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Regional Water Quality Synthesis for Southeast Coastal Parks

Natural Resource Report NPS/NRSS/WRD/NRR—2012/518



ON THE COVER
Sunrise at Canaveral National Seashore
Photograph by: Candace Carter

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Executive Summary

This report presents the results of analyses of the coastal water quality and other data for the southeast Atlantic coastal region, and places the condition of National Park waters in a regional perspective. Data were obtained from federal, state, and local agencies. Using water quality assessment criteria developed in U.S. Environmental Protection Agency's National Coastal Assessment Reports (U.S. EPA, 2008), water quality, sediment contamination, and fish tissue contamination were rated "good," "fair," or "poor" at sampling sites throughout the southeast coastal region within 20 miles of parks. The data were used to compare conditions inside parks to conditions outside park boundaries. The combination of water quality data from federal, state, and local agencies combined with information from individual park watershed condition assessments provides local, state and regional perspectives on water quality issues. The data synthesis was limited by different sampling designs and time scales employed by the federal, state, and local agencies that collected the data.

Generally, water, sediment, and fish tissue quality were higher inside the parks compared to areas surrounding the parks. Cape Hatteras National Seashore (CAHA) and Cape Lookout National Seashore (CALO) are relatively pristine and water quality at Canaveral National Seashore (CANA) is good. Fort Pulaski National Monument (FOPU), Cumberland Island National Seashore (CUIS), and Timucuan Ecological and Historic Preserve (TIMU) have low dissolved oxygen, high dissolved inorganic phosphorus, and metal contamination in sediment and fish tissue.

High dissolved inorganic nitrogen and dissolved inorganic phosphorus concentrations occurred throughout the region, inside and outside parks, with a high percentage of sites ranking "poor" in many of the estuaries in Georgia (St. Marys River, Cumberland Sound, St. Andrews Sound, Satilla River, Savannah River, Brunswick River) and Florida (Indian River Lagoon near CANA and St. Johns River near Jacksonville and TIMU). Low dissolved oxygen concentrations were found in the Georgia coastal parks (CUIS and FOPU) and the surrounding region (Savannah and Ogeechee rivers). Chlorophyll a was elevated, especially in the Neuse River (near CALO) and St. Johns River (near TIMU), raising concerns about eutrophication and harmful algal blooms.

There was very little sediment contamination and the majority of sediment contaminants ranked "good" throughout the region. Elevated arsenic, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls concentrations were found in fish tissue samples inside and outside most parks. There was little evidence of mercury contamination at any of the sampled sites.

The probabilistic surveys conducted by the U.S. Environmental Protection Agency and National Park Service provide excellent spatial coverage for a regional overview of water quality at a particular point in time. The sampling design allows broad conclusions about the region, but the protocol does not measure seasonal variations or micro-scale processes that contribute to water quality. This project combined the probabilistic sampling with fixed site station data, but caution is warranted when comparing results as the objectives of the sampling designs are different. Both survey methods have benefits and increased probabilistic surveys and continuous monitoring of fixed stations are needed in the southeast coastal region to better inform management decisions. More uniform sampling protocols for all parameters would improve the ability to compare water quality across organizations.

North Carolina, Georgia, and Florida have laws and regulations for sanitary control of the shellfish industry (oysters, clams, and mussels). None of the shellfish beds in CAHA and CALO (North Carolina) or in FOPU or CUIS (Georgia) have been closed in recent times. Shellfish beds near TIMU have been closed and shellfish beds in and around CANA (Florida) have been classified as "approved," "conditionally approved," and "prohibited."

North Carolina had relatively few days when beaches were closed due to elevated enterobacteria and none of the closures occurred at beaches within park boundaries. Georgia had the highest frequency of beach closures, but none of the closures occurred at a beach within park boundaries. The frequency of Florida beach closures fell between North Carolina and Georgia, but there were no beaches closures within park boundaries.

There were few significant trends in water quality at the index sites. This finding is consistent with the National Coastal Condition Report III (U.S. EPA, 2008), which demonstrated that none of the water quality and sediment indices or components had significant temporal trends in the percent of coastal area rated "poor." This project found that a significantly greater percentage of the coastal area was rated poor for sediment contaminants from 1994−1997 compared to 2000−2002 suggesting that sediment conditions have improved.

The most pressing water quality concerns are related to the increasing human population along the southeast coast and the development of urban and exurban areas. Urban runoff, wastewater treatment, and atmospheric deposition will require continued management attentions. As evidenced by periodic eutrophic conditions, nonpoint sources represent the largest threat to overall water quality in and around parks. However, nutrient load estimates for many systems in the region are unknown or under studied (Bricker et al., 2007). Research is needed to quantify total organic/inorganic nutrient loads and to identify the major sources of pollutants to guide management actions.

The broader understanding of water quality issues developed in this project can help park managers identify potential management actions, priority areas for focusing their efforts to protect park water quality, and areas that require partnerships with other federal, state, and local agencies to address broader problems.

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Acronyms

BEACH: Beaches Environmental Assessment and Coastal Health
BOD: Biochemical oxygen demand
CAHA: Cape Hatteras National Seashore
CALO: Cape Lookout National Seashore
CANA: Canaveral National Seashore
COJ: City of Jacksonville
CUIS: Cumberland Island National Seashore
DDE: Dichlorodiphenyldichloroethylene
DDT: Dichlorodiphenyltrichloroethane
DIN: Dissolved inorganic nitrogen
DIP: Dissolved inorganic phosphorus
DO: Dissolved oxygen
EPA: Environmental Protection Agency
FDACS: Florida Department of Agriculture and Consumer Services
FL-DEP: Florida Department of Environmental Protection
FL-FWCC: Florida Fish and Wildlife Conservation Commission
FOPU: Fort Pulaski National Monument
GAEPD: Georgia Environmental Protection Department
GCE-LTER: Georgia Coastal Ecosystems Long-Term Ecological Research
GIS: Geographic Information Systems
ISSC: Interstate Shellfish Sanitation Conference
LTER: Long-Term Ecological Research
NCA: National Coastal Assessment
NC-DENR: North Carolina Department of the Environment and Natural Resources
NERRS: National Estuarine Research Reserve System
NOAA: National Oceanic and Atmospheric Administration
NMFS: National Marine Fisheries Service
NPS: National Park Service
NSSP: National Shellfish Sanitation Program
OCRB: Ocean and Coastal Resources Branch
PAH: Polycyclic aromatic hydrocarbon
PCB: Polychlorinated biphenyls
SCECAP: South Carolina Estuarine and Coastal Assessment Program
SEAS: Shellfish Environmental Assessment Section
SECN: Southeast Coast Network
SJRWMD: St. Johns River Water Management District

STORET: Storage and Retrieval System
TDN: Total dissolved nitrogen
TDP: Total dissolved phosphorus
TIMU: Timucuan Ecological and Historic Preserve
TN: Total nitrogen
TOC: Total organic carbon
TP: Total phosphorus
TSS: Total suspended solids
USFDA: United States Food and Drug Administration
VCEHL: Volusia County Environmental Health Lab
WCA: Watershed Condition Assessment

Introduction

The National Park Service (NPS) has completed Watershed Condition Assessments (WCA) for more than 30 coastal parks. The assessments provide an overview of resource issues and identify potential sources of impairment for individual park waters and NPS is working to integrate the results into park management and planning. This report is the first attempt to synthesize existing water quality and other data to produce a regional "snapshot" of coastal conditions across the southeast Atlantic coastal region of the United States. The focus of this work spans Florida, Georgia, and North and South Carolina, and includes the following national parks: Cape Hatteras National Seashore (NC), Cape Lookout National Seashore (NC), Fort Pulaski National Monument (GA), Cumberland Island National Seashore (GA), Timucuan Ecological and Historic Preserve (FL), and Canaveral National Seashore (FL) (Figure 1).

This report is written for coastal managers, scientists, and the informed public interested in aquatic resource issues. While this project takes a broad scope and considers a variety of indicators of coastal ecosystem condition, it is not an exhaustive literature and data review of coastal information. In addition to providing a synoptic regional survey of current coastal water quality conditions, the project uses data sets from the late 1990s to 2010 to present general water quality trends over time. Finally, the project highlights knowledge and information gaps that park managers must overcome to make informed assessments of the condition of their coastal resources.

The report examines the condition of park waters within a larger regional context. Since this is a pilot project, emphasis is placed on data analyses and how data and metadata are acquired. When making broad water quality comparisons that rely on data collected by a variety of organizations, it is important to understand the different sampling, laboratory, and reporting methods used. By carefully documenting and addressing metadata concerns, the approach used in this pilot project can be applied to regional analyses of watershed conditions in other areas.

Background

Coastal areas provide critical habitat for a unique assortment of plants and wildlife. These areas contain important spawning grounds and nurseries, and provide shelter and food for a diverse array of finfish, shellfish, birds, mammals, and other wildlife. Coastal areas are biologically productive because they are located at the transition between freshwater, provided by rivers, and saltwater from the sea. In coastal estuaries, the freshwater and sediment flux from upstream rivers mixes with tidal inputs from the ocean to create a unique environment that supports a variety of fisheries and wildlife, often in a large network of wetlands. Aside from providing essential habitat, the wetlands provide an important ecosystem service by physical and biological filtering of agricultural, residential, and industrial runoff, resulting in better water quality.

Human populations tend to settle on or near the coastal margin and benefit from the natural ecosystem services provided. In the southeast coastal region of the United States, communities have benefited from access to large shipping ports (Charleston, SC; Savannah, GA; Jacksonville, FL) and some of the most productive commercial and recreational fisheries. The Albemarle-Pamlico estuary system is one of the largest and most productive aquatic systems in North America. Aside from the commercial fishery industry, the southeast coastal region has remarkable recreational value as well. Every year, millions of visitors flock to the region to

enjoy the numerous beaches, sport fishing, boating, and diving. The tourism industry, in combination with commercial fishing, provide a strong income base for the state economies of North Carolina, South Carolina, Georgia, and Florida (U.S. EPA, 2008).

Due to the natural and economic resources of the region, population growth has increased at a rapid rate. Between 1980 and 2003, the coastal counties of the southeast coastal region recorded the largest increase (58%) of any coastal region in the U.S. The Florida population alone increased by 7.1 million people, a 75% rate of growth during this period (Crossett et al., 2004). With a large influx of the human population, the natural resources of the region are exposed to increasing pressures due to the associated development. The estuaries and rivers that support these coastal populations receive the waste discharge of industries and municipalities, as well as non-point source pollution from urban and agricultural runoff. Wetland areas have been converted to residential and urban use causing changes in the timing of natural flows critical to estuary health.

As of result of increasing human presence, coastal ambient water and sediment quality has declined presenting resource managers with the challenge of increased water quality management. The economy and environmental health of the southeastern U.S. is based on ensuring the future health of estuarine systems. Understanding water quality conditions is critical to inform estuarine-based management decisions.

This report presents the results of analyses of the coastal water quality and other data for the southeast coastal region, and places the condition of National Park waters in a broader perspective. The project developed scientifically sound methods to synthesize water quality information for the ocean and coastal parks. The data synthesis is limited by the different sampling designs and time scales among the various data sources used. The combination of water quality data from federal, state, and local agencies combined with information from individual park watershed condition assessments provides local, state, and regional perspectives on water quality issues. At the regional level, the data synthesis is a snapshot of water quality inside and outside park boundaries and a new perspective on ocean and coastal water quality. This broader understanding of water quality issues within and beyond park boundaries can help park managers identify potential management actions, the most effective areas to focus their efforts to protect park water quality, and areas that will require partnerships with other federal, state, and local agencies to address broader problems.

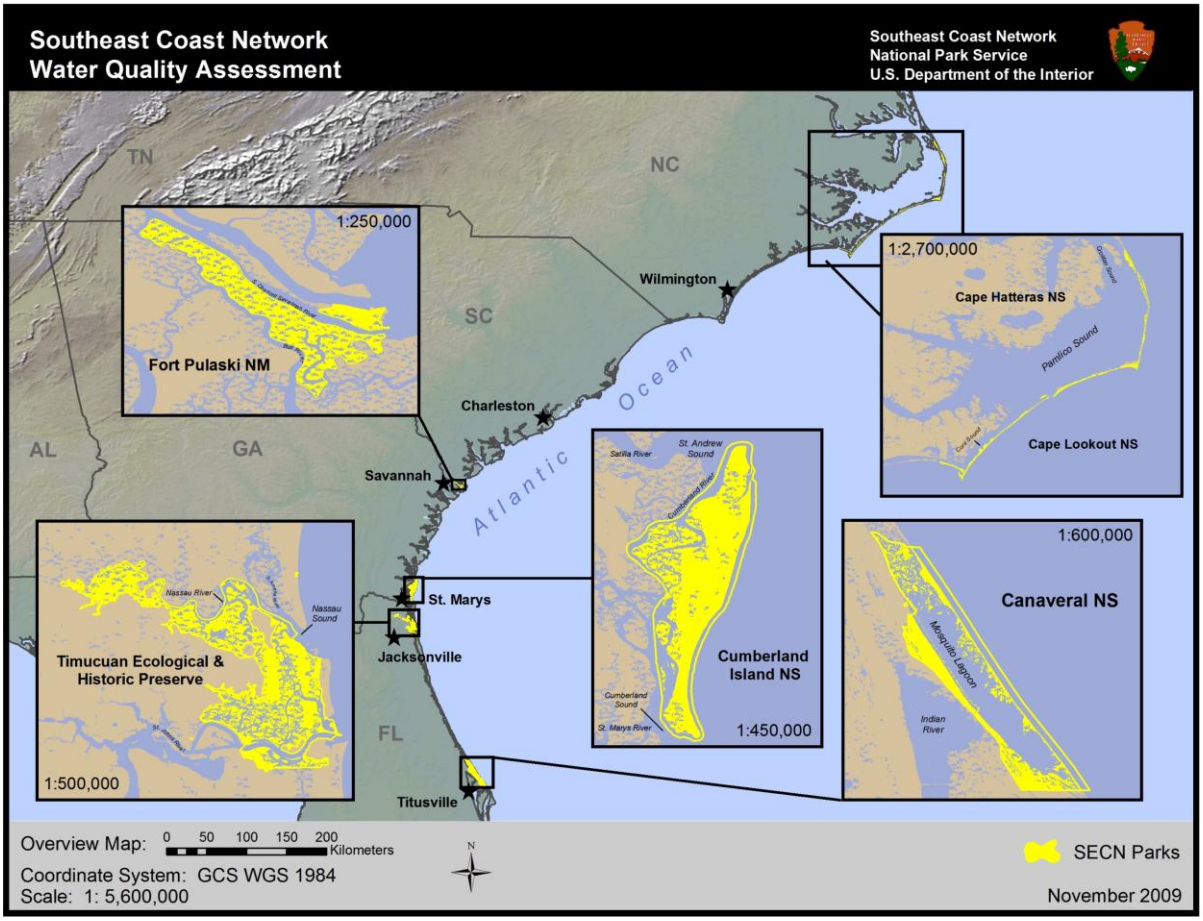


Figure 1. Map of the southeast Atlantic coastal region highlighting the National Park units in this report: Cape Hatteras National Seashore (NC), Cape Lookout National Seashore (NC), Fort Pulaski National Monument (GA), Cumberland Island National Seashore (GA), Timucuan Ecological and Historic Preserve (FL), and Canaveral National Seashore (FL).

Objectives

The objectives of the project were to:

1) Acquire water quality and other related datasets from the U.S. Environmental Protection Agency's (EPA) STORET and other database systems.

2) Develop screening criteria for identifying relevant and useful data.

3) Develop a database for relevant retrieved data and metadata.

4) Develop appropriate assessment criteria for comparing water quality inside and outside park boundaries.

Methods

Temporal and Spatial Scales

The first step in acquiring water quality data for the region was establishing study area boundaries associated with each park. Consultations with park managers helped determine the extent of these areas. Considering the regional scale of the project and the fact that water flows into and out of parks, simply using the park boundary as a query area was inappropriate. However, using the entire watershed as the study area would generate superfluous sampling sites and potentially irrelevant data not representative of the region surrounding the parks. Initially, a modified hydrologic boundary was adopted with a distance of three miles extending away from the park boundaries. After the initial data screen, this zone was extended to 20 miles from park boundaries. Considering the regional scope of the project, the wider zone was deemed appropriate. Although the distance is somewhat arbitrary, the approach was automated and it still limited the sampling sites to areas that are of most importance to the parks.

A current copy of each park's boundary was obtained in digital format from the NPS Water Resources Division in Fort Collins, Colorado. Using GIS techniques, the boundary was used to create the 20-mile zone and the resulting latitude and longitude data were included in queries for sampling sites within the designated zone. For a few parks, the study areas were increased to include areas of concern or interest to resource specialists familiar with water quality threats and/or sampling programs beyond the 20-mile zone (e.g., sites south of CANA). In general, the 20-mile zone extending from park boundaries was the study area used in comparing the water quality outside parks to water quality within the six parks. There were no instances in which sites near but outside parks were used to represent water quality inside parks.

The second criterion for inclusion of water quality data was temporal coverage. To provide a current snapshot of water quality issues, data were retrieved from January 1, 2000 to January 1, 2010. This 10-year record is consistent with the time period used to develop the planning list of potentially impaired waters according to Florida, Georgia, and North Carolina state water quality standards. Based on the initial geographic and temporal screening, over 3,000 sites were identified for possible inclusion in the project (Figure 2).

While the number of potential water quality and sediment sampling sites generated from the STORET query and participating agencies was large, not all of these sites contained enough information to be included in the analyses due to limitations in sampling frequency. In some cases, a site was only sampled for select parameters on a single day over a 10-year period. In other cases, sites were sampled frequently for two years, then not sampled again. The result of this variability in sampling frequency is a scattered snapshot of water quality from 2000−2010 (Figure 3). While in any given year there might be a large number of sites reporting data, there is a lack of consistency across the years.

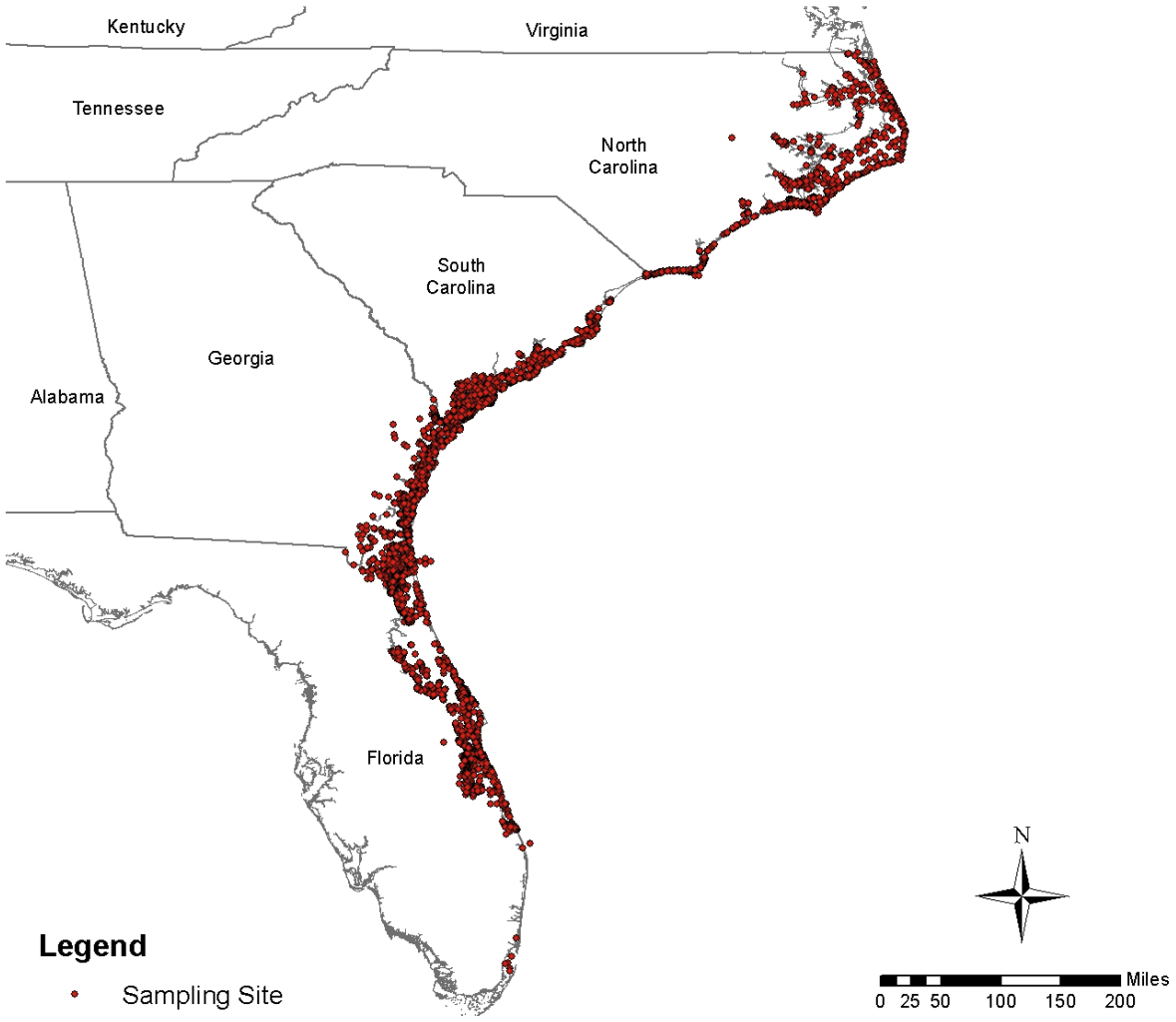


Figure 2. Sampling sites identified for possible inclusion in this project based on the initial geographic and temporal screening between 2000−2010.

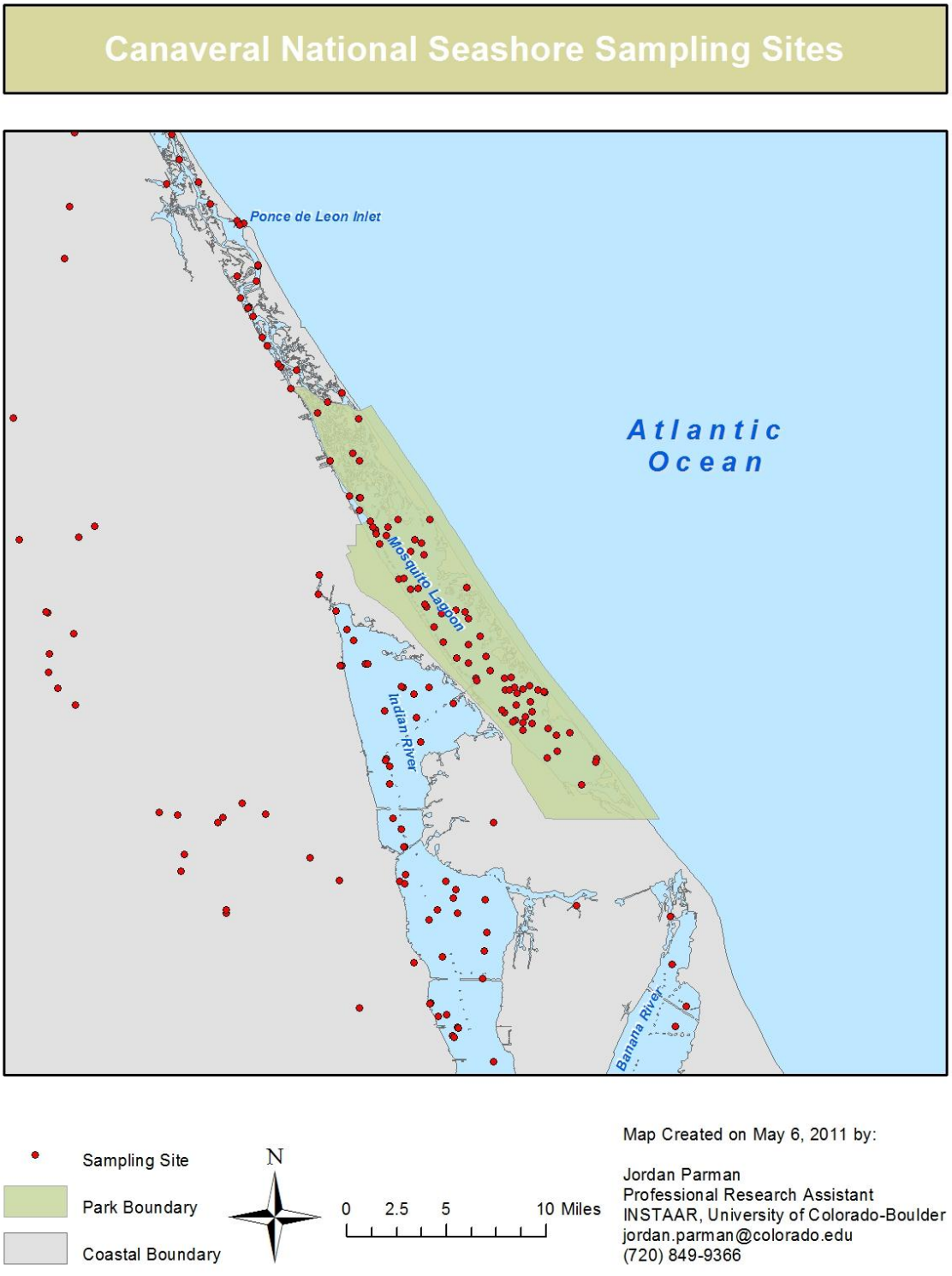


Figure 3. Sampling sites used for this project between 2000−2010 for the region inside and surrounding Canaveral National Seashore.

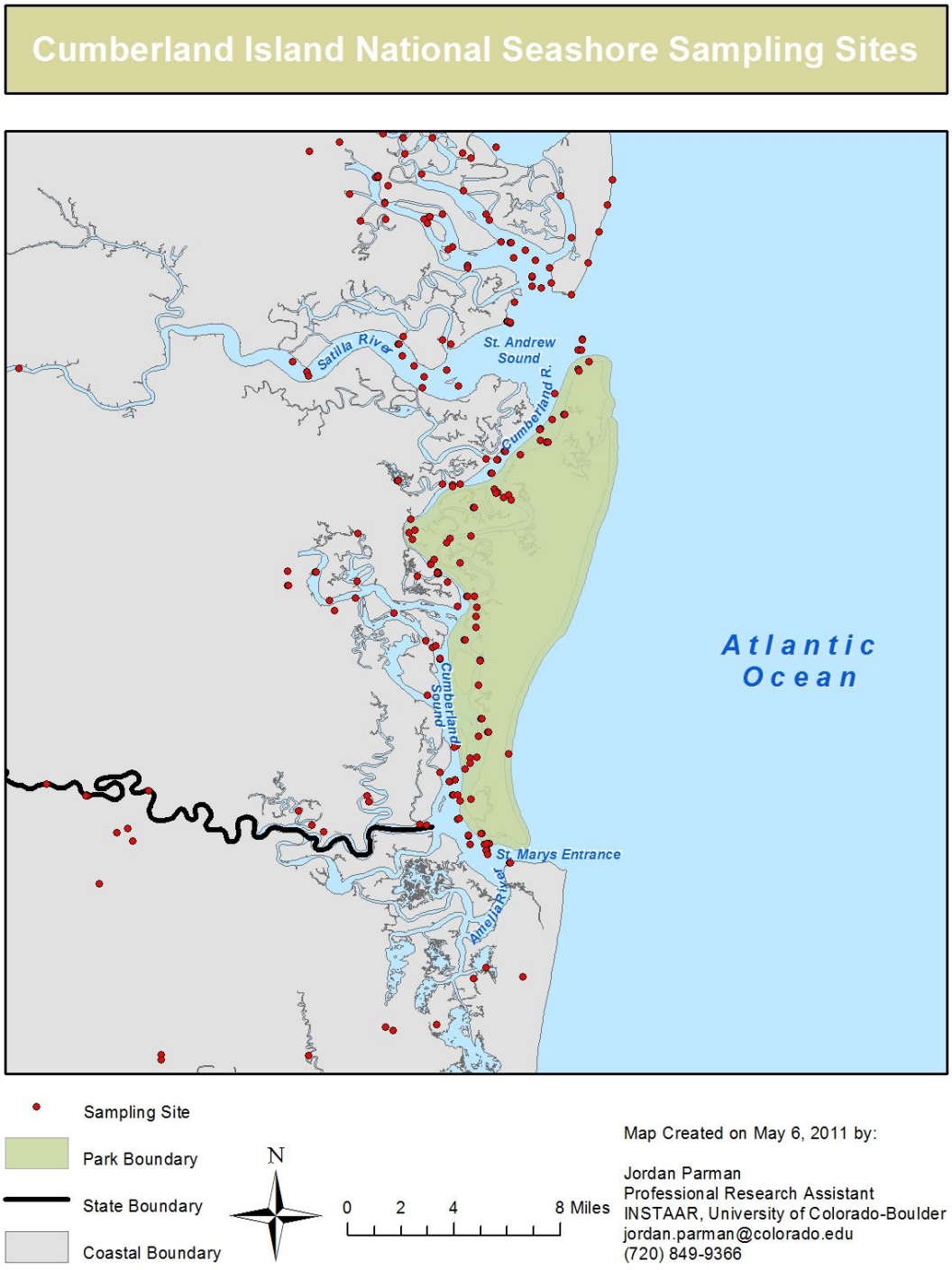


Figure 4. Sampling sites used for this project between 2000−2010 for the region inside and surrounding Cumberland Island National Seashore.

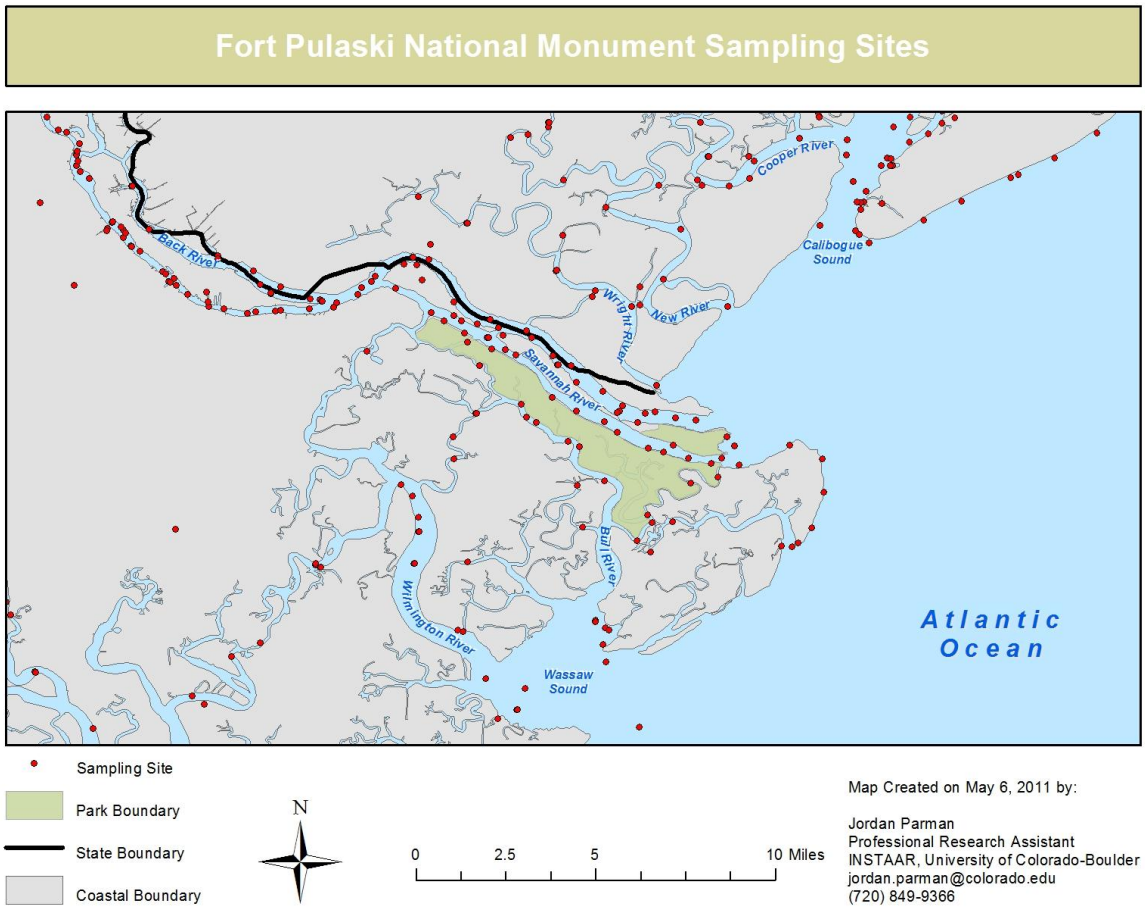


Figure 5. Sampling sites used for this project between 2000−2010 for the region inside and surrounding Fort Pulaski National Monument.

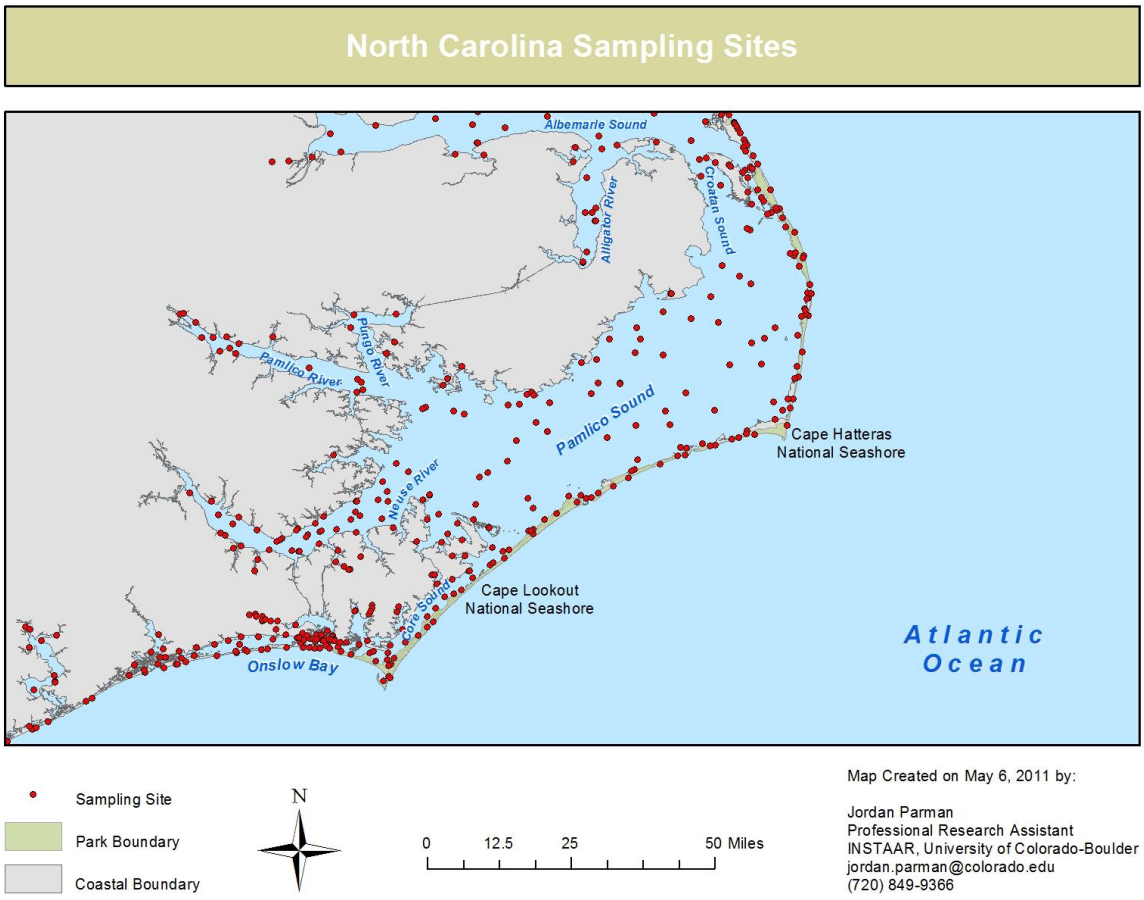


Figure 6. Sampling sites used for this project between 2000−2010 for the region inside and surrounding the North Carolina parks Cape Hatteras National Seashore and Cape Lookout National Seashore.

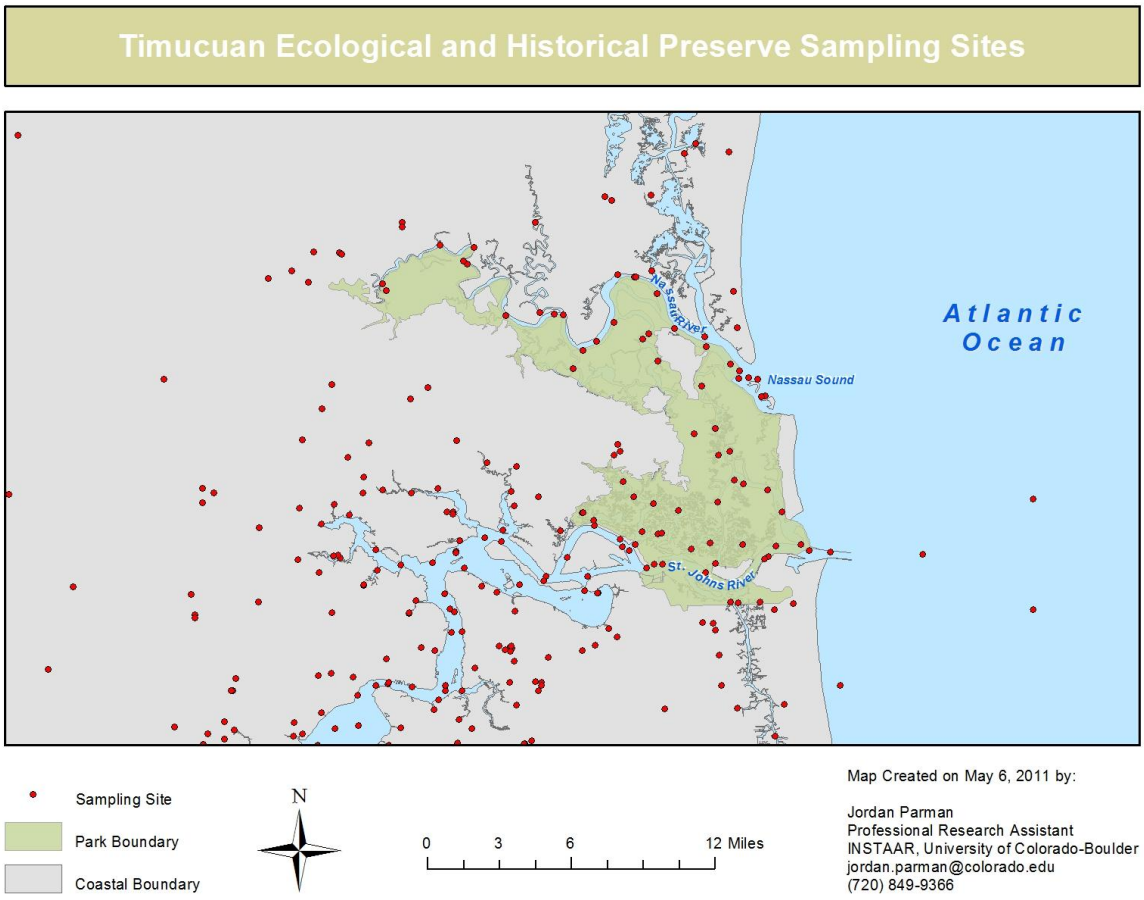


Figure 7. Sampling sites used for this project between 2000−2010 for the region inside and surrounding Timucuan Ecological and Historical Preserve.

Data Limitations

Data collecting organizations differ in the water quality parameters they analyze in the laboratory. In general, as evidenced in the metadatabase, laboratories use similar sampling and laboratory analysis protocols. However, sites varied in the parameters that were measured. In some cases, it was difficult to present a strong synoptic survey due to the lack of consistency in parameters measured.

Data Sources

National

EPA STORET

Most of the water quality and sediment data for sites outside of park boundaries were retrieved from the EPA STORET (STOrage and RETrieval System) database (http://www.epa.gov/storet/). Water quality data is entered in STORET by public agencies (federal, state, or local) that collect and/or analyze water samples. STORET is a "user-beware" water quality database system and the EPA imposes only minimum quality control criteria on the data generated and input to the system. Thus we assume that data quality assurance/quality control procedures were properly implemented by the organization generating the data that was submitted.

Data only exist in STORET if collectors upload their data. Therefore, if an area does not contain sampling sites in the STORET, it does not necessarily mean that no data were collected. There may be existing data in published and unpublished reports or in agency-specific databases. As part of this project, every feasible effort was made to contact relevant agencies to obtain any datasets that may not have been uploaded to STORET. Below are the agencies and organizations that provided water quality data included for this project. Table 1 provides a summary of all data sources used in this project.

EPA BEACH Act (2000-present)

The Beaches Environmental Assessment and Coastal Health (BEACH) Act of 2000, an amendment to the Clean Water Act, provides grants to coastal states to monitor their beaches for bacteria that indicate the presence of disease-causing pathogens and to notify the public when there is a potential risk to human health. The states report their notification data to the EPA and the data are included in a national database. This project used this database and reports of beach closure days for beaches along the southeast coast, including beaches within park boundaries.

EPA Probabilistic Survey (2000-2004)

The EPA initiated the National Coastal Assessment (NCA) in 2000 to integrate coastal monitoring programs across the coastal states. They developed survey methods to address spatially variable coastal and estuarine resources using multiple sampling intensities to capture the geographically unique characteristics of water quality. This unbiased survey design allows for the interpretation of local water quality monitoring results within a regional context. The EPA probabilistic survey collected data between 2000−2004 for a total of 563 sites (68 sites within park boundaries and 495 sites outside park boundaries) that were incorporated into this report, providing excellent, unbiased data on dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), water clarity, chlorophyll a, and dissolved oxygen (DO).

National Estuarine Research Reserve System (2000-present)

The National Estuarine Research Reserve System (NERRS) is a partnership program between the National Oceanic and Atmospheric Administration and the coastal states. The primary goal of NERRS is to provide a platform for long-term monitoring and reference sites for comparative studies. The system maintains 28 reserves and samples surface water monthly for ammonium, phosphate, total dissolved phosphorus (TDP), DIP, total dissolved nitrogen (TDN), DIN, chlorophyll a, total suspended solids (TSS), DO, pH, turbidity, and Secchi depth. They also maintain ambient monitoring stations with continuous water quality measurements for DO, salinity, pH, turbidity, conductance, and temperature. For this report, data was used from the Guana Tolomato Matanzas Reserve in Florida, the Sapelo Island Reserve in Georgia, the ACE Basin and North Inlet Winyah Bay reserves in South Carolina, and the North Carolina Reserve.

NOAA Bioeffects (1991-present)

The “Bioeffects” program is a NOAA-sponsored program designed to quantify the current status of environmental quality in estuarine and marine areas. While there have been many multidisciplinary studies implemented since 1991 in the project area, this report focuses on sediment quality, as measured in over 100 chemical contaminants including PAHs, DDTs, chlorinated pesticides, and toxic trace elements.

NOAA Mussel Watch (1986-present)

NOAA initiated the "Mussel Watch" program in 1986 and it is the longest-running contaminant monitoring program in U.S. coastal waters (NOAA 2010). Sediment and bivalve tissue samples are collected at over 300 coastal sites and the samples are analyzed for chemical and biological contaminants. Samples are tested for over 100 organic and inorganic pollutants, including PAHs, DDTs, chlorinated pesticides, and toxic trace elements.

Regional

NPS Southeast Coast Network Survey (2007-2010)

The Southeast Coast Network (SECN) adopted a sampling protocol similar to the EPA probabilistic survey and conducted sampling within park boundaries between 2007−2010. This sampling provides excellent baseline data, collected in the summer, for parameters such as TDN, TDP, water clarity, chlorophyll a, and DO. Samples were collected for Cumberland Island National Seashore (CUIS) and Fort Pulaski (FOPU) in 2007, Timucuan Historic and Ecological Preserve (TIMU) in 2008, Canaveral National Seashore (CANA) in 2009, and Cape Lookout National Seashore (CALO) and Cape Hatteras National Seashore (CAHA) in 2010. Each park contained 30 sampling sites with the exception of CALO and CAHA who shared a study design and combined together had a total of 30 sampling sites, with 13 in CALO and 17 in CAHA.

NPS Southeast Coast Network Fixed Site (2007-2010)

In addition to the probabilistic surveys conducted from 2007 to 2010, the SECN maintains one or two fixed water quality sampling sites in each park. Following protocols developed by the NERRS, fixed site dataloggers record pH, DO, salinity, temperature, turbidity, and depth every half-hour. Additionally, TDN, TDP, chlorophyll a, and Secchi depth are collected on a monthly basis. Quarterly the nutrients are separated into their organic and inorganic fractions.

State

City of Jacksonville (Timucuan, Tributary, and River Run) (1997-present)

The surface water quality monitoring program affiliated with the City of Jacksonville maintains three separate monitoring programs. The "Tributary Program" focuses on the monitoring of tributaries to the St. Johns River in the city of Jacksonville. This program comprises over 100 sample stations that collect quarterly for DO, fecal coliform, and salinity. The "River Run" program samples monthly at 10 stations along the mainstream of the St. Johns River. Parameters tested include DO, pH, temperature, salinity, specific conductance, major nutrients, turbidity, TSS, biochemical oxygen demand (BOD), and fecal coliform. The "Timucuan Program" started in 1997 sampling surface water in or adjacent to the Timucuan Preserve. Twelve stations are sampled bi-monthly for DO, chlorophyll a, major nutrients, fecal coliform, and salinity.

Fish Kill Reports (1986-present)

Fish kill data can be an indicator of coastal health. Along the southeast coast, reporting of fish kill events is undertaken by individual states, without a large regional or national database in place to consolidate the information. Fish kill and disease events often involve a variety of factors and underlying causes; it can be difficult to identify the cause(s) of the event. For this reason, most states attempt to gather as much information as possible surrounding an event. This report synthesizes available data and provides a qualitative assessment of spatial and temporal trends associated with large fish kill events in North Carolina and Florida (Georgia has not reported sufficient information on fish kill events). Fish kill events have been reported to the

Florida Fish and Wildlife Conservation Commission for over 10 years, with data available for number of deaths, data, and probable cause. In North Carolina, fish kill events are reported to the North Carolina Department of Environmental and Natural Resources (NC-DENR) (Division of Water Quality). Data are available for location, mortality, and probable cause. These datasets should not be considered comprehensive documentation of all fish kill events in these states; not all events are reported to the respective state agency.

Florida Fish & Wildlife Conservation Commission (2000-present)
The Florida Fish & Wildlife Conservation Commission (FL-FWCC) has maintained a database documenting reported fish kill events since 2000. The records include the date, location, probable cause, and a mortality count for each reported event. This database is not an exhaustive list of fish kill events throughout the state; only events that were reported directly to the FL-FWCC are included in the database.

Georgia Coastal Ecosystems Long-Term Ecological Research Station (2001-present)
The Georgia Coastal Ecosystems Long-Term Ecological Research Station (GCE-LTER) was established by the National Science Foundation in 2000 and includes three adjacent sounds (Altahama, Sapelo, Doboy) that encompass upland, intertidal, and submerged habitats. The GCE-LTER has recorded near real-time hydrographic data at the Meridien Landing monitoring site in cooperation with the U.S. Geological Survey. Parameters measured include temperature, conductivity, salinity, DO, pH, and turbidity.

Georgia Environmental Protection Department (2000-present)
The Georgia Environmental Protection Department (GA-EPD) maintains an extensive network of ambient surface water quality monitoring stations throughout the entire state. The department submits their monthly water quality data to STORET and parameters measured include ammonium, nitrate, chlorophyll a, Secchi depth, DO, fecal coliform, pH, TN, TP, salinity, specific conductance, temperature, and turbidity.

North Carolina Department of Environmental and Natural Resources (2000-present)
The North Carolina Department of Environmental and Natural Resources (NC-DENR) maintains an extensive network of ambient surface water quality monitoring stations across the state. The department submits their water quality data to STORET and parameters measured include ammonium, nitrate, chlorophyll a, Secchi depth, DO, fecal coliform, pH, TN, TP, salinity, specific conductance, temperature, and turbidity. The Division of Water Quality within NC-DENR has also kept a record of reported fish kill events throughout the state since 1997. These reports include locations, dates, mortality count, and a comment section that attempts to explain the cause of the fish kill event.

Shellfish Closure Information
Classification of coastal waters for shellfish harvesting are done by means of a sanitary survey with guidelines from the National Shellfish Sanitation Program (NSSP) administered by the U.S. Food and Drug Administration (USFDA). Compliance with NSSP Model Ordinance guidelines must be met in the classification of shellfishing waters for shellfish to be shipped in Interstate Commerce. The USFDA conducts annual reviews of state programs for compliance. If the minimum requirements for a sanitary survey are not meet for any shellfish growing area, USFDA would require immediate closure of all waters in that growing area.

This report uses shellfish closure data provided by the North Carolina Department of Environmental Health: Shellfish Sanitation and Recreational Water Quality, the Georgia Coastal Resources Division: Shellfish Sanitation Program and the Florida Department of Agriculture and Consumer Services: Division of Aquaculture's Shellfish Harvesting Program.

South Carolina Estuarine and Coastal Assessment Program (1999-present)
The South Carolina Estuarine and Coastal Assessment Program (SCECAP) samples approximately 60 stations each year, randomly selected as part of a probabilistic survey. All sites are located within the coastal zone extending from the saltwater-freshwater interface to near the mouth of each estuarine drainage basin, and extending from the Little River Inlet at the North Carolina border to the Wright River near the Georgia border. Water quality parameters tested include chlorophyll a, DO, pH, Secchi depth, DIN, TN, TP, fecal coliform, salinity, and TSS. Sediment and whole body fish tissue samples were also taken in 1999-2009 and tested for metals and organic pollutants (same parameters as the EPA probabilistic survey).

St. Johns River Water Management District (FL) (2000-present)
The St. Johns River Water Management District (SJRWMD) in Florida maintains an extensive network of ambient surface water quality monitoring stations along the mainstream of the St. Johns River, as well as along some smaller tributaries. The SJRWMD submits their water quality data to STORET and parameters measured include ammonium, nitrate, DIN, DIP, TOC, chlorophyll a, Secchi depth, DO, total nitrogen (TN), total phosphorus (TP), pH, salinity, silica, TSS, specific conductance, temperature, and turbidity.

Volusia County Environmental Health Laboratory (FL) (1998-present)
The Volusia County Environmental Health Laboratory (VCEHL) surface water program samples 12 sites in Mosquito Lagoon (FL) and 29 sites along the St. Johns River (FL) on a monthly basis. Parameters tested include temperature, salinity, DO, Secchi depth, pH, conductance, TSS, DIN, DIP, chlorophyll a, fecal coliform, and enterococcus group bacteria. Currently, four of the 12 Mosquito Lagoon sites are sampled monthly and eight of the 12 sites are sampled quarterly.

Table 1. Data sources used in this project, including years, number of sites (#), parameters sampled, level of source (national, regional, or state), and whether the samples were inside or outside of national park boundaries or both.

Data Source	Years	# Sites	Parameters	National, Regional, or State	Inside/ Outside parks
EPA Beach Act (2000-present)	2007-2009	587	beach closure days	National	Both
EPA Probabilistic Survey (2000-2004)	2000-2004	563	DIN, DIP, DO, Water Clarity, chlorophyll a	National	Both
National Estuarine Research Reserve System (NERRS) (2000-present)	2000-2007	79	TDP, DIP, TDN, DIN, chlorophyll a, TSS, DO, pH, turbidity, Secchi depth, salinity, conductance, and temperature	National	Outside
NOAA Bioeffects (1991-present)	1994-2004	136	100+ sediment contaminants including PAHs, DDTs, chlorinated pesticides, and toxic trace elements	National	Outside
NOAA Mussel Watch (1986-present)	2003-2008	13	100+ organic and inorganic pollutants, including PAHs, DDTs, chlorinated pesticides, and toxic trace elements	National	Outside
NPS Southeast Coast Network Probabilistic Survey (2007-2010)	2007-2010	180	TDN, TDP, water clarity, chlorophyll a, and DO	Regional	Inside
NPS Southeast Coast Network Fixed Site (2007-present)	2007-2010	7	pH, DO, salinity, temperature, turbidity, depth, TDN, TDP, chlorophyll a, and Secchi depth	Regional	Inside
City of Jacksonville (Timucuan, Tributary, and River Run) (1997-present)	2000-2009	171	DO, chlorophyll a, fecal coliform, pH, temperature, salinity, specific conductance, major nutrients, turbidity, TSS, and BOD	State	Both
Fish Kill Reports (2000-present)	2000-2010	n/a	location, mortality, and probable cause	State	Both

Table 1 (continued).

Data Source	Years	# Sites	Parameters	National, Regional, or State	Inside/ Outside parks
Florida Fish & Wildlife Conservation Commission (2000-2010)	2000-2010	n/a	date, location, probable cause, and a mortality count of fish kill events	State	Both
Georgia Coastal Ecosystems Long-Term Ecological Research Station (2001-present)	2001-2010	1	temperature, conductivity, salinity, DO, pH, and turbidity	State	Outside
Georgia Environmental Protection Department (2000-present)	2001-2009	142	ammonium, nitrate, chlorophyll a, Secchi depth, DO, fecal coliform, pH, TN, TP, salinity, specific conductance, temperature, and turbidity	State	Outside
North Carolina Department of Environmental and Natural Resources (NC-DENR) (2000-present)	2000-2009	247	ammonium, nitrate, chlorophyll a, Secchi depth, DO, fecal coliform, pH, TN, TP, salinity, specific conductance, temperature, and turbidity	State	Outside
Shellfish Closure Information (1982-present)	1997-2010	n/a	shellfish closures	State	Both
South Carolina Estuarine and Coastal Assessment Program (1999-present)	1999-2008	521	chlorophyll a, DO, pH, Secchi depth, DIN, TN, TP, fecal coliform, salinity, TSS, sediment and whole body fish tissue contaminants	State	Outside
St. Johns River Water Management District (FL) (2000-present)	2000-2009	991	ammonium, nitrate, DIN, DIP, TOC, chlorophyll a, Secchi depth, DO, TN, TP, pH, salinity, silica, TSS, specific conductance, temperature, and turbidity	State	Both
Volusia County Environmental Health Laboratory (FL) (1998-present)	1998-2008	43	temperature, salinity, DO, Secchi depth, pH, conductance, TSS, DIN, DIP, chlorophyll a, fecal coliform, and enterococcus group bacteria	State	Outside

Data Handling and Reporting

The park area boundaries were used to select the water quality stations associated with the park units, and the 20-mile zone extending from the park boundaries was used as query area for the regions outside the park units. After downloading the water quality data associated with the stations, screening criteria were applied to select appropriate stations and parameters. The data were first screened and analyzed in Microsoft Excel and then reformatted into a Microsoft Access database.

The processes for analyzing the data are summarized below:

1) Reformat the data into Microsoft Access format
2) Eliminate questionable data outside the STORET edit criteria ranges
3) Display on a GIS map the location of water quality monitoring stations along with other water resources themes
4) Determine whether select stations are inside or outside park boundaries in ArcView GIS
5) Determine frequency of water quality observations by station and parameter
6) Generate appropriate descriptive annual and seasonal analyses of the water quality in a tabular format
7) Generate maps depicting seasonal analyses of water quality parameters
8) Compare the water quality data against relevant EPA national criteria
9) Compare the water quality data inside park boundaries to water quality outside parks

Microsoft Access Database

The database was assembled in Microsoft Access to be compatible with the National Park Service National Inventory and Monitoring database. This allows water quality data to be easily transferred between databases and provides flexibility for programmers to develop databases independently since Access is a common platform for database management.

Most of the water quality data used in this project was acquired from STORET, but other organizations and agencies also provided datasets. Often, the acquired datasets had different structure and contained different and varying degrees of information regarding water quality observations. Microsoft Access provides a useful platform for linking datasets together via a relational database (Figure 8). This ability to relate specific columns of data to a column of data in another table can help bridge the gap between different datasets. For example, different organizations might sample at the same station (Site_ID), and via a relationship, one can search for all observations at this site regardless of which organization was actually sampling.

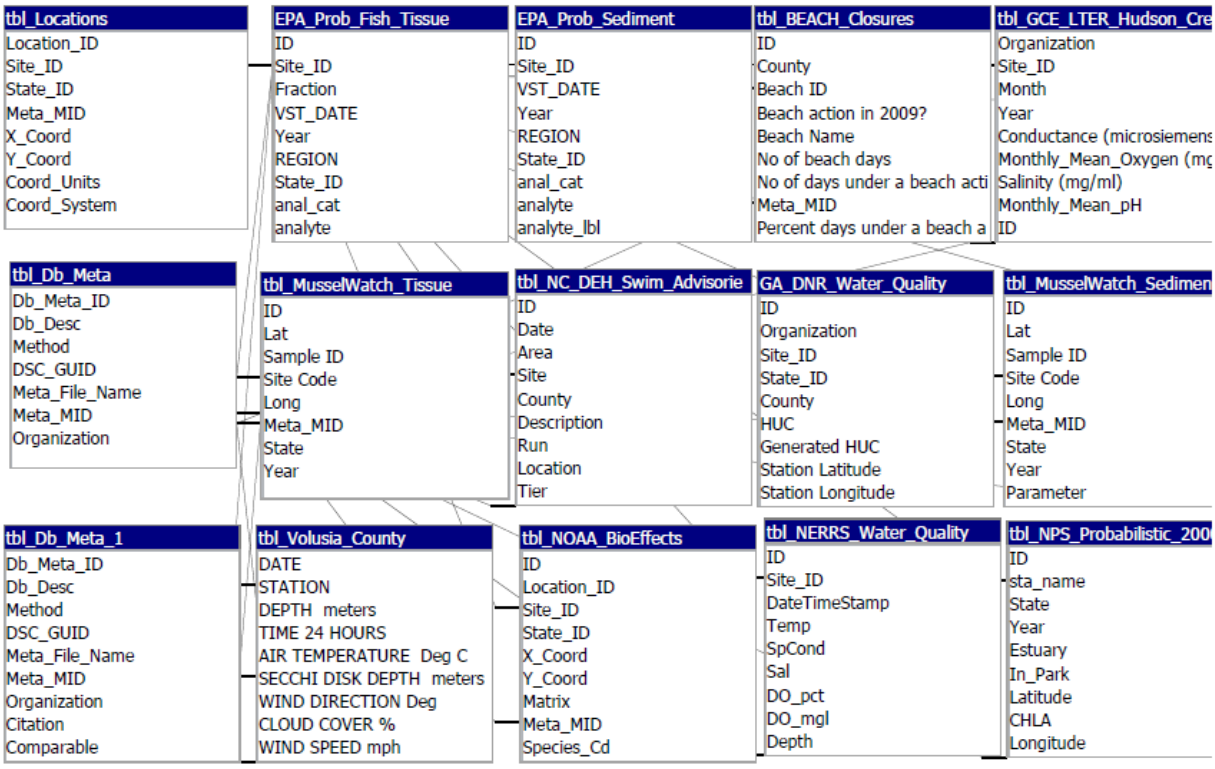


Figure 8. Microsoft Access relationship map for datasets used in this project.

For any water quality synthesis and comparison project, it is important to verify that samples are collected and analyzed in the same manner. Therefore, the metadata associated with these various datasets are integral components to the overall database and report. In this database, every observation has an associated metadata "tag" (Meta_MID). This metadata "tag" is joined to a metadata table that contains all the provided information pertaining to how the sample was collected and analyzed (Figure 9). The imported STORET data contain valuable information pertaining to which organization collected the sample, how the sample was collected, and what analytical methods were used. Every effort was made to collect similar metadata for the datasets provided by other organizations and this information is compiled in the metadata table of the Microsoft Access database. Information in the metadata includes:

1) Organization conducting sampling

2) Organization contact information

3) Program associated with particular observation

4) Duration of program

5) Collection method

6) Analytical method

7) Comparable national standard

8) Website of the organization

9) Website access if data downloaded online

10) Link to Microsoft Word document detailing further metadata information

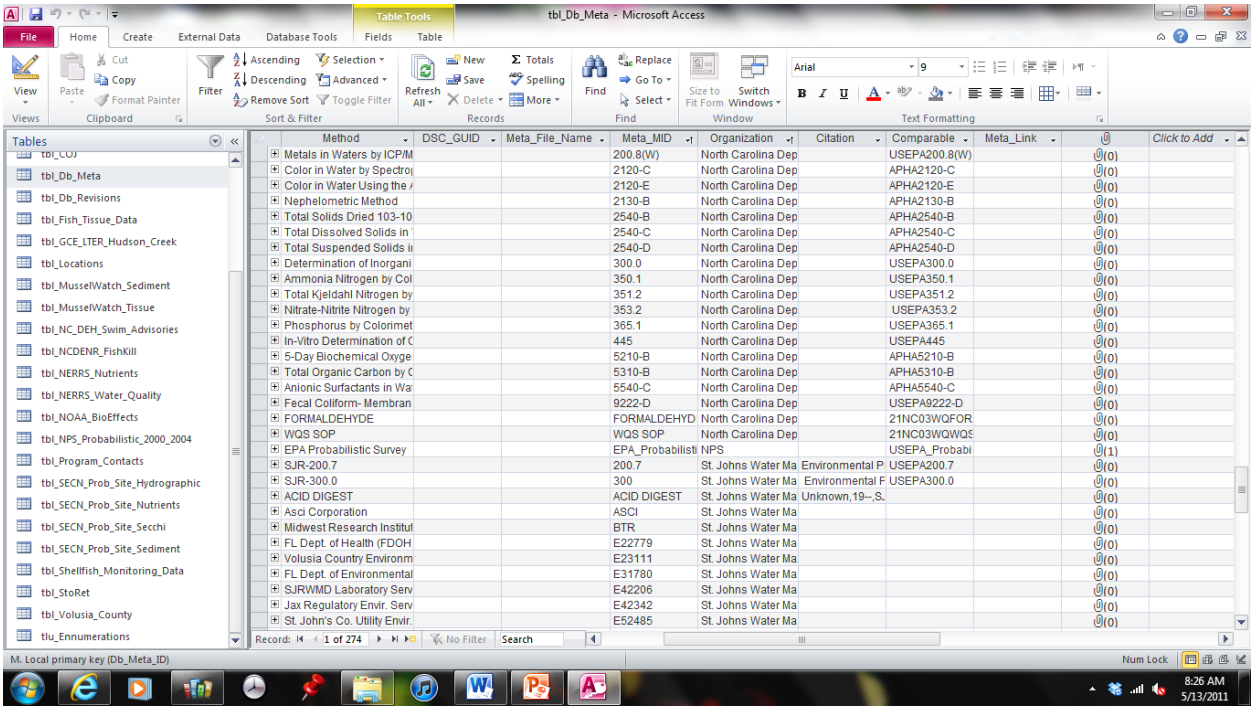


Figure 9. Screenshot of metadata table in Microsoft Access database. The "Meta_MID" column relates to the unique metadata identification code included with each observation in the database.

Screening Methodologies

It became evident after the preliminary analysis of downloaded and provided data that many stations had records of dubious quality. A comprehensive screening process was developed to screen out stations and results that were inappropriate for the project. The screening processes were conducted in Microsoft Excel and can be simplified into two categories: 1) screens that apply to stations and 2) screens that apply to parameters. The types of screens are summarized below.

<u>Date Screen</u>

STORET users can enter incorrect dates for water quality observations. Any observations with a suspect date (e.g., a month greater than 12; a day greater than 31) were discarded.

<u>Station Type</u>

STORET contains data from a variety of stations classified by the type of water body (e.g., stream, canal, lake, estuary, etc.). Considering the scope of this project, only data listed as stream, canal, lake, reservoir, spring, freshwater wetland, saltwater wetland, estuary, and ocean were retrieved.

Parameter
STORET can provide a wealth of meteorological information (e.g., rainfall, stream stage, precipitation, barometric pressure, water temperature, etc.) and other interesting observations for many stations, but these parameters were not included in this analysis. To focus on regional comparisons of water quality, only common water, sediment, and fish tissue parameters were queried in STORET. This screening process eliminated excessive data. See Appendix A for a list of queried parameters.

Media Type
Water samples can be taken in any number of aqueous media, including different portions of the water column. Water quality data were used in this project only if the media were WATER, SED (sediment), or VERT (vertically integrated). These categories encompass the vast majority of samples in STORET.

Remark Code
Users uploading to STORET can provide qualifying remarks for each observation that can inform those downloading data of potential problems. Observations were eliminated if the result was estimated (not result of analytic measurement), presence verified (but not quantified), analysis lost, presumptive evidence of presence, less than lowest value reportable, and if there were too many colonies present to count (for fecal coliform). In many cases, there were results below detection limits for the specific parameter; these results were changed by using half the detection limit, a common approach in water quality data analysis (Ward et al., 1990; Gilbert 1987). While this method is defensible, statistics generated using the "half the detection" limit observations are subject to bias.

Assessment Criteria

The data retrieval and screening process results in a large number of water quality observations from a variety of different agencies. It is important to ensure that methods used for sample collection and laboratory analysis are similar among the agencies. Fortunately, for most of the traditional water quality indicators, the EPA has developed standard method protocols as part of implementation of the Clean Water Act. In the rare case where an organization did not use the EPA protocol or a comparable method, the data were not included in the analysis. To assess the relative "ranking" of water quality throughout the region, this project relies on indices developed and described by the EPA in the National Coastal Condition Report III (U.S. EPA, 2008). Water quality, sediment, and fish tissue indices were used for this project.

Water Quality

Dissolved Oxygen
Dissolved oxygen concentrations provide a general indicator of coastal health that integrates many of the symptoms of degraded water quality associated with other parameters (Table 2). Low dissolved oxygen concentrations can occur as a result of harmful algal blooms that sink to the bottom of water bodies where bacteria use up oxygen in the process of breaking down the algal biomass. Sometimes low dissolved oxygen concentrations are measured at the bottom of an estuary where relatively lighter freshwater discharge on the surface overrides the saltier and denser bottom water. These low dissolved oxygen levels (hypoxia), or complete lack of oxygen (anoxia), often negatively affect organisms that live in the sediments. Hypoxic bottom waters can result in the initiation of bacterial degradation creating algal scums and foul odors.

However, low dissolved oxygen levels occur periodically as part of the natural ecology of estuarine systems. Therefore, synoptic snapshots of dissolved oxygen concentrations may indicate eutrophication processes or naturally occurring hypoxia. The sites included in this report were rated based on the criteria listed in Table 1 (Diaz and Rosenberg, 1995; U.S. EPA, 2000a). For each rating of "good," "fair," or "poor," a concentration range is provided (Table 2). For example, a sample with a DO concentration of 3 mg/L would be rated as "fair."

Table 2. Water quality and sediment ratings based on the EPA's assessment criteria (U.S. EPA, 2008). For each parameter, water or sediment quality at a site is rated "good," "fair," or "poor" based on the range of concentration.

Parameter	Good	Fair	Poor
Dissolved oxygen (mg/L)	>5	2 to 5	<2
Chlorophyll a (µg/L)	<5	5 to 20	>20
Dissolved inorganic nitrogen (mg/L)	<0.1	0.1 to 0.5	>0.5
Dissolved inorganic phosphorus (mg/L)	<0.01	0.01 to 0.05	>0.05
Water clarity (% surface light at 1 meter)			
Naturally high turbidity (a=1.0)	<2.30	2.30-2.99	>2.99
Normal turbidity (a=1.4)	<1.61	1.61-2.30	>2.30
Naturally low turbidity (a=1.7)	<0.92	0.92-1.61	>1.61
Total organic carbon (% dry wt. of sediment)	<2	2-5	>5

Chlorophyll a

Chlorophyll a concentrations can indicate that elevated nutrient levels are contributing to degraded water quality in coastal water bodies. Chlorophyll a is a standard measure of phytoplankton (microscopic algae) biomass. Surface concentrations of chlorophyll a used in this project were measured from filtered portions of the water sample. Concentrations at each site with chlorophyll a data were rated "good," "fair," or "poor" by the criteria listed in Table 2. Indicator values were determined by Bricker et al. (1999), as well as selected state criteria.

Dissolved Inorganic Nitrogen and Phosphorus

Nitrogen and phosphorus are generally limiting natural nutrients in coastal waters necessary for the growth of phytoplankton. Excessive concentrations of inorganic nitrogen and phosphorus can result in the proliferation of harmful algal blooms. In general, DIN is responsible for eutrophication of marine and estuarine water bodies, while high DIP concentrations are linked more frequently with phytoplankton growth in tidal-fresh water portions of estuarine environments (U.S. EPA, 2008).

DIN and DIP concentrations are measured at most water quality sampling sites and are determined chemically from filtered surface water samples. The inorganic portion of total nitrogen and phosphorus measured at these sites include the nutrients that are left after assimilation by phytoplankton, benthic microalgae, and aquatic plants. While trophic state cannot be determined by DIN and DIP concentrations alone, higher levels are associated with a greater risk of eutrophication. To gain a better understanding of trophic state, these concentrations should be assessed in combination with chlorophyll a, dissolved oxygen, and water clarity measures.

To be consistent with the EPA's National Coastal Assessment analyses, this report presents summer concentrations of DIN and DIP rather than annual average concentrations. In general, there is more phytoplankton uptake and growth during the summer months, thus DIN and DIP concentrations are expected to be lower than at other times during the year. The assessment criteria for DIN and DIP (Table 2) are derived from Bricker et al. (1999) and listed in the National Coastal Condition Report III (U.S. EPA, 2008).

Water Clarity

Water clarity is important in coastal areas for both aesthetic and biological reasons. Clear water is valued for recreation and it allows enough light penetration to support submerged aquatic vegetation (SAV), a source of food and habitat for various aquatic biota. However, naturally turbid waters can also support productive ecosystems by supplying sediment via deposition to create estuarine habitats such as wetlands. Dissolved organic material and nutrients associated with higher turbidity also provide food and protection to marine biota. Unnaturally high turbidity can harm ecosystem health by burying benthic communities with sediment and blocking light critical for seagrass production.

Methods for measuring water clarity vary by sampling program, but the NCA uses equipment that compares the amount of light reaching the water surface to the amount of light at a depth of 1 m. However, many programs use the more traditional Secchi depth measurement. For this report, Secchi depth measurements were converted to the NCA transparency at 1 m depth based on Smith et al. (2006) who that determined the light attenuation coefficient from Secchi depth measurements and a reflectance property constant. The following equation was used for the conversion:

$$k = \frac{a}{z^{Secchi}}$$

where:

k = light attenuation coefficient,

a = constant derived from reflectance properties and the ratio of scattering to absorption ranging from turbid to clear water bodies, and

z = Secchi depth in meters.

There is some local variability when assessing water clarity between different regions; therefore, the water clarity indicator is based on a ratio of observed water clarity compared to reference conditions at 1 m. For example, reference conditions for a site rated "poor" were set at 5% for locations with naturally high turbidity such as some parts of South Carolina and Georgia, whereas reference conditions for a site rated poor was 20% for regions with significant SAV beds, such as portions of Florida (EPA, 2008). Reference conditions were determined from available data for each U.S. region (Smith et al., 2006). For this project, *a* was assigned based on the three categories of water clarity where *a* = 1.0, 1.4, and 1.7 for naturally turbid (high), moderately turbid (moderate), and clear water (low) estuaries, respectively. These constants were estimated for each water clarity class based on literature values reported for estuarine water clarity (Keefe et al., 1976; Landwehr et al., 1999; Tett, 2002). Table 2 lists the criteria for water clarity ratings.

Sediment Quality

Sediment quality offers another perspective on the health of coastal water bodies and generally integrates contamination in an area over a longer period. Various metals and organic compounds are discharged into coastal waters and tributaries via point and non-point sources of pollution. Of particular concern are organic substances such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and pesticides derived from urban, agricultural, and industrial sources throughout the watershed. These and other contaminants adsorb onto suspended particles in the water and eventually accumulate in the sediment, where they can harm benthic invertebrates, shellfish, and other crustaceans that rely on the sediment for their habitat. Potential contaminants can bioaccumulate in biota, thereby posing a health risk to other organisms in the food web and to people who consume them.

Research has shown that organic-rich sediments tend to be re-suspended and transported to distant locations along the water body, effectively scavenging pollutants along the way (U.S. EPA, 2008). Therefore, silty sediments with a high total organic carbon (TOC) content are greater potential sources of contamination. As part of the NCA survey, sediment quality was determined via three indicators: sediment toxicity, sediment contaminant concentrations, and sediment TOC. Sediment toxicity is not addressed in this report because it requires the measurement of the survival rate of the marine amphipod *Ampelisca abdita* following a 10-day exposure to the sediments under laboratory conditions (U.S. EPA, 1995a), which most programs did not measure. The focus of sediment quality in this project is on sediment contamination.

Sediment TOC

Total organic carbon exists naturally in coastal sediments as a result of degradation of autochthonous and allochthonous organic material, but anthropogenic sources of industrial wastes and untreated sewage can elevate the TOC in sediments. The TOC can be a source of food for benthic invertebrates and when there is a significant source of anthropogenic TOC, the benthic community structure can shift towards greater dominance of pollution-tolerant species. Areas with high TOC concentrations are likely to be depositional sites for fine sediments that can accumulate contaminated sediments. The TOC is an indicator of sediment toxicity from organic matter according to the assessment criteria from the NCCR III based on the %TOC concentration in dry-weight samples. Site condition is rated "good" if TOC is <2%, fair if TOC is 2-5%, and poor if TOC is >5% (U.S. EPA, 2008).

Sediment Contaminants

To assess the degree of sediment contamination, the concentrations obtained for this project were compared to the effects range low (ERL) and effects range median (ERM) concentrations of Long et al. (1995). The ERM is the median concentrations (50^{th} percentile) of a contaminant observed to have adverse biological effects in the literature studies. The ERL is a more conservative measure (10^{th} percentile) of a contaminant observed to have adverse biological effects (Long et al., 1995; U.S. EPA, 2008). Ecological effects are unlikely to occur at concentrations below the ERL. Table 3 lists the ERM and ERL concentrations and sediment contamination assessment criteria for this project. Site condition is rated "good" if the contaminant concentration is less than the ERL, "fair" if it is between the ERL and ERM, or "poor" if it is greater than the ERM.

Table 3. Effects range for sediment contaminants from the NCCR III (U.S. EPA, 2008). Site condition is rated "good" if the contaminant concentration is less than the ERL, "fair" if it is between the ERL and ERM, or "poor" if it is greater than the ERM.

Analytes	Contaminant	ERL	ERM
Metals (µg/g = ppm)	Arsenic	8.2	70
	Cadmium	1.2	9.6
	Chromium	81	370
	Copper	34	270
	Lead	46.7	218
	Mercury	0.15	0.71
	Nickel	20.9	51.6
	Silver	1	3.7
	Zinc	150	410
Organics (ng/g = ppb)	Acenaphthene	16	500
	Acenaphthylene	44	640
	Anthracene	85.3	1,100
	Flourene	19	540
	2-Methylnaphthalene	70	670
	Naphthalene	162	2,100
	Phenanthrene	240	1,500
	Benz(a)anthracene	261	1,600
	Benzo(a)pyrene	430	1,600
	Chrysene	384	2,800
	Dibenzo(a,h)anthracene	63.4	260
	Fluoranthene	600	5,100
	Pyrene	665	2,600
	LMW PAHs	552	3,160
	HMW PAHs	1,700	9,600
	Total PAHs	4,020	44,800
	4'4 DDE	2.2	27
	DDT	1.6	46.1
	PCB	22.7	180

Fish Tissue Contamination

Fish tissue contamination is an indicator of coastal health that integrates water and sediment quality. Marine organisms can accumulate chemical pollutants by direct uptake from polluted water, consumption of polluted sediment, or consumption of contaminated organisms. Often, these contaminants are not easily degraded and remain in the organism's tissues and, in some cases, can build up over time. This accumulation of contaminants can be magnified moving up the food web and can pose a threat to human health from consuming contaminated organisms. There are three methods for measuring chemical contaminants in fish – a fillet, whole body or a specific organ. The EPA developed risk-based advisory guidance values for recreational fishers (U.S. EPA, 2000b). In this report, different sampling programs used different methods and their approach is noted in the associated metadatabase and in the report text where appropriate.

