Spatial and Temporal Characterization of Water Quality at Cape Romain National Wildlife Refuge

NOAA Technical Memorandum NOS NCCOS 33

Citation for this Report

Kracker, L.M. and G.M. Meaburn, 2006. Spatial and Temporal Characterization of Water Quality at Cape Romain National Wildlife Refuge.
NOAA Technical Memorandum NOS NCCOS 33. 36 pp.
Cover Photo Credit: Bill Kracker

Spatial and Temporal Characterization of Water Quality at Cape Romain National Wildlife Refuge

Laura M. Kracker and G. Malcolm Meaburn
Center for Coastal Environmental Health and Biomolecular Research
NOAA/NOS/NCCOS
219 Fort Johnson Road
Charleston, South Carolina 29412-9110

NOAA Technical Memorandum NOS NCCOS 33

April, 2006

United States Department of Commerce	National Oceanic and Atmospheric Administration	National Ocean Service
Carlos M. Gutierrez Secretary	Conrad C. Lautenbacher, Jr. Administrator	John (Jack) H. Dunnigan Assistant Administrator

Table of Contents

1.0 Executive Summary

Coastal stewardship involves recognizing important aspects of landscape function in order to identify and mitigate impacts affecting the sustainability of ecosystems and communities. In collaboration with the US Fish and Wildlife Service (USFWS), NOAA's National Ocean Service has worked to enhance our understanding of current conditions and potential impacts at Cape Romain National Wildlife Refuge (CRNWR) with the goal of sustaining the ecological and aesthetic value of this coastal ecosystem. This document summarizes the results of our work toward an ecological characterization of CRNWR, with an emphasis on the water quality component.

In 2001, NOAA's Center for Coastal Environmental Health and Biomolecular Research (CCEHBR) implemented a water quality study to acquire measurements of environmental parameters useful in detecting anthropogenic and natural changes within CRNWR. The objective of this study is to better understand spatial and temporal variation and inter-annual trends in environmental conditions at CRNWR. Over a period of four years, we obtained nearly continuous measurements of key water quality parameters (temperature, salinity, pH, dissolved oxygen, turbidity) at temporary, random sites and one permanent, stationary site in Little Papas Creek. In addition, we collected the same measurements using a flow-through data logger while traversing the study area.

This study allowed us to examine both spatial and temporal patterns. Overall, conditions within the Refuge vary with location, tidal stage and season, much as expected in a coastal saltmarsh system. Temporal differences were observed with a shift from dry to wet years. This can be seen, in part, by examining the salinity record. Spatial variation included an increasing salinity gradient from the northeast to the southwest area of the Refuge, especially with periods of heavy rainfall. The effect of heavy rains and freshwater released down the Santee River system resulted in low salinity in 2003 and coincided with a harmful algal bloom (HAB) of *Heterosigma akashiwo* in Bulls Bay.

We found that the permanent site was fairly representative of the other sites sampled throughout the Refuge except in terms of percent dissolved oxygen (DO). Based on EPA guidelines regarding DO, we observed up to seven instances where severe hypoxia levels (DO concentration $<2.0 mg\ L^{-1}$) were recorded. (Note: two of the seven occurrences might be attributable to instrument drift). The low DO events occurred over a period of one, three or twelve days, primarily in the summer months during dry years.

2.0 Introduction

A Memorandum of Understanding between USFWS Cape Romain National Wildlife Refuge and NOAA's Center for Coastal Environmental Health and Biomolecular Research laid the foundation for characterizing and monitoring the terrestrial/aquatic ecology of this coastal Refuge. The overall goal of this effort is to broadly characterize environmental conditions within CRNWR and increase our understanding of the stressors on ecosystem processes at this location. As a starting point, CCEHBR produced a literature review to identify potential stressors and aid in developing a research agenda for the Refuge (Kracker 2003). The literature review provides an overview of the physical and biological processes of coastal landscapes, in general, and CRNWR, in particular. The review focuses on information regarding the intertidal environment; sediment characteristics and geomorphology; contaminants in air, water and sediments; nearshore and offshore fisheries; and inventories of terrestrial plants and animals. In addition, a review of fisheries data and research relevant to the Refuge was produced (Jennings and Kracker 2003). In April 2001, we implemented a water quality study to acquire baseline measurements for detecting the effects of both anthropogenic and natural changes. This document summarizes the results of our work toward an ecological characterization of CRNWR, with an emphasis on the water quality component.

As populations expand along the coast of the southeast US, the function of these ecosystems may be adversely impacted. Pressures associated with coastal population growth and development include waste production, runoff, degraded water and sediment quality, loss of wetlands and other habitats, physical changes and impaired ecological function (EPA 2005). Population growth and the changing demographics along coastal South Carolina have the potential to impact coastal resources (Bailey 1996) resulting in increased chemical and biological contaminants, the addition of nutrients and sediments, and changes in fish and shellfish populations (Scott and Lawrence 1982; Vernberg et al 1992, Vernberg 1996; Weinstein 1996). CCEHBR implemented a water quality study in cooperation with USFWS to provide baseline information that will be useful in monitoring change and predicting potential impacts from natural processes and human activities in and around CRNWR. Two progress reports were submitted to USFWS (NOAA 2002, NOAA 2004) on the ecological characterization of CRNWR, which contained results from water quality monitoring up to that time. A more complete description of the equipment used in this study and the methods of deployment are described in Bauersfeld and Meaburn (2006). The 2002 progress report also includes socio-economic considerations and addresses the interplay between CRNWR and the surrounding communities. Our findings on the perception that people have of the Cape Romain area and how they interact with the natural landscape are reported elsewhere (Kracker and Preston 2004).

This Technical Memorandum emphasizes our efforts aimed at understanding spatial and temporal variation and trends in environmental conditions of the Refuge through a random water quality study. The overall sampling design described here mirrors the monitoring program at National Estuarine Research Reserve (NERRS) sites (Wenner and Geist 2001), with some modification. The sampling program at CRNWR provides in-situ data from YSI 6920 multi-parameter data loggers at random sites and one permanent site to monitor changes in water quality and identify differences in environmental characteristics throughout the Refuge. Additionally, a flow-through system captures data while traversing the waterways of the Refuge, providing a snapshot of conditions over a broad area.

2.1 The landscape

Cape Romain National Wildlife Refuge is a dynamic environment with over 64,000 acres of embayments, barrier islands, tidal creeks, salt marshes, and open water. It stretches over 20 miles along the Atlantic coast just northeast of Charleston, SC (Figure 1). The Refuge was established in 1932 and is managed by the Department of Interior USFWS - Refuges. CRNWR is home to nearly 350 species of birds; is a nesting rookery for brown pelicans, terns, and gulls; and has the largest nesting population of loggerhead sea turtles outside of Florida. (USFWS 2006).

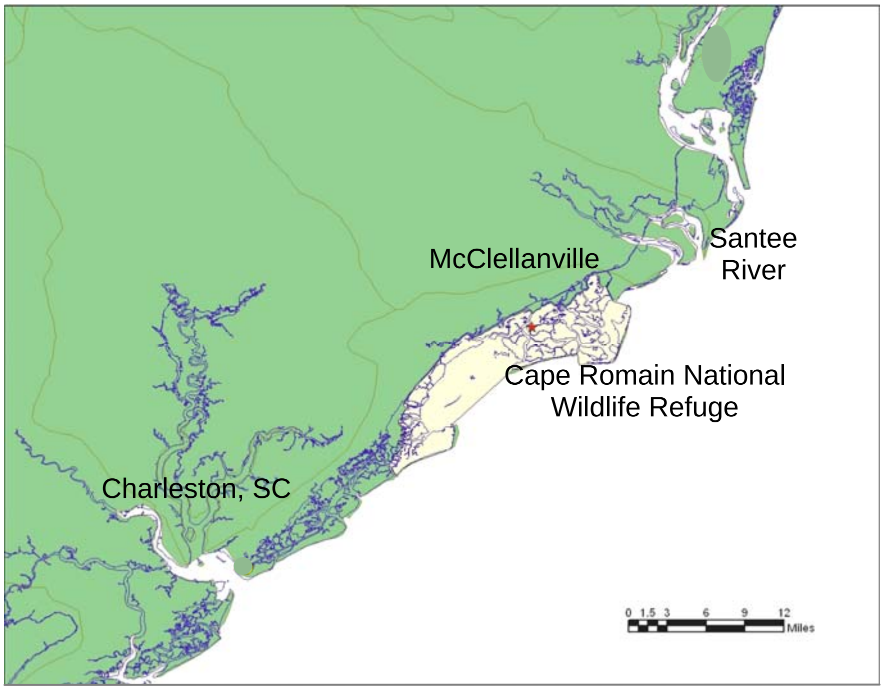


Figure 1. Cape Romain National Wildlife Refuge is located in coastal South Carolina.

This region has unique ecological, historic, cultural, and aesthetic characteristics. The communities in and around CRNWR are connected to the coastal landscape through subsistence, commercial, and recreational activities. Historically, this region provided a means by which basketmaking, fishing, claming, oystering, crabbing, and shrimping have thrived. The cultural identities of local communities, as well as their socio-economic well-being are tied to the ecology of the coastal landscape (Kracker and Preston 2004). The nature of these activities is changing as the landscape changes and coastal development progresses. The fishing community centered in McClellanville, SC reflects the socio-economic changes taking place. In the late 1800s and early 1900s, there was a thriving oyster industry here. In the early 1900s, the shrimping industry became mechanized and profitable. Today the fishing industry is impacted by pressures such as fuel costs, increasing capital expenses, closures of polluted grounds, foreign imports, and conflicting interests (Blount 2000, Kracker and Preston 2004).

The coastal barrier islands are continually shaped by sedimentation, storms, erosion, sea-level rise and development (Daniels et al 1993, Sexton 1995, Pilkey and Dixon 1996, Titus and Richman 2001). The landscape of SC has been reconfigured through the damming of major rivers (Stephen et al 1975) and massive earth moving efforts during construction of plantation rice fields (Carney 1996). The nearshore and intertidal waterways function as spawning and nursery areas (Gracy and Keith 1972, Shenker and Dean 1979, McGovern and Wenner 1990, Saucier and Baltz 1992), oyster production (Battle 1892, Lunz 1938, Anderson et al 1978, USFWS 1981), and in recycling of nutrients (Spurrier and Kjerfve 1988). Historically, this coastal area was an extensive floodplain, drained by both the Santee and Cooper Rivers. However, damming of the Santee River and the creation of diversion canals has altered the hydrology and geomorphology of the region (Brown 1977, Hockensmith 2004). In 1942, the creation of the canal from Lake Marion to Lake Moultrie diverted about 88% of the flow from the Santee to the Cooper River (Kjerfve and Greer 1978). In 1985 much of that flow was rediverted back to the Santee River so that water released through the dam flows predominantly down the Santee River, to prevent sedimentation in navigation channels and the Charleston harbor. In the current configuration, periodic releases of fresh water through the Santee Cooper Dam cause very high, punctuated water levels. Periodic discharges of freshwater from the dam, along with a likely decrease from historic sedimentation rates (Peterson et al 1997), have resulted in an altered hydrologic regime and geomorphology in the region, with repercussions for the Refuge which lies just south of the mouth of the S. Santee River.

2.2 Assessing coastal water quality

EPA's current National Coastal Assessment is based on five primary indices of ecological condition: water quality index (including dissolved oxygen, chlorophyll a, nitrogen, phosphorus, and water clarity), sediment quality index (including sediment toxicity, sediment contaminants, and sediment total organic carbon), benthic index, coastal habitat index, and a fish tissue contaminants index (EPA 2005). Excessive loading of nitrogen, phosphorus, and sediments are increasingly found to be the major reason for impairment of our nation's estuaries (EPA 2005). Water quality criteria such as dissolved oxygen, turbidity, nutrients and chlorophyll-a (chl a) are useful in assessing nutrient loading and sedimentation in estuaries and coastal waters. The NERRS system-wide monitoring program implemented in 1995 includes a water quality component that measures pH, conductivity, temperature, dissolved oxygen, turbidity and water level (Wenner and Geist 2001).

The water quality parameters reported here are indicative of various aspects of environmental condition that affect the health, composition and abundance of biota. For instance, dissolved oxygen levels can limit the distribution and survival of biota. The decomposition of organic material, stimulated by increased nutrients in an ecosystem, depletes oxygen. Low DO in bottom waters can result in death in severe or prolonged instances and has been shown to degrade finfish habitat by reducing benthic macroinvertebrates, resulting in a dietary shift of demersal finfish (Powers et al 2005). Low DO conditions can be exasperated where there is a strong halocline hindering mixing between the top and bottom layers of a salinity gradient (Stanley and Nixon 1992). Many organisms are adapted to a given range of salinity and pH, which delineates potential habitats for a particular species. Turbidity, a measure of suspended solids in the water column, determines the amount of light penetration through the water column and can be an indicator of surface runoff. High turbidity can limit photosynthesis and siltation can interfere with filter feeders (Wenner and Geist 2001).

3.0 Objectives

The objective of this study is to better understand spatial and temporal variation and trends in environmental conditions of CRNWR through water quality monitoring. The overall sampling design is a modification of the monitoring program established by the NERRS program. As in the NERRS Program, our goal is to identify and track short-term variability and long-term changes in the integrity of this estuarine ecosystem. These data provide a foundation for examining the relationship among environmental and meteorological conditions and anthropogenic factors such as variation in water discharge from the Santee River system.

4.0 Methods

The basic strategy of this study was to select one “non-impacted” reference site to be sampled continuously, together with a concurrent random site sampled for a 14 day period. For over four years, we obtained nearly continuous in-situ measurements (every 30 minutes) of temperature, salinity, pH, dissolved oxygen, and turbidity at one permanent site and 87 random sites. Data collected from a fixed site provide information on changing conditions at one location and will allow comparison with long-term monitoring conducted at NERRS sites in other coastal regions. The sampling design also allows for wide spatial coverage by moving a YSI 9620 multi-parameter data logger throughout the Refuge to consecutive temporary sites that are sampled for about 14 days. Since the selection of these temporary sites is based on a random design, it is possible to make statistical comparisons between concurrent permanent and temporary sites, as well as comparisons among temporary sites, accounting for seasonal differences.

The location of the permanent sampling site is in Little Papas Creek, a tributary of Five Fathom Creek. Sondes are typically deployed at the permanent and temporary sites every 14 days. In addition, the locations of one hundred random sites within the Refuge boundary were computer generated within a 500m buffer of Mean High Water (Figure 2). Of those sites, eighty-seven temporary sites were actually sampled. Sites that were inaccessible or posed high risk of damage or loss of equipment were not included. At any one time, the permanent site and one random site were monitored simultaneously with YSI 9620 data loggers. The sondes are placed 0.5m from the bottom within a PVC tube, anchored, and equipped with a sonic release that sends a float to the surface for retrieval. Water quality measurements were taken every 30 minutes for approximately two weeks. After two weeks, the next temporary random site was sampled. Measurements at the permanent site were taken every 30 minutes for the entire study.

