



Fixed-Station Water Quality Monitoring at Cape Lookout National Seashore

Data Summary 2010

Natural Resource Data Series NPS/SECN/NRDS—2012/323



ON THE COVER

Middle Marsh area of the Rachel Carson Reserve. Photograph by John Fear, NCNERR Staff.

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Julie Dingle
National Park Service
Ft. Sumter National Monument
Sullivan's Island, South Carolina 29482

M. Brian Gregory
National Park Service
160 Phoenix Road
Athens, Georgia 30605

Christina Wright
National Park Service
100 Alabama Street
Atlanta, Georgia 30303

Emma Thompson
National Park Service
100 Alabama Street
Atlanta, Georgia 30303

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

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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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 were operational during 2010 at the Shackleford Banks Dock and the Middle Marsh area. Stations collected pH, dissolved oxygen, temperature, salinity, conductivity, turbidity and water level data. Additional water quality measurements were made by NCNERR staff and include monthly measurements of water clarity conditions, total dissolved phosphorus, total dissolved nitrogen, and chlorophyll *a* levels. 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 collects data in the vicinity of nine coastal parks along the southeastern U.S. coast (DeVivo et al. 2008). Information provided by this monitoring program is designed to help managers understanding trends and variability related to water-quality conditions in and around park waters. Summary data are presented in annual data reports published by the SECN. Highlights from the 2010 data record are summarized below.

- Monthly sampling at both stations monitored at Cape Lookout indicated overall *good to fair* water quality conditions. Nutrient levels indicated *fair* levels of both dissolved nitrogen and phosphorus. A single dissolved phosphorus value was elevated and rated as *poor* at CALO 2 in September 2010. All other discreet water quality measurements including those for water clarity, chlorophyll *a*, and dissolved oxygen were within ranges considered *good* by criteria set for coastal waters by the USEPA.
- Continuous data indicated similar trends at both sites with respect to measured water quality parameters. Annual median tidal range at both sites was 1.4 feet with the smallest tidal amplitude occurring between May and August.
- Salinity ranges were typically greater at CALO 2 than at CALO 1 due to CALO 2 being the more inland location and in closer proximity to sources of freshwater inflow. At both sites minimum salinity levels were observed during the winter months when rainfall was highest; salinity peaked during the summer.
- Mean daily dissolved oxygen levels dropped below 5 mg/L on only two days at the CALO 2 station during July and August when water temperatures were at their highest levels. The lowest dissolved oxygen levels observed at both sites occurred during the summer months although no dissolved oxygen levels below 2 mg/L were recorded during 2010 at either site.
- Monthly mean pH values at both sites were near 8.00 with the highest values occurring during the winter months. Presumably due to its more inland location, the CALO 2 station exhibited slightly more monthly variation as well as a stronger seasonal trend.
- Turbidity values were generally correlated with precipitation events at both sites and were typically higher during the winter and spring months and lowest during the summer when rainfall was lowest. An extended period of elevated turbidity occurred just prior to and after the passing of Hurricane Earl during late August.

Introduction

Estuaries are semi-enclosed coastal bodies of water that have free connection with the open sea and within which sea water mixes with fresh water. A key defining feature of an estuary is that it is an interface between sea water and fresh water and there is an influence of the ocean tide creating a dynamic relationship between the two waters. 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 (Weinstein 1979) while providing recreational opportunities including boating, fishing, and bird watching. These areas also contain fragile ecosystems and are vulnerable to impacts caused by uses and changes in the surrounding watersheds.

Impacts to estuarine water may be due to urban and industrial development, including alterations to hydrodynamic processes, exposure to chemical contaminants that cause mortality, altered growth and reduced reproduction, and exposure to frequent and severe hypoxia (Lerberg et al. 2000). Excessive nutrient loading into these systems can cause problems; however, some nutrient inputs to coastal waters are natural and necessary for a healthy, functioning estuarine ecosystem. 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. Excess nutrients can lead to excess plant production, and thus, to increased chlorophyll, which can decrease water clarity and lower concentrations of dissolved oxygen as decomposition occurs. 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 estuarine areas with increased impervious cover in the surrounding watershed, stormwater runoff is flashier and occurs in greater volumes than in undeveloped areas. Hydrologic changes such as these can affect the quality and quantity of freshwater inputs to estuaries, including the introduction of a wide variety of low-level contaminants to water, sediments, and biota (Holland et al. 2004).

Cape Lookout National Seashore (CALO) 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 (Figure 1). 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. CALO extends into the Atlantic Ocean from its southern end. The other barrier system within the Seashore, Shackleford Banks, extends westward from Cape Lookout.

Instead of exhibiting the typical 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 triangular 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. With high dunes significantly reducing overwash, thickets have further stabilized the flats of the Cape's interior. A long spit extends from the western tip of Cape Lookout, where a jetty built in the early 1900s has encouraged accretion in this direction.

Specific issues of concern to CALO include off-road vehicle use and associated impacts to dunes, threatened and endangered species, commercial fishing, military over-flights, and non-native species. Additionally, the Back Sound off Shackleford Banks at Cape Lookout drains the populated areas of Morehead City and Beaufort. Numerous water bodies in the vicinity of the Seashore 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 mercury in fish and elevated bacteria levels. Areas in the Core and Bogue Sounds have also been listed for elevated pathogen levels which have caused shell fishing areas to be closed or only conditionally approved (USEPA 2011).

Purpose and Scope

In 2007, the SECN began a cooperative effort with the NCNERR collecting continuous water quality and monthly nutrient data in the waters around CALO in order to assess water quality conditions and examine trends in temporal variability. This report provides a summary of data collected at two sites (Figure 1; Table 1) during 2010 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. The sites monitored on CALO are part the SECN estuarine water quality monitoring program, which collected data in the vicinity of nine coastal parks located along the Southeastern U.S. coast described by DeVivo et al. (2008).

Table 1. Continuous water quality monitoring sites at Cape Lookout National Seashore during 2010.