The EPA risk-based, fish advisory recommendations assess the risk of consuming fish fillets; the concentration criteria can also be used to assess the risk of whole-body contaminants in fish for estimating advisory determinations (U.S. EPA, 2000b). Where whole fish samples were collected instead of fillet samples, "ecological thresholds" were calculated based on non-cancer and cancer health endpoints determined by a 154-pound adult human's safe consumption of four 8-ounce fish meals per month. For each contaminant, if the concentration falls below the range of the EPA Advisory Guidelines, the fish sample analyzed is rated "good" for that contaminant. If the measured concentration falls within the concentration range, a fish sample receives a "fair" rating for that contaminant, and if the measured concentration exceeds the range, the fish sample is rated "poor" for that contaminant. Table 4 lists the assessment criteria for fish tissue contaminants used in this project.

Table 4. Fish tissue contamination indices based on EPA Advisory Guidelines Concentration range (ppm) associated with non-cancer and cancer health endpoints risk (U.S. EPA, 2000b). Sampling site are rated "good" if the concentration is below the range of the EPA guidelines, "fair" if it falls within the range, or "poor" if it is above the range.

Contaminant	EPA Advisory Guidelines Concentration Range (µg/g=ppm)	Health Endpoint (µg/g=ppm)
Arsenic (inorganic)	0.35-0.70	non-cancer
Cadmium	1.2-2.3	non-cancer
Mercury (methylmercury)*	0.12-0.23	non-cancer
Selenium	5.9-12.0	non-cancer
Chlordane	0.59-1.2	non-cancer
DDT	.59-1.2	non-cancer
Dieldrin	0.059-0.12	non-cancer
Endosulfan	7.0-14.0	non-cancer
Endrin	0.35-0.70	non-cancer
Heptachlor epoxide	0.015-0.031	non-cancer
Hexachlorobenzene	0.94-1.9	non-cancer
Lindane	0.35-0.70	non-cancer
Mirex	0.23-0.47	non-cancer
PAHs (benzo(a)pyrene)+	0.0016-0.0032	cancer
PCBs	0.023-0.040	non-cancer

* The conservative assumption was made that all mercury is present as methylmercury because most mercury in fish and shellfish is present as methylmercury and because the analysis for total mercury is less expensive (U.S. EPA, 2000a).
+ Benzo(a)pyrene does not have a non-cancer range (U.S. EPA, 2008).

Analysis of Uncertainty

The NCA probabilistic surveys were designed to generate sound estimates of environmental condition for the region surveyed and use the EPA's data quality objectives to set the overall level of data quality needed to make management decisions. As explained in the NCCR III, to determine the level of uncertainty the cumulative distribution function of each parameter of condition was used to estimate the portion of the resource in degraded condition within ±10% of

the overall system and ±10% for subregions, with 90% confidence based on a completed sampling regime (U.S. EPA, 2008). Table 5 shows the levels of uncertainty that was determined for the southeast coastal region from the NCCR III associated with the estimate of proportion of area in poor condition with data acquired via probabilistic sampling from the years 2000 to 2001. Because the fish tissue contaminants index is expressed as a percentage of stations where fish were caught, the uncertainty associated with areal estimates of ecological condition cannot be determined.

Table 5. Uncertainty associated with the estimate of proportion of area in poor condition for parameters tested in probabilistic surveys for the southeast coastal region from 2001−2002. The cumulative distribution function of each parameter was used to estimate the portion of the resource in degraded condition within ±10% of the overall system and ±10% for sub-regions, with 90% confidence based on a completed sampling regime (U.S. EPA, 2008). NA = not applicable.

Parameter	Uncertainty
Nitrogen	2%
Phosphorus	6%
Chlorophyll a	6%
Water Clarity	9%
Dissolved Oxygen	3%
Sediment Contaminants	2%
Fish Tissue Contaminants*	NA

* Because the fish tissue contaminants index is expressed as a percentage of stations where fish were caught, the uncertainty associated with areal estimates of ecological condition cannot be determined (U.S. EPA, 2008).

Index Sites

Several sites in the southeast coastal region have a continuous monitoring record a number of years. These sites can help frame water quality in terms of long-term trends. These "index" sites were chosen based on the completeness and length of record, as well as proximity to the national park boundaries. Unfortunately, no sites within the parks have continuous water quality records reaching back more than a few years, so this report relies on sites maintained by other agencies to assess temporal trends.

A period of record screen was used to remove stations with limited sampling frequency and intervals. To be considered a potential "index" site, a station met the following criteria: period of record of at least eight consecutive years, at least nine observations in each of the years of record, measure all parameters contained in the EPA's water quality assessment criteria, and be located within five miles of (or within) the park boundary. Figure 10 illustrates the time series of mean monthly DO concentrations measured in bottom water samples for the Georgia Coastal Ecosystems LTER index site at Meridien near FOPU and CUIS. Dissolved oxygen periodically falls below the 5 mg/L concentration (indicated by the red line), the EPA rating threshold between "fair" and "good."

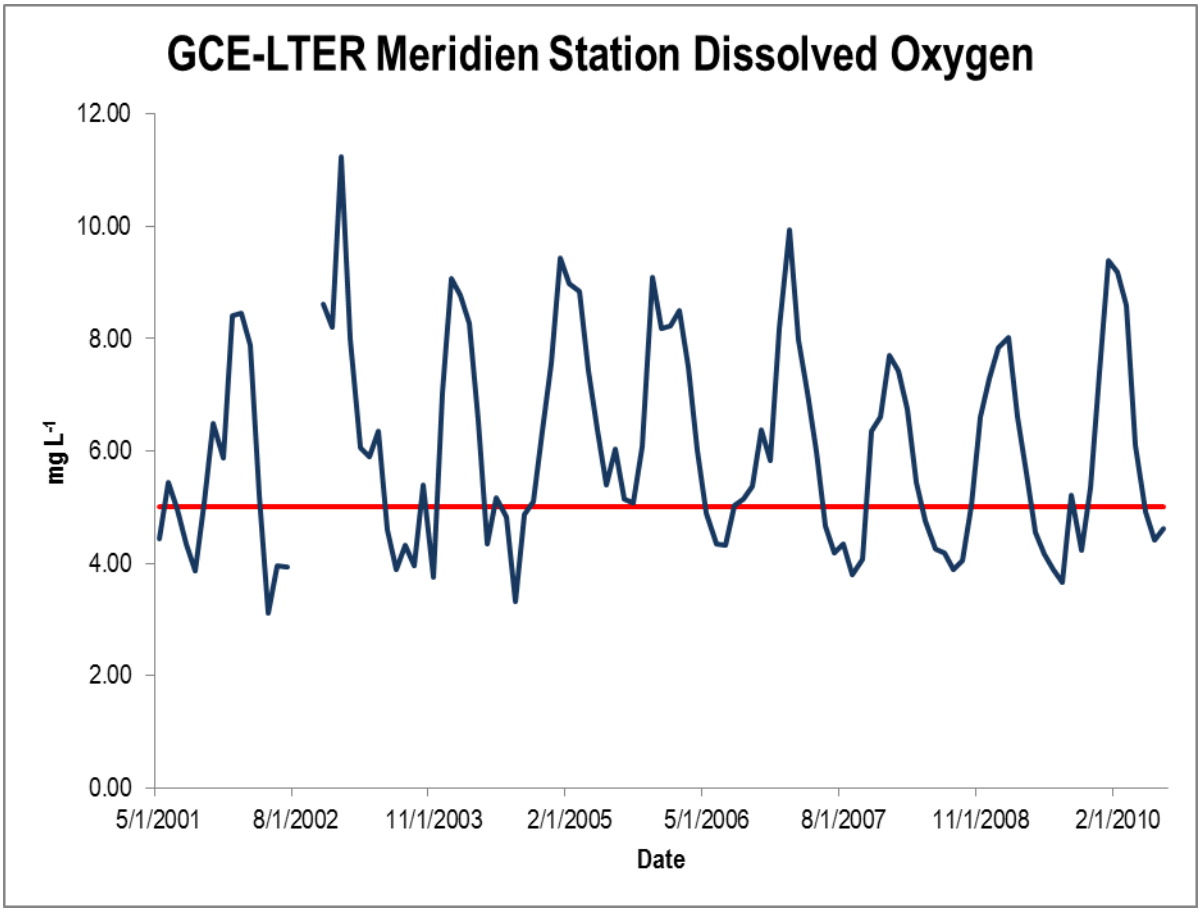


Figure 10. Time series of mean monthly dissolved oxygen concentrations taken from bottom water samples for the Georgia Coastal Ecosystems LTER index site at Meridien near the Georgia parks (FOPU and CUIS). The red line indicates the EPA rating threshold between "fair" and "good."

The NC-DENR sampling site at Back Creek near Merrimon, NC was used for the North Carolina national seashores (CAHA and CALO). This site has nutrient and water quality data for 2002−2009. While this is not a long time series, the availability of nutrient data made this site attractive.

For the Georgia national parks (FOPU and CUIS), we analyzed the Meridien site, continuously monitored by the USGS and Georgia Coastal Ecosystems LTER project since 1990. This site lies between FOPU and CUIS and is the only site in Georgia with continuous data for the parameters of interest in this project. The Georgia Environmental Protection Department (GAEPD) site along the Savannah River at Houlihan Bridge, upstream from FOPU, was used as an indicator of long-term trends in water quality.

The Volusia County Environmental Health Lab (VCEHL) has been sampling water quality sites throughout the St. Johns River and Mosquito Lagoon in Florida for over 20 years. Measurements include general water quality parameters (DO, turbidity, temperature, salinity), as well as nutrient data (DIN, DIP, chlorophyll a). For CANA, we analyzed the long-term record at ML01, which is located in Mosquito Lagoon adjacent to CANA. The City of Jacksonville has

been routinely sampling inside TIMU boundaries since 1999. We used TIM1for the TIMU index site.

Long-term trends in water quality parameters were tested using the nonparametric seasonal Kendall test (Helsel and Hirsch, 1992). Seasonality is accounted for with periodic (sin and cosine) functions. The seasonal Kendall test is performed on the residuals of the linear regression model. Slopes are calculated as Sen slopes without filtering or removing the outliers that are typical hydrologic anomalies (Sen 1968).

Inside/Outside Park Comparison

EPA Rating System

The EPA NCA system that assigns "good," "fair," and "poor" ratings provides a useful way to rapidly assess conditions in a study area that includes thousands of sampling stations (U.S. EPA, 2008). For this project, only summertime concentrations (July through September) were used for the water quality. This is when the benthic biota are most active and hypoxia is most prevalent (EPA, 2001), and thus the time of year when the worst water quality conditions are to be expected.

Ranks were determined for each site for a given year and the results were plotted on a map to identify spatial patterns. For example, Figure 11 shows the spatial distribution of nickel ratings throughout the southeast coastal region.

Where the number of annual samples was small, years were aggregated to provide a greater geographical representation of the region. For sediment and fish tissue samples, the project timeframe included all years between and including 2000−2010. For water quality parameters, a greater sampling frequency allowed us to summarize samples taken between 2000−2004 and 2005−2010. These periods coincided with the EPA and SECN probabilistic surveys, which provided a large number of samples over a wide geographic area.

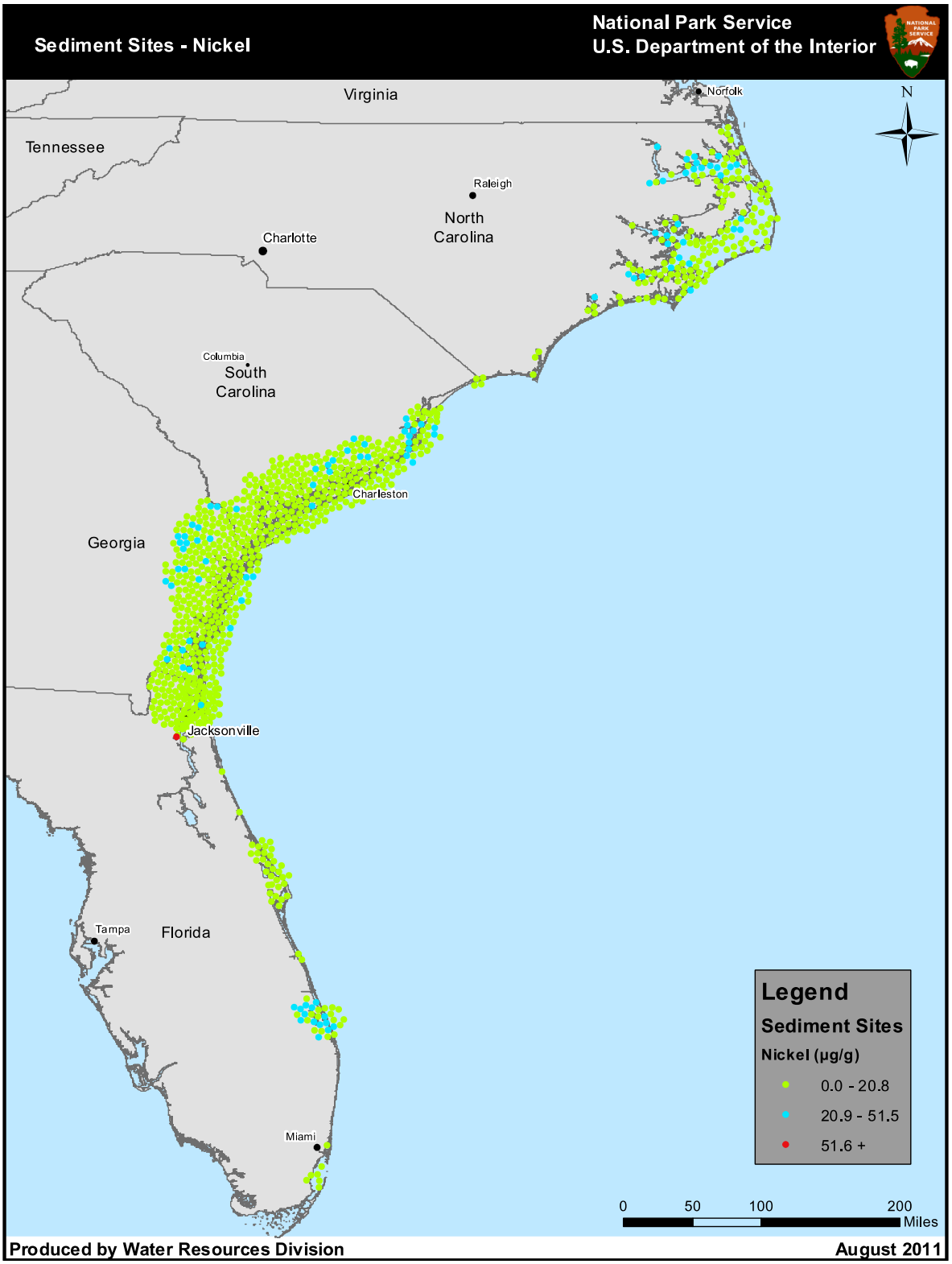
In addition to generating synoptic maps to present water quality rankings, a simple comparison of site assessments inside and outside park boundaries were conducted. All sampling sites within 20 miles of each park boundary were used for the outside comparison. Based on the total number of sampling locations inside and outside the park boundaries, percentages of "good," "fair," and "poor" sites were calculated and presented. This method provides a simple snapshot of the relative quality of water of the parks in a broader regional context.

Alternative Measures of Water Quality

Information such as shellfish harvesting and beach closures may resonate more strongly than water quality parameters with the general public. It is difficult to generate a robust regional snapshot for these indicators because not all states conduct sanitary surveys in the same manner. However, within each state in the southeast coastal region, shellfish closures and beach closure protocols are relatively consistent and presenting these data can provide useful information for park managers.

By plotting shellfish closures, we are able to provide qualitative descriptions of the location of these closures with proximity to parks. While these descriptions lack the statistical power of traditional water quality parameters, they still provide relevant information to park managers and the general public. Fish kill reports from North Carolina and Florida also provided descriptive,

Figure 11. Synoptic sampling map of nickel sediment quality for the southeast coastal region (2000-2010). The green sites are “good,” blue is “fair,” and red is “poor” sediment quality according to the EPA ranking criteria (U.S. EPA, 2008).



but valuable information regarding potential event-level water quality concerns throughout the region. Fish kills are not reported in Georgia

Beach closure data are an important alternative indicator of water quality considering the number of visitors that come to the parks to recreate at the beaches. Data were presented as the percent of beach days that specific beaches were closed throughout 2006−2009. This information is useful for the inside/outside comparison because park beaches are included in the regional datasets provided as part of the EPA BEACH Act.

Results

Water Quality

Dissolved Oxygen

Ideally, dissolved oxygen (DO) should be measured at the bottom of the water column because there is greater concern of low DO near the bottom and DO often decreases with depth. While most samples were collected at the bottom, samples at some sites were only collected at the surface, or the metadata did not specify where the samples were taken. While some discrepancies exist in the comparison of DO levels among sites due to inconsistent sampling protocols, all DO data were used. Table 6 lists water quality results for each data source and Appendix B presents synoptic water quality results.

Outside parks

None of the summertime concentrations measured at the synoptic sites was classified "poor" according to EPA assessment criteria for dissolved oxygen (<2 mg/L). The following regions outside of the park boundaries were classified as "fair" for dissolved oxygen (2−5 mg/L) (U.S. EPA, 2008), and all the following sites measured DO at the bottom of the water column:

- Halifax River (6 out of 30 stations) (2001)
- Indian River North (3 out of 30 stations) (2002)
- Indian River South (4 out of 30 stations) (2003)
- Back Creek near Merrimon (NC-DENR) (2000 and 2005)
- North St. Johns River (2 out of 30 stations) (2000)
- Newport River at Newport (NCDENR) (2000-2009)
- Calico Creek at Morehead City (NCDENR) (2005−2008).

The following regions outside of park boundaries were also classified as "fair" for dissolved oxygen. Note that VCEHL samples were taken at an unspecified depth:

- Mosquito Lagoon (VCEHL) (especially years between 2004−2006)
- Savannah River stations near Savannah (GAEPD)(2002)
- Ogeechee River near Savannah (GAEPD) (2001−2004).

Inside Parks

Within park boundaries, there is evidence of low dissolved oxygen levels, although no sites were rated "poor" for years 2007−2010 in the SECN probabilistic surveys. The North Carolina parks generally had higher DO concentrations; all 17 sites rated "good" at CAHA.

The following sites inside of park boundaries were classified as "fair" for dissolved oxygen:

- 1 of 13 stations at CALO (2010)
- 24 of 32 stations rated at FOPU (2007)
- 18 of 30 sites at CUIS (2007)
- 10 of 32 stations at TIMU (2008)
- 1 of 30 stations at CANA (2009)
- Timucuan Program sites (COJ) (2000−2002 and 2008).

All other stations (inside and outside parks) not mentioned were ranked as "good" according to EPA assessment criteria for dissolved oxygen.

Dissolved Inorganic Nitrogen

In contrast to dissolved oxygen, dissolved inorganic nitrogen (DIN) concentrations in the southeast coastal region were present at higher levels (Table 6).

Outside Parks

The following regions outside of park boundaries sites were classified as "fair" according to the EPA rating criteria for DIN (0.1−0.5 mg/L) (U.S. EPA, 2008):

- Savannah River stations near Savannah (GAEPD) (2002−2003)
- Brunswick River stations near Brunswick (GAEPD) (2001−2002)
- St. Marys River at US 301 (2004)
- Turtle River off Hermitage Island and Georgia Highway 303 (GAEPD) (2000−2004)
- Guana-Tolomato Matanzas NERRS stations (2002−2004)
- North Carolina NERRS stations (2002−2006)
- Sapelo Island NERRS stations (2004−2006)
- Timucuan Program (COJ) stations (2004)
- 12 of the 30 Indian River South sites (2003).

The following stations outside of park boundaries were rated as "poor" for DIN concentrations (>0.5 mg/L):

- Spanish Creek near Folkston (GAEPD)(2003)
- Halifax River stations (2001)
- All Indian River North sites (2002)
- 18 of the 30 Indian River South sites (2003)
- North St. Johns River stations (2000)
- Calico Creek at Morehead (2003−2009).

All other stations outside of park boundaries not mentioned were rated "good" according to the EPA rating criteria for DIN (<0.1 mg/L).

Inside Parks

Inside the parks, data on summertime concentrations of DIN are limited. However, fixed site DIN concentrations measured quarterly inside the parks from 2007−2010, rated "good" with a few exceptions (Figure 12). CUIS experienced elevated DIN concentrations in August of 2007 and October 2009. FOPU experienced several elevated DIN concentrations beginning in the fall of 2008 and extending through the summer of 2010, with three "poor" ratings over the three-year period.

Table 6. Water quality parameters and percent of sampling sites ranked "good," "fair," and "poor" (U.S. EPA, 2008) for sampling programs[1] at sites along the southeast Atlantic coast. 'NA' indicates no sampling sites. DO=dissolved oxygen, DIN=dissolved inorganic nitrogen, DIP=dissolved inorganic phosphorus, Clarity=water clarity at 1-meter, Chl a=chlorophyll a.

Parameter	CAHA	CALO	FOPU	CUIS	TIMU	CANA	NC-DENR	GAEPD	NOC_NERR	SAP_NERR
% DO Good	100.0	92.3	20.0	40.0	68.8	96.8	85.6	72.2	100.0	93.3
% DO Fair	0.0	7.7	80.0	60.0	31.3	3.2	14.4	27.8	0.0	6.7
% DO Poor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Sites	17	13	30	30	32	31	104	18	27	30
% DIN Good	100.0	100.0	NA	100.0	NA	NA	65.4	40.0	20.0	63.6
% DIN Fair	0.0	0.0	NA	0.0	NA	NA	11.5	56.7	80.0	36.4
% DIN Poor	0.0	0.0	NA	0.0	NA	NA	23.1	3.3	0.0	0.0
Total Sites	17	13	NA	30	NA	NA	52	30	20	22
% DIP Good	94.1	100.0	NA	7.4	NA	NA	2.2	0.0	40.0	0.0
% DIP Fair	0.0	0.0	NA	88.9	NA	NA	43.5	13.3	55.0	50.0
% DIP Poor	5.9	0.0	NA	3.7	NA	NA	54.3	86.7	5.0	50.0
Total Sites	17	13	NA	27	NA	NA	46	30	20	22
% Clarity Good	100.0	100.0	100.0	100.0	96.7	67.6	87.1	NA	NA	NA
% Clarity Fair	0.0	0.0	0.0	0.0	3.3	14.7	8.1	NA	NA	NA
% Clarity Poor	0.0	0.0	0.0	0.0	0.0	17.6	4.8	NA	NA	NA
Total Sites	17	13	32	30	30	34	62	NA	NA	NA
% Chl a Good	80.0	95.0	0.0	32.4	3.3	47.1	NA	NA	55.0	10.0
% Chl a Fair	20.0	5.0	66.7	67.6	90.0	52.9	NA	NA	40.0	75.0
% Chl a Poor	0.0	0.0	33.3	0.0	6.7	0.0	NA	NA	5.0	15.0
Total Sites	20	20	3	34	30	34	NA	NA	20	20

[1]CAHA = Cape Hatteras National Seashore), CALO = Cape Lookout National Seashore, FOPU = Fort Pulaski National Monument, CUIS = Cumberland Island National Seashore, TIMU = Timucuan Ecological and Historic Preserve, CANA = Canaveral National Seashore, NC-DENR = North Carolina Department of the Environment and Natural Resources, GAEPD = Georgia Environmental Protection Department, NOC_NERR = North Carolina National Estuarine Research Reserve System, SAP_NERR = Georgia National Estuarine Research Reserve System, GTM_NERR = Florida National Estuarine Research Reserve System, SJR = St. John's River, TIM = Timucuan Program, IRS = Indian River South, IRN = Indian River North, SCECAP = South Carolina Estuarine and Coastal Assessment Program, ML = Mosquito Lagoon, and NSJ = North St. John's River.

Table 6 (continued).

Parameter	GTM_NERR	SJR	TIM	IRS	IRN	Halifax	SCECAP	ML	NSJ
% DO Good	100.0	71.6	41.7	86.7	90.0	80.0	28.1	77.5	93.3
% DO Fair	0.0	25.5	58.3	13.3	10.0	20.0	71.5	22.5	6.7
% DO Poor	0.0	2.9	0.0	0.0	0.0	0.0	0.4	0.0	0.0
Total Sites	23	204	36	30	30	30	463	102	30
% DIN Good	65.0	NA	100.0	0.0	0.0	0.0	90.9	NA	0.0
% DIN Fair	30.0	NA	0.0	40.0	0.0	0.0	9.1	NA	0.0
% DIN Poor	5.0	NA	0.0	60.0	100.0	100.0	0.0	NA	100.0
Total Sites	20	NA	132	30	29	30	482	NA	30
% DIP Good	10.0	NA	0.0	10.0	0.0	0.0	NA	NA	0.0
% DIP Fair	75.0	NA	4.5	16.7	0.0	0.0	NA	NA	0.0
% DIP Poor	15.0	NA	95.5	73.3	100.0	100.0	NA	NA	100.0
Total Sites	20	NA	132	30	29	30	NA	NA	30
% Clarity Good	NA	88.9	80.0	55.9	NA	83.3	74.8	100.0	90.0
% Clarity Fair	NA	10.1	8.0	30.5	NA	6.7	14.9	0.0	6.7
% Clarity Poor	NA	1.0	12.0	13.6	NA	10.0	10.3	0.0	3.3
Total Sites	NA	207	25	59	NA	30	429	104	30
% Chl a Good	65.0	22.5	NA	55.7	NA	13.3	14.8	52.0	20.0
% Chl a Fair	35.0	28.4	NA	38.4	NA	76.7	79.1	42.2	76.7
% Chl a Poor	0.0	49.0	NA	5.9	NA	10.0	6.1	5.9	3.3
Total Sites	20	204	NA	440	NA	30	522	102	30

Because SECN probabilistic surveys measured TDN and TDP and did not break them down into the inorganic portions, DIN and DIP values were determined based on the ratio of fixed site DIN:TDN and DIP:TDP. This ratio was applied to probabilistic TDN and TDP to determine summertime DIN and DIP. Thus, it is important that reported values are not measured DIN and DIP inside the parks, but it is the best that can be accomplished with available data. Based on this conversion, all stations within CALO, CAHA, and CUIS during July were rated "good" for DIN. (Data are not available for CANA, TIMU, or FOPU).

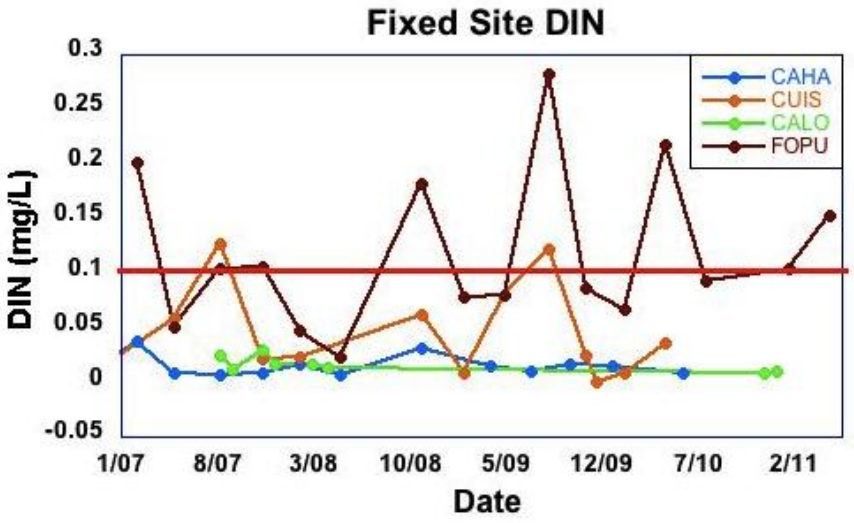


Figure 12. Quarterly dissolved inorganic nitrogen (DIN) concentrations from Southeast Coast Network fixed sites measured between 2007 and May 2011 at Cape Hatteras National Seashore (CAHA) (blue), Cumberland Island National Seashore (CUIS) (orange), Cape Lookout National Seashore (CALO) (green), and Fort Pulaski National Monument (FOPU) (brown). The red line indicates the threshold between "fair" and "good" according to EPA assessment criteria of 0.1 mg/L (U.S. EPA, 2008). Values below the line are rated "good."

Dissolved Inorganic Phosphorus

In contrast to dissolved oxygen, dissolved inorganic phosphorus (DIP) concentrations in the southeast coastal region are generally high (Table 6).

Outside Parks

The following regions outside of park boundaries were classified as "fair" according to the EPA rating criteria for DIP (0.01−0.05 mg/L) (U.S. EPA, 2008):

- Guana-Tolomato Matanzas NERRS sites (2002−2006)
- West Thorofare Bay and Thorofare Canal sites near Atlantic (NCDENR) (2000 and 2001)
- North Carolina NERRS sites (2002−2006)
- Morehead City Harbor (2001)
- North River near Bettie and Beaufort stations (2000 and 2001)
- Bogue Sound sites near Salter Path and Emerald Isle (2000−2004)
- Back Sound at Harker's Island (2000−2001)
- Core Sound stations at Jarrett Bay and Nelson Bay (2001 and 2002).

The following stations outside of park boundaries were rated "poor" for DIP concentrations (>0.05 mg/L):

- Savannah River stations near Savannah (GAEPD) (2000−2004)
- Turtle River stations (2000−2004)
- Brunswick River at Brunswick (GAEPD) (2001−2004)
- Satilla River (GAEPD) (2000−2002)
- St. Andrews Sound (GAEPD) (2000 and 2002)
- St. Marys River (GAEPD) (2000 and 2004)
- Cumberland Sound (GAEPD) (2000)
- Halifax River stations (2001)
- Indian River North (2002)
- Indian River South (2003)
- Back Creek at Merrimon (2001, 2003−2007)
- All St. Johns River sites (2000−2001, 2004)
- Calico Creek at Morehead (2003−2007)
- Ward Creek near Otway (2000, 2001, and 2003)
- Broad Creek at Masontown (2000 and 2001)
- Sapelo Island NERRS sites (2000, 2002−2004)
- Timucuan Program (2/3 of sites) (2001−2003).

All other stations not mentioned outside parks were considered "good" according to the EPA rating criteria for DIP (<0.01 mg/L).

Inside Parks

Inside the parks, data on summertime concentrations of DIP are limited. Fixed site DIP concentrations measured quarterly inside the parks from 2007−2010 have "good" ratings for CAHA and CALO (Figure 13). CUIS and FOPU experienced consistently elevated DIP concentrations that rated "fair" 83−94% of the time, with one site rated "poor" in FOPU during June 2009.

Based on the converted SECN probabilistic data, all CALO sites and 16 out of 17 sites within CAHA were rated "good." In CUIS, 24 out of 27 sites were rated "fair," two were "good," and one was "poor." Data are not available for CANA, TIMU, or FOPU.

Water Clarity

To account for the natural turbidity of various estuaries along the southeast coast, this report uses Secchi depth readings with a natural clarity ranking (low, moderate, high). The results presented here are based on the transmissivity of the water to sunlight at a 1-m depth (Table 6).

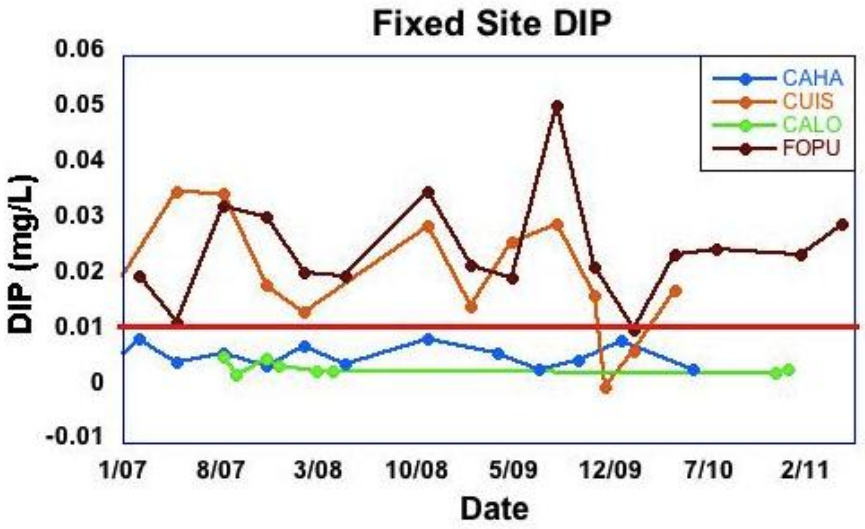


Figure 13. Quarterly dissolved inorganic phosphorus (DIP) concentrations from Southeast Coast Network fixed sites measured between 2007 and May 2011 at Cape Hatteras National Seashore (CAHA) (blue), Cumberland Island National Seashore (CUIS) (orange), Cape Lookout National Seashore (CALO) (green), and Fort Pulaski National Monument (FOPU) (brown). Red line indicates the threshold between "fair" and "good" according to EPA assessment criteria of 0.01 mg/L (U.S. EPA, 2008). Values below this line are rated "good."

Outside Parks

The following sites were rated "fair" based on the EPA guidelines for ratings criteria (U.S. EPA, 2008):

- 23 of 235 sites along the St. Johns River sampling program (2000−2008)
- 2 of 30 sites along the Halifax River (2001)
- 2 of 30 sites along the North St. Johns River (2000)
- 18 of 30 sites in the North Indian River Lagoon sampling program (2003).

The following sites were rated "poor":

- 3 or 13 sites in the Timucuan Program (COJ) (2000, 2002, and 2008)
- 3 of 30 sites along the Halifax River (2001)
- 1 of 30 sites along the North St. Johns River (2000)
- Calico Creek at Merrimon (2005, 2008, and 2009)
- 8 of 30 sites in the North Indian Lagoon sampling program (2003).

Inside Parks

Within park boundaries, the following sites were rated "fair" based on the EPA guidelines for ratings criteria (U.S. EPA, 2008):

- 1 of the 30 sites at TIMU (2008)
- 5 of 34 sites at CANA (2009).

The following sites were rated "poor":

- 6 of 34 sites at CANA (2009).

All other stations inside and outside park boundaries not mentioned above were rated "good" for water clarity according to EPA criteria.

Chlorophyll a

Chlorophyll a concentrations provide a useful metric to assess the trophic state of estuarine waters. Given the high nutrient (DIN and DIP) concentrations in some areas, it is useful to determine if the addition of these normally limiting nutrients has had an effect on phytoplankton abundance.

Outside Parks

The following areas outside park boundaries were rated "fair" based on the EPA guidelines for ratings criteria (U.S. EPA, 2008):

- 8 of 20 sites at the North Carolina NERRS site (2002)
- 15 of 20 sites at the Sapelo Island NERRS site (2002−2006)
- 7 of 20 sites at the Guana-Tolomato Matanzas NERRS site (2002−2006)
- 28% of the St. Johns River sites (2002, 2004, and 2005)
- 38% of the Indian River Lagoon sites (2002−2003)
- 76% of the Halifax River sites (FL) (2001)
- Over 80% of the SCECAP South Carolina sites (1999−2008)
- 42% of the Mosquito Lagoon Sites (2002−2007)
- 77% of the North St. Johns River sites (2000).

The following sites outside park boundaries were rated "poor" for chlorophyll a concentrations:

- 15% of Sapelo Island NERRS sites (2000−2004)
- Over 50% of the St. Johns River sites (2000−2008)
- 10% of the Halifax River sites (2001)
- 6% of the SCECAP South Carolina sites (1999−2007)
- 4% of the North St. Johns River sites (2000).

Inside Parks

Inside park boundaries, the following sites were rated "fair" for chlorophyll a concentrations:

- 4 of 20 sites at CAHA (2010)
- 1 of 20 sites at CALO (2010)
- 23 of 34 sites at CUIS (2007)
- 27 of 30 sites at TIMU (2008)
- 18 of 34 sites at CANA (2009).

The following sites outside park boundaries were rated "poor" for chlorophyll a concentrations:

- 2 of 30 sites at TIMU (2008).

While TIMU was the only park that experienced "poor" ratings for summertime concentrations of chlorophyll a, fixed site data indicates that chlorophyll a concentrations were consistently elevated at CUIS, FOPU, and TIMU between 2007−2010 reaching "poor" rankings a few times in CUIS, FOPU, and TIMU (Figure 14).

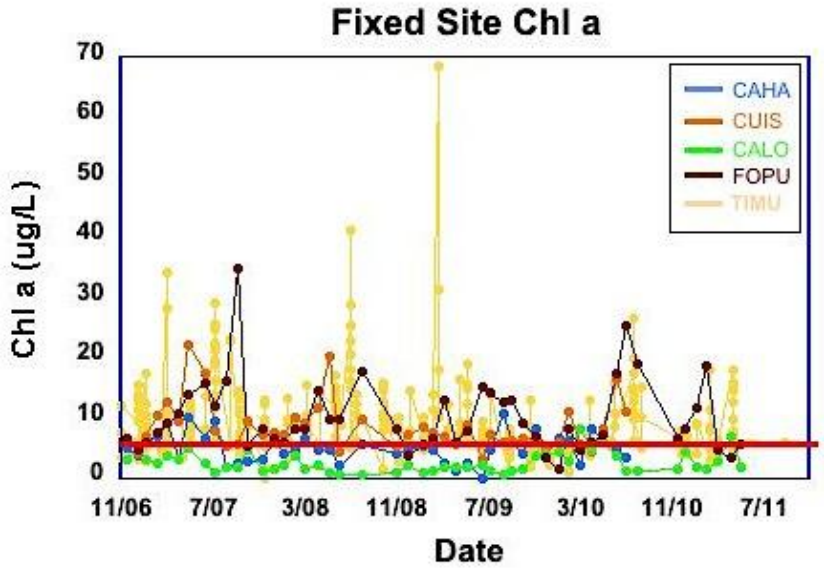


Figure 14. Monthly chlorophyll a (Chl a) concentrations from fixed sites measured between November 2006 and May 2011 at Cape Hatteras National Seashore (CAHA) (blue), Cumberland Island National Seashore (CUIS) (orange), Cape Lookout National Seashore (CALO) (green), Fort Pulaski National Monument (FOPU) (brown), and Timucuan Ecological and Historic Preserve (TIMU) (yellow). Concentrations that fall below the red line at 5 µg/L are rated "good," while samples above the line are considered "fair" or "poor" according to the EPA assessment criteria (U.S. EPA, 2008).

Sediment Quality

Sediment contaminants are evidence of accumulation of metal and organic pollution through time. Most of data on sediment quality came from the probabilistic surveys conducted in 2000−2004 and 2007−2009. We report parameters that are components of the sediment contamination index (U.S. EPA, 2008).

With a few exceptions, all of the sediment contaminant concentrations inside and outside parks were rated "good" throughout the region (Appendix C). Over 95% of the sites in this project were rated "good" for parameters in the EPA sediment quality index. At CANA, CALO, and CAHA, all parameters rated "good." Arsenic concentrations were elevated and 21% of the sites were rated "fair." These sites were scattered throughout the southeast coast and were not concentrated in a particular region or waterbody. Also, 5% of the sites were ranked "fair" and 6% of the sites were ranked "poor" for the total organic carbon. The sites were not concentrated in any estuaries or regions.

While the other parameters were ranked mostly "good," there were a few areas with sediment contamination. The Savannah River and Charleston River had elevated concentrations of 2-methylnaphthalene, acenaphthene, acenaphthylene, anthracene, flourene, flouranthene, naphthalene, and phenanthrene. FOPU is located downriver from the Savannah River sampling sites near Savannah. Seven of the 30 sites sampled in FOPU were rated "fair" for nickel.

In North Carolina, the Neuse River had sampling sites rated "fair" for mercury and total DDT. Some sampling sites near Port St. Lucie, Florida had elevated levels of contaminants, especially 4'4'-DDE, 4'4'-DDT, copper and mercury. The St. Johns River near Jacksonville also contained a few sites rated "poor" for PCBs and mercury. The TIMU sampling sites within the park had two of 30 sites that ranked "fair" for 4'4'-DDT, five of 30 sites that ranked "fair" for cadmium, and five of 30 sites that ranked "fair" for silver.

Overall though, there do not appear to be major sediment contamination problems as evidenced by the high percentage of sites that ranked "good" (Table 7).

Fish Tissue Contamination

All of the fish sampling sites were rated "good" for all parameters tested in the fish tissue index (U.S. EPA, 2008) with a few exceptions (Table 8, Appendix D).

Arsenic. Over 72% of the sampling sites were ranked "poor" throughout South Carolina and Georgia, with many of those sites located in the Pamlico Sound area,. Most of the sites in Florida were also ranked "poor" with the exception of a few "fair" and "good" sites along the St. Johns River near TIMU. None of fish sampling sites located inside parks (CALO, FOPU, CUIS, and TIMU) were ranked "good" and over 94% ranked "poor," with many of those sites located in CUIS, FOPU, and TIMU.

PCB. Most sites were rated "good" except for some "poor" sites near Brunswick, Georgia and Jacksonville, FL. Overall, over 95% of the sites in the southeast coastal region were still ranked "good." Of those sites inside parks, only 10% of sites rated "fair," with most of these sites located throughout the Georgia parks.

PAH. There were "poor" and "good" sites relatively equally scattered throughout the entire southeast coastal area. Overall, 66% of the sites were rated "good" and almost 32% were rated "poor." Most of the poor sites were located in Georgia near or in the Savannah River or along the Neuse River in North Carolina. Inside parks, 59% of the sites were "good," and 41% were rated "poor," with sites distributed throughout CALO, CUIS, FOPU, and TIMU.

There was little evidence of mercury contamination as measured by whole body fish samples at any of the sampled sites. Usually, mercury contamination is the most widespread cause of fish consumption advisories. Over 98% of the fish samples were rated "good," although there were scattered "fair" samples located in Georgia (Back River, Altahama River, Jointer Creek), Florida (Biscayne Bay, Banana River, Indian River Lagoon), North Carolina (Bogue Sound, Little Alligator River), and South Carolina (Combahee River).

Table 7. Sediment quality index parameters and percent of southeast coastal sampling sites ranked "good," "fair" and "poor." Because some sampling sites did not sample all parameters, the number of total sites varies for different parameters. HMW = high molecular weight; LMW = low molecular weight; TOC = total organic carbon.

Parameter	Total Sites	% Good	% Fair	% Poor
2-Methylnaphthalene	1525	99.3	0.7	0.0
4'4'-DDE	975	97.0	3.0	0.0
4'4'-DDT	950	98.2	1.8	0.0
Acenaphthene	1540	97.5	2.5	0.0
Acenaphthylene	1540	99.2	0.8	0.0
Anthracene	1540	99.1	0.9	0.0
Arsenic	1506	79.3	20.7	0.0
Benz(a)anthracene	1431	99.6	0.4	0.0
Benzo()pyrene	865	99.8	0.2	0.0
Cadmium	1567	96.7	3.3	0.0
Chromium	1571	98.3	1.7	0.0
Chrysene	1306	99.6	0.4	0.0
Copper	1542	97.8	2.1	0.1
Dibenzo(a,h)anthracene	127	100.0	0.0	0.0
Flourene	1543	98.0	2.0	0.0
Flouranthene	1543	99.5	0.5	0.0
Lead	1572	99.2	0.8	0.0
LMW PAHs	739	100.0	0.0	0.0
Mercury	1569	97.1	2.9	0.1
HMW PAHs	739	99.3	0.7	0.0
Naphthalene	1541	99.7	0.3	0.0
Nickel	1567	96.4	3.5	0.1
Phenanthrene	1457	99.2	0.8	0.0
Pyrene	1541	99.8	0.2	0.0
Silver	1568	99.4	0.6	0.1
Total DDT	1260	97.2	2.8	0.0
TOC	935	89.6	4.6	5.8
Total PAHs	1261	99.6	0.4	0.0
Total PCBs	1250	99.7	0.2	0.2
Zinc	1567	98.8	1.0	0.3

Table 8. Fish tissue quality index parameters and percent of southeast coastal sampling sites ranked "good", "fair," and "poor." Because some agencies did not sample all parameters at every site, the total number of sites varies parameter to parameter.

Parameter	Total Sites	% Good	% Fair	% Poor
Arsenic	766	9.3	18.1	72.6
Cadmium	766	100.0	0.0	0.0
Mercury	765	98.4	1.6	0.0
Selenium	766	100.0	0.0	0.0
Chlordane	763	100.0	0.0	0.0
DDT	763	100.0	0.0	0.0
Dieldrin	763	100.0	0.0	0.0
Endosulfan	763	100.0	0.0	0.0
Endrin	580	100.0	0.0	0.0
Heptachlor epoxide	763	100.0	0.0	0.0
Hexachlorobenzene	763	100.0	0.0	0.0
Lindane	663	100.0	0.0	0.0
Mirex	763	100.0	0.0	0.0
Toxaphene	489	100.0	0.0	0.0
PAHs	763	65.8	2.8	31.5
PCBs	763	95.3	3.9	0.8

Shellfish Closures

Many shellfish (oysters, clams, and mussels) thrive in estuaries with mixtures of fresh and saltwater. Shellfish are filter feeders that obtain food and oxygen by pumping water across their gills. During feeding, shellfish take in bacteria, viruses, and contaminants adsorbed to particles, and can concentrate them in their digestive system and tissues over 100 times the levels in the water. Because they are often eaten raw or partially cooked, shellfish harvested from polluted areas are a health hazard if consumed. Diseases resulting from consumption of shellfish harvested from polluted waters include typhoid, hepatitis, and salmonellosis.

North Carolina, Georgia, and Florida are members of the Interstate Shellfish Sanitation Conference (ISSC), a voluntary, cooperative association of states, the U.S. Food and Drug Administration (USFDA), National Marine Fisheries Service (NMFS), EPA, and the shellfish industry. States adopt laws and regulations for the sanitary control of the shellfish industry, formulate comprehensive shellfish harvesting area surveys, and adopt control measures to ensure that shellfish are grown, harvested, and processed in a safe, sanitary manner. The USFDA reviews methods for classification and management of shellfish areas proposed by the ISSC, and incorporates those methods consistent with standard health practice into the National Shellfish Sanitation Program (NSSP) Manuals of Operations. The USFDA reviews each state shellfish control program annually to determine conformity with the NSSP standards and guidelines. NMFS and EPA comment to the ISSC. The shellfish industry comments to the ISSC Conference, obtains shellfish from safe sources, maintains sanitary operating conditions, and makes records available that document location of harvest and sale of all shellfish (NSSP, 2007).

The NSSP consists of water quality monitoring, permitting shellfish harvesters, sanitary surveys, and report writing. The NSSP Manual of Operations (Part 1, Section C-3, a) requires that states show that shellfish harvest areas are " not subject to contamination from human and/or animal fecal matter in amounts that in the judgment of the SSCA [State Shellfish Control Authority] may present an actual or potential hazard to public health" (NSSP, 2007). Standards of the NSSP further require the state to regularly collect and analyze water samples from each approved harvest area to ensure that the area is below the established fecal coliform threshold.

A comprehensive sanitary survey is written for each shellfish harvesting area to document the methods and findings of these surveys, as well as proposed changes in classification and management. NSSP guidelines require that these reports be maintained annually, reevaluated every three years, and resurveyed every 12 yrs. The USFDA conducts annual reviews for program compliance. If the minimum requirements for a sanitary survey are not met for a shellfish growing area, USFDA requires immediate closure of all waters in that growing area. If the waters are not closed, the USFDA, through the Interstate Shellfish Sanitation Conference (ISSC) Unresolved Issue process, would de-list all shellfish dealers on the Interstate Shellfish Shippers List (ISSL) essentially denying the shipment of any shellfish in out of state commerce (David Wiggins, USFDA Shellfish Specialist, personal communication).

A sanitary survey includes a bacteriological survey of coastal waters, a shoreline survey of potential pollution sources, and a hydrographic survey of point source pollution. The bacteriological survey analyzes water samples for fecal coliforms to classify a water body. Because monitoring for all human pathogens is not feasible, indicator bacteria are used to assess the likelihood that human pathogens are present. The analysis for fecal coliform takes 24 hrs and the results are expressed in the Most Probable Number (MPN) per 100 milliliters (ml) (NSSP, 2007).

Results of the most recent 30 sets of samples must meet a fecal coliform standard not to exceed a median or geometric mean MPN of the water sample results of 14/100 ml, and the estimated 90^{th} percentile shall not exceed an MPN of 43/100 ml for a five-tube decimal dilution test. Water sampling stations exceeding this standard must be closed to shellfish harvesting.

Rainfall and the resultant stormwater runoff is the major contributor to increases in fecal coliform bacteria levels in coastal waters (NSSP, 2007). Tide, rainfall, river stage, and river discharge are evaluated to identify environmental conditions that may have an association with fecal coliform levels in the water. Equations are developed for each station and used to predict rainfall and river levels when fecal coliform levels equal the NSSP 14 and 88 values. Rainfall or rivers exceeding these levels are defined as adverse pollution conditions. Fecal coliform data at each station are compared to the NSSP fecal coliform standards with respect to adverse pollution conditions to investigate the classification of each portion of shellfish areas as Approved, Conditionally Approved, Restricted, Conditionally Restricted, Prohibited, or Unclassified (i.e., Unapproved) (NSSP, 2007).

Approved Areas are normally open to shellfish harvesting but may be temporarily closed under extraordinary circumstances, such as red tides, hurricanes, and sewage spills. The 14/43 standard must be met for all combinations of defined adverse pollution conditions (tide, rainfall, river, tide/rainfall, tide/river, and tide/rainfall/river).

Conditionally Approved Areas are periodically closed to shellfish harvesting based on pollution events, such as rainfall or increased river flow. The 14/43 standard must be met when the management plan parameter (rainfall, river stage, and/or river discharge) is less than the adverse pollution condition during all other adverse pollution conditions. The Conditionally Approved classification provides a means to use the resource that would otherwise be unusable or lost due to intermittent increases in fecal coliform bacteria concentrations above the approved classification.

Restricted Areas are normally open to relayed or controlled purification, allowed only by special permit and supervision, and may be temporarily closed under extraordinary circumstances such as red tides, hurricanes, and sewage spills. The NSSP 88/260 standard (median or geometric mean must not exceed 88 MPN/100 ml and not more than 10% may exceed 260 MPN/100 ml) for all combinations of defined adverse pollution conditions (tide, rainfall, river, tide/rainfall, tide/river, and tide/rainfall/river).

Conditionally Restricted Areas temporarily suspend relay and controlled purification activity based on pollution events, such as rainfall or increased river flow. The 88/260 standard must be met when the management plan parameter (rainfall, river stage, and/or river discharge) is less than the adverse pollution condition during all other adverse pollution conditions.

Prohibited Areas do not allow shellfish harvesting due to actual or potential pollution. This classification is least desirable, and is used only when standards are exceeded for Approved, Conditionally Approved, Restricted, and Conditionally Restricted classification management schemes. These include areas in the vicinity of wastewater treatment plants and marinas.

Unclassified Areas prohibit shellfish harvesting pending bacteriological and sanitary surveys.

To reopen an area following temporary closure associated with a pollution event, sample results must meet the appropriate NSSP standard (14/43 or 88/260), and adequate time must elapse for shellfish to purify.

North Carolina

The following areas are within a two-mile buffer of park boundaries in North Carolina and are listed by the North Carolina Department of Environment and Natural Resources (NC-DENR) Division of Environmental Health (DEH) − Shellfish Sanitation and Recreational Water Quality Section as "Closed Shellfish Harvesting Areas" (CSHA).

- Buxton/Frisco: Brigand Bay, Brooks Point, Cape Creek, Joe Saur Creek, Hatteras Colony, Ferry Landing, Sandy Bay
- Beaufort/Newport: Town Creek, Mill Creek, Broad Creek
- North of CAHA: Whalebone, Oregon Inlet Fishing Center
- Western shoreline of Bodie/Hatteras Island: Avon Harbor, Askins Harbor, Mill Creek
- Harker's Island: Coat's Landing Harbor, Fisherman's Inn Marina, Calico Jack's Marina, Barbour's Harbor Marina, Knuckles Landing Harbor, National Park Service Boat Basin

- Across Core Sound from CALO: Atlantic, Clayton Fulcher's Fish House
- Ocracoke Silver Lake Area: Horsepen Point.

Because so many of the prohibited areas are located inside or within two miles of CAHA (Figure 15) and CALO (Figure 16), park managers could be concerned that closed shellfish harvesting areas negatively affect visitor experience and perceptions of park water quality. The prevalence of closed areas near urban and more developed parts of the coast (Nags Head, Beaufort, Harker's Island, etc.) suggests a connection between population centers and areas with elevated bacteria levels that can result in shellfish closures.

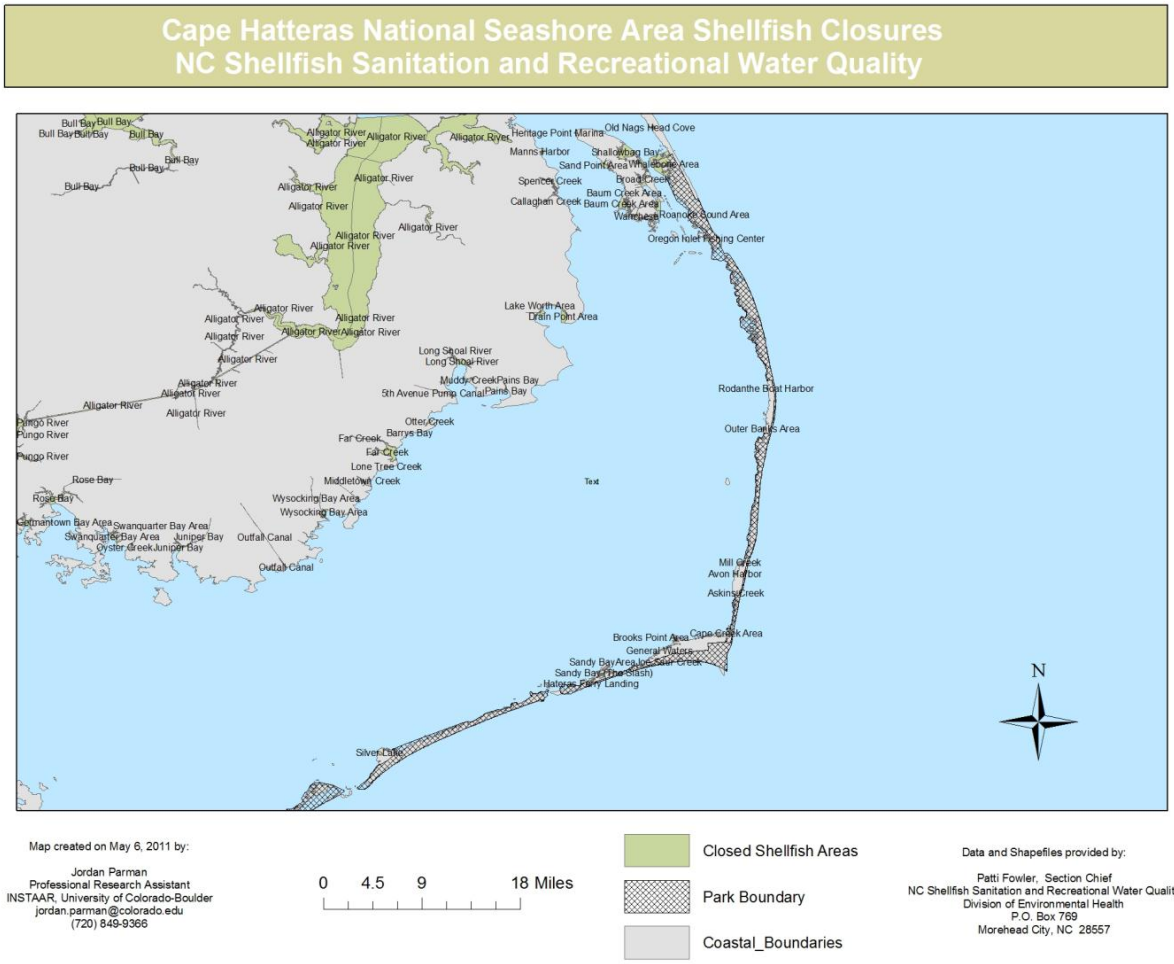


Figure 15. Shellfish closure areas at Cape Hatteras National Seashore (North Carolina Shellfish Sanitation and Recreational Water Quality. (http://www.deh.enr.state.nc.us/shellfish/shellfish.htm).

Georgia

Water quality sampling occurs monthly at 68 stations in five counties on the coast of Georgia, including Chatham, Liberty, McIntosh, Glynn, and Camden counties. The program maintains recreational harvest of clams and oysters only from designated classified areas in Chatham, McIntosh, Glynn, and Camden counties. Recreational harvest for personal use does not require a

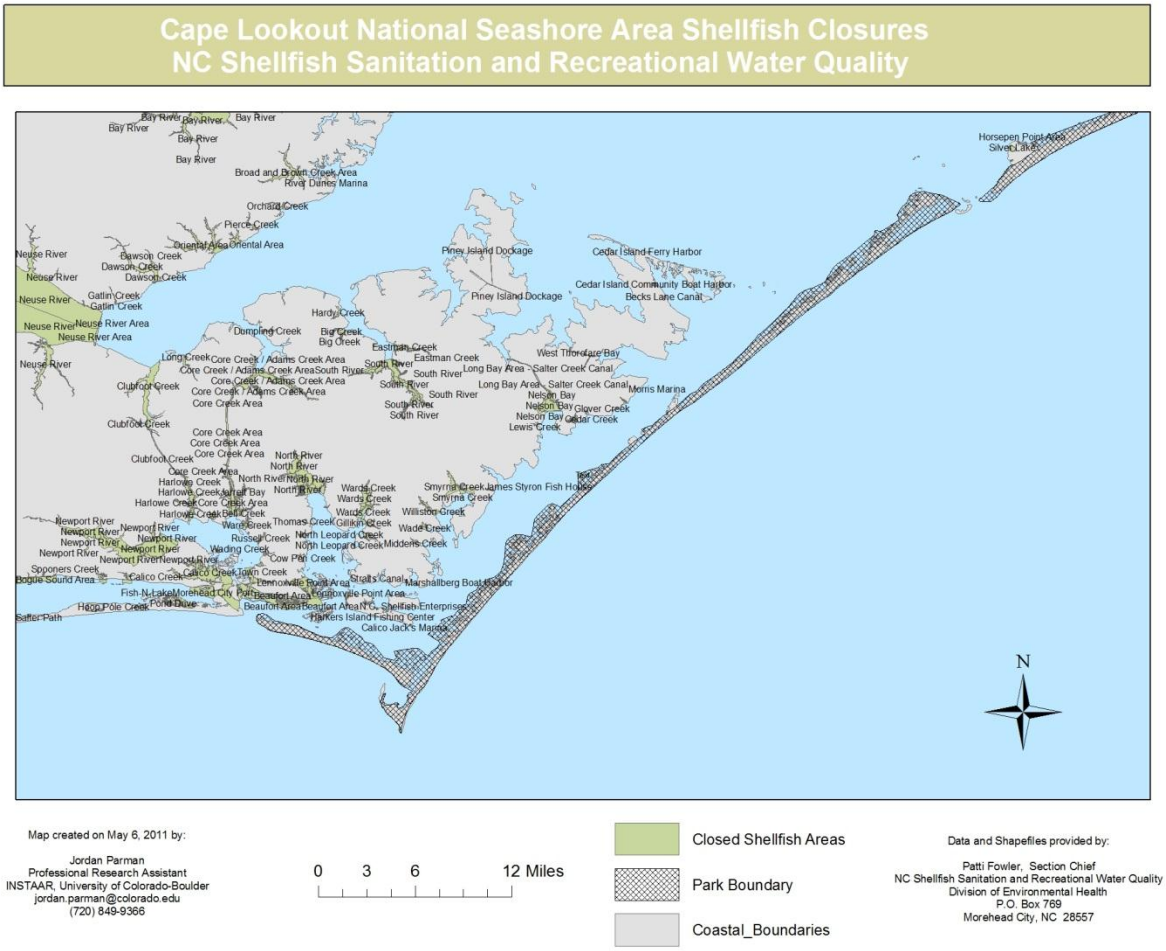


Figure 16. Shellfish closure areas at Cape Lookout National Seashore (North Carolina Shellfish Sanitation and Recreational Water Quality (http://www.deh.enr.state.nc.us/shellfish/shellfish.htm).

permit. Daily harvest limits are two bushels of oysters and one bushel of clams per person per day not to exceed six bushels of oysters and one bushel of clams per boat per day.

As of January 1, 1997, Georgia has had two classifications for shellfish waters − Approved and Prohibited. The last time a harvest was closed was in 1998 due to a major rainfall event in the Bainbridge/Flint area. Due to the high discharge, the harvest areas were closed for all shellfish between March 2 and April 23 (Dominic Guadagnoli, Georgia Coastal Resources Division of the Georgia Department of Natural Resources, personal correspondence, 2011).

However, the shellfish harvest areas in Georgia are located in remote areas with little risk for bacterial contamination (Figure 17). Short of a major tropical storm or hurricane, these approved areas remain open at all times throughout the year. The one exception is a routine oyster-only closure from June 1 to September 30 that has been implemented since 2008. This closure is for *Vibrio* control, a naturally occurring bacterium whose populations increase during the summer and early fall months due to warmer water temperatures (Dominic Guadagnoli, Georgia Coastal Resources Division of the Georgia Department of Natural Resources, personal correspondence, 2011).

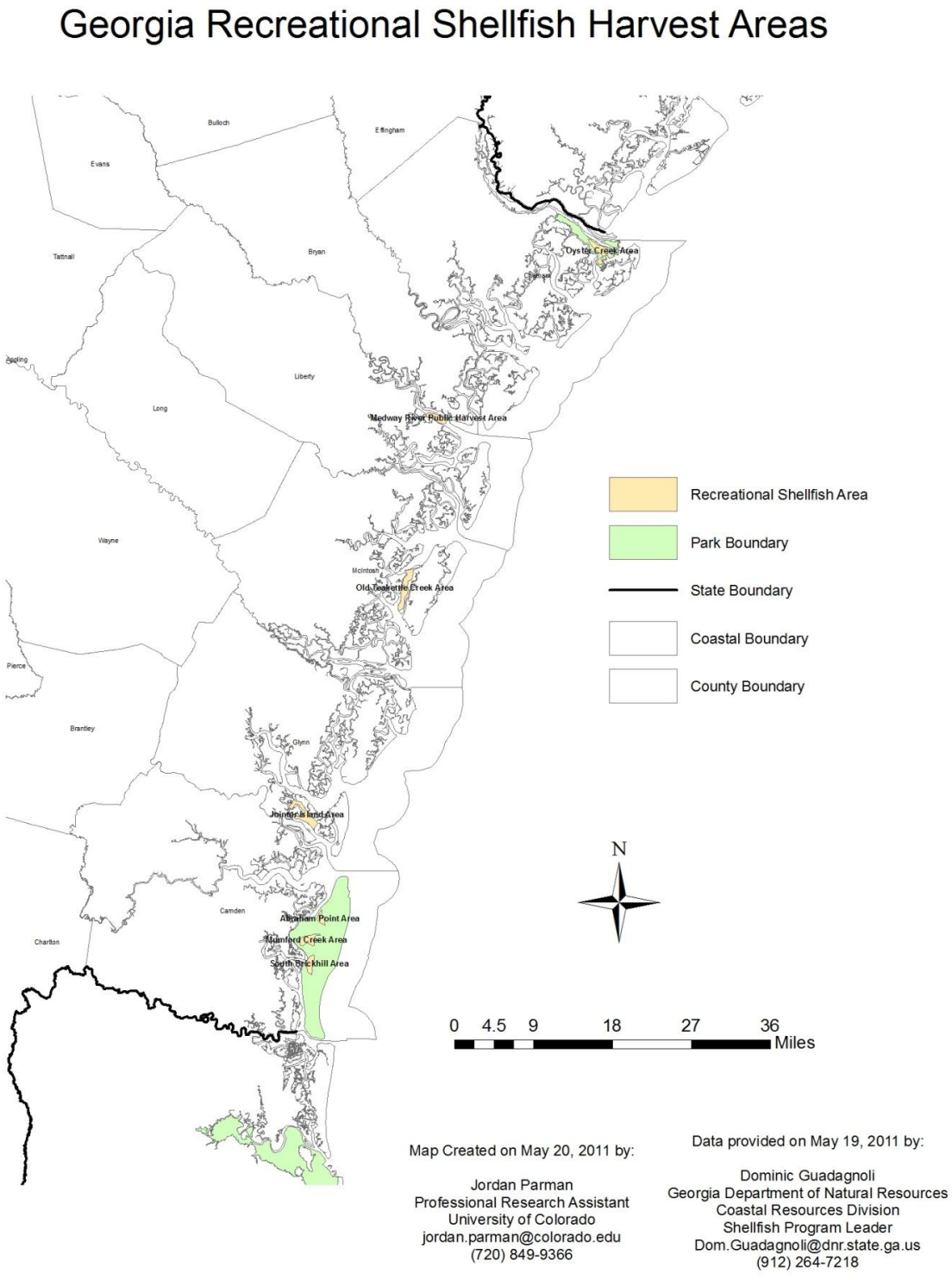


Figure 17. Recreational shellfish harvest areas in Georgia (D. Guadagnoli, Georgia Coastal Resources Division of the Georgia Department of Natural Resources, personal correspondence, 2011).

There are seven public shellfish harvest areas in Georgia and several commercial lease areas that change year to year. The Oyster Creek Area, located along the south channel of the Savannah River, is within the boundaries of FOPU. There are three recreational harvest areas located within the boundaries of CUIS on the western side of Cumberland Island (Abraham Point, Mumford Creek, and South Brickhill areas). The other three harvesting areas in Georgia are the Medway River area, Old Teakettle Creek along the western edge of Sapelo Island, and the Jointer Island area at the mouth of the Brunswick River. None of these areas has experienced any closures except for the event in 1998. Four of the seven recreational harvesting areas are located within park boundaries; shellfish harvesting is an important contributor to the visitor experience at these parks. These areas are approved and are rarely closed, thus providing a special experience for visitors.

Florida

In Florida, oysters and clams are important aquatic species. The annual value of shellfish to the seafood industry in Florida exceeds $20,000,000, with as many as 2,500 people employed in harvesting, processing, and distribution.

The Shellfish Environmental Assessment Section (SEAS) in the Bureau of Aquaculture Environmental Services (a division of the Florida Department of Agriculture and Consumer Services (FDACS) classifies and manages Florida shellfish harvesting areas. Their goals are to maximize use of shellfish resources and reduce the risk of shellfish-borne illness. The FDACS Bureau of Aquaculture Environmental Services routinely monitors fecal coliform and water quality parameters at established stations in each of Florida's shellfish harvesting areas (Figure 18). SEAS is responsible for 1,200 bacteriological sampling stations in 39 shellfish harvesting areas encompassing 1,430,854 acres and shellfish classification of the following coastal waters:

- Panama City office: Florida-Alabama line through East Bay in Bay County on the Gulf coast;
- Apalachicola office: St. Joseph Bay in Gulf County through Wakulla County;
- Gainesville office: Horseshoe Beach in Dixie County through Homosassa Springs in Citrus County;
- Port Charlotte office: Boca Ciega Bay in Pinellas County through Ten Thousand Islands in Collier County; and
- Palm Bay office: Martin County north to the Florida-Georgia line on the Atlantic coast (FDACS, 2009).

Most shellfish harvesting areas in Florida are classified as Conditionally Approved, with management plans calling for temporary closure following rainfall. On the Atlantic coast of Florida, the southernmost shellfish harvesting area lies just south of Vero Beach in Indian Lagoon, where most of the lagoon is classified as Restricted or Prohibited. Moving north to Merritt Island, the Indian River Lagoon harvest area is Conditionally Restricted. At Banana River near Cocoa Beach, the area is listed as Conditionally Approved. At CANA, Mosquito Lagoon is approved for shellfish harvesting, as is the portion of the Indian River Lagoon across

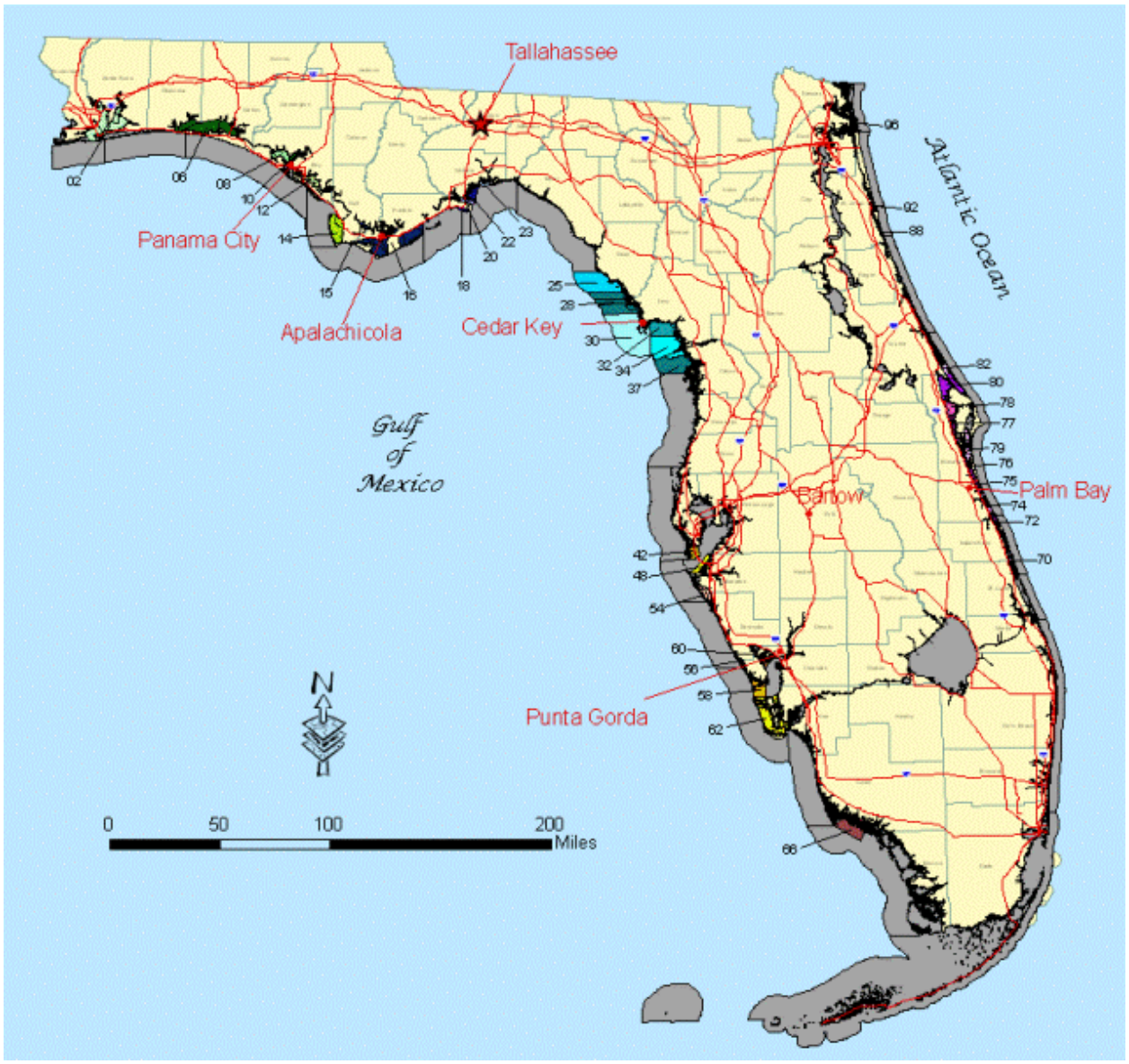


Figure 18. Map of shellfish locations in Florida (http://www.floridaaquaculture.com/SEAS/SEAS_intro.htm).

Haulover Canal (Figure 19). Mosquito Lagoon is an Approved or Conditionally Approved area until just south of New Smyrna Beach, at which point shellfish harvesting is prohibited.

North of CANA along the Matanzas River outlet waters are classified as Conditionally Approved, although to the north, the terminus of the Tolomato River is Conditionally Restricted. There are no shellfish harvesting areas north of the Tolomato River until some small harvesting areas surrounding Little Talbot Island and Talbot Island. The areas located near TIMU are prohibited due to exceedances of the fecal coliform standards (Figure 20).

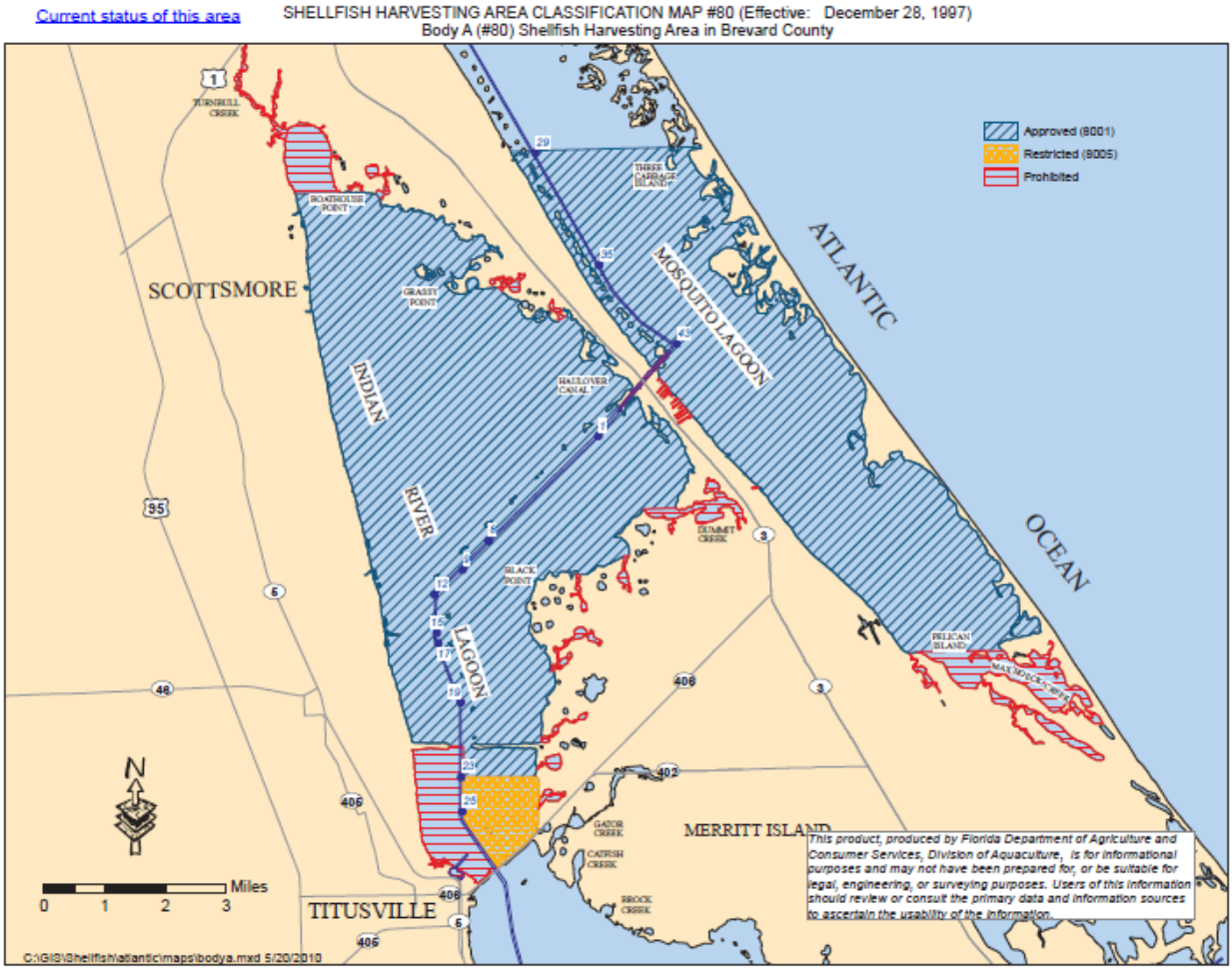


Figure 19. Florida Division of Aquaculture shellfish harvesting area classification map of area near Canaveral National Seashore. (http://www.floridaaquaculture.com/SEAS/SEAS_intro.htm).