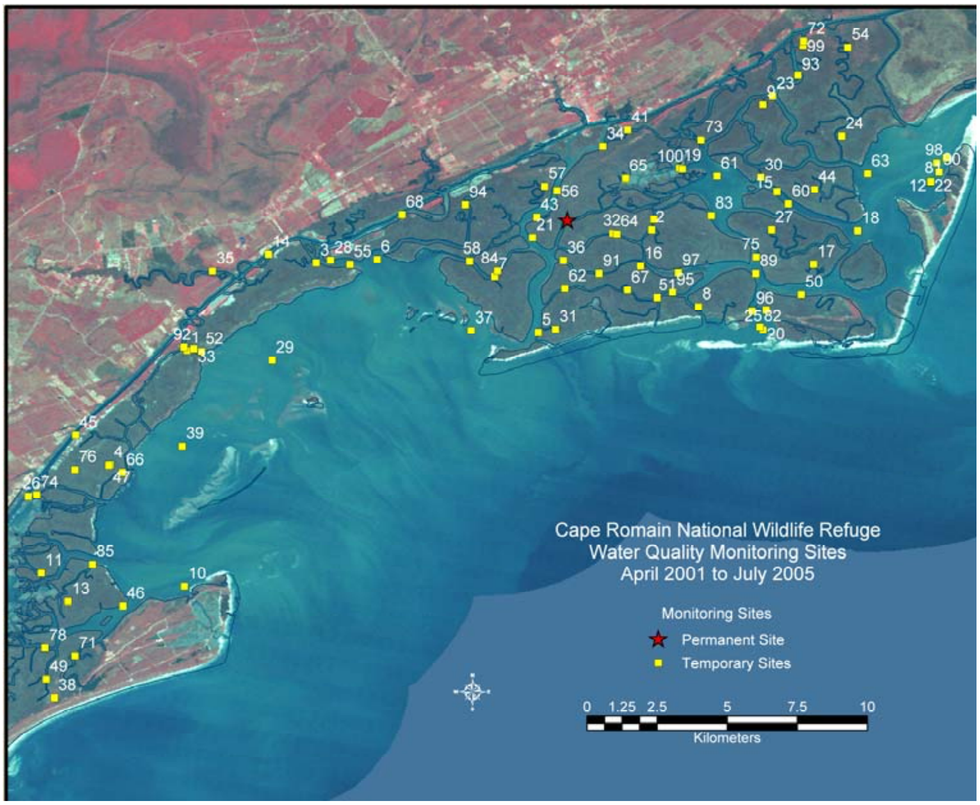


Figure 2. Location of the permanent and temporary water quality sampling sites (April 2001 – July 2005).

There were several components to the data collection effort (Table 1). At the permanent and temporary sites, nearly continuous measurements of temperature, salinity, pH, dissolved oxygen, and turbidity were collected as described above from 4/6/2001 to 7/20/2005 except for two time periods (September 18, 2002 to February 19, 2003 and July 1, 2004 to September 1, 2004). In addition, water column profiles were derived by measuring the same parameters at the surface, mid-water and near the bottom at each station visited on field days beginning in June 2002. This typically included the permanent and temporary site, bi-weekly.

To obtain surface water quality parameters over the extent of the Refuge on sampling days, a YSI flow cell unit was used to obtain continuous surface water readings while traveling through the Refuge and recording GPS coordinates. A simple system was devised to collect surface water while the boat is in motion using a PVC pipe to collect water, send it through the flow cell, and discharge it through the back of the boat. Measurements of the same five parameters were obtained every four seconds while traveling at about 32 mph.

In addition, to address concerns regarding nutrient loading and harmful algal blooms, water samples were collected throughout the Refuge at Jeremy Creek, Garris Landing (formerly called Moore's Landing), Awendaw Creek, Key Creek, Romain River, and the permanent site in Little Papas Creek (Figure 3). These water samples were analyzed for a suite of nutrients and harmful algae by Dr. Alan Lewitus, Belle W. Baruch Institute, University of South Carolina. Results of sampling conducted between September 2002 and August 2003 were provided to CCEHBR (Lewitus and Hayes, unpublished data).

Table 1. Components of water quality monitoring

Type of Sampling	Range of Dates	Sampling Rate	Site Location	Parameters
Permanent continuous	April 2001 to July 2005*	Every 30 minutes	Little Papas Creek	Water temperature (^oC) Dissolved oxygen (%DO and conc mg/l) Salinity (ppt) pH Turbidity (NTU) Depth+
Temporary continuous	April 2001 to July 2005*	Every 30 minutes	New random site every 2 weeks	
Water column profile	June 2002 to July 2005*	One reading each top, mid-water, bottom. Bi-weekly	Each site visited on field days	
Surface flow-through	March 2003 to July 2005*	Every 4 seconds Bi-weekly	Various paths traversing Refuge	

* Except from 9/18/2002 to 2/19/2003 and 7/1/2004 to 9/1/2004
\+ Recorded with some of the instruments, typically deployed at the permanent site.
GPS coordinates were collected at each site using a Garmin GPSMap 168 Sounder.

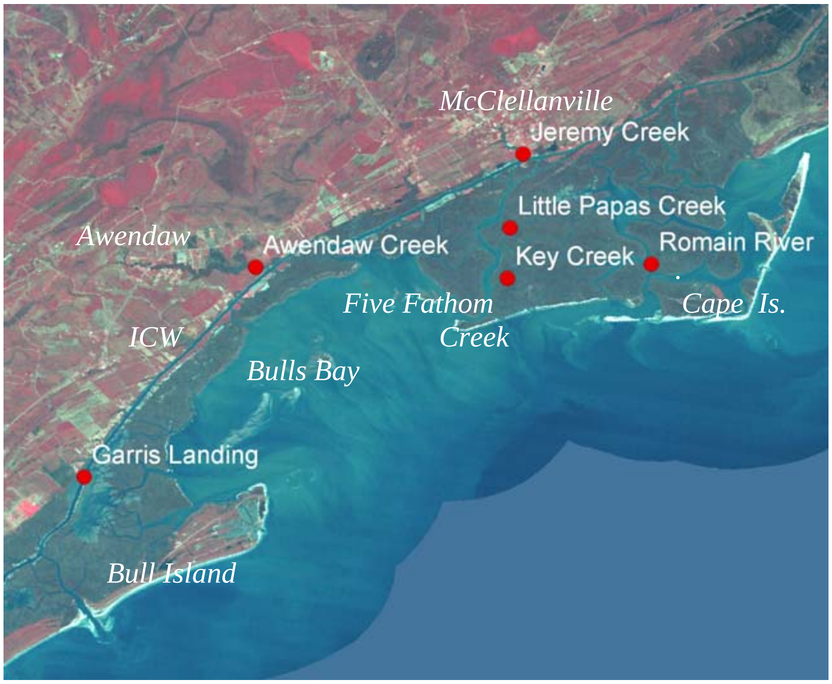


Figure 3. Select locations within CRNWR.

5.0 Results

Information collected during this study was examined in relation to events such as freshwater releases and HABs, trends at the permanent site, a statistical summary of conditions at temporary sites, and a comparison between the permanent and temporary sites. Over the course of this study, the area experienced drought conditions, storm events and algal blooms, including a significant bloom of *Heterosigma akashiwo* that occurred in April 2003 in Bulls Bay.

5.1 Harmful Algal Bloom Event

Toxic algal blooms of the flagellate *Heterosigma akashiwo* can result in mortality of fish and adverse physiological effects on oysters (Chang et al 1993, Keppler et al 2005). The development of algal blooms of *H. akashiwo* is associated with eutrophication in embayments and requires a suitable temperature and salinity for growth. In addition, these blooms require iron and magnesium, as well as nitrogen, phosphorus and vitamin B_{12} (Honjo 1993). Environmental conditions such as run-off, low DO in bottom waters, and mixing of bottom sediments into the water column are implicated in contributing to blooms (Honjo 1993). Honjo associates an increase in *H. akashiwo* blooms in the Seto Inland Sea of Japan with the increase of nitrate, total inorganic nitrogen and phosphorus concentrations due to increasing development near coastal waters. Temperatures suitable for growth of *H. akashiwo* range from 15-30^{o}C and suitable salinity ranges depend on the strain, suggesting an acclimation to various habitats (Honjo 1993). Bioavailable iron has found to be a limiting factor in *H. akashiwo* production in Osaka Bay, Japan (Yamochi 1989) and a limiting factor in phytoplankton growth in a SC salt marsh estuary (Lewitus et al 2004). The addition of nitrogen and vitamins from a salmon farm likely contributed to a bloom of *H. akashiwo* in Big Glory Bay, New Zealand in 1989, resulting in the death of 600 tonnes of caged salmon (Chang et al 1993). *H. akashiwo* cells multiply rapidly and then disintegrate within a few days (Tarutani et al 2000).

On April 29, 2003, SCDNR reported a large algal (*H. akashiwo*) bloom in the area of Bulls Bay (Figure 4) while conducting a routine aerial survey. The SC Task Group on Harmful Algae investigated this event and estimated the abundance at 9.5 x 10^{-4} cells m L^{-1} and reported that the water temperature in Bulls Bay was 22.8^{o}C and the salinity was 21.9 ppt. The combination of warm temperatures and low salinity after the release of water through the Santee River and a rainy spring likely contributed to the development of the bloom (SC Task Group on Harmful Algae 2004). The bloom extended 6-8 km offshore and resulted in the mortality of an estimated 1 x 10^{-4} fish (Keppler 2005). By examining biomarkers indicative of cellular damage response and detoxification, Keppler (2005) demonstrated that the high cell densities associated with this bloom could have adverse sub-lethal effects on oysters collected in Bulls Bay and that this exposure could have long-term effects. High chl a concentrations at the time of this bloom are evident in satellite imagery processed for ocean color by NOAA’s CoastWatch program (Figure 5).

Figure 4. Harmful algal bloom in the area of Bulls Bay April 29, 2003. Photos courtesy of Tom Murphy SCDNR.

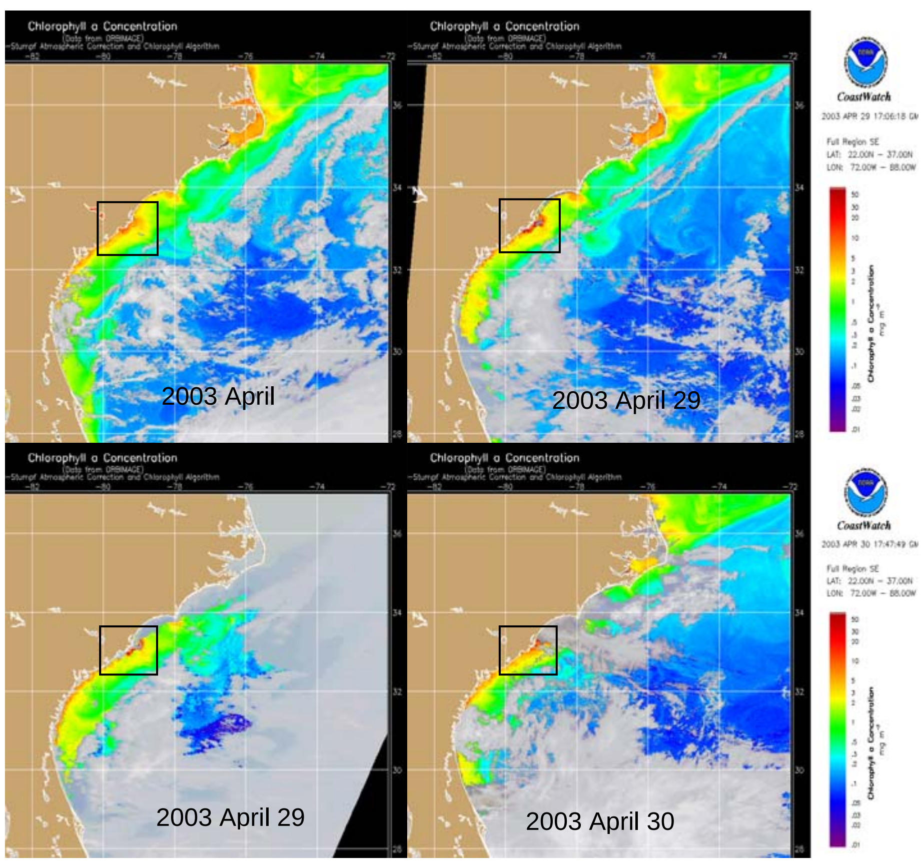
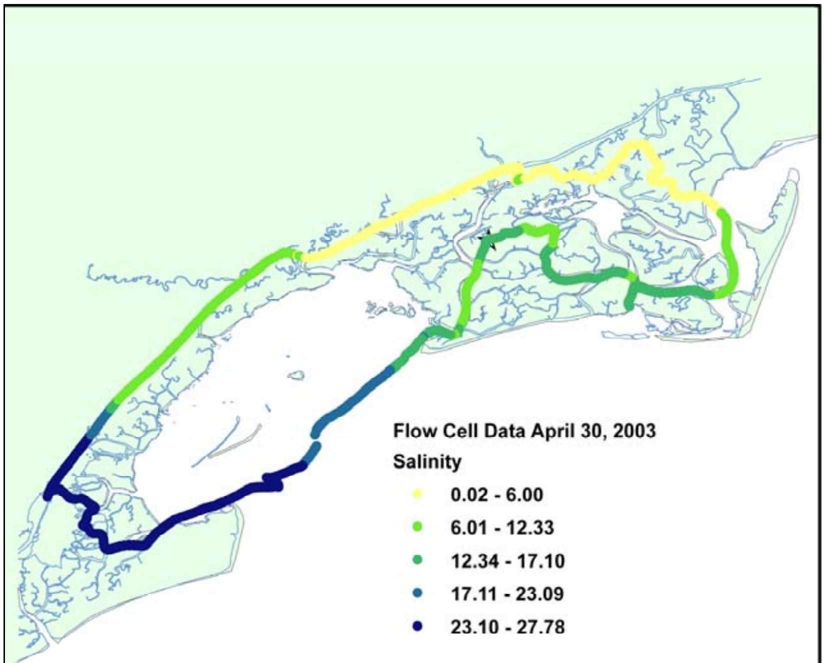


Figure 5. Ocean color data from SeaWiFS satellite imagery indicates high concentrations of chlorophyll a in the region of Bulls Bay Apr 28-30, 2003.

On April 30, 2003 we circled the Refuge with the surface flow-through data logger, the day after the HAB was reported by SCDNR. Low salinity in the northern end of the Refuge on that date indicates freshwater inputs from the Santee River system (Figure 6 upper) that extends into the southern end of the Refuge (Bulls Bay and Sewee Bay) with relatively low salinity (<28 ppt). The warmest water temperature recorded on this day occurred in shallow Bulls Bay and behind Cape Island and Bull Island (Figure 6 lower).



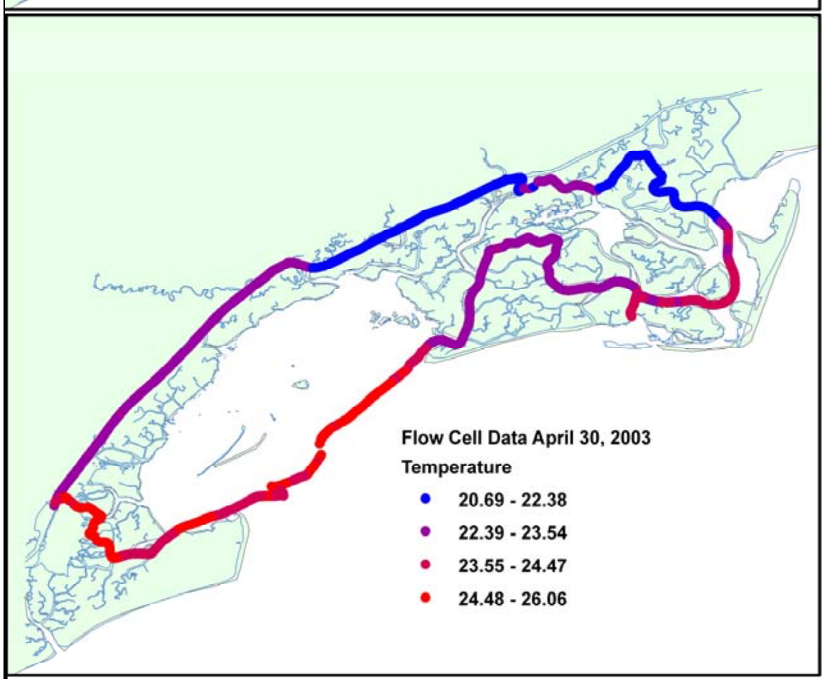


Figure 6. Salinity (ppt) (upper) and water temperature (^oC) (lower) on April 30, 2003.