Name	Location Description	Location (lat /long)	Period of Record
CALO 01	Shackleford Banks Dock	34.68692/-76.64364	09/2007-Present
CALO 02	Middle Marshes	34.41671/-76.37110	05/2008-Present

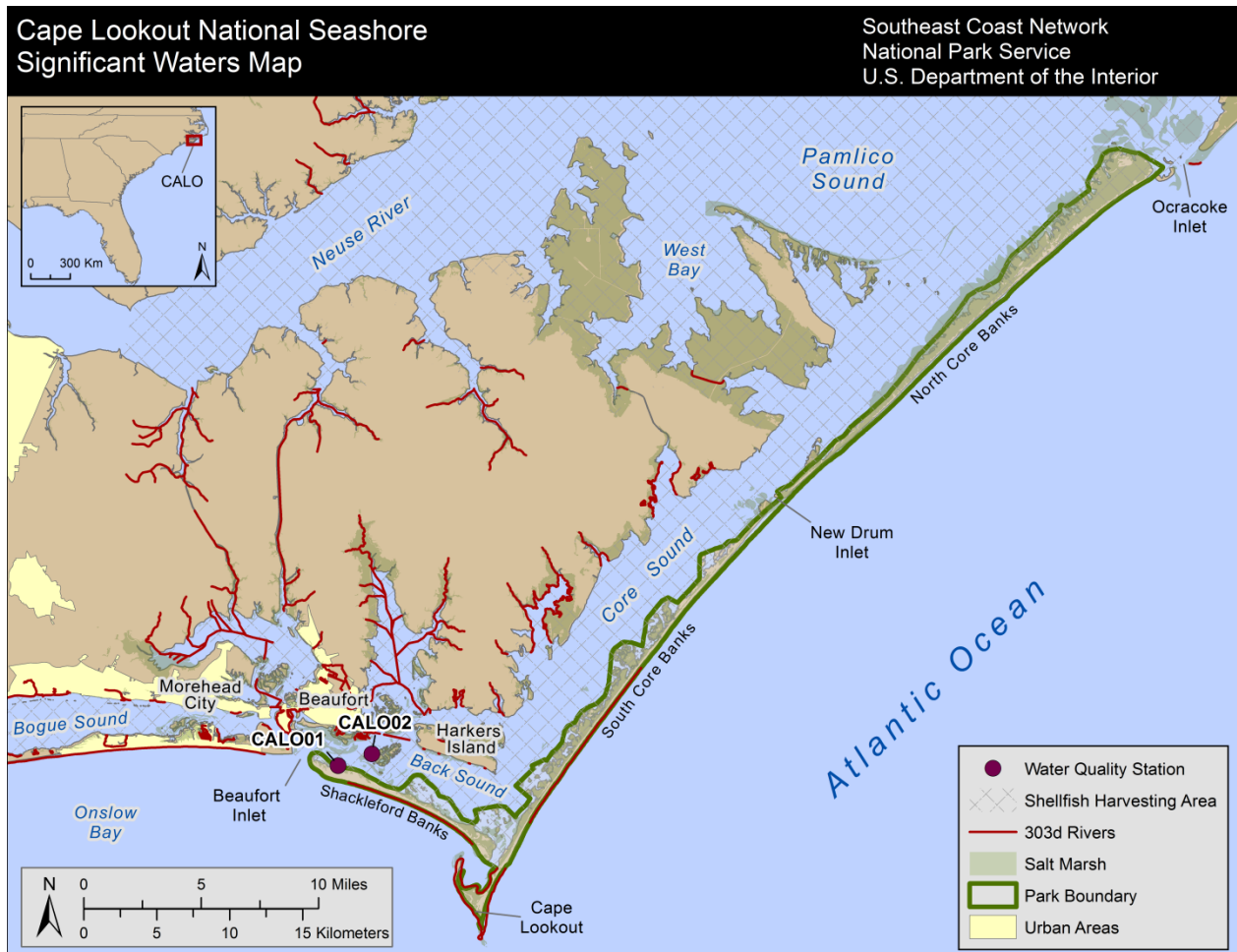


Figure 1. Locations of continuous water quality monitoring stations at Cape Lookout National Seashore, in 2010.

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. (*in review*). Methods for both are briefly summarized in the following sections. Local precipitation and temperature departures (NOAA 2011), daily precipitation data (NCDC 2011) in the vicinity of the park, and relative water levels/tidal amplitude information collected by the SECN are made available in this report to provide additional relevant data to help interpret changes and patterns observed in water quality data.

Continuous Data

Continuously collected data includes dissolved oxygen, pH, specific conductivity, temperature, depth and turbidity. 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 consists of a 4-inch diameter PVC tube attached vertically to pilings or rails of docks with the sonde suspended within and approximately 1 m from the bottom. Water is allowed to freely circulate via openings cut into the PVC housing which are covered with 0.25 inch mesh screen to prevent fish, crabs, and detritus from entering the protective housing which could skew measurements or damage the instrument's probes. A locking cap on the top of the PVC tube prevents unwanted tampering, and a carriage bolt inserted through the housing at the submerged end prevents instrument loss should the attachment hardware fail. Anti-fouling paint and copper tape are used on the sonde probes and the PVC pipe to extend deployment intervals which are sometimes shortened due to excessive biofouling. Due to the shallow waters in the vicinity of the Middle Marsh area, the sonde is not mounted in the standard configuration as described above but is mounted to a submerged platform which holds the sonde above the benthic sediments. Figures 2 and 3 show photos of each station's mounting configuration. Additional details on site selection and installation procedures are reported in Gregory et al. (*in review*).

Prior to deployment, the data sonde is calibrated according to YSI recommendations for pH, dissolved oxygen, specific conductivity, and turbidity (YSI 2006) with additional instructions provided by Gregory et al. (*in review*). 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 deployment with methods outlined by YSI (2006). Performance specifications of the YSI 6600 data loggers 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 depending on the cause, data may be 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.

Table 2. Performance specifications of YSI 6600 EDS data loggers deployed at continuous monitoring site (YSI 2006).