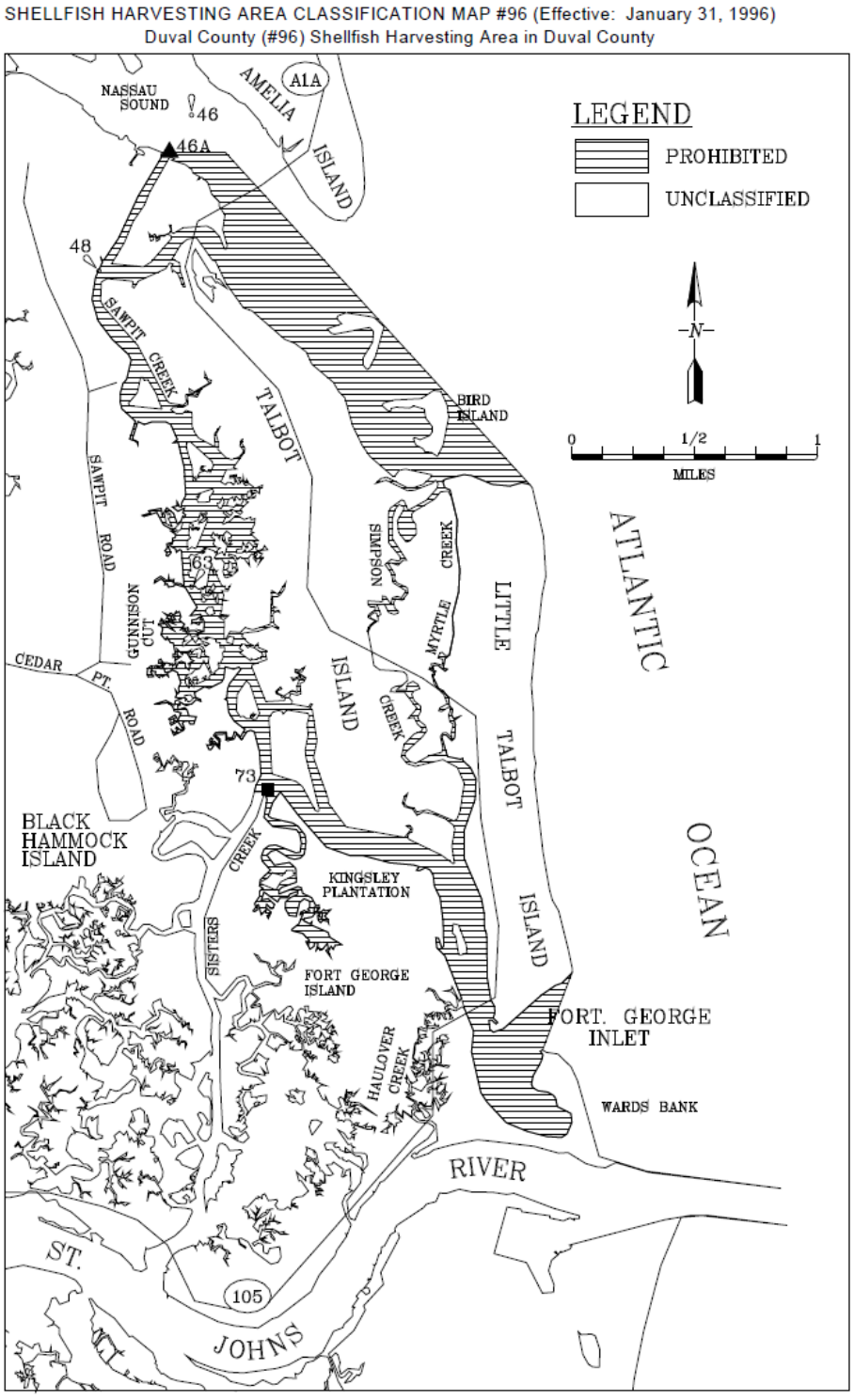


Figure 20. Florida Division of Aquaculture shellfish harvesting area classification map of area near Timucuan Ecological & Historical Preserve. (http://www.floridaaquaculture.com/SEAS/SEAS_intro.htm).

Fish Kill Events

North Carolina

Fish kill events reported to the NC-DENR (Division of Water Quality) for 2000−2010 did not provide much information, most likely due to under-reporting. Fourteen events were reported, of which four cases were attributed to bycatch (not water quality). Another event was related to a broken sewage pipe, four events were from an unknown cause, four were related to low dissolved oxygen levels, and one event was attributed to an algal bloom. The five events attributed to low dissolved oxygen and algal blooms were located near Whortonsville in Pamlico County, across Pamlico Sound from the Outer Banks. Most of the mortality reported during the period was due to these events near Whortonsville, NC.

Florida

Fish kill events from 2000−2010 in Florida reported to the Florida Fish and Wildlife Conservation Commission provide a more detailed snapshot of potential water quality issues throughout the state. Of the more than 2,000 events reported, 466 incidents (23% of total events) were due to unknown causes (Table 9). Approximately 43% of the reported events and 25% of the total mortality were due to red tides, algal blooms, and low dissolved oxygen levels, which are indicators of degraded water quality. Cold weather accounted for 22% of the total mortality and 14% of the events. Disease, stranding, and bycatch accounted for 3% of total mortality and 20% of events.

Table 9. Fish kill events in Florida reported to the Florida Fish and Wildlife Conservation Commission between 2000−2010. Events reported do not include shellfish. Data are available at: http://research.myfwc.com/fishkill/.

Cause	# of Events	% of Total Events	Fish Mortality	% of Total Mortality
Algae bloom	215	10.7	23,339	2.15
Low dissolved oxygen	521	26.0	177,702	16.34
Boat collision	7	0.3	16	0.00
Cold weather	286	14.3	238,868	21.96
Disease	15	0.7	16	0.00
Drowning/entanglement	5	0.2	5	0.00
Fishing Violations	2	0.1	107	0.01
Hurricane/tropical storm	23	1.1	7,835	0.72
Lesions/ulcers	160	8.0	2,576	0.24
Net dumps	38	1.9	12,076	1.11
Other	68	3.4	5,434	0.50
Parasites	29	1.4	352	0.03
Pollution	29	1.4	5,258	0.48
Red tide	125	6.2	72,455	6.66
Tumors	5	0.2	9	0.00
Stranding	9	0.4	185	0.02
Unknown	466	23.3	541,523	49.78

These findings highlight potential water quality concerns close to park boundaries. For example, red tide events were reported in the fall of 2007 at Amelia Island, Huegenot Park, and Little Talbot Island State Park near TIMU. During the same period, a red tide fish kill event was reported at New Smyrna Beach north of CANA. Low dissolved oxygen associated a fish kill was reported in Mosquito Lagoon near Oak Hill, the Indian River Lagoon at Titusville, and at the Banana River near Merritt Island near CANA (summers of 2001, 2002, 2003, 2005, 2006, 2008 and 2010). Algal blooms were reported with a fish kill event in the Indian River Lagoon and Indian River near Titusville, FL.

Beach Closures

Beach closure data provide valuable information relevant to visitor experience in parks. Data were compiled from the EPA's Beaches Environmental Assessment and Coastal Health Act (BEACH Act) program, which summarizes the data by county and state. Table 10 summarizes the beach closures in North Carolina, Florida, and Georgia between 2007−2009.

North Carolina

The North Carolina Department of Environment and Natural Resources (NC-DENR) obtains samples from the ocean surface 16 ft from the sampler's body using a telescopic golf ball retriever (6−12 in below the surface of the water). North Carolina prioritizes beaches for sampling based on usage and potential for contamination. Tier 1 beaches are located near resort areas and are used on a daily basis. While all ocean beaches are Tier 1, Tier 2 beaches include areas in tidal creeks and the Intracoastal Waterway. Tier 2 sites are used most frequently on the weekends. Tier 3 beaches are used an average of four times a month.

North Carolina uses the Enterolert® method for analysis (as opposed to membrane filtration). Results are given as Most Probable Number (mpn), rather than colony forming units (cfu). During the swim season (May 1 to September 30), standards at Tier 1 beaches are a single-sample maximum of 104 mpn/100 ml and a running monthly geometric mean of 35 mpn/100 ml. At Tier 2 sites, the standard is a single-sample maximum of 276 mpn/100 ml and at Tier 3 beaches, the single-sample maximum is 500 mpn/100 ml. Alerts are issued for Tier 1 beaches when the enterococcus levels are between 104−500 mpn/100 ml. If this occurs, a second sample is obtained, and if levels in the resample exceed 104 mpn/100 ml, an advisory is issued. The procedure is similar at the Tier 2 and 3 beaches, with alerts and advisories corresponding to their respective water quality standards.

Monitoring data suggest that water quality at ocean beaches is not affected by rainfall except near storm drains. For this reason, preemptive rainfall advisories are not issued. However, during times with extreme rains (tropical storms and hurricanes), the NC-DENR may issue blanket advisories that cover large areas or all of coastal North Carolina. Permanent signs are also posted on either side of storm drain outfalls warning that swimming between signs is not recommended due to potential contaminated discharge.

North Carolina had 241 beaches monitored during 2007−2009. Compared to the other southeast coastal states, the state had relatively few beach action days (days in which the beach was closed due to elevated enterobacteria counts). Only 5.3% of beaches were affected by a beach action in 2007 and only 10% were affected in 2009. During the three years, there was never a year in which more than 1% of the total days in the state at all beaches were under a beach action.

None of the action days occurred at beaches within park boundaries. Beaches monitored within or near CAHA included the Island Creek beach in Avon, Sunset Strip Drive beach in Frisco, Cape Hatteras Lighthouse, Canadian Hole, and Oregon Inlet. Beaches monitored within or near CALO included the Coast Guard Dock, Park Service Dock, and Shackleford Banks (by restrooms and Buoy #2). While there were no beach action days at any of these sites, there were beach closures in Core Sound off of Harker's Island in 2007 and 2008 due to elevated enterobacteria counts.

Table 10. Data on beach closures in North Carolina, Georgia, and Florida from 2007 to 2009 collected in compliance with EPA BEACH Act (U.S. EPA, 2010).

State	Year	Beaches Affected by Action (%)	Days Under Beach Action (%)
NC	2009	10	0.9
NC	2008	7.9	0.3
NC	2007	5.3	0.4
GA	2009	37	4
GA	2008	44.4	0.9
GA	2007	51.9	2.2
FL	2009	33.4	3.1
FL	2008	35.7	4.8
FL	2007	32.1	5.3

Georgia

The Georgia Department of Natural Resources (GA-DENR) administers the beach monitoring and notification program and reports results to the EPA. The Coastal Resources Division of the GA-DENR oversees the sampling protocol, which consists of weekly grab samples 15−30 centimeters below the surface in about three feet of water. The monitoring frequency for a particular beach increases when an exceedance occurs. This results in higher exceedance rates and lower closing/advisory days than there would be if their sampling frequency did not increase after an initial exceedance is found.

Georgia measures are based upon colony forming unites (cfu) rather than Most Probable Number (mpn). Georgia uses the EPA standard for enterococcus of a single-sample maximum of 104 cfu/100 ml and a geometric mean of 35 cfu/100 ml. The GA-DENR issues an advisory when either the single-sample maximum or geometric mean standard is exceeded. Beach water quality does not correlate strongly with rainfall, so Georgia does not issue preemptive advisories based on storms or use predictive models for issuing closures.

Georgia had 41 beaches monitored during 2007-2009. Compared to the other southeast coastal states, it had the highest frequency of beach action days. Over half of the beaches were affected by a beach action in 2007 and 37% were affected in 2009. The total percent of days under a beach action in 2009 was the highest of the three years, with closures occurring on over 4% of the beach days.

None of the beach action days occurred at a beach within park boundaries. There were no beaches monitored within the boundaries of FOPU, but several beaches were sampled on Tybee Island. The Tybee Island North beach was under a beach action for three days in 2007 due to elevated enterobacteria counts and for two days in 2009. The Tybee Island beach at Polk Street was closed for an entire week in 2007 and the Tybee Island South site was closed for three days in 2007. There were no beaches monitored within the boundaries at CUIS, but the beach at the adjacent Fort Clinch State Park remained open during every beach day throughout the three-year study period. To the south, the Amelia Island Beach Club beach was closed for seven days in 2009.

Florida

Florida's beach water monitoring is administered by the Florida Department of Health. Weekly samples are collected 18 in below the surface in water that is 36 in deep. The Department of Health issues warnings for fecal coliform exceedances and advisories for enterococcus exceedances. Florida applies the EPA standard for enterococcus (single-sample maximum and geometric mean). For the "warnings," a fecal coliform single-sample standard of 400 cfu/100 ml is applied. For most counties, Department of Health officials issue an advisory if any of the three standards is exceeded. However, the county can conduct a follow-up sample within the same week that an initial sample exceeds a standard. If the re-sample does not exceed the standard, an advisory will be delayed. If the resample does exceed any of the three standards, an advisory is issued.

Several counties have preemptive rainfall standards, including Pinellas and Monroe counties. Most counties warn against swimming after a sewage spill until sampling results confirm bacteria levels. Precautionary advisories can be issued after a hurricane or tropical storm comes ashore, though there are no formal guidelines for when to apply these advisories

Florida had 305 beaches monitored during the 2007-2009 period. About one-third of the beaches were affected by closures in each of the three years. In 2007, over 5% of the total beach days throughout the state were closed due to elevated enterobacteria counts. While many of the beach action days occurred outside of the project area (Miami-Dade County and Gulf Region counties), there was evidence of periodic closures in the project area.

There were no beach action days at any beaches within park boundaries. At TIMU, Huegenot Park, located inside the park never experienced closures. Beaches at North Little Talbot Island and South Little Talbot Island were monitored and were never closed due to bacteria. Whereas, the Playalinda beach inside the park boundaries was constantly monitored and never had high enterobacteria counts. However, areas near CANA, including New Smyrna Beach and Cocoa Beach, were closed for a number of days in each of the three years indicating nearby pollution problems that could impact visitor experience.

Index Site Results

Because the bulk of the data used in this report consist of probabilistic, water quality surveys during the summer, it is difficult to infer long-term trends. The "index" sites examined in this project help to put water quality in a temporal context. Appendix E presents detailed time series of water quality parameters at index sites.

Cape Lookout and Cape Hatteras National Seashores

The index site for the North Carolina parks, located on Back Creek near Merrimon, did not exhibit significant trends between 2000−2009 (Table 11). The median dissolved oxygen (7.5 mg/L) and dissolved inorganic nitrogen (0.03 mg/L) concentrations were ranked "good" at this site. The median DIP concentration (0.17 mg/L) was high and ranked "poor."

Table 11. Seasonal Kendall test statistics for water quality parameters measured at Back Creek, North Carolina by the North Carolina Department of the Environment and Natural Resources from 2000-2009. MK=Mann-Kendall Statistic, which describes if the temporal trend is increasing (MK>0), decreasing (MK<0), or if no trend can be determined (MK=0).

Variable	MK statistic	p-value (two-sided)	Slope (change/yr)	Median
Fecal coliform bacteria	0	1.00	0.00	16.00
Dissolved oxygen	4	0.72	0.12	7.45
Dissolved inorganic nitrogen	-5	0.65	0.00	0.03
Dissolved inorganic phosphorus	-1	0.93	-0.01	0.17
pH	4	0.72	0.04	7.75
Turbidity	10	0.37	0.34	6.40
Salinity	11	0.33	1.20	19.09
Conductance	9	0.42	1762.33	30741

Fort Pulaski National Monument

The index site used for FOPU, located up the Savannah River at the Houlihan Bridge in Savannah, did not exhibit significant trends between 2000−2009 (Table 12). The median dissolved oxygen concentration (5.31 mg/L) ranked "good." The median DIN concentration (0.28 mg/L) ranked "fair" and the median DIP concentration (0.15 mg/L) ranked "poor." The results are similar to the synoptic survey results that found elevated nutrient levels along the Savannah River near Savannah. Despite elevated nutrient concentrations, the dissolved oxygen levels remained above the threshold for "good" ranking.

Cumberland Island National Seashore

The index site used for CUIS, located north of the park at the GCE-LTER Meridien, did not exhibit significant trends between 2001 and 2009 (Table 13). While nutrient data were not available for the Meridien site, the median dissolved oxygen concentration (6.03 mg/L) places this site in the "good" ranking. DO can drop below 5 mg/L during the summer (Appendix E), which raises questions about the trophic state and health of estuarine ecosystems.

Timucuan Ecological and Historic Preserve

The City of Jacksonville has been monitoring water quality inside TIMU since 1999. The only measured parameter that changed significantly from 1999−2009 was dissolved oxygen, which increased at a small, but statistically significant rate of 0.07 mg/L/yr. None of the other parameters changed significantly during the period (Table 14). While the significant increase in DO is encouraging, the 10-year median concentration of 4.8 mg/L places this site in the "fair"

Table 12. Seasonal Kendall test statistics for water quality parameters measured at the Georgia Environmental Protection Department Savannah River-Houlihan Bridge in Savannah from 2000-2009. MK=Mann-Kendall Statistic, which describes if the temporal trend is increasing (MK>0), decreasing (MK<0), or if no trend can be determined (MK=0).

Variable	MK statistic	p-value (two-sided)	Slope (change/yr)	Median
Alkalinity	7	0.19	3.33	39.50
Fecal coliform bacteria	-1	0.85	0.00	30.00
Dissolved oxygen	3	0.57	0.04	5.31
Dissolved inorganic nitrogen	9	0.06	0.00	0.28
Dissolved inorganic phosphorus	5	0.35	0.01	0.15
pH	5	0.35	0.05	7.28
Turbidity	7	0.19	3.33	22.00
Conductance	5	0.35	1378	6517
Total suspended solids	5	0.35	4.50	33.50

Table 13. Seasonal Kendall test statistics for water quality parameters of dissolved oxygen (DO), pH, turbidity, salinity, and conductance measured at the Georgia Coastal Ecosystems Long-Term Ecological Research Meridien site from 2001-2009. MK=Mann-Kendall Statistic, which describes if the temporal trend is increasing (MK>0), decreasing (MK<0), or if no trend can be determined (MK=0).

Variable	MK statistic	p-value (two-sided)	Slope (change/yr)	Median
DO	1	0.93	0.03	6.03
pH	-5	0.65	0.00	7.50
Turbidity	-7	0.53	-1.17	26.14
Salinity	-11	0.33	-0.31	25.11
Conductance	-11	0.33	-457	39405

category. The median DIN concentration (0.05 mg/L) ranks as "good," while the median DIP (0.12 mg/L) is "poor," similar to other sites in the estuarine areas of Florida. These results are similar to the synoptic results, which indicate that elevated phosphorus loading potentially impacts the trophic state of the Florida estuaries. This index site is particularly useful because it is the only water quality monitoring within a national park along the southeast coastal region that has been in place for more than a few years.

Canaveral National Seashore

The Volusia County Environmental Health Laboratory measures water quality at Mosquito Lagoon site ML01, which is located near CANA. Total suspended solid concentrations significantly increased by 4.99 mg/L/yr from 2000−2008 (Table 15). The ortho-phosphate concentration significantly decreased 0.002 mg/L during the same period. The median dissolved oxygen concentration (6.0 mg/L) ranks "good." The median nitrate/nitrite concentration (0.01 mg/L) and orthophosphate concentration (0.01 mg/L) ranked "good." However, the phosphorus level is close to being ranked "fair." Chlorophyll a concentrations were low enough to rank as "good," (median concentration of 3.05 µg/L), perhaps related to the "good" nutrient levels.

Table 14. Seasonal Kendall test statistics for water quality parameters of ammonia (NH3), dissolved oxygen (DO), dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), turbidity, and total suspended solids (TSS) measured at City of Jacksonville TIM01 by the City of Jacksonville from 1999-2009. MK=Mann-Kendall Statistic, which describes if the temporal trend is increasing (MK>0), decreasing (MK<0), or if no trend can be determined (MK=0). DIN = dissolved inorganic nitrogen, DIP = dissolved inorganic phosphorus, DO = dissolved oxygen, NH_3 = ammonia, TSS = total suspended solids.

Variable	MK statistic	p-value (two-sided)	Slope (change/yr)	Median
TIM01 NH_3	0	1.00	0.00	0.05
TIM01 DO	32	0.01	0.07	4.84
TIM01 DIN	8	0.53	0.00	0.05
TIM01 DIP	-4	0.75	0.00	0.12
TIM01 Turbidity	10	0.43	0.10	11
TIM01 TSS	22	0.09	0.75	24

Table 15. Seasonal Kendall test statistics for water quality parameters measured at Volusia County Environmental Health Lab's Mosquito Lagoon 01 site from 2000-2008. MK=Mann-Kendall Statistic, which describes if the temporal trend is increasing (MK>0), decreasing (MK<0), or if no trend can be determined (MK=0).

Variable	MK statistic	p-value (two-sided)	Slope (change/yr)	Median
Secchi disk depth	-12	0.21	-0.10	1.20
pH	10	0.30	0.01	7.96
Conductivity	12	0.21	620	54127
Dissolved oxygen	14	0.14	0.19	6.00
Salinity	12	0.21	0.47	35.83
Turbidity	13	0.17	0.65	5.40
Total suspended solids	20	0.04	4.99	16.80
Nitrogen Kjeldahl	-4	0.68	-0.03	0.32
Nitrate/nitrite-nitrogen	-11	0.24	0.00	0.01
Total nitrogen	-8	0.40	-0.07	0.33
Total phosphorus	10	0.30	0.00	0.06
Ortho-phosphate	-25	0.01	0.002	0.01
Chlorophyll a corrected	8	0.40	0.33	3.05
Chlorophyll a	8	0.40	0.22	3.87

Discussion

Cape Hatteras National Seashore

While largely isolated from nonpoint sources pollution on the mainland, CAHA still experiences degraded water quality associated with population growth along the Outer Banks, from Nags Head to the north. Septic systems on the barrier island have been linked to elevated fecal coliform, DIN, and DIP concentrations in groundwater on Bodie Island (Mallin et al., 2006). The drainage ditches have elevated copper, ammonium, and lower dissolved oxygen concentrations compared to the marsh on the island.

Inside park boundaries, overall water quality was better than surrounding areas as indicated by a higher percentage of sites that ranked "good" for DO, DIN, DIP, water clarity, and chlorophyll a (Table 16). Of the sites inside the park, 94% of DIP samples were rated "good" during 2010 versus only 66% sites that rated "good" in the 20 miles surrounding the park. Water clarity was "good" at all sites inside the park, while 22% of sites surrounding the park were "good" and 78% were "fair." Long-term trends in the median concentration of DIP were "poor" between 2000−2009. These findings suggest that runoff from nearby development has not had a large influence on water quality inside the park.

The high levels of arsenic and PAHs in fish tissue at sites outside of CAHA (Table 16) are likely a result of automobile pollution and surface runoff associated with an increasing population and development (Mallin et al., 2006). For arsenic, 63% of the sites were "poor" and only 15% were "good." For PAHs, 75% of the sites "good" and 25% were "poor." The lack of data on sediment and fish tissue inside CAHA prevents comparisons with the park. This information for sites within the park would provide a clearer picture of how surrounding development is influencing the park's overall water quality.

Due to elevated bacteria levels, certain shellfish areas inside or adjacent to the park have been closed in the past including sites near Oregon Inlet, Frisco, and off the southern tip of Ocracoke Island. Large fish kill events have not been reported near the park; the closest event occurred across Pamlico Sound in Whortonsville, which was reportedly caused by an algal bloom. CAHA is popular with visitors in large part because of the beaches and from the 2006−2009 EPA BEACH Act data, there were no reported beach closures. Many of the beaches in the area were monitored, including sites near Frisco, Cape Hatteras Lighthouse, Canadian Hole, and Oregon Inlet. While there were no reported beach closures from 2006−2009, past studies documented periodic beach closures at the Canadian Hole and Oregon Inlet beach sites (Mallin et al., 2006).

Cape Lookout National Seashore

Due to its isolation from the mainland and limited development, CALO water quality remains relatively pristine, although there are potential concerns. The resident feral horse population on the islands is a potential source of fecal coliforms and organic matter. Compared to CAHA to the north and to the mainland, CALO has fewer water quality issues − there are no TMDLs, algal blooms, beach closures, or shellfish closures. Like CAHA, some wells in CALO contain elevated nitrate levels, most likely due to septic leachate.

Table 16. Comparison of water quality inside and outside of Cape Hatteras National Seashore. Data are the percentage of sites rated "good," "fair," or "poor" (U.S. EPA, 2008). Outside = sampling sites within 20 miles of park boundary. The number of sampling sites is in parentheses. '---' indicates no sampling sites. DDE=Dichlorodiphenyldichloroethylene, DDT= dichlorodiphenyltrichloroethane, DIN = dissolved inorganic nitrogen, DIP = dissolved inorganic phosphorus, PAH=polycyclic aromatic hydrocarbon, PCB=polychlorinated biphenyls, TOC=total organic carbon.

Variable	Inside Park Good (%)	Outside Park Good (%)	Inside Park Fair (%)	Outside Park Fair (%)	Inside Park Poor (%)	Outside Park Poor (%)
WATER QUALITY						
Dissolved oxygen	100(17)	100(76)	0(0)	0(0)	0(0)	0(0)
DIN	100(17)	80(60)	0(0)	5(4)	0(0)	15(11)
DIP	94(16)	61(46)	0(0)	32(24)	6(1)	7(5)
Water clarity	100(17)	22(25)	0(0)	78(89)	0(0)	0(0)
Chlorophyll a	80(16)	44(50)	20(4)	51(58)	0(0)	5(5)
SEDIMENT CONTAMINANTS						
2-Methylnaphthalene	100(25)	100(71)	0(0)	0(0)	0(0)	0(0)
4'4'-DDE	100(25)	100(71)	0(0)	0(0)	0(0)	0(0)
Acenaphthene	100(25)	100(71)	0(0)	0(0)	0(0)	0(0)
Acenaphthylene	100(25)	100(71)	0(0)	0(0)	0(0)	0(0)
Anthracene	100(25)	100(71)	0(0)	0(0)	0(0)	0(0)
Arsenic	100(25)	93(65)	0(0)	7(5)	0(0)	0(0)
Copper	100(25)	100(70)	0(0)	0(0)	0(0)	0(0)
Flourene	100(25)	100(71)	0(0)	0(0)	0(0)	0(0)
Flouranthene	100(25)	100(71)	0(0)	0(0)	0(0)	0(0)
Mercury	100(25)	99(69)	0(0)	1(1)	0(0)	0(0)
Naphthalene	100(25)	100(71)	0(0)	0(0)	0(0)	0(0)
Phenanthrene	100(25)	100(60)	0(0)	0(0)	0(0)	0(0)
Total DDT	---	97(68)	---	3(2)	---	0(0)
TOC	100(25)	83(59)	0(0)	11(8)	0(0)	6(4)
Total PCBs	100(25)	100(70)	0(0)	0(0)	0(0)	0(0)
FISH CONTAMINANTS						
Arsenic	---	15(16)	---	21(22)	---	64(66)
PAHs	---	75(78)	---	0(0)	---	25(26)
PCBs	---	100	---	0(0)	---	0(0)

Water quality results indicate much better quality inside CALO than surrounding areas (Table 17). The percentage of sites inside the park that ranked "good" for DIN, DIP, water clarity, and chlorophyll a was higher by 30−70% compared to sites outside, and the median DO and DIP concentrations from fixed stations between 2000−2009 were also ranked "good."

Fish tissue results from inside the park indicate a higher percentages of sites that rated "fair" and "poor" for arsenic and PAHs compared to outside park sites. Mallin et al (2004) reported high

PAH and metal concentrations on Core Banks, possibly from an above-ground storage tank, incinerator, and refueling pad on the island.

Areas near Beaufort and Newport have degraded water quality as evidenced by shellfish closures due to elevated bacteria counts. Shellfish closures have also occurred off the eastern portion of Harker's Island, across the sound from CALO. There have been no documented fish kills in the vicinity of CALO; the closest reported fish kill came from Whortonsville. Beaches at the Coast Guard dock, NPS dock, and Shackleford Banks are routinely monitored for bacteria, but no closures occurred during 2006−2009.

Fort Pulaski National Monument

Because it is near Savannah, FOPU is susceptible to degraded water quality from the multiple point and nonpoint sources of pollution in the heavily urbanized and industrial region. Wastewater treatment plants and paper/pulp mills are potential sources of organic matter and nutrient loading to the Savannah River. Alterations to the Savannah River channel and dredge spoils from industry sites along the river are other sources of contamination. A new proposal to deepen the river channel may affect water quality in the park (McFarlin and Alber, 2005).

Water quality in and near FOPU is degraded, with low dissolved oxygen concentrations along the Savannah River and high DIN and DIP concentrations. Limited observations inside the park by McFarlin and Alber (2005) found 63% of the DIN observations to be "good," 37% were "fair," and none were "poor"; 93% of the DIP observations were "fair," 5% were "good," and 2% were "poor." Similarly, index site results between 2000−2009 had a median DIN concentration ranked "fair" and a median DIP concentration ranked "poor." The frequency of high DIN and DIP concentrations reported suggest high DIN and DIP is a consistent problem inside and surrounding FOPU.

Within FOPU, 20% of sites ranked "good" and 80% ranked "fair" for DO compared to 34% of sites surrounding the park that rated "good" and 66% of sites that ranked "fair" (Table 18). There were no chlorophyll a concentrations that ranked "good" inside the park, 67% of sites ranked "fair," and 33% ranked "poor." In the areas surrounding the park, 17% ranked "good," 78% were "fair," and 6% were "poor."

Sites along the Savannah River had elevated metal and organic contaminant concentrations in sediment and fish tissues (acenaphthene, acenaphthylene, arsenic, anthracene, cadmium, flourene, mercury, and DDT). The percentage of sites ranked "good" for sediment contaminants was similar to or slightly higher inside the park compared to sites surrounding the park (Table 18). Metal contamination was found at dredge disposal sites near the park boundary (Winger et al., 2000).

Fish tissue samples indicate high levels of arsenic, PAHs, and PCBs inside and outside FOPU. The percentage of sites ranking "good," "fair," and "poor" were similar inside and outside the park for all parameters (Table 18). For PCBs, fewer sites ranked "good" and more sites ranked "poor" compared to surrounding areas.

Table 17. Comparison of water quality inside and outside of Cape Lookout National Seashore. Data are the percentage of sites rated "good," "fair," or "poor" (U.S. EPA, 2008). Outside = sampling sites within 20 miles of park boundary. The number of sampling sites is in parentheses. '---' indicates no sampling sites. DDE=Dichlorodiphenyldichloroethylene, DDT=dichlorodiphenyltrichloroethane, DIN = dissolved inorganic nitrogen, DIP = dissolved inorganic phosphorus, PAH=polycyclic aromatic hydrocarbon, PCB=polychlorinated biphenyls, TOC=total organic carbon.

Variable	Inside Park Good (%)	Outside Park Good (%)	Inside Park Fair (%)	Outside Park Fair (%)	Inside Park Poor (%)	Outside Park Poor (%)
WATER QUALITY						
Dissolved oxygen	92(12)	92(161)	8(1)	7(12)	0(0)	1(1)
DIN	100(13)	71(87)	0(0)	10(13)	0(0)	19(23)
DIP	100(13)	29(34)	0(0)	42(51)	0(0)	29(34)
Water clarity	100(13)	40(37)	0(0)	60(56)	0(0)	0(0)
Chlorophyll a	95(19)	39(36)	5(1)	57(52)	0(0)	4(4)
SEDIMENT CONTAMINANTS						
2-Methylnaphthalene	100(25)	100(81)	0(0)	0(0)	0(0)	0(0)
4'4'-DDE	100(25)	99(80)	0(0)	1(1)	0(0)	0(0)
Acenaphthene	100(25)	100(81)	0(0)	0(0)	0(0)	0(0)
Acenaphthylene	100(25)	100(81)	0(0)	0(0)	0(0)	0(0)
Anthracene	100(25)	100(81)	0(0)	0(0)	0(0)	0(0)
Arsenic	100(25)	82(66)	0(0)	18(15)	0(0)	0(0)
Copper	100(25)	100(82)	0(0)	0(0)	0(0)	0(0)
Flourene	100(25)	100(81)	0(0)	0(0)	0(0)	0(0)
Flouranthene	100(25)	100(81)	0(0)	0(0)	0(0)	0(0)
Mercury	100(25)	94(76)	0(0)	6(5)	0(0)	0(0)
Naphthalene	100(25)	100(81)	0(0)	0(0)	0(0)	0(0)
Phenanthrene	100(25)	100(63)	0(0)	0(0)	0(0)	0(0)
Total DDT	----	96(74)	---	4(3)	---	0(0)
TOC	100(25)	84(69)	0(0)	10(8)	0(0)	6(5)
Total PCBs	100(25)	100(77)	0(0)	0(0)	0(0)	0(0)
FISH CONTAMINANTS						
Arsenic	0(0)	6(6)	0(0)	17(17)	100(7)	77(79)
PAHs	57(4)	68(70)	0(0)	3(3)	43(3)	28(29)
PCBs	100(7)	99(101)	0(0)	1(1)	0(0)	0(0)

Table 18. Comparison of water quality inside and outside of Fort Pulaski National Monument. Data are the percentage of sites rated "good," "fair," or "poor" (U.S. EPA, 2008). Outside = sampling sites within 20 miles of park boundary. The number of sampling sites is in parentheses. '---' indicates no sampling sites. DDE=Dichlorodiphenyldichloroethylene, DDT=dichlorodiphenyltrichloroethane, DIN = dissolved inorganic nitrogen, DIP = dissolved inorganic phosphorus, PAH=polycyclic aromatic hydrocarbon, PCB=polychlorinated biphenyls, TOC=total organic carbon.

Variable	Inside Park Good (%)	Outside Park Good (%)	Inside Park Fair (%)	Outside Park Fair (%)	Inside Park Poor (%)	Outside Park Poor (%)
WATER QUALITY						
Dissolved oxygen	20(6)	34(46)	80(24)	66(89)	0(0)	0(0)
DIN	---	30(32)	---	47(50)	---	23(25)
DIP	---	0(0)	---	47(50)	---	53(57)
Water clarity	100(32)	100(107)	0(0)	0(0)	0(0)	0(0)
Chlorophyll a	0(0)	17(33)	67(2)	78(155)	33(1)	6(12)
SEDIMENT CONTAMINANTS						
2-Methylnaphthalene	100(35)	97(254)	0(0)	3(7)	0(0)	0(0)
4'4'-DDE	100(31)	100(234)	0(0)	0(0)	0(0)	0(0)
Acenaphthene	100(35)	91(237)	0(0)	9(23)	0(0)	0(0)
Acenaphthylene	100(35)	99(259)	0(0)	1(2)	0(0)	0(0)
Anthracene	100(35)	99(257)	0(0)	1(4)	0(0)	0(0)
Arsenic	100(34)	86(174)	0(0)	14(28)	0(0)	0(0)
Copper	100(35)	0(0)	0(0)	0(0)	0(0)	0(0)
Flourene	100(35)	93(240)	0(0)	7(19)	0(0)	0(0)
Flouranthene	100(35)	99(258)	0(0)	1(3)	0(0)	0(0)
Mercury	97(34)	97(254)	3(1)	3(7)	0(0)	0(0)
Naphthalene	100(35)	99(259)	0(0)	1(2)	0(0)	0(0)
Phenanthrene	100(35)	97(233)	0(0)	3(8)	0(0)	0(0)
Total DDT	100(30)	98(172)	0(0)	2(3)	0(0)	0(0)
TOC	100(34)	18(37)	0(0)	5(10)	0(0)	77(154)
Total PCBs	100(30)	100(175)	0(0)	0(0)	0(0)	0(0)
FISH CONTAMINANTS						
Arsenic	0(0)	1(2)	10(1)	12(19)	90(9)	87(136)
PAHs	60(6)	60(93)	30(3)	7(11)	10(1)	33(51)
PCBs	90(9)	98(152)	0(0)	1(2)	10(1)	1(1)

There were no data on the occurrence or causes of fish kill events in Georgia. The Oyster Creek shellfish harvesting area located inside FOPU boundaries remains open. There are some concerns for visitor experience due to elevated bacteria levels that have historically resulted in beach closures at the Tybee Island North, Tybee Island Middle, and Tybee Island South beach sites.

Cumberland Island National Seashore

Located on a less developed barrier island, CUIS water quality is relatively pristine compared to more heavily populated areas along the Georgia coast. However, nearby point and nonpoint sources of pollution could degrade water quality. In addition to many industrial sites and municipal waste facilities (particularly urban Brunswick to the north), the submarine base at Kings Bay is a potential concern for water quality at CUIS. Elevated DIN and DIP concentrations were identified in the Satilla and St. Marys river basins, both of which contribute nutrient loads to Cumberland Sound.

Numerous animal feed lots are a possible source of nitrogen and phosphorus in the Satilla River, and fertilizer from urban and agricultural sources may contribute to high nutrient loading. It appears that these nutrients do not reach the estuary at CUIS, but the high number of animals and fertilizers used in the area a concern. The largest water quality concern within the park appears to be low dissolved oxygen at sites in Cumberland Sound. The large feral horse population is a potential source of organic material to the water resources of the island, particularly in the inland ponds, tidal creeks, and marshes (Alber et al., 2005).

A higher percentage of sites that ranked "good" inside the park versus the surrounding areas for DIN, DIP, and chlorophyll (Table 19). However, DO levels were lower inside CUIS; 40% of the sites ranked "good" and 60% that ranked "fair" compared to 60% of sites that ranked "good" and 40% that ranked "fair" outside park boundaries. While long-term trends in DO were overall "good" between 2001−2009, decreasing DO concentrations during the summer months suggest a significant influence of organic material from the feral horses.

The percentage of sites ranked "good" for sediment contaminants was similar to or slightly higher inside the park compared to sites surrounding the park (Table 19). There are a number of Superfund sites located in Brunswick 16 miles from CUIS in Glynn County, as well as other industrial sites in the continuously developing region, that could adversely affect sediment and fish tissue quality in CUIS.

Of concern is a greater number of sites that ranked "poor" for TOC and PAHs inside the park. Only 61% of sites inside CUIS ranked "good" for TOC versus 73% of sites that ranked "good" outside the park. A little more than half of the sites inside and outside the park ranked "good" for PAHs.

There were no data on the occurrence or causes of fish kill events in Georgia. The Abraham Point, Mumford Creek, and South Brickhill shellfish harvesting areas on the western side of CUIS remain open. There are some concerns for visitor experience due to elevated bacteria levels that have historically resulted in beach closures at the Amelia Island Beach Club site near CUIS.

Table 19. Comparison of water quality inside and outside of Cumberland Island National Seashore. Data are the percentage of sites rated "good," "fair," or "poor" (U.S. EPA, 2008). Outside = sampling sites within 20 miles of park boundary. The number of sampling sites is in parentheses. '---' indicates no sampling sites. DDE=Dichlorodiphenyldichloroethylene, DDT=dichlorodiphenyltrichloroethane, DIN = dissolved inorganic nitrogen, DIP = dissolved inorganic phosphorus, PAH=polycyclic aromatic hydrocarbon, PCB=polychlorinated biphenyls, TOC=total organic carbon.

Variable	Inside Park Good (%)	Outside Park Good (%)	Inside Park Fair (%)	Outside Park Fair (%)	Inside Park Poor (%)	Outside Park Poor (%)
WATER QUALITY						
Dissolved oxygen	40(12)	60(96)	60(18)	40(64)	0(0)	0(0)
DIN	100(30)	50(74)	0(0)	31(46)	0(0)	19(28)
DIP	7(2)	2(2)	89(24)	39(50)	4(1)	59(76)
Water clarity	100(30)	100(130)	0(0)	0(0)	0(0)	0(0)
Chlorophyll a	32(11)	13(17)	68(23)	74(93)	0(0)	13(16)
SEDIMENT CONTAMINANTS						
2-Methylnaphthalene	100(28)	99(140)	0(0)	1(1)	0(0)	0(0)
4'4'-DDE	100(11)	100(39)	0(0)	0(0)	0(0)	0(0)
Acenaphthene	100(28)	100(145)	0(0)	0(0)	0(0)	0(0)
Acenaphthylene	100(28)	100(145)	0(0)	0(0)	0(0)	0(0)
Anthracene	100(28)	100(145)	0(0)	0(0)	0(0)	0(0)
Arsenic	96(26)	88(127)	4(1)	12(17)	0(0)	0(0)
Copper	100(26)	100(149)	0(0)	0(0)	0(0)	0(0)
Flourene	100(28)	99(145)	0(0)	1(1)	0(0)	0(0)
Flouranthene	100(28)	100(146)	0(0)	0(0)	0(0)	0(0)
Mercury	100(27)	99(148)	0(0)	1(1)	0(0)	0(0)
Naphthalene	100(28)	100(145)	0(0)	0(0)	0(0)	0(0)
Phenanthrene	100(24)	99(126)	0(0)	1(1)	0(0)	0(0)
Total DDT	100(11)	98(101)	0(0)	2(2)	0(0)	0(0)
TOC	61(17)	72(108)	0(0)	2(3)	39(11)	26(38)
Total PCBs	100(11)	98(99)	0(0)	2(2)	0(0)	0(0)
FISH CONTAMINANTS						
Arsenic	0(0)	1(1)	3(1)	13(17)	97(36)	86(117)
PAHs	54(20)	57(77)	3(1)	4(5)	43(16)	39(52)
PCBs	86(32)	84(112)	14(5)	14(18)	0(0)	2(3)

Timucuan Ecological and Historic Preserve

Because it is near the major metropolitan area of Jacksonville and industrial sites, TIMU is susceptible to degraded water quality. In addition to Superfund sites and landfills, nonpoint sources of pollution from agricultural and urban runoff are potential concerns. There are low dissolved oxygen concentrations in the Nassau River and lower St. Johns River, including sites sampled by the COJ in the park boundaries. High DIP concentrations were found within park boundaries, as well as in the Nassau River and St. Johns River near Jacksonville. Sediment samples had elevated mercury and PCBs in the St. Johns River near Jacksonville. Spanish Pond has elevated metal concentrations and oils, probably derived from automobile traffic on the road nearby. The tidal creeks at TIMU are not well flushed with long pollutant residence times that prevent dilution and flushing.

Inside the park, there was a greater percentage of sites with low DO levels and "fair" water clarity compared to sites around the park (Table 20). However, long-term trends show that DO concentrations have improved since 1999. TIMU has many tidal creeks that experience naturally low DO values during the summer (DiDonato et al., 2005), so these results are of only moderate concern.

The percentage of sites ranked "good" for sediment contaminants was similar to or slightly higher inside the park compared to sites surrounding TIMU (Table 20). The only sediment contaminant that had fewer than 100% of sites that ranked "good" was arsenic. Inside and outside the park, 91% of sites that ranked "good" for arsenic; the remaining sites were ranked "fair." Fish tissue contaminants were similar inside and outside the park. However, 90% of sites within the park ranked "poor" for arsenic compared to 85% that ranked "poor" outside the park. The high levels of arsenic are likely a result of increased development in several areas surrounding the park (Anderson et al., 2005).

The degraded water quality around TIMU is also reflected in the prohibited shellfish harvesting areas surrounding Talbot Island and Little Talbot Island[2]. Multiple red tide events resulted in large fish kill events at Amelia Island, Huegenot Park, and Little Talbot Island State Park. Between 2006−2009, the beaches at Huegenot Park, Little Talbot Island, and Talbot Island remained open year-round.

Canaveral National Seashore

The water bodies connected to Mosquito Lagoon and Indian River Lagoon in CANA are susceptible to high nutrient loading due to agricultural and urban nonpoint source pollution. This has resulted in low dissolved oxygen concentrations in the lagoons, as well as high DIN and DIP concentrations in the Indian River Lagoon (North and South). Phosphorus is probably derived from septic leachate and residential fertilizer. Mosquito Lagoon is P limited and increases in P may encourage biotic production further affecting water clarity and dissolved oxygen levels.

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[2]Shellfish closures are enforced because recent data are lacking as opposed to current data that indicate that the closures should be maintained. The State will not lift the ban without an existing monitoring program that shows the shellfish are safe. However, no one is collecting data to check if conditions have changed (Joe DeVivo, SECN, personal communication, December 2011).

Table 20. Comparison of water quality inside and outside of Timucuan Ecological and Historic Preserve. Data are the percentage of sites rated "good," "fair," or "poor" (U.S. EPA, 2008). Outside = sampling sites within 20 miles of park boundary. The number of sampling sites is in parentheses. '---' indicates no sampling sites. DDE=Dichlorodiphenyldichloroethylene, DDT=dichlorodiphenyltrichloroethane, DIN = dissolved inorganic nitrogen, DIP = dissolved inorganic phosphorus, PAH=polycyclic aromatic hydrocarbon, PCB=polychlorinated biphenyls, TOC=total organic carbon.

Variable	Inside Park Good (%)	Outside Park Good (%)	Inside Park Fair (%)	Outside Park Fair (%)	Inside Park Poor (%)	Outside Park Poor (%)
WATER QUALITY						
Dissolved oxygen	69(22)	100(1)	31(10)	0(0)	0(0)	0(0)
DIN	---	89(8)	---	0(0)	---	11(1)
DIP	---	0(0)	---	22.2	---	77.8
Water clarity	97(29)	100(144)	3(1)	0(0)	0(0)	0(0)
Chlorophyll a	3(1)	20(24)	90(27)	75(106)	7(2)	5(10)
SEDIMENT CONTAMINANTS						
2-Methylnaphthalene	100(23)	95(80)	0(0)	5(4)	0(0)	0(0)
4'4'-DDE	100(23)	100(91)	0(0)	0(0)	0(0)	0(0)
Acenaphthene	100(27)	100(91)	0(0)	0(0)	0(0)	0(0)
Acenaphthylene	100(27)	100(90)	0(0)	0(0)	0(0)	0(0)
Anthracene	100(27)	100(90)	0(0)	0(0)	0(0)	0(0)
Arsenic	91(20)	91(84)	9(2)	9(8)	0(0)	0(0)
Copper	100(27)	98(84)	0(0)	2(2)	0(0)	0(0)
Flourene	100(27)	100(94)	0(0)	0(0)	0(0)	0(0)
Flouranthene	100(27)	100(93)	0(0)	0(0)	0(0)	0(0)
Mercury	100(27)	96(89)	0(0)	4(4)	0(0)	0(0)
Naphthalene	100(27)	100(86)	0(0)	0(0)	0(0)	0(0)
Phenanthrene	100(27)	100(75)	0(0)	0(0)	0(0)	0(0)
Total DDT	100(27)	100(76)	0(0)	0(0)	0(0)	0(0)
TOC	63(17)	91(80)	0(0)	2(2)	37(10)	7(6)
Total PCBs	100(2)	97(78)	0(0)	0(0)	0(0)	3(2)
FISH CONTAMINANTS						
Arsenic	0(0)	4(2)	10(1)	15(8)	90(9)	81(44)
PAHs	60(6)	56(30)	0(0)	4(2)	40(4)	40(22)
PCBs	90(9)	85(46)	0(0)	11(6)	10(1)	4(2)

Coastal waters in more populated areas to the north, such as New Smyrna, have high turbidity and TSS. Mosquito Lagoon has limited water circulation and tidal exchange with the Atlantic Ocean due to its long, narrow, and shallow (1 m) morphology. Consequently, aeolian processes are the primary mechanisms for water mixing and movement in the lagoon (Hall et al., 2001). As a result of its sluggish circulation, Mosquito Lagoon experiences long pollutant residence times and reduced pollutant flushing. This may partly explain why TSS concentrations increased significantly between 2000−2008.

Water quality inside the park is much better than outside the park as indicated by a higher percentage of sites ranked "good" for DO, water clarity, and chlorophyll a (Table 21). Inside parks 67% of sites were ranked "good" for water clarity, 15% ranked "fair," and 18% ranked "poor" compared to 58% of sites outside the park that ranked "good" and 42% that ranked "poor." Median concentrations of DO, nitrate/nitrite, and phosphorus between 2000−2008 ranked "good," indicating better water quality conditions inside CANA relative to surrounding areas. While water clarity is better inside CANA than outside, the percentage of "good" sites is relatively low. There is little evidence of sediment contamination inside or outside parks, although there is some evidence of fish tissue contamination outside the park.

Based on shellfish classifications, Mosquito Lagoon has fewer issues with elevated bacteria levels than Indian River Lagoon. Shellfish harvesting in Mosquito Lagoon north to New Smyrna is classified as "Approved" while the areas in the Indian River Lagoon are mostly "Restricted." There have been numerous fish kill events related to low levels of dissolved oxygen and algal blooms near CANA, including events in Mosquito Lagoon near Oak Hill, Banana River adjacent to Merritt Island, and in the Indian River Lagoon near Titusville. The Playalinda Beach inside CANA was not closed due to elevated bacteria levels between 2006−2009. However, nearby beaches, including New Smyrna Beach and Cocoa Beach, had temporary closures due to exceedance of fecal coliform standards.

Table 21. Comparison of water quality inside and outside of Canaveral National Seashore. Data are the percentage of sites rated "good," "fair," or "poor" (U.S. EPA, 2008). Outside = sampling sites within 20 miles of park boundary. The number of sampling sites is in parentheses. '---' indicates no sampling sites. DDE=Dichlorodiphenyldichloroethylene, DDT=dichlorodiphenyltrichloroethane, DIN = dissolved inorganic nitrogen, DIP = dissolved inorganic phosphorus, PAH=polycyclic aromatic hydrocarbon, PCB=polychlorinated biphenyls, TOC=total organic carbon.

Variable	Inside Park Good (%)	Outside Park Good (%)	Inside Park Fair (%)	Outside Park Fair (%)	Inside Park Poor (%)	Outside Park Poor (%)
WATER QUALITY						
Dissolved oxygen	97(30)	53(53)	3(1)	44(44)	0(0)	3(3)
DIN	---	5(2)	---	3(1)	---	92(37)
DIP	---	10(4)	---	3(1)	---	87(34)
Water Clarity	67(23)	58(36)	15(5)	0(0)	18(6)	42(26)
Chlorophyll a	47(16)	36(21)	53(18)	53(31)	0(0)	11(6)
SEDIMENT CONTAMINANTS						
2-Methylnaphthalene	100(23)	100(4)	0(0)	0(0)	0(0)	0(0)
4'4'-DDE	100(23)	100(4)	0(0)	0(0)	0(0)	0(0)
Acenaphthene	100(24)	100(4)	0(0)	0(0)	0(0)	0(0)
Acenaphthylene	100(24)	100(4)	0(0)	0(0)	0(0)	0(0)
Anthracene	100(24)	100(4)	0(0)	0(0)	0(0)	0(0)
Arsenic	100(24)	100(4)	0(0)	0(0)	0(0)	0(0)
Copper	100(24)	100(4)	0(0)	0(0)	0(0)	0(0)
Flourene	100(24)	100(4)	0(0)	0(0)	0(0)	0(0)
Flouranthene	100(24)	100(4)	0(0)	0(0)	0(0)	0(0)
Mercury	100(24)	100(4)	0(0)	0(0)	0(0)	0(0)
Naphthalene	100(24)	100(4)	0(0)	0(0)	0(0)	0(0)
Phenanthrene	100(24)	100(4)	0(0)	0(0)	0(0)	0(0)
Total DDT	100(24)	100(4)	0(0)	0(0)	0(0)	0(0)
TOC	----	100(4)	----	0(0)	----	0(0)
Total PCBs	100(24)	100(4)	0(0)	0(0)	0(0)	0(0)
FISH CONTAMINANTS						
Arsenic	---	14(1)	---	43(3)	---	43(4)
PAHs	---	75(6)	---	0(0)	---	25(2)
PCBs	---	100(8)	---	0(0)	---	0(0)

Regional Water Quality Trends

The southeast coastal region is subject to water pollution from point and nonpoint sources. Bricker et al. (2007) noted that 13 of the 15 major estuaries in the region have high or moderate nitrogen loading. Nonpoint sources from agricultural activities (animal feedlots, crops, etc.), wastewater treatment, atmospheric deposition, and urban/exurban runoff contribute to high nutrient loads (nitrogen and phosphorus). Animal operations increase the susceptibility of the estuaries to eutrophication and harmful algal blooms, especially in North and South Carolina. Compounding potential water quality problems is the restricted tidal exchange and low dilution capacity of some estuaries. Limited tidal flushing was documented by DiDonato et al. (2005) at TIMU, indicating that even though water quality within park boundaries is better than in the surrounding area, the potential for degraded water quality exists within park boundaries due to nonpoint sources of nutrients from upstream drainage areas.

Despite potentially high nutrient loading of estuaries, the overall trophic state in the region remains mostly moderate and low (Bricker et al., 2007). They found that elevated chlorophyll a was the most common sign of eutrophication, especially in the Neuse and St. Johns rivers. This project found similarly high levels of chlorophyll a in these rivers, but also in most other areas in the region. Based on the EPA ranking system (U.S. EPA, 2008), every park in this project contained sites with "fair" rankings for chlorophyll a (>5 µg/L). As a further measure of trophic status, this project found low DO concentrations in the Georgia coastal parks (CUIS and FOPU) and surrounding region (Savannah and Ogeechee Rivers). The DIN and DIP concentrations were rated "poor" throughout many of the Georgia estuaries (St. Marys River, Cumberland Sound, St. Andrews Sound, Satilla River, Savannah River, Brunswick River), as well as in Florida in the Indian River Lagoon and north St. Johns River area near Jacksonville and TIMU.

Based on 2004 survey results from the Bricker et al. (2007), water quality experts and managers expected the southeast coastal eutrophic condition to worsen in the future due primarily to an expected increase in nutrient loads and development associated with population growth in the region. The exception was the St. Johns River where respondents expected to see improved water quality due to the development of new total maximum daily loads. Based on findings in this project, the St. Johns River still experiences symptoms of eutrophication (high chlorophyll a expression, low DO, high DIN and DIP).

There were very few significant trends in water quality at the index sites. This finding is consistent with the National Coastal Condition Report III (U.S. EPA, 2008) that demonstrated that none of the water quality and sediment indices or components showed any significant linear trends over time in the percent of coastal area rated "poor." However, when the time periods (1994−1997 and 2000−2002) were compared, differences were observed. This project found that a significantly greater percentage of the coastal area was rated poor for sediment contaminants from 1994−1997 than from 2000−2002 ($z=2.028$; $p<0.05$), suggesting that sediment conditions have improved.

Conclusions

The transition between freshwater rivers and saltwater from the ocean creates a unique environment that supports important fisheries and wildlife. Economic benefits associated with these ecosystems have caused an increase in human population and land-use development in coastal areas. In response to the increasing human development, coastal ambient water and sediment quality has declined from natural conditions, presenting the need for effective management from natural resource managers. Understanding the water quality conditions of the regions is critical for future management decisions.

This report is the first attempt to synthesize existing water quality and other data to present a regional "snapshot" of coastal conditions inside and outside national parks across the southeast Atlantic coast of the United States. The results allow park managers to identify potential sources of contamination of park waters, which may be effective areas to focus their efforts to protect park water quality.

Data were collected from federal, state, and local agencies and used to develop a water quality database for the southeast coastal region. Using water quality assessment criteria developed in EPA's National Coastal Condition Report III (U.S. EPA, 2008), water quality condition, sediment contamination, and fish tissue contamination were rated as "good," "fair," or "poor" at sampling sites within 20 miles of parks throughout the southeast coastal region. The data were used to compare conditions inside parks to conditions outside park boundaries.

While many datasets were available, difficulties were encountered trying to synthesize information due to different sampling designs and time scales. Despite these limitations, several important findings were highlighted that place parks in the context of regional water quality conditions across the southeast coast.

Point and nonpoint sources of water pollution have resulted in elevated chlorophyll a, especially in the Neuse and St. Johns rivers raising concerns about eutrophication and harmful algal blooms. Low DO concentrations occur in the Georgia coastal parks (CUIS and FOPU) and the surrounding region (Savannah and Ogeechee Rivers). High DIN and DIP concentrations occur inside and outside parks throughout the southeast coastal region. A high percentage of sites ranked "poor" in many of the Georgia estuaries (St. Marys River, Cumberland Sound, St. Andrews Sound, Satilla River, Savannah River, Brunswick River), as well as in Florida in the Indian River Lagoon and north St. Johns River area near Jacksonville and TIMU.

Little sediment contamination was evident and the majority of sites throughout the southeast coastal region ranked "good" for sediment contamination. Elevated arsenic, PAH, and PCB levels were found in fish tissue sampled inside and outside park boundaries. Few sites ranked "good" for arsenic and <70% of sites ranked "good" for PAHs.

Generally, water, sediment, and fish tissue quality were higher inside the parks compared to areas surrounding parks. However, the influence of pollution sources outside park boundaries was evident inside parks. While CAHA and CALO remain relatively pristine, FOPU, CUIS, and TIMU had low dissolved oxygen, high DIP, and metal contamination in sediment and fish tissue. A high percentage of sites ranked "fair" or "poor" for several water quality parameters inside

FOPU. More data are needed for CAHA and CANA to gain a better understanding of how water quality in these parks compares to surrounding areas. Continued monitoring will help to develop a better understanding of water quality inside and outside the southeast costal parks and help resource managers in making important management decisions.

An important management concern for the southeast coastal region is increasing nutrient loads to estuaries. As evidenced by periodic eutrophic conditions, nonpoint sources represent the largest threat to overall water quality. Unfortunately, management of nonpoint sources of pollution is more difficult than regulating point source discharges, but regional cooperation with organizations in the upper portion of the watersheds could reduce nutrient loading to the estuaries and park waters.

The U.S. EPA STORET database provides easy access to a large amount of water quality data from many sources. However, significant gaps exist and prevent a more robust analysis of water quality throughout the southeast coastal region. While there are many sampling sites in the region, some of the sites do not have enough data (limited sampling frequency) to be included in the analyses.

There were differences in sampling frequency and temporal collection of samples among surveys inside and outside of park boundaries. And the lack of sites with continuous sampling prevents a thorough analysis of long-term trends. With increasing coastal development and nutrient loading expected in the future, additional "index" sites in the region would be helpful for tracking trends. Additional "index" sites are needed to determine if water quality has changed in the region. Many areas do not have regular monitoring and some agencies, such as the NC-DENR, are reducing spatial coverage of their water quality sampling stations.

The probabilistic surveys conducted by the EPA and SECN provide excellent spatial coverage for a regional snapshot of water quality at a particular point in time. This sampling design allows broad conclusions about the region, but the protocol does not measure seasonal variations or micro-scale processes that contribute to water quality. This report combined the probabilistic sampling with fixed site station data, but caution is warranted when comparing results because the objectives of the sampling designs are different. Increased probabilistic surveys and continuous monitoring at fixed stations in the southeast coastal region would better inform management decisions. And more consistent sampling protocols for all parameters would improve the ability to compare water quality across organizations.

There were very few significant trends in water quality at the index sites from 1999−2009. This is consistent with the National Coastal Condition Report III (U.S. EPA, 2008) that demonstrated that none of the water quality and sediment indices or components showed significant linear trends over time in the percent of coastal area rated "poor." However, when the time periods (1994−1997 and 2000−2002) were compared, some differences were observed. This project found that a significantly greater percentage of the coastal area was rated poor for sediment contaminants from 1994−1997 than from 2000−2002, suggesting that sediment conditions have improved.

The most pressing concerns are related to the increasing human population along the southeast coast and the associated development of urban and exurban areas. Urban runoff, wastewater

treatment, nonpoint source pollution, and atmospheric deposition will require continued management attention. Nutrient load estimates for many systems in the region are unknown or under studied (Bricker et al., 2007). In North Carolina, addressing nonpoint source pollution from animal operations could result in water quality improvements. Future research is needed to not only quantify the total organic/inorganic nutrient loads, but also to identify the major sources of pollutants to guide management actions.

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Appendix A: STORET Parameters

Table 22. Parameters used to query STORET to limit the number of observations that were not relevant to this project.

Characteristic Name	Activity Medium	Station Type	Date
2-Methylnaphthalene	WATER	Lake	Month = 1-12
4,4'-DDE	VERT	Stream	Day = 1-31
Acenaphthene	SED	Canal	Year = 2000 – 2010
Acenaphthylene		Reservoir	
Aluminum		Spring	
Ammonia		Fresh water wetland	
Ammonium		Salt water wetland	
Amphipod Survival		Estuary	
Anthracene		Ocean	
Arsenic			
Benz(a)anthracene			
Benzo(a)pyrene			
Cadmium			
Carbon, Total			
Chlordane			
Chlorophyll a			
Chromium			
Chrysene			
Copper			
DDT, Total			
Dibenzo(a,h)anthracene			
Dieldrin			
Depth, Secchi			
Dissolved Oxygen			
Endosulfan			
Endrin			
Fecal Coliform			
Flouranthene			
Flourene			
Heptachlor epoxide			
Hexachlorobenzene			
Inorganic Nitrogen			
Iron			
Kjeldahl Nitrogen			
Lead			
Lindane			
Mercury			
Mirex			
Naphthalene			
Nickel			
Nitrate			
Nitrite			
PAH, Total			
PCB, Total			
pH			
Phenanthrene			
Phosphate			
Pyrene			

Characteristic Name	Activity Medium	Station Type	Date
Salinity			
Selenium			
Silver			
Specific Conductivity			
Temperature			
TOC			
Toxaphene			
TSS			
Turbidity			
Zinc			

Appendix B: Water Quality Synoptic Results

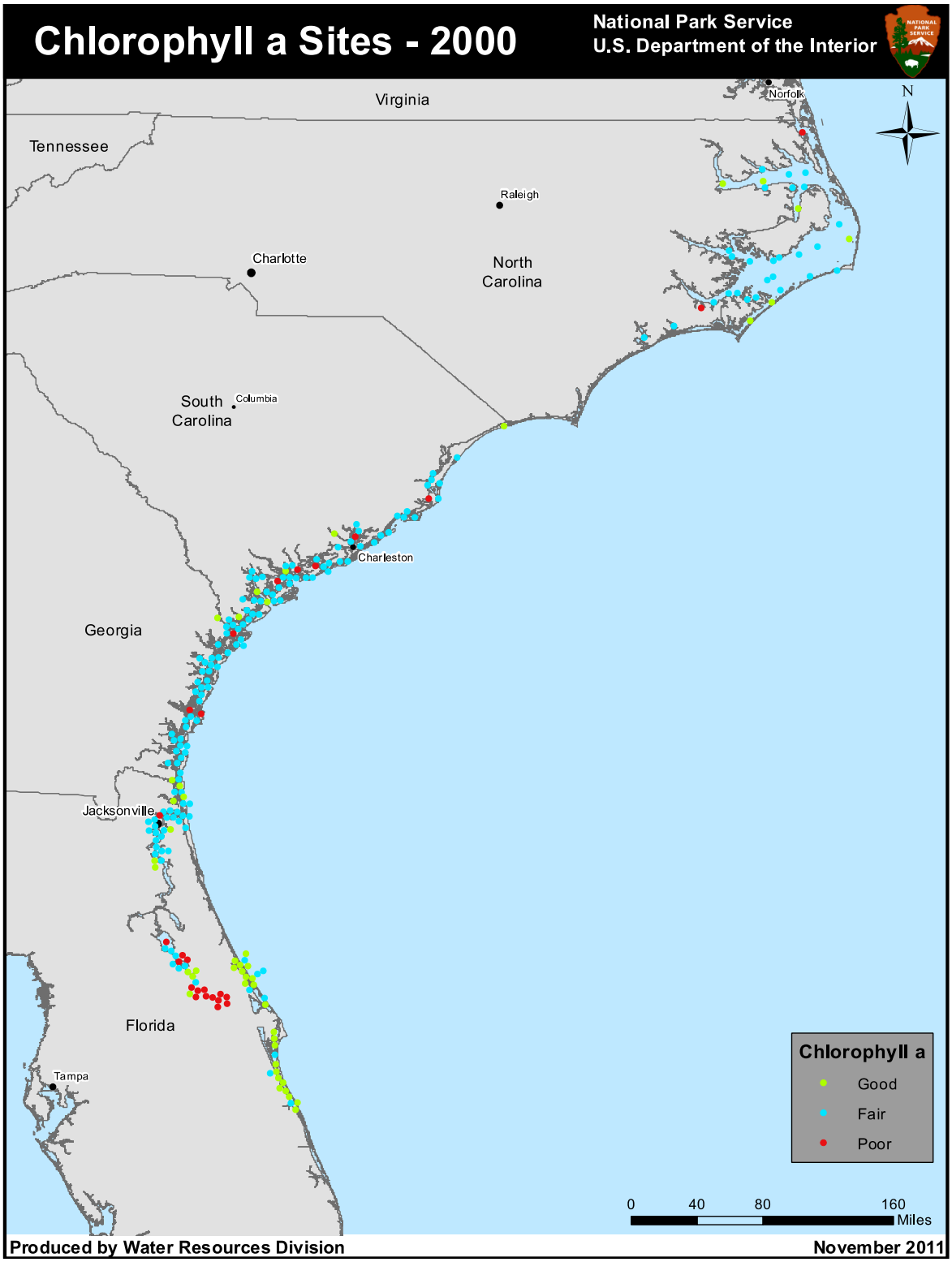


Figure 21. Synoptic sampling map of chlorophyll a for the southeast coastal region (2000). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2008).