Chlorophyll a and nutrient data collected from six locations throughout the Refuge provide an overview of seasonal changes from September 2002 to August 2003. (Figure 7 date of HAB noted). Chl a concentrations typically increase during the summer in South Carolina. Nitrate/nitrite levels, which can be limiting, show an increase at some locations in April to July – especially in Jeremy and Awendaw Creeks. Both creeks are a source of freshwater input. Typically, southeastern marshes and nearshore waters in SC contain very low levels of nitrate or ammonia; what is present comes from freshwater input from river discharge and precipitation, as well as deep water intrusion (Haines 1975, Lewitus et al 1998, Morris and Bradley 1999, White et al 2004). Lewitus and Hayes (unpublished data) analyzed nutrient data from six locations throughout the Refuge and reported that all six sites exhibited at least medium eutrophication (0.1 to 1 μM L^{-1}) with respect to nitrogen in the period from 2002 to 2003. In addition, they reported low to moderate levels of chl a except at Jeremy Creek and Moore's Landing where levels were high (20-60 μg L^{-1}) in July and August 2003, respectively.

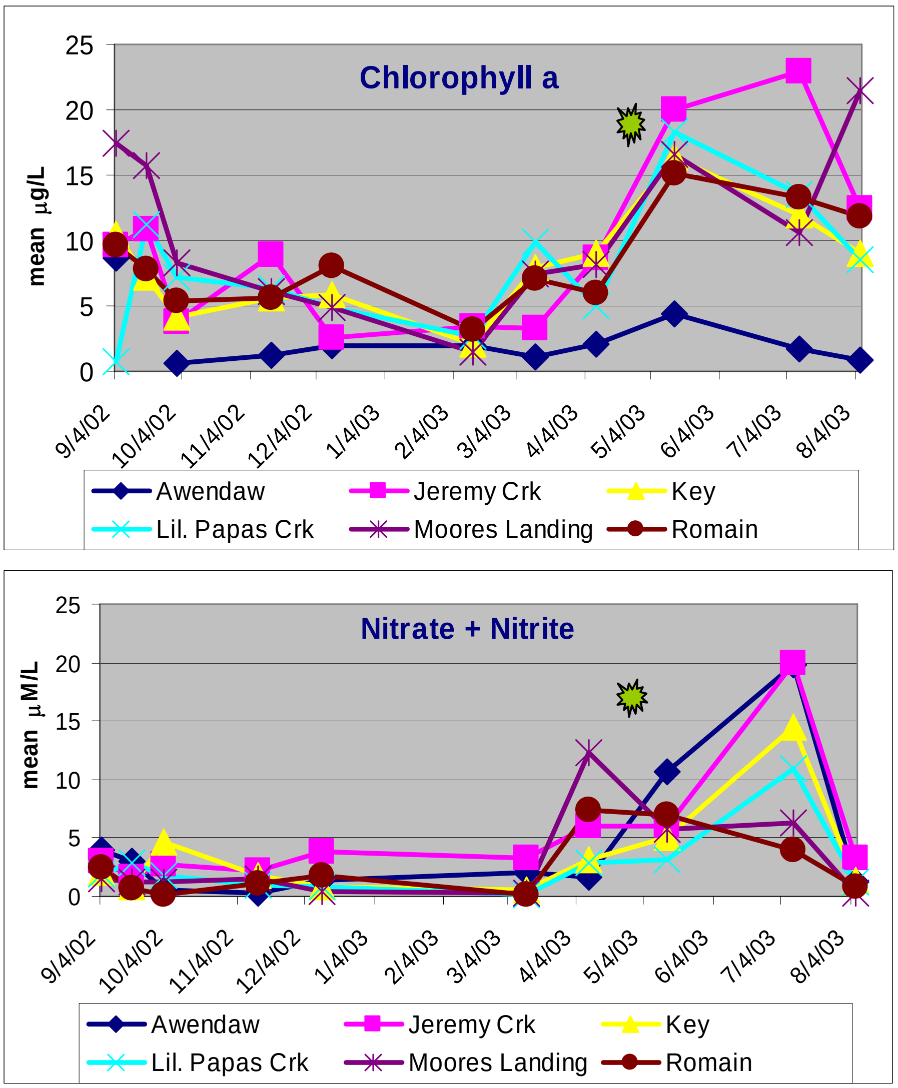


Figure 7. Chlorophyll-a and dissolved nitrate and nitrite data collected from six locations throughout the Refuge. HAB (4/29/03).

5.2 Freshwater Inputs

Over the course of this study, weather conditions in SC shifted from dry conditions in 2001 to heavy, drought-breaking rainfall in 2003. Rainfall measurements from two precipitation gauges (Georgetown to the north and Sullivan's Island to the south) show daily precipitation from April 2001 to January 2004 (Figure 8). The North and South Santee Rivers, just to the north of the Refuge, can have a major influence on the conditions of CRNWR, especially in the northern part of the Refuge.

The alteration of the Santee River through damming and diversion canals over the past 65 years has resulted in changes to flow, sedimentation, and plant and animal communities extending to the Cape Romain area (Kelley 2006). Prior to damming in 1941, the Santee was the fourth largest river system in terms of streamflow on the east coast (Hockensmith 2004). With the construction of the dams forming Lakes Marion and Moultrie, much of the streamflow was diverted from the Santee River into the Cooper River. The annual mean discharge of the Santee below the dam was reduced from 18,500 to 2600 cubic feet per second (cfs) (Hockensmith 2004). The rate at which sediment was trapped and accumulated in the lakes after impoundment was 79 percent of the total sediment inflow (Patterson et al 1997). Flow diverted to the Cooper River caused increased sedimentation and the need for dredging. In 1985, the flow to the Cooper River was rediverted back to the Santee, causing a decrease in salinity in the Santee. Between October 1986 and September 2000, Hockensmith (2004) recorded an average streamflow at the Jamestown station on the Santee River of 10,900 cfs. Between 1996 and 2002, there was a strong relationship between dam releases and streamflow at Jamestown and an inverse relationship between specific conductance and dam releases (Hockensmith 2004).

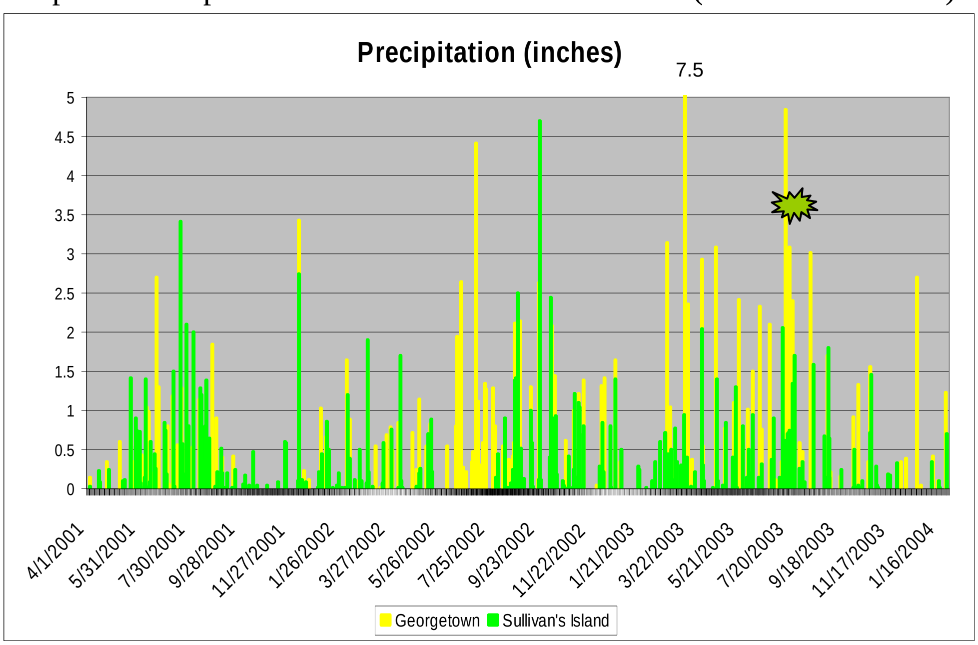


Figure 8. Precipitation data (April 2001 to Jan. 2004) from NWS Cooperative weather stations Georgetown (ID 383468) and Sullivan's Island (ID 388405). HAB (4/29/03)

River stage (average daily feet) measured on the South Santee River reflects the differences in flow regime in dry years (with little or no manipulation of water flow) versus wet years (Figure 9). Heavy spring rains in 2003 led to a release of water down the river from the Santee Cooper Dam. The timing of this release coincided with the HAB observed in April 2003.

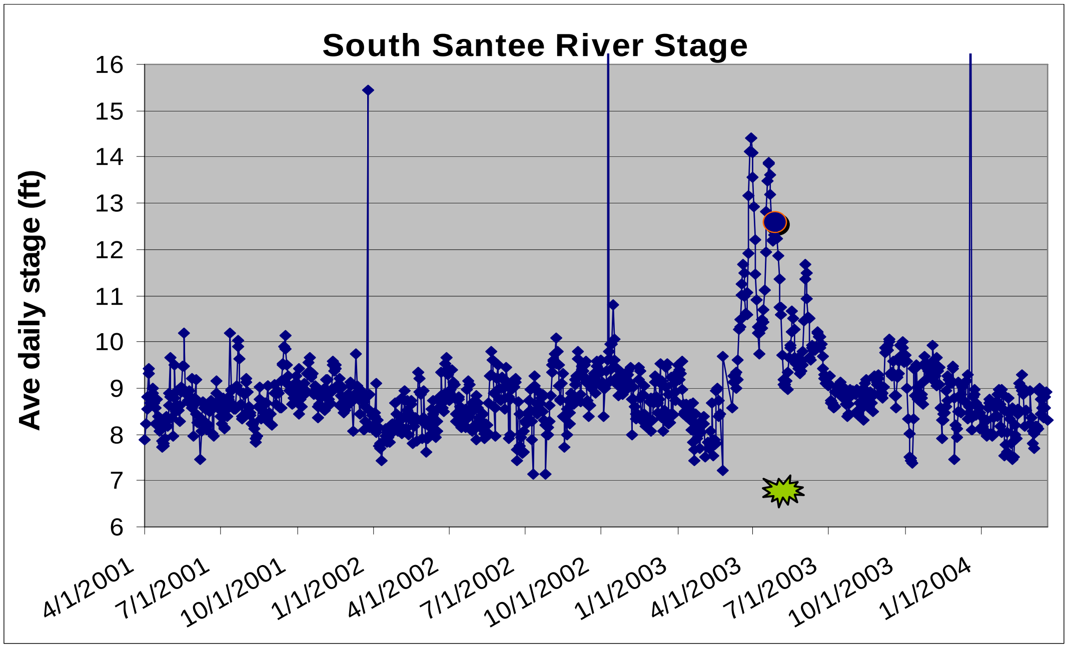
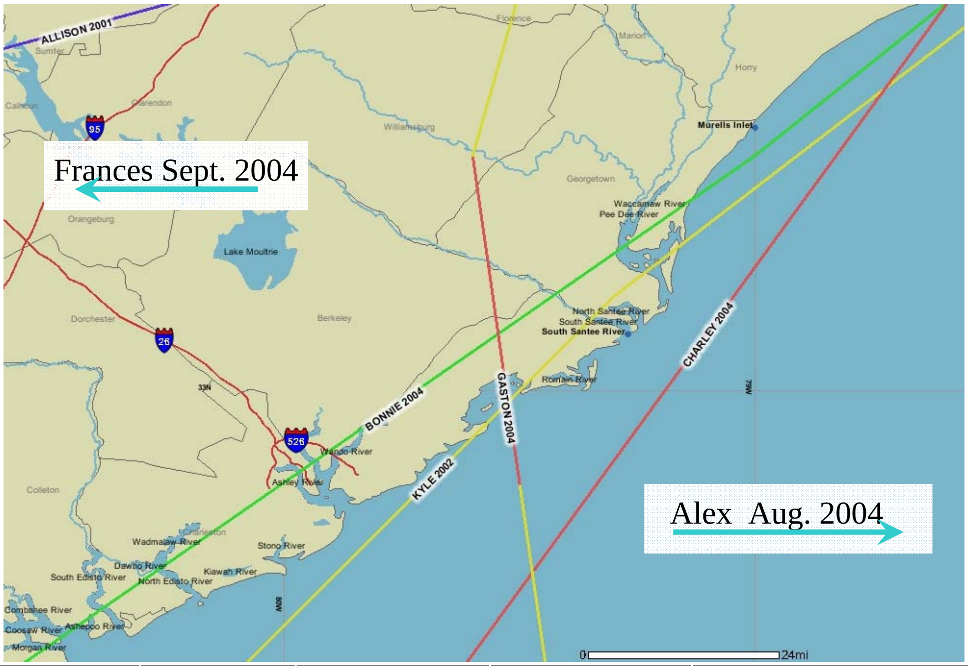


Figure 9. River stage (average daily ft.) on the South Santee River (USGS gauge 02171850). The date of the HAB event is indicated.

5.3 Storms

Several storms passed through the area during the period of this study (Figure 10). Unfortunately, we did not have equipment in the water during the time when these more extreme events occurred except for Allison in June 2001 and Frances in Sept. 2004 which passed through Atlanta, GA. Weather graphs for 2003 through 2005 are provided in the Appendix.



DATE	STORM NAME	WIND SPEED (MPH)	PRESSURE (MB)	CATEGORY
June 13, 2001	ALLISON	29	1006	Subtropical depression
Oct. 11, 2002	KYLE	40	1011	Tropical storm
Aug. 1, 2004	ALEX	40	1009	Tropical storm
Aug. 13, 2004	BONNIE	29	1008	Tropical depression
Aug. 14, 2004	CHARLEY	86	993	Hurricane cat 1
Aug. 29, 2004	GASTON	75	986	Hurricane cat 1
Sept. 8, 2004	FRANCES	Note: Passed 250 miles west		Tropical depression

Figure 10. Storms passing within 100 miles of Awendaw, SC during the study period.
http://hurricane.csc.noaa.gov/hurricanes/viewer.html

5.5 Statistical summary of data from permanent and temporary sites

Summary statistics for the permanent site over the entire study period, as well as data from the combined temporary sites are presented in Table 2. The most obvious difference between conditions at the permanent site and the combined temporary sites is the lower mean percent DO at the permanent site (87.9%) versus the combined temporary sites (95.6%). In addition, the temporary sites represent a range of conditions throughout the Refuge, with slightly greater variation (eg. turbidity) when compared to the permanent site.

Table 2. Summary statistics*

Permanent Site:

	Temperature °C	Salinity ppt	DO Percent %	DO Conc mg/l	pH	Turbidity NTU
Min:	4.56	2.25	1.000	0.07	6.93	1.0
Mean:	21.20	29.89	87.93	6.75	7.71	33.65
Max:	32.77	40.18	157.30	15.41	8.53	299.10
Std Dev:	6.61	5.00	19.46	2.13	0.24	27.61

Temporary Sites:

	Temperature °C	Salinity ppt	DO Percent %	DO Conc mg/l	pH	Turbidity NTU
Min:	4.17	0.13	6.90	0.45	6.76	1.0
Mean:	20.79	29.53	95.60	7.38	7.72	32.39
Max:	32.59	38.06	165.30	15.13	8.21	299.60
Std Dev:	6.84	6.28	20.61	2.12	0.25	33.21

The correlation between variables at the permanent site and the combined temporary sites is presented in Table 3. At the permanent site, a negative correlation exists between water temperature and pH. DO and pH are positively correlated at the permanent site. Both pH and DO decrease in mid summer as water temperatures increase. At the combined temporary sites, pH and salinity are positively correlated. The negative relationship between salinity and site ID (as a surrogate for date) is indicative of the shift from dry to wet years as this study progressed.

