/2009 14:00
		9/22/2009 14:15	9/22/2009 14:30
		11/5/2009 15:15	11/5/2009 15:15

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