Parameter	Range	Resolution	Accuracy
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.
Conductivity	0–100 mS/cm	0.001 or 0.1 mS/cm; range dependent	+/- 0.5% of reading + 0.001 mS/cm
Temperature	-5–45 °C	0.01 °C	+/- 0.15 °C
pH	0–14 units	0.01unit	+/- 0.2 unit
Depth	0–9 m (0–30 ft)	0.001m (0.001ft)	+/- 0.02m (+/- 0.06 ft.)
Salinity	0–70 ppt	0.01 ppt	+/- 1% of reading or 0.1 ppt, whichever is greater.
Turbidity	0–1000 NTU	0.1 NTU	+/- 5% of reading or 2 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. Measurements including pH, conductivity, dissolved oxygen and turbidity are extracted from sonde readings at time of sampling. Secchi depth is measured as an average of two readings using standard equipment. Water samples are collected as grabs in clean, field rinsed, unpreserved sample containers. Samples are filtrated using a 0.45 micron filter usually within 15 minutes of sample collection and prior to preservation. Samples and chlorophyll *a* filters are shipped to water quality analysis labs on wet ice. QA/QC field sampling includes both field blanks and duplicates. Filtered samples, unfiltered samples and chlorophyll filters are placed on ice prior to shipment for lab analyses. QA/QC sampling includes the use of duplicates samples. Original chain of custody paperwork accompanies all samples to the laboratory. Data collection standard operating procedures are further documented in Gregory (*in review*). Samples were analyzed by Chesapeake Biological Laboratory in Solomons, Maryland.

Water clarity index 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 bodies' 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 Cape Lookout 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 are 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.



Figure 2. Photo of continuous data collection station at Shackleford Banks Dock (CALO 01) at Cape Lookout. Photo by John Fear NCNERR staff.



Figure 3. Photo of continuous data collection station in Middle Marshes (CALO 02) at Cape Lookout. Photo by John Fear, NCNERR staff.

Assessment Criteria

Water quality condition was assessed monthly using data collected at the time of sampling for chlorophyll *a*, nutrients, dissolved oxygen and water clarity following the East/Gulf Coast site criteria in EPA's National Coastal Assessment II Report (USEPA 2005). The categorical assessments (i.e., *Good*, *Fair*, and *Poor*) use measurements of chlorophyll *a*, nutrients, dissolved oxygen and water clarity (Table 3) and are intended to characterize acutely degraded water quality conditions and does not consistently identify a location experiencing occasional or infrequent hypoxia, nutrient enrichment, or decreased water clarity. As a result, a rating of *Poor* for the water quality index means that the site is likely to have consistently exhibited *Poor* conditions before or after the assessment period. If a site is designated as *Fair* or *Good*, the site did not experience *Poor* condition on the date sampled, but could be characterized by *Poor* conditions for short time periods. 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.

Table 3. USEPA (2005) coastal water quality monitoring condition criteria for water quality parameters collected by the Southeast Coast Network.

Rating	Water Clarity ¹ (k)	Chlorophyll a (ug/L)	Total Dissolved Nitrogen (mg/L)	Total Dissolved Phosphorus (mg/L)	Dissolved Oxygen (mg/L)
Good	<2.3	<5	<0.1	<0.01	>5
Fair	2.30–2.99	5–20	0.1–0.5	0.01–0.05	2–5
Poor	>2.99	>20	>0.5	>0.05	<2

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 criteria for the assessed water.

Results

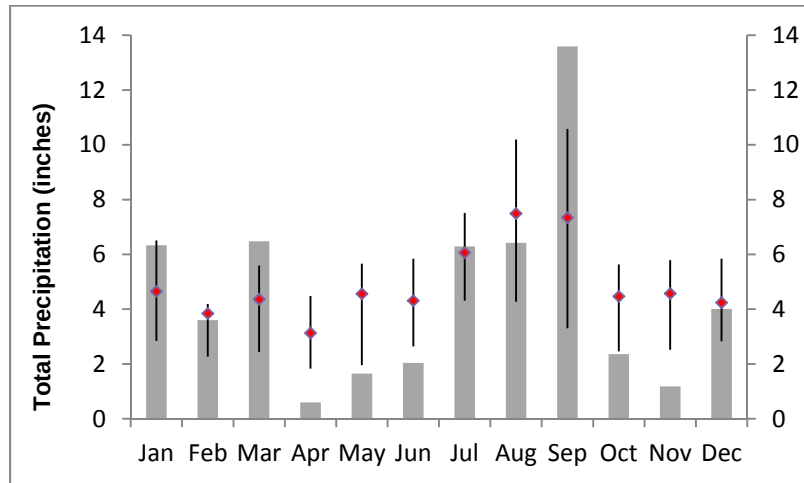
Climate Overview

Regional climate overviews are included in this report as an aid to interpreting water quality results and were collected either at Morehead City 2WNW and Ocracoke by the COOP (<http://www.ncdc.noaa.gov/oa/ncdc.html>). The Morehead City 2WNW and Ocracoke stations are located 4.8 miles WSW and 4 miles NE, respectively, from CALO. These data are presented as monthly precipitation and temperature departures from normal for the period 1981–2010 (Figure 4). Precipitation and temperature departure graphs were made using Climate Data Screener and Summarizer software (Tercek 2011). Daily precipitation at the Morehead City and Ocracoke weather stations are shown in Figure 5.

Temperature departures were greatest during December where maximum and minimum temperatures were cooler than normal (Wright et al. 2012). Summer minimum and maximum temperatures ranged from near normal to slightly above normal in the vicinity of Cape Lookout. Average monthly precipitation was generally above average during the late winter and September and below normal for the rest of the year (Figure 4).

Overall during 2010, the Southeastern U.S. region experienced a relatively calm hurricane year with normal, to slightly cooler than normal winter months and warmer than average summer months. The only hurricane to threaten CALO during 2010 was Hurricane Earl which weakened as its center gradually curved to the northeast and tracked just off the Atlantic coast and passed approximately 100 miles off the coast of the Outer banks between August 25 and September 4, 2010. Hurricane Earl caused only minor damage due to winds and flooding from the storm surge.

A.



B.