Table 3. Correlation between variables*

Permanent Site:

	Salinity	DO Percent	pH	Turbidity
Temperature	0.091	-0.489	**-0.538**	0.126
Salinity		-0.011	0.258	0.025
DO Percent			**0.627**	-0.040
pH				0.001

Temporary Sites:

	Salinity	DO Percent	pH	Turbidity	Site ID
Temperature	0.053	-0.283	-0.438	0.126	-0.242
Salinity		-0.097	**0.503**	0.034	-0.453
DO Percent			0.366	-0.102	0.410
pH				0.055	-0.171
Turbidity					-0.023

* Note: although the database contains all nephelometric turbidity units (NTU) up to 1000 units, only values ranging from 1 to 300 NTU are included here. The lower limit NTU follows the NERRS protocol. Also, all records where data are flagged as questionable are omitted.

To examine the question of whether or not the permanent site is reflective of the temporary sites scattered throughout the Refuge, a two sample difference of means test (pooled variance; sign. level .05) was performed (S-Plus 2005) on the mean of each variable (water temperature, percent dissolved oxygen, salinity, turbidity, and pH). The mean for each sampling period from all temporary sites were compared with the mean from all data collected at the permanent site (Table 4). The test results indicate that the permanent site is similar in all characteristics, except mean DO, when compared to the collective temporary sites (p=0.016). This finding can be useful in designing long term monitoring for this area.

Table 4. Comparison of mean bi-weekly values of permanent site to all temporary sites (N=87)

Variable	Permanent site	Temporary sites	p-value
Mean percent DO	87.93	95.60	***0.016***
Mean salinity (ppt)	28.89	29.53	0.577
Mean pH	7.71	7.72	0.765
Mean turbidity (NTU)	33.65	32.39	0.830
Mean temperature (^{o}C)	21.2	20.79	0.939

5.6 Inter-annual trends at the permanent site

Examining the mean values for each two week sampling period over the entire study period reveals seasonal trends in water temperature, pH, DO, turbidity, and salinity (Figures 11-15). Mean pH (Figure 12) and mean DO (Figure 13) both increase in the winter and decrease in the summer. Turbidity fluctuates seasonally to some degree (Figure 14). The highest turbidity readings occur in the summer and fall and peak during windy conditions. For example, in May 2003 and September of 2003 and 2004 maximum wind gusts near 30 mph were recorded at Georgetown, SC (See Appendix). The trend in salinity is associated with dry versus wet years. Salinity readings in 2001 and 2002 are generally higher than the period 2003 through 2005 (Figure 15). The lowest mean salinity readings occur in April and May of 2003 during a time of heavy rainfall and fresh water releases from the Santee River dam.

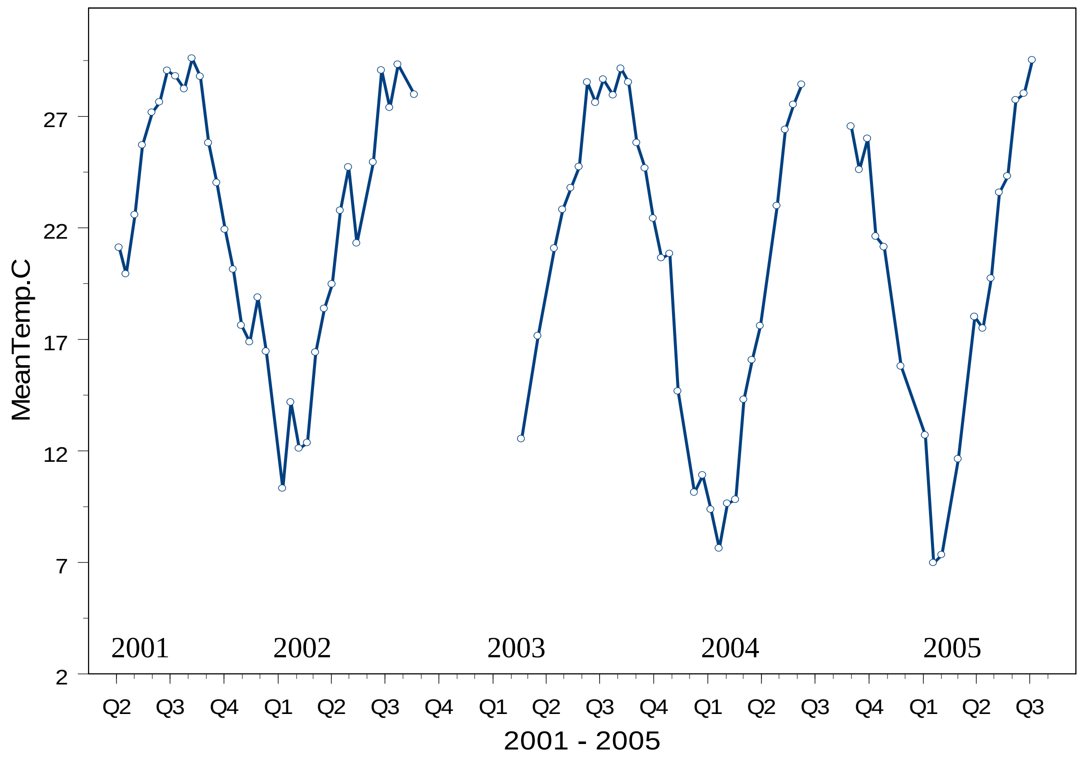


Figure 11. Mean water temperature (^oC) at the permanent site April 2001 to July 2005.

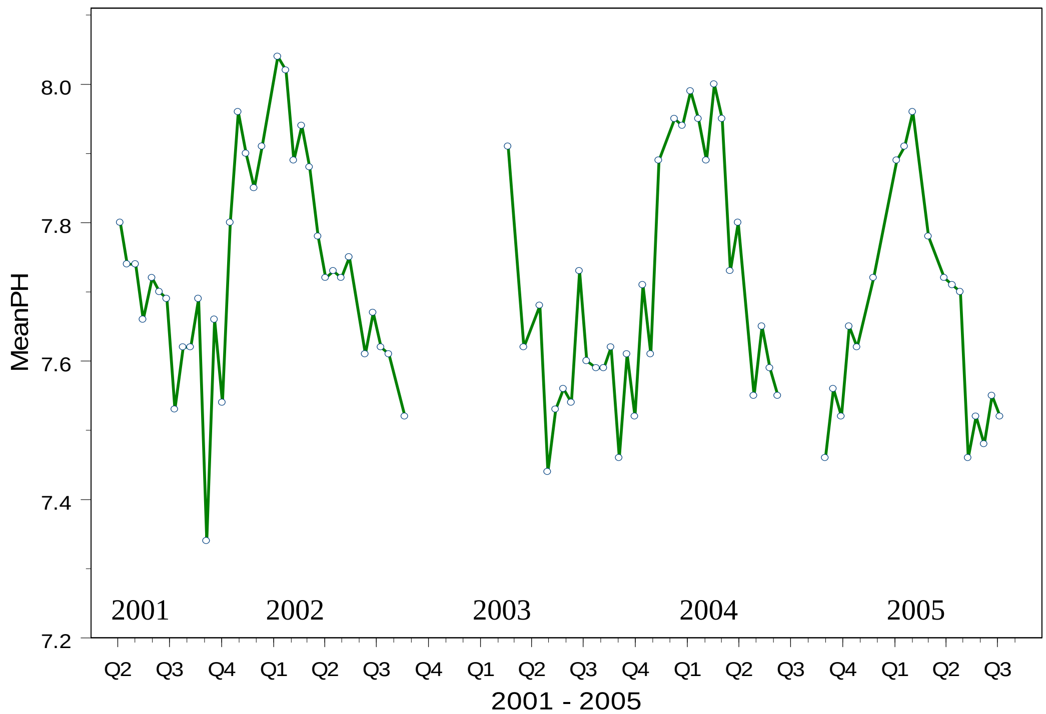


Figure 12. Mean pH at the permanent site April 2001 to July 2005.

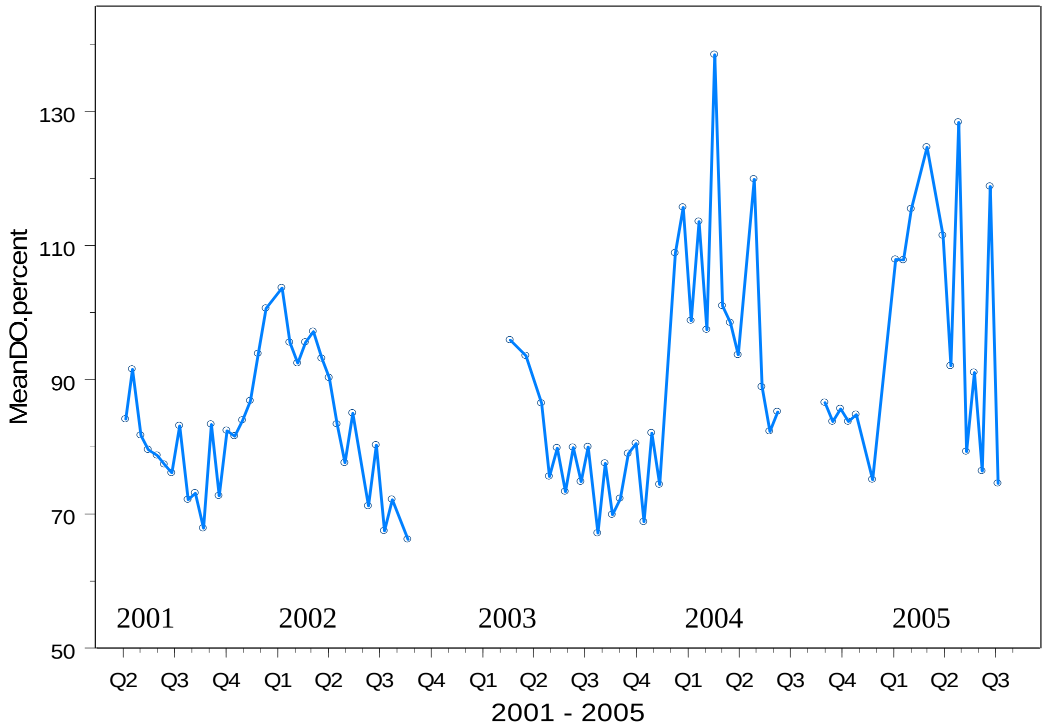


Figure 13. Mean percent DO at the permanent site April 2001 to July 2005.

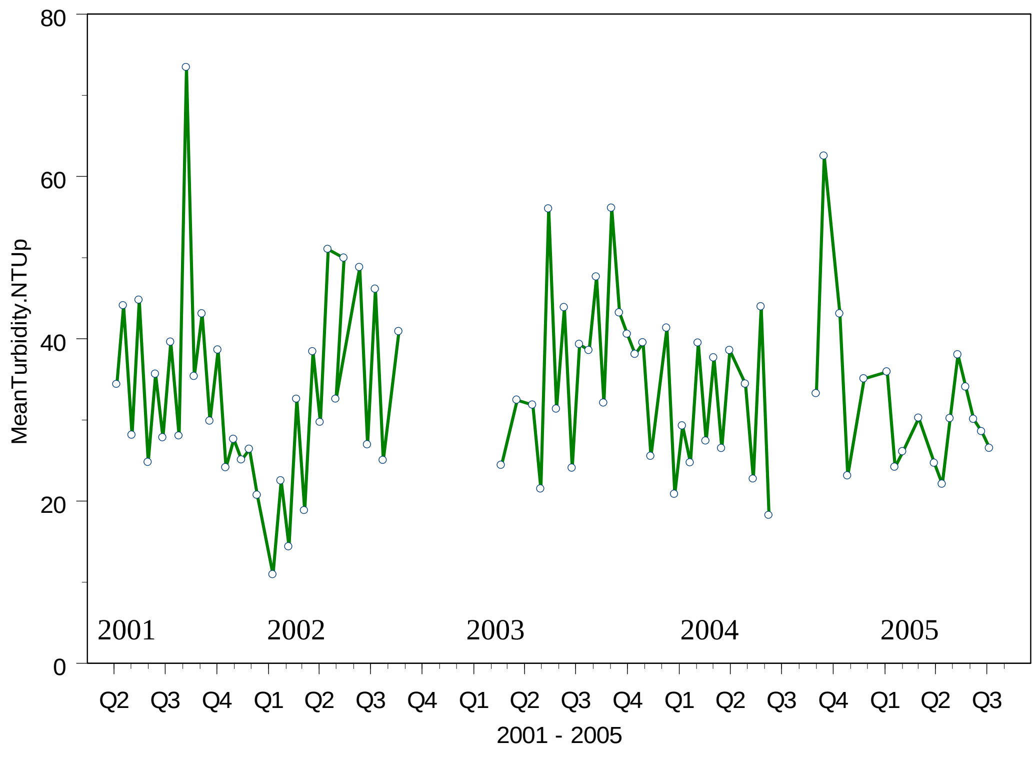


Figure 14. Mean turbidity (NTU) at the permanent site April 2001 to July 2005.

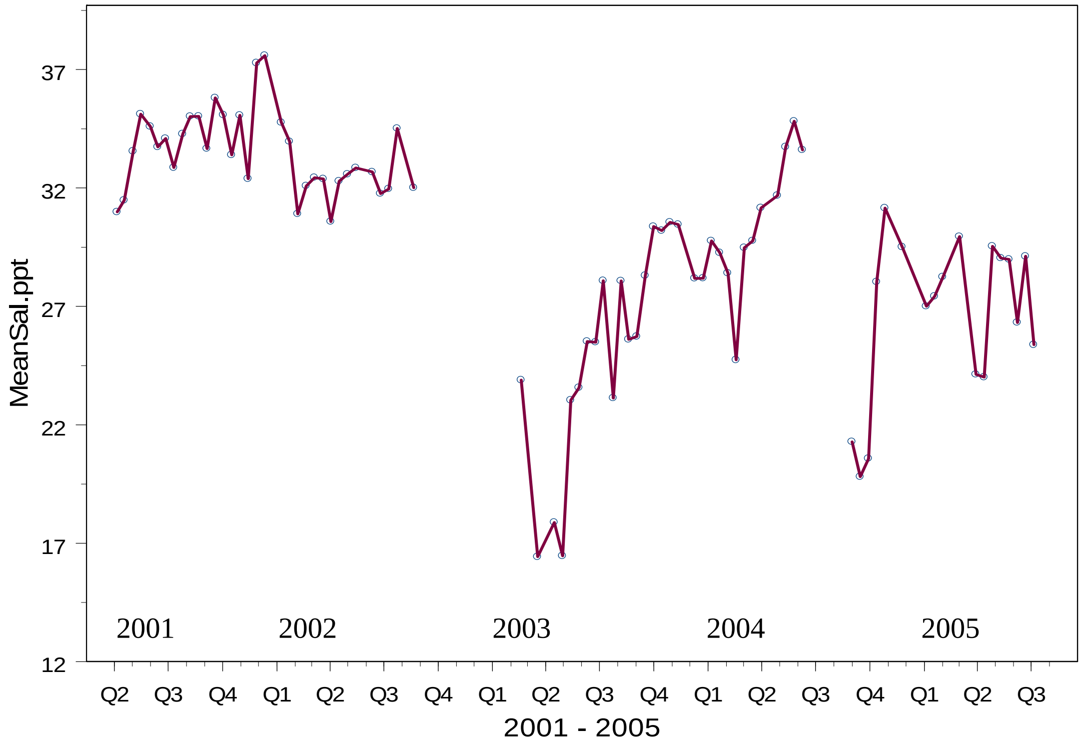


Figure 15. Mean salinity (ppt) at the permanent site April 2001 to July 2005.