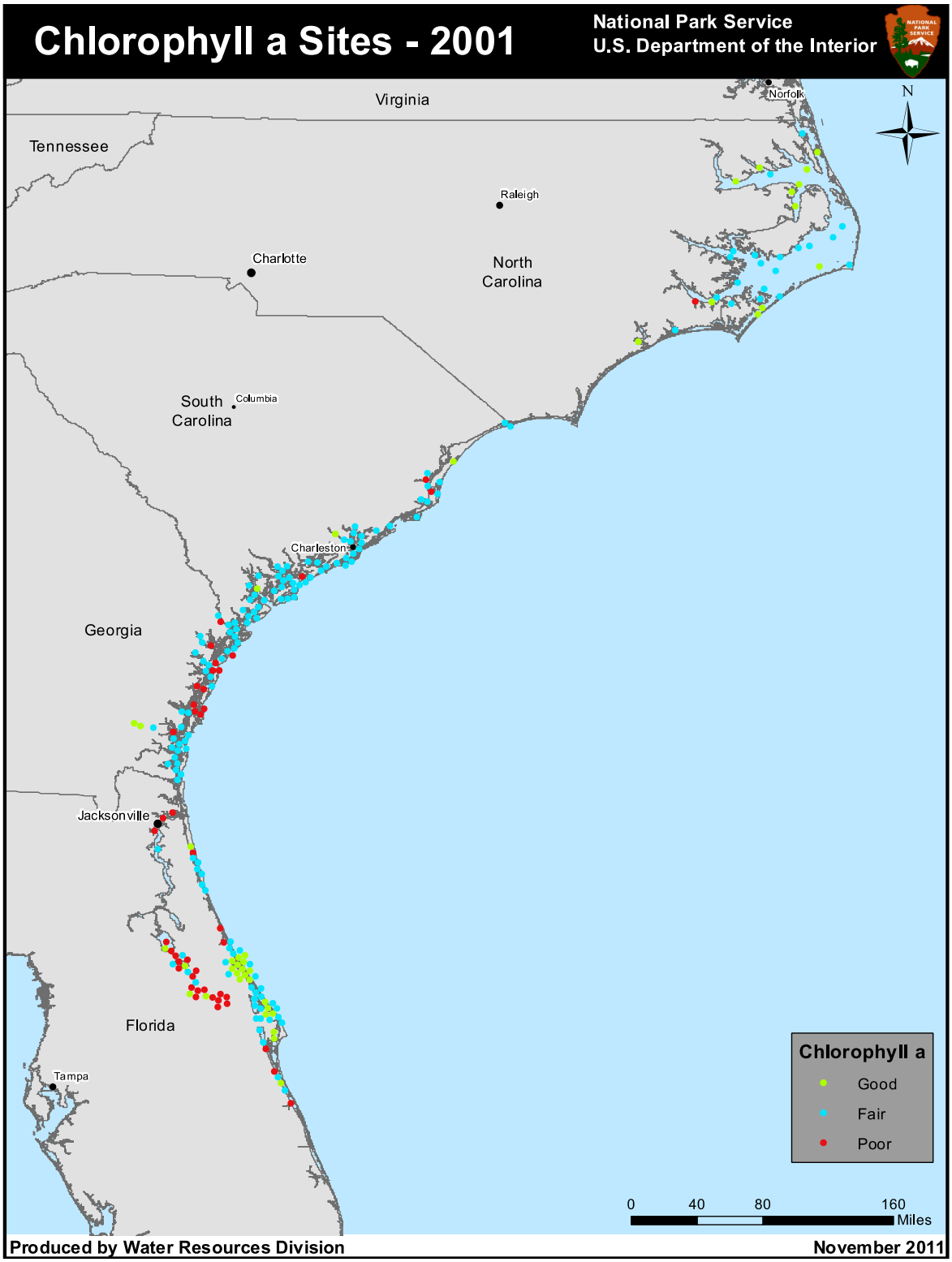


Figure 22. Synoptic sampling map of chlorophyll a for the southeast coastal region (2001). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

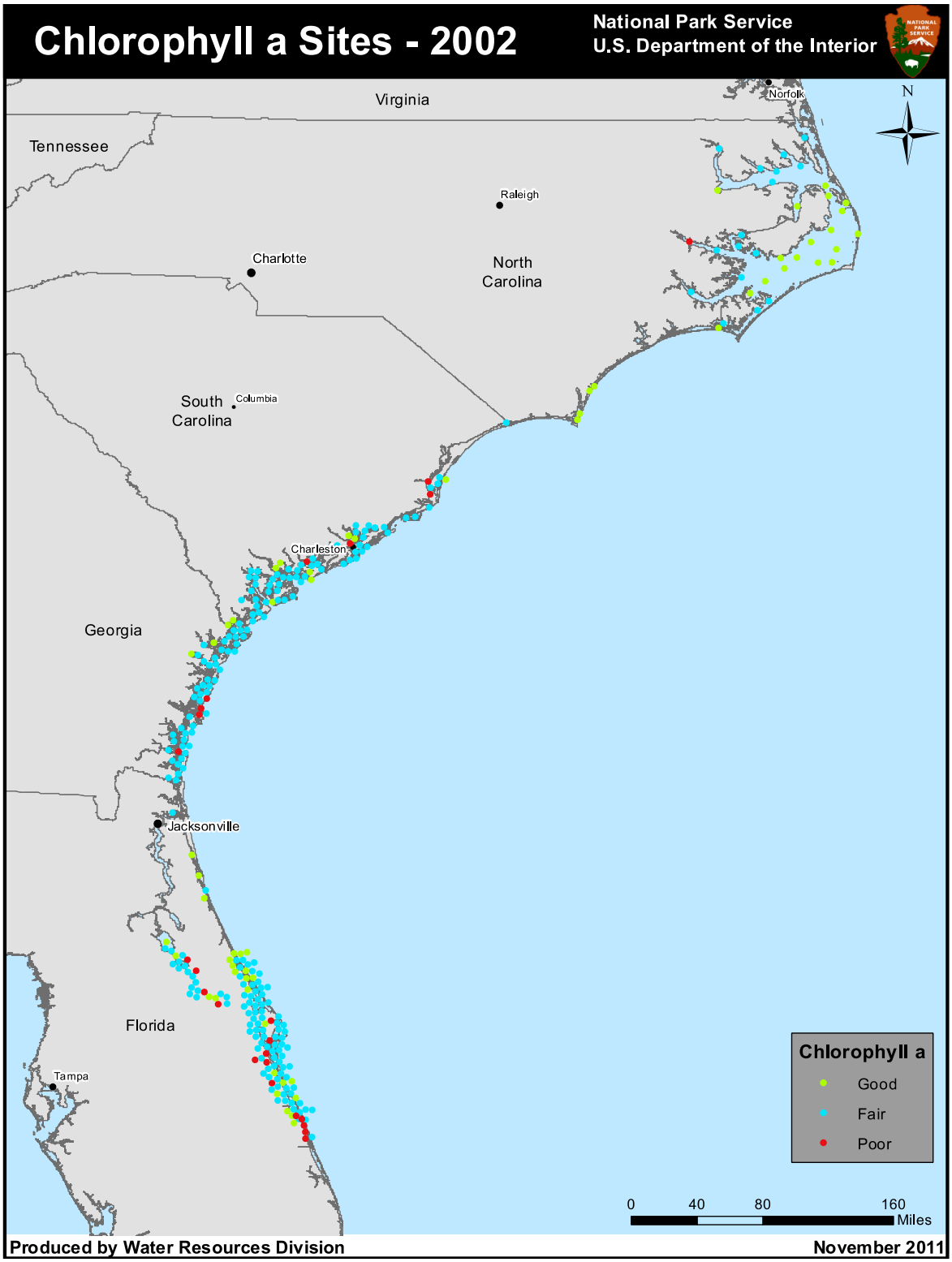


Figure 23. Synoptic sampling map of chlorophyll a for the southeast coastal region (2002). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

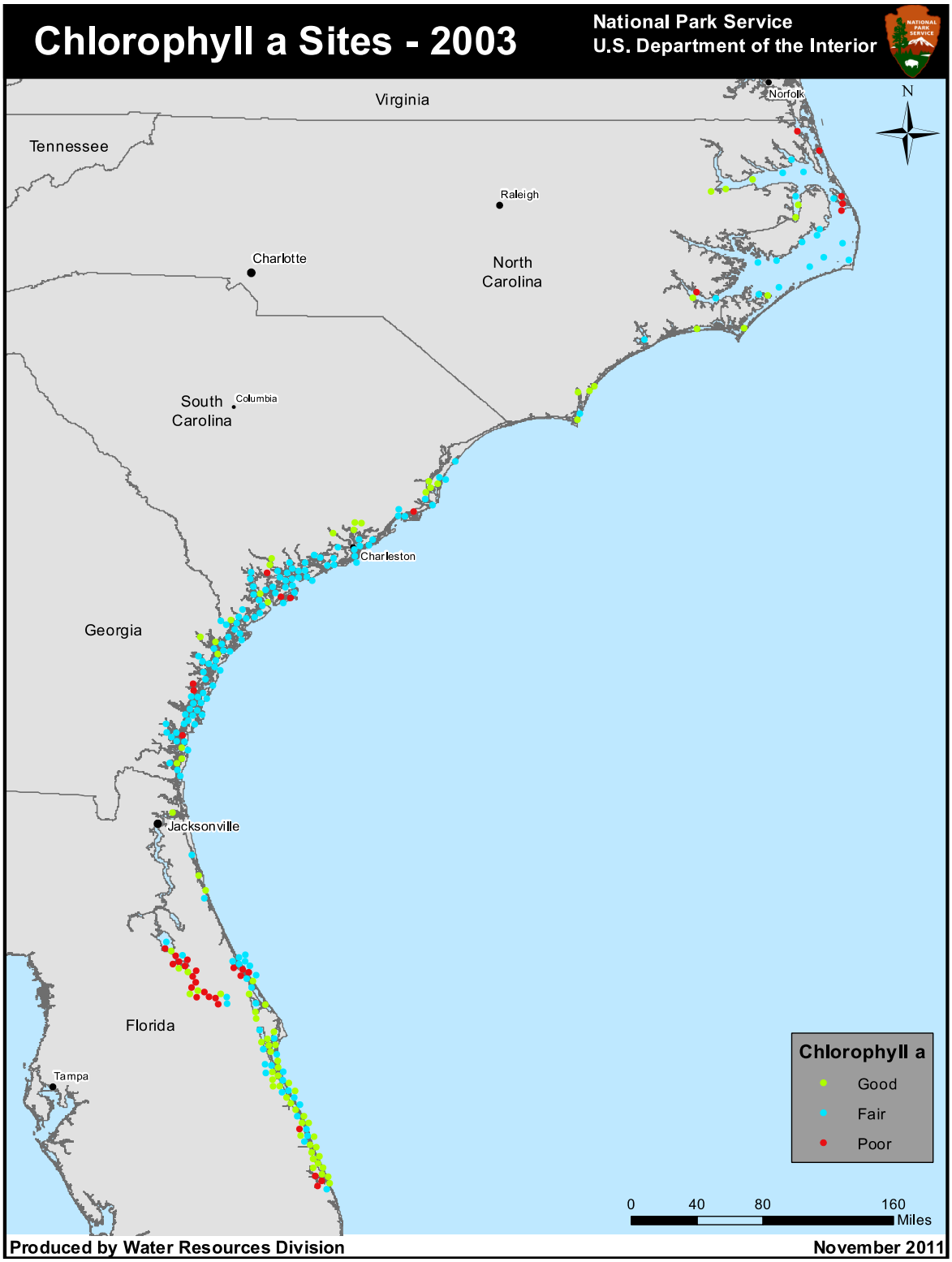


Figure 24. Synoptic sampling map of chlorophyll a for the southeast coastal region (2003). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

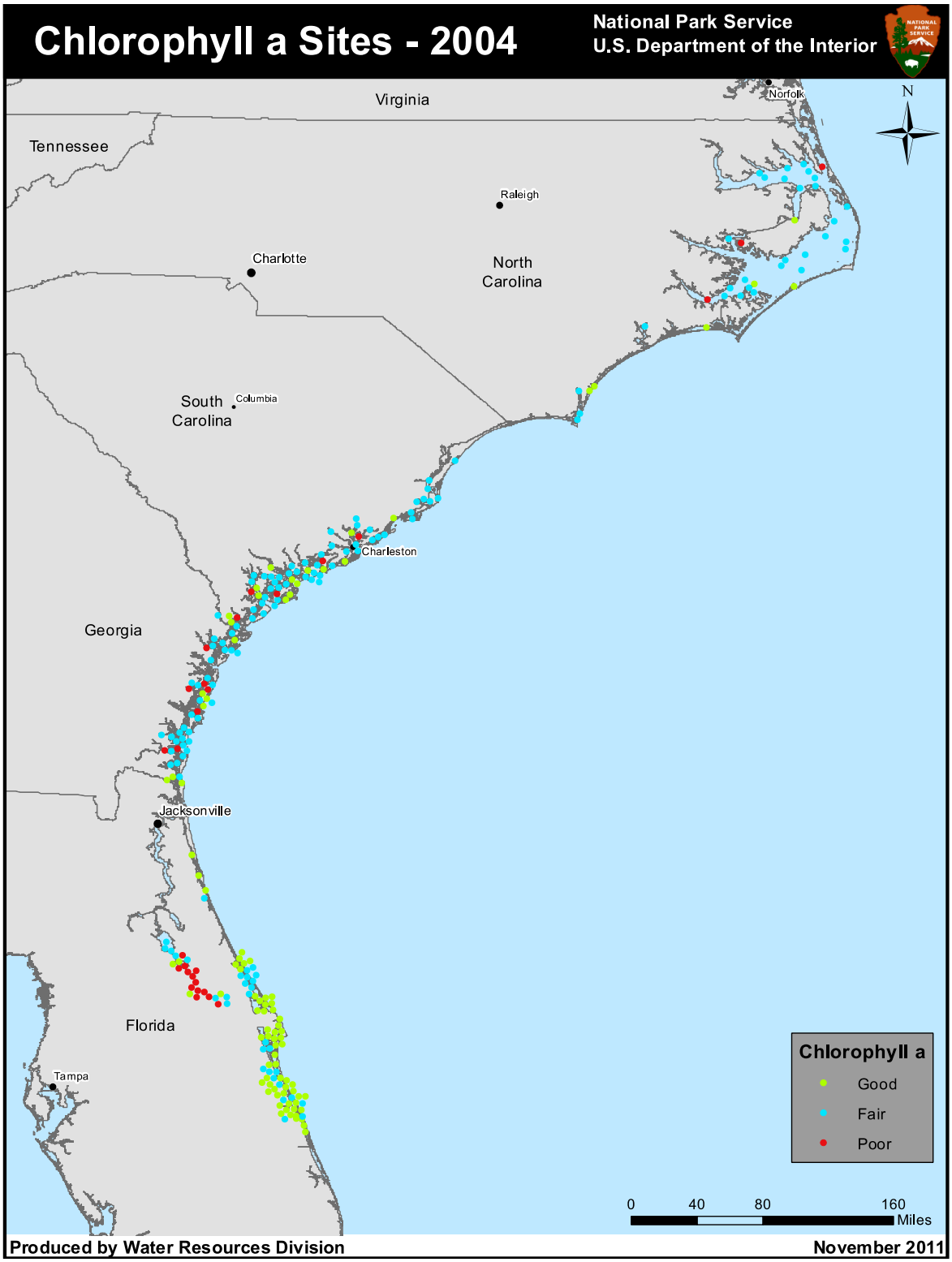


Figure 25. Synoptic sampling map of chlorophyll a for the southeast coastal region (2004). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

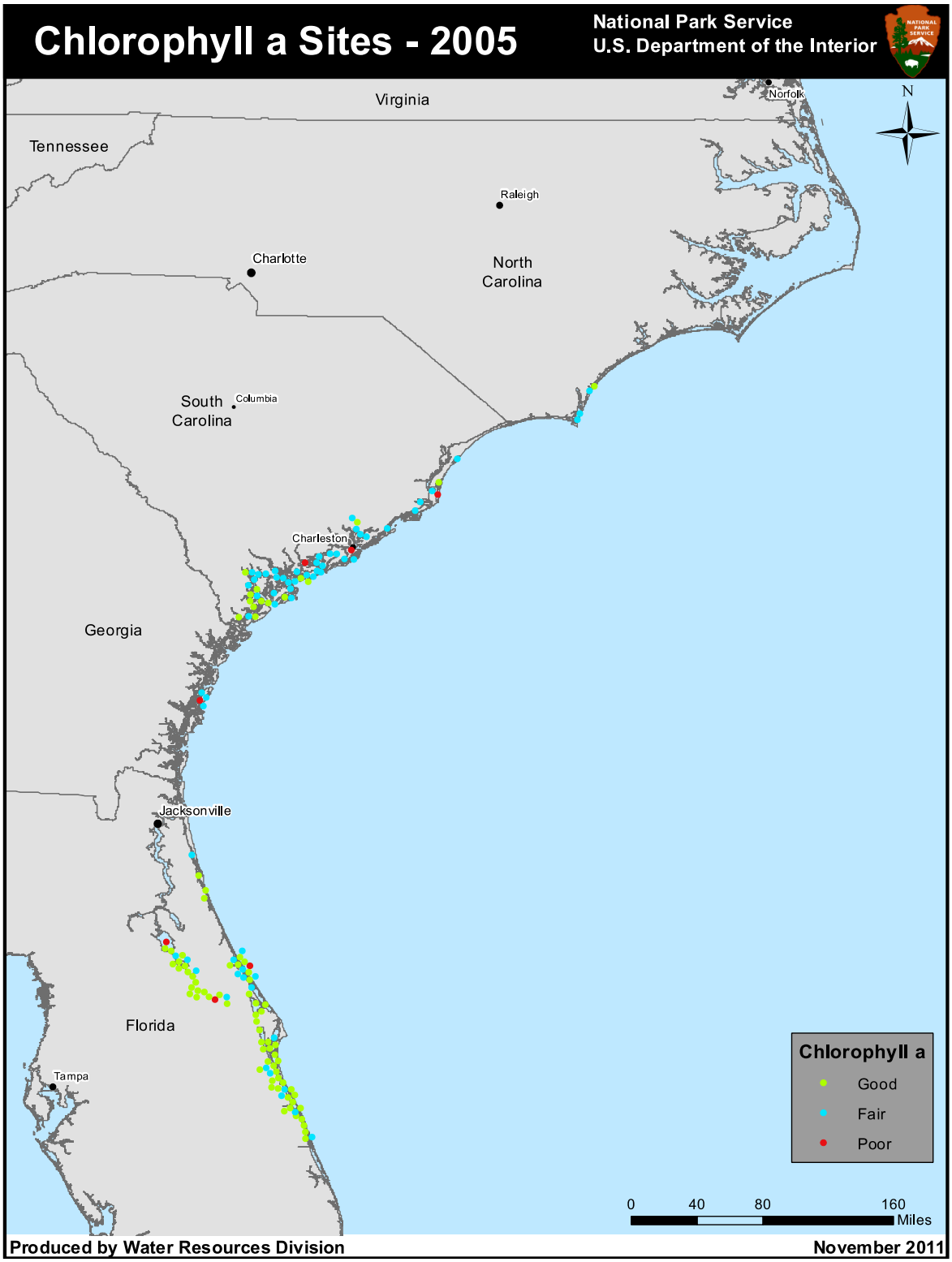


Figure 26. Synoptic sampling map of chlorophyll a for the southeast coastal region (2005). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

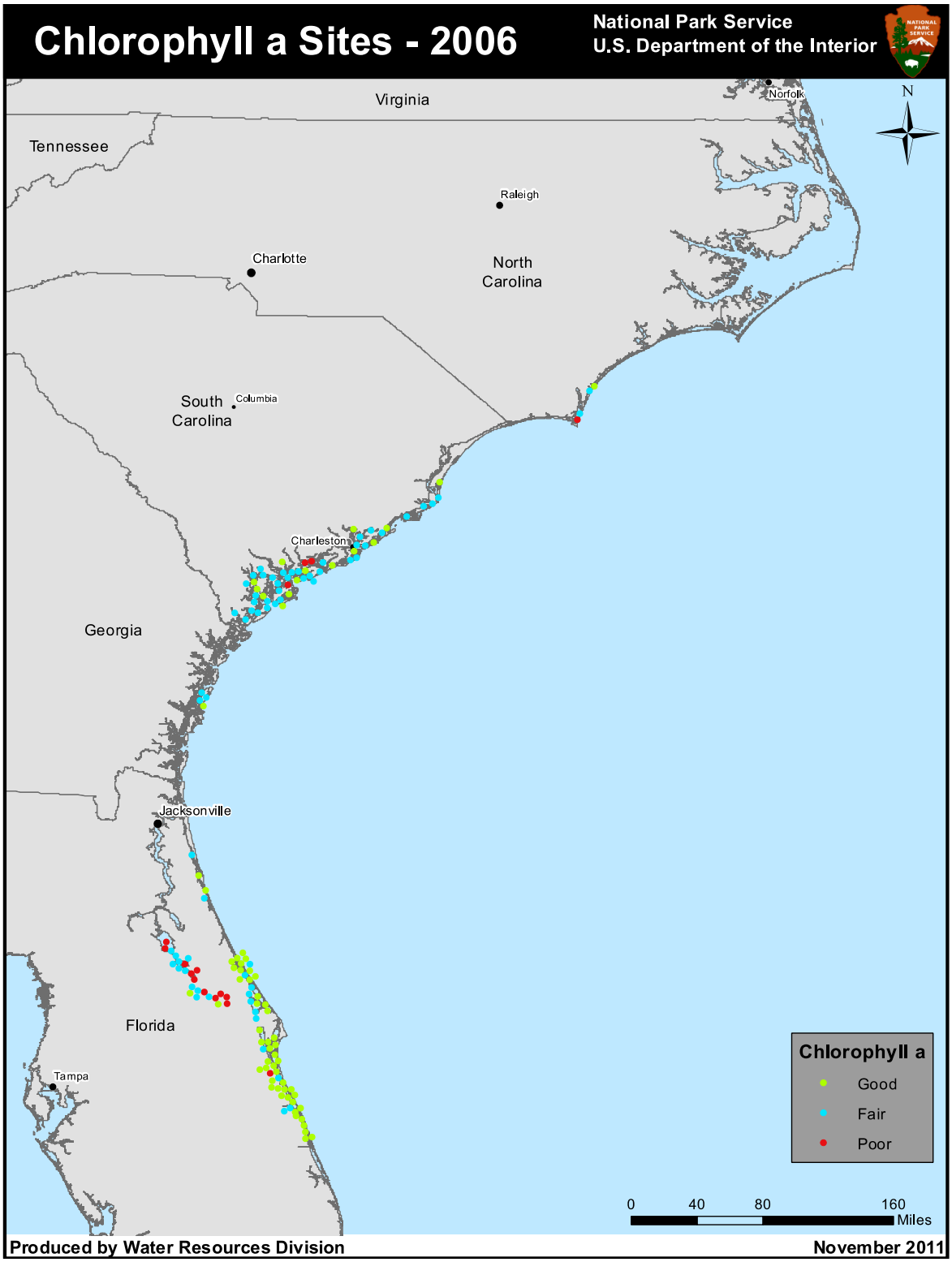


Figure 27. Synoptic sampling map of chlorophyll a for the southeast coastal region (2006). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

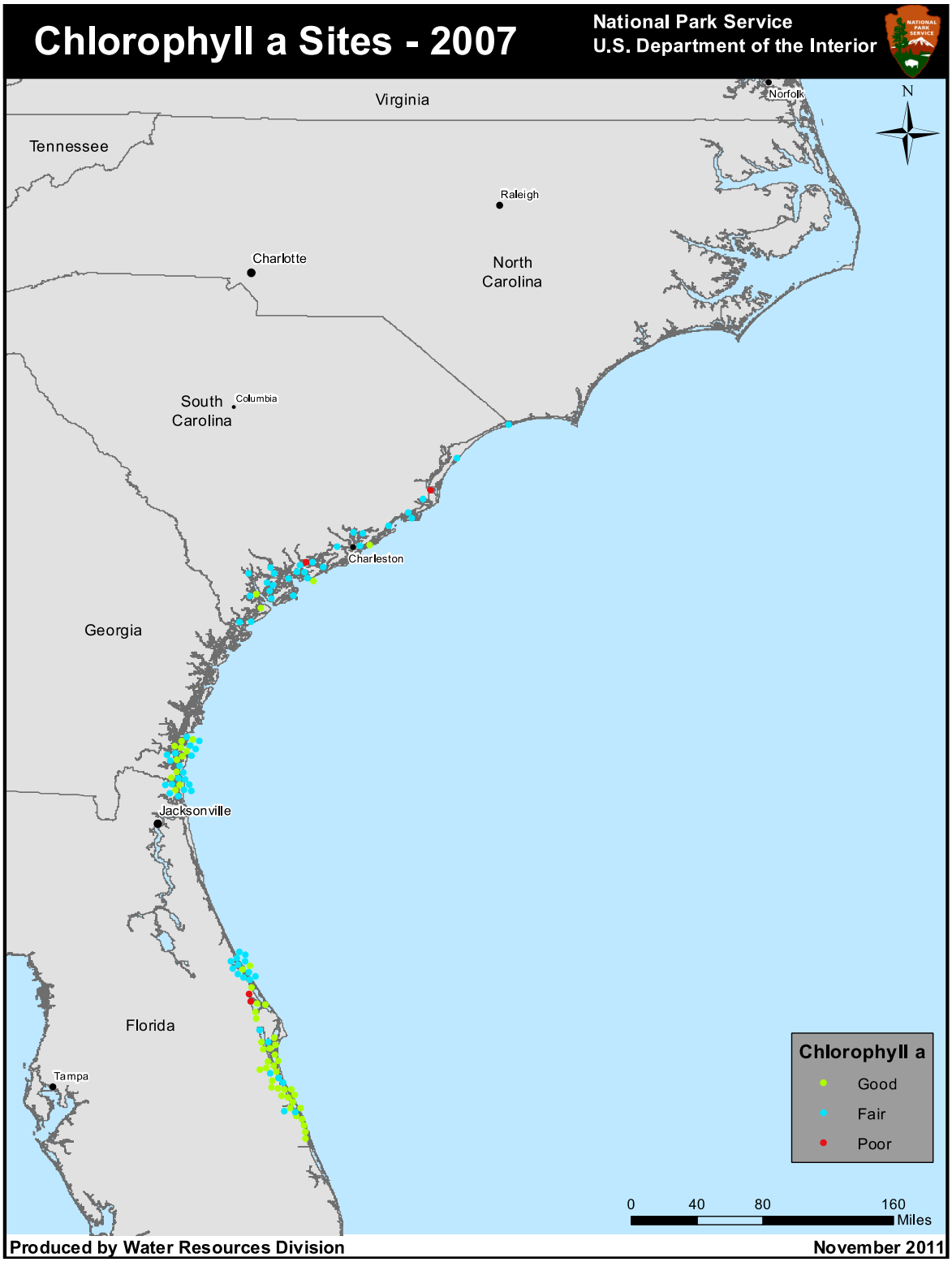


Figure 28. Synoptic sampling map of chlorophyll a for the southeast coastal region (2007). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

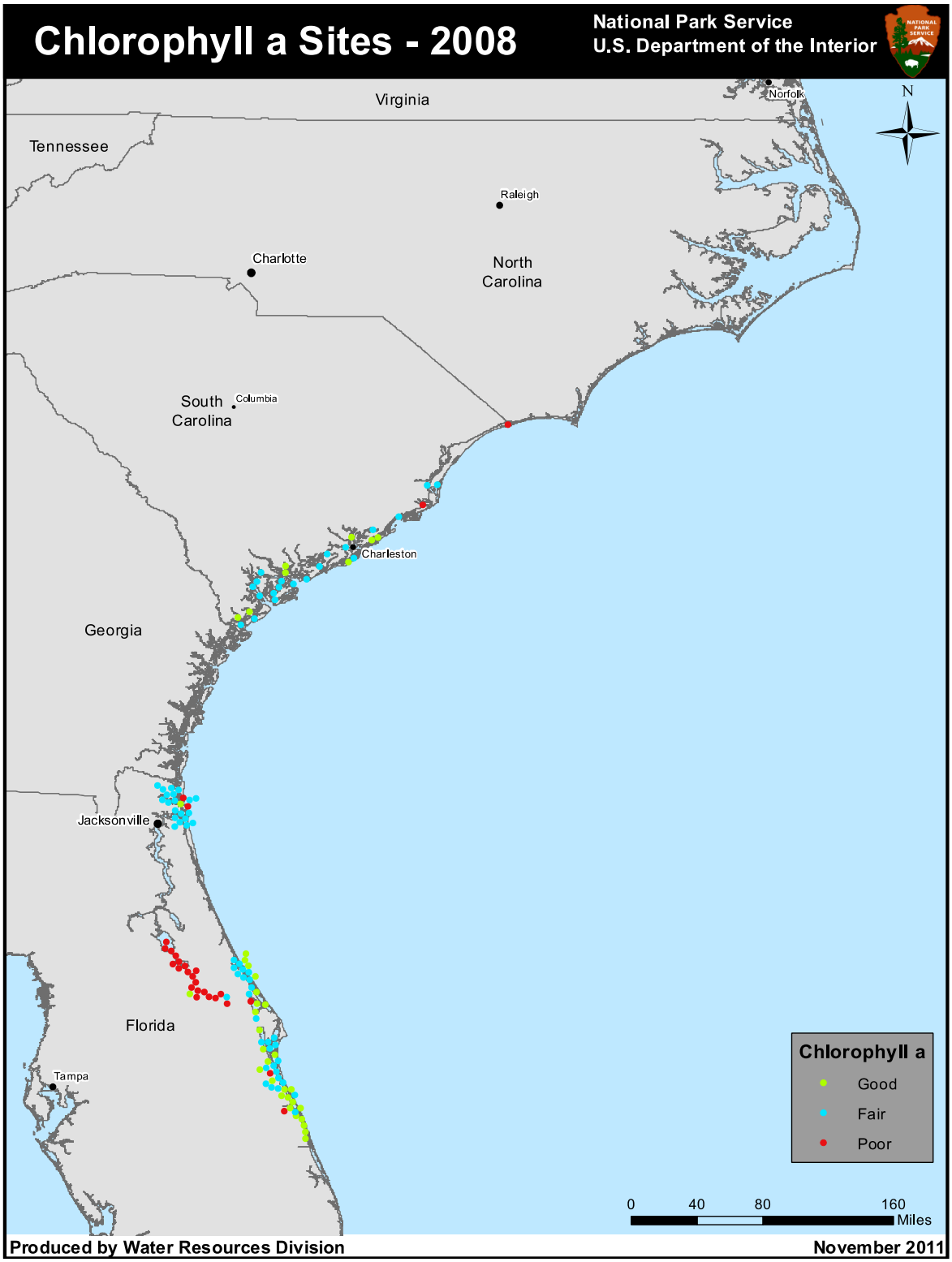


Figure 29. Synoptic sampling map of chlorophyll a for the southeast coastal region (2008). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

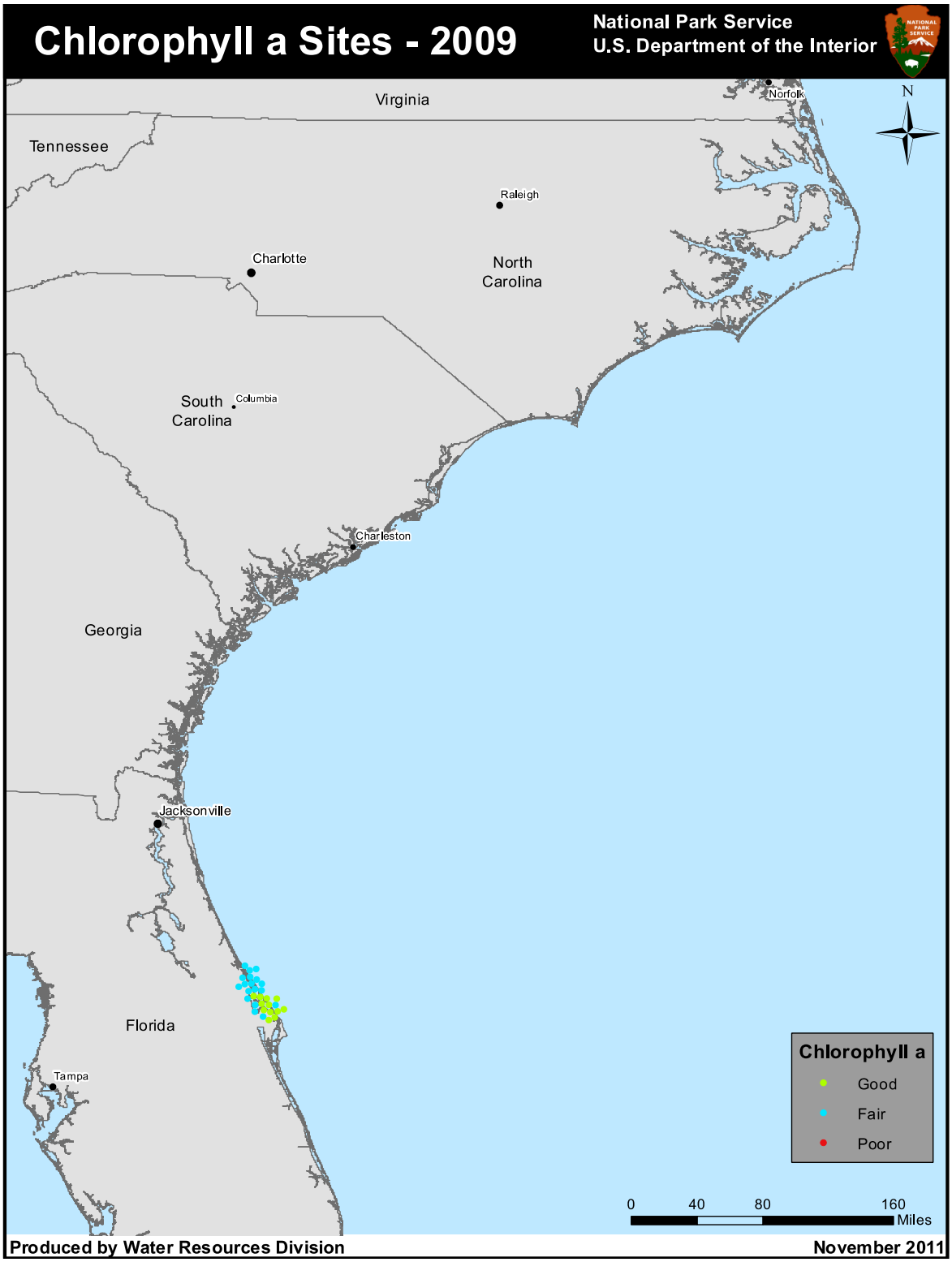


Figure 30. Synoptic sampling map of chlorophyll a for the southeast coastal region (2009). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

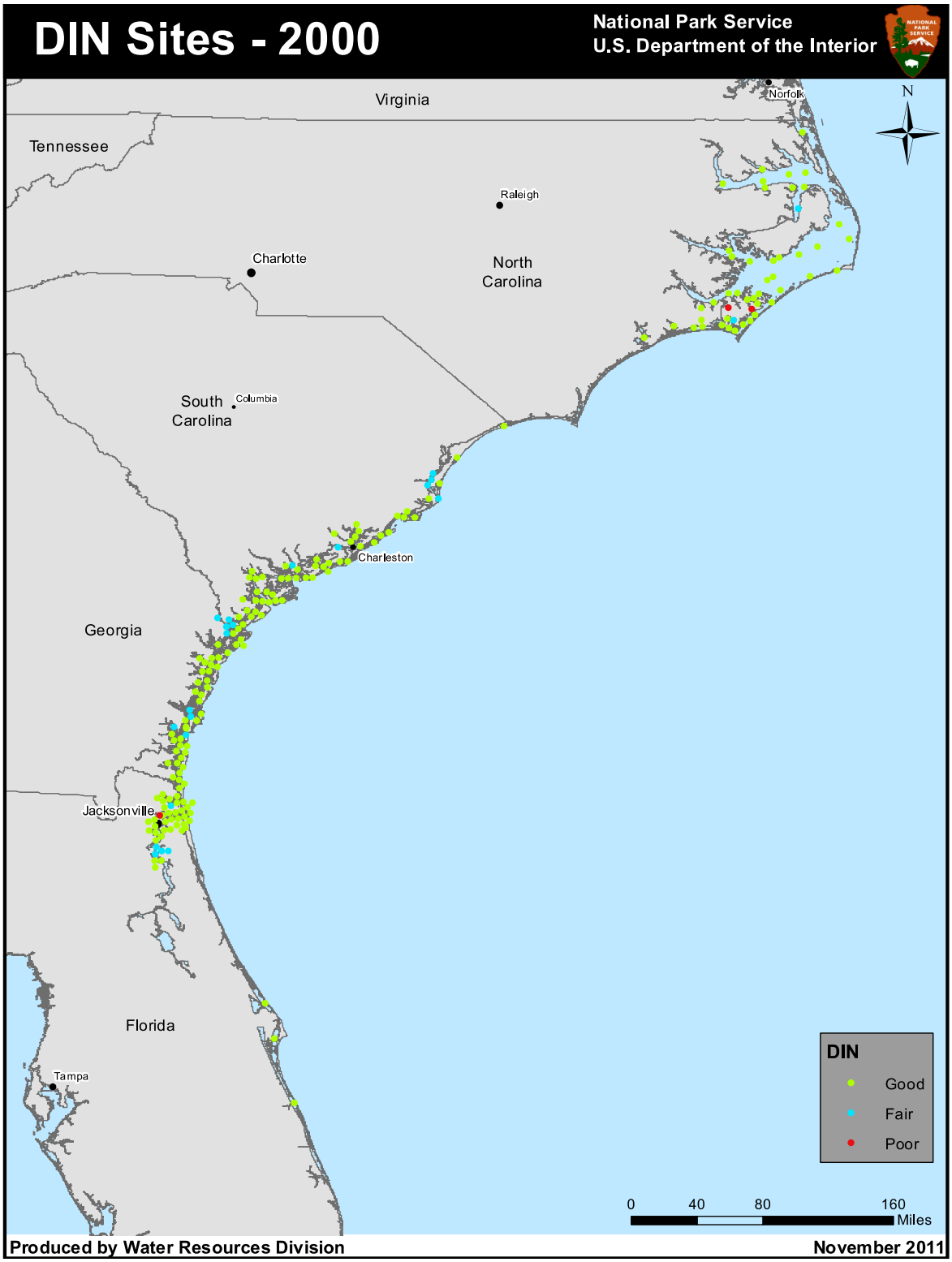


Figure 31. Synoptic sampling map of dissolved inorganic nitrogen for the southeast coastal region (2000). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

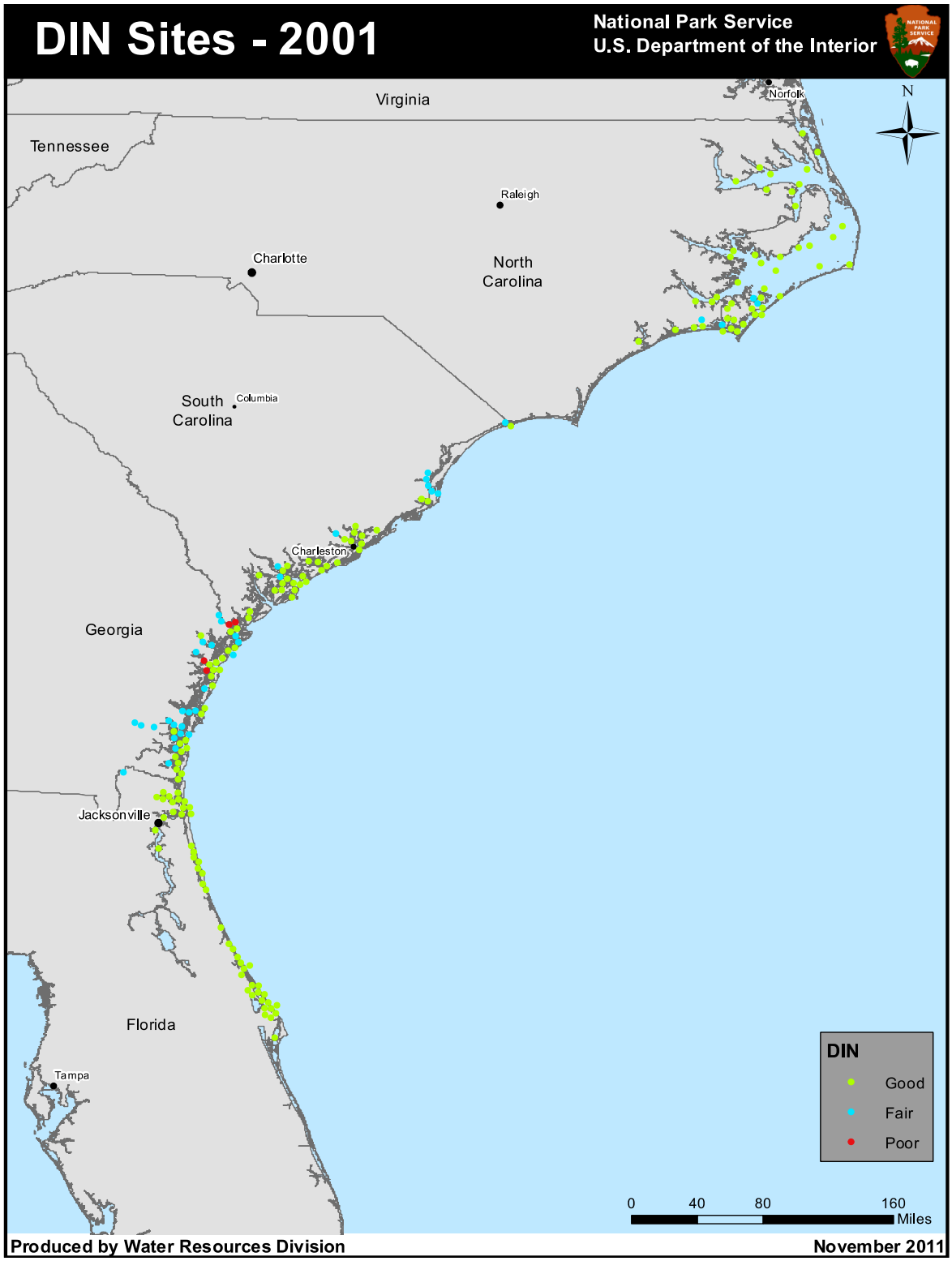


Figure 32. Synoptic sampling map of dissolved inorganic nitrogen (DIN) for the southeast coastal region (2001). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

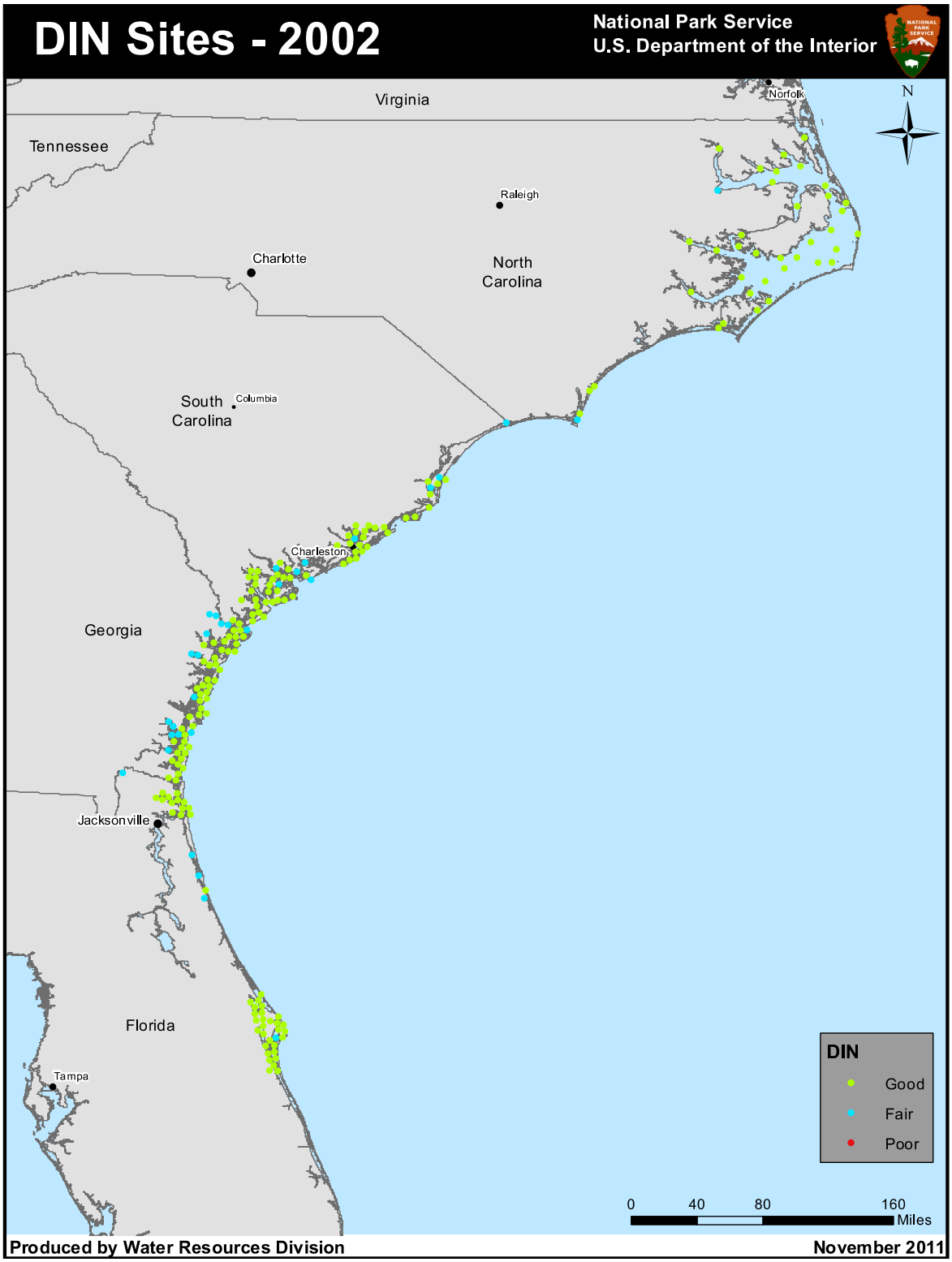


Figure 33. Synoptic sampling map of dissolved inorganic nitrogen (DIN) for the southeast coastal region (2002). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

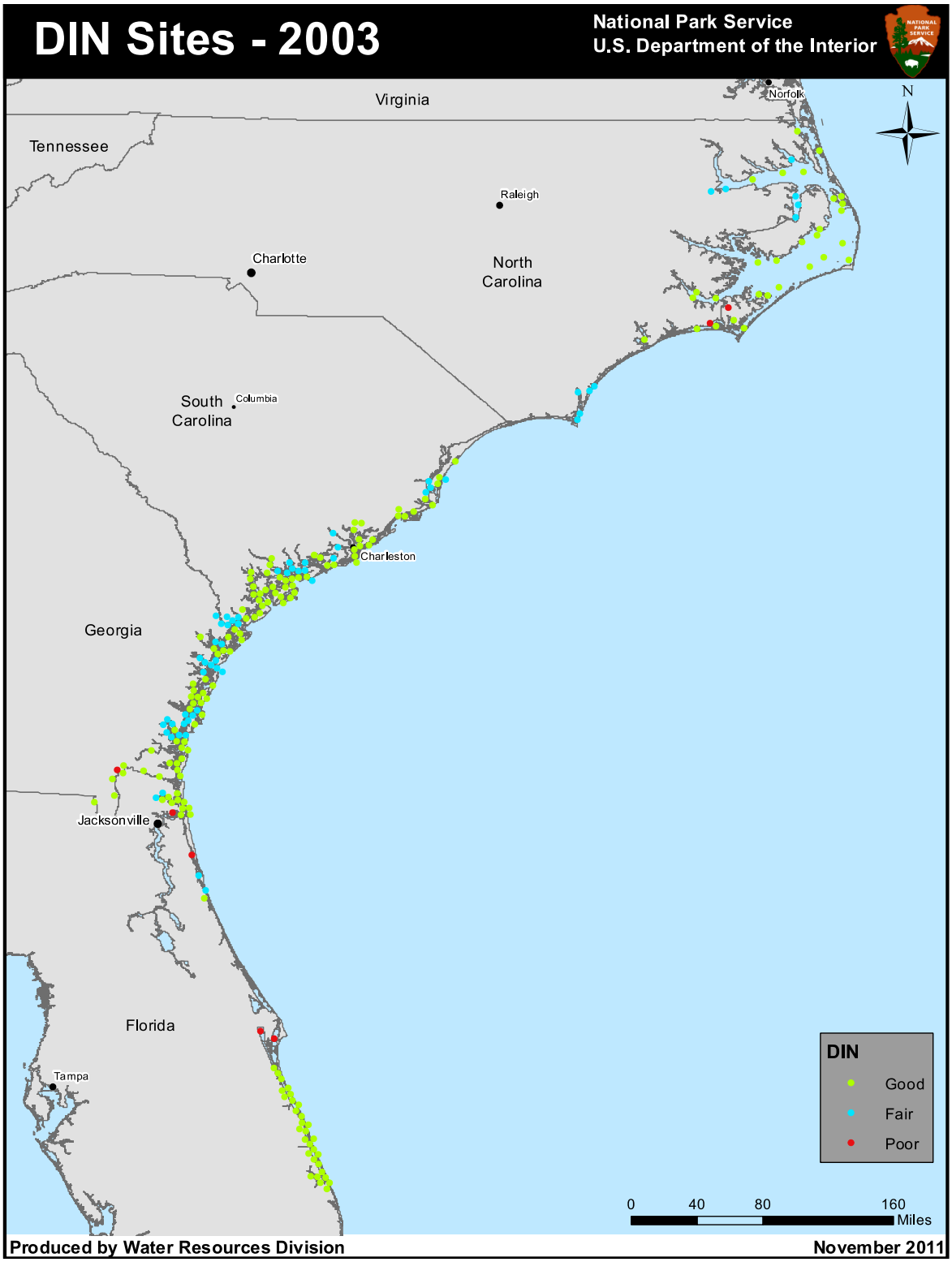


Figure 34. Synoptic sampling map of dissolved inorganic nitrogen (DIN) for the southeast coastal region (2003). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

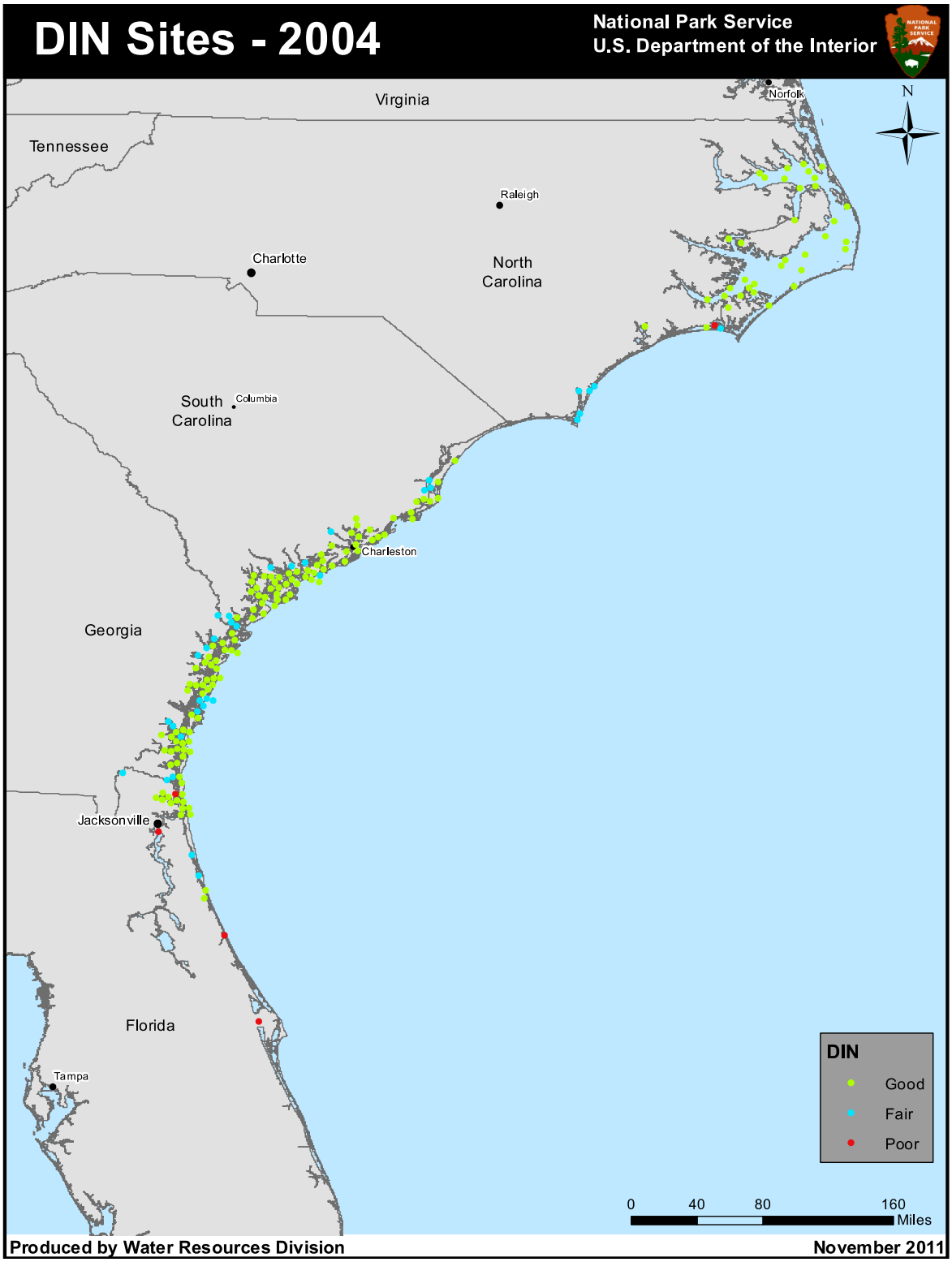


Figure 35. Synoptic sampling map of dissolved inorganic nitrogen (DIN) for the southeast coastal region (2004). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

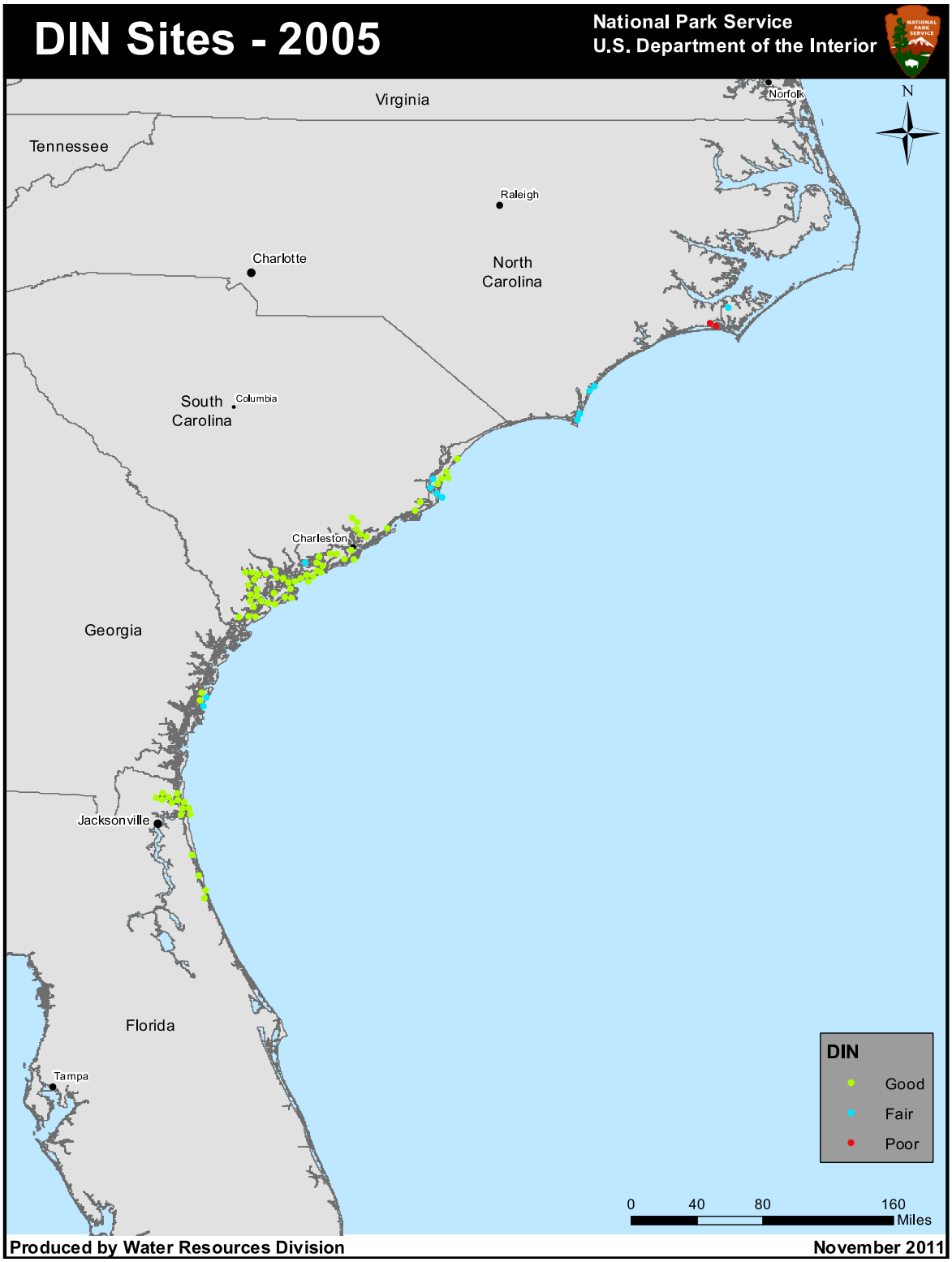


Figure 36. Synoptic sampling map of dissolved inorganic nitrogen (DIN) for the southeast coastal region (2005). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

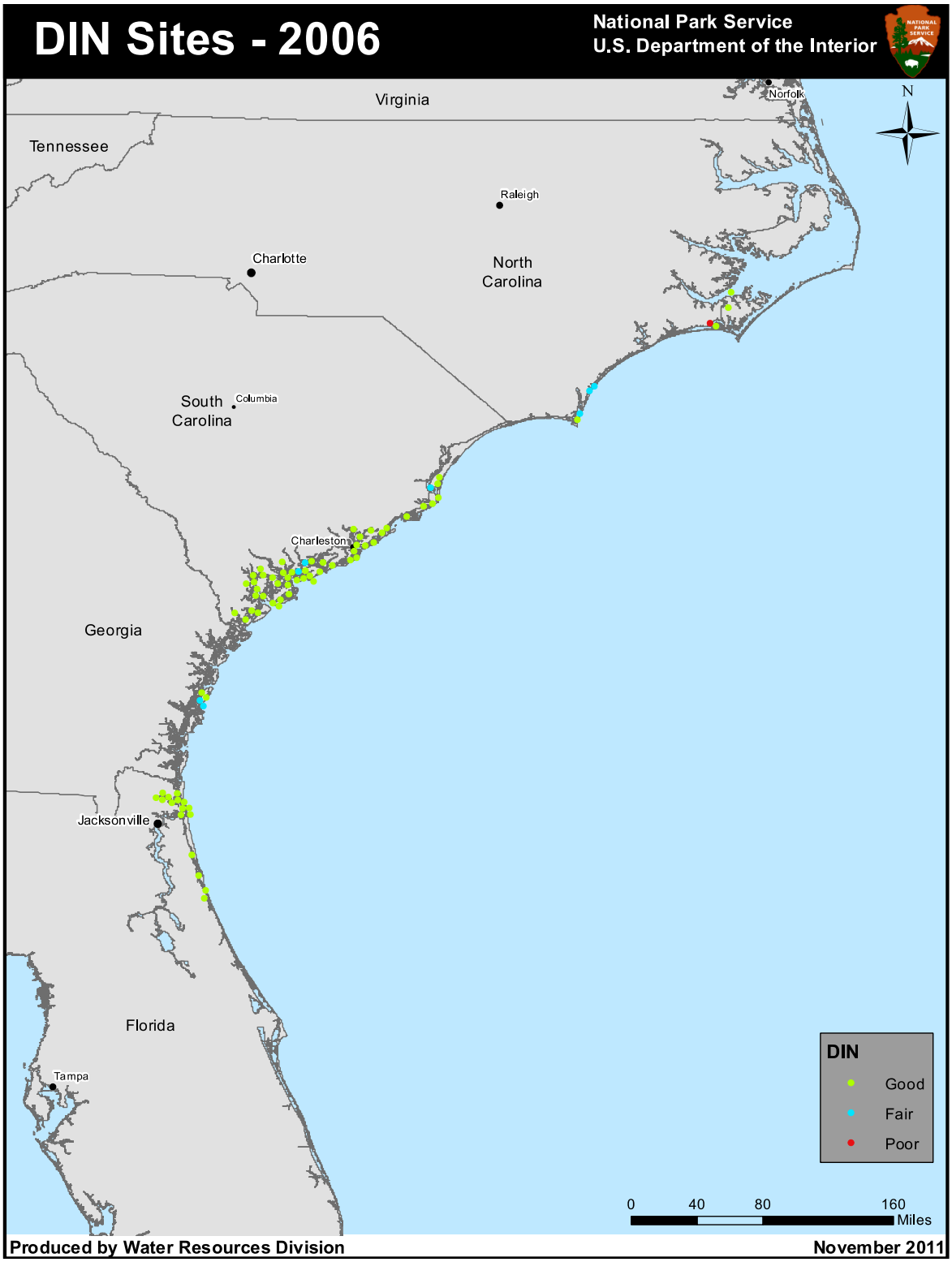


Figure 37. Synoptic sampling map of dissolved inorganic nitrogen (DIN) for the southeast coastal region (2006). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

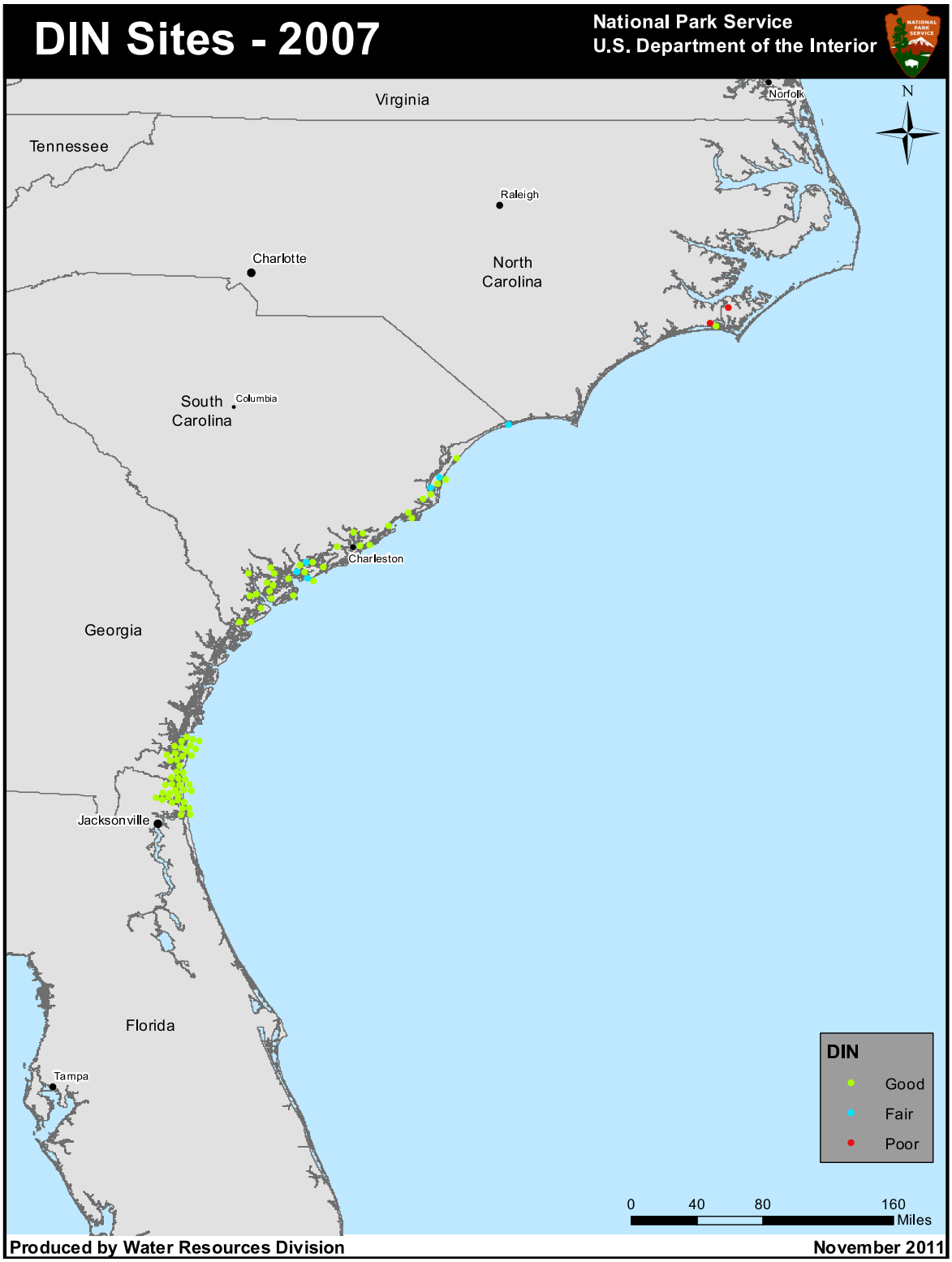


Figure 38. Synoptic sampling map of dissolved inorganic nitrogen (DIN) for the southeast coastal region (2007). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

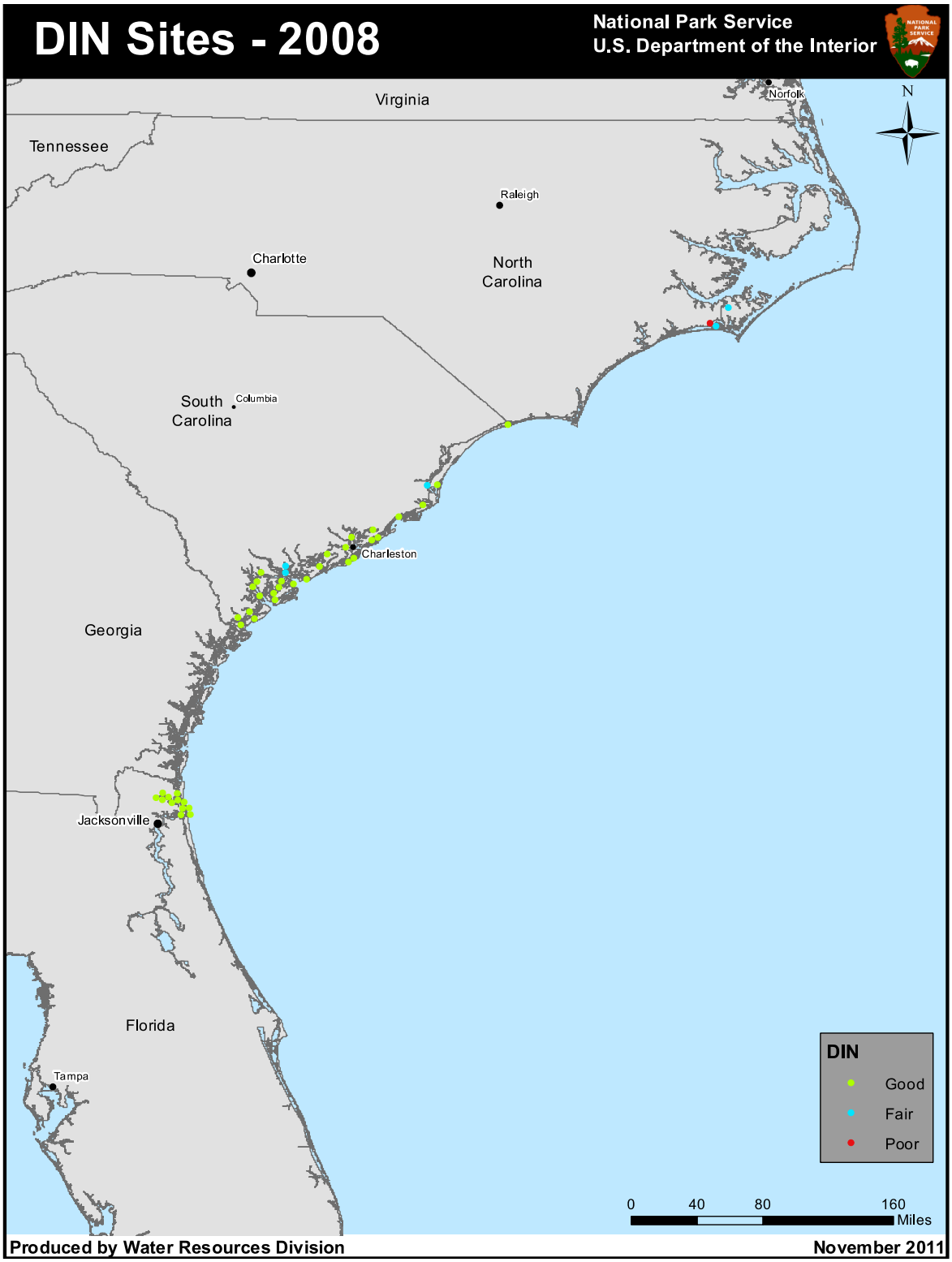


Figure 39. Synoptic sampling map of dissolved inorganic nitrogen (DIN) for the southeast coastal region (2008). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

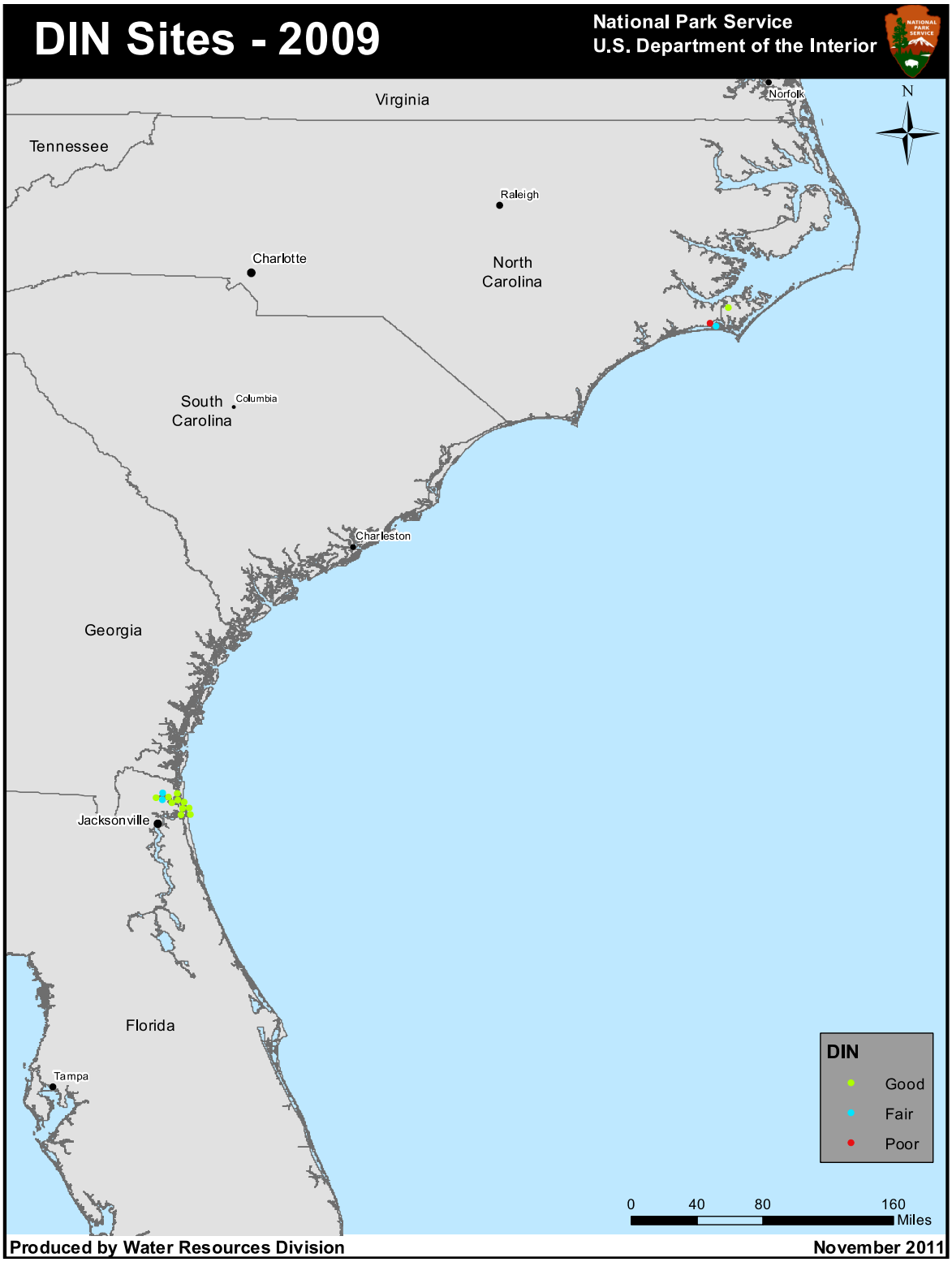


Figure 40. Synoptic sampling map of dissolved inorganic nitrogen (DIN) for the southeast coastal region (2009). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

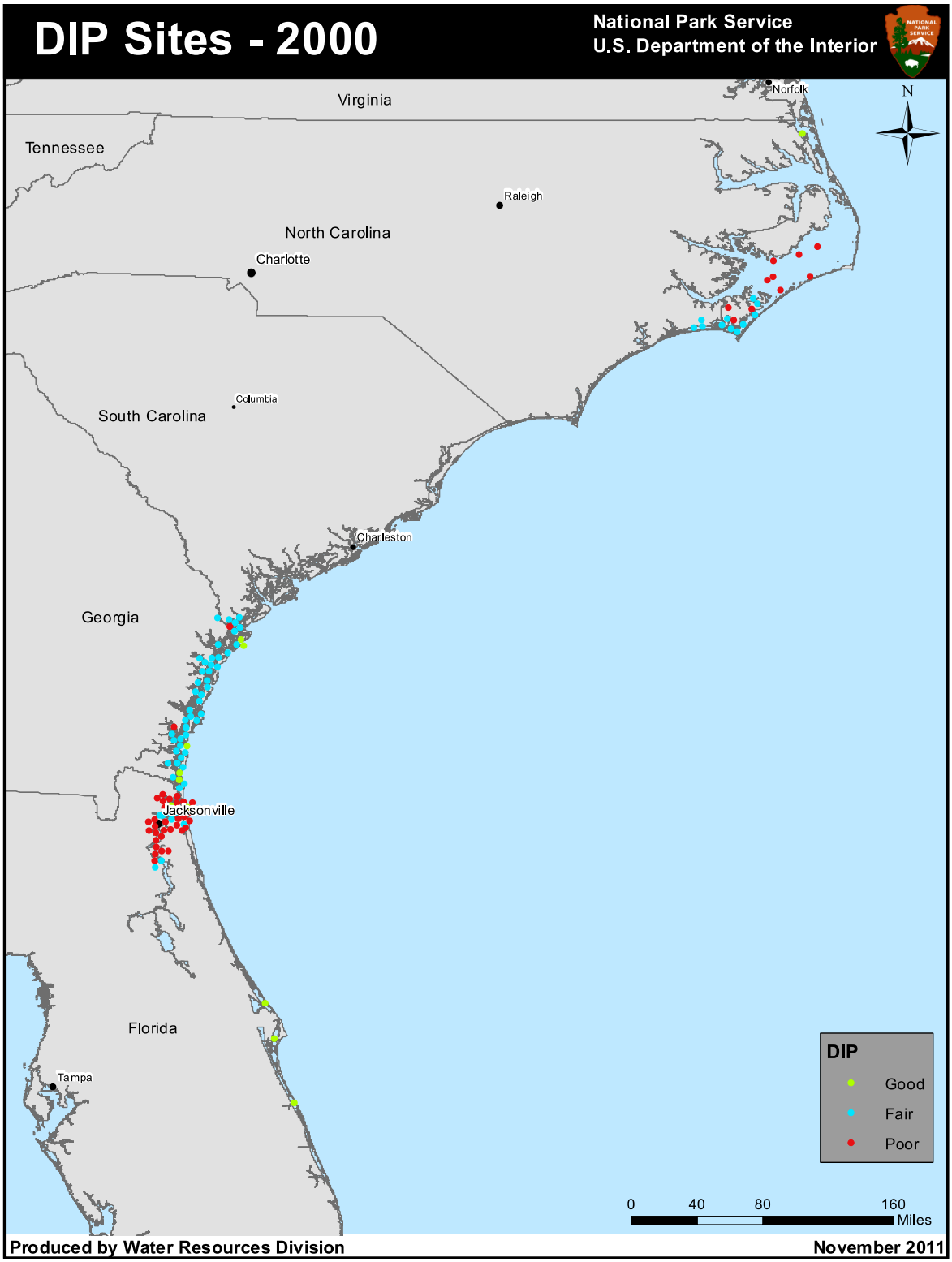


Figure 41. Synoptic sampling map of dissolved inorganic phosphorus (DIP) for the southeast coastal region (2000). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

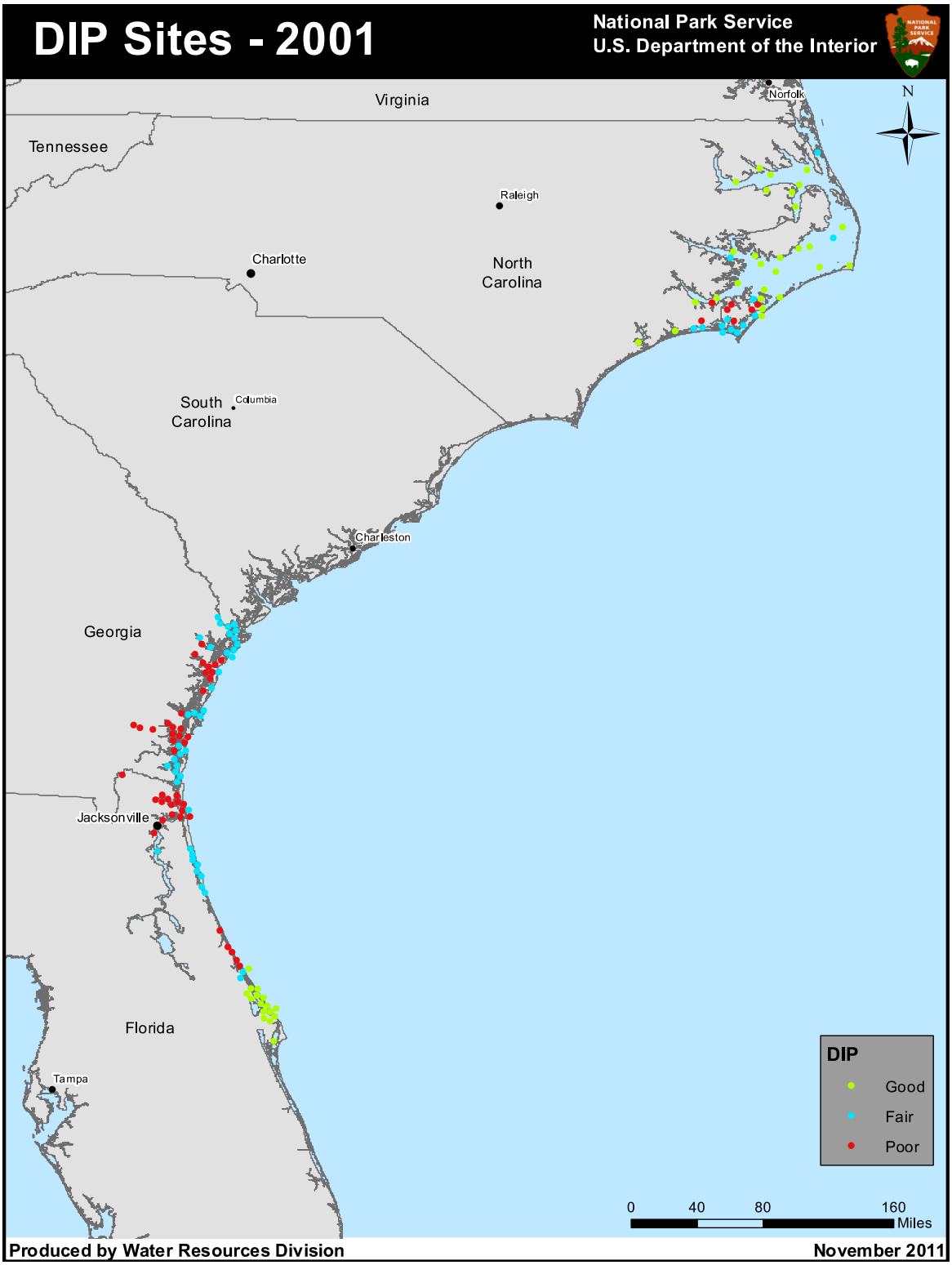


Figure 42. Synoptic sampling map of dissolved inorganic phosphorus (DIP) for the southeast coastal region (2001). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

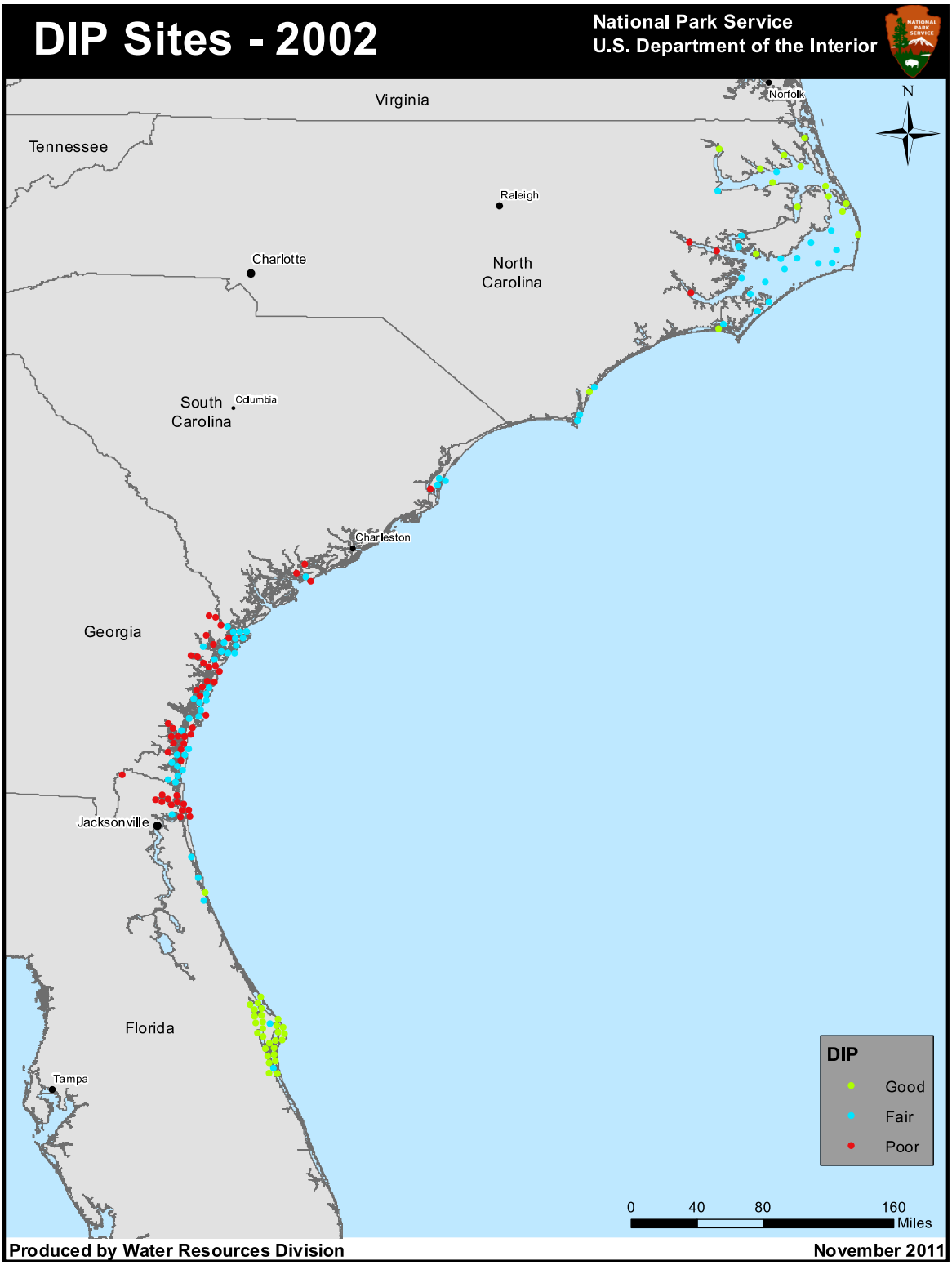


Figure 43. Synoptic sampling map of dissolved inorganic phosphorus (DIP) for the southeast coastal region (2002). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