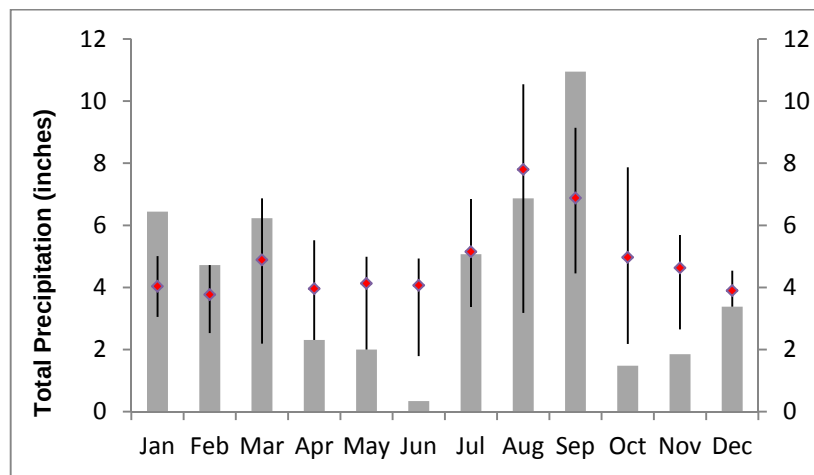


Figure 4. Total monthly precipitation during 2010 and the 30-year (1981 - 2010) monthly averages for **A.** Morehead City and **B.** Ocracoke stations. The gray columns represent 2010 total monthly precipitation. The red circles represent the 30-year average; the lines indicate the 25th and 75th percentile of the 30-year normal data for each month.

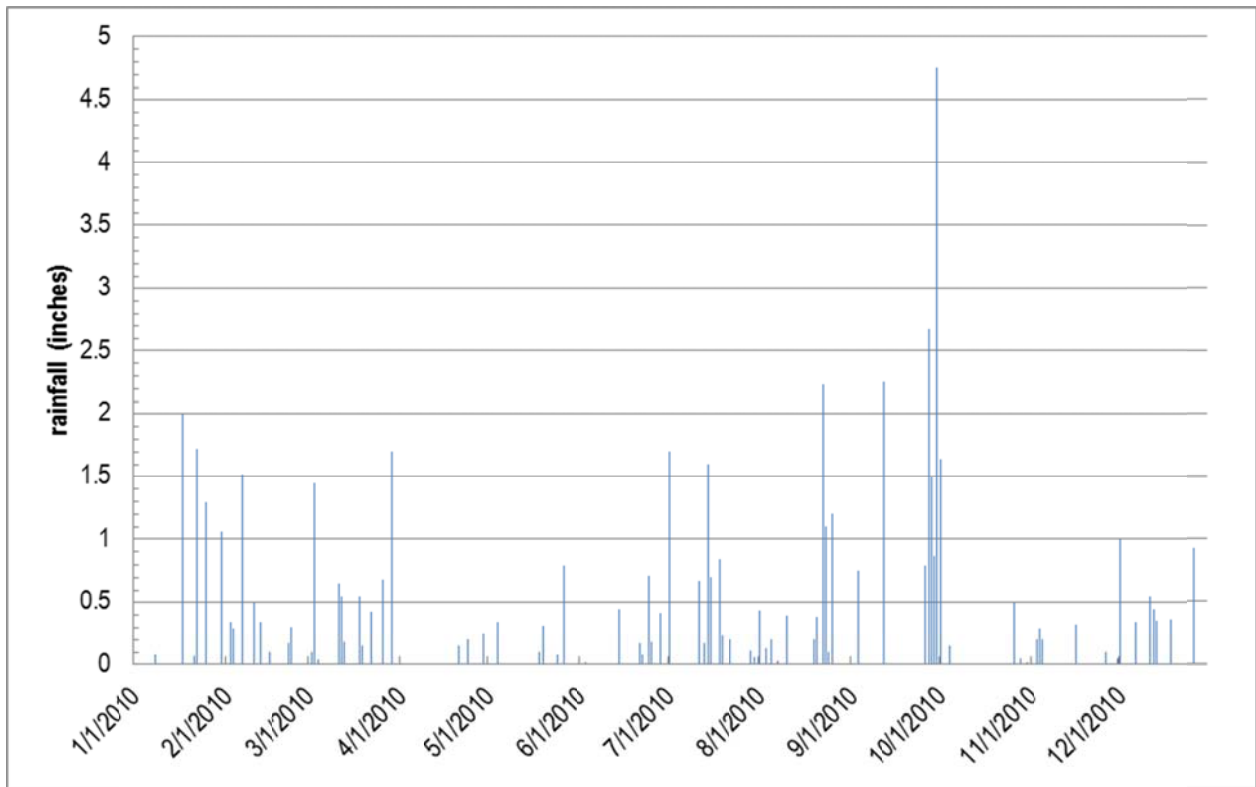


Figure 5. Daily precipitation at Morehead City during 2010 Data sources: Morehead City 2WNW (NOAA 2011).

Anomalies and Missing Data

Table 4 provides a chronological listing of parameters affected by data anomalies and descriptions for possible error sources. Periods of time with missing data may be due to several factors, including equipment malfunction, operator error or personnel issues. No corrections were applied to data.

Table 4. Description of anomalous and deleted data and associated periods of record for the data collection platforms at Cape Lookout National Seashore during 2010.

Parameters Affected	Anomaly Description	Start DateTime	End DateTime
CALO 02			
pH	Data are suspect due to an unknown sonde malfunction.	12/3/2010 9:44	12/31/2010 23:45
Specific Conductance	Data are marked suspect due to heavy fouling.	9/9/2010 17:45 11/1/2010 1:30	9/21/2010 23:45 12/3/2010 9:15
All	All data are marked suspect due to a calibration error.	3/2/2010 8:45 1/1/2010 0:00 9/24/2010 15:30	3/5/2010 13:15 1/27/2010 11:30 9/24/2010 15:30
Turbidity	Data marked suspect due to optical wiper malfunction.	10/26/2010 15:45	10/27/2010 14:45
		11/1/2010 16:30	11/1/2010 16:30
		11/13/2010 9:30	12/3/2010 9:15
	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.	2/2/2010 9:30	2/6/2010 1:00
		5/27/2010 12:45	7/1/2010 14:45
		8/9/2010 23:00	8/10/2010 9:30
		8/9/2010 10:00	8/9/2010 10:00
		8/16/2010 0:30	8/16/2010 3:15
		8/19/2010 16:30	8/19/2010 16:30
		8/20/2010 18:45	8/20/2010 18:45
		12/17/2010 15:30	12/17/2010 15:30
		12/20/2010 16:30	12/20/2010 16:30
		12/20/2010 17:45	12/20/2010 17:45
		12/20/2010 19:00	12/20/2010 19:00
	Turbidity readings marked suspect due to heavy fouling on and around probes during deployment.	7/22/2010 17:30	7/28/2010 13:15
		9/19/2010 1:15	9/21/2010 23:45

Table 4. Continued.