5.7 Comparison of the permanent site with concurrent temporary sites

A comparison of readings taken at the permanent site with readings taken simultaneously at the temporary sites serves to characterize conditions at various locations throughout the Refuge (Figures 16-27). These graphs represent the mean value for the two week period of sampling at a temporary site, along with the mean value for the same two week period at the permanent site for each of the five variables. The associated maps show the location of select temporary sites that are most different from the permanent site during the same sampling period. Mean water temperature agrees very well between the permanent and temporary sites (Figure 16).

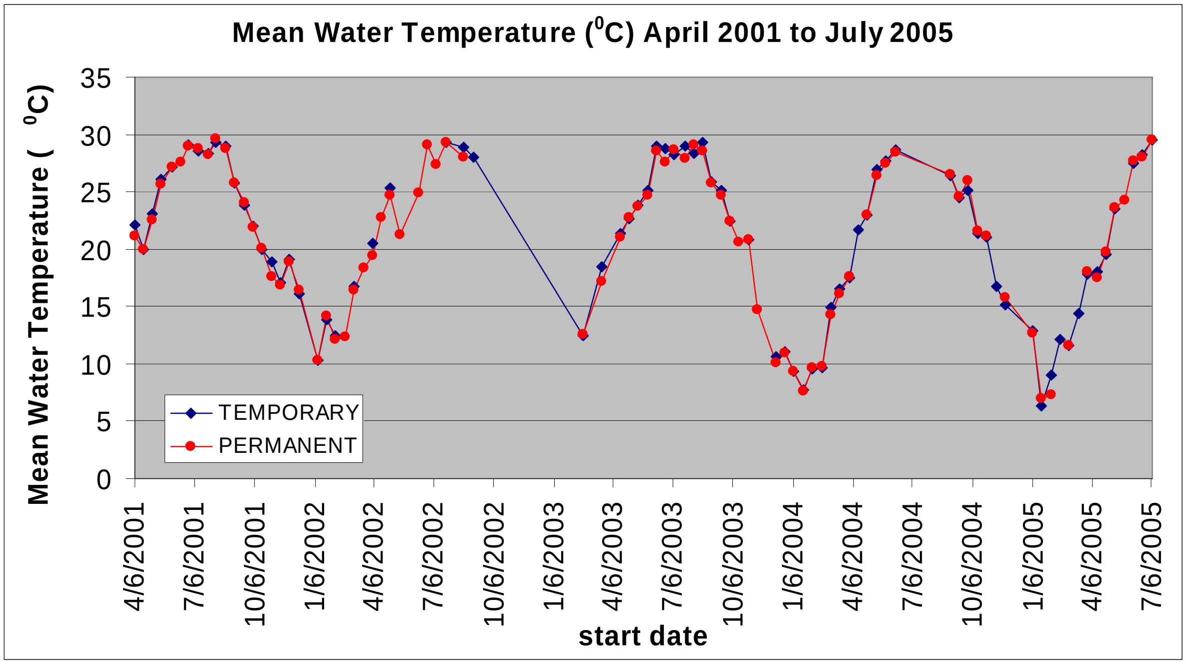


Figure 16. Mean water temperature (^{o}C) at the permanent and temporary sites.

From April 2001 until August 2002, mean salinity for all sites monitored in the Refuge, including the permanent site, remained above 30 ppt (Figure 17). During this dry period, the mean salinity at the temporary sites was very similar to mean salinity at the permanent site. During the wet years, there are greater differences in salinity between the permanent and temporary sites.

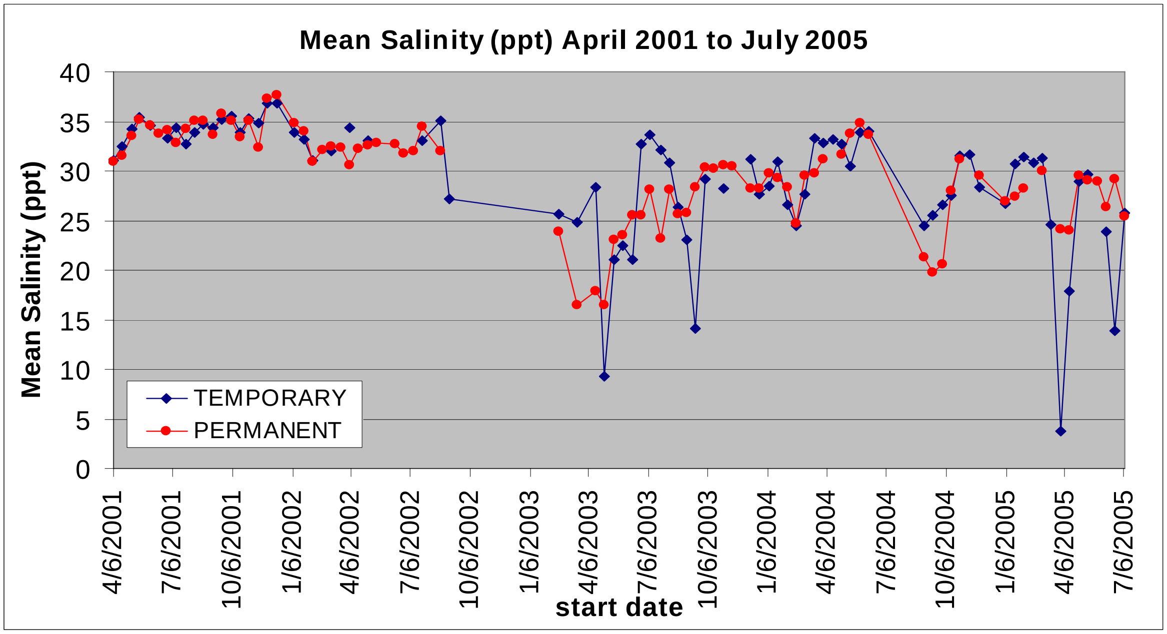


Figure 17. Mean salinity (ppt) at the permanent and temporary sites.

The locations of temporary sites that are most different from the permanent site in terms of salinity were mapped (Figure 18). When comparing mean salinity of the temporary site with mean salinity at the permanent site, the greatest differential occurs in the northeast region of the Refuge which is influenced by freshwater releases through the Santee River dam. At three temporary sites in this area, mean salinity is 14 to 20 ppt lower than at the permanent site. (Sept. 2003, March 2005, June 2005). A site near the ICW sampled just after the HAB also had a lower mean salinity than the permanent site.

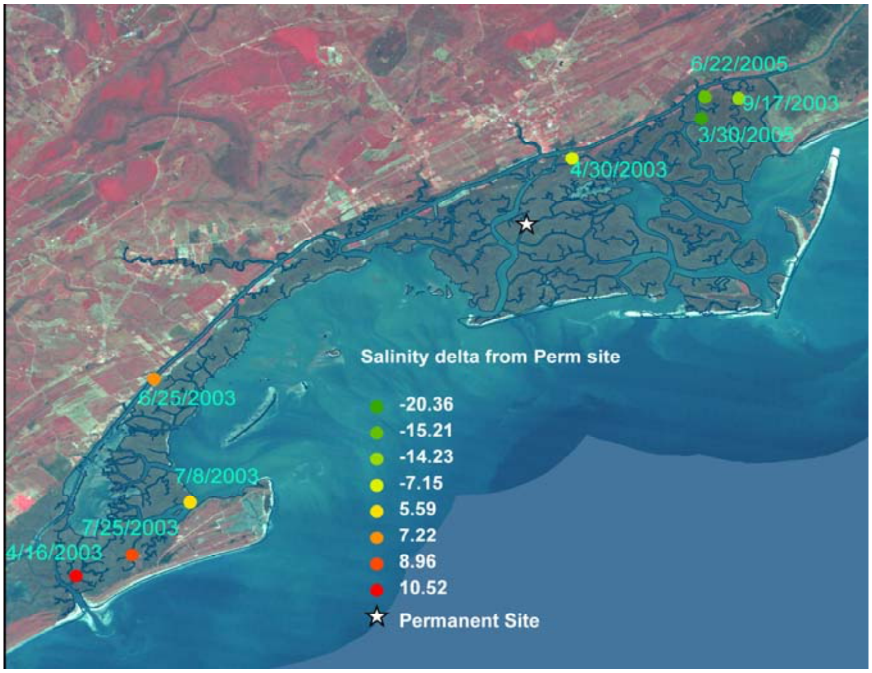


Figure 18. Temporary sites that differ most from the permanent site in terms of salinity.

In the southwest area of the Refuge, there are four temporary sites that have a higher mean salinity than the permanent site sampled at the same time (April 2003, June 2003 and two in July 2003). In general, higher salinity occurs in the southwest region of the Refuge; while lower salinity occurs in the northeast region near the Santee River. In addition, Jeremy Creek in McClellanville and Awendaw Creek add freshwater inputs to the system. A gradient of increasing salinity is evident moving from the northeast to the southwest.

The temporary sites sampled during dry years generally exhibit lower mean percent DO than those sampled during wet years (Figure 19). Temporary sites that differed most from the permanent site with respect to DO were mapped (Figure 20). Temporary sites that have a much higher mean DO than the permanent site (July 2003, October 2003, Dec. 2003, and June 2004) are generally located in exposed areas (Figure 20). Greater fetch and increased wind may account for higher DO at these locations. Two temporary sites that have a much lower mean DO than the permanent site are located in small tidal creeks – one behind Bull Island and one in a small creek off Shiner Creek near Muddy Bay (July 2001 and April 2004).

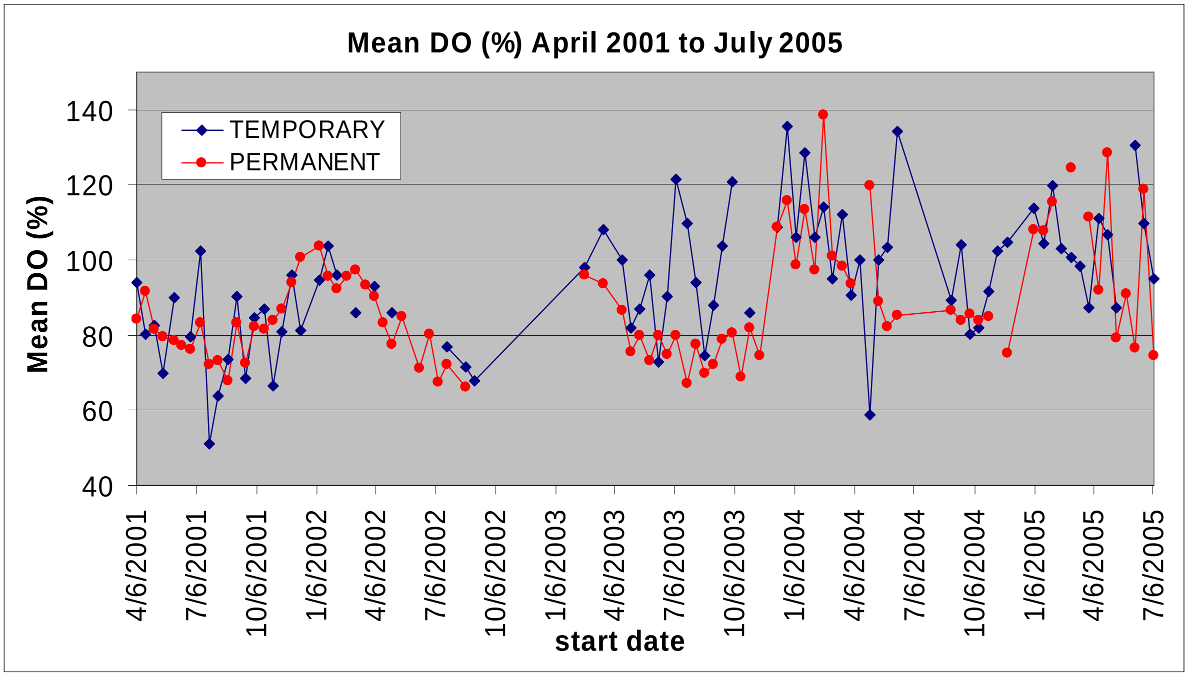


Figure 19. Mean DO at the permanent and temporary sites.

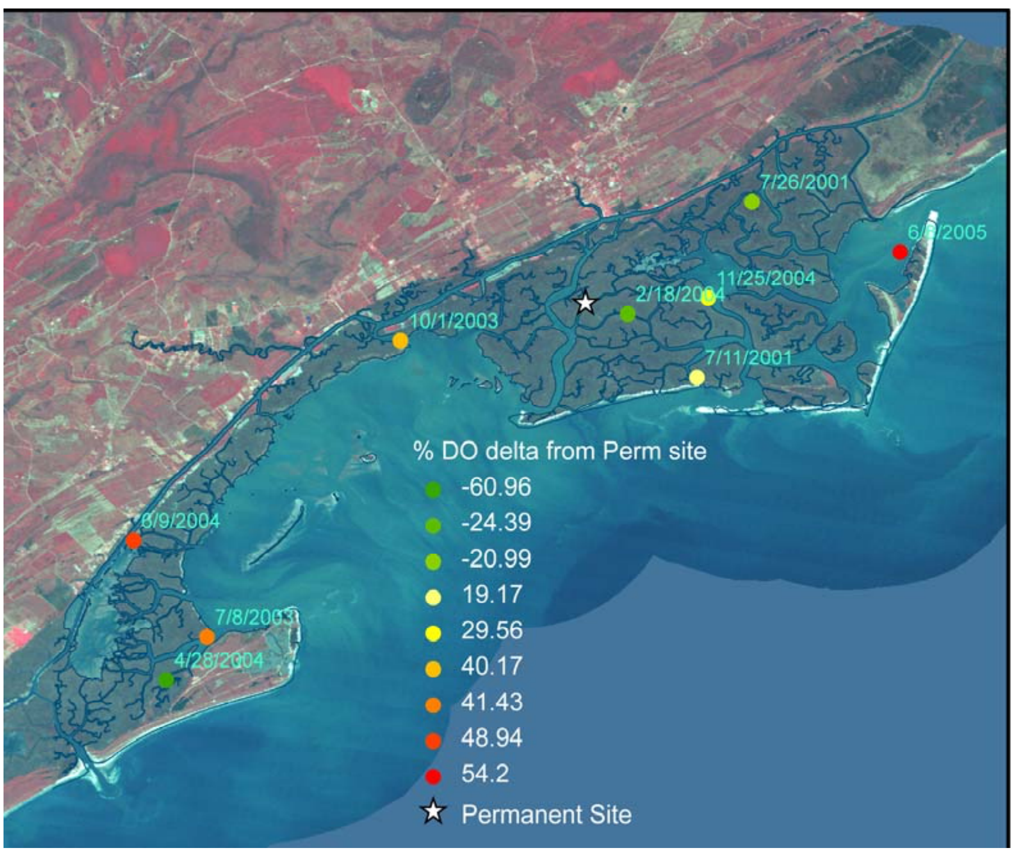


Figure 20. Temporary sites that differ most from the permanent site with respect to DO.

EPA defines waters with dissolved oxygen between 2 and 5 mg/L as hypoxic. Below 2 mg/l stress and death may occur. Based on EPA guidelines regarding DO, we observed up to seven instances where severe hypoxia levels were recorded. Four of these events occurred at the permanent site (Figure 21, Figure 23). (Note: two of these occurrences during sampling periods starting July 10, 2002 and July 24, 2002 at the permanent site might be attributable to instrument drift). Three instances of DO < 2.0 mg L^{-1} occurred at temporary sites (Figure 22, Figure 23). The low DO events occurred over a period of one, three or twelve days, primarily in the summer months during 2001-2002. The timing and location of extremely low DO events are presented in Figures 21-23.