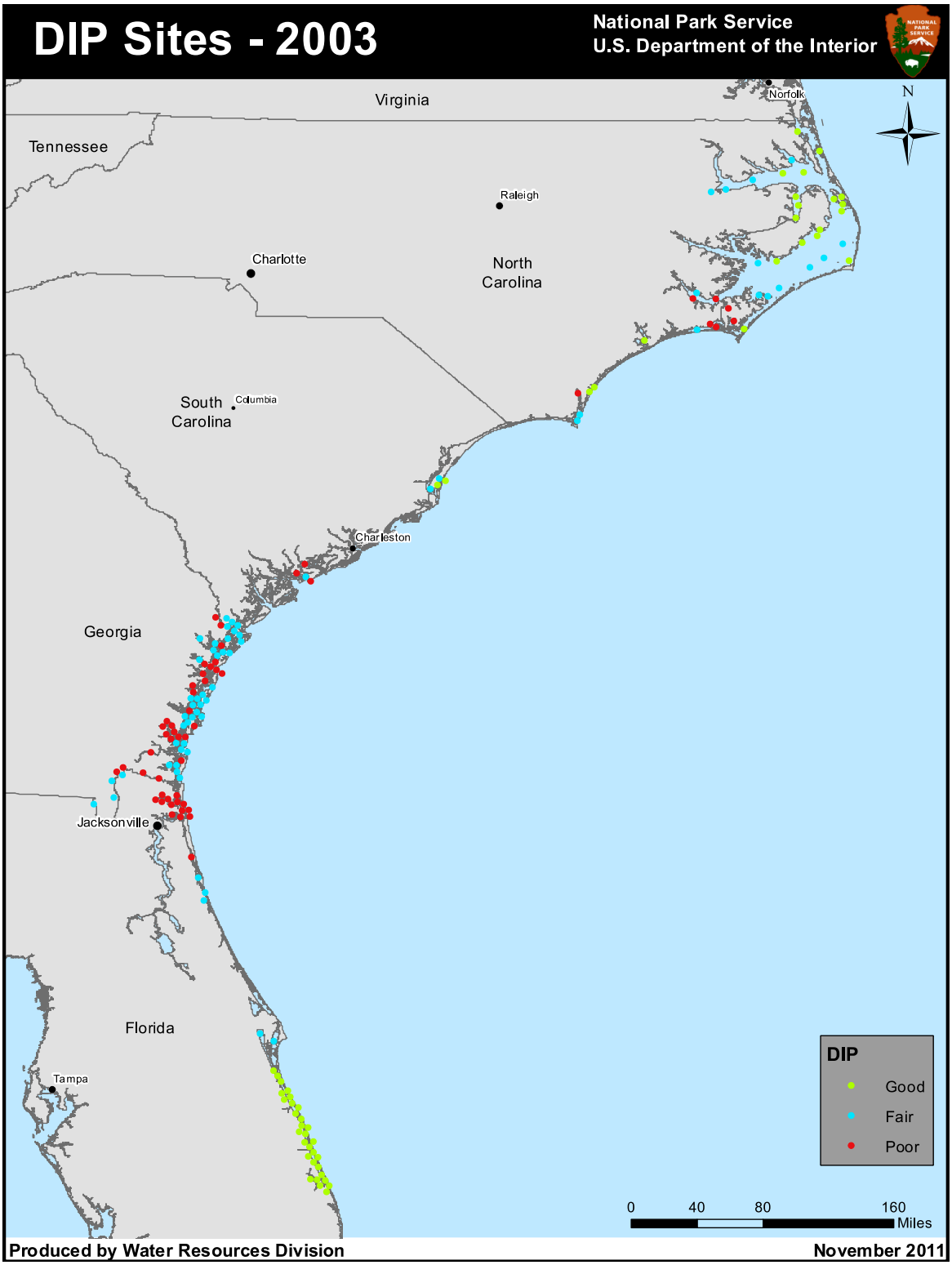


Figure 44. Synoptic sampling map of dissolved inorganic phosphorus (DIP) for the southeast coastal region (2003). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

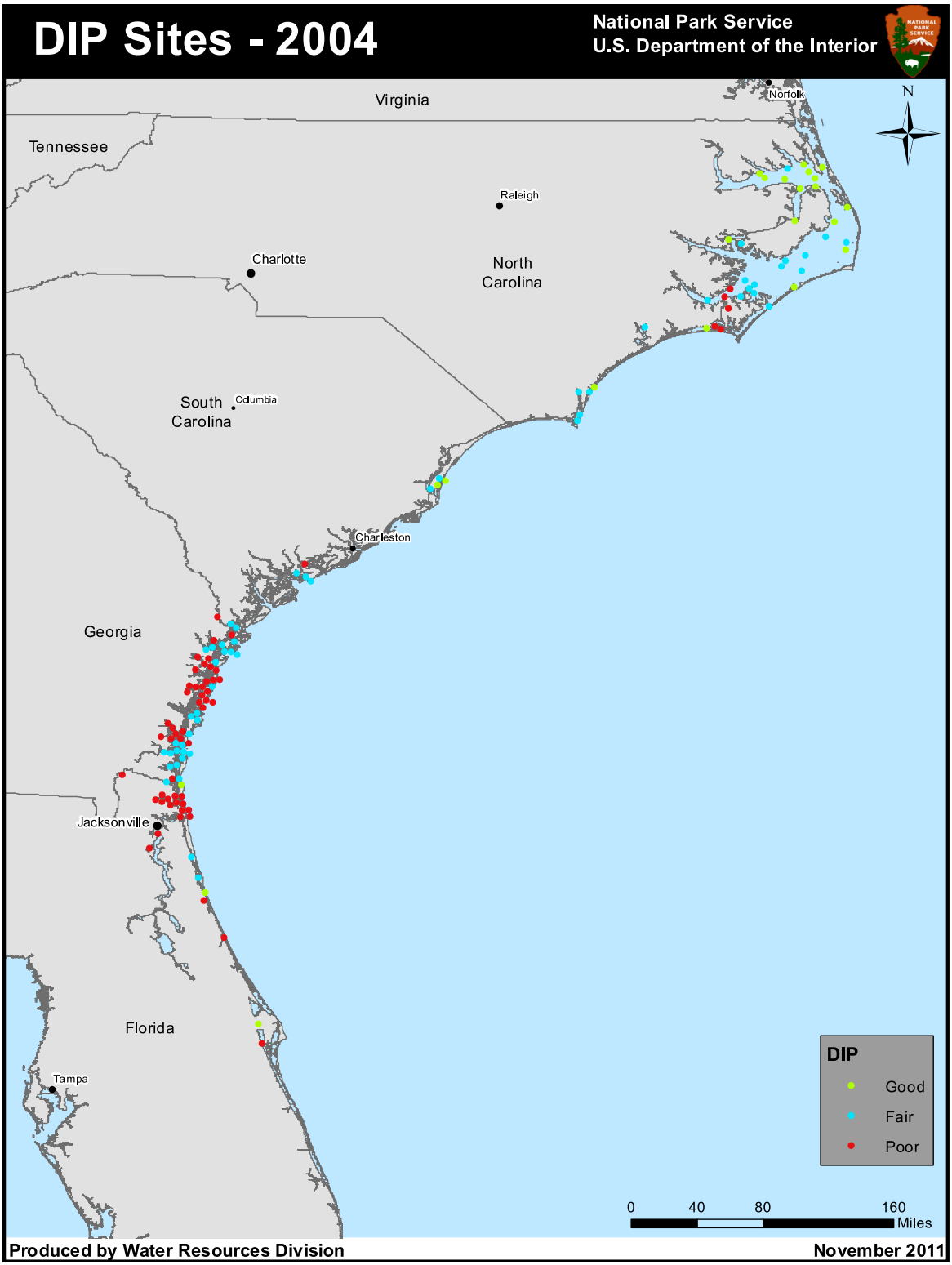


Figure 45. Synoptic sampling map of dissolved inorganic phosphorus (DIP) for the southeast coastal region (2004). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

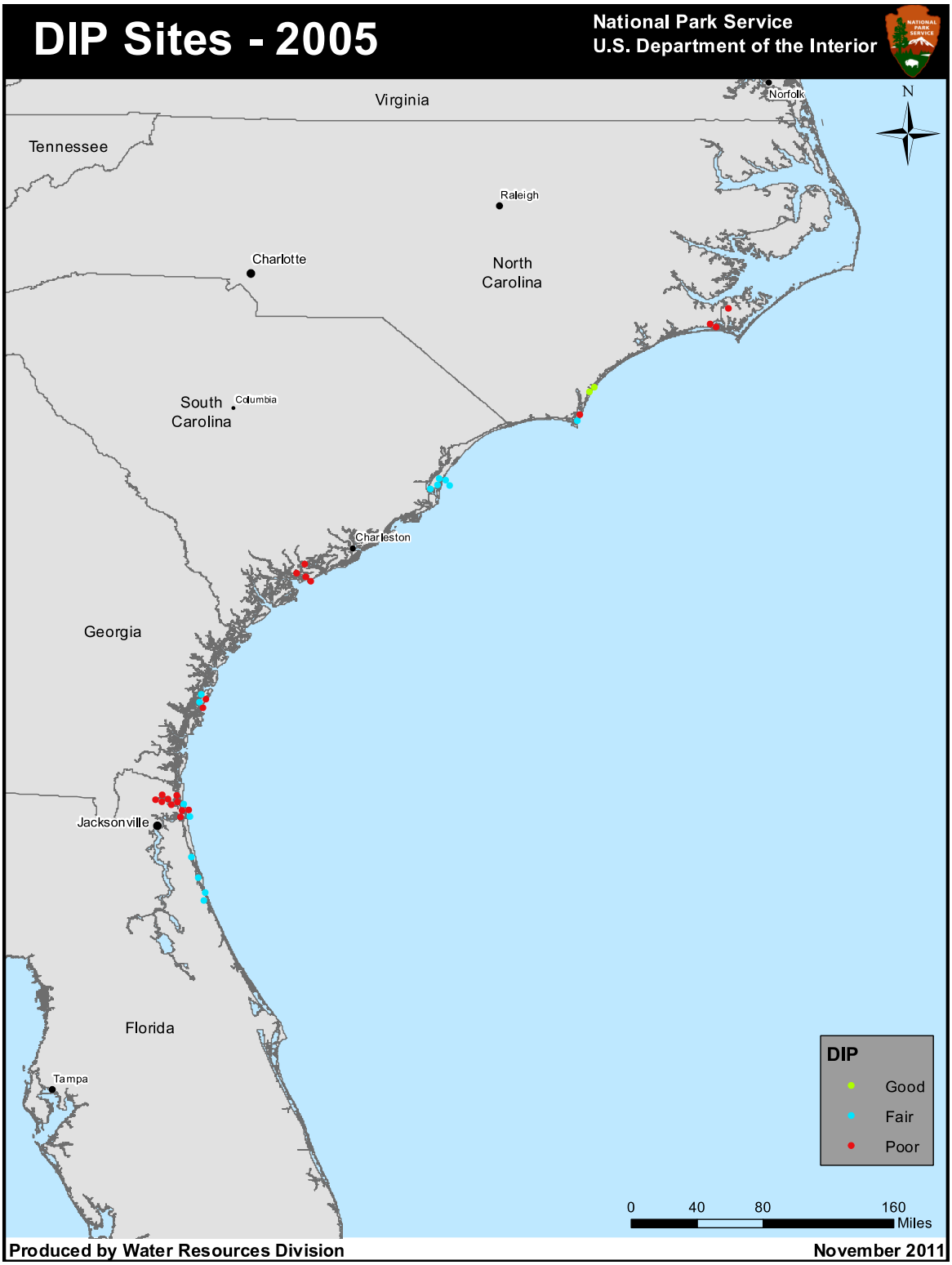


Figure 46. Synoptic sampling map of dissolved inorganic phosphorus (DIP) for the southeast coastal region (2005). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

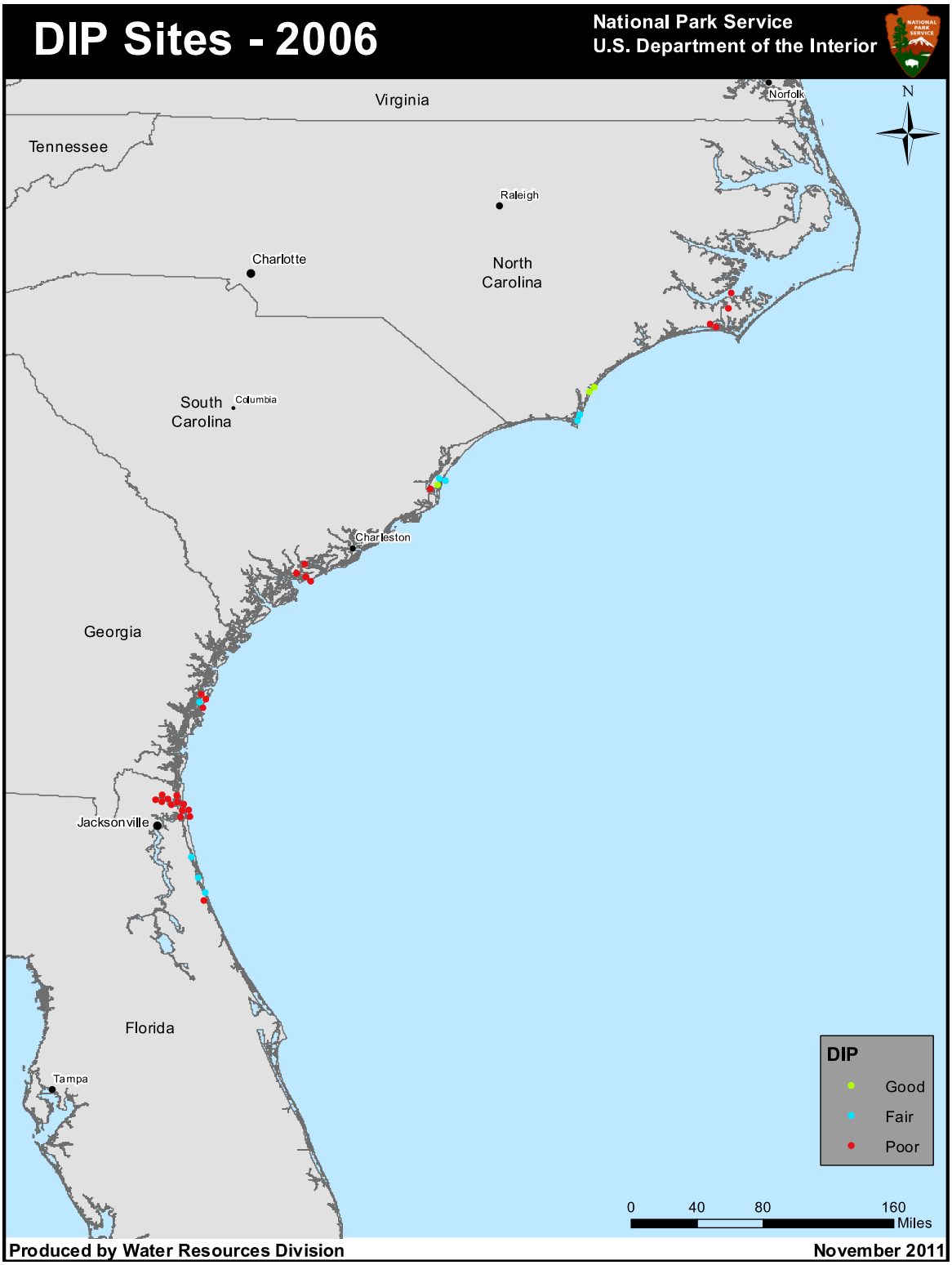


Figure 47. Synoptic sampling map of dissolved inorganic phosphorus (DIP) for the southeast coastal region (2006). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

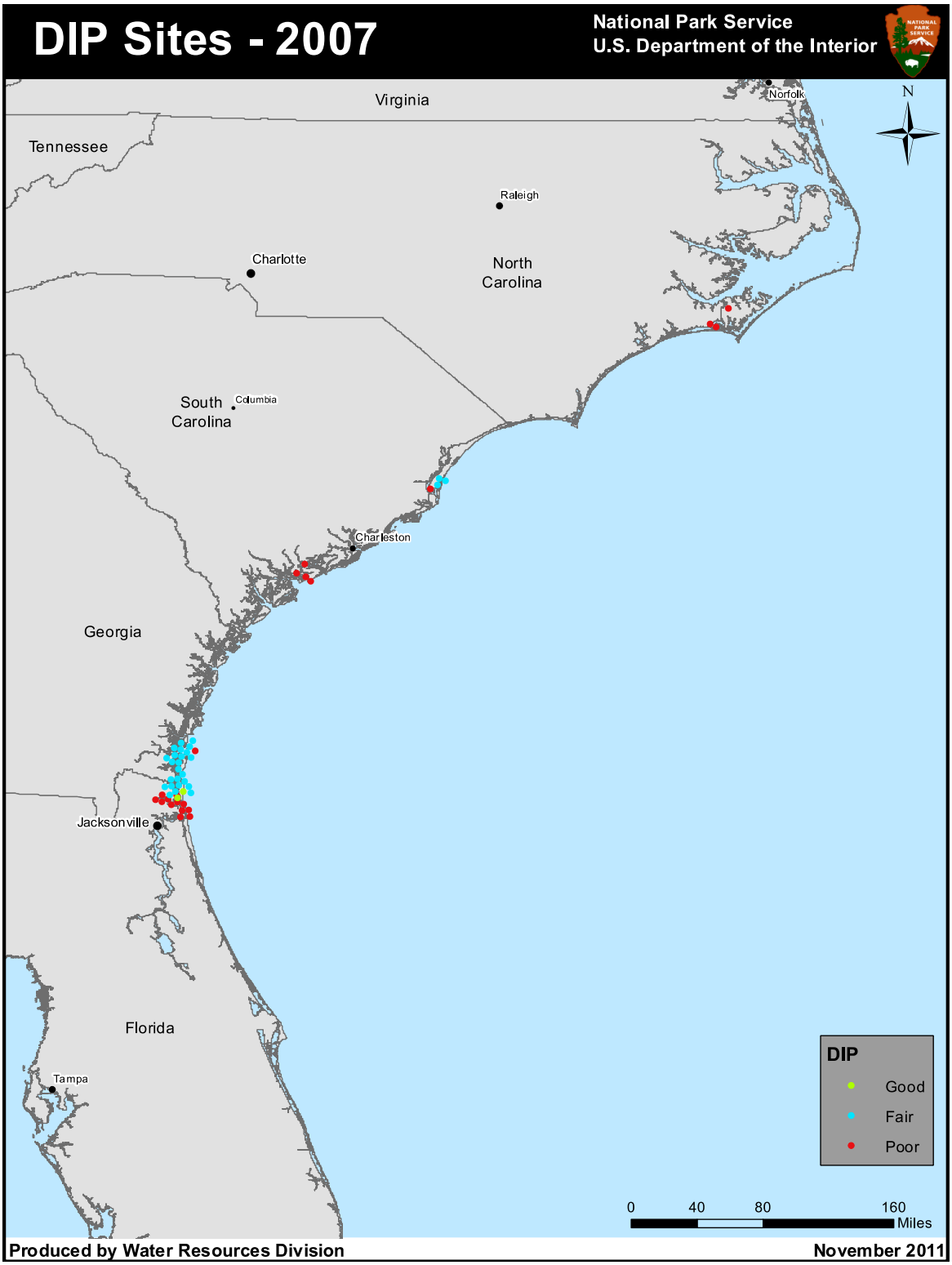


Figure 48. Synoptic sampling map of dissolved inorganic phosphorus (DIP) for the southeast coastal region (2007). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

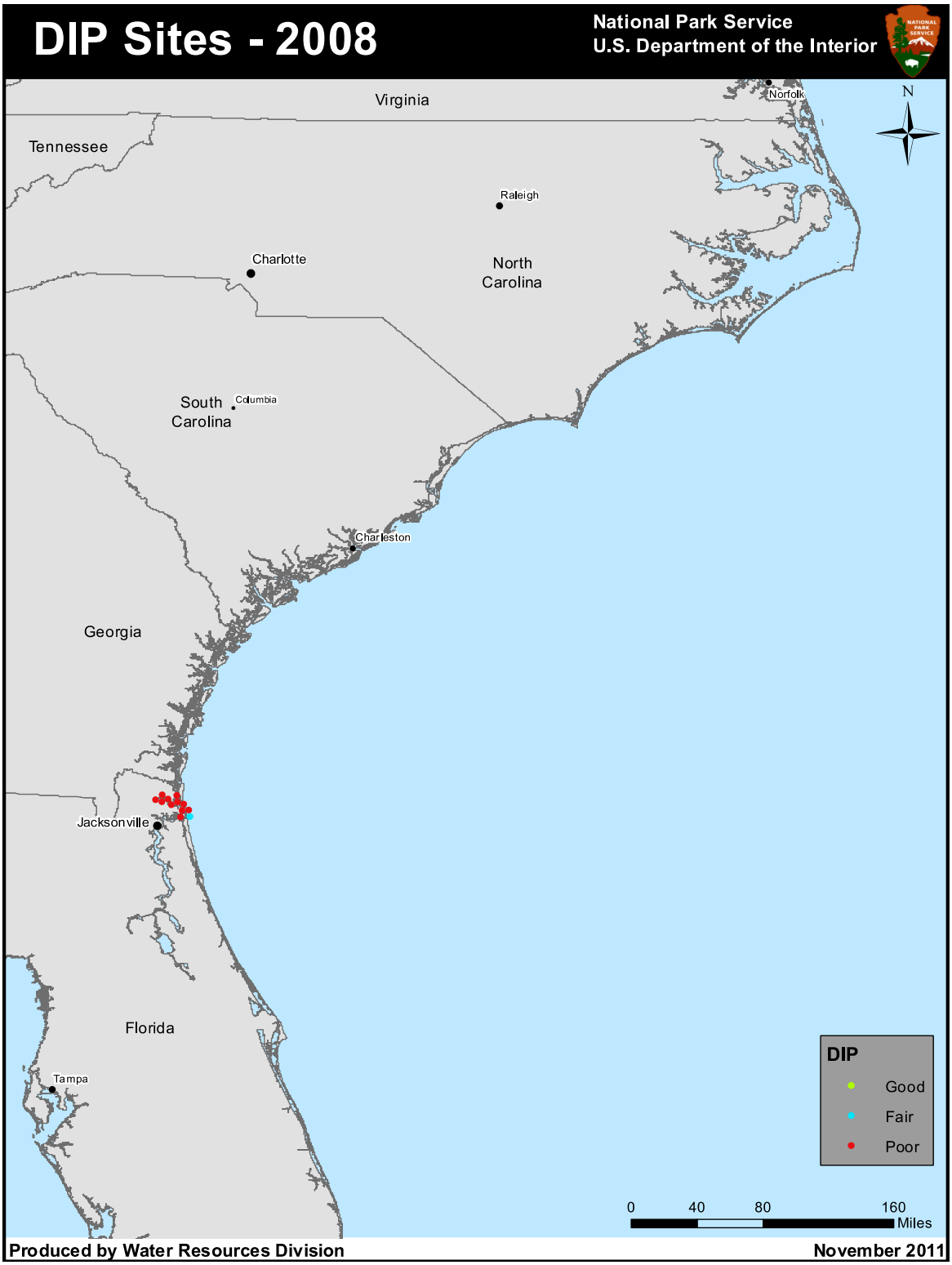


Figure 49. Synoptic sampling map of dissolved inorganic phosphorus (DIP) for the southeast coastal region (2008). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

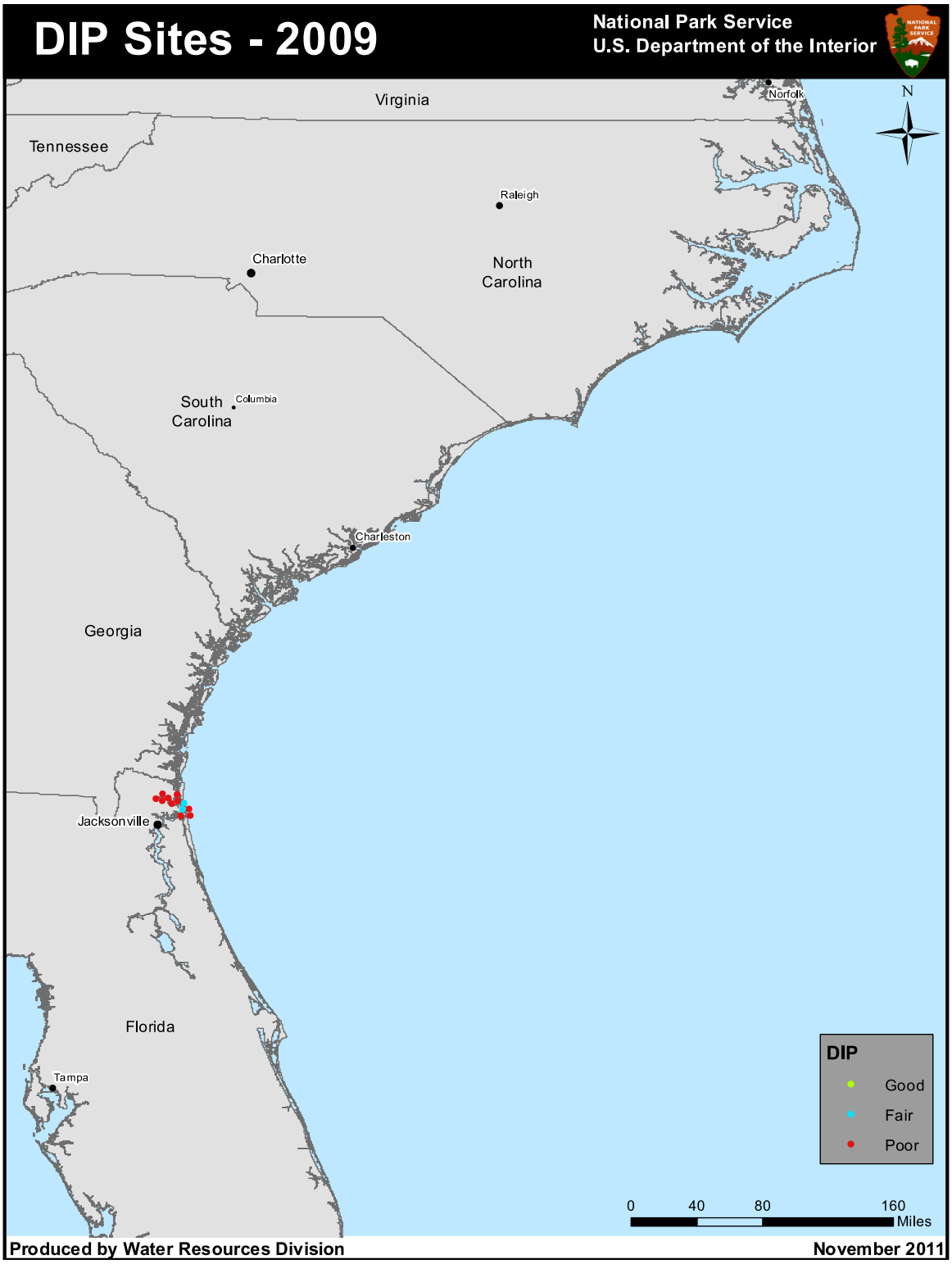


Figure 50. Synoptic sampling map of dissolved inorganic phosphorus (DIP) for the southeast coastal region (2009). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

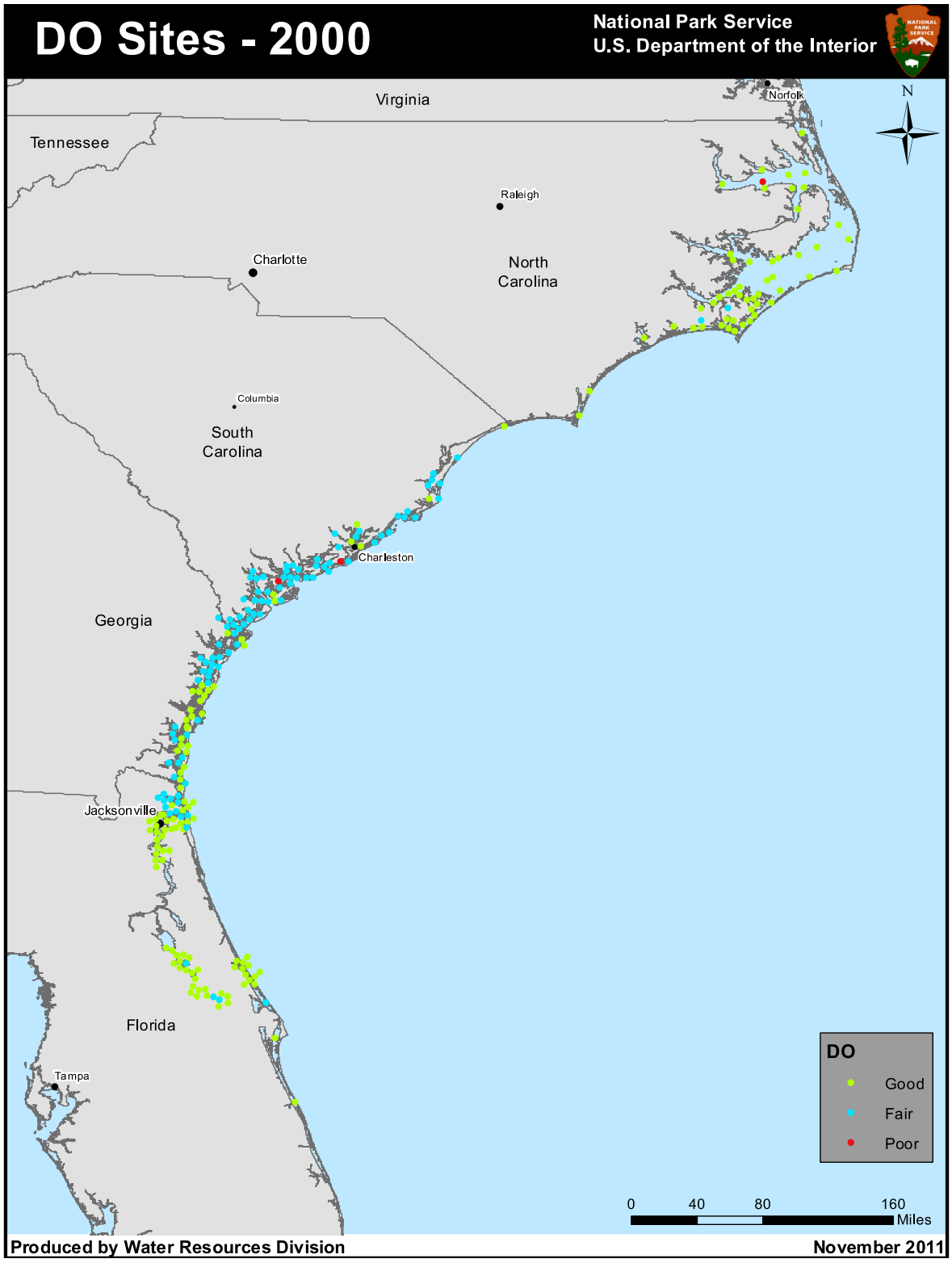


Figure 51. Synoptic sampling map of dissolved oxygen (DO) for the southeast coastal region (2000). The green sites are “good,” blue is “fair,” and red is “poor” sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

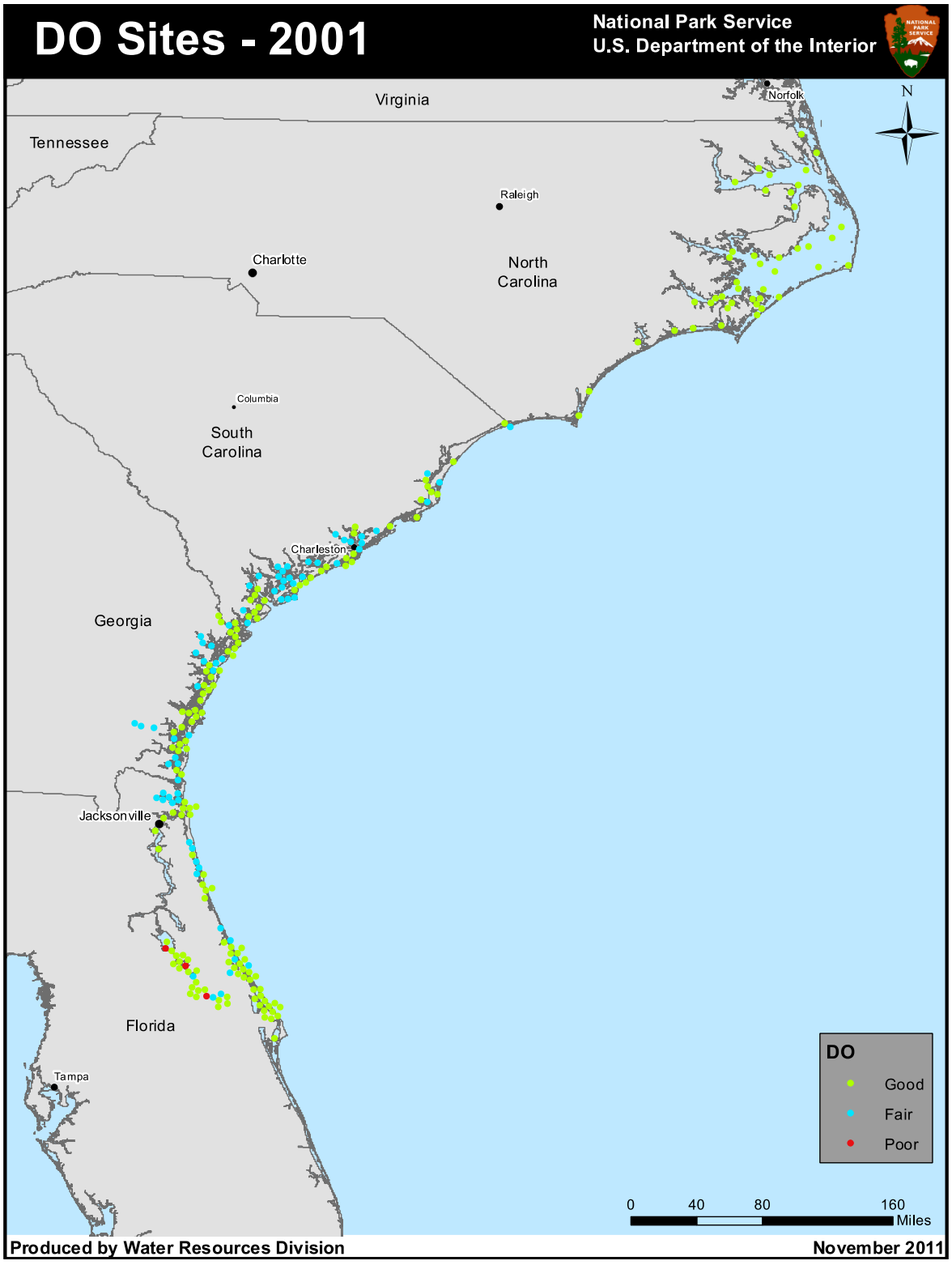


Figure 52. Synoptic sampling map of dissolved oxygen (DO) for the southeast coastal region (2001). The green sites are “good,” blue is “fair,” and red is “poor” sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

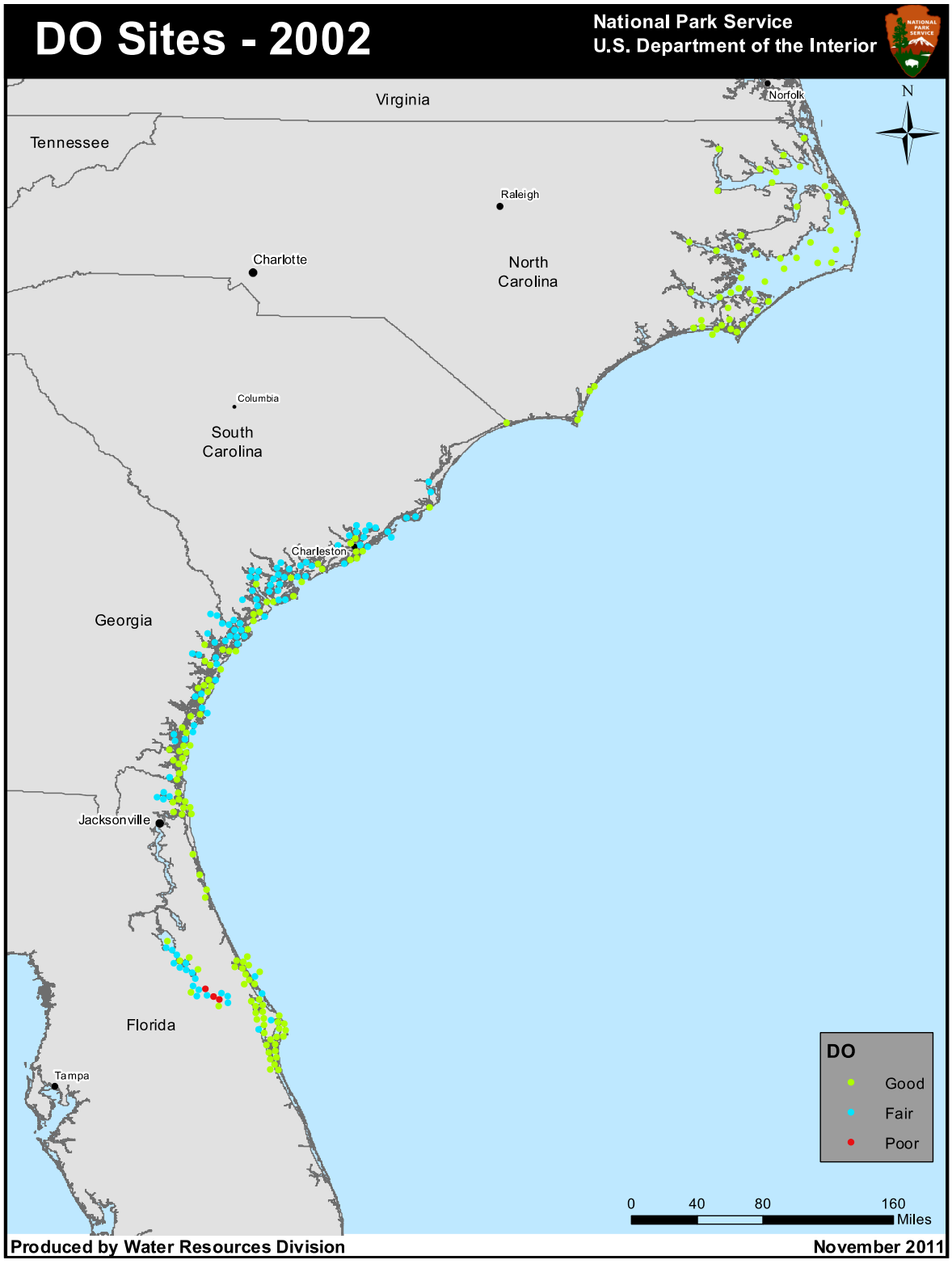


Figure 53. Synoptic sampling map of dissolved oxygen (DO) for the southeast coastal region (2002). The green sites are “good,” blue is “fair,” and red is “poor” sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

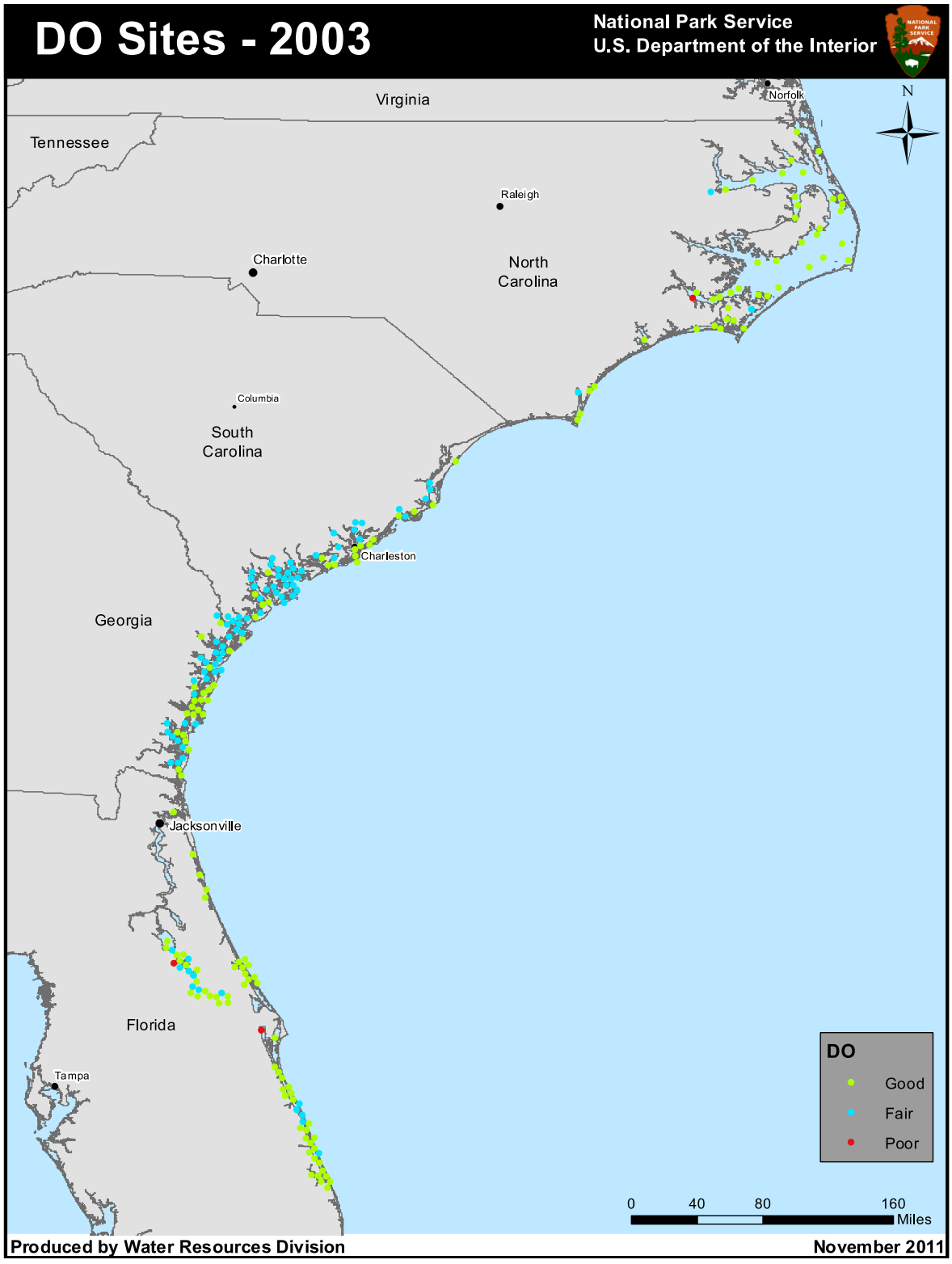


Figure 54. Synoptic sampling map of dissolved oxygen (DO) for the southeast coastal region (2003). The green sites are “good,” blue is “fair,” and red is “poor” sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

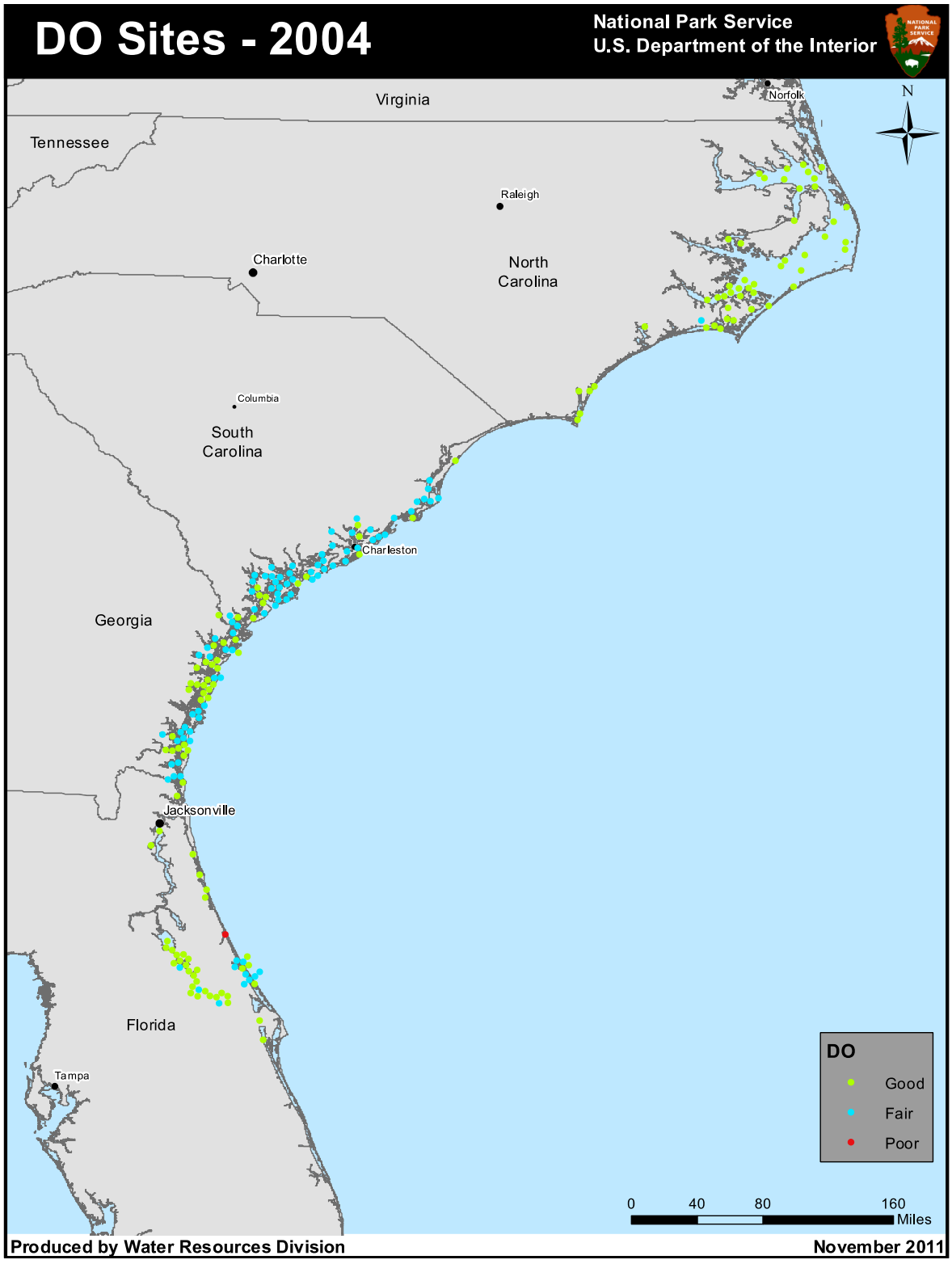


Figure 55. Synoptic sampling map of dissolved oxygen (DO) for the southeast coastal region (2004). The green sites are “good,” blue is “fair,” and red is “poor” sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

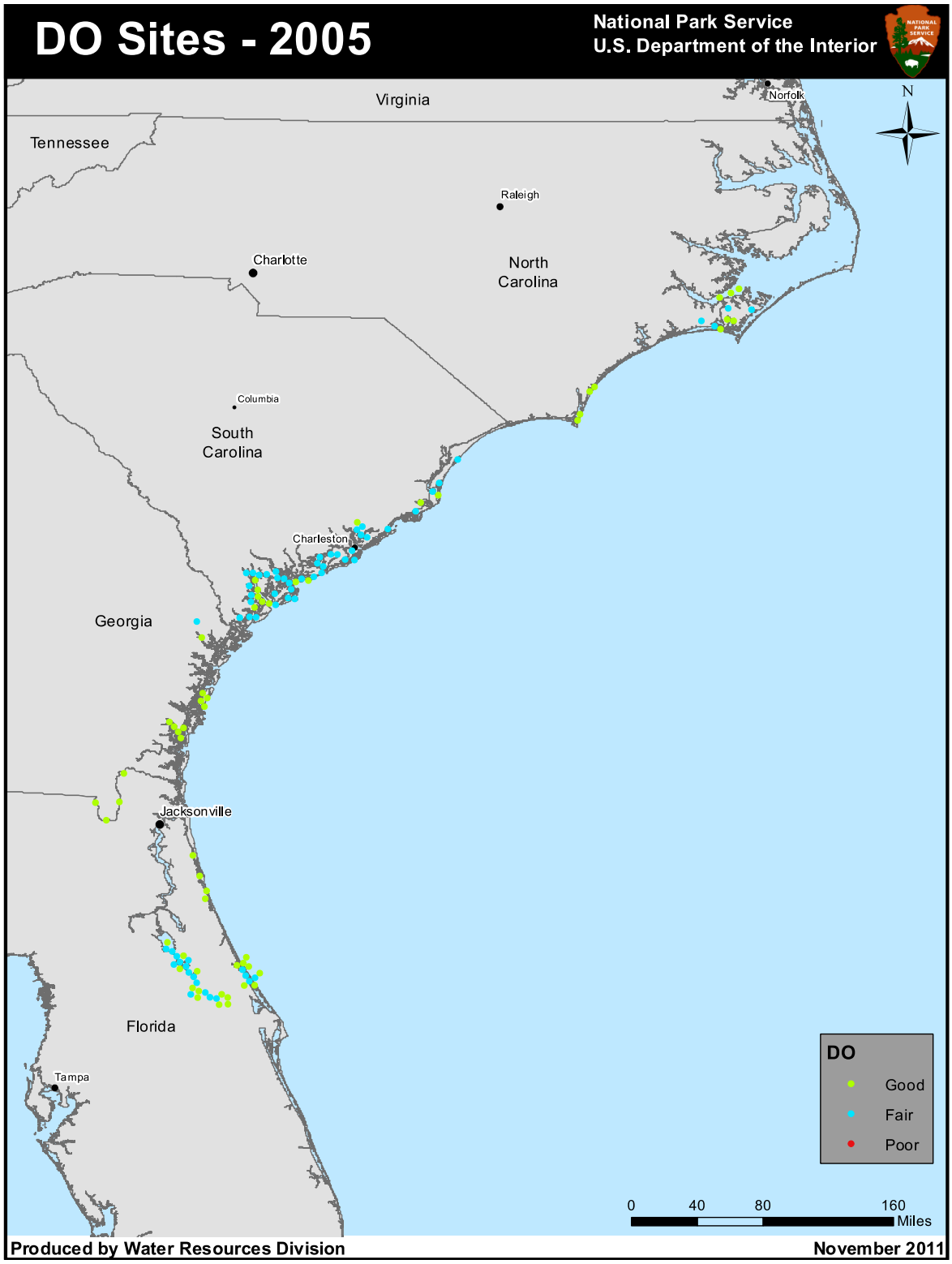


Figure 56. Synoptic sampling map of dissolved oxygen (DO) for the southeast coastal region (2005). The green sites are “good,” blue is “fair,” and red is “poor” sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

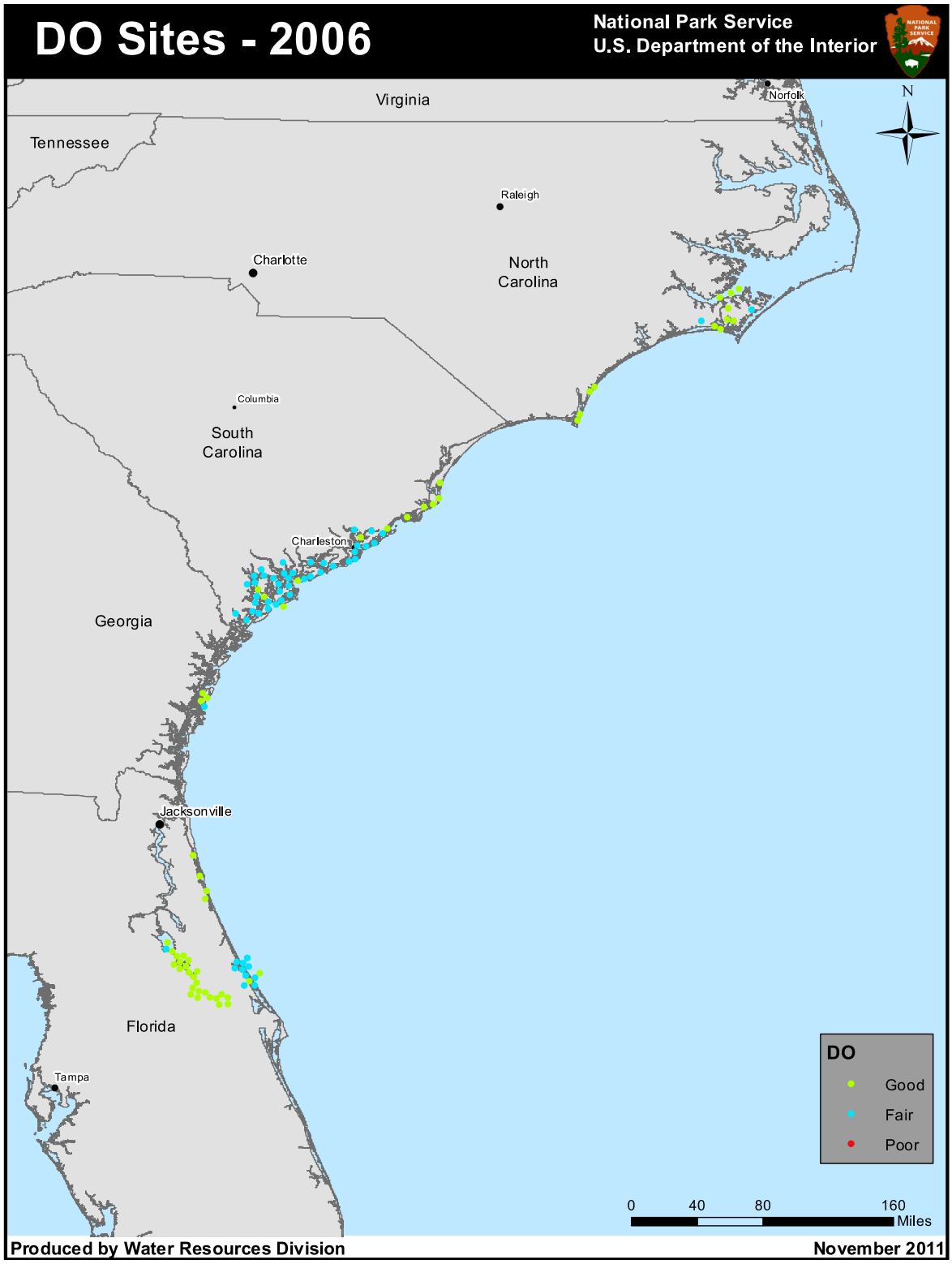


Figure 57. Synoptic sampling map of dissolved oxygen (DO) for the southeast coastal region (2006). The green sites are “good,” blue is “fair,” and red is “poor” sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

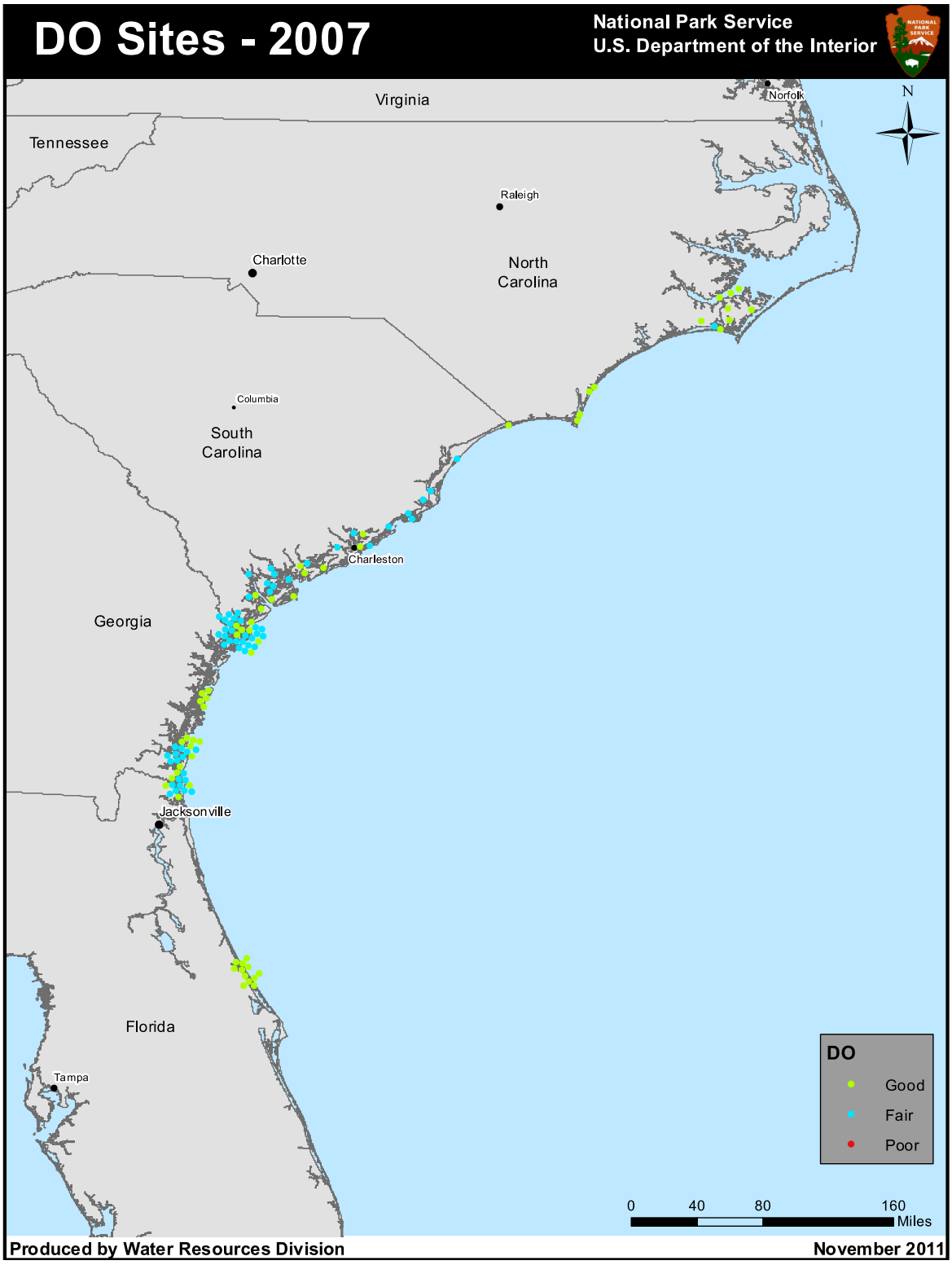


Figure 58. Synoptic sampling map of dissolved oxygen (DO) for the southeast coastal region (2007). The green sites are “good,” blue is “fair,” and red is “poor” sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

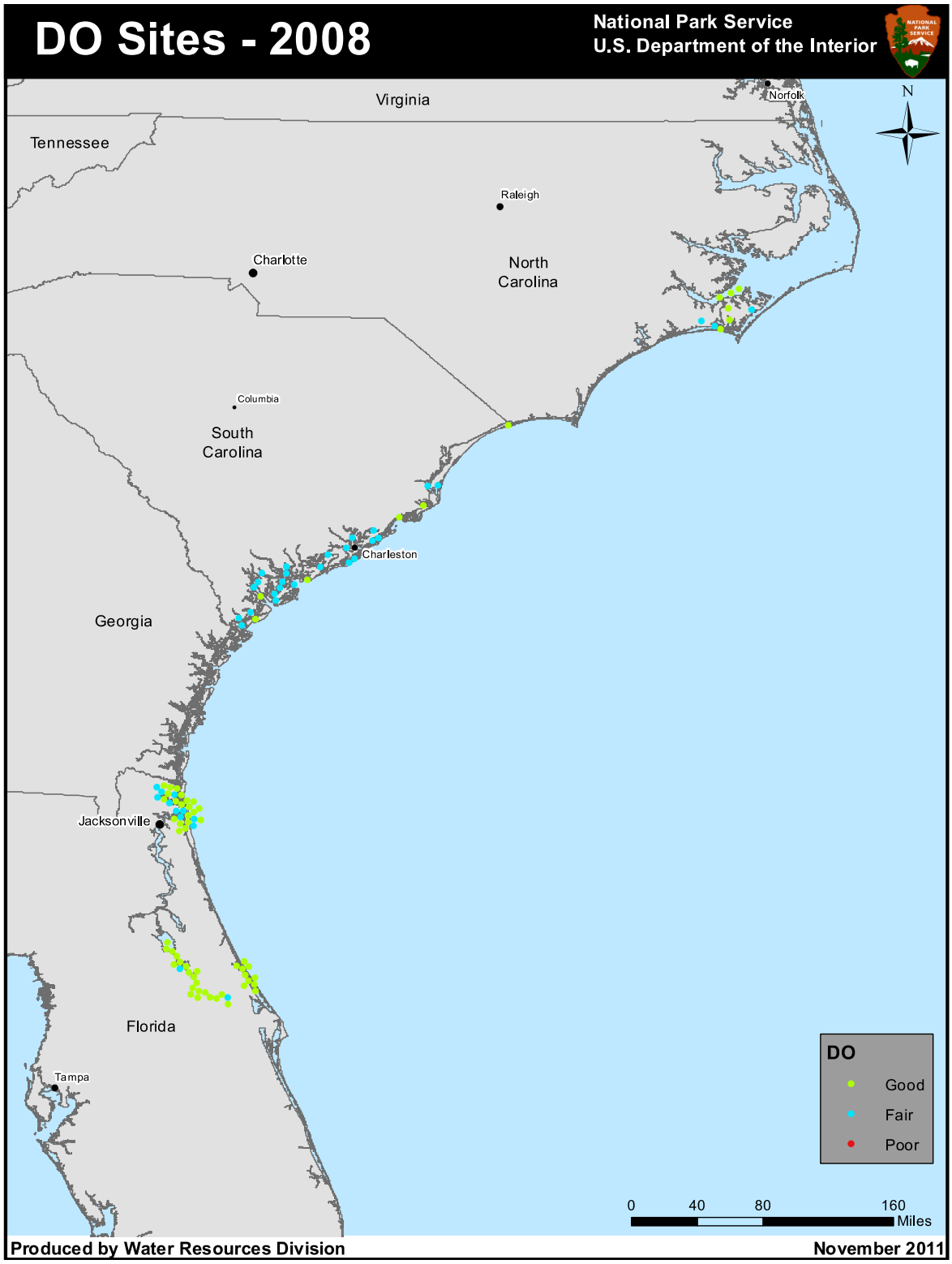


Figure 59. Synoptic sampling map of dissolved oxygen (DO) for the southeast coastal region (2008). The green sites are “good,” blue is “fair,” and red is “poor” sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

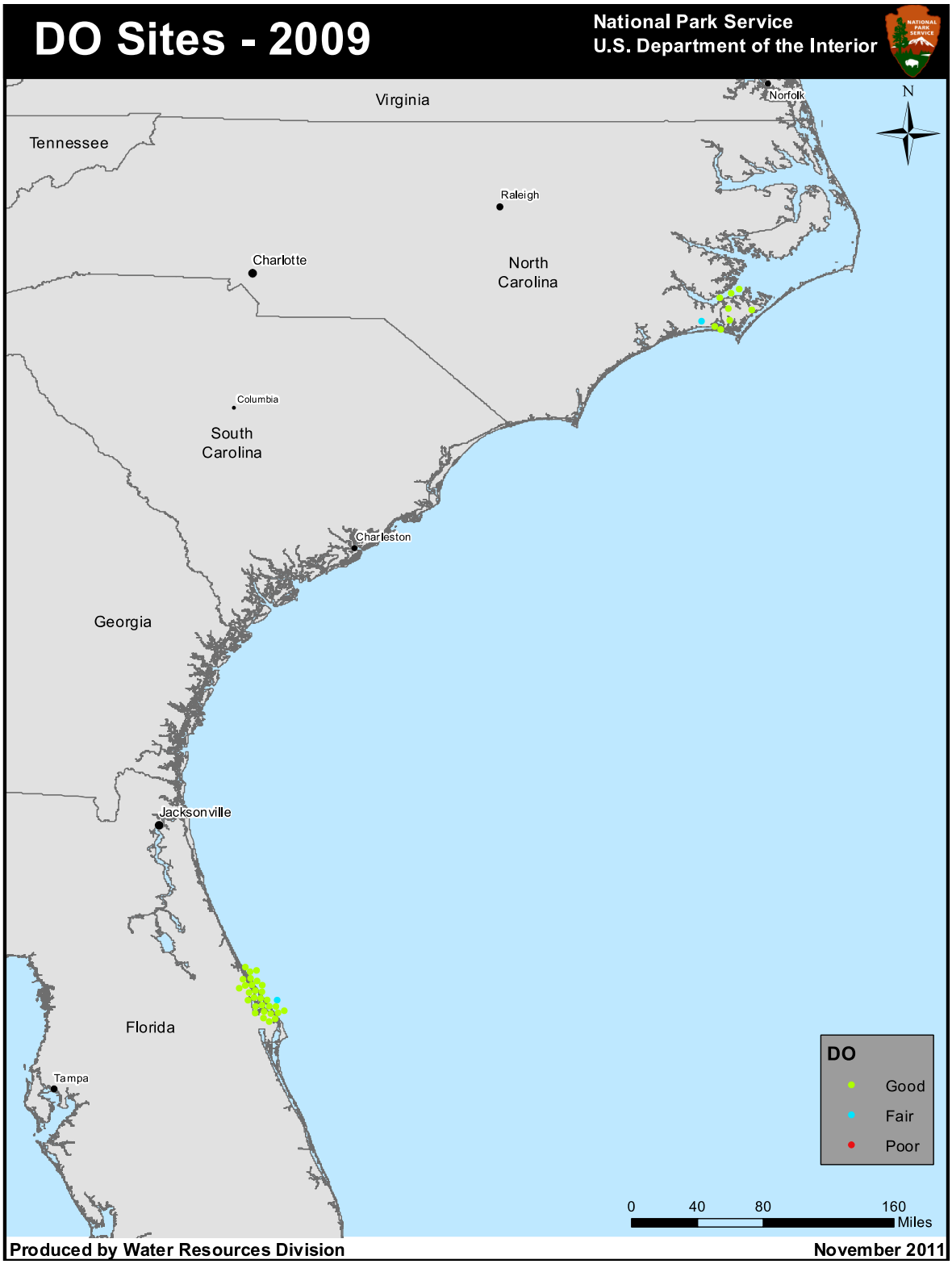


Figure 60. Synoptic sampling map of dissolved oxygen (DO) for the southeast coastal region (2009). The green sites are “good,” blue is “fair,” and red is “poor” sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

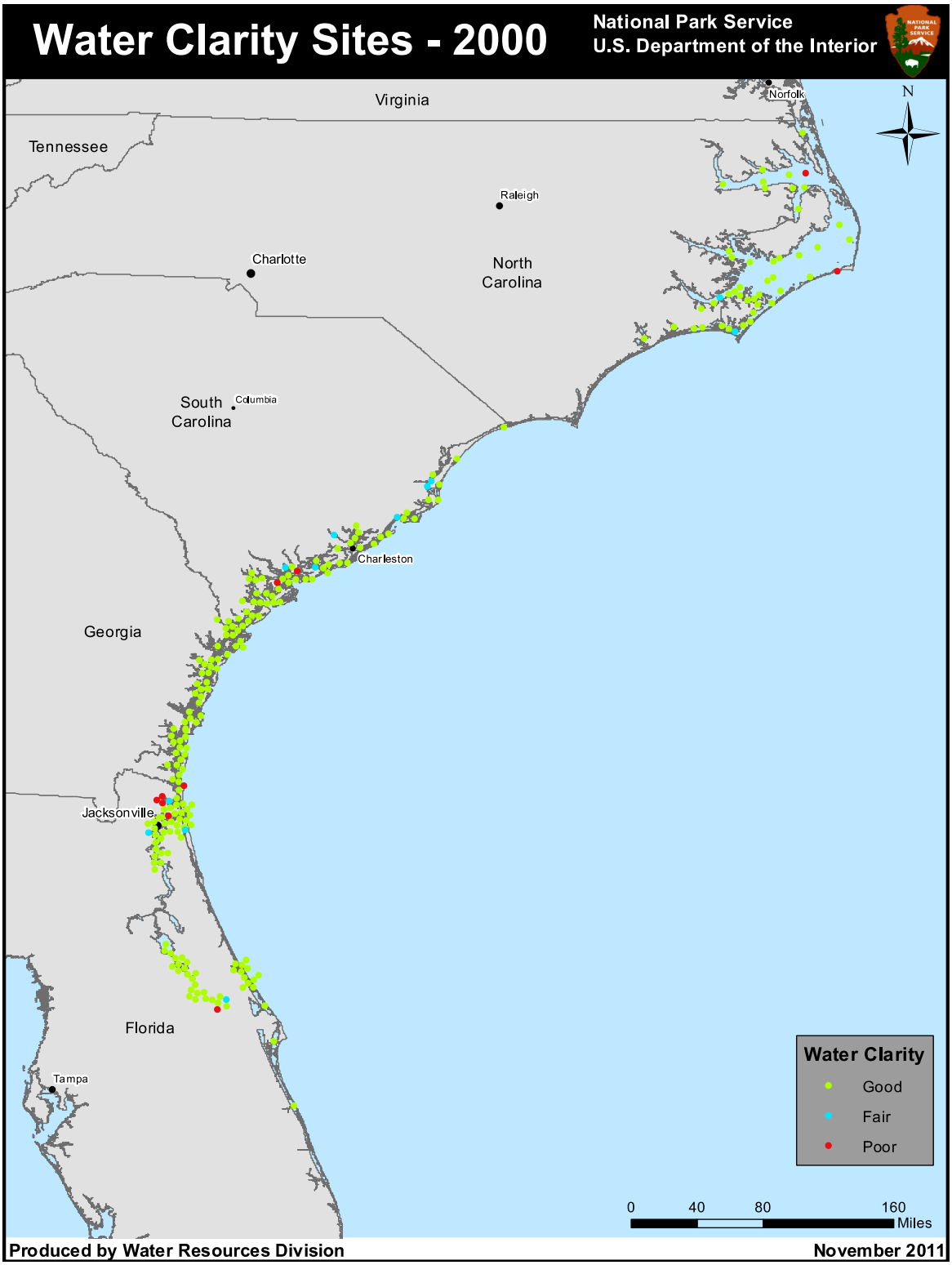


Figure 61. Synoptic sampling map of water clarity, measured by Secchi depth, for the southeast coastal region (2000). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

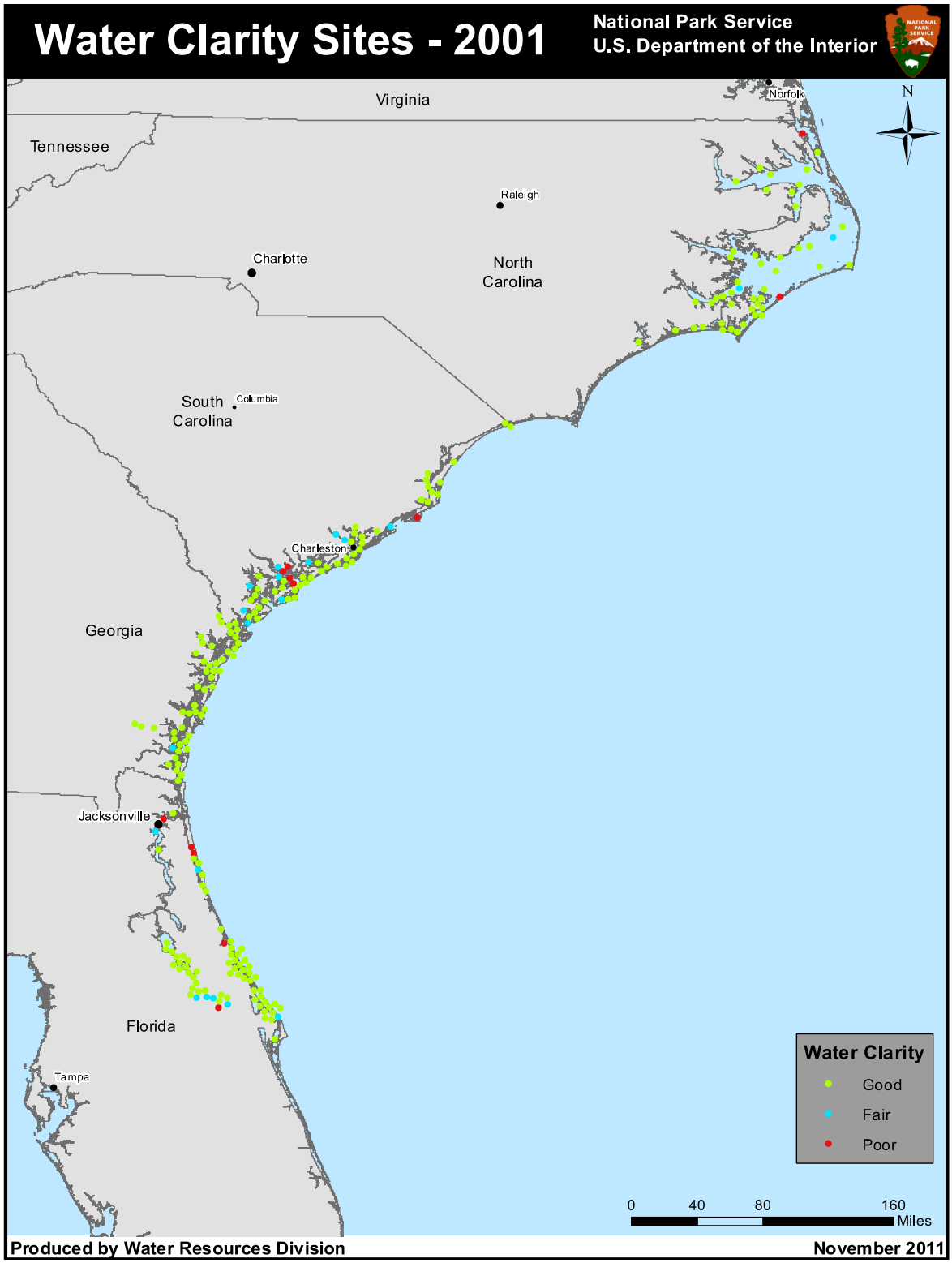


Figure 62. Synoptic sampling map of water clarity, measured by Secchi depth, for the southeast coastal region (2001). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