Parameters Affected	Anomaly Description	Start DateTime	End DateTime
CALO 01			
Dissolved Oxygen	Data are suspect due to an unknown sonde malfunction.	2/23/2010 10:15 12/22/2009 16:00	3/25/2010 9:15 1/27/2010 10:30
pH	Data are suspect due to an unknown sonde malfunction.	2/23/2010 10:15	3/16/2010 16:15
	Data are suspect due to an unknown sonde malfunction.	3/25/2010 10:00	4/21/2010 9:15
	pH data were deleted due to probe failure during the deployment.	1/27/2010 11:45	2/23/2010 10:00
Salinity	Data are marked suspect due to a malfunctioning temperature probe.	10/27/2010 13:45	11/25/2010 2:15
	Data are marked suspect due to heavy fouling.	9/3/2010 0:00	9/28/2010 14:45
Salinity, Turbidity	Data are suspect due to an unknown sonde malfunction.	5/27/2010 12:30	7/1/2010 14:30
Specific Conductance	Data are suspect due to an unknown sonde malfunction.	5/27/2010 12:30	7/1/2010 14:30
All	Data were deleted due to a temperature probe failure.	11/25/2010 2:30	12/3/2010 9:00
	Data were deleted due to YSI 6600 data sonde being out of water.	7/6/2010 11:15	7/6/2010 11:15
Turbidity	Data are marked suspect due to heavy fouling.	9/9/2010 13:30	9/28/2010 14:45
		2/23/2010 10:15	2/23/2010 10:15
		6/10/2010 9:45	6/14/2010 5:30
	Data are suspect due to an unknown sonde malfunction.	7/14/2010 0:00	7/28/2010 13:45
		7/28/2010 14:15	8/26/2010 12:45
		10/24/2010 19:15	10/27/2010 14:45
		6/14/2010 5:45	7/1/2010 14:30
		2/7/2010 15:45	2/7/2010 15:45
		2/17/2010 23:00	2/17/2010 23:00
		2/20/2010 22:00	2/20/2010 22:00
	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.	2/20/2010 22:45	2/20/2010 22:45
		2/20/2010 23:30	2/20/2010 23:30
		2/21/2010 1:45	2/21/2010 1:45
		2/21/2010 4:00	2/21/2010 4:00
		2/21/2010 4:30	2/21/2010 4:30
		2/21/2010 5:15	2/21/2010 5:15
		2/22/2010 23:15	2/23/2010 0:00

Continuous Data

Figures 6 and 7 graphically depict the daily means data for 2010 by parameter. Relative water depth collected by NC NERR staff at these sites is included in this section as an aid for data interpretation because it includes information that relates daily tidal fluctuations to parameter values. Salinity values are calculated from specific conductance values.

Minimum, and maximum values with the mean and standard deviation for each month are shown in Tables 5 and 6. Values in percentage valid n rows 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 those months where all of the data was either missing and/or flagged, the percentage of values is 0% and no statistics (mean, maximum or minimum) are presented. When the percentage of values is low, the statistics (mean, maximum and minimum) may be less informative than for those months where all or nearly all of the data were used in the calculation of summary statistics.

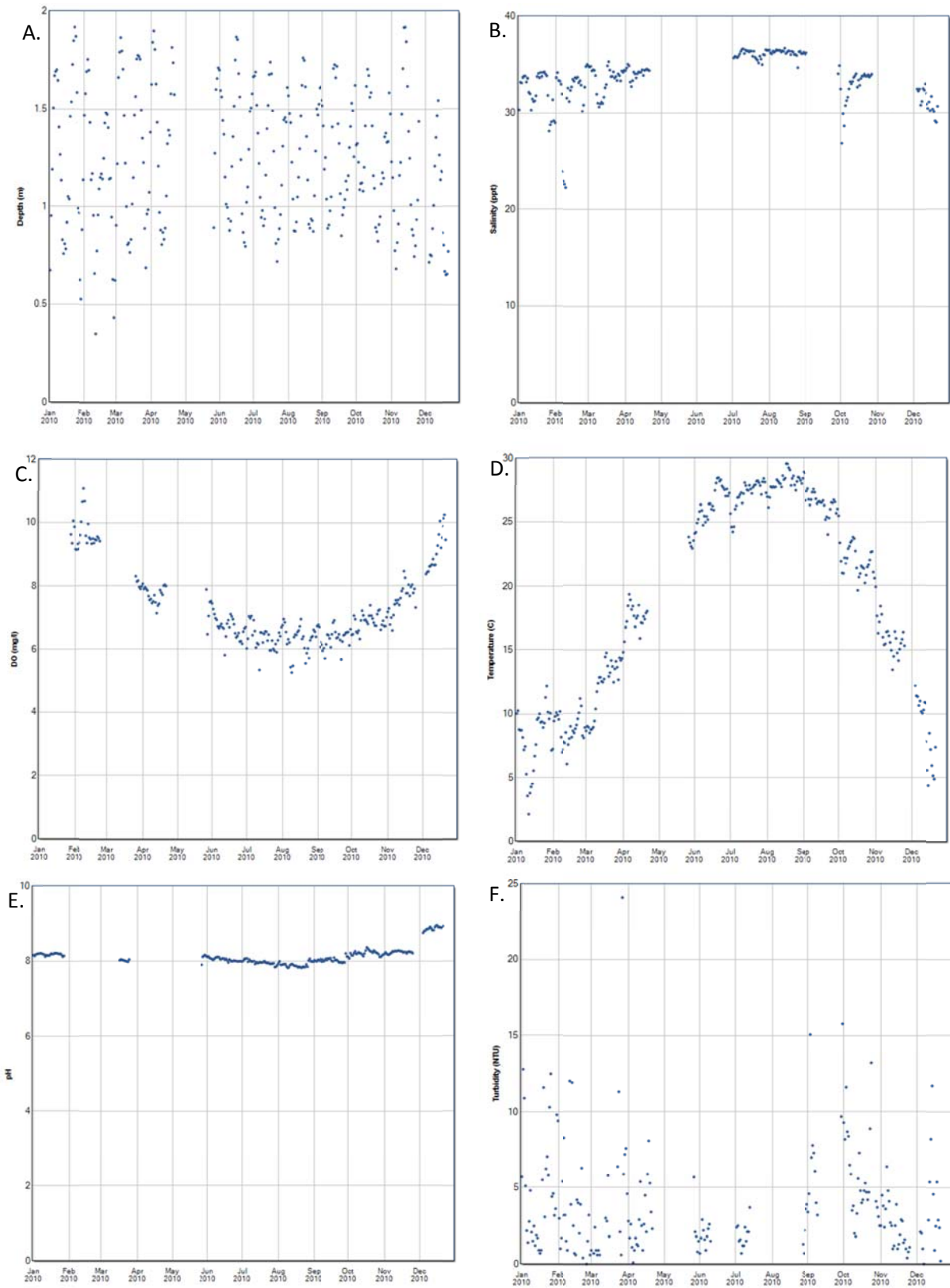


Figure 6. Mean daily values for water quality parameters at CALO 01 at Cape Lookout National Seashore during 2010: A) relative depth/tidal range, B) salinity, C) dissolved oxygen (DO), D) temperature, E) pH, and F) turbidity (NTU). Breaks in data record indicate missing and/or flagged data.