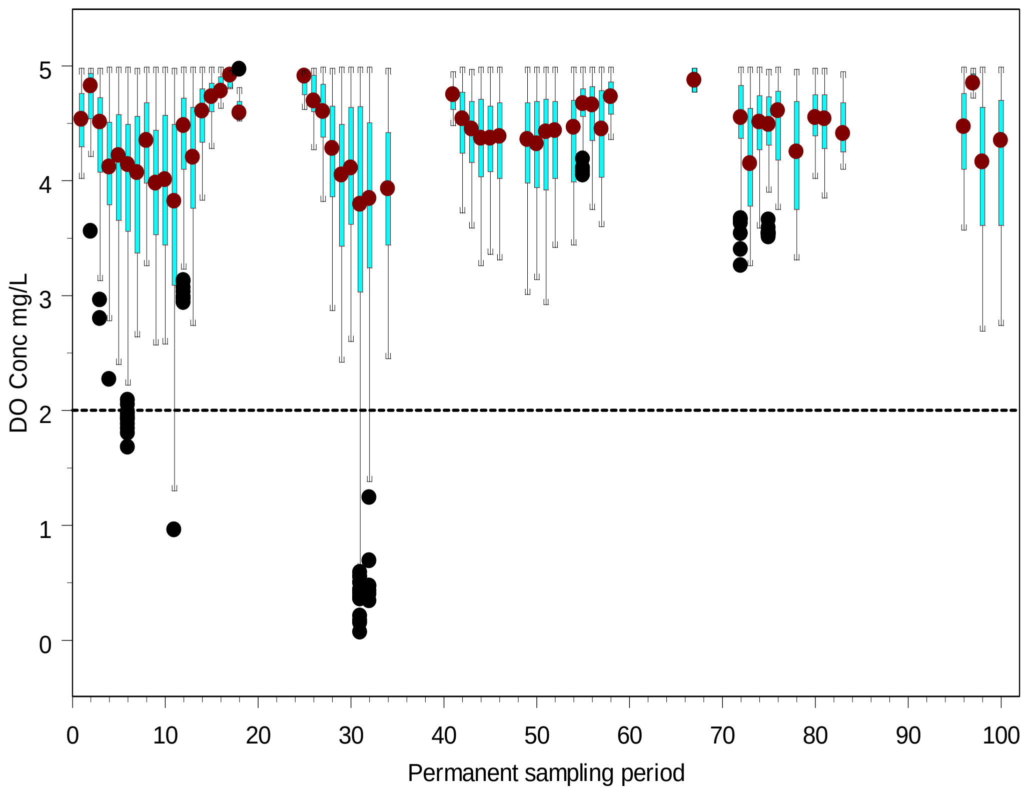


Figure 21. Box and whisker plots of DO concentration <5.0 mg L^{-1} recorded at the permanent site aggregated by sampling period. The red dot indicates the median value, the box edges represent the 25^{th} and 75^{th} percentile and the whiskers indicate 1.5 interquartile ranges from the top and bottom. Points outside the whiskers indicate extreme observations. The dotted line delineates DO concentration <2.0 mg L^{-1} recorded at the permanent site during sampling periods beginning on 6/14/2001 (period 6), 8/22/2001 (period 11), 7/10/2002 (period 31), 7/24/2002 (period 32).

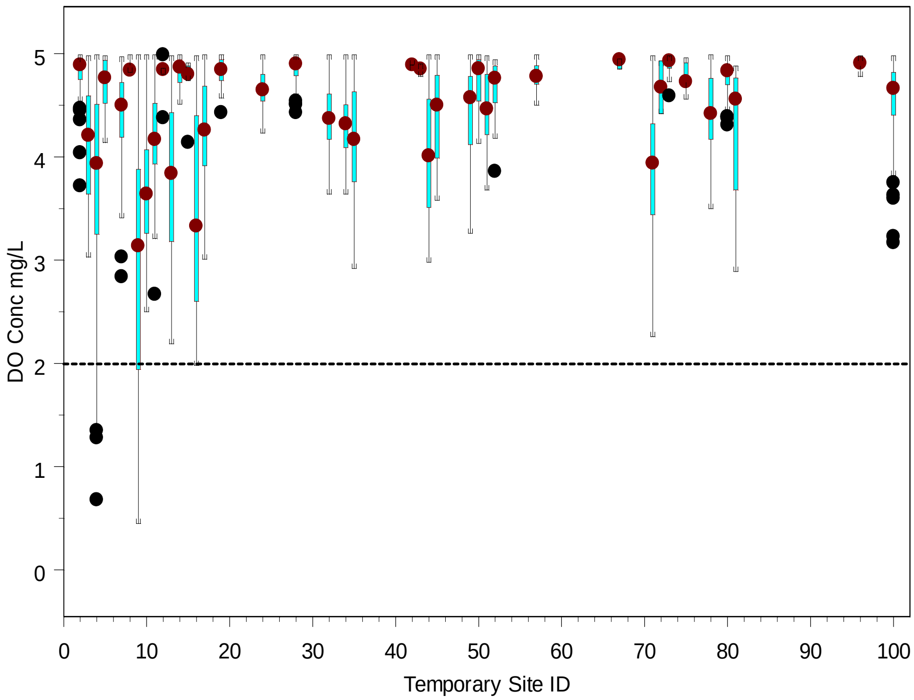


Figure 22. Box and whisker plots of DO concentration <5.0 mg L^{-1} recorded at the temporary sites. The red dot indicates the median value, the box edges represent the 25th and 75th percentile and the whiskers indicate 1.5 interquartile ranges from the top and bottom. Points outside the whiskers indicate extreme observations. The dotted line delineates DO concentration <2.0 mg L^{-1} recorded at temporary sites during sampling periods beginning 5/16/2001(site 4), 7/26/2001 (site 9), and 10/31/2001 (site 16).

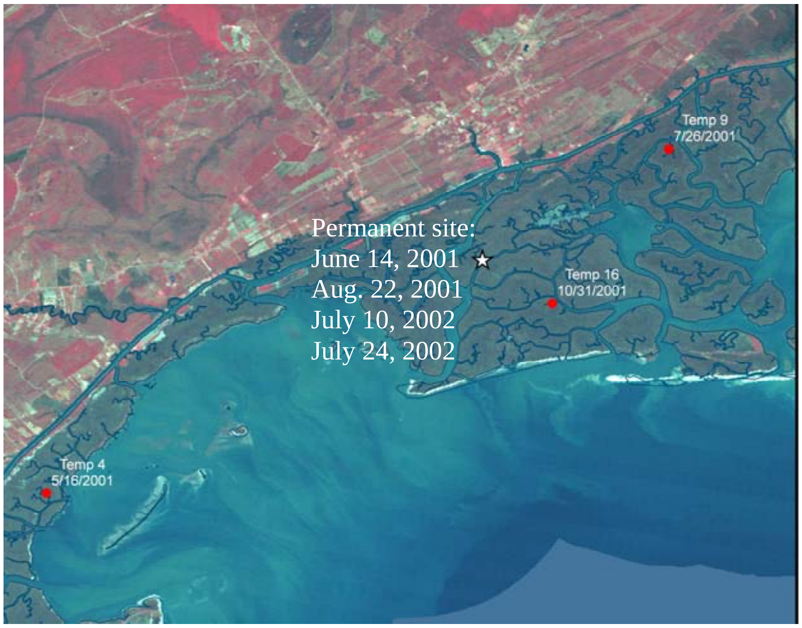


Figure 23. Location and start dates of sampling periods with DO conc <2.0 mg L^{-1}.

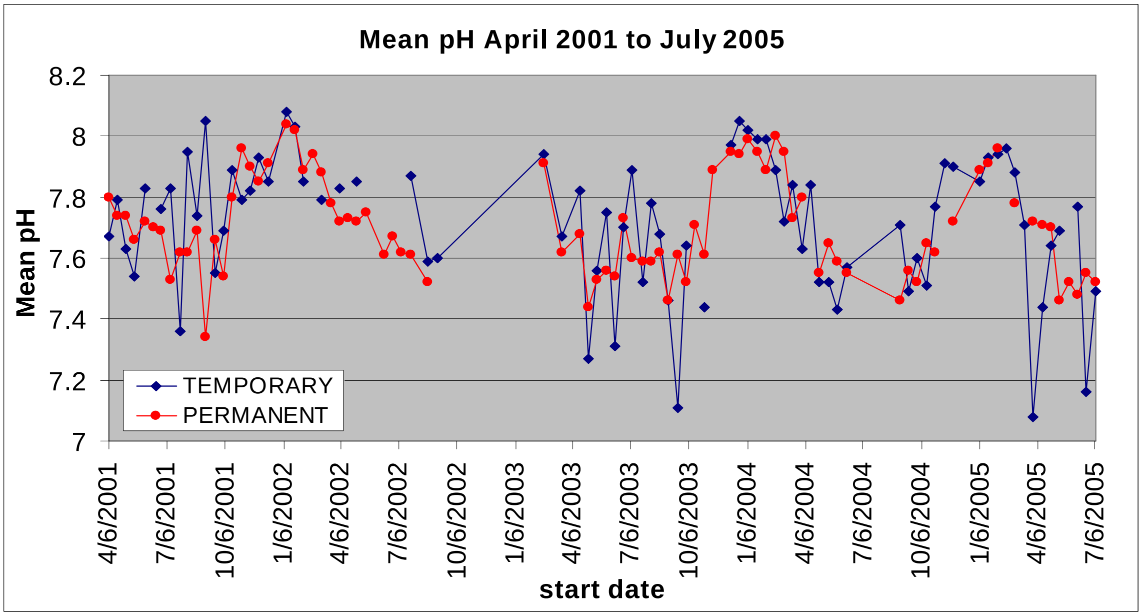


Figure 24. Mean pH at the permanent and temporary sites.

When comparing mean pH recorded at the permanent site with mean pH at the combined temporary sites (Figure 24), the temporary site that differs the most from the permanent site (Figure 25) is an open water site behind Cape Island (Sept. 2001). Three temporary sites that have a lower pH than the permanent site all occur in the northeast corner of the Refuge, near the ICW and the South Santee River (Sept. 2003, March 2005, and June 2005).

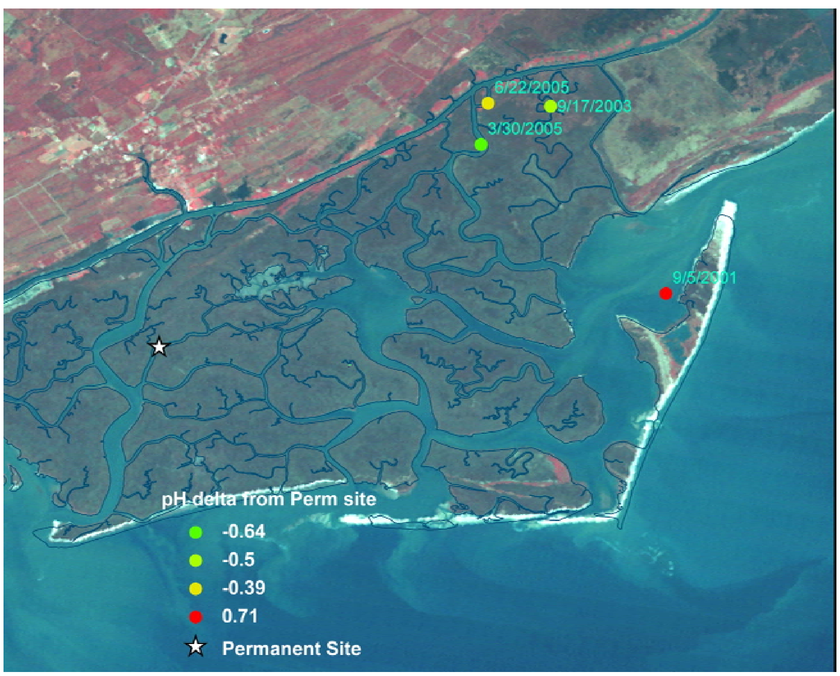


Figure 25. Temporary sites that differ most from the permanent site with respect to pH.

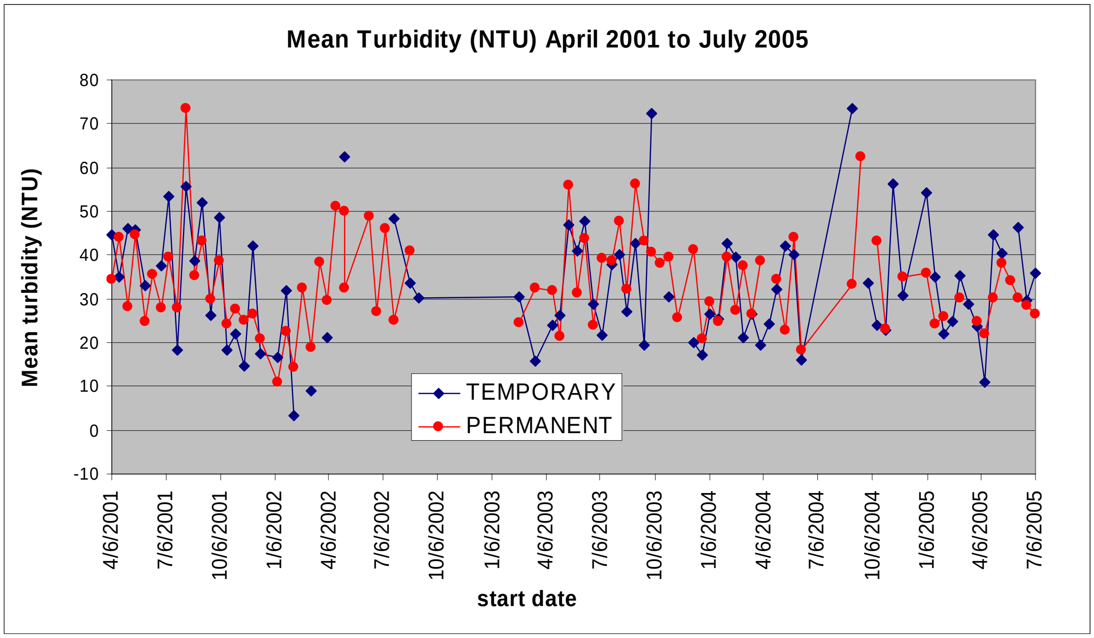


Figure 26. Mean turbidity (NTU) at the permanent and temporary sites.

A comparison of mean turbidity (NTU) recorded at the permanent and combined temporary sites over the study period is shown in Figure 26. Two temporary sites with a higher mean turbidity than the permanent site are shown in Figure 27. One site is located in an exposed area close to Bulls Bay (Oct. 2003) and in the other in the Romain River near Key Inlet (Sept. 2004). This same Bulls Bay site also had a much higher mean percent DO than the permanent site. The site near Key Inlet was sampled during the time when tropical storm Frances was passing through Atlanta 250 miles to the west. A temporary site with a lower mean turbidity than the Permanent site, sampled in August 2001, is located near Bull Island.

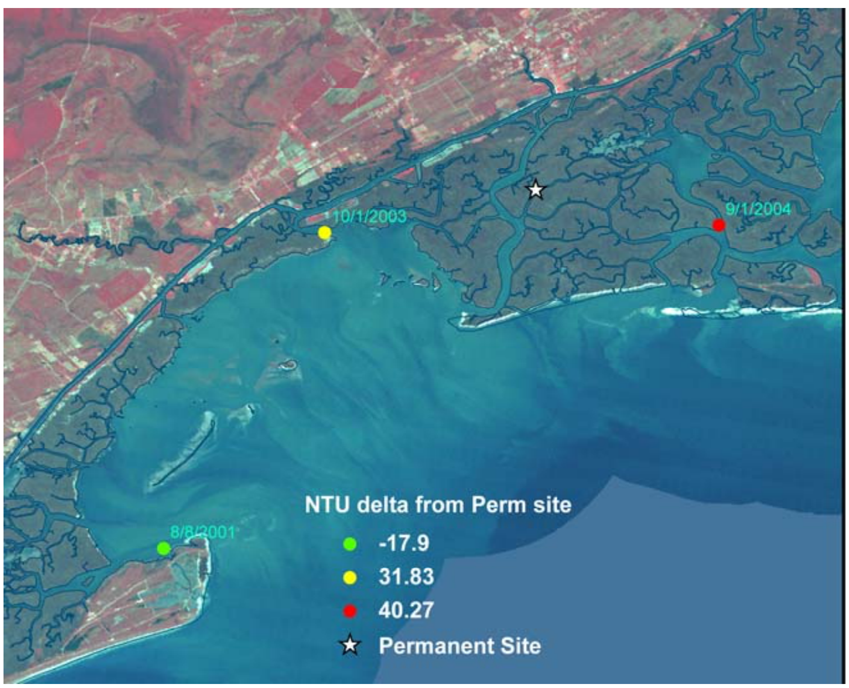


Figure 27. Temporary sites that differ most from permanent site with respect to turbidity.