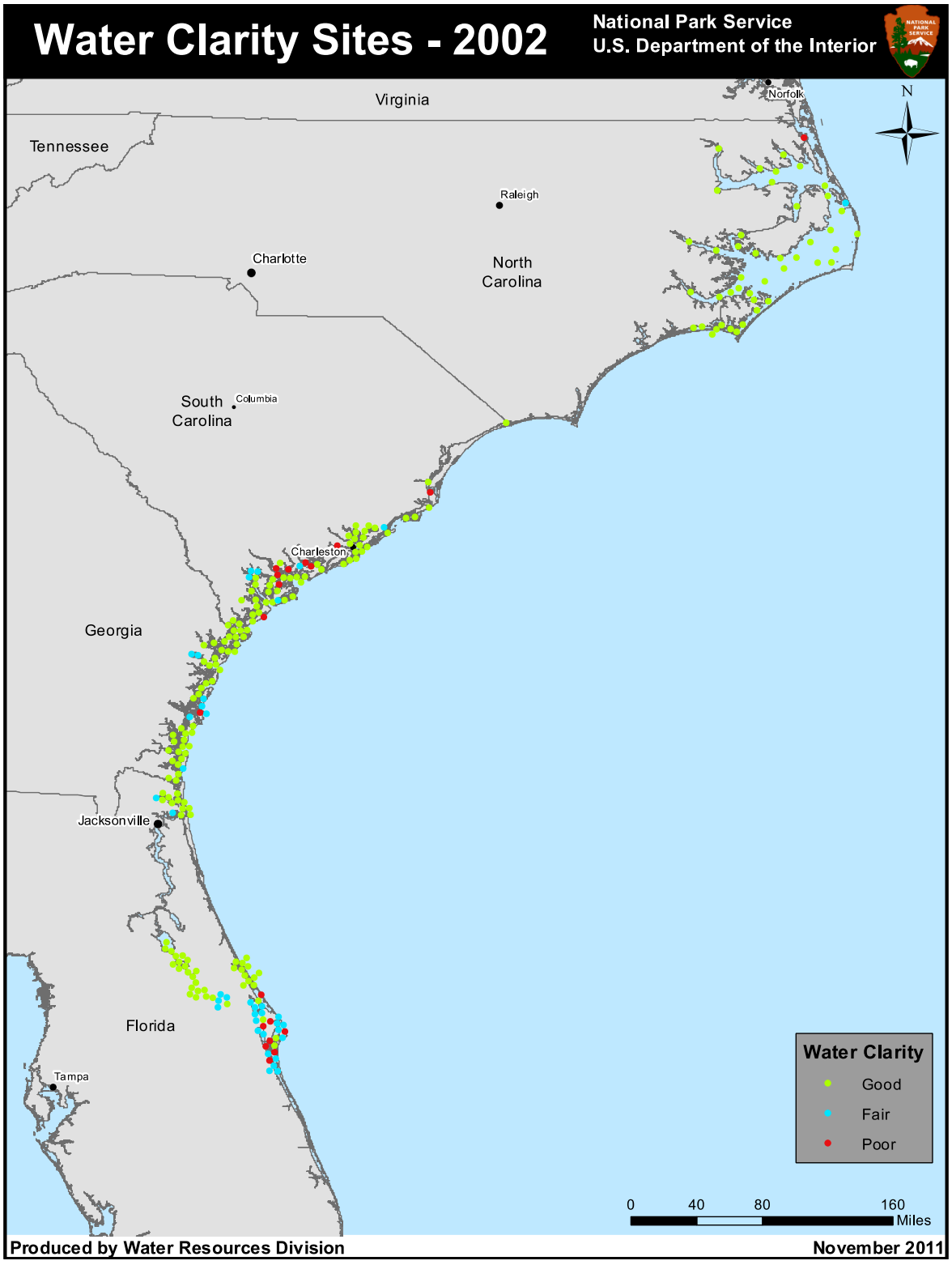


Figure 63. Synoptic sampling map of water clarity, measured by Secchi depth, for the southeast coastal region (2002). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

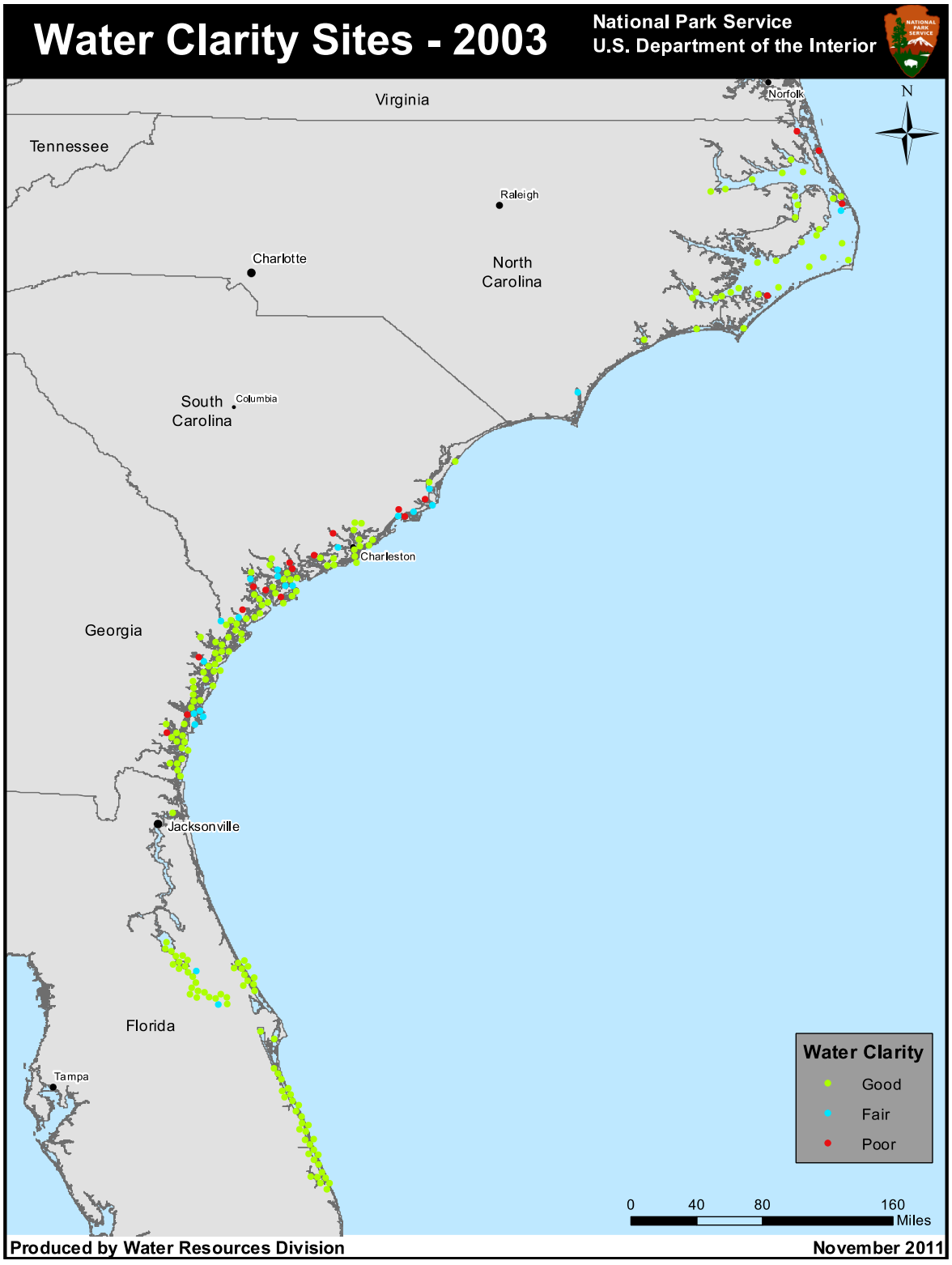


Figure 64. Synoptic sampling map of water clarity, measured by Secchi depth, for the southeast coastal region (2003). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

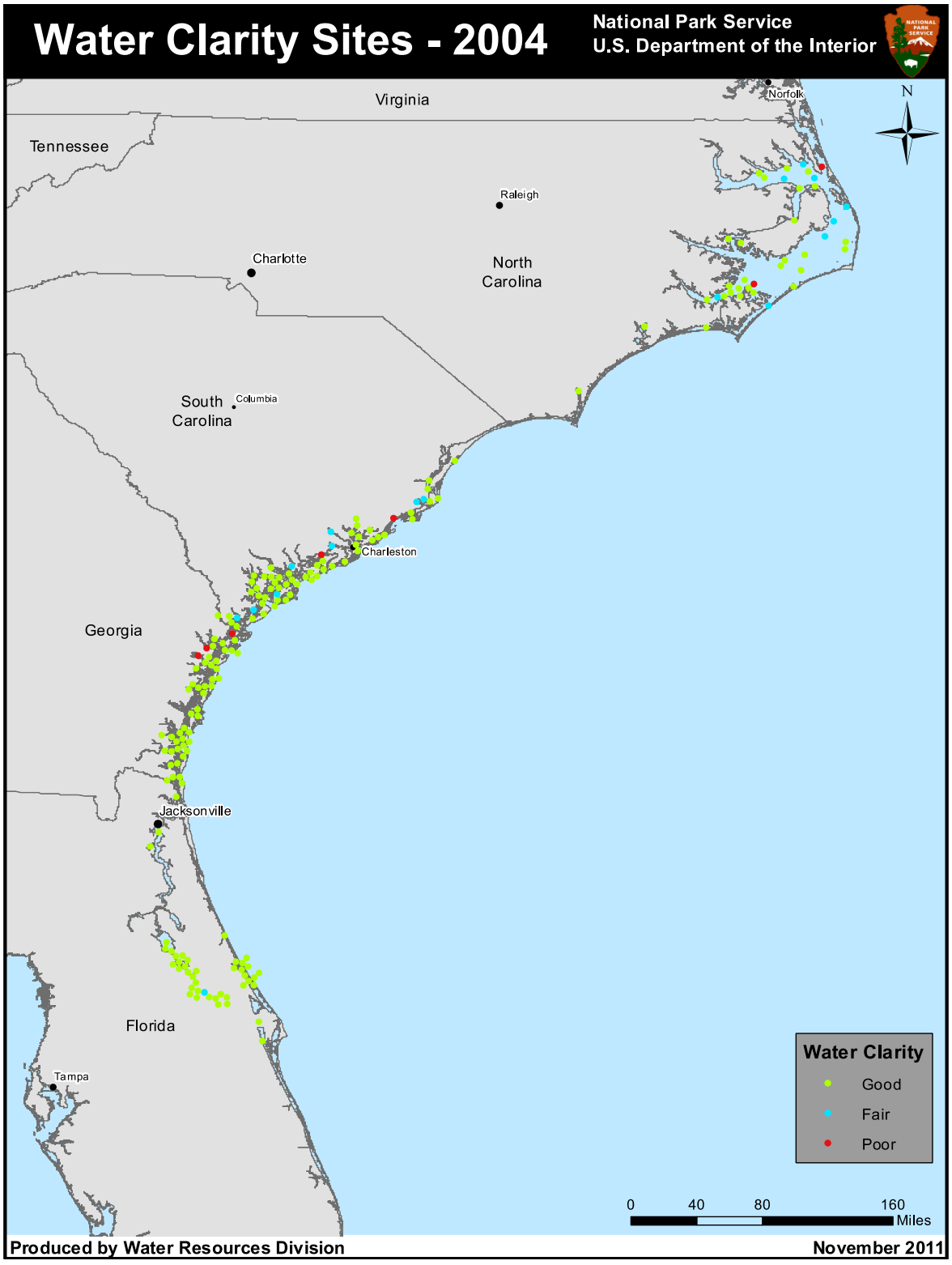


Figure 65. Synoptic sampling map of water clarity, measured by Secchi depth, for the southeast coastal region (2004). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

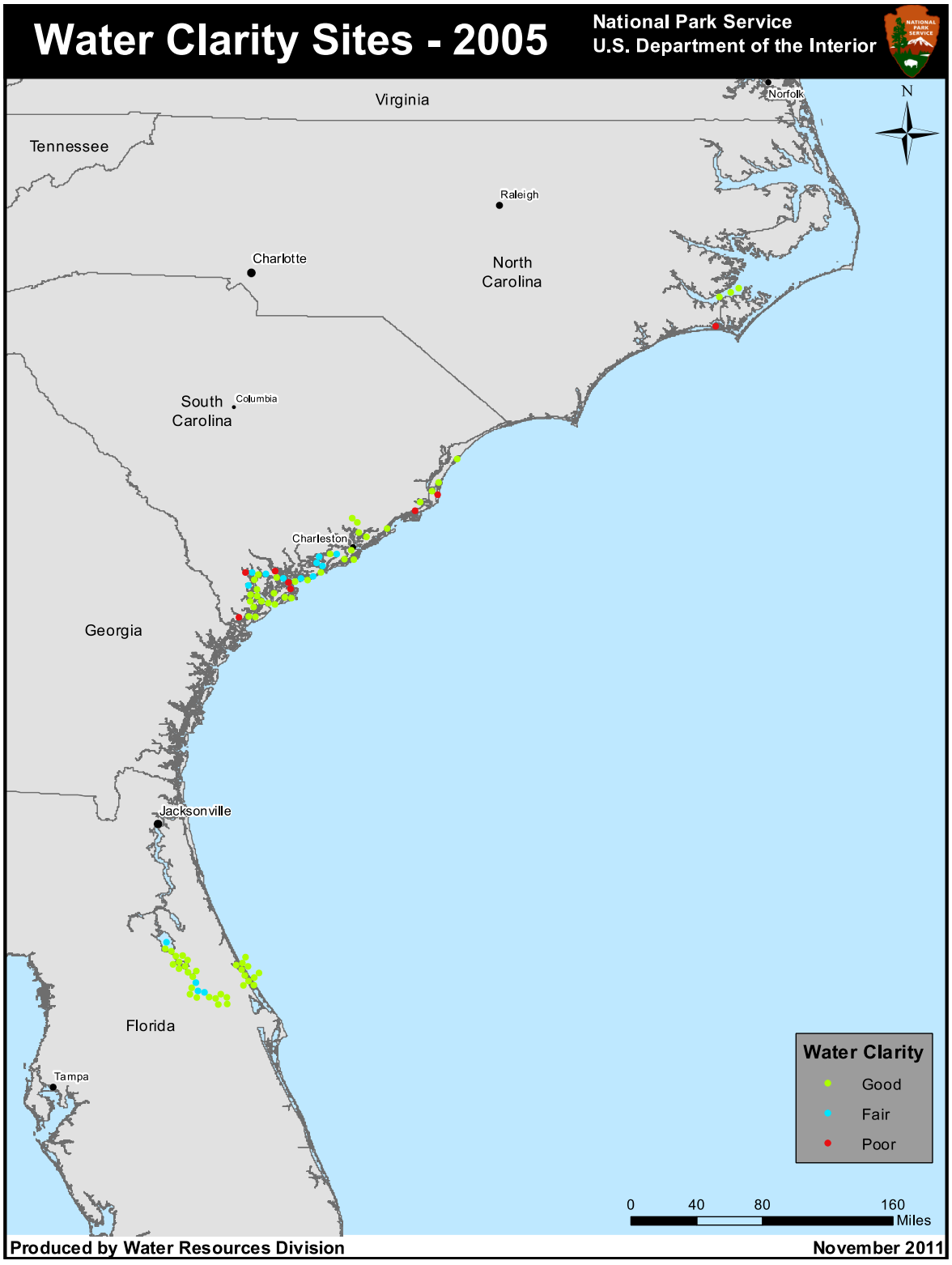


Figure 66. Synoptic sampling map of water clarity, measured by Secchi depth, for the southeast coastal region (2005). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

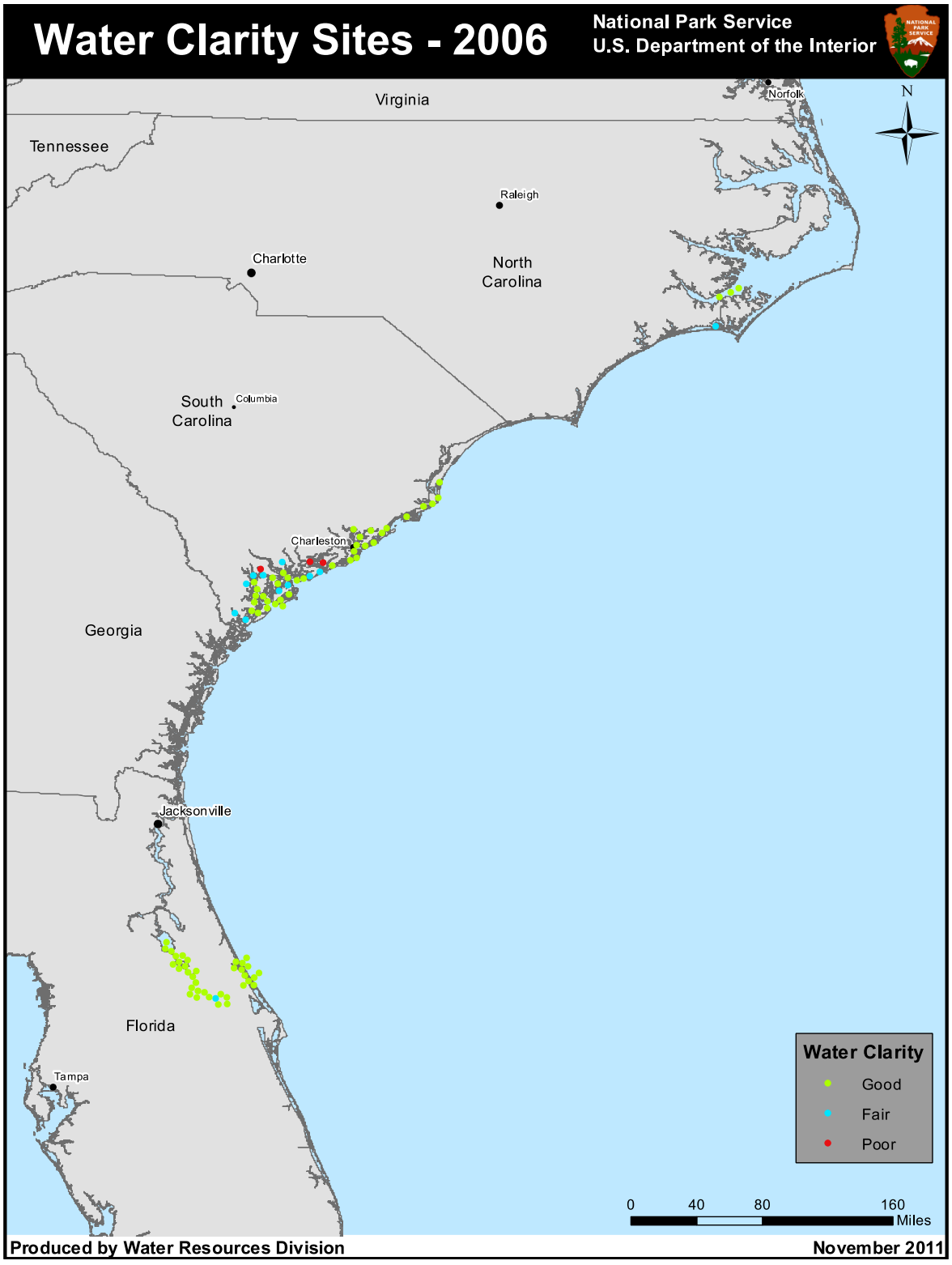


Figure 67. Synoptic sampling map of water clarity, measured by Secchi depth, for the southeast coastal region (2006). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

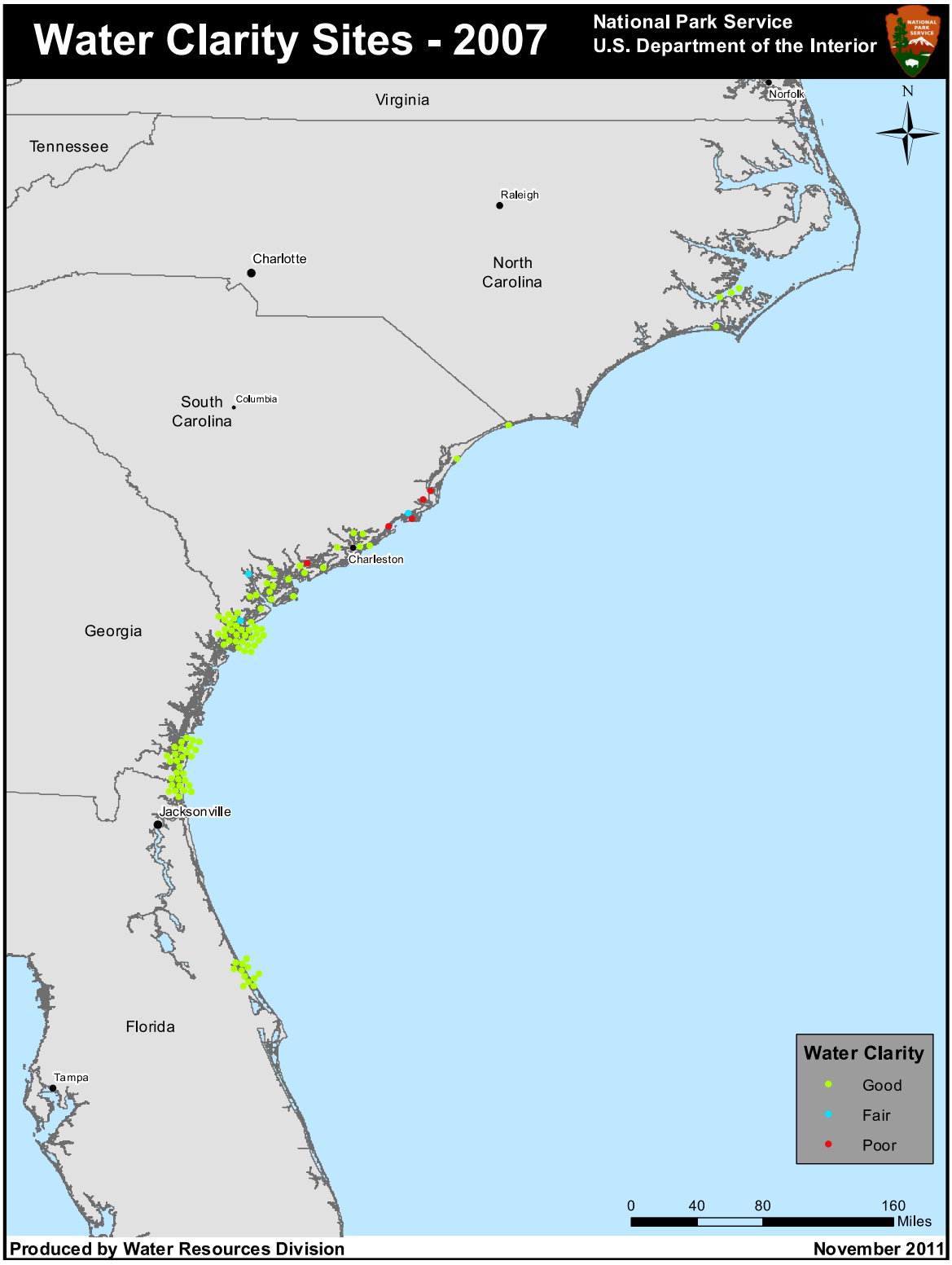


Figure 68. Synoptic sampling map of water clarity, measured by Secchi depth, for the southeast coastal region (2007). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

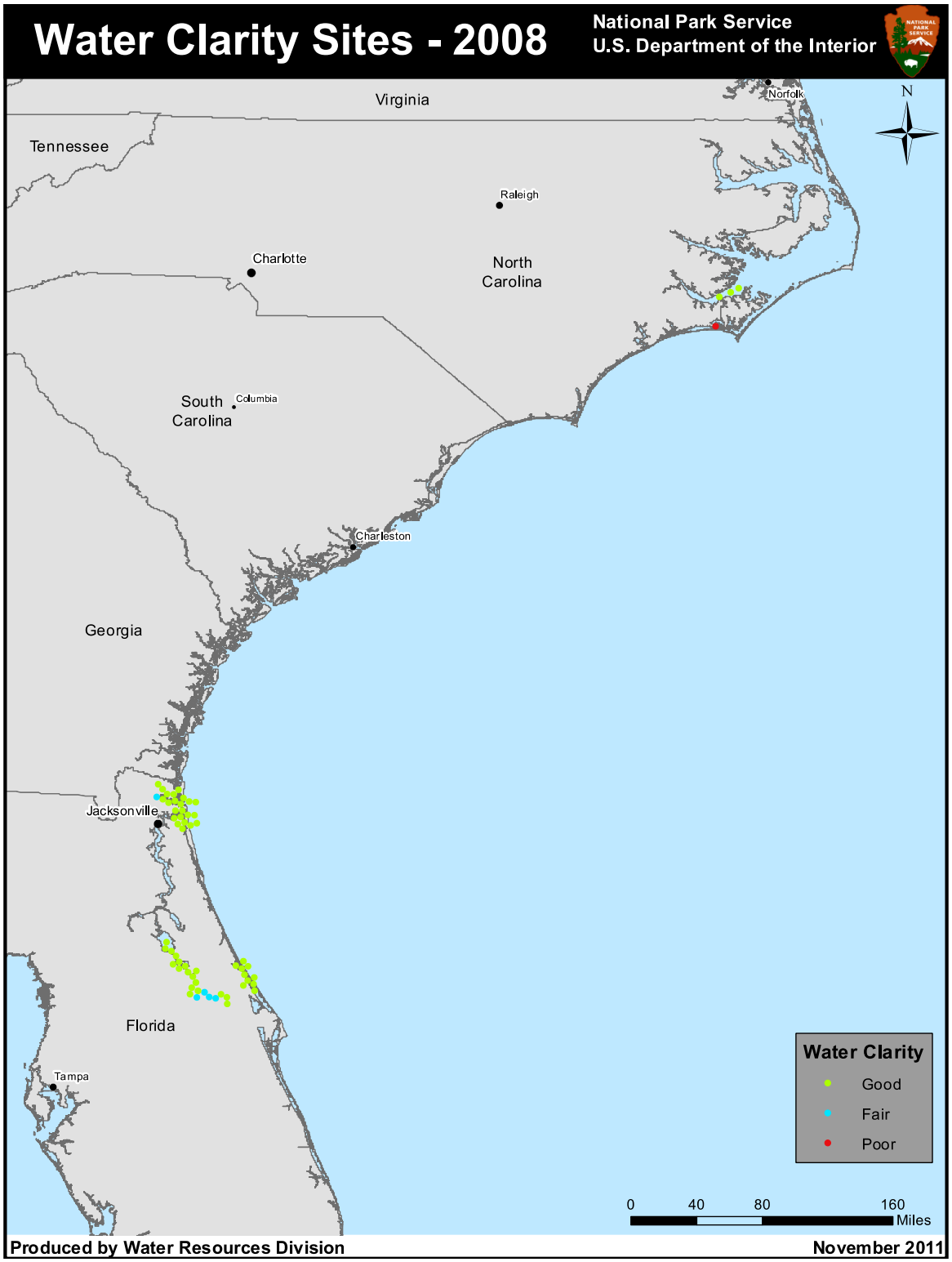


Figure 69. Synoptic sampling map of water clarity, measured by Secchi depth, for the southeast coastal region (2008). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

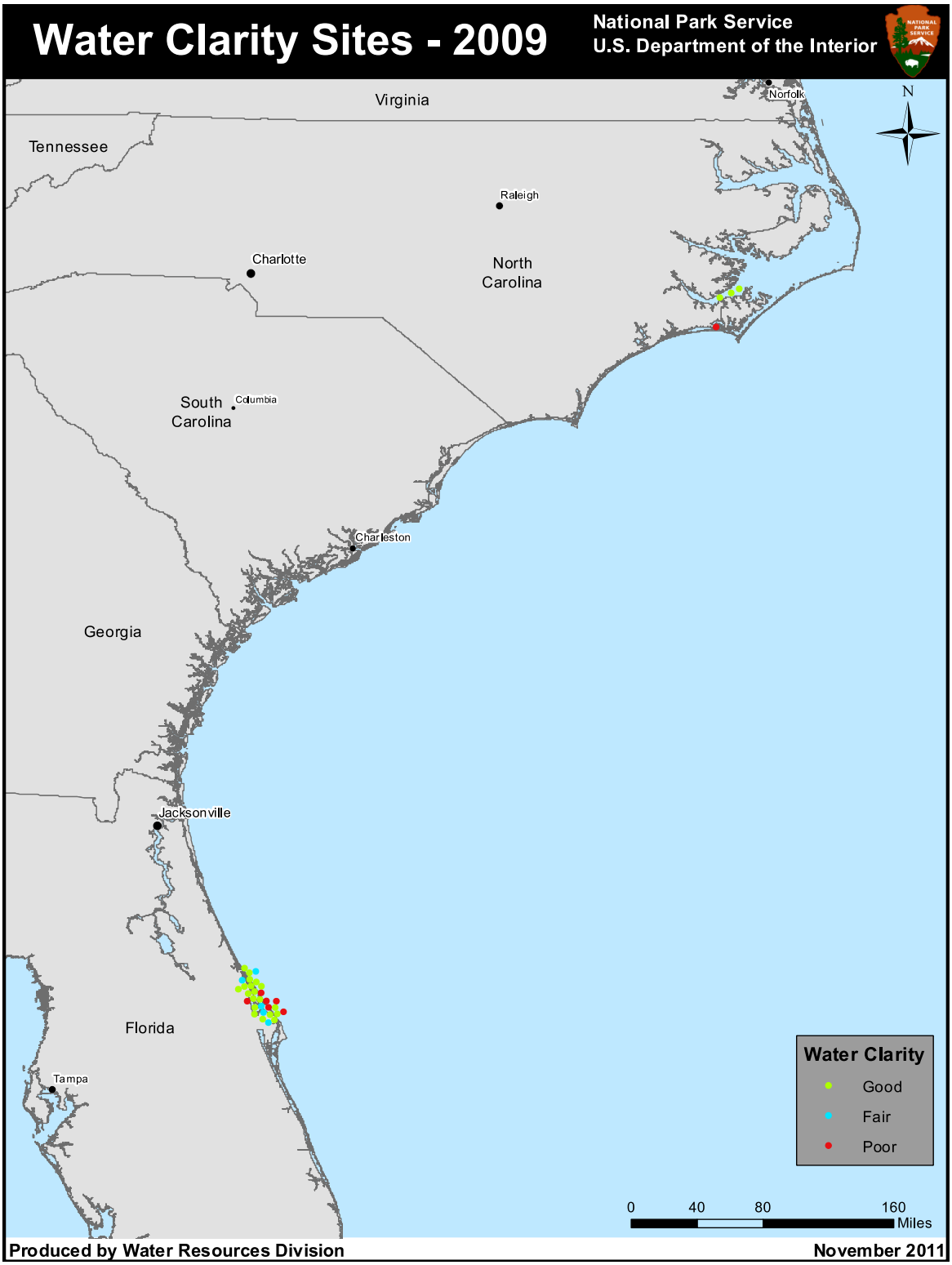


Figure 70. Synoptic sampling map of water clarity, measured by Secchi depth, for the southeast coastal region (2009). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

Appendix C: Sediment Survey Synoptic Results

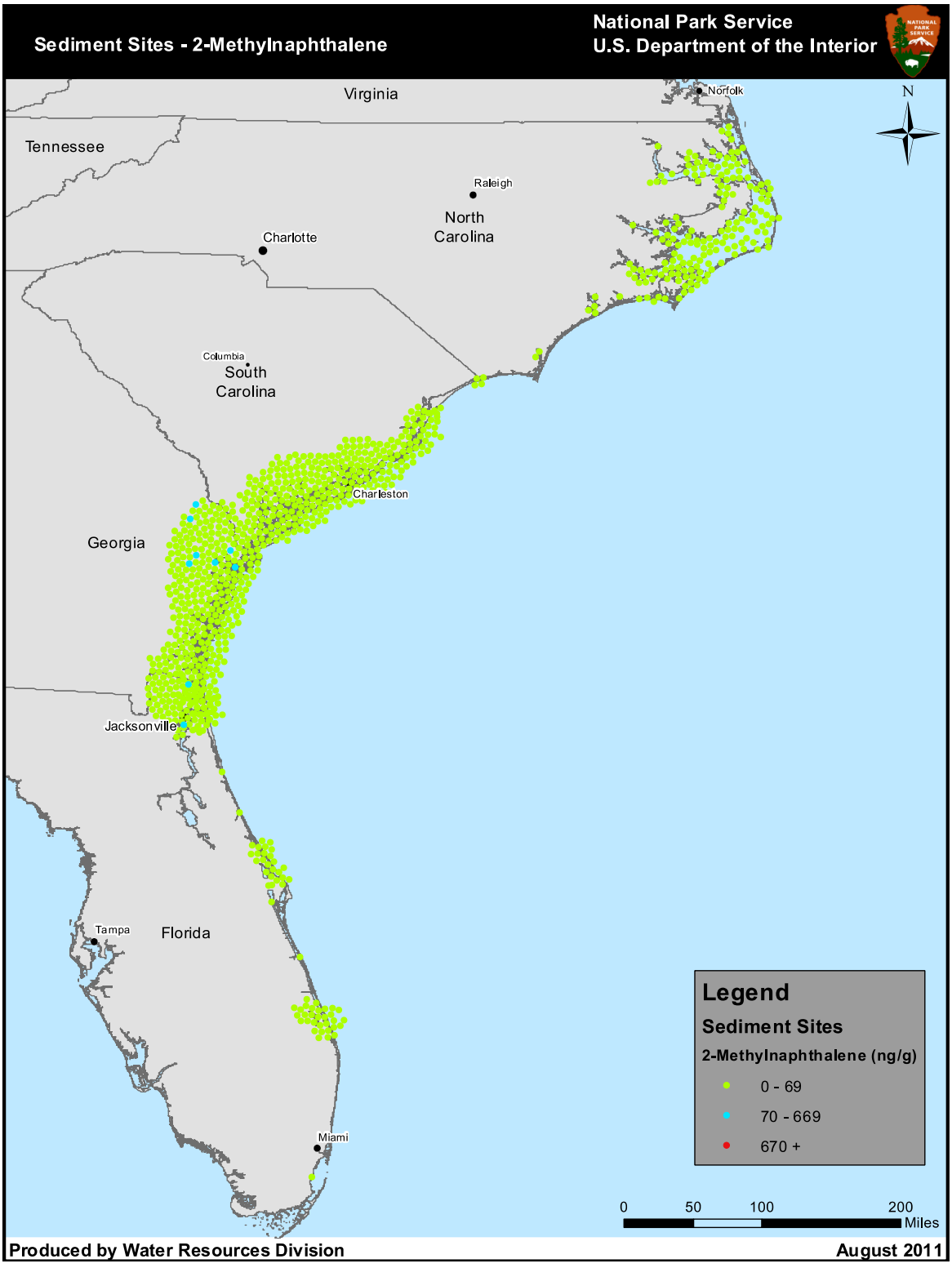


Figure 71. Synoptic sampling map of 2-methylnaphthalene sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

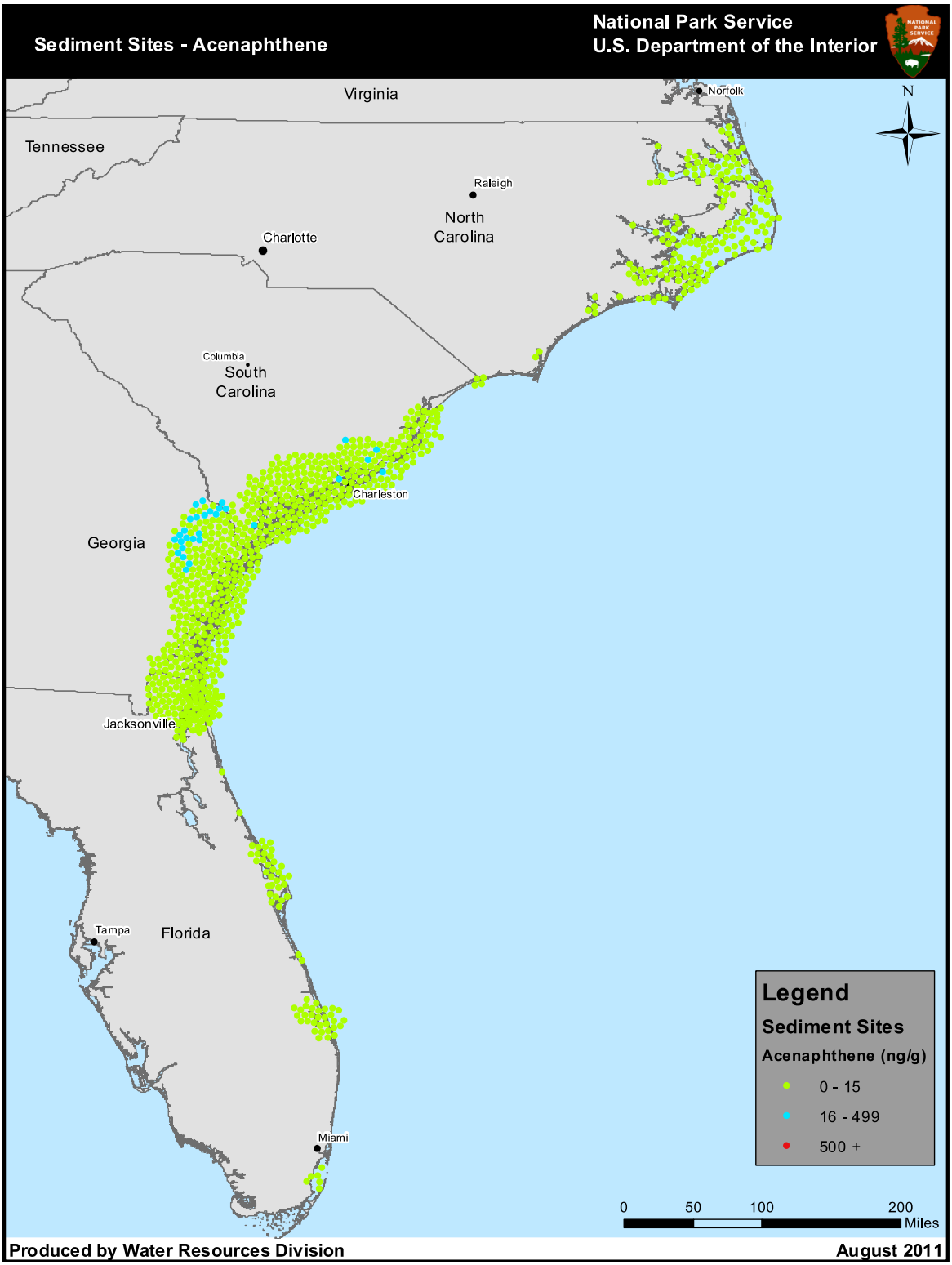


Figure 72. Synoptic sampling map of acenaphthene sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

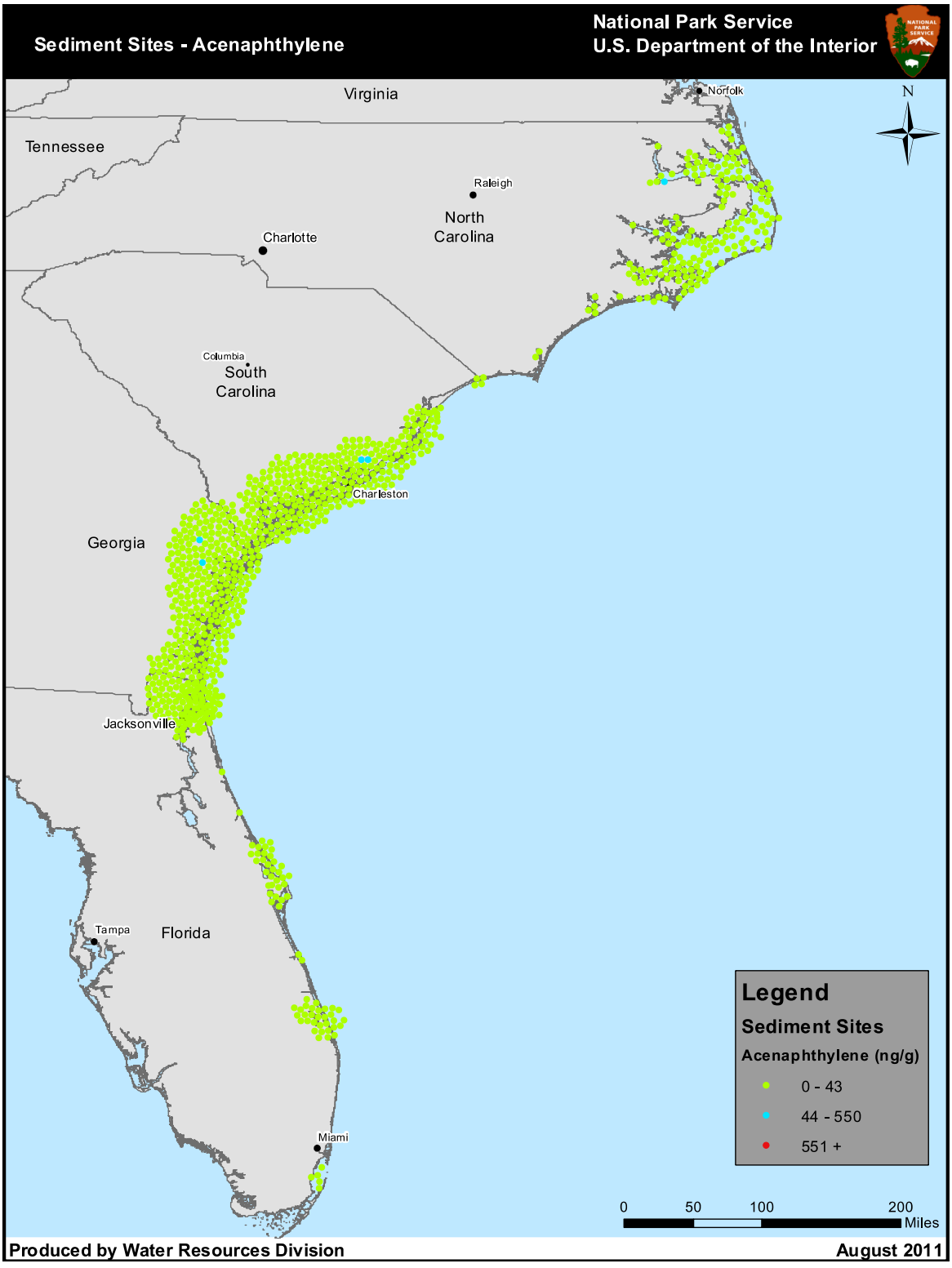


Figure 73. Synoptic sampling map of acenaphthylene sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

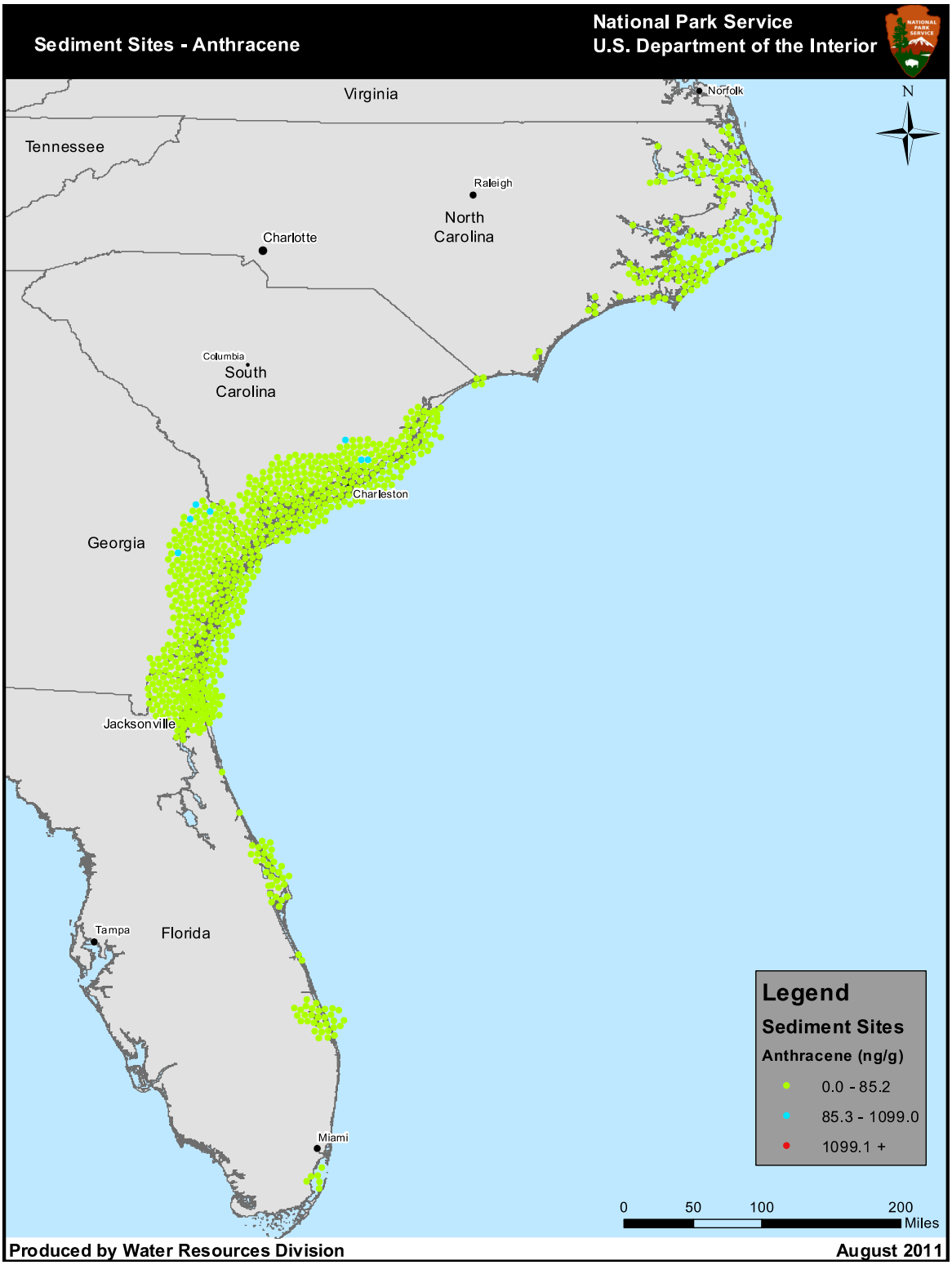


Figure 74. Synoptic sampling map of anthracene sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

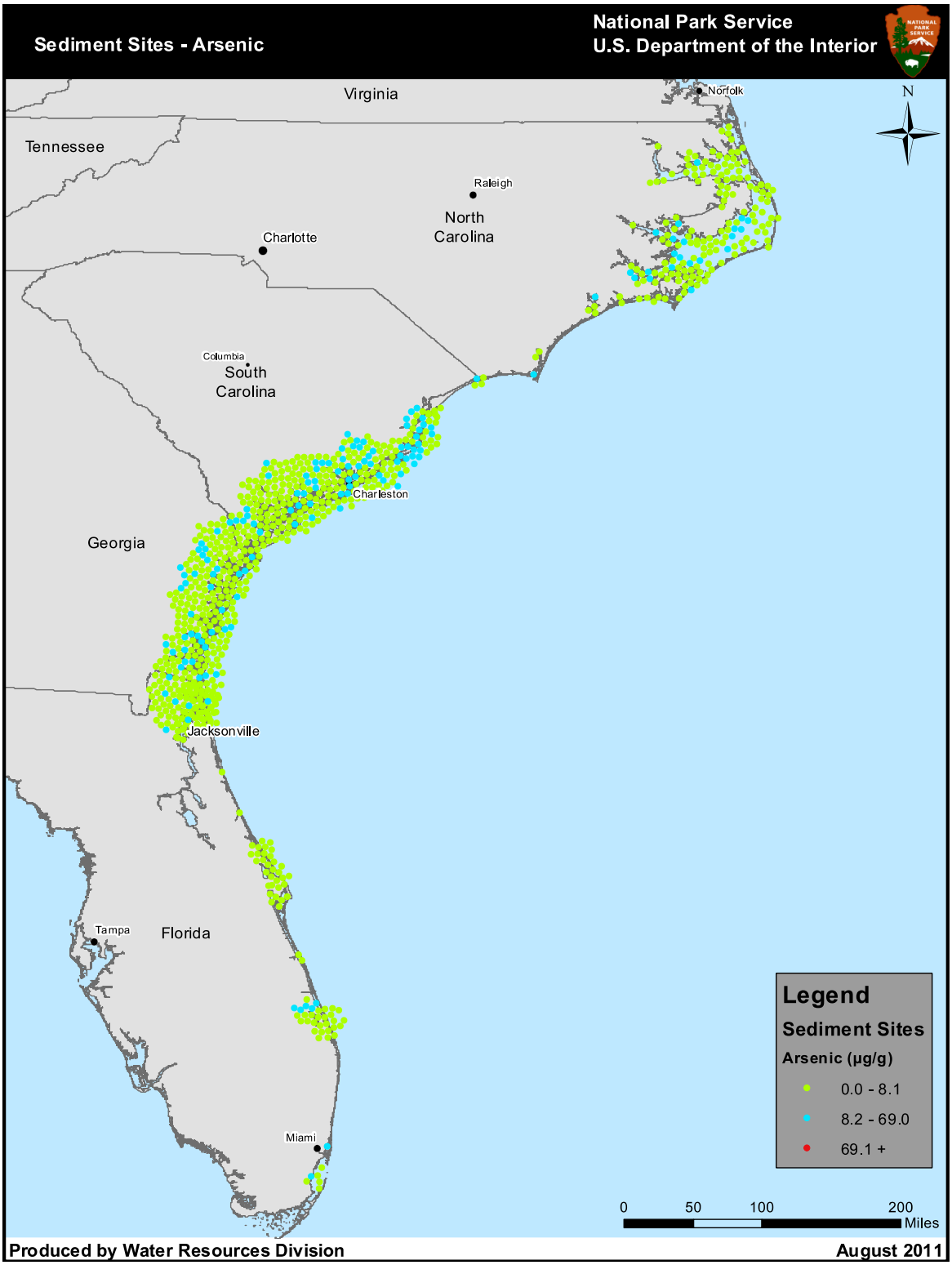


Figure 75. Synoptic sampling map of arsenic sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

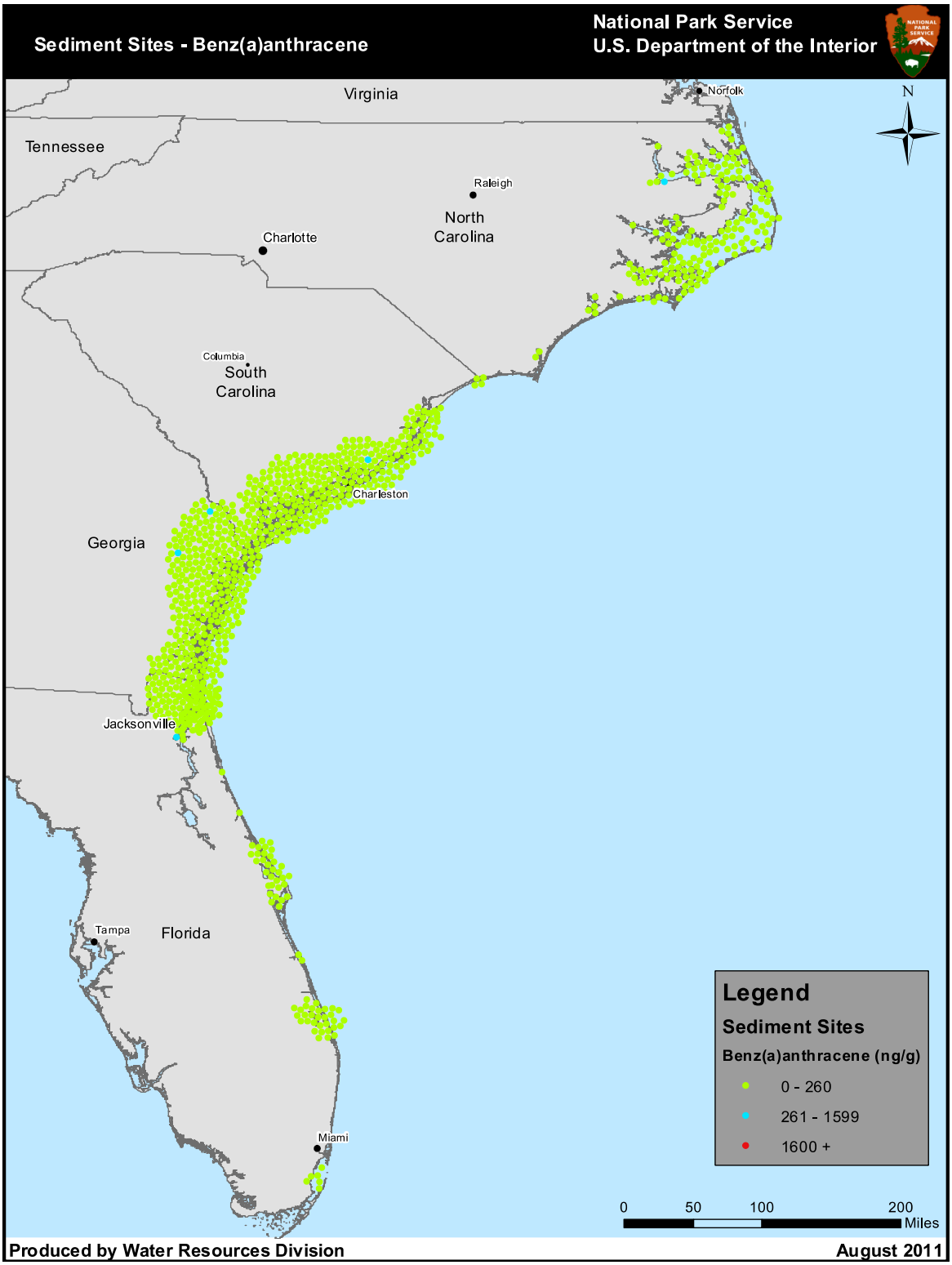


Figure 76. Synoptic sampling map of benz(a)anthracene sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

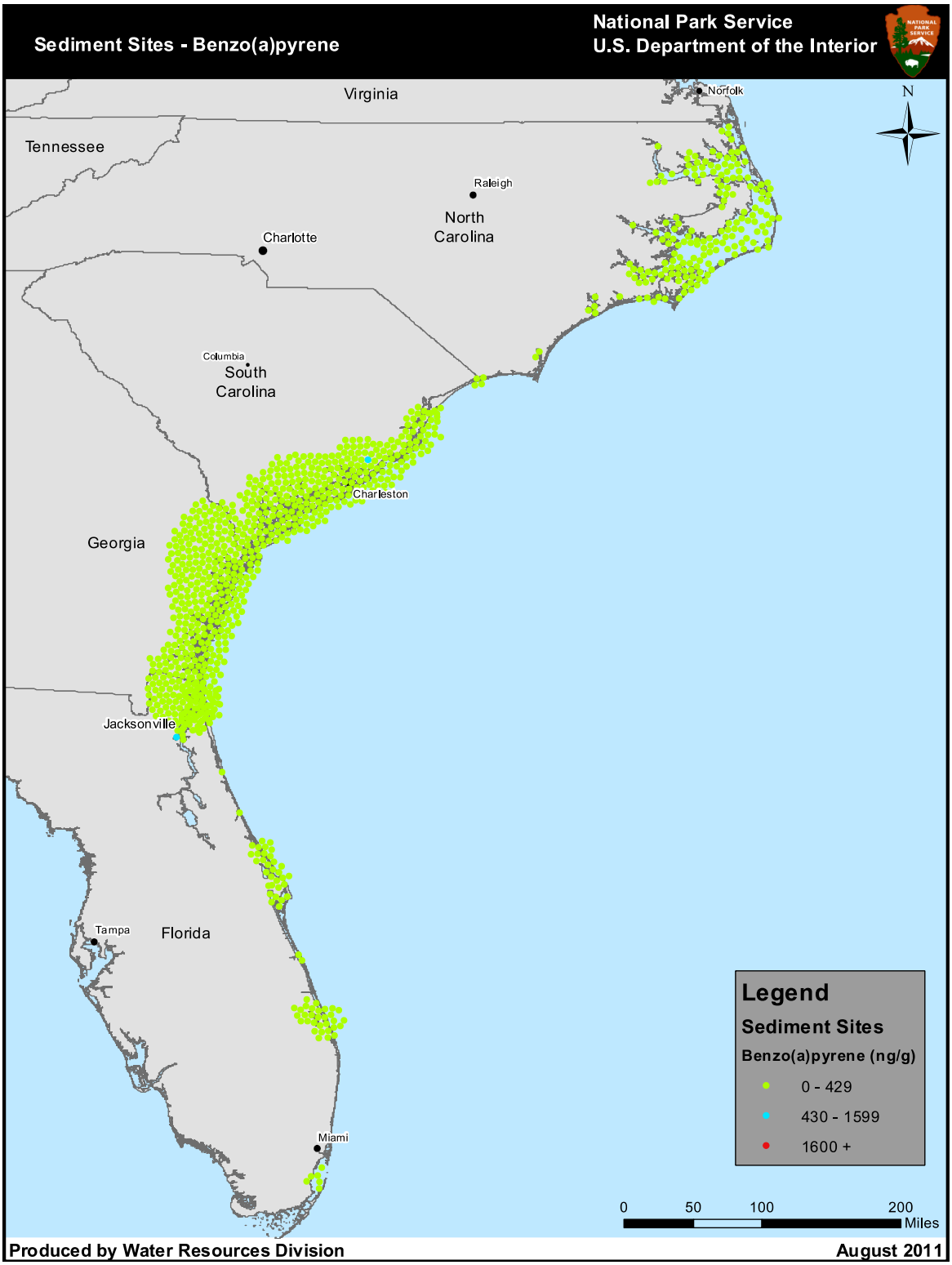


Figure 77. Synoptic sampling map of benz(a)pyrene sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

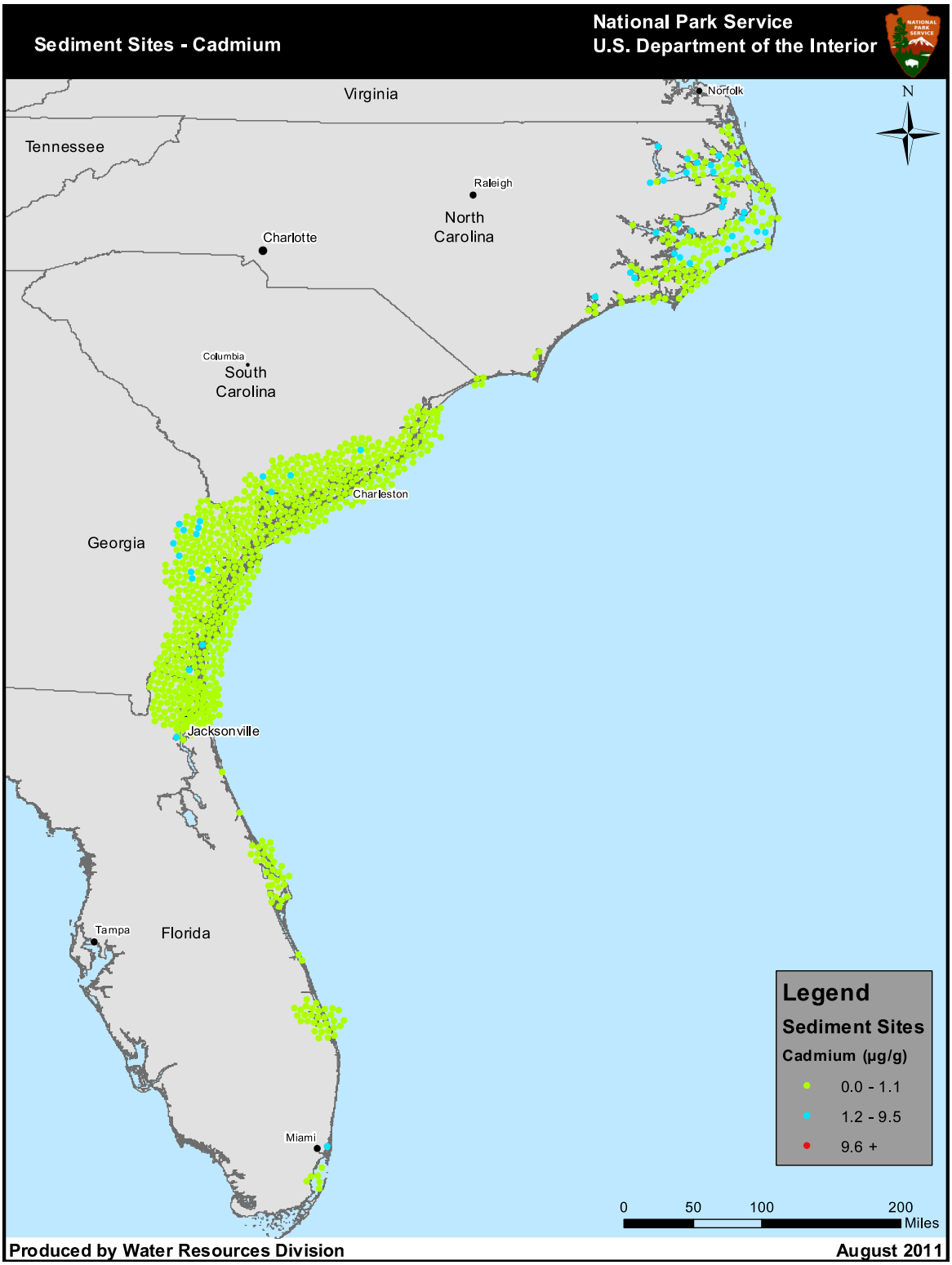


Figure 78. Synoptic sampling map of cadmium sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

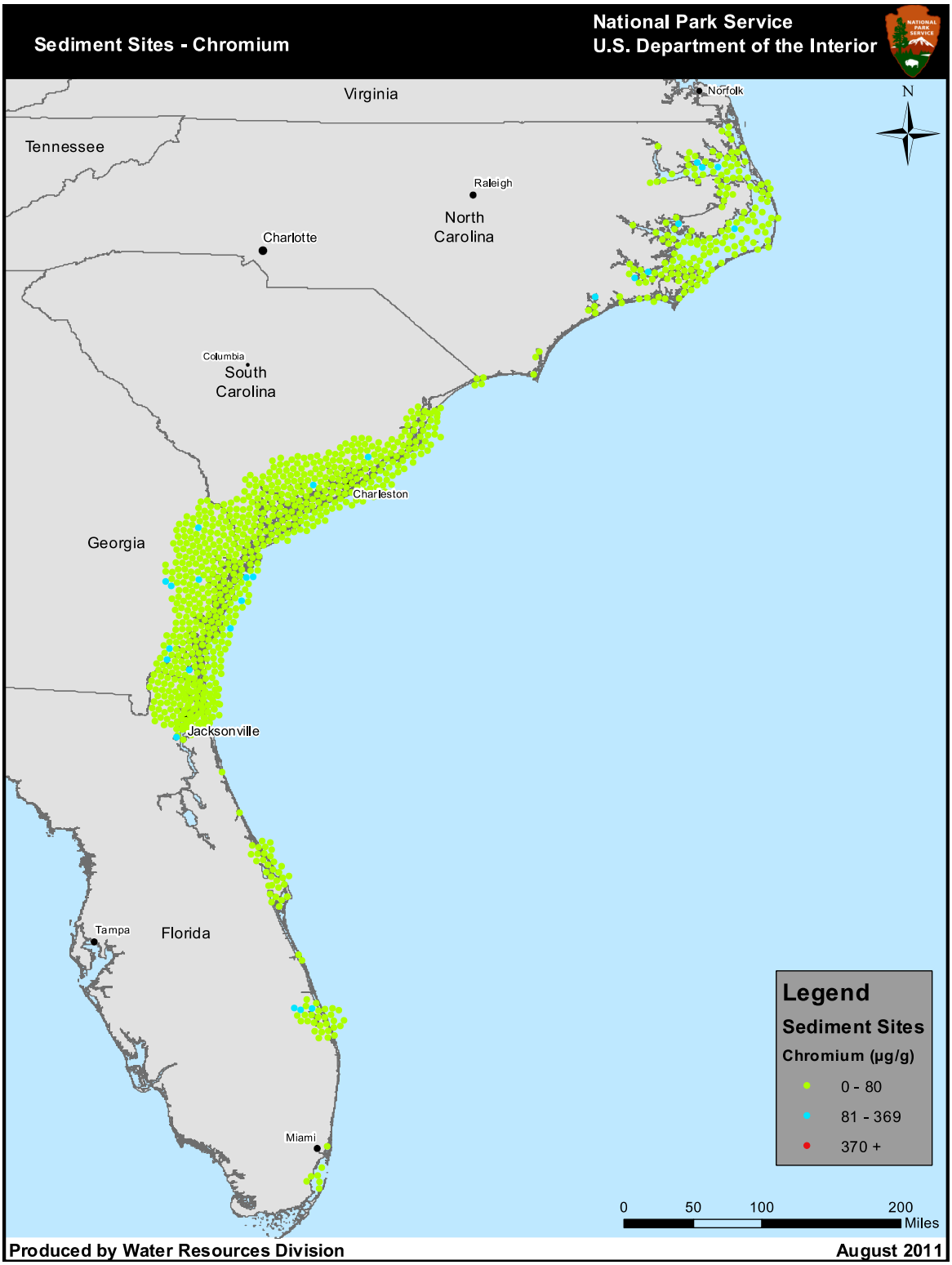


Figure 79. Synoptic sampling map of chromium sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

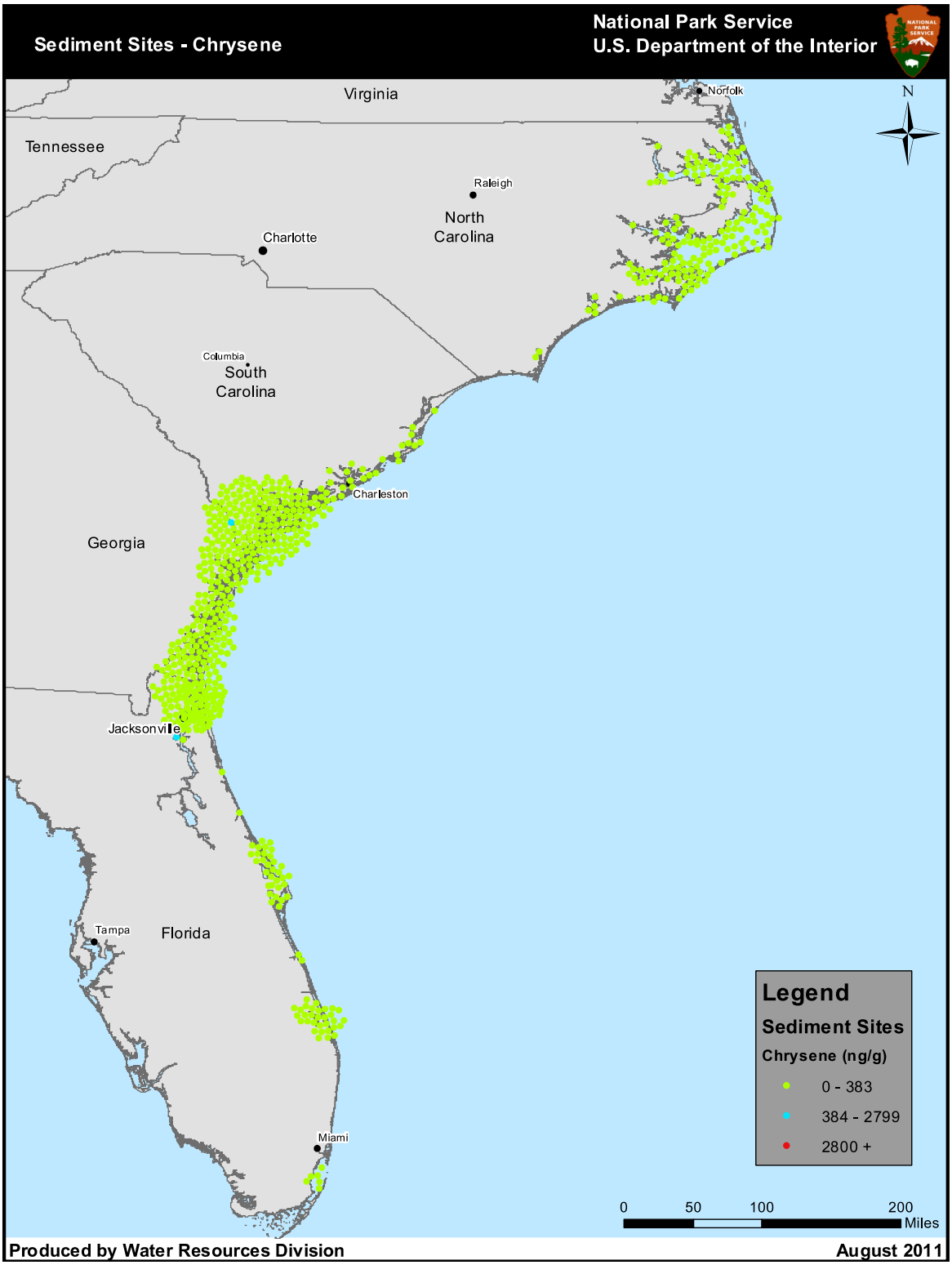


Figure 80. Synoptic sampling map of chrysene sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

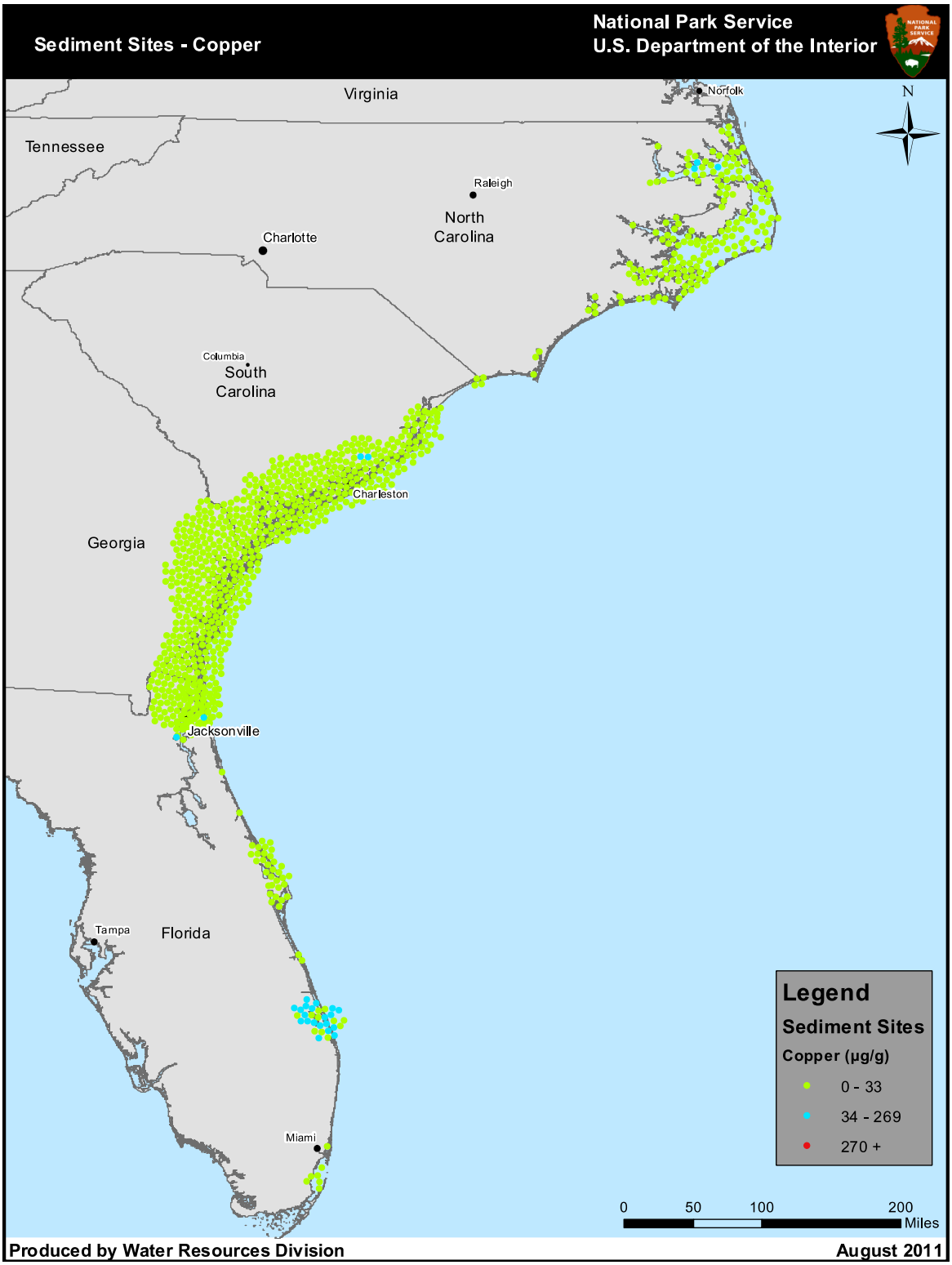


Figure 81. Synoptic sampling map of copper sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

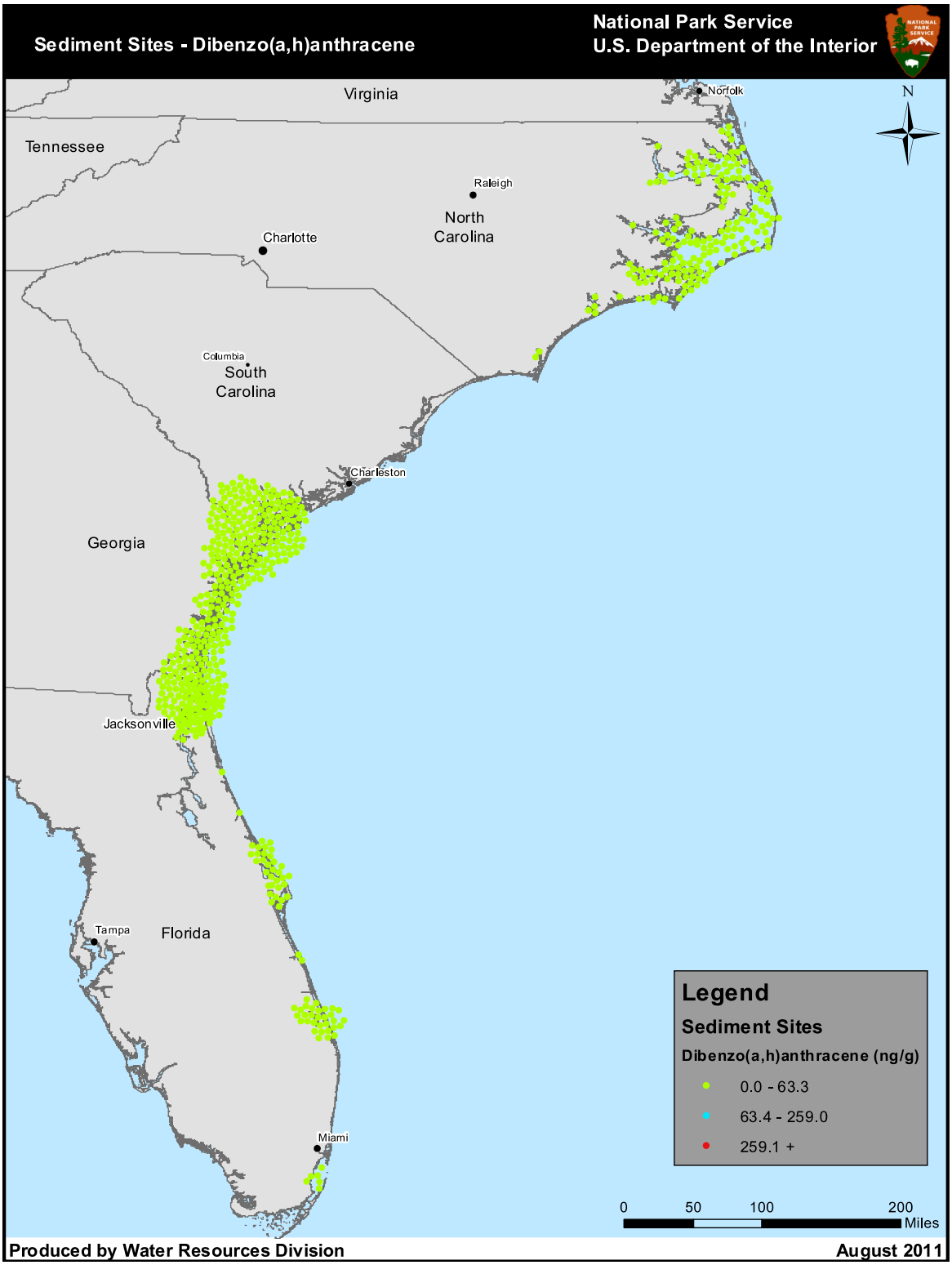


Figure 82. Synoptic sampling map of dibenzo(a,h)anthracene sediment quality for the southeast coastal region (2000-2010). The green sites are “good,” blue is “fair,” and red is “poor” sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