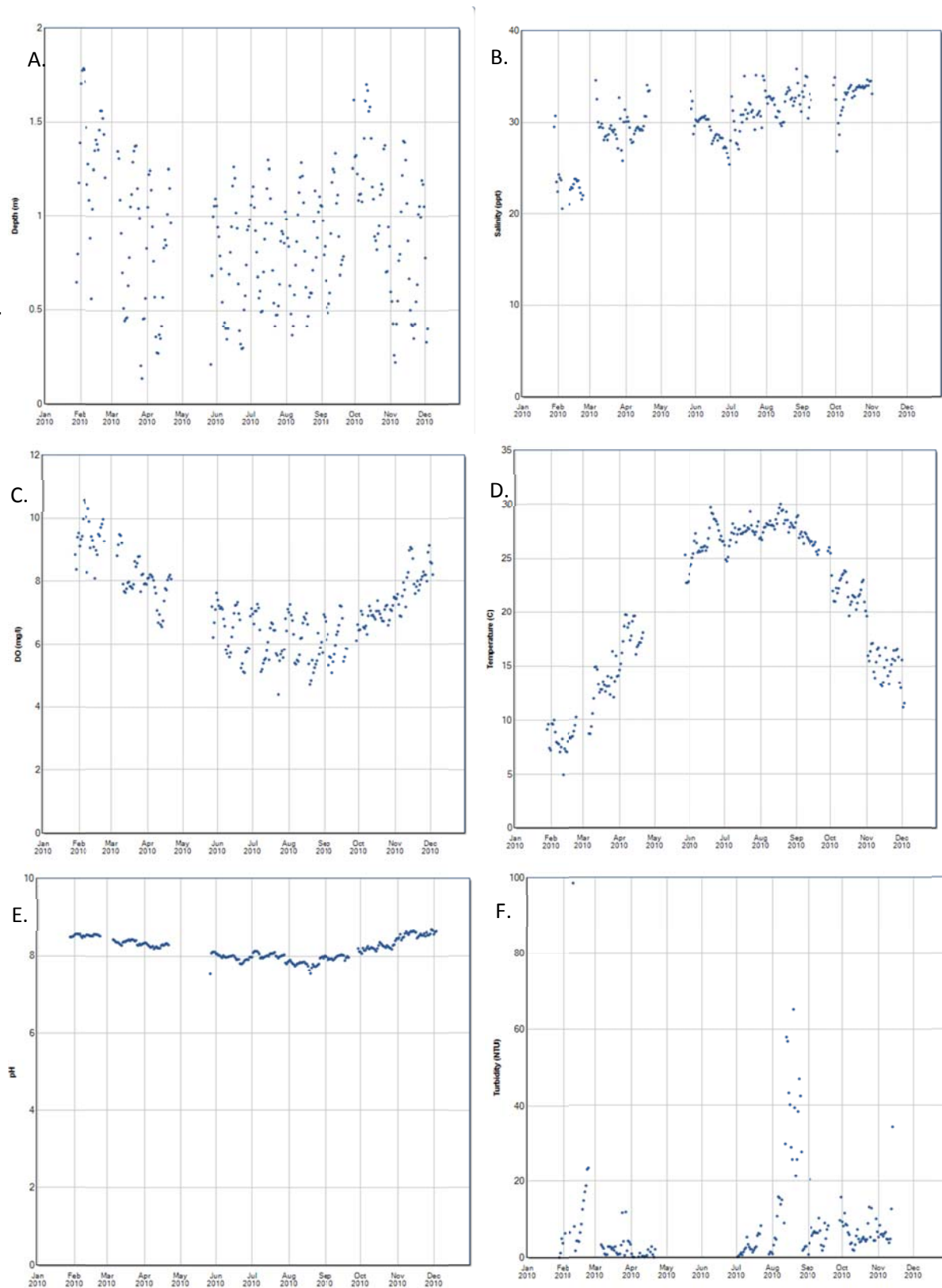


Figure 7. Mean daily water quality parameters at CALO 02 at Cape Lookout National Seashore during 2010: A) relative depth/tidal range, B) salinity, C) dissolved oxygen (DO), D) temperature, E) pH, and F) turbidity (NTU). Breaks in data record indicate missing and/or flagged data.

Table 5. Monthly minimum, maximum and mean values for water-quality parameters collected at Shackleford Banks Dock (CALO 01) at Cape Lookout National Seashore during 2010. Standard deviation (stdev) of the mean values are provided in parentheses. Values for percent valid n, indicates the percent of valid data points collected during the calendar month.