6.0 Discussion

Examining four years of water quality information collected throughout CRNWR provides a good picture of overall conditions within the Refuge. An obvious change within the Refuge over this time period occurred with a shift from dry to wet years. In addition, variation in salinity was observed with freshwater inputs from heavy rainfall in the spring of 2003 and fresh water released through the Santee River system. Our data suggests that the periodic discharge of freshwater released through the Santee River dam, along with heavy rainfall, influences water quality within the Refuge, especially in the northern section. The timing and amount of water released likely has an effect on biota and warrants further study. During the study period, a harmful algal bloom developed in Bulls Bay in April 2003 and coincided with low salinity and freshwater releases from the Santee dam. This event is a clear reminder that the waters of the Refuge are susceptible to HABs resulting in fish kills. Therefore, pressures from coastal development and alteration of the landscape should continue to be monitored to reduce and mitigate potential impacts.

We recorded relatively few low DO events. Based on EPA guidelines regarding DO, we observed instances where severe hypoxia levels (DO concentration $<2.0 mg\ L^{-1}$) were recorded at some time during seven of the eighty-seven sampling periods. Four of these events occurred at the permanent site (two of which may be attributable to instrument drift). Three instances of DO concentration $<2.0 mg\ L^{-1}$ occurred at temporary sites. The low DO events occurred over a period of one, three or twelve days, primarily in the summer months during dry years.

In designing future monitoring programs, it is important to note that the permanent site was fairly representative of the other sites sampled throughout the Refuge, except in percent DO. Mean DO was found to be significantly lower at the permanent site than at the combined temporary sites. Future monitoring could involve an array of permanent sensors to better capture variation in DO. Also, it may be advantageous to monitor a few select sites that appear to exhibit the most extreme conditions. This data can be further explored with the expressed purpose of choosing the best locations for long-term monitoring, based on specific objectives.

In this study, variation associated with tidal and seasonal cycles, typical of a marine-influenced saltmarsh ecosystem, was observed. Future analysis, such as comparison with data collected at NERRS sites, will be possible. In addition, since these data were collected every 30 minutes, analysis using spectral and temporal techniques may reveal information about how this system works at much shorter time scales. Most of the analysis presented here utilized mean values over a two-week sampling period, and therefore ignored some of the shorter term processes that may be occurring. In addition, spatial statistical techniques with greater specificity to location, in conjunction with a multivariate approach, will help to further differentiate important habitat characteristics within the Refuge.

7.0 References

Anderson, W.D., Keith, W.J., Mills, F.H., Bailey, M.E., and J.L. Steinmeyer. 1978. A survey of South Carolina hard clam resources. South Carolina Marine Resources Center Technical Report Number 32.

Bailey, W.P. 1996. Population trends in the coastal area, concentrating on South Carolina. In: Vernberg, F.J., Vernberg, W.B., Siewicki, T. (eds) Sustainable development in the southeastern coastal zone. University of South Carolina Press. Columbia, SC, p. 55-73.

Bauersfeld, P.E. and G.M. Meaburn. 2006. Ecological Characterization of a Coastal Refuge: Cape Romain National Wildlife Refuge. NOAA Tech. Memo. NOS-NCCOS-CCEHBR (In press).

Battle, J.D. 1892. An investigation of the coast waters of South Carolina with reference to oyster culture. Bulletin of the U.S. Fish Commission. 10:303-330.

Blount, B. 2000. Coastal Refugees: Marginalization of African Americans in marine fisheries of Georgia. Urban Anthropology. 29(3): 285-313.

Brown, P.J. 1977. Variations in South Carolina coastal morphology. Southeastern Geology. 18(4):249-264.

Carney, J. 1996. Landscapes of technology transfer: Rice cultivation and African continuities. Technology and Culture. 37(1): 5-35.

Chang, F.H., Pridmore, R. and N. Boustead. 1993. Occurrence and distribution of *Heterosigma cf. akashiwo* (Raphidophyceae) in a 1989 bloom in Big Glory Bay, New Zealand. In: Toxic Phytoplankton Blooms in the Sea. Eds. T.J. Smayda and Y. Shimizu. Elsevier Science Publishers. Amsterdam, The Netherlands.

Daniels, R.C., White, T.W., and K. K. Chapman. 1993. Sea-level rise: Destruction of threatened and endangered species habitat in South Carolina. Environmental Management. 17(3):373-385.

EPA. 2005. Summary of findings: 2005 National Coastal Condition Report. Accessed April 2006. http://www.epa.gov/owow/oceans/nccr/2005/summary.html

Gracy, R.C. and W.J. Keith. 1972. Survey of the South Carolina oyster fishery. SC Wildlife and Marine Resources Department. Marine Resources Center. Technical Report No.3. Charleston, SC. 28p.

Haines, E.B. 1975. Nutrient inputs to the coastal zone: The Georgia and South Carolina shelf. *Estuarine Research*. Volume 1: chemistry, biology, and the estuarine system. Academic Press. New York, NY.

Hockensmith, B. L. 2004. Flow and Salinity Characteristics of the Santee River Estuary, South Carolina. SC Dept. of Natural Resources. Land, Water and Conservation Division. Water Resources Report 35. 42 p.

Honjo, T. 1993. Overview of bloom dynamics and physiological ecology of *Heterosigma akashiwo*. In: Toxic Phytoplankton Blooms in the Sea. Smayda, T.J. and Y. Shimizu (eds). Elsevier Science Publishers. Amsterdam, The Netherlands.

Jennings, J.A. and L.M. Kracker. 2003. Fisheries Databases for Assessing Habitat Functions of Cape Romain NWR. NOAA Tech. Mem. NOS-NCCOS-CCEHBR-0009. 19p.

Kelley, J., 2006. Plant succession in South Carolina tidal former rice fields: Ecological and human use implications. Accessed April 2006. http://www.carolinagoldricefoundation.org/kellypaper1.pdf

Keppler, C.J., Hoguet, J.H., Smith, K., Ringwood, A.H., and A.J. Lewitus. 2005. Sublethal effects of the toxic alga *Heterosigma akashiwo* on the southeastern oyster (*Crassostrea virginica*). Harmful Algae 4:275-285.

Kjerfve, B. and J.E. Greer. 1978. Hydrography of the Santee River during moderate discharge conditions. Estuaries 1(2):111-119.

Kracker, L.M. 2003. Literature review for a resource characterization of Cape Romain National Wildlife Refuge NOAA Tech. Mem. NOS-NCCOS-CCEHBR-0008. 59p.

Kracker, L.M. and C. Preston. 2004. Linking ecology and culture through a coastal landscape. Proceedings from The Coastal Society 19th Biennial Conference. Newport, RI. May 23-26, 2004.

Lewitus, A. and Hayes, K. unpublished data. Data summary for Romain River estuary, South Carolina, U.S.A. September 2002 thru August 2003. Belle W. Baruch Institute for Marine and Coastal Sciences, University of South Carolina.

Lewitus, A.J., Koepfler E.T., and J.T. Morris. 1998. Seasonal variation in the regulation of phytoplankton by nitrogen and grazing in a salt-marsh estuary. Limnology and Oceanography. 43(4):636-646.

Lewitus, A.J., Kawaguchi, T., DiTullio, G.R., and J.D.M. Keesee. 2004. Iron limitation in an urbanized vs. forested southeastern U.S. salt marsh estuary. Journal of Marine Biology and Ecology 298:233-254.

Lunz, G.R., Jr., 1938. Oyster culture with reference to dredging operations in South Carolina (Part 1) and the effects of the flooding of the Santee River in April 1936 on oysters in the Cape Romain Area of South Carolina (Part2). USACOE. Report no. AAE-6420.

McGovern, J.C. and C.A. Wenner. 1990. Seasonal recruitment of larval and juvenile fishes into impounded and non-impounded marshes. Wetlands. 10(2):203-221.

Morris, J.T. and P.M. Bradley. 1999. Effects of nutrient loading on the carbon balance of coastal wetland sediments. Limnology and Oceanography. 44(3)699-702. Part 1.

NOAA 2002. The ecological characterization of Cape Romain National Wildlife Refuge. Progress Report. Prepared by Center for Coastal Environmental Health and Biomolecular Research, National Ocean Service, Charleston, SC. April 2002.

NOAA 2004. The ecological characterization of Cape Romain National Wildlife Refuge with socio-economic consideration. Progress Report. Prepared by Center for Coastal Environmental Health and Biomolecular Research, National Ocean Service, Charleston, SC. October 2004.

Patterson, G.C., Cooney, T.W., and R.M. Harvey. 1997. The sediment transport and deposition in Lakes Marion and Moultrie, South Carolina, 1942-85. Water Resources Investigations Report: 95-4239.

Pilkey, O.H. and K.L. Dixon. 1996. The Corps and the Shore. Island Press. Washington, DC.

Powers, S.P., Peterson, C.H., Christian, R.R., Sullivan, E., Powers, M.J., Bishop, M.J., and C.P. Buzzelli. 2005. Effects of eutrophication on bottom habitat and prey resources of demersal fishes. Marine Ecology Progress Series. 302:233-243.

Saucier, M.H. and D.M. Baltz. 1992. Hydrophone identification of spawning sites of spotted seatrout *Cynoscion nebulosus* (Osteichthys: Sciaenidea) near Charleston, South Carolina. Northeast Gulf Science. 12(2):141-145.

Scott, G.I. and D.R. Lawrence. 1982. The American Oyster as a coastal zone pollution monitor: a pilot study. Estuaries. 5(1):40-46.

Sexton, W.J. 1995. The post-storm hurricane Hugo recovery of the undeveloped beaches along the South Carolina coast: Capers Island to the Santee Delta. Journal of Coastal Research. 11(4):1020-1025.

Shenker, J.M. and J.M. Dean. 1979. The utilization of an intertidal salt marsh creek by larval and juvenile fishes: abundance, diversity and temporal variation. Estuaries. 2(2):154-163.

South Carolina Task Group on Harmful Algae 2004. Massive "Red Tide" in Bull Bay. Vol. 5, No.1. Accessed April 2006. http://www.scseagrant.org/hab/schab_news_spr04.htm#tide

S-Plus 7. 2005. Guide to Statistics. Insightful Corporation. Seattle, WA.

Spurrier, J.D. and B. Kjerfve. 1988. Estimating the net flux of nutrients between a salt marsh and a tidal creek. Estuaries. 11(1):10-14.

Stanley, D.W. and S.W. Nixon. 1992. Stratification and bottom-water hypoxia in the Pamlico River Estuary. Estuaries. 15(3):270-281.

Stephen, M.F., Brown, P.J., Fitzgerald, D.M., Hubbard, D.K., and M.O. Hayes. 1975. Beach erosion of Charleston County, South Carolina: A preliminary report. South Carolina SeaGrant Technical Report No. 4. SC-SG-75-4. 79 p.

Titus, J.G. and C. Richman. 2001. Maps of lands vulnerable to sea level rise: Modeled elevations along the US Atlantic and Gulf coasts. Climate Research 18:205-228.

Tarutani, K. Nagasaki, K, and M. Yamaguchi. 2000. Viral impacts on total abundance and clonal composition of the harmful bloom-forming phytoplankton *Heterosigma akashiwo*. Applied and Environmental Microbiology. 66(11):4916-4920.

USFWS. 1981. The ecology of intertidal oyster reefs of the south Atlantic coast: a community profile. Biological Services Program. FWS/OBS-81-5.

USFWS. 2006. Cape Romain National Wildlife Refuge – Facts. Accessed April 2006. http://www.fws.gov/southeast/pubs/facts/crmcon.pdf

Vernberg, F.J., Vernberg, W.B., Blood, E., Fortner, A., Fulton, M., McKellar, H., Michener, W., Scott, G., Sieweicki, T. and K. El Figi. 1992. Impact of urbanization on high-salinity estuaries in the southeastern United States. Netherlands Journal of Sea Research. 30:239-248.

Vernberg, F.J. 1996. Ecology od southeastern Salt Marshes. In: Vernberg, F.J., Vernberg, W.B., Siewicki, T. (eds) Sustainable development in the southeastern coastal zone. University of South Carolina Press. Columbia, SC, p 117-133.

Weinstein, E. 1996. Anthropogenic impacts on salt marshes. In: Vernberg, F.J., Vernberg, W.B., Siewicki, T. (eds) Sustainable development in the southeastern coastal zone. University of South Carolina Press. Columbia, SC, p 135-170.

Wenner and Geist 2001. The National Estuarine Research Reserves Program to Monitor and Preserve Estuarine Waters. Coastal Management. 29:1-17.

White, D.L., Porter, D.E., and A.J. Lewitus. 2004. Spatial and temporal analyses of water quality and phytoplankton biomass in an urbanized versus a relatively pristine salt marsh estuary. Journal of Experimental Marine Biology and Ecology. 298:255-273.

Yamochi, S. 1989. Mechanisms for outbreak of *Heterosigma akashiwo* red tide in Osaka Bay, Japan. Proceedings of the International Symposium on Red Tides. Takamatsu (Japan), 10-14 Nov 1987.

Acknowledgements

Many individuals assisted in the field:

Sachin Agnihortri
Ervin Ashley
Bob Baldwin
Karen Bauersfeld
Laura Bauersfeld
Paul Bauersfeld
Daniel Barton
David Carter
Jonathan Colarusso
Paul Comar
John DeVane
Tom Edwards
Greg Frampton
June Heckman
Ilias Jennane
Jill Jennings
Chad Johnson
Jason Kempton
Pete Key
Carl Kinerd
Amy Kracker
Laura Kracker
Tracy Kracker
Lew LaCoss
Alice Lowndes
Malcolm Meaburn
Town of McClellanville use of ramp
Kumanan Murugesan
Paul Pennington
Samantha Ryan
Craig Sasser
Pat Smallwood
USFS use of ramp at Buck Hall
USFWS use of ramp/pier at Garris Landing
Blaine West
Darren Wray
Many commercial crabbers

Ilias Jenanne and Sachin Agnihotri built the Cape Romain Information System and software application for managing and graphing the data in a SQL Server database.