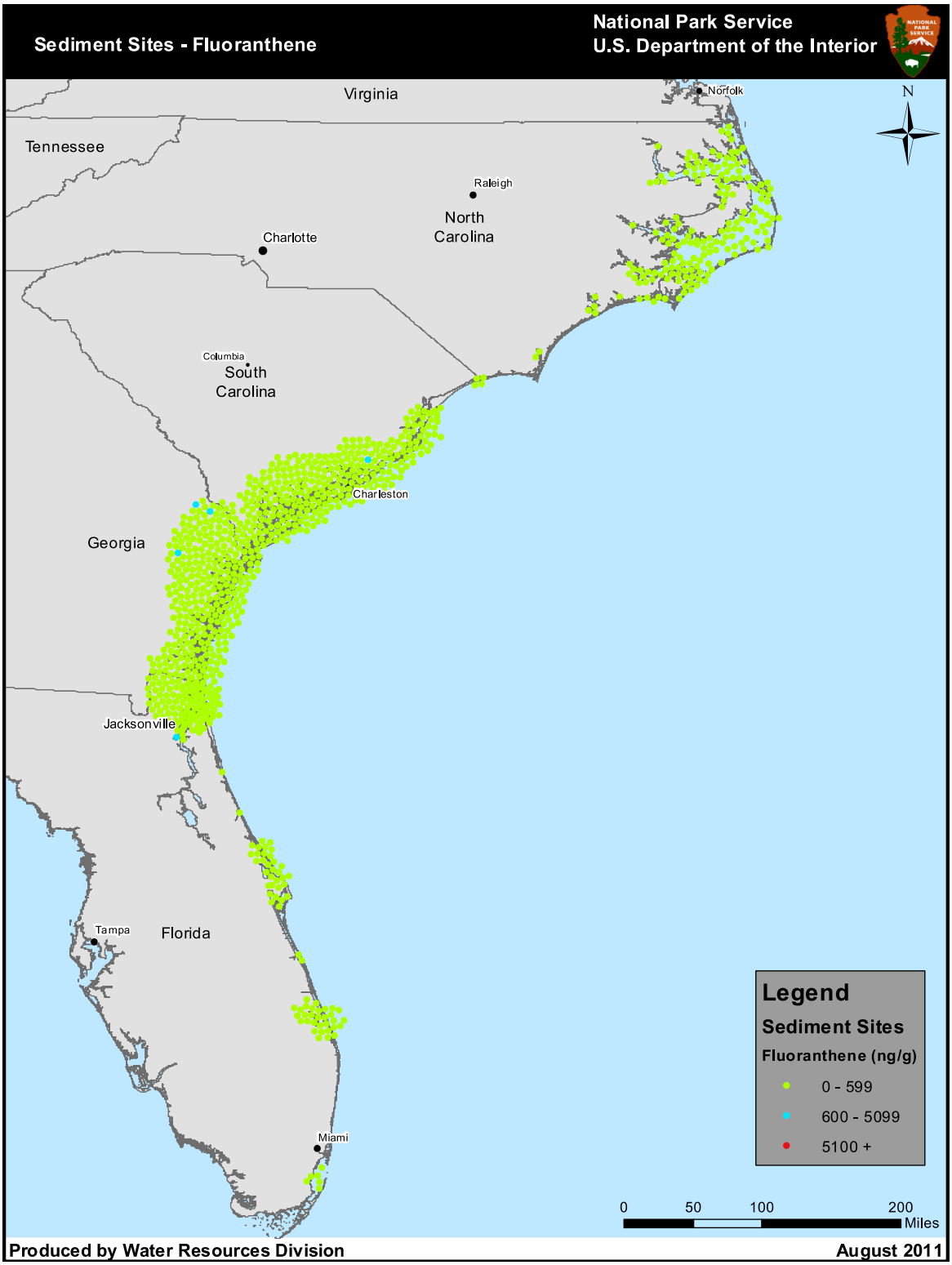


Figure 83. Synoptic sampling map of fluoranthene sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

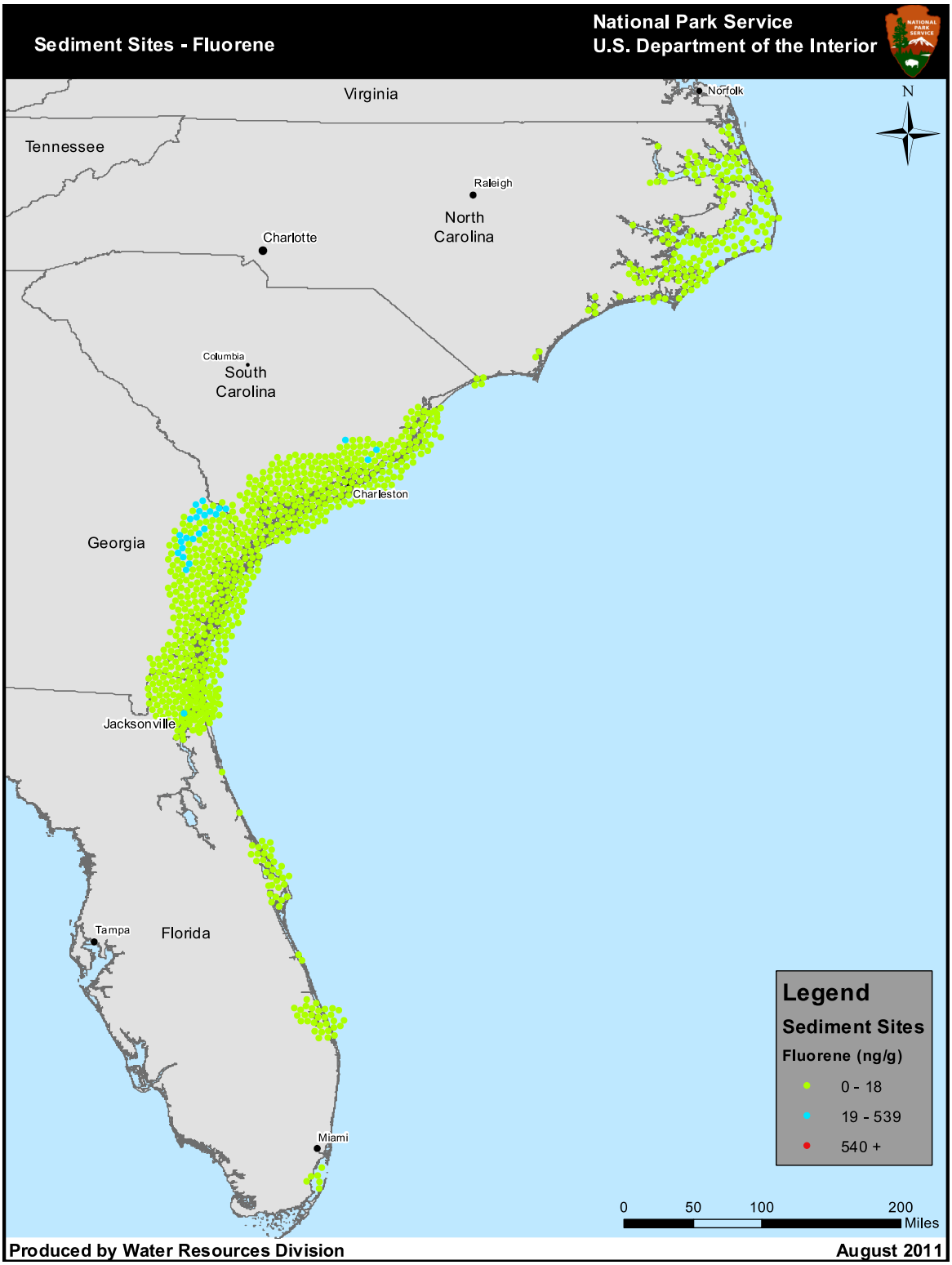


Figure 84. Synoptic sampling map of fluorene sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

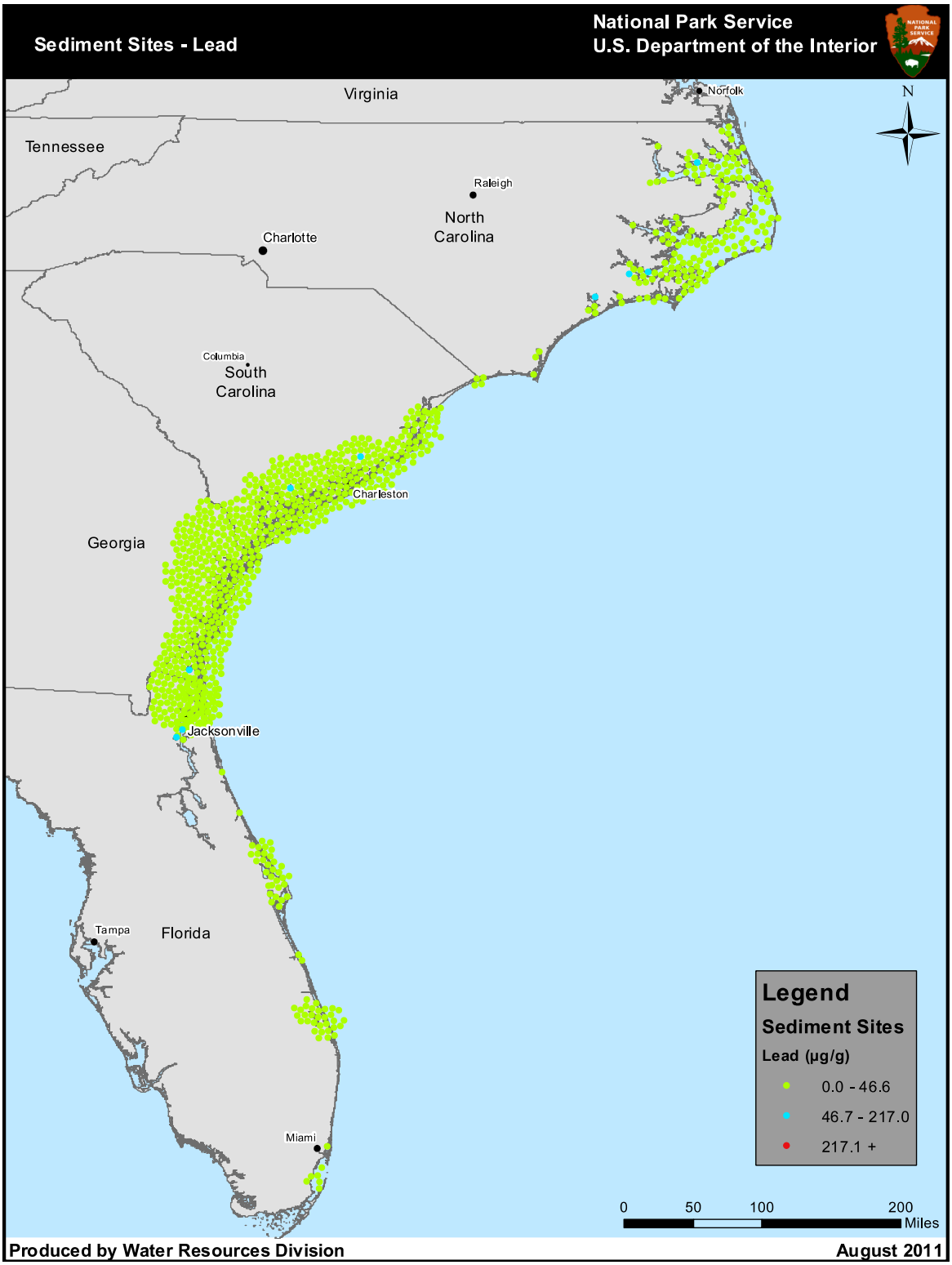


Figure 85. Synoptic sampling map of lead sediment quality for the southeast coastal region (2000-2010). The green sites are “good,” blue is “fair,” and red is “poor” sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

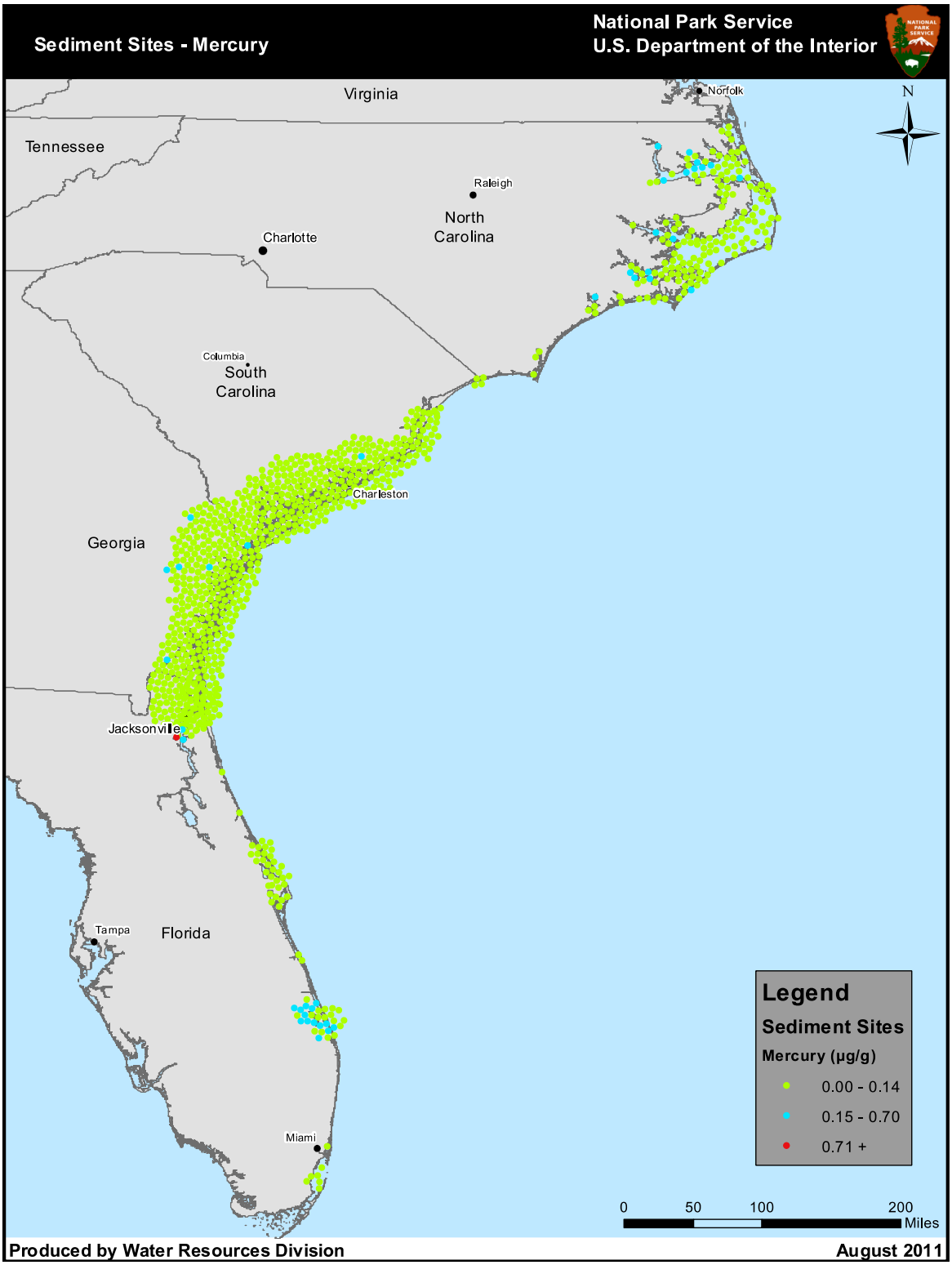


Figure 86. Synoptic sampling map of mercury sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

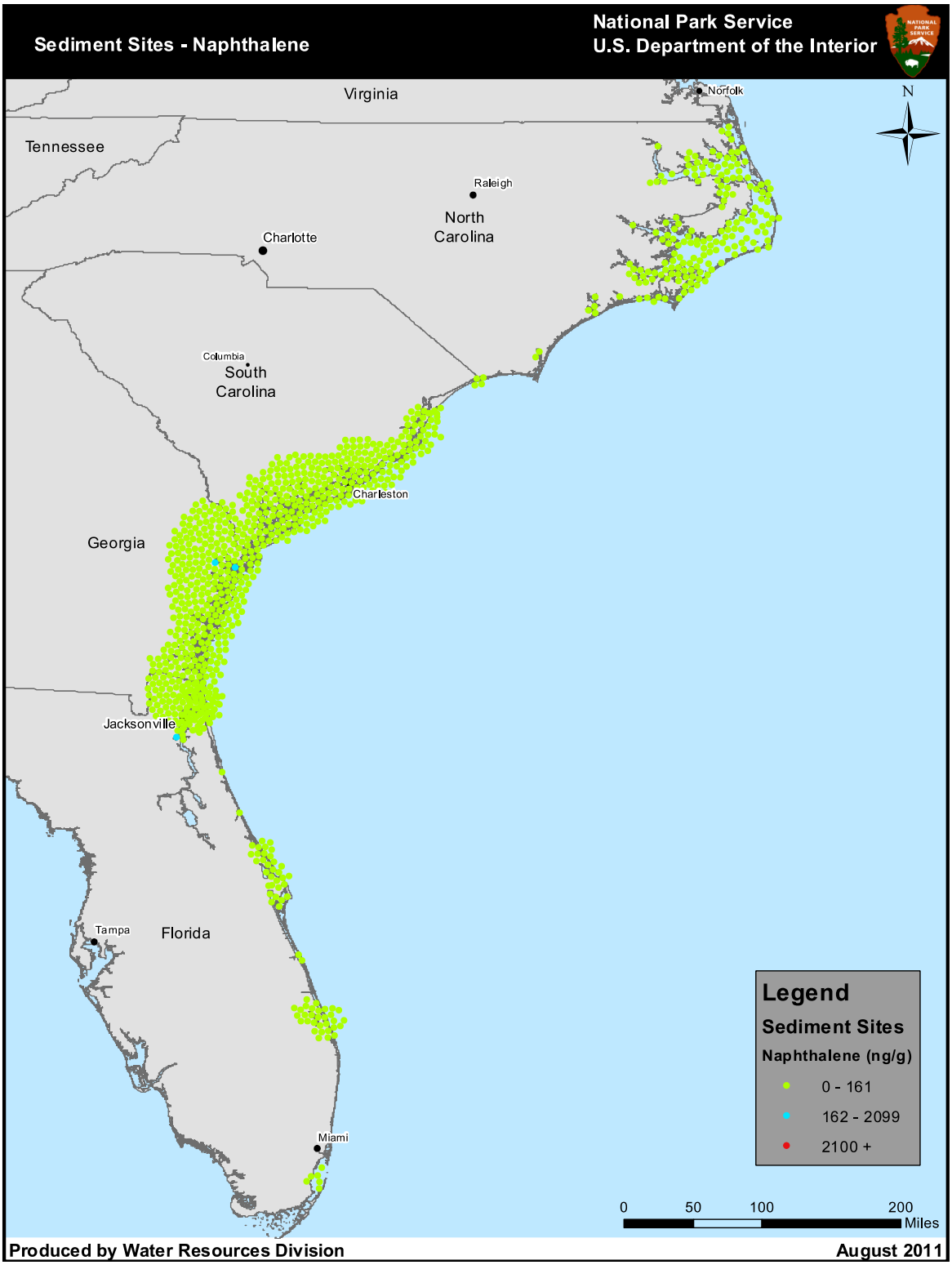


Figure 87. Synoptic sampling map of naphthalene sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

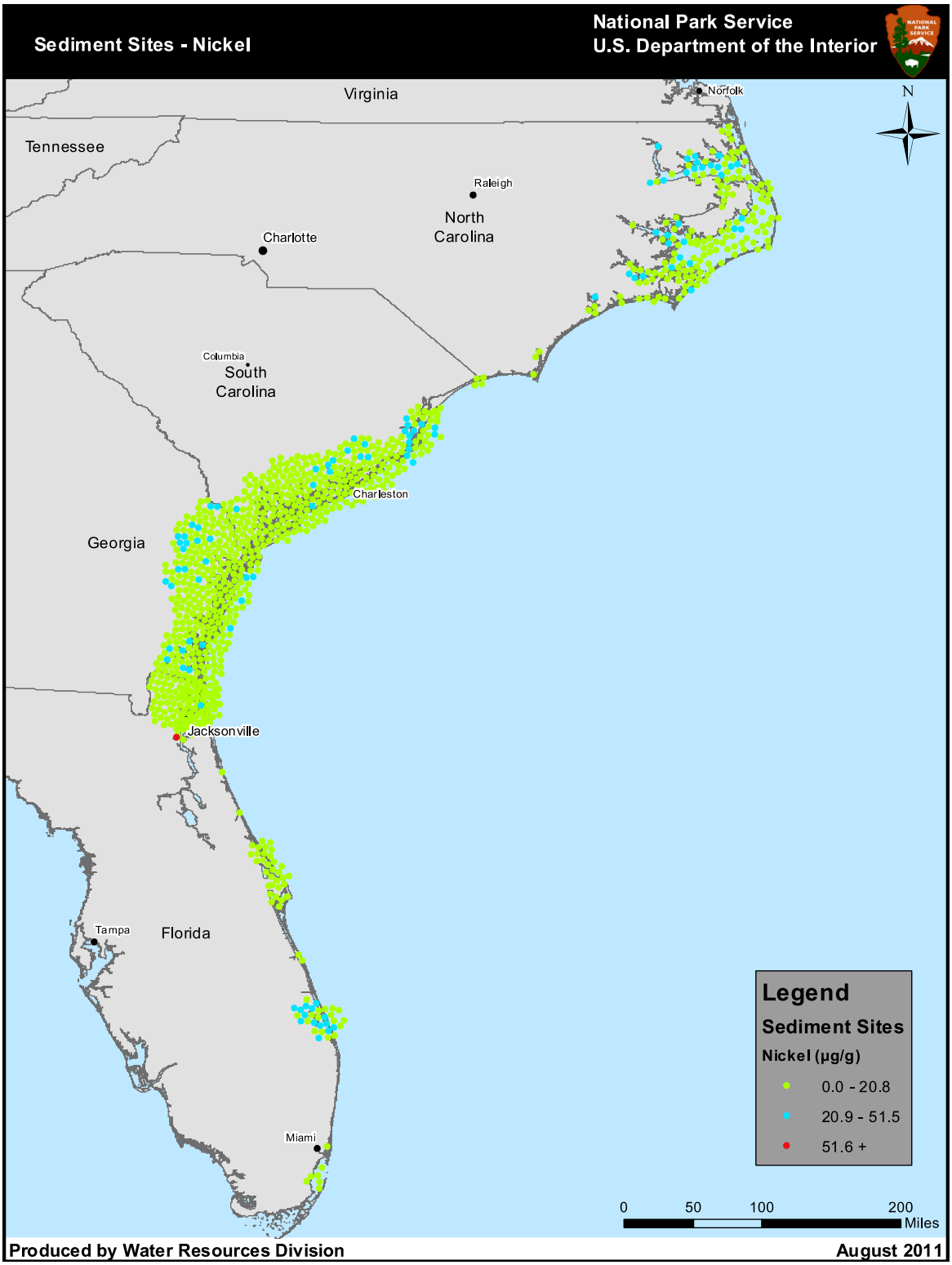


Figure 88. Synoptic sampling map of nickel sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

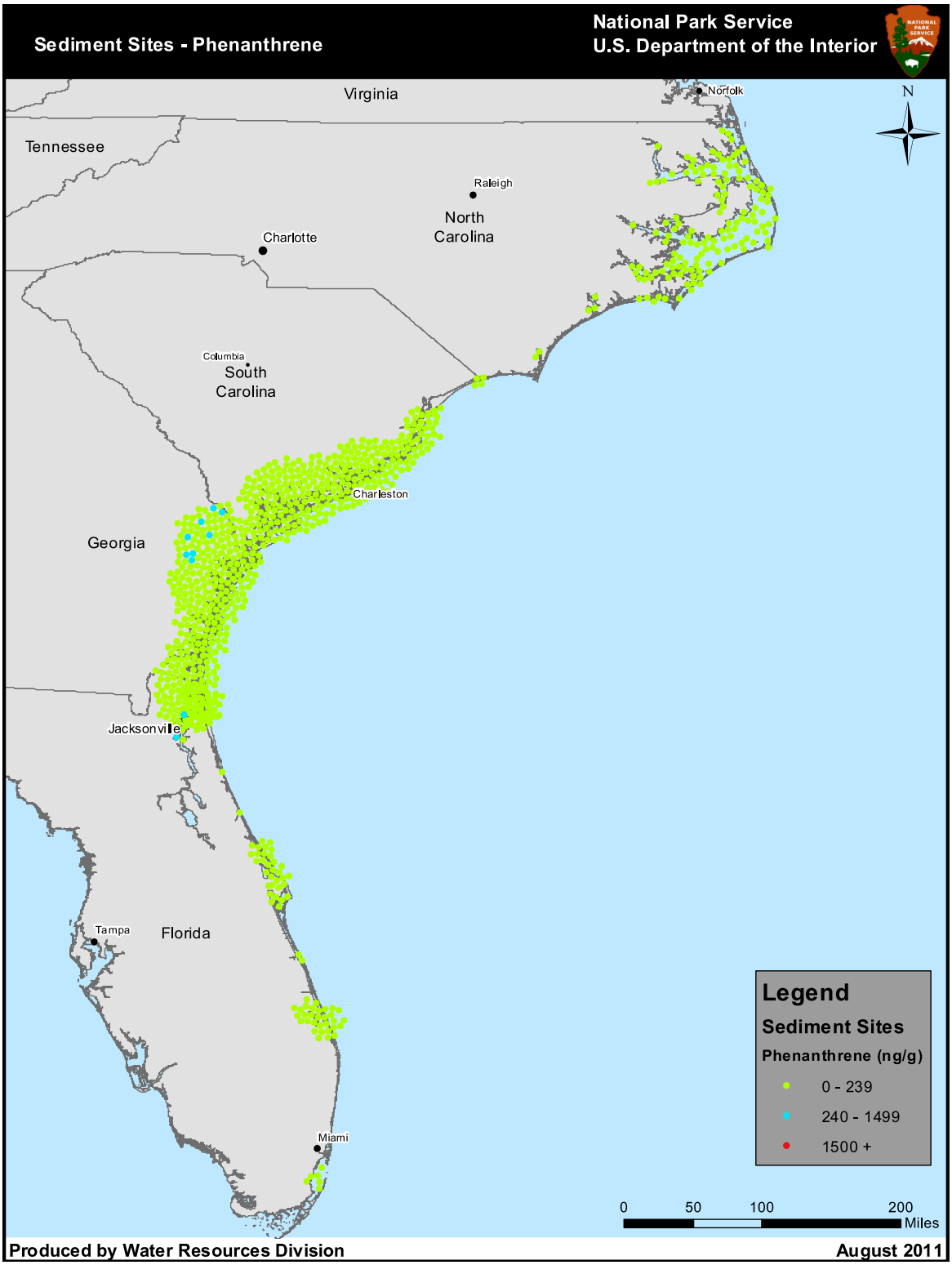


Figure 89. Synoptic sampling map of phenanthrene sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

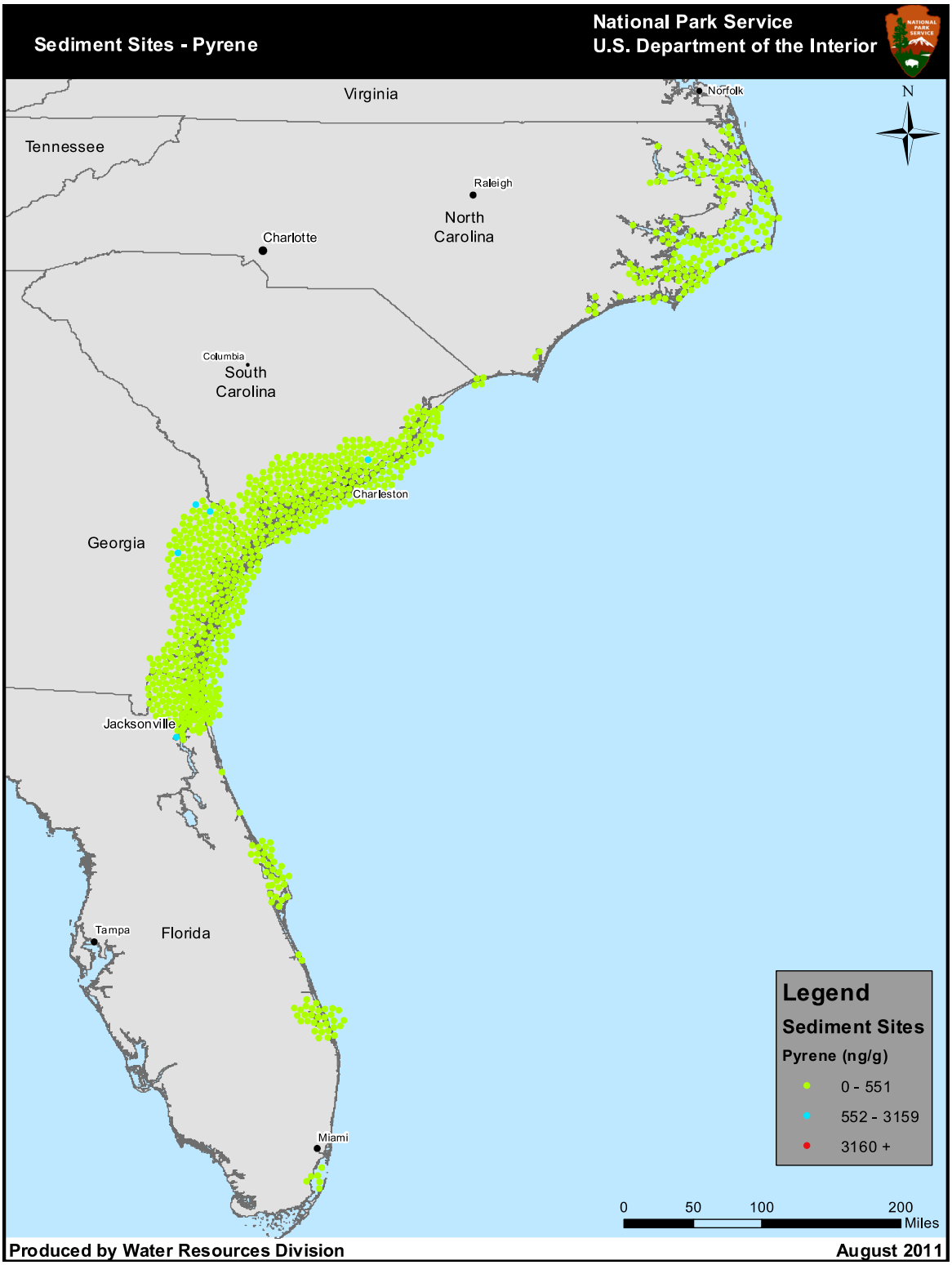


Figure 90. Synoptic sampling map of pyrene sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

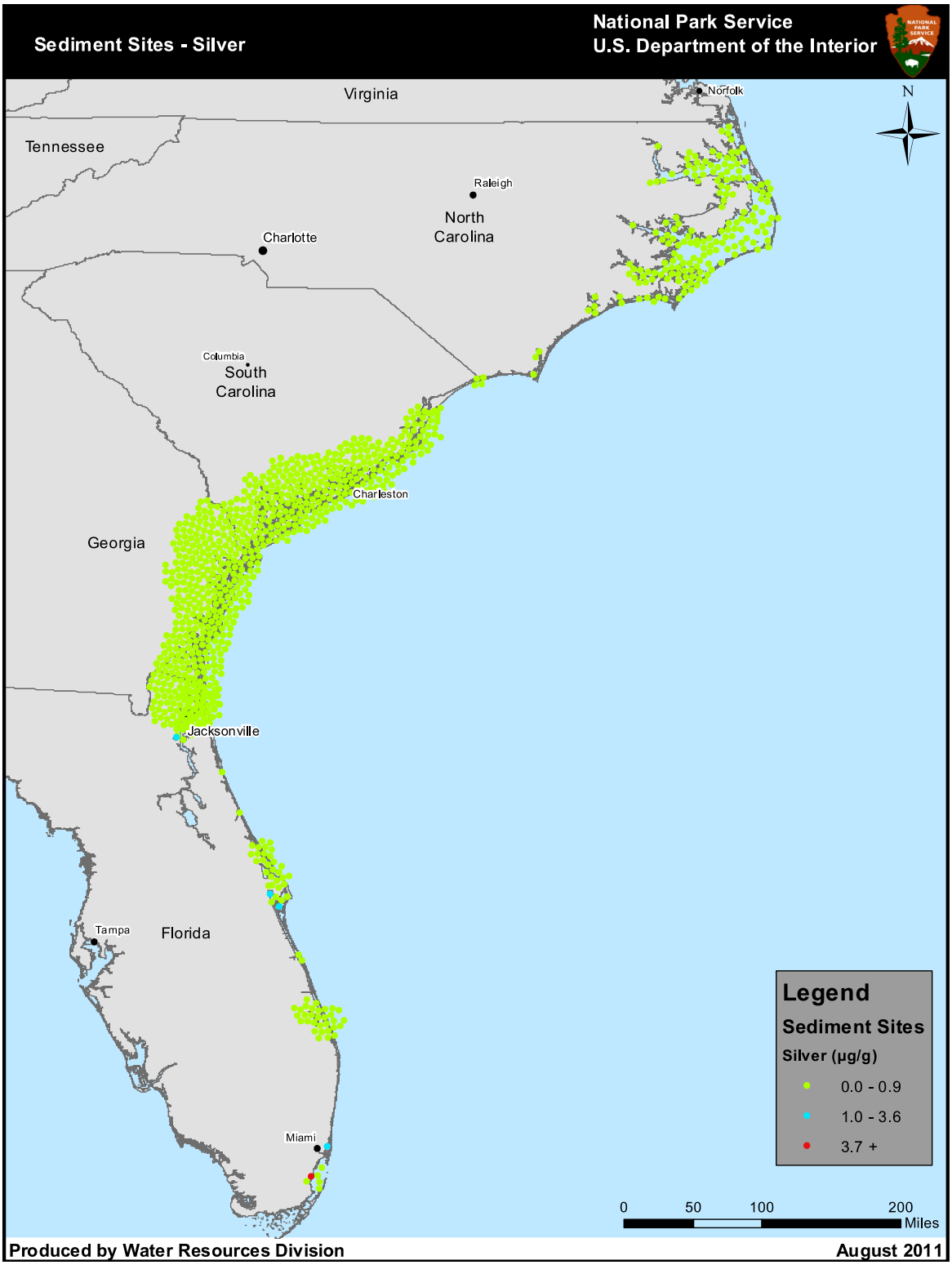


Figure 91. Synoptic sampling map of silver sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

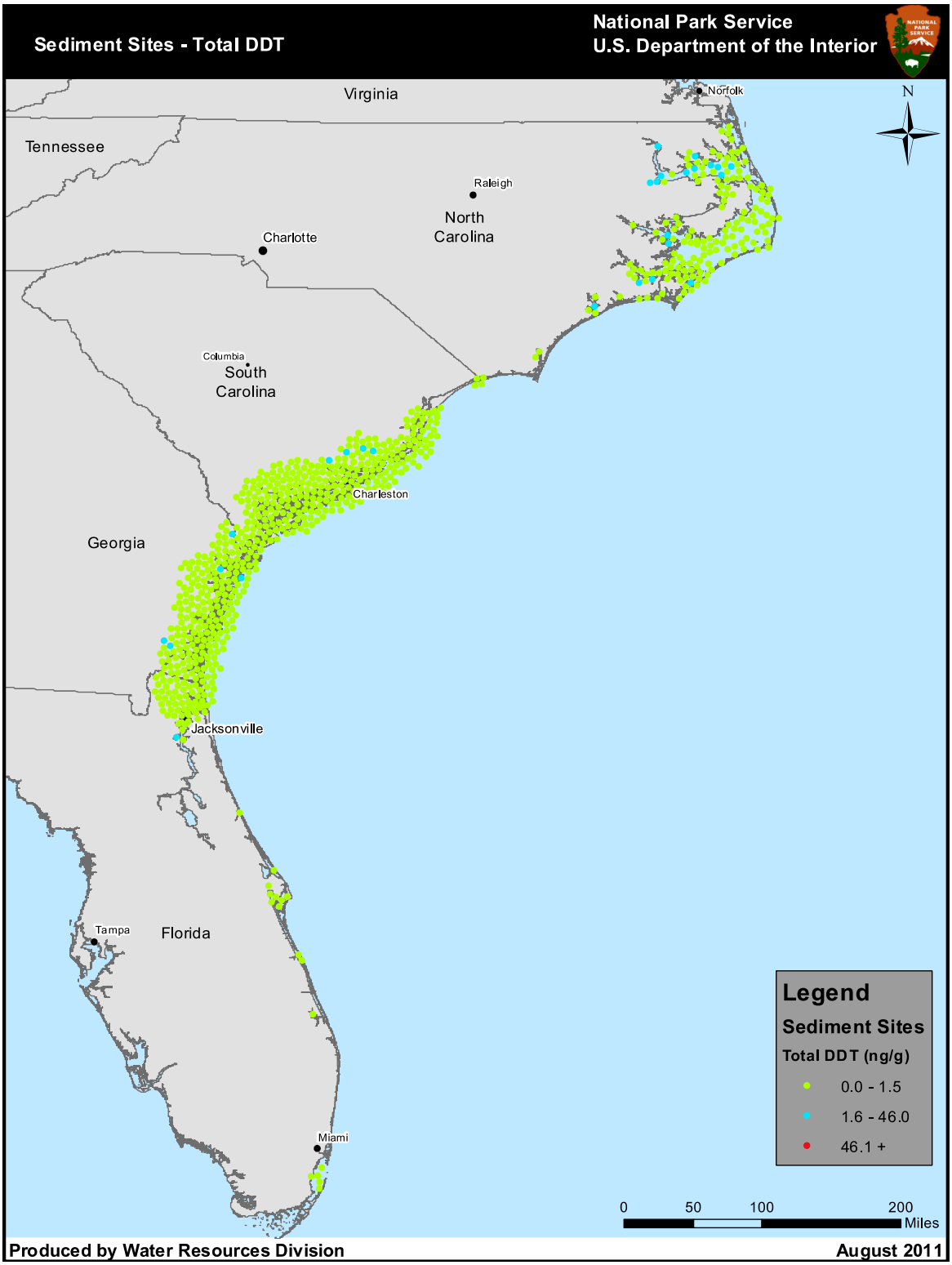


Figure 92. Synoptic sampling map of total DDT sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

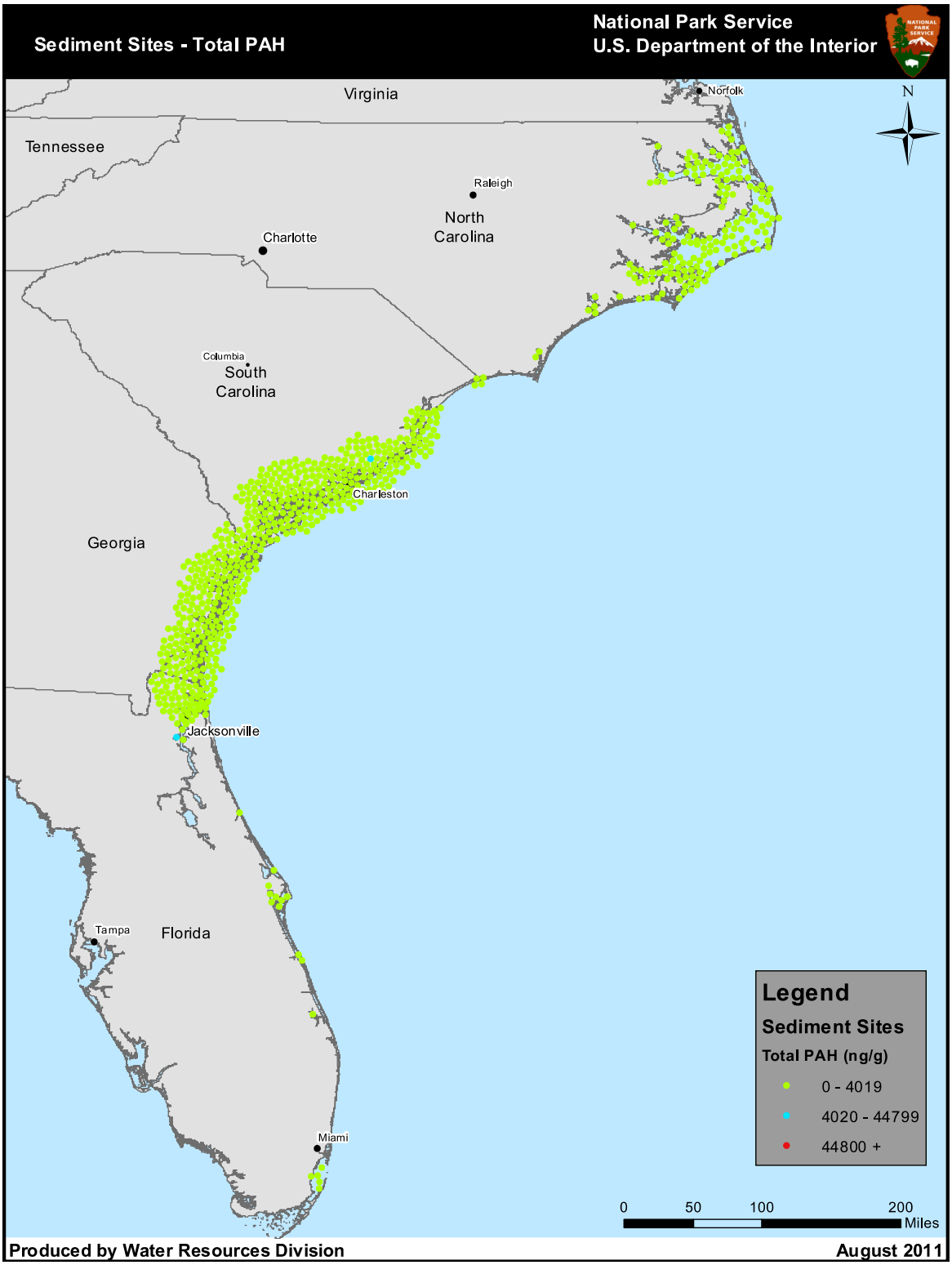


Figure 93. Synoptic sampling map of total PAH sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

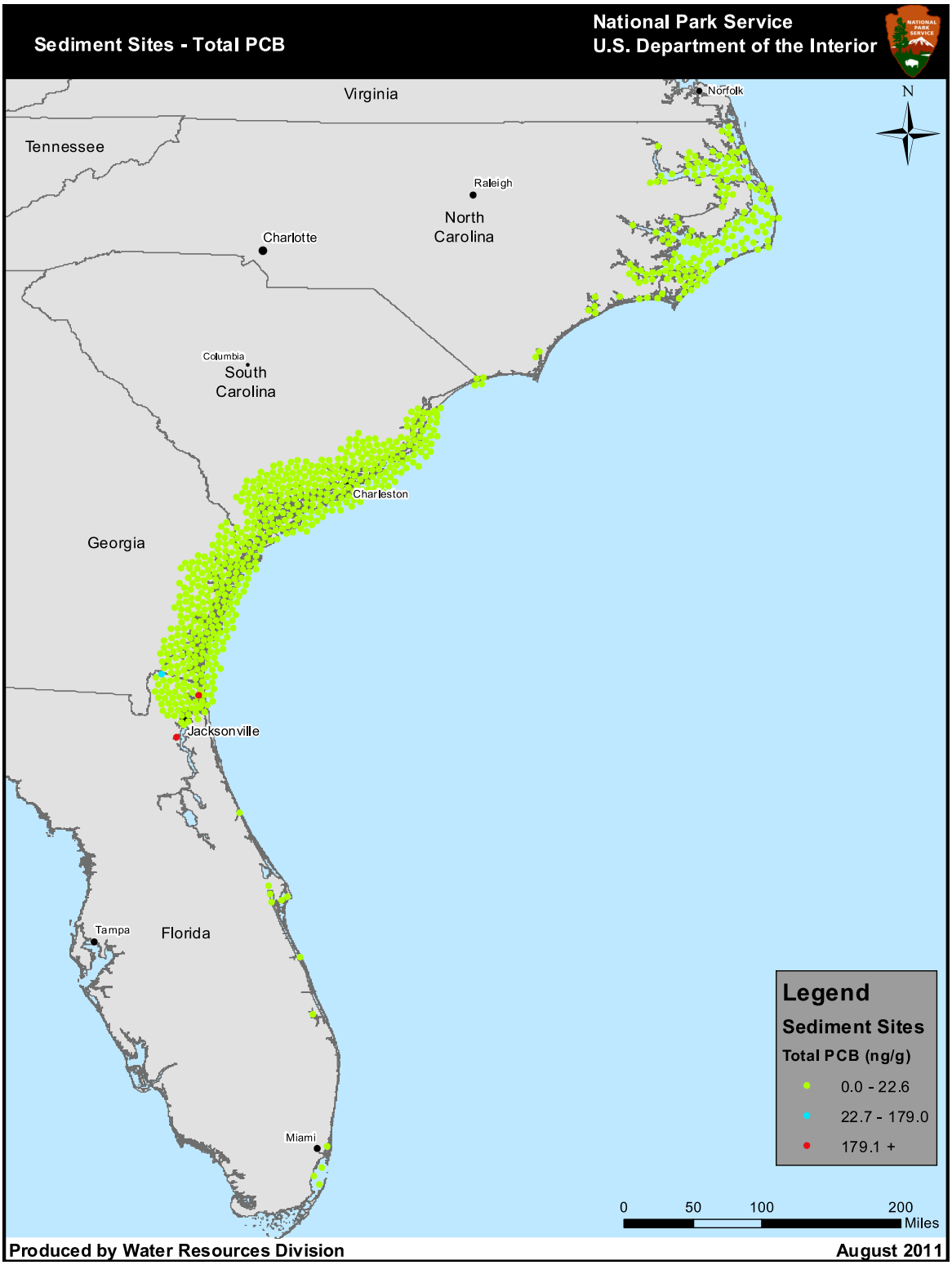


Figure 94. Synoptic sampling map of total PCB sediment quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

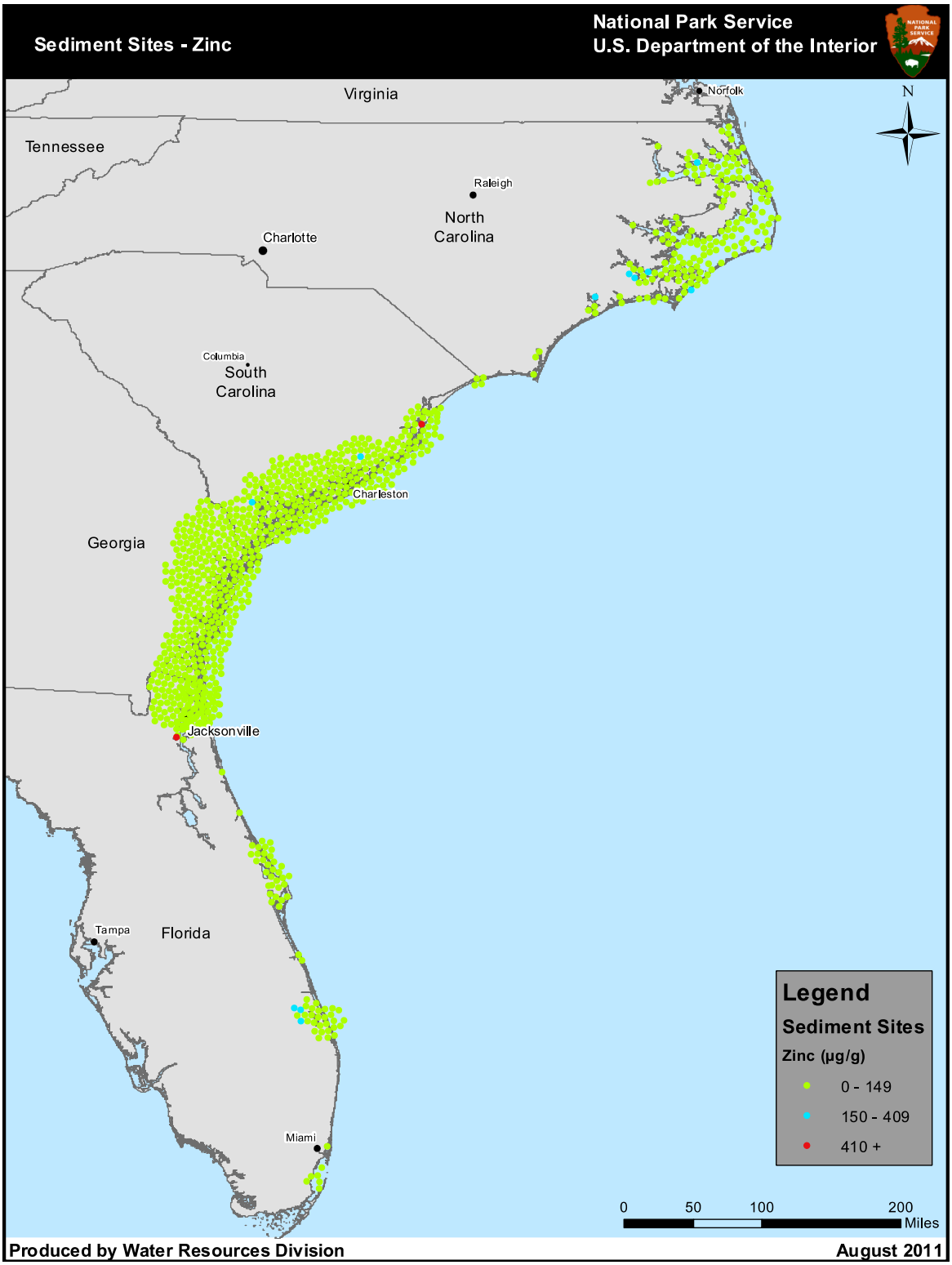


Figure 95. Synoptic sampling map of zinc sediment quality for the southeast coastal region (2000-2010). The green sites are “good,” blue is “fair,” and red is “poor” sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

Appendix D: Fish Tissue Survey Synoptic Results

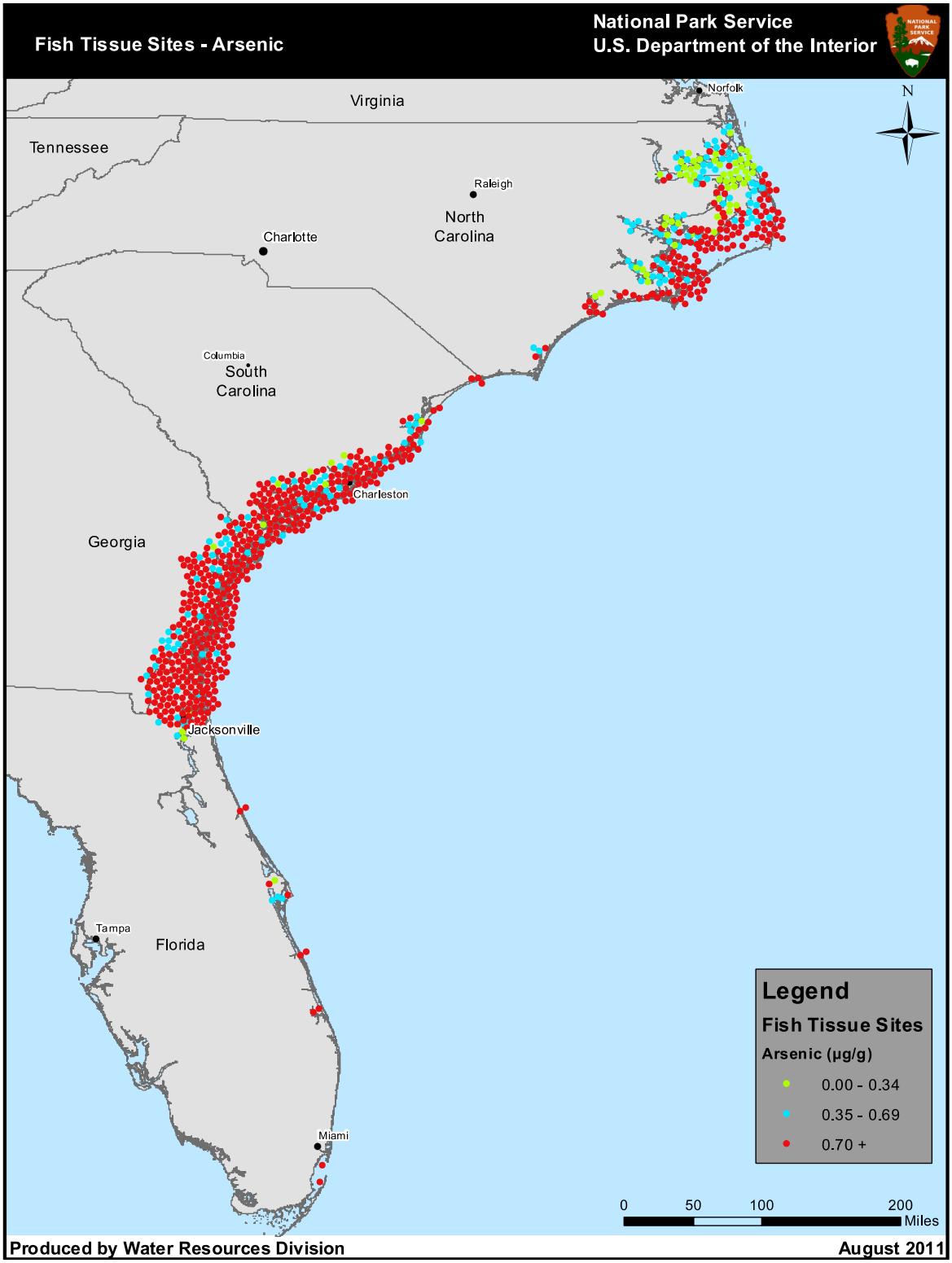


Figure 96. Synoptic sampling map of arsenic fish tissue quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

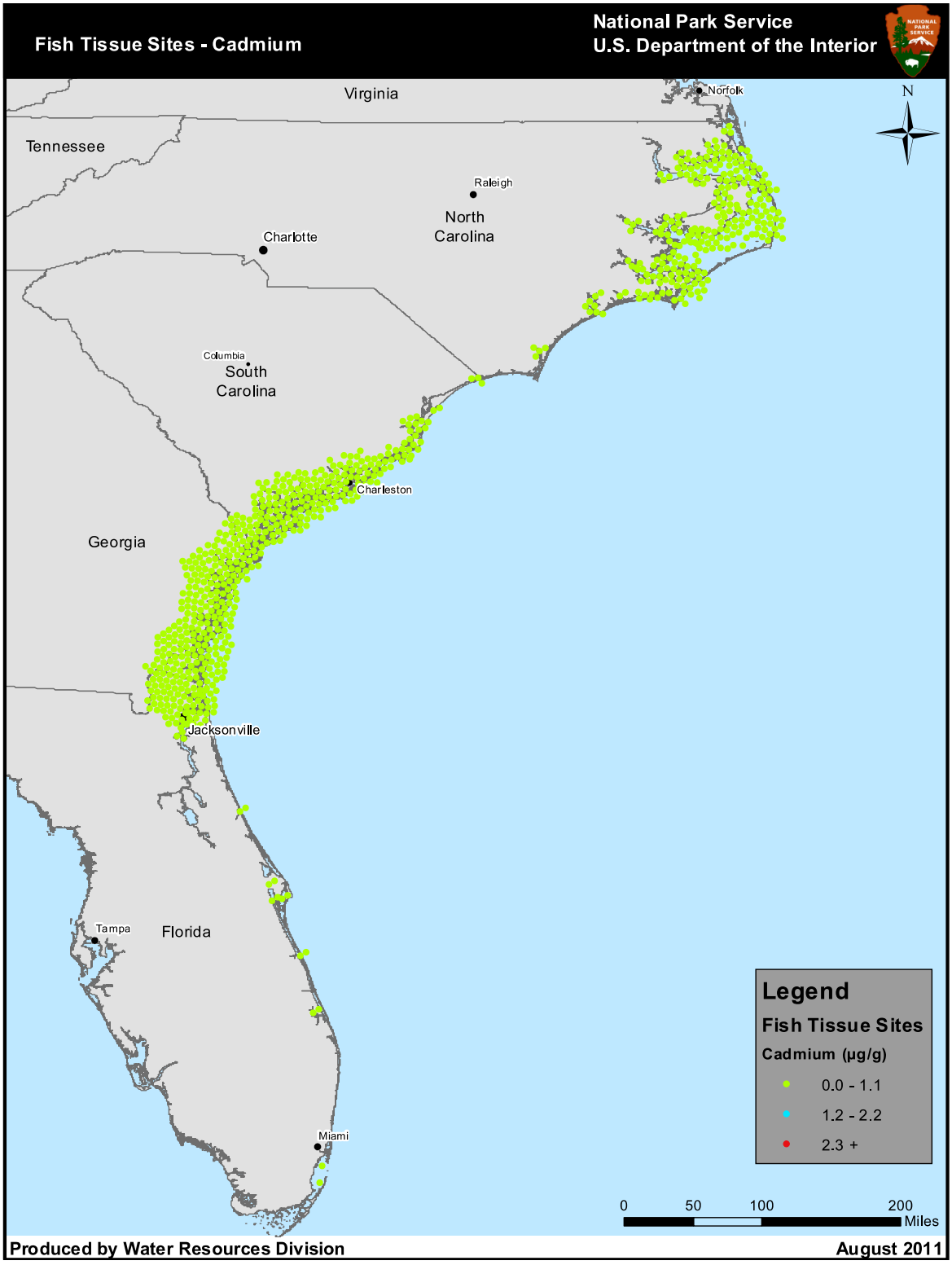


Figure 97. Synoptic sampling map of cadmium fish tissue quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

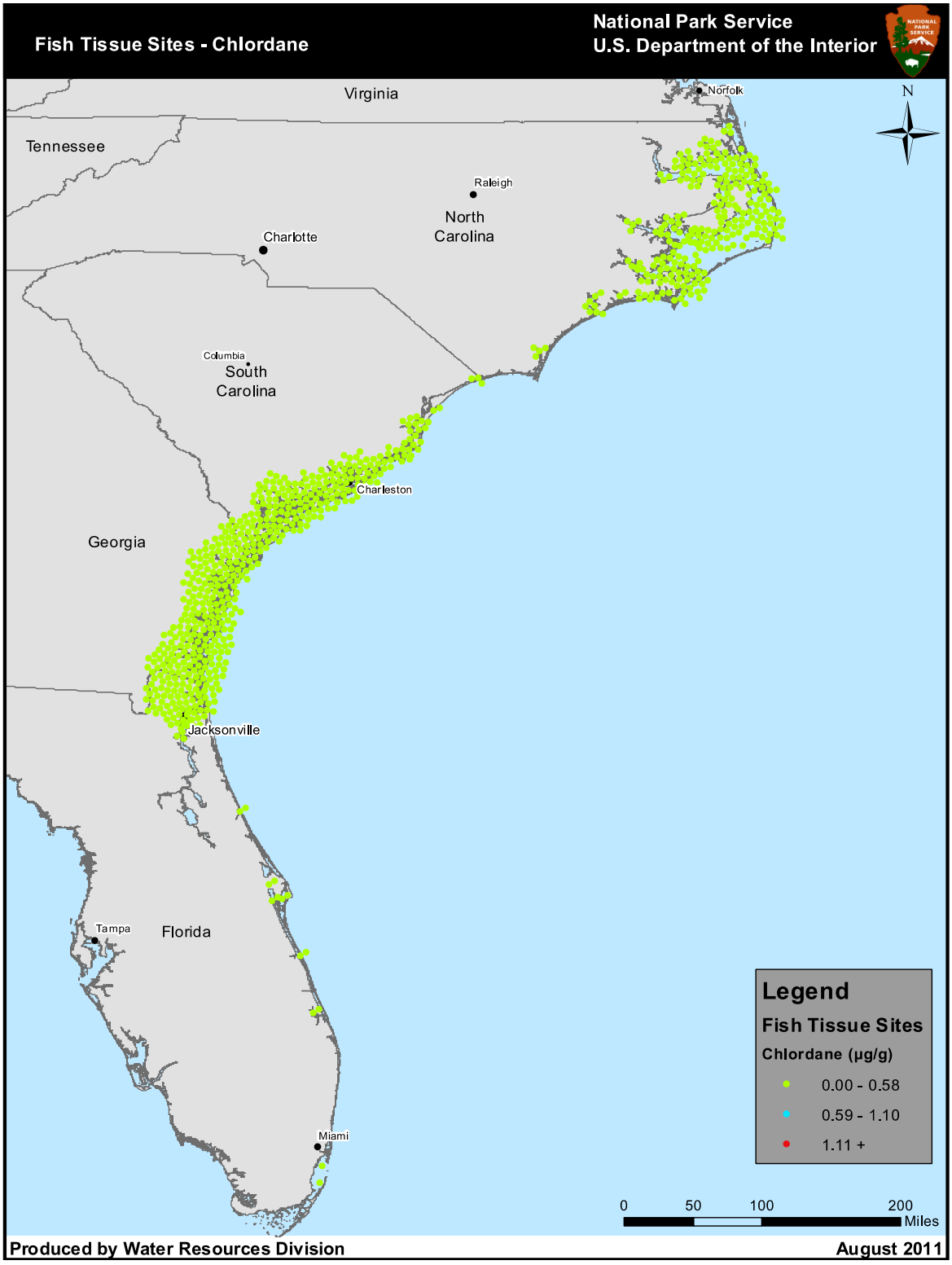


Figure 98. Synoptic sampling map of chlordane fish tissue quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

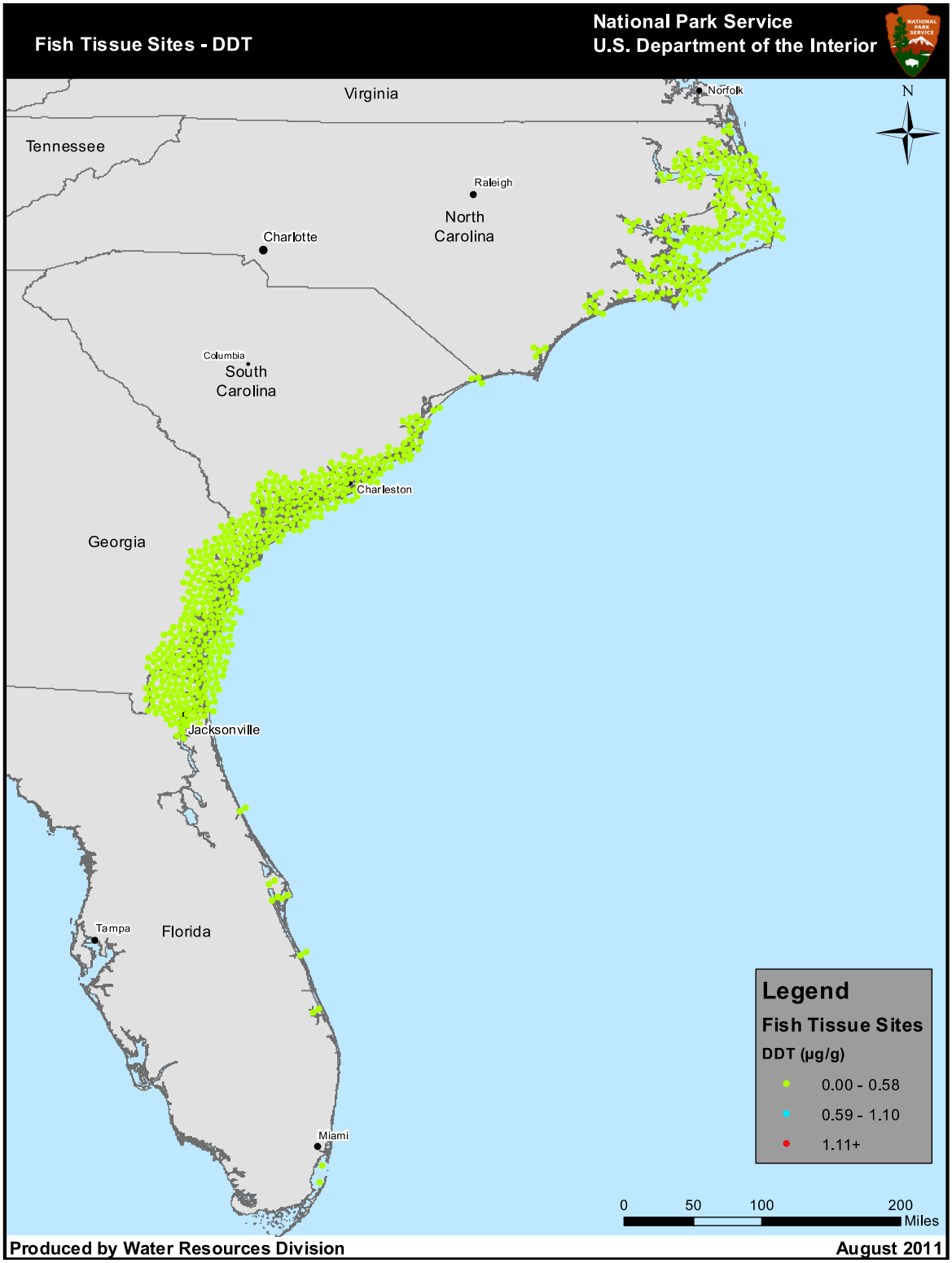


Figure 99. Synoptic sampling map of DDT fish tissue quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

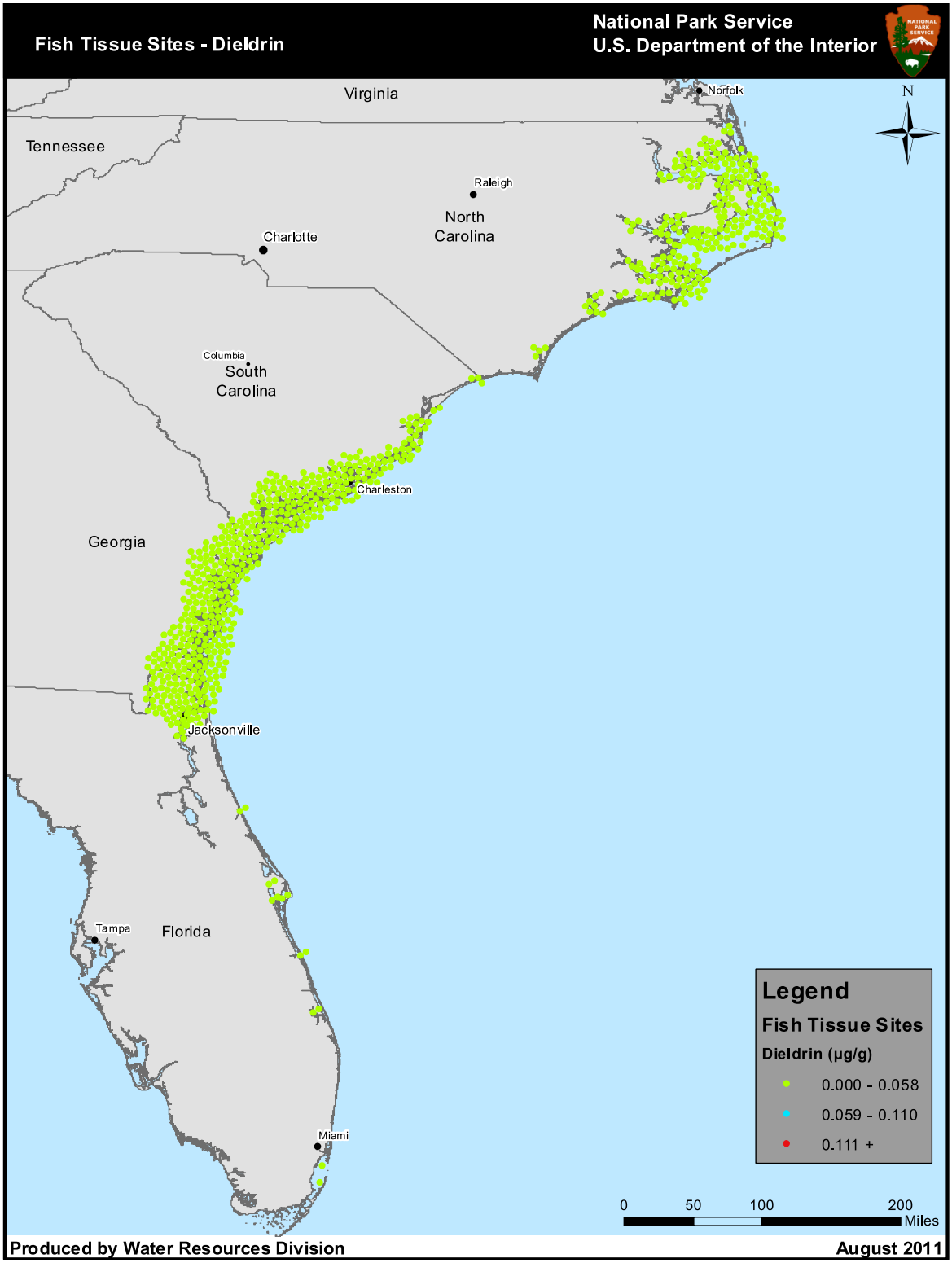


Figure 100. Synoptic sampling map of dieldrin fish tissue quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

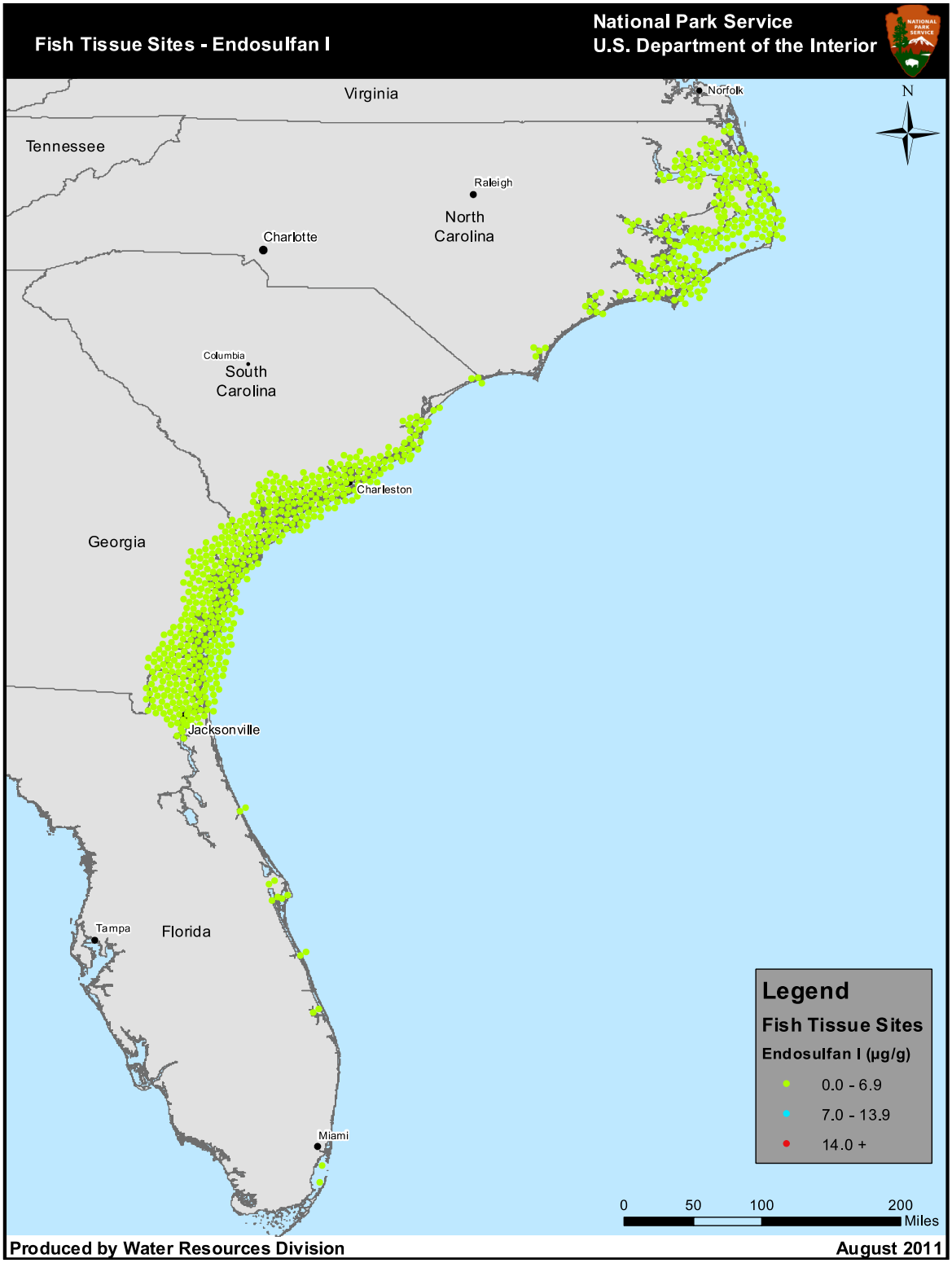


Figure 101. Synoptic sampling map of endosulfan I fish tissue quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