Month (expected n)		Relative Depth (m)	Salinity (ppt)	Dissolved Oxygen (mg/L)	Temperature	pH	Turbidity (NTU)
January (n=2976)	Minimum	0.46	23.47	8.63	2.06	8.09	0
	Mean (stdev)	1.3 (0.4)	32.2 (2.1)	9.6 (0.5)	8.2 (2.1)	8.2 (0.0)	5.3 (4.8)
	Maximum	2.01	34.9	11.06	12.33	8.22	38.3
	% valid n	100%	100%	15%	100%	85%	100%
February (n=2688)	Minimum	0.34	21.6	9.06	4.03	*	0
	Mean (stdev)	1.1 (0.3)	31.3 (3.2)	9.8 (0.5)	8.5 (1.2)	*	4.2 (4.9)
	Maximum	1.91	35.16	11.51	11.33	*	110.7
	% valid n	100%	100%	80%	100%	0%	92%
March (n=2976)	Minimum	0.45	28.98	7.58	6.83	7.96	0
	Mean (stdev)	1.3 (0.3)	33.1 (1.4)	8.2 (0.2)	12.1 (2.3)	8.0 (0.0)	4.2 (4.9)
	Maximum	2.01	35.84	8.72	17.09	8.05	50.9
	% valid n	100%	100%	21%	100%	28%	67%
April (n=2880)	Minimum	0.49	31.49	6.87	14.32	*	0
	Mean (stdev)	1.2 (0.3)	33.9 (0.6)	7.8 (0.3)	17.8 (1.2)	*	3.7 (4.2)
	Maximum	1.94	35.14	8.66	21.86	*	38.3
	% valid n	68%	68%	68%	68%	0%	64%
May (n=2976)	Minimum	0.74	*	5.98	22.82	7.9	0.6
	Mean (stdev)	1.3 (0.3)	*	7.3 (0.5)	23.9 (0.9)	8.1 (0.0)	2.9 (1.6)
	Maximum	2.01	*	8.09	27.31	8.18	11
	% valid n	14%	0%	14%	14%	14%	14%
June (n=2880)	Minimum	0.57	*	5.07	23.66	7.91	0.7
	Mean (stdev)	1.2 (0.3)	*	6.8 (0.4)	26.7 (1.3)	8.0 (0.0)	3.0 (2.7)
	Maximum	1.92	*	7.68	30.37	8.17	22.9
	% valid n	100%	0%	100%	100%	100%	31%
July (n=2976)	Minimum	0.56	33.76	4.09	22.65	7.72	0.7
	Mean (stdev)	1.2 (0.3)	36.0 (0.5)	6.4 (0.5)	27.3 (1.2)	8.0 (0.1)	3.3 (5.2)

Table 5. Continued.

Month (expected n)		Relative Depth (m)	Salinity (ppt)	Dissolved Oxygen (mg/L)	Temperature	pH	Turbidity (NTU)
July (n=2976)	Maximum	1.91	36.81	7.52	30.96	8.16	112.7
	% valid n	100%	98%	100%	100%	100%	40%
August (n=2976)	Minimum	0.56	34.48	4.98	25.31	7.76	0.6
	Mean (stdev)	1.2 (0.3)	36.3 (0.2)	6.5 (0.4)	28.3 (0.9)	7.9 (0.1)	8.8 (43.2)
	Maximum	1.96	37.13	7.69	31.25	8.15	458.6
	% valid n	100%	100%	100%	100%	100%	18%
	Minimum	0.6	31.83	5.32	23.62	7.88	1.8
September (n=2880)	Mean (stdev)	1.3 (0.3)	35.4 (1.0)	6.6 (0.4)	26.7 (0.9)	8.0 (0.0)	10.6 (20.1)
	Maximum	2.06	36.6	7.78	30.25	8.2	290.2
	% valid n	98%	12%	98%	98%	98%	34%
	Minimum	0.6	25.83	5.84	19.16	8.02	0.4
	Mean (stdev)	1.3 (0.3)	33.0 (1.5)	7.0 (0.4)	22.2 (1.3)	8.2 (0.1)	6.2 (4.4)
October (n=2976)	Maximum	2.12	39.53	8.59	25.97	8.42	46.1
	% valid n	100%	86%	100%	100%	100%	91%
	Minimum	0.65	*	6.21	11.78	8.12	0
	Mean (stdev)	1.4 (0.3)	*	7.7 (0.4)	16.2 (1.6)	8.2 (0.0)	3.5 (3.3)
	Maximum	2.07	*	8.6	20.6	8.29	70.3
November (n=2880)	% valid n	80%	0%	80%	80%	80%	80%
	Minimum	0.55	27.36	7.83	3.45	8.56	0
	Mean (stdev)	1.1 (0.3)	31.3 (1.0)	9.2 (0.6)	9.0 (2.3)	8.9 (0.1)	3.8 (3.7)
	Maximum	1.93	33.47	10.67	14.33	8.98	19.7
	% valid n	62%	62%	62%	62%	62%	49%
December (n=2976)	Minimum	0.55	27.36	7.83	3.45	8.56	0
	Mean (stdev)	1.1 (0.3)	31.3 (1.0)	9.2 (0.6)	9.0 (2.3)	8.9 (0.1)	3.8 (3.7)
	Maximum	1.93	33.47	10.67	14.33	8.98	19.7
	% valid n	62%	62%	62%	62%	62%	49%
	Minimum	0.55	27.36	7.83	3.45	8.56	0

Table 6. Monthly minimum, maximum and mean values for water-quality parameters collected at Middle Marshes(CALO 02) at Cape Lookout National Seashore during 2010. Standard deviation (stdev) of the mean values are provided in parentheses. Values for percent valid n, indicates the percent of valid data points collected during the calendar month.

Month (expected n)		Relative Depth (m)	Salinity (ppt)	Dissolved Oxygen (mg/L)	Temperature	pH	Turbidity (NTU)
January (n=2976)	Minimum	0.63	18	7.71	4.26	8.31	0
	Mean (stdev)	1.3 (0.4)	25.8 (4.2)	9.5 (0.7)	8.9 (1.7)	8.5 (0.0)	5.2 (3.8)
	Maximum	2.06	33.28	11.37	12	8.6	18.4
	% valid n	14%	14%	14%	14%	14%	14%
February (n=2688)	Minimum	0.56	18	2.85	3.55	8.35	0
	Mean (stdev)	1.3 (0.3)	21.8 (1.7)	9.3 (1.4)	8.1 (1.5)	8.5 (0.0)	11.5 (17.1)
	Maximum	1.99	25.4	11.75	11.54	8.66	132.8
	% valid n	80%	70%	80%	80%	80%	63%
March (n=2976)	Minimum	0.05	24.01	7.17	6.6	8.13	0
	Mean (stdev)	0.8 (0.3)	29.0 (2.1)	8.6 (0.6)	13.1 (2.1)	8.4 (0.1)	3.1 (5.7)
	Maximum	1.52	34.8	10.43	19.11	8.56	201.1
	% valid n	85%	85%	83%	85%	85%	84%
April (n=2880)	Minimum	0.01	26.56	4.81	14.61	8.07	0
	Mean (stdev)	0.6 (0.3)	29.6 (1.7)	7.8 (0.7)	18.5 (1.9)	8.3 (0.0)	2.4 (3.4)
	Maximum	1.28	34.3	9.39	25.86	8.38	65.9
	% valid n	68%	68%	63%	68%	68%	49%
May (n=2976)	Minimum	0.08	28.27	5.09	22.32	7.53	*
	Mean (stdev)	0.7 (0.3)	29.9 (1.0)	7.0 (0.8)	24.7 (2.0)	8.0 (0.1)	*
	Maximum	1.32	33.4	8.25	29.84	8.15	*
	% valid n	14%	14%	12%	14%	14%	0%
June (n=2880)	Minimum	0.05	24.16	3.89	23.87	7.73	*
	Mean (stdev)	0.6 (0.3)	28.8 (1.6)	6.6 (0.9)	27.4 (1.9)	7.9 (0.1)	*
	Maximum	1.27	31.1	8.27	33.25	8.12	*
	% valid n	100%	100%	87%	100%	100%	0%
July (n=2976)	Minimum	0.09	25.31	4.16	22.5	7.66	0
	Mean (stdev)	0.8 (0.3)	31.2 (2.3)	6.4 (0.7)	27.7 (1.6)	8.0 (0.1)	4.8 (6.7)