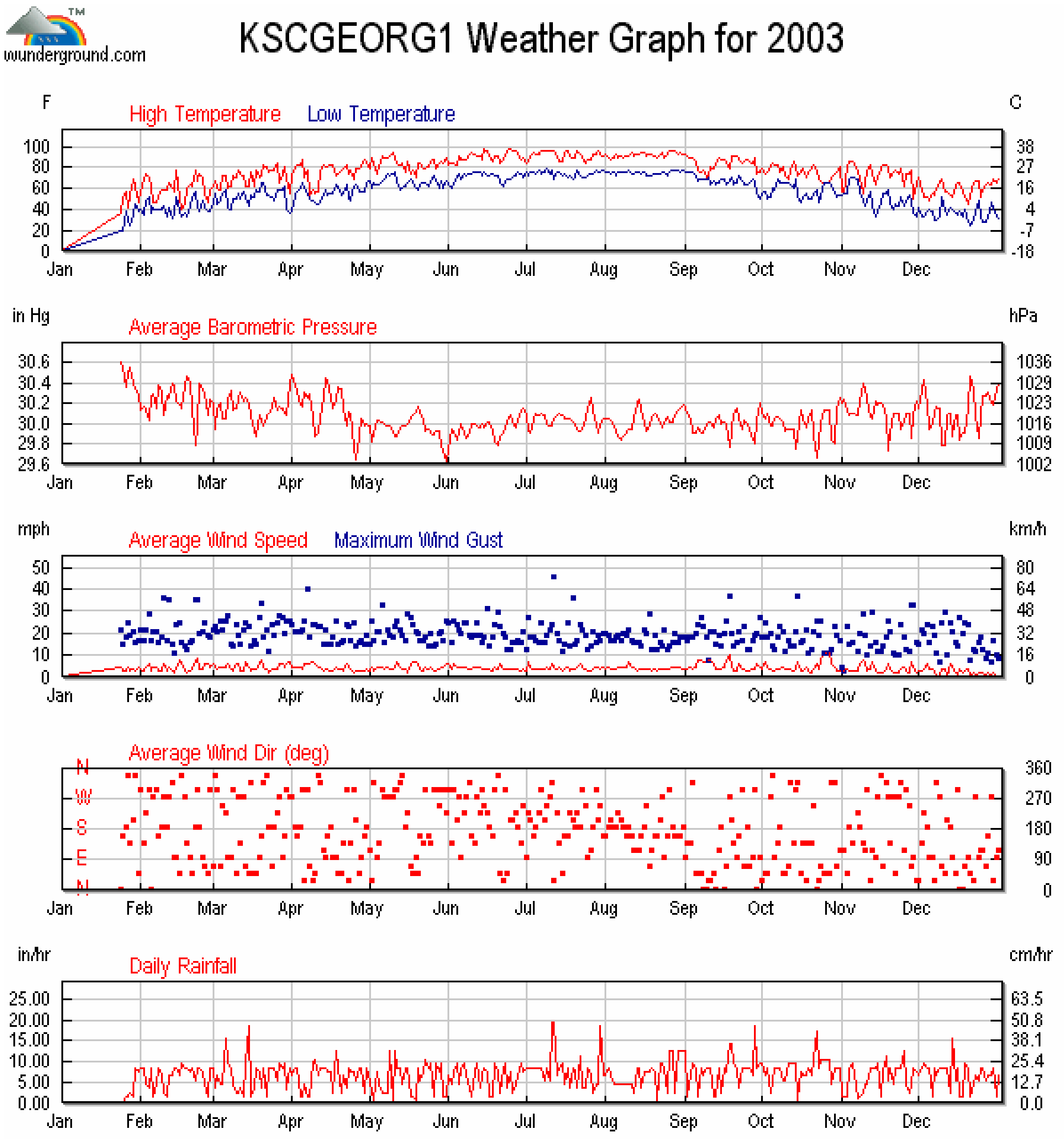
Paul Bauersfeld maintained, modified and deployed the field equipment. He also provided input on the design of the database and software interface. In addition, he loaded, managed, and performed preliminary quality control on the field data, as well as produced bi-weekly reports for this project.

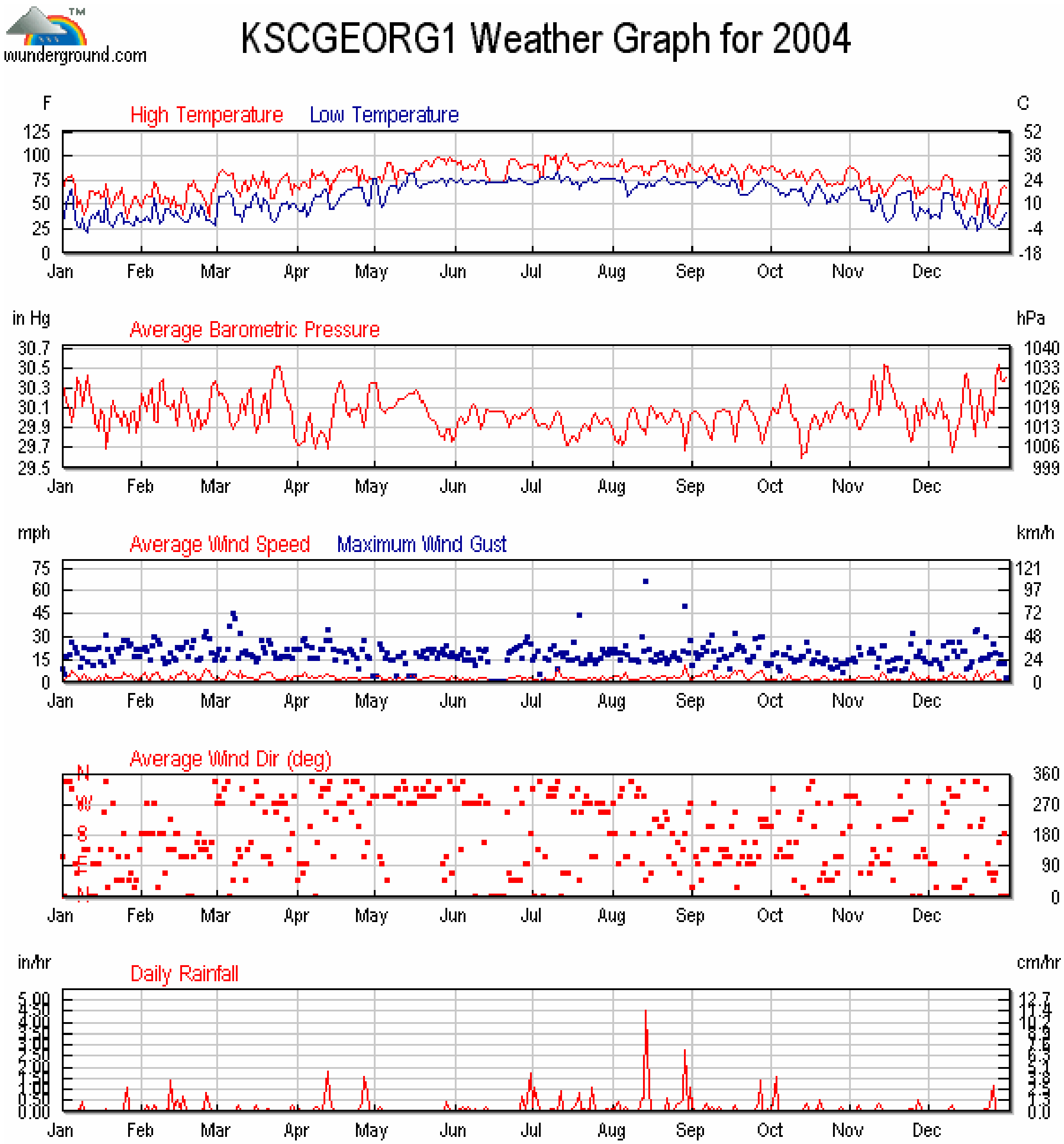
The following reviewers provided helpful comments during the development of this document: Jeff Adams, Len Balthis, Christopher Buzzelli, Arpita Choudhury, and Marie Delorenzo.

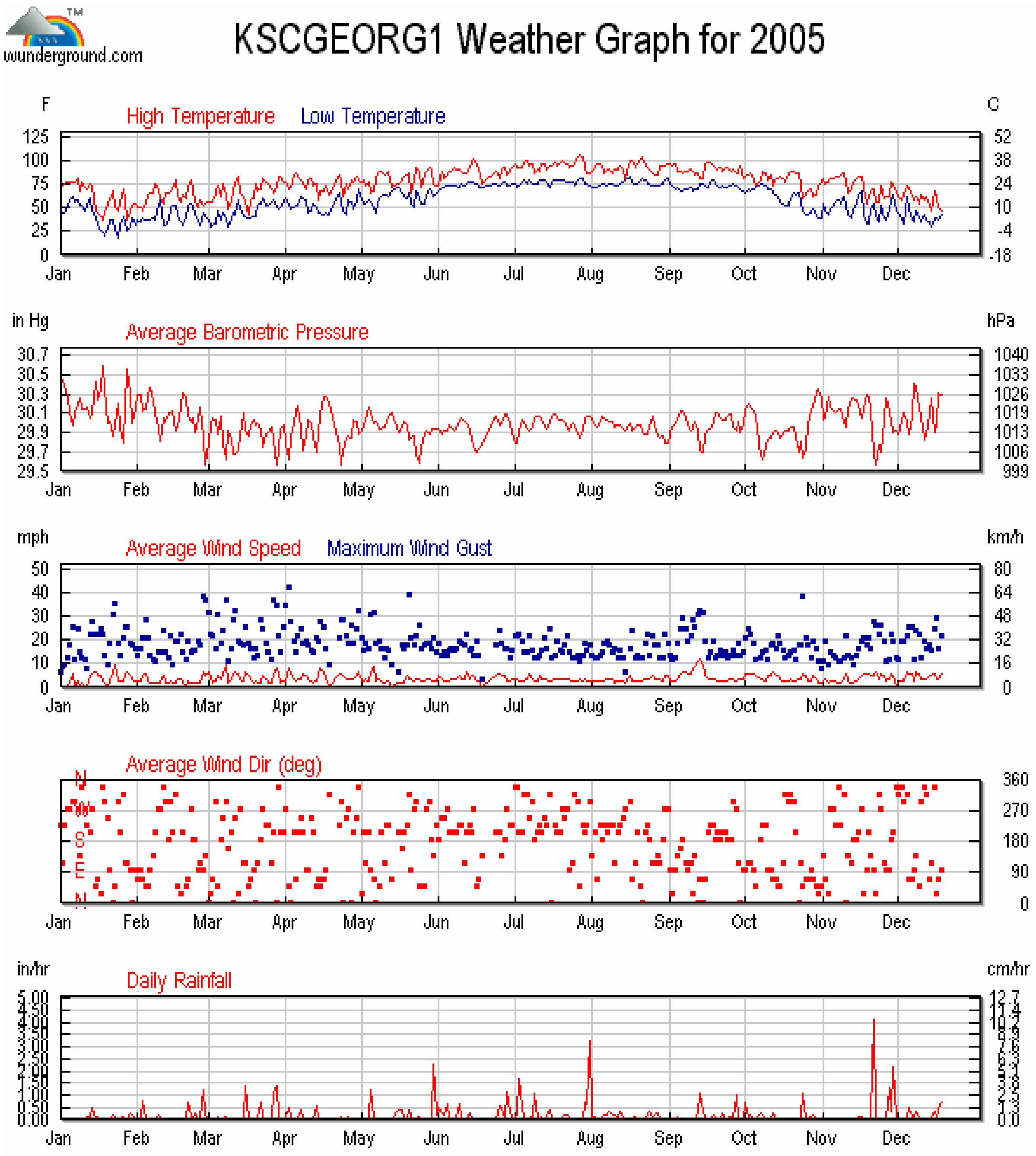
Data Disclaimer - the data included in this report have been subjected to initial quality control procedures and are released for limited public use as preliminary data to be used with appropriate caution.

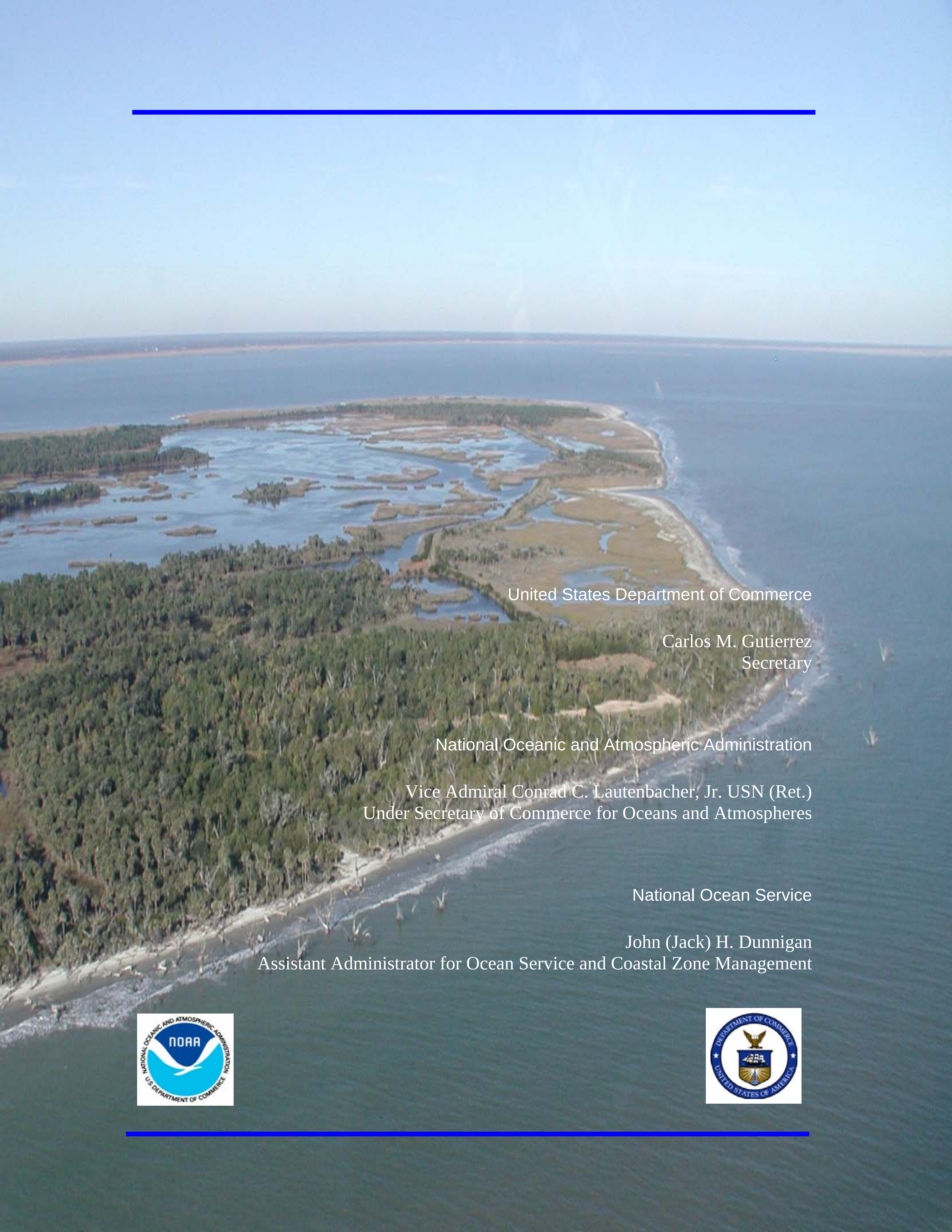
8.0 Appendix.

Weather data 2003-2005 City Fire Station, Georgetown, SC




wunderground.com
KSCGEORG1 Weather Graph for 2004
F
High Temperature
Low Temperature
C
125
100
75
50
25
0
52
38
24
10
-4
-18
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
in Hg
Average Barometric Pressure
hPa
30.7
30.5
30.3
30.1
29.9
29.7
29.5
1040
1033
1026
1019
1013
1006
999
mph
Average Wind Speed
Maximum Wind Gust
km/h
75
60
45
30
15
0
121
97
72
48
24
0
Average Wind Dir (deg)
N
W
S
E
N
360
270
180
90
0
in/hr
Daily Rainfall
cm/hr


wunderground.com
KSCGEORG1 Weather Graph for 2005
High Temperature
Low Temperature
Average Barometric Pressure
Average Wind Speed
Maximum Wind Gust
Average Wind Dir (deg)
Daily Rainfall
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec



United States Department of Commerce

Carlos M. Gutierrez
Secretary

National Oceanic and Atmospheric Administration

Vice Admiral Conrad C. Lautenbacher, Jr. USN (Ret.)
Under Secretary of Commerce for Oceans and Atmospheres

National Ocean Service

John (Jack) H. Dunnigan
Assistant Administrator for Ocean Service and Coastal Zone Management