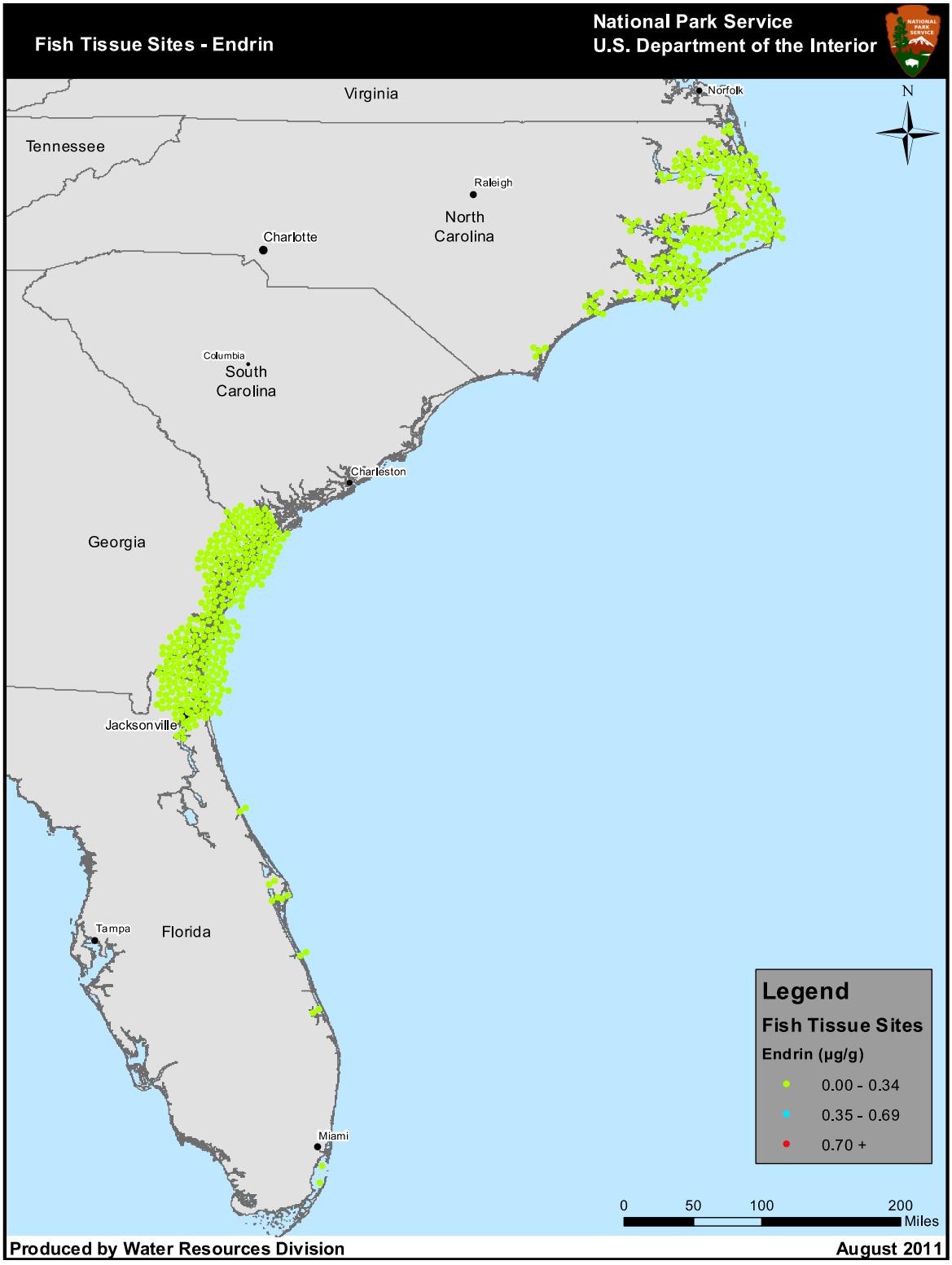


Figure 102. Synoptic sampling map of endrin fish tissue quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

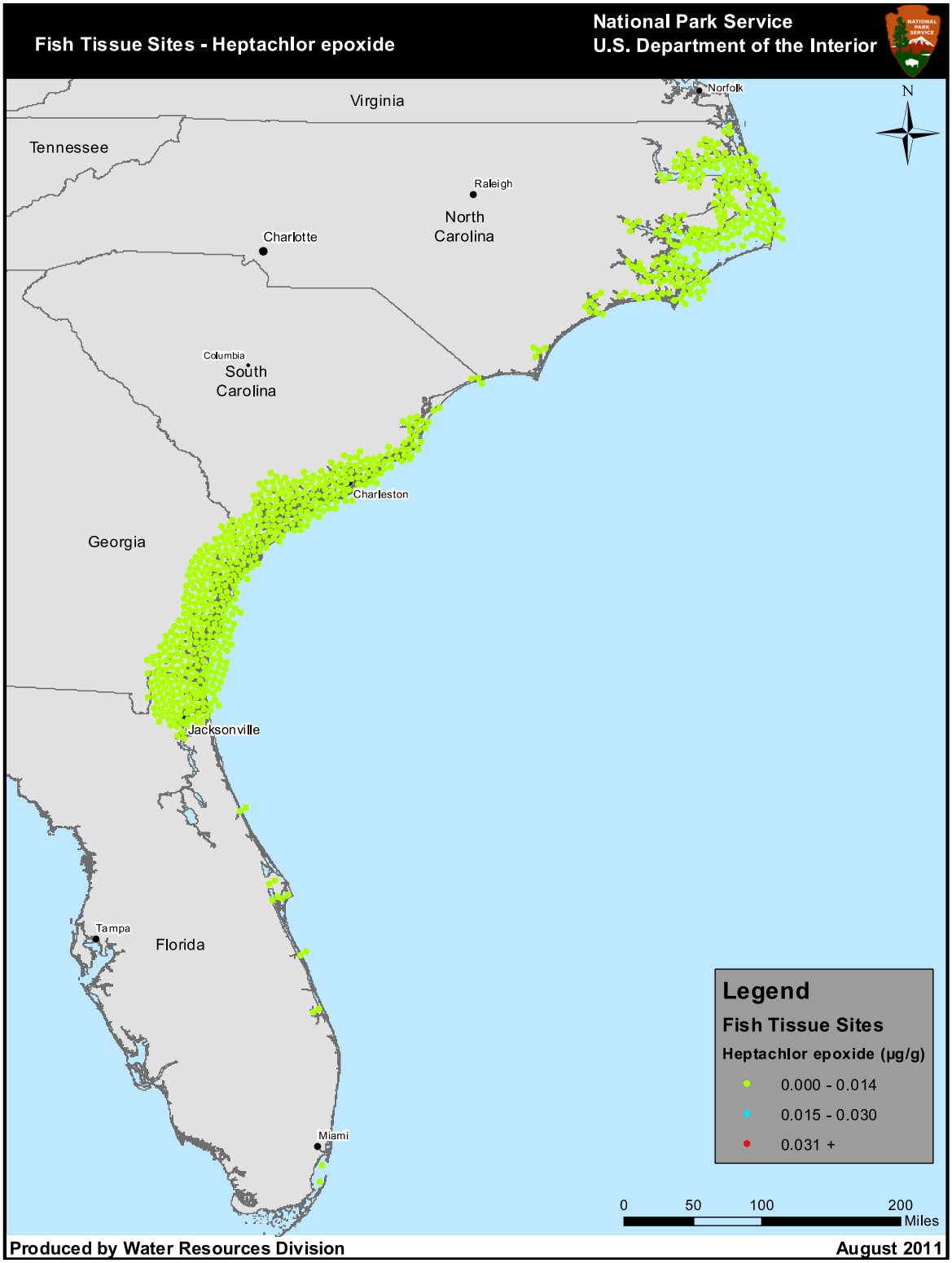


Figure 103. Synoptic sampling map of heptachlor fish tissue quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

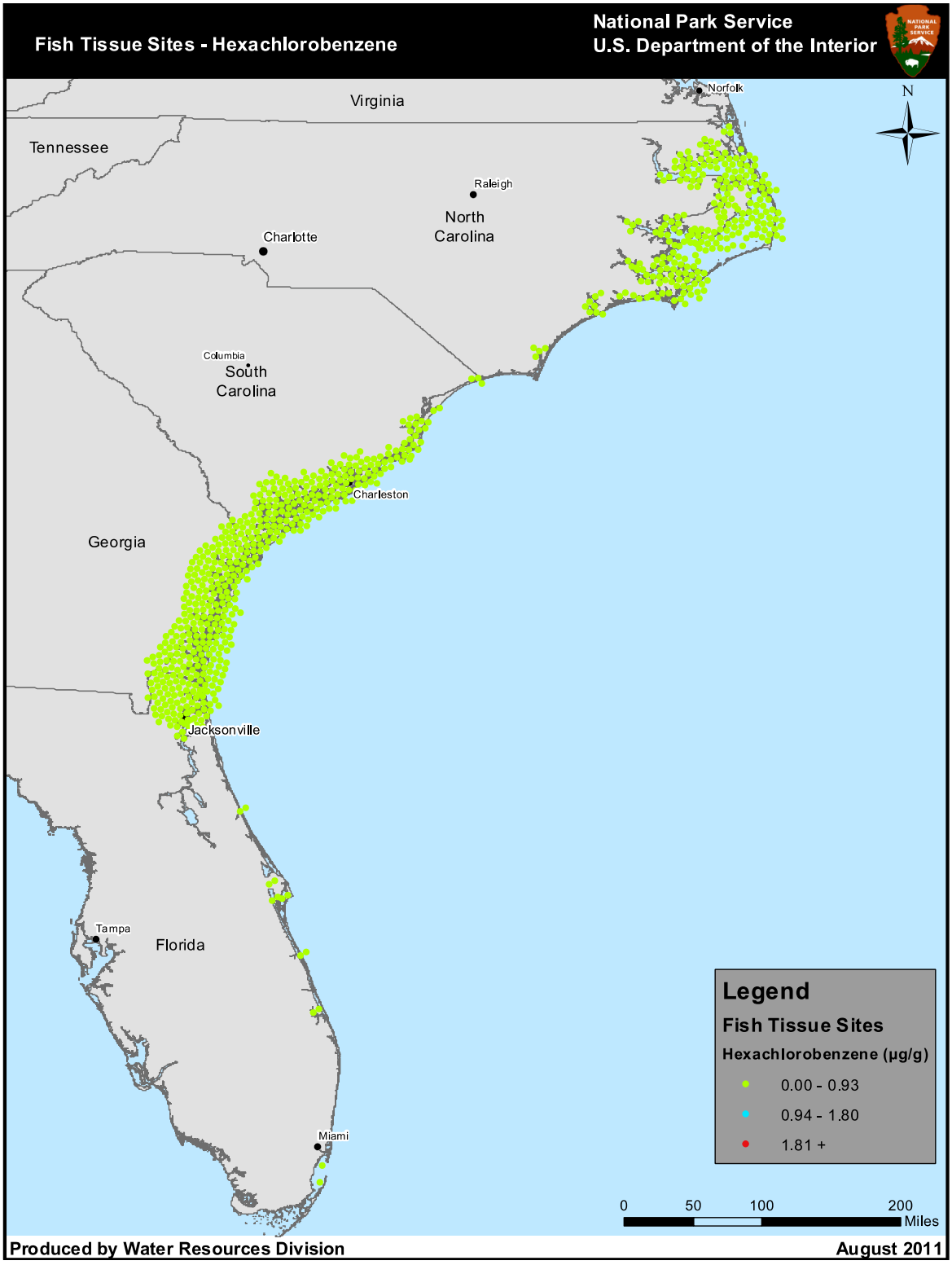


Figure 104. Synoptic sampling map of hexachlorobenzene fish tissue quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

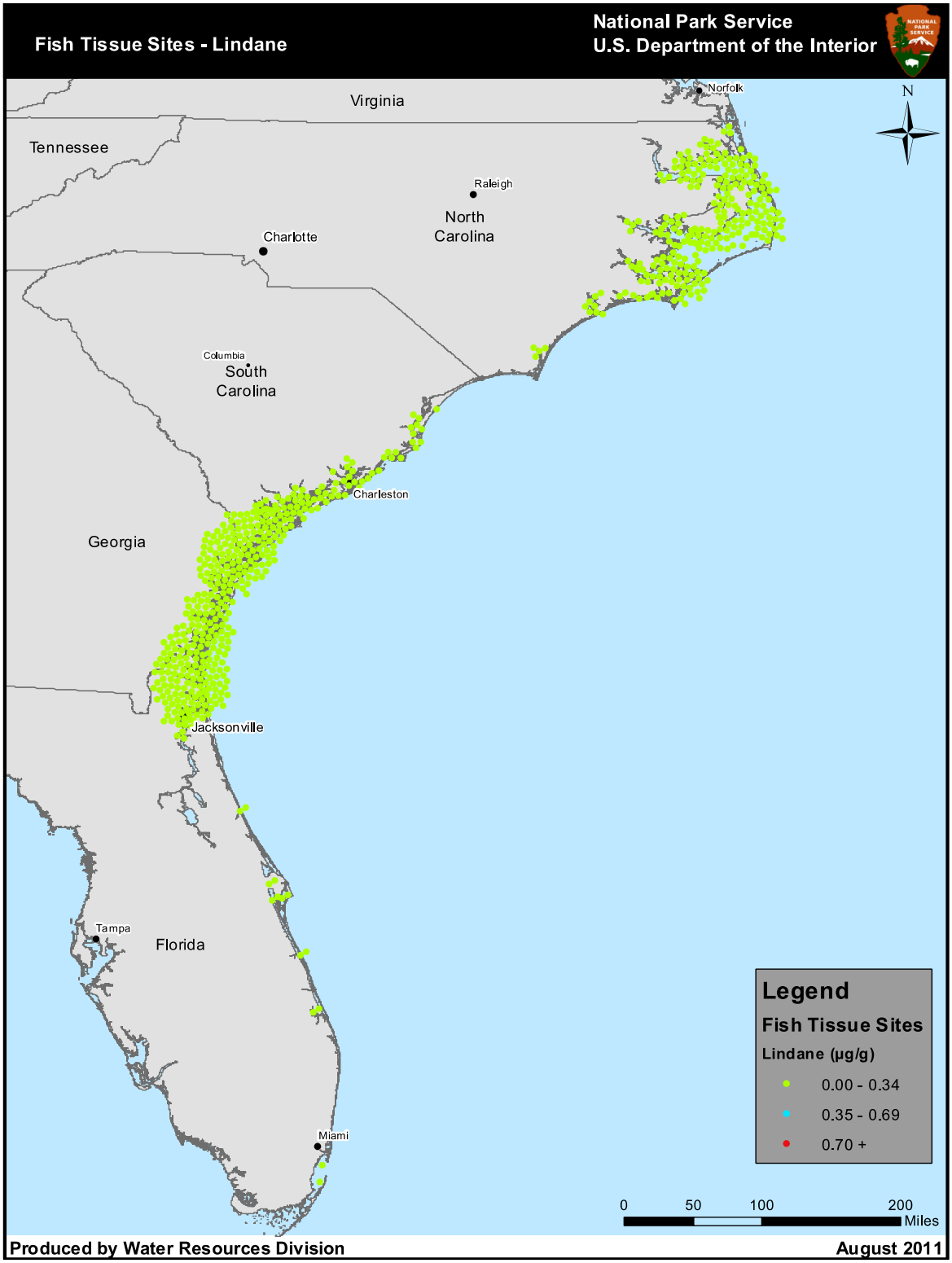


Figure 105. Synoptic sampling map of lindane fish tissue quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

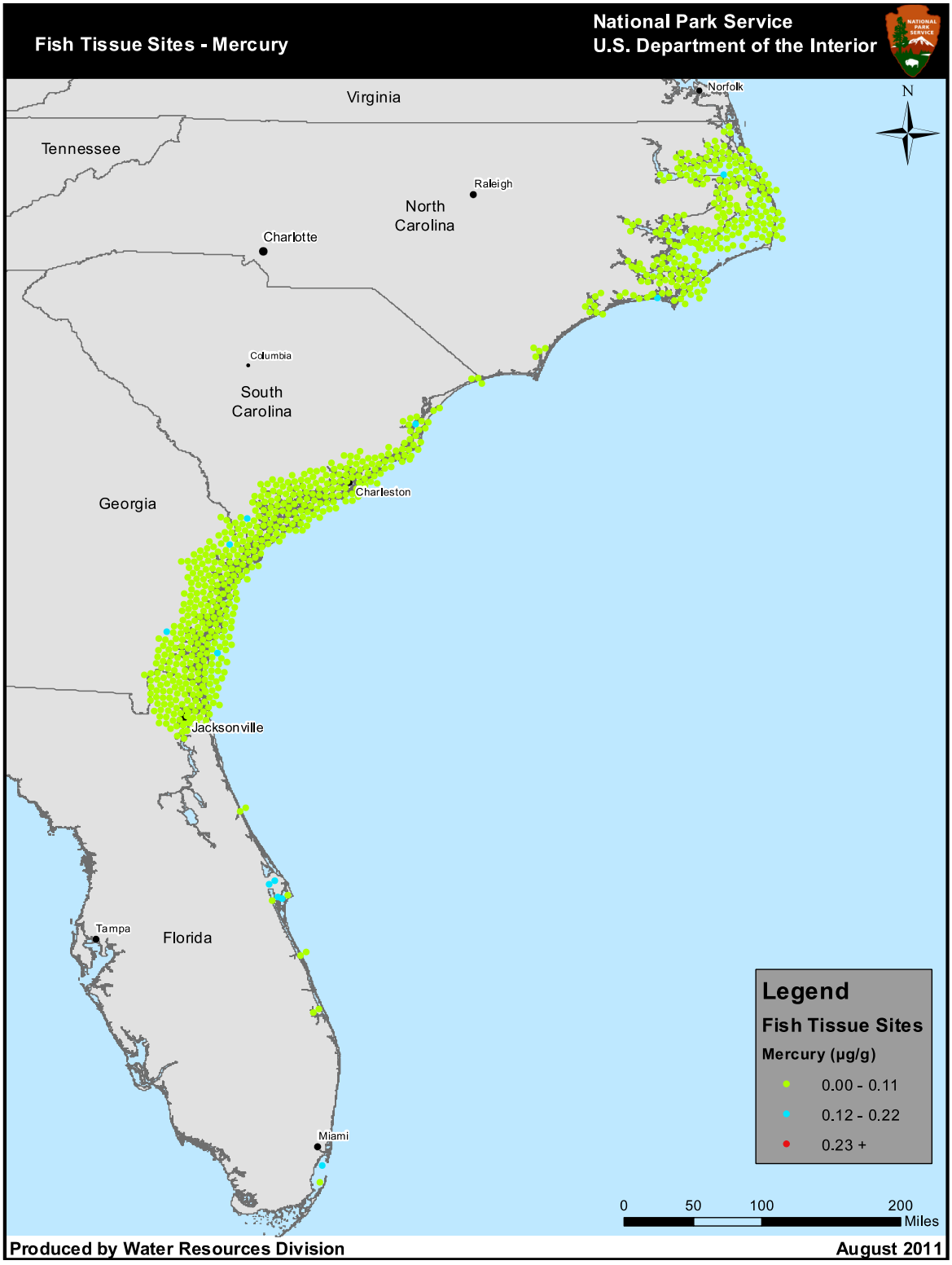


Figure 106. Synoptic sampling map of mercury fish tissue quality for the southeast coastal region (2000-2010). The green sites are “good,” blue is “fair,” and red is “poor” sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

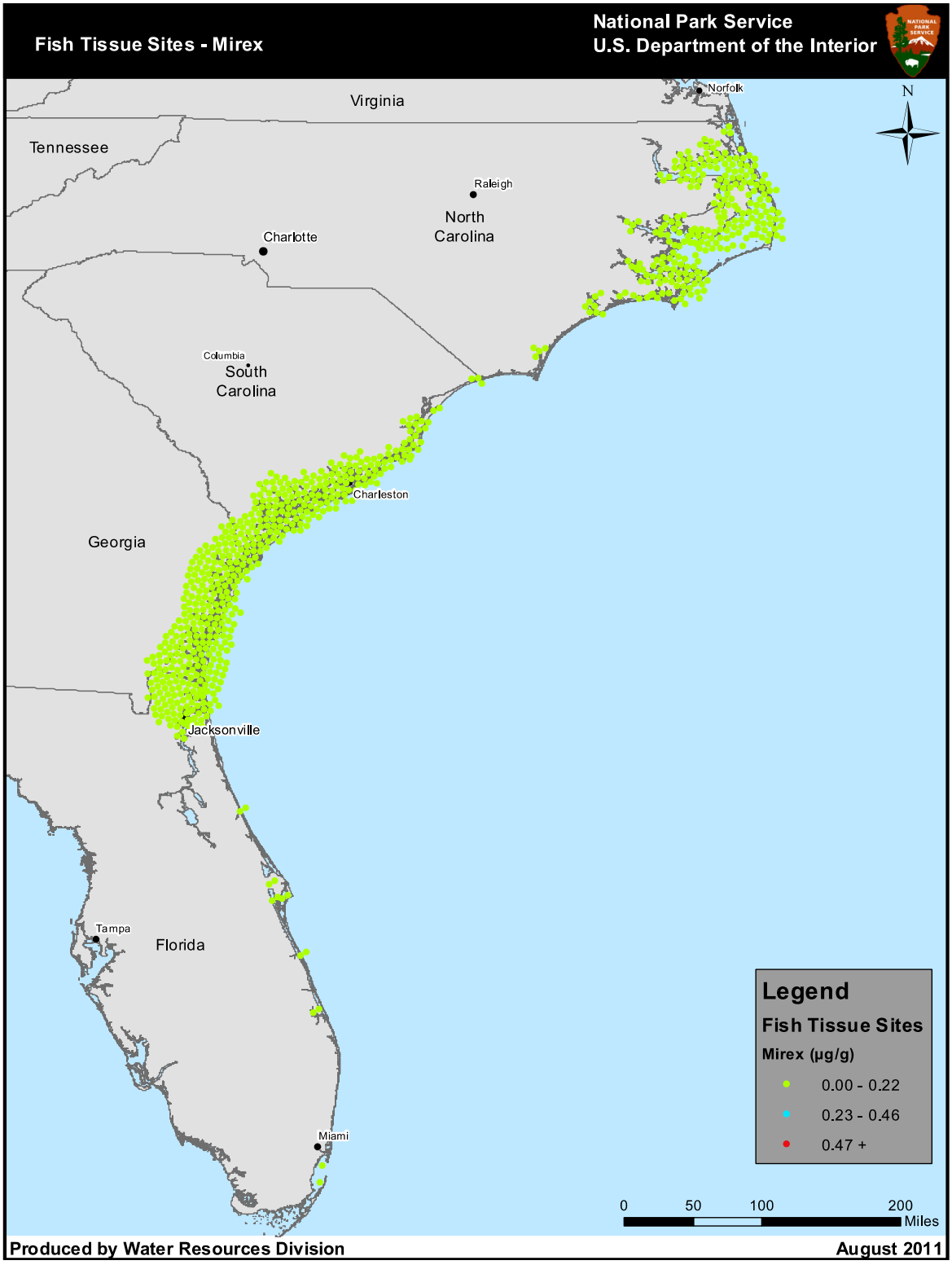


Figure 107. Synoptic sampling map of mirex fish tissue quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

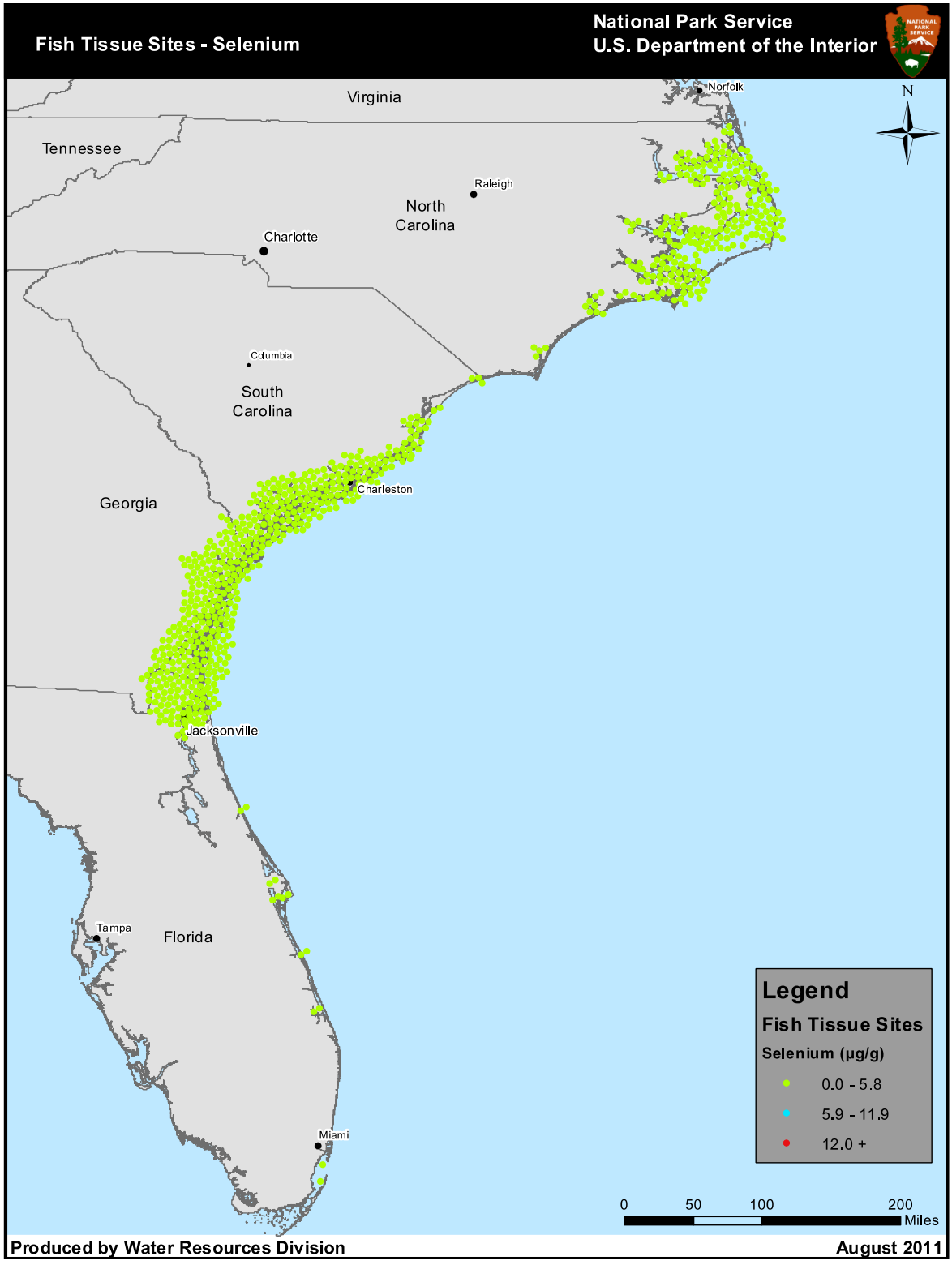


Figure 108. Synoptic sampling map of selenium fish tissue quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

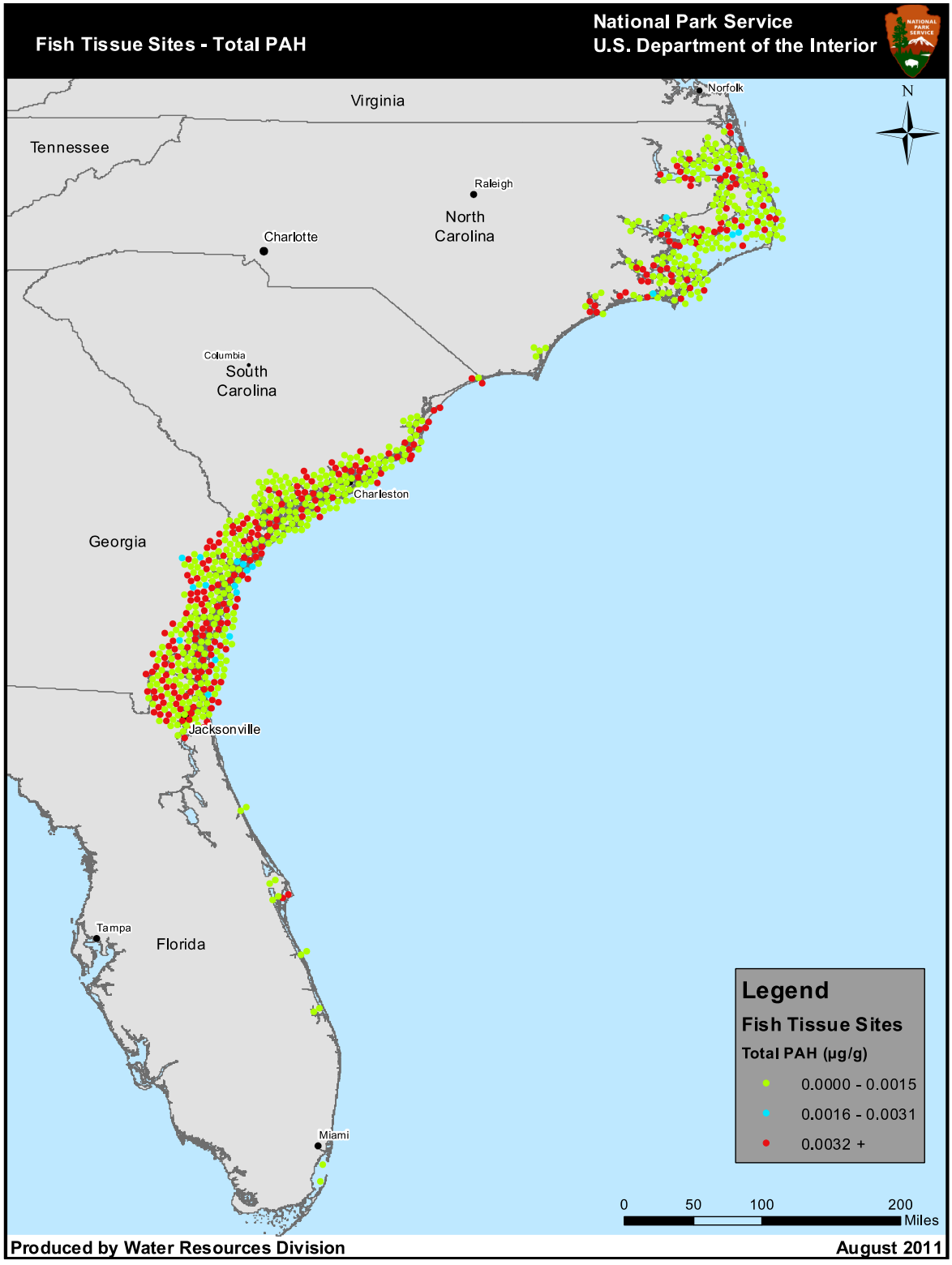


Figure 109. Synoptic sampling map of total PAH fish tissue quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

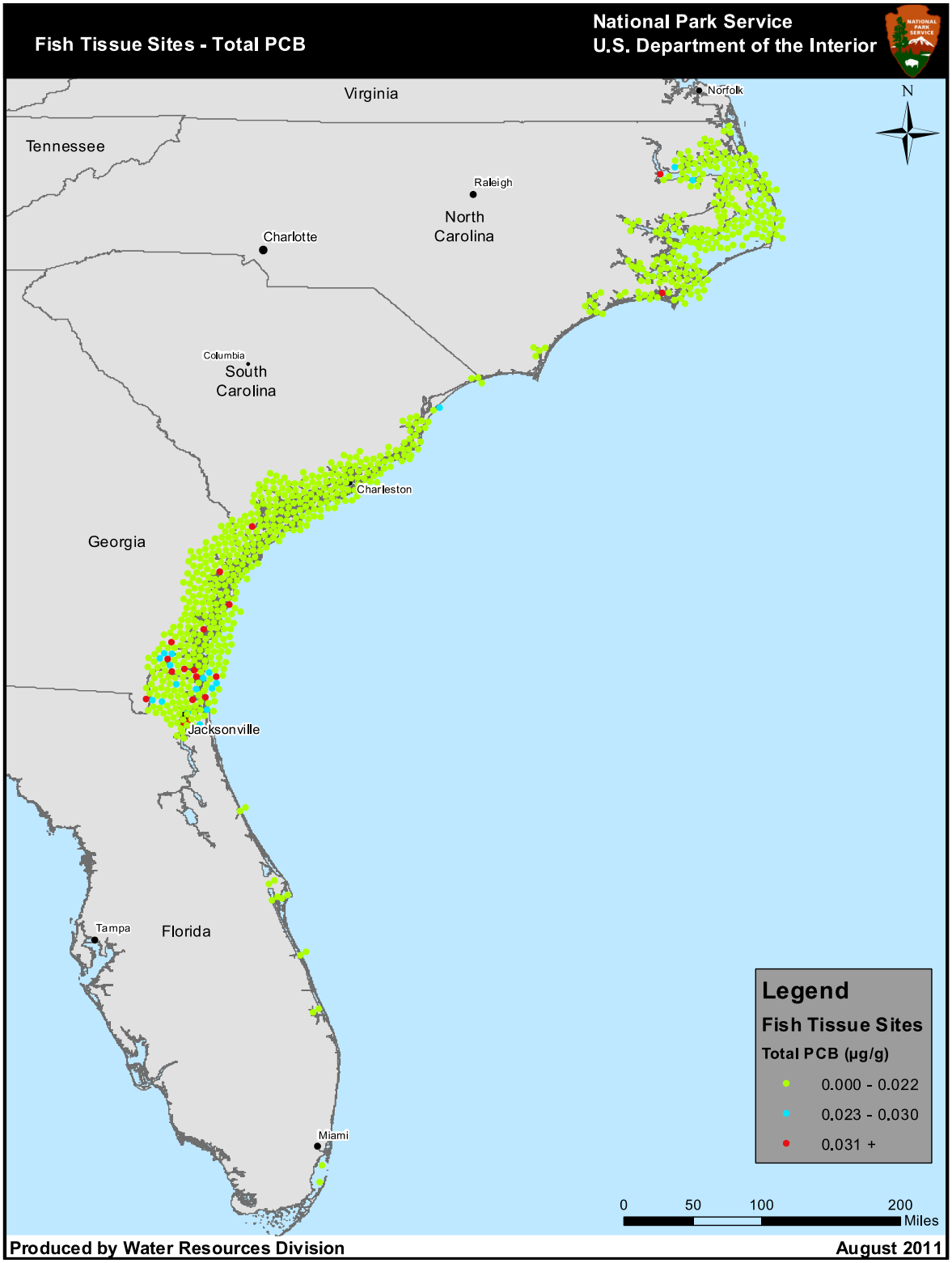


Figure 110. Synoptic sampling map of total PCB fish tissue quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

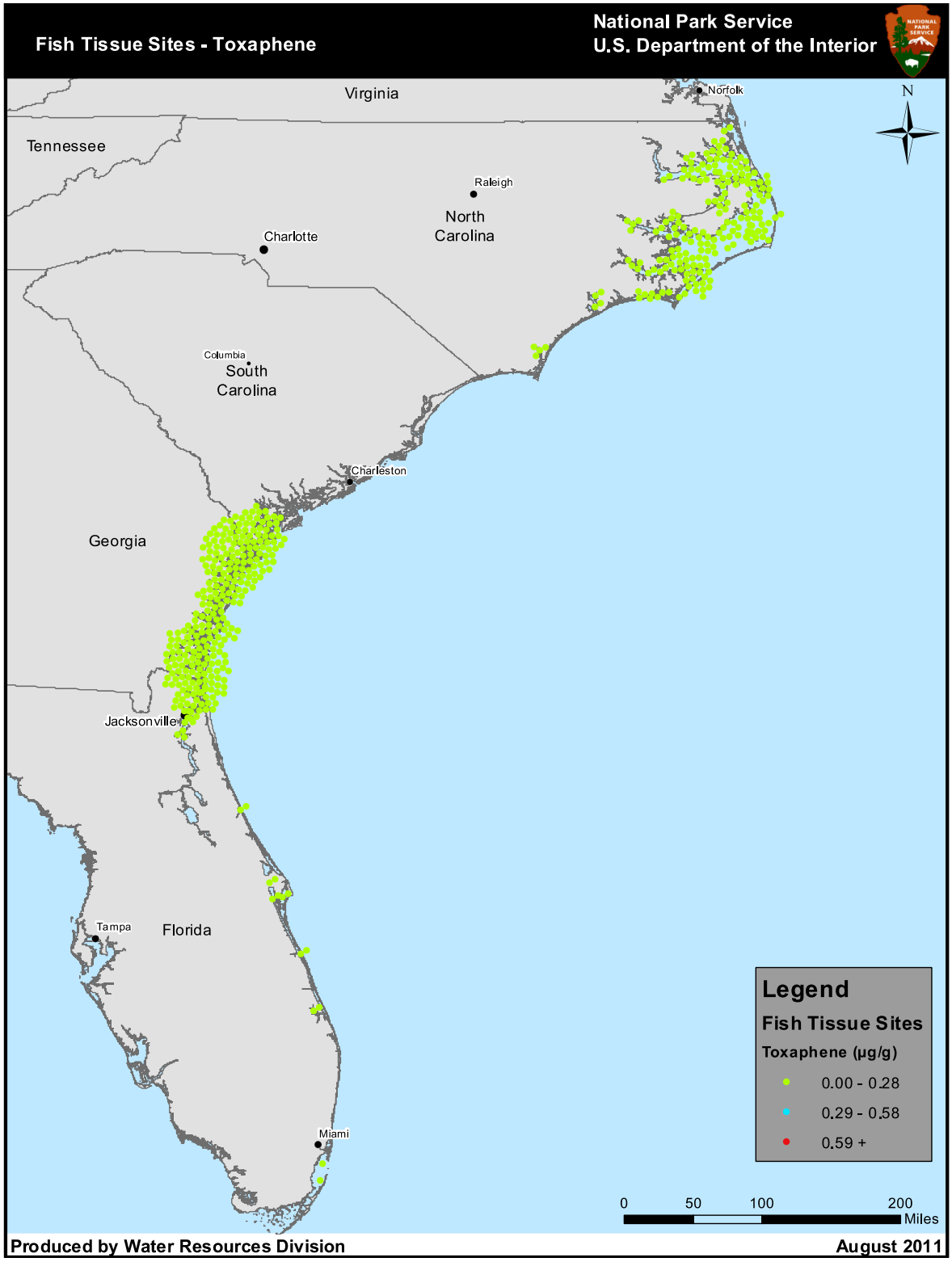


Figure 111. Synoptic sampling map of toxaphene fish tissue quality for the southeast coastal region (2000-2010). The green sites are "good," blue is "fair," and red is "poor" sediment quality as determined by the EPA ranking criteria (U.S. EPA, 2001).

Appendix E: Water Quality Time Series for Index sites

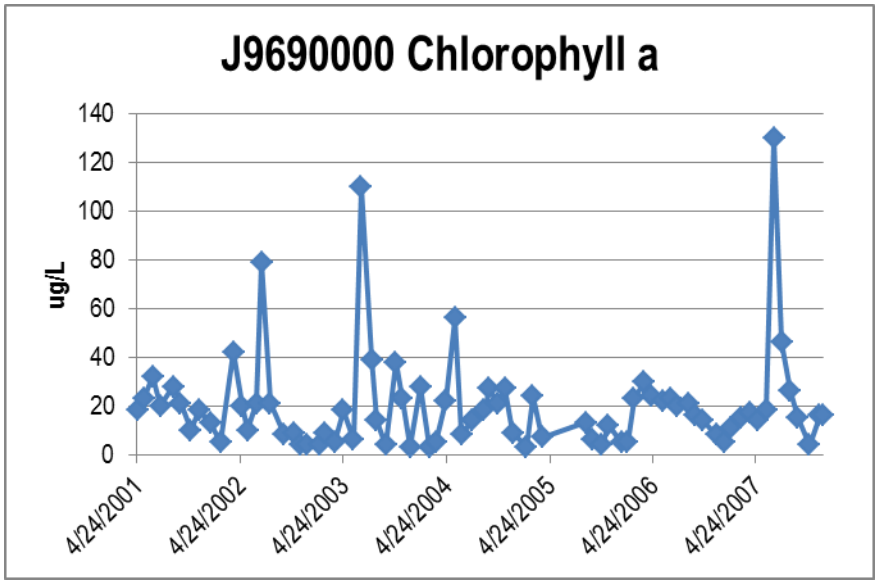


Figure 112. Time series of chlorophyll a at index site J969000 located Back Creek near Merrimon, NC, which located near CAHA and CALO.

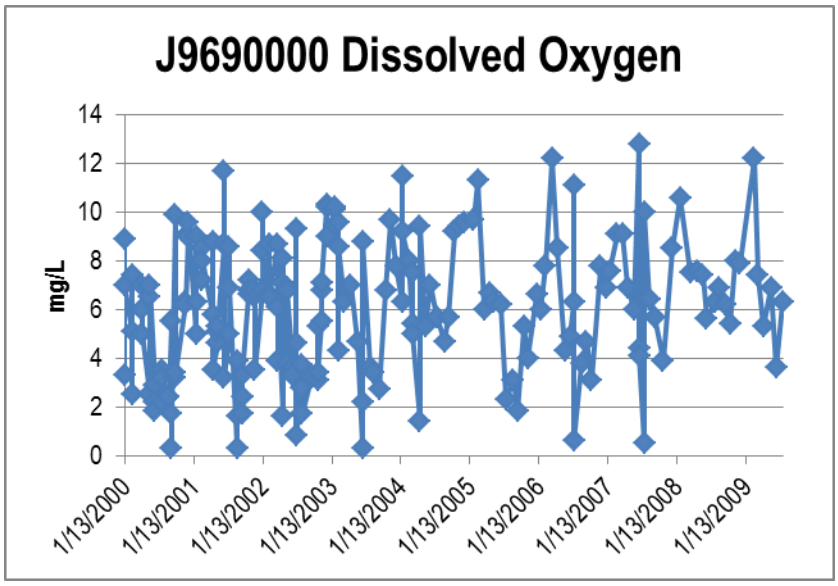


Figure 113. Time series of dissolved oxygen at index site J969000 located Back Creek near Merrimon, NC, which located near CAHA and CALO.

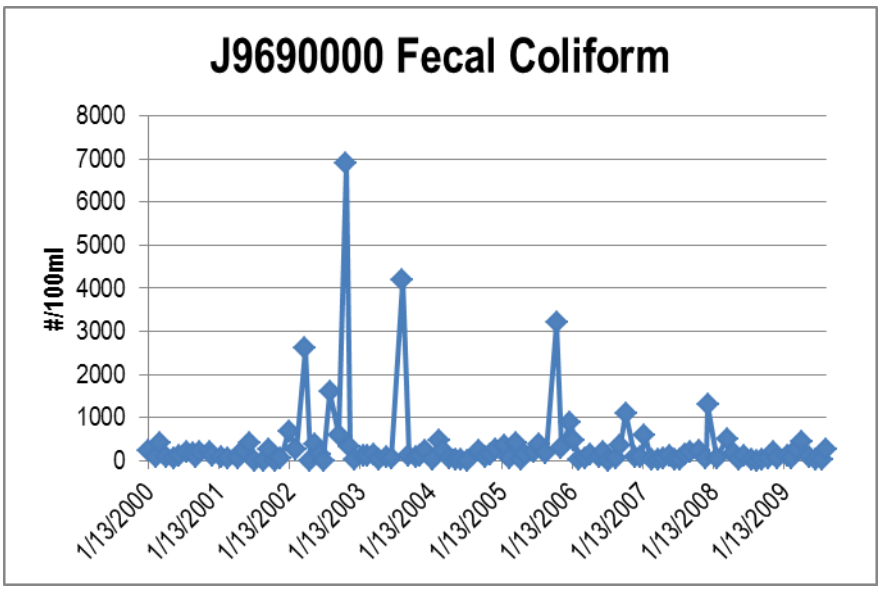


Figure 114. Time series of fecal coliform at index site J969000 located Back Creek near Merrimon, NC, which located near CAHA and CALO.

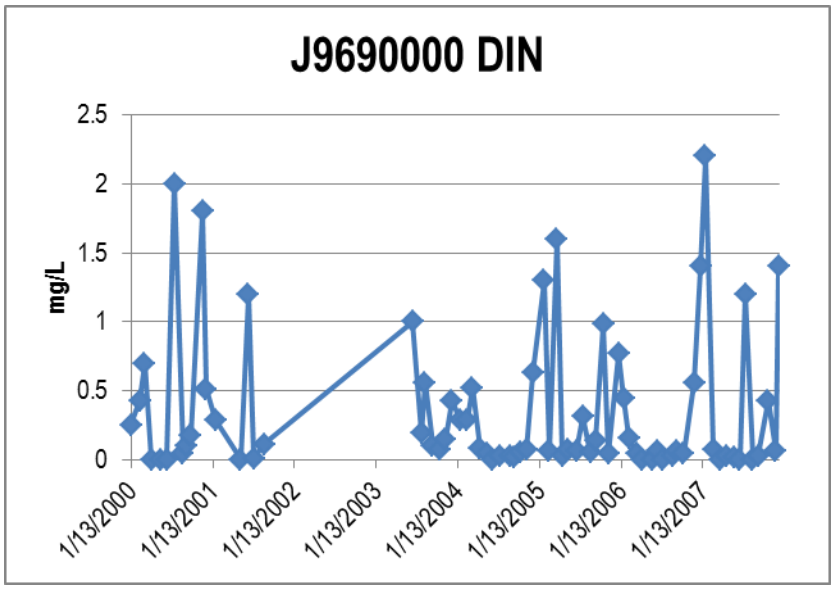


Figure 115. Time series of DIN at index site J969000 located Back Creek near Merrimon, NC, which located near CAHA and CALO.

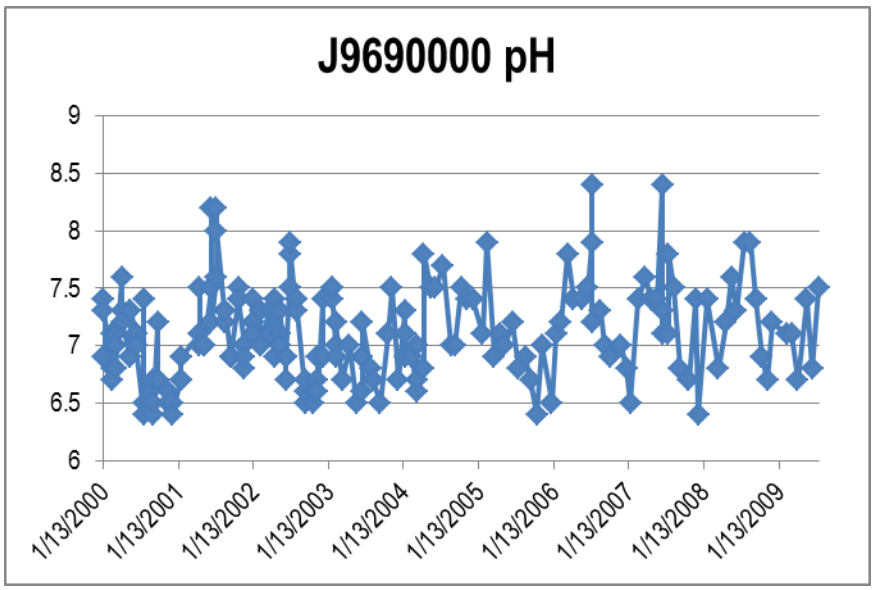


Figure 116. Time series of pH at index site J969000 located Back Creek near Merrimon, NC, which located near CAHA and CALO.

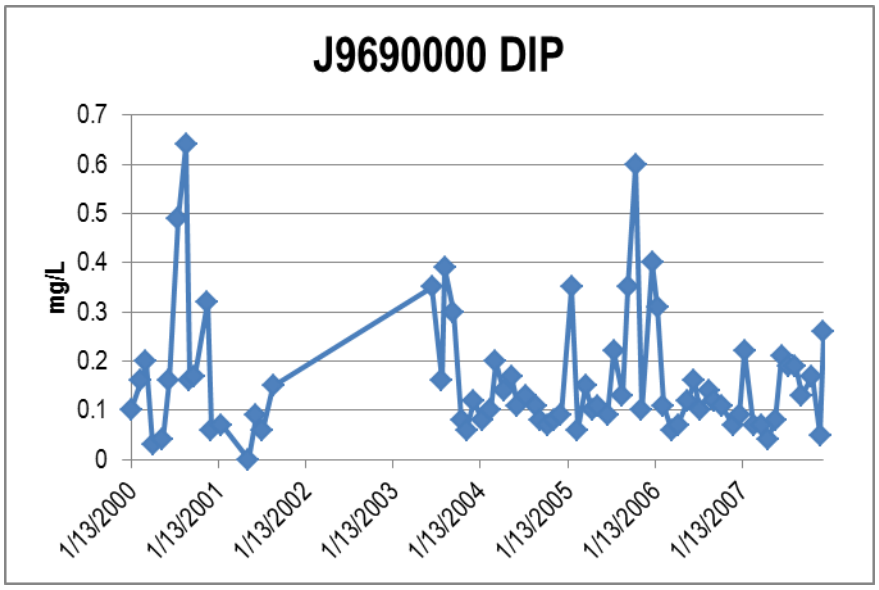


Figure 117. Time series of DIP at index site J969000 located Back Creek near Merrimon, NC, which located near CAHA and CALO.

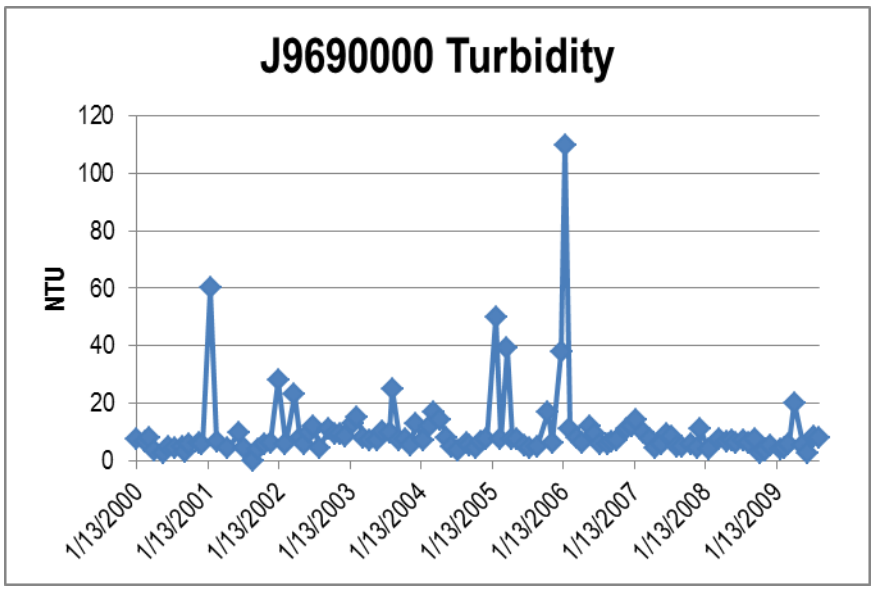


Figure 118. Time series of Turbidity at index site J969000 located Back Creek near Merrimon, NC, which located near CAHA and CALO.

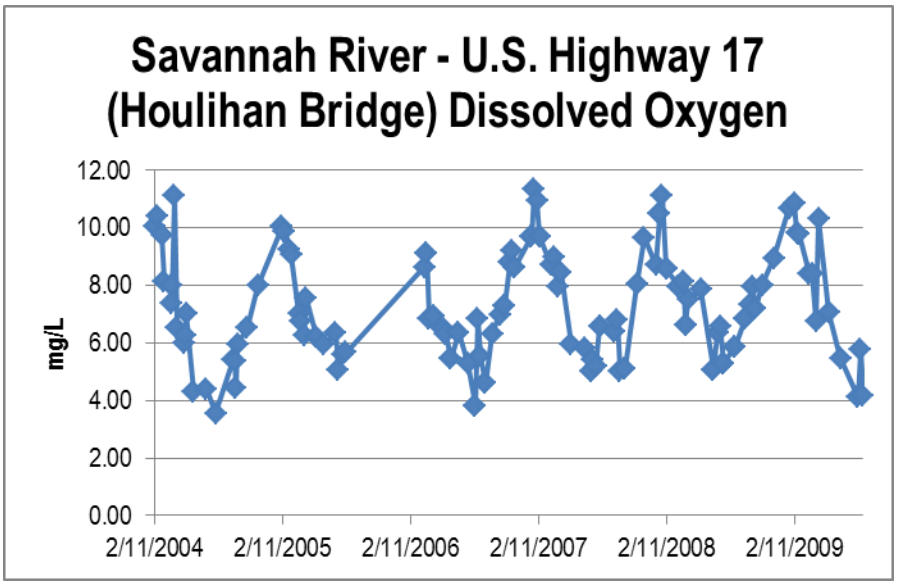


Figure 119. Time series of dissolved oxygen at the Savannah River-U.S. Highway 17 (Houlihan Bridge) index site located upstream of FOPU.

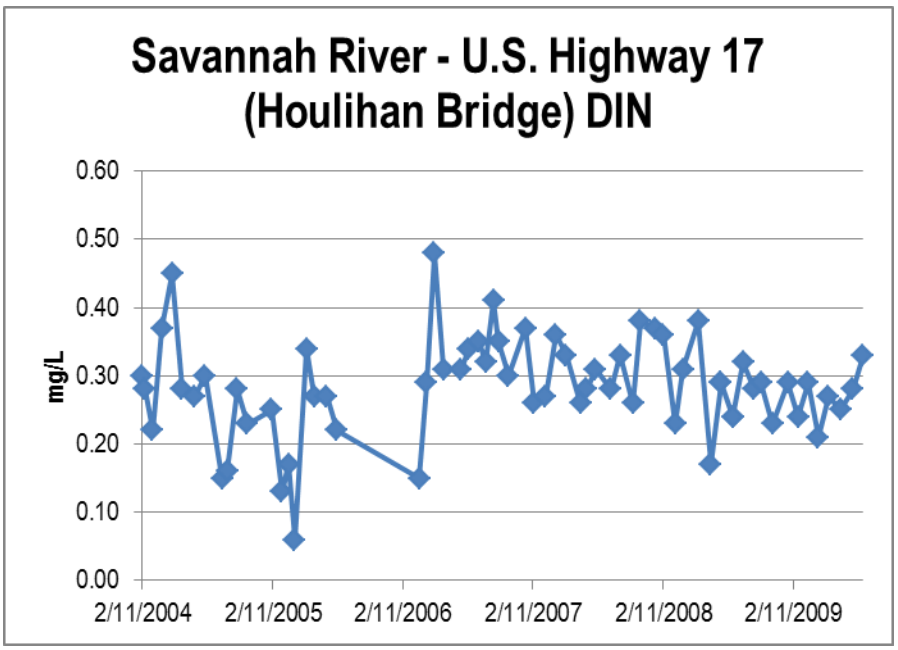


Figure 120. Time series of DIN at the Savannah River-U.S. Highway 17 (Houlihan Bridge) index site located upstream of FOPU.

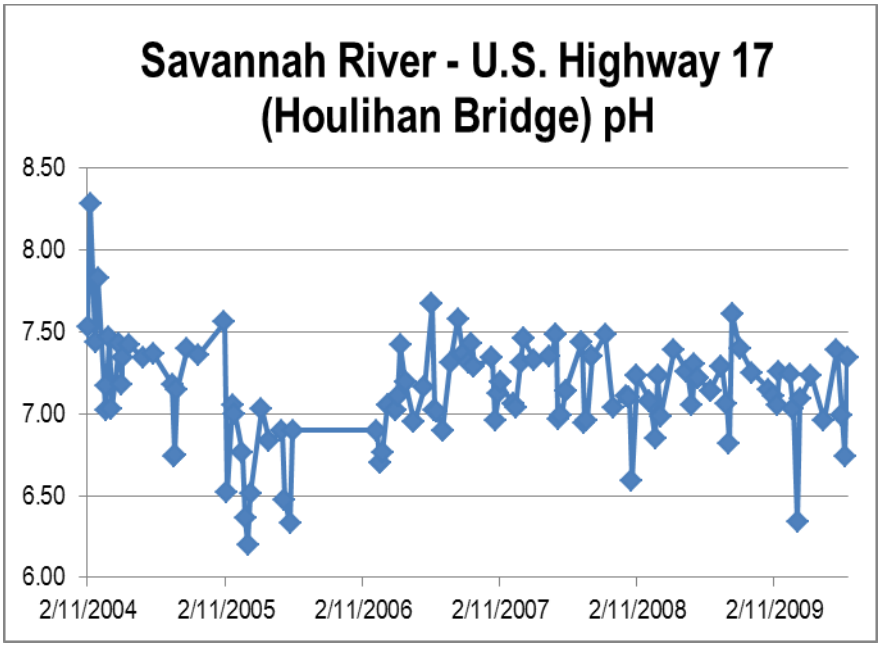


Figure 121. Time series of pH at the Savannah River-U.S. Highway 17 (Houlihan Bridge) index site located upstream of FOPU.

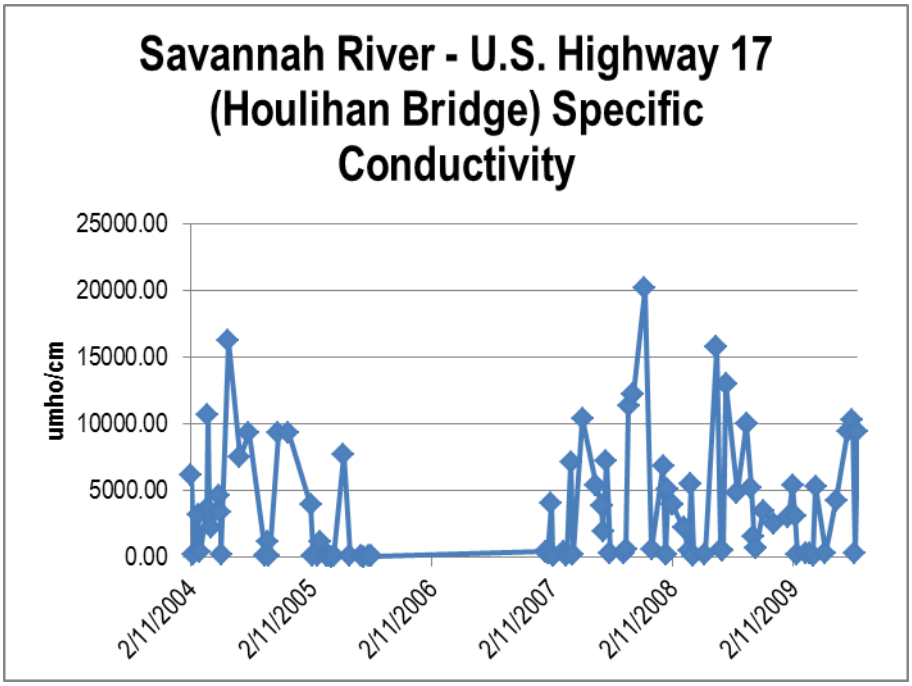


Figure 122. Time series of specific conductivity at the Savannah River-U.S. Highway 17 (Houlihan Bridge) index site located upstream of FOPU.

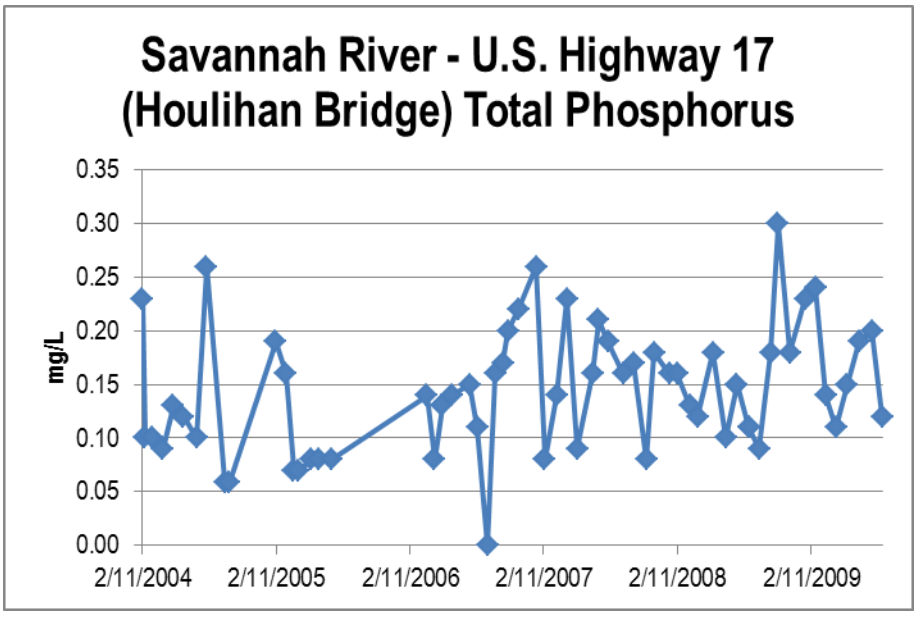


Figure 123. Time series of total phosphorus at the Savannah River-U.S. Highway 17 (Houlihan Bridge) index site located upstream of FOPU.

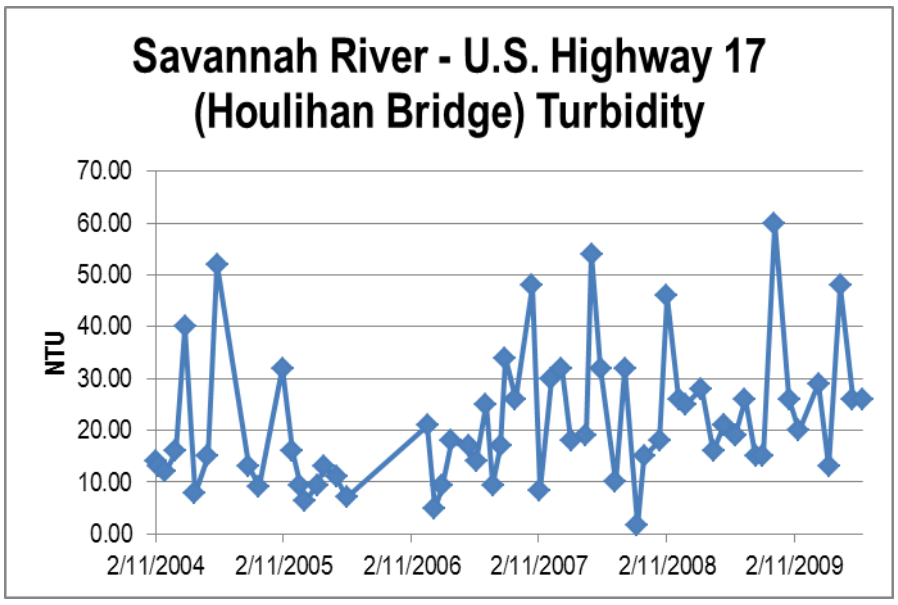


Figure 124. Time series of turbidity at the Savannah River-U.S. Highway 17 (Houlihan Bridge) index site located upstream of FOPU.

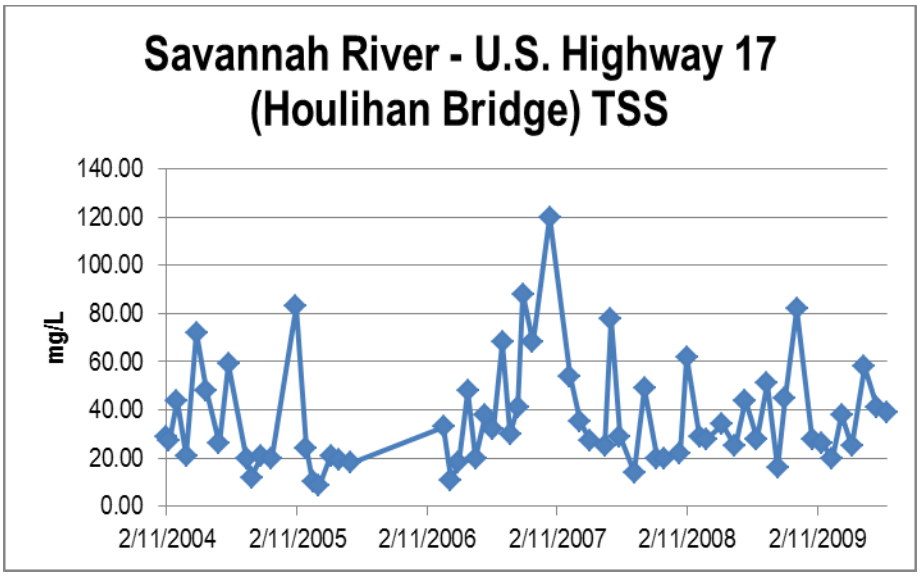


Figure 125. Time series of TSS at the Savannah River-U.S. Highway 17 (Houlihan Bridge) index site located upstream of FOPU.

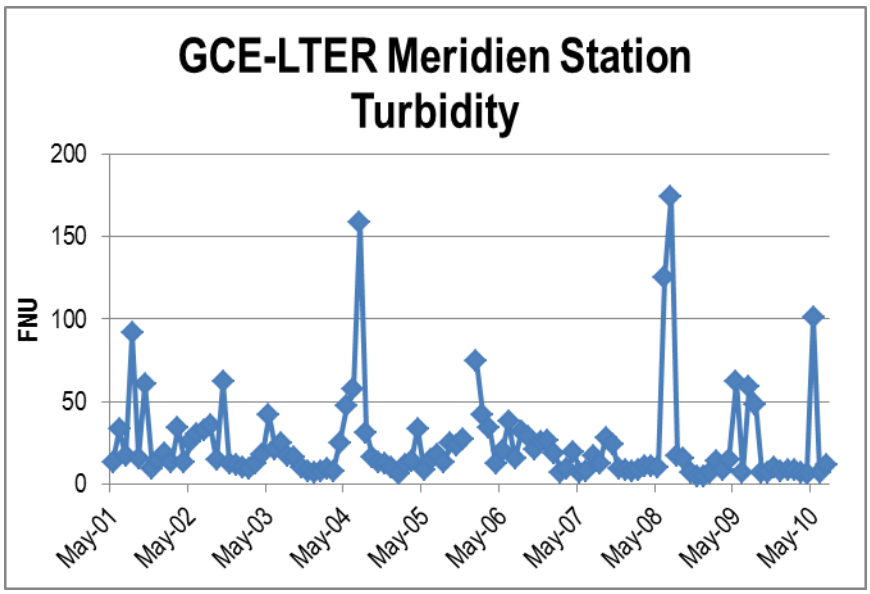


Figure 126. Time series of turbidity at the GCE-LTER Meridien index site located near FOPU and CUIS.

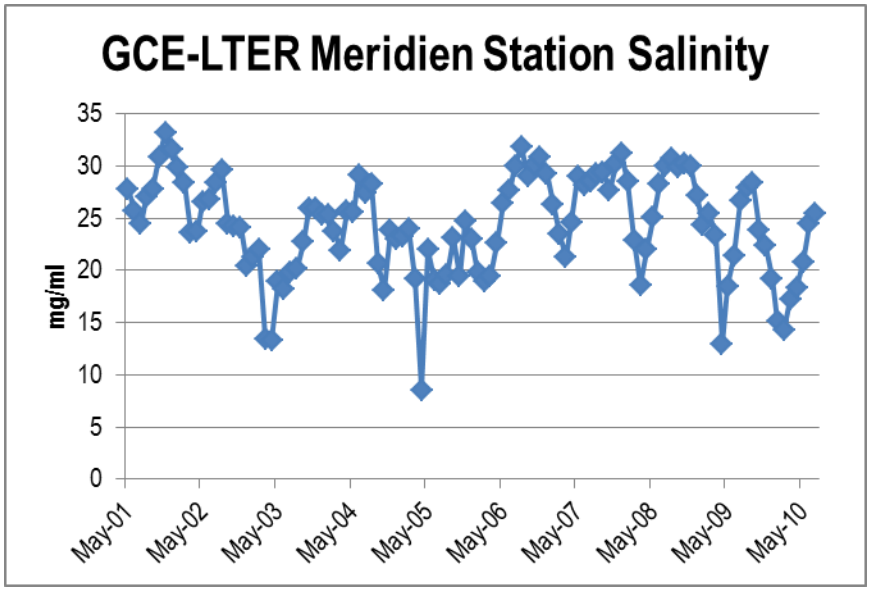


Figure 127. Time series of salinity at the GCE-LTER Meridien index site located near FOPU and CUIS.

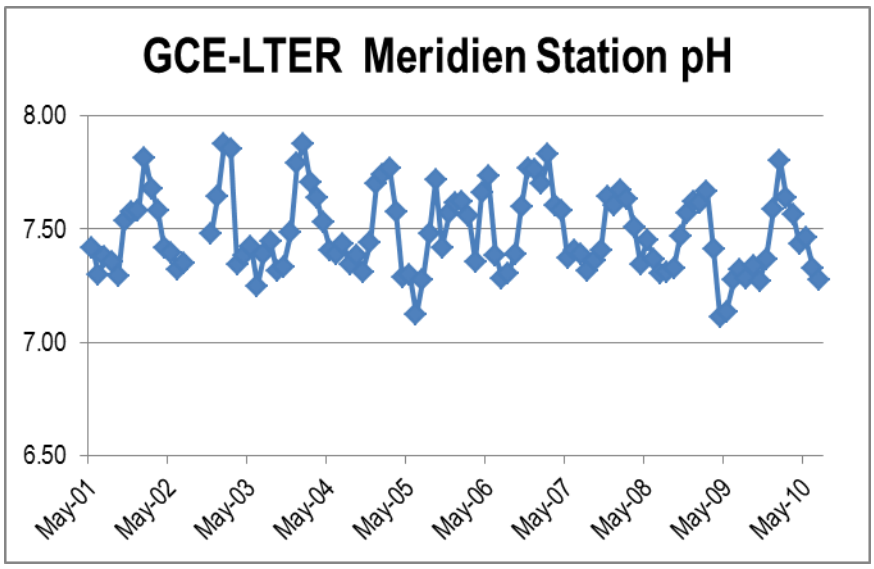


Figure 128. Time series of pH at the GCE-LTER Meridien index site located near FOPU and CUIS.

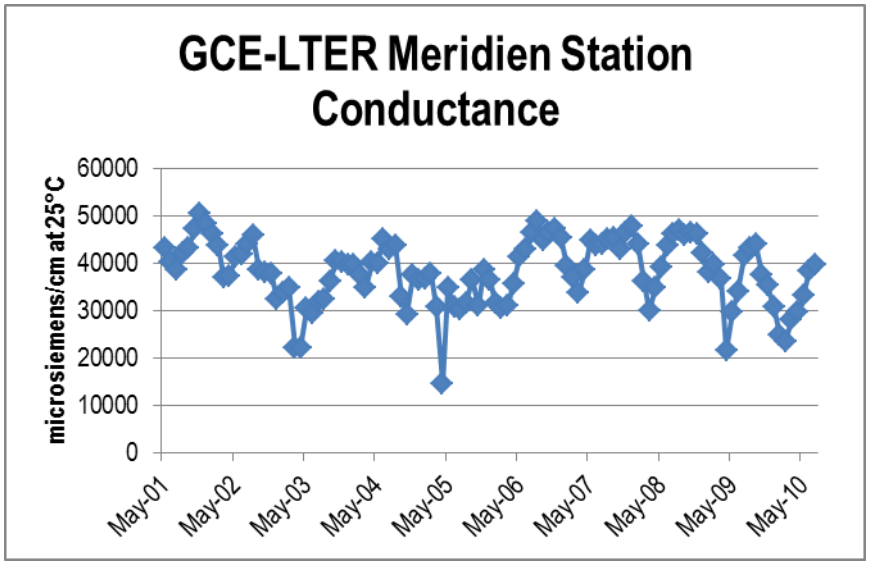


Figure 129. Time series of conductance at the GCE-LTER Meridien index site located near FOPU and CUIS.

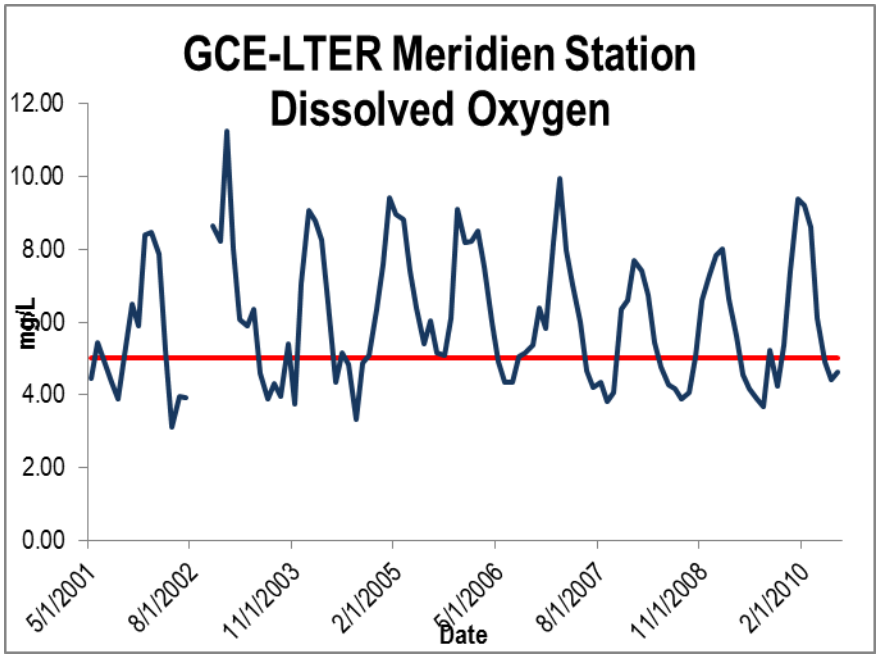


Figure 130. Time series of dissolved oxygen at the GCE-LTER Meridien index site located near FOPU and CUIS.

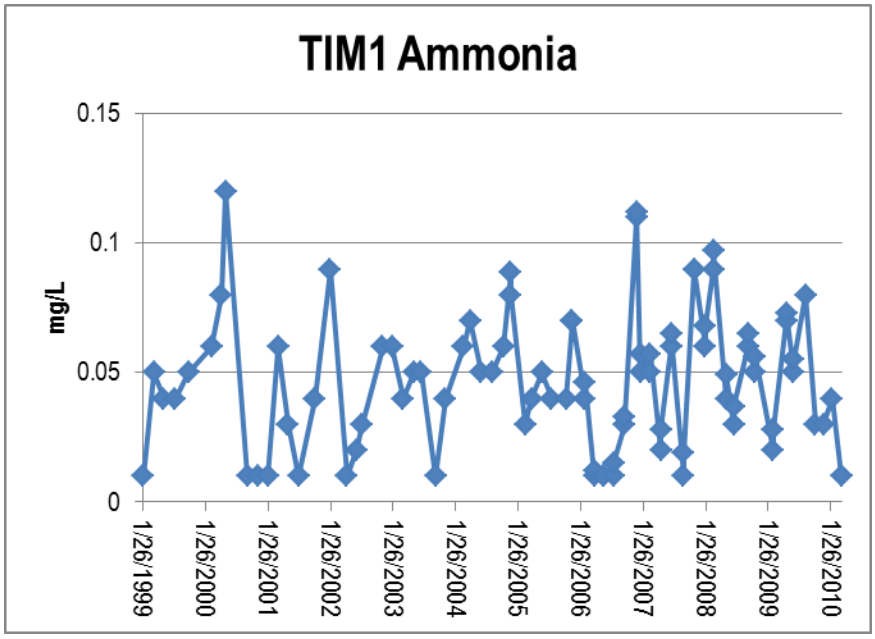


Figure 131. Time series of ammonia at the TIM1 index site located near TIMU.