Table 6. Continued.

Month (expected n)		Relative Depth (m)	Salinity (ppt)	Dissolved Oxygen (mg/L)	Temperature	pH	Turbidity (NTU)
July (n=2976)	Maximum	1.44	35.96	8.29	33.33	8.17	230.3
	% valid n	100%	100%	99%	100%	100%	77%
August (n=2976)	Minimum	0.19	28.86	4.16	24.94	7.54	0
	Mean (stdev)	0.8 (0.3)	32.4 (1.4)	6.2 (0.7)	28.5 (1.2)	7.9 (0.1)	25.7 (28.1)
	Maximum	1.44	36.35	7.56	32.7	8.41	428.4
	% valid n	100%	100%	100%	100%	100%	97%
September (n=2880)	Minimum	0.29	29.84	4.23	23.51	7.83	0
	Mean (stdev)	1.0 (0.3)	33.8 (1.2)	6.4 (0.6)	26.8 (1.2)	8.0 (0.1)	9.3 (11.8)
	Maximum	1.89	36.04	7.83	31.04	8.2	251.8
	% valid n	75%	35%	75%	75%	75%	65%
October (n=2976)	Minimum	0.07	25.83	5.84	16.13	8.02	1.2
	Mean (stdev)	1.2 (0.4)	33.2 (1.5)	7.0 (0.4)	22.1 (1.5)	8.2 (0.1)	8.5 (28.9)
	Maximum	2.12	35.36	8.59	25.97	8.51	765.6
	% valid n	100%	100%	100%	100%	100%	97%
November (n=2880)	Minimum	0.19	32.68	6.36	10.98	8.34	2.5
	Mean (stdev)	0.9 (0.3)	32.9 (0.2)	8.2 (0.6)	15.8 (1.7)	8.6 (0.1)	8.8 (6.1)
	Maximum	1.55	33.12	9.61	20.82	8.76	52.9
	% valid n	100%	0%	100%	100%	100%	41%
December (n=2976)	Minimum	0.14	28.97	6.94	0.92	8.45	1.7
	Mean (stdev)	0.7 (0.3)	33.3 (0.9)	9.5 (0.7)	7.6 (3.2)	8.6 (0.1)	8.8 (22.7)
	Maximum	1.52	35.07	11.03	17.34	8.7	512.8
	% valid n	100%	92%	100%	100%	8%	92%

Discrete Data

Monthly water quality data collected at Cape Lookout National Seashore during 2010 are shown in Table 7 below. Condition categories of assessed parameters from USEPA (2005) 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). Condition categories generally correspond to those used by USEPA in the National Coastal Condition Report II (2005).

Table 7. Monthly water quality data collected at two sites at Cape Lookout National Seashore during 2010. 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 (2005). Condition of other assessed parameters from USEPA (2005). [Green, *good*; yellow, *fair*; and red, *poor*; gray, *missing data*; k , light attenuation coefficient; ug/L, micrograms per liter; mg/L, milligrams per liter; *, missing data; – , no calculation or analyses conducted].

Collection Date	Water Clarity Index (k)	Chlorophyll a (ug/L)	Dissolved Oxygen (mg/L)	TDN (mg/L)	DIN, (mg/L)	TDP (mg/L)	DIP (mg/L)
CALO 01							
1/29/2010	–	*	9.37	*	*	*	*
2/23/2010	1.0	1.24	9.12	0.19	–	0.0104	–
3/25/2010	1.1	1.61	8.31	0.28	–	0.0112	–
4/21/2010	1.3	1.09	7.51	0.21	–	0.016	–
5/28/2010	1.0	2.09	7.53	0.26	0.0107	0.0206	0.0032
7/1/2010	–	1.19	6.79	0.23	–	0.0157	–
7/28/2010	–	3.2	6.77	0.27	–	0.0148	–
8/26/2010	1.2	1.55	7.16	0.28	0.0123	0.0142	0.0033
9/28/2010	0.7	4.23	6.72	0.4	–	0.0248	–
10/27/2010	0.7	3.44	7.22	0.27	0.0124	0.0202	0.0035
12/3/2010	0.3	2.95	7.96	0.29	*	0.0169	*
CALO 02							
1/27/2010	0.5	*	8.6	*	*	*	*
2/23/2010	–	0.66	7.98	0.18	–	0.0108	–
3/25/2010	–	0.51	8.08	0.2	–	0.0111	–
4/21/2010	–	0.9	6.45	0.22	–	0.022	–
5/27/2010	–	2.24	7.2	0.26	0.0092	0.0179	0.0025
7/1/2010	–	1.04	7.63	0.25	–	0.0136	–
7/28/2010	–	1.26	6.95	0.27	–	0.0167	–
8/26/2010	–	1.84	6.56	0.23	0.0156	0.0153	0.0232
9/28/2010	0.7	2.87	6.12	0.45	–	0.0617	–
10/27/2010	0.7	1.82	7.35	0.27	0.014	0.0196	0.0047
12/3/2010	0.7	1.98	8.16	0.25	–	0.0185	–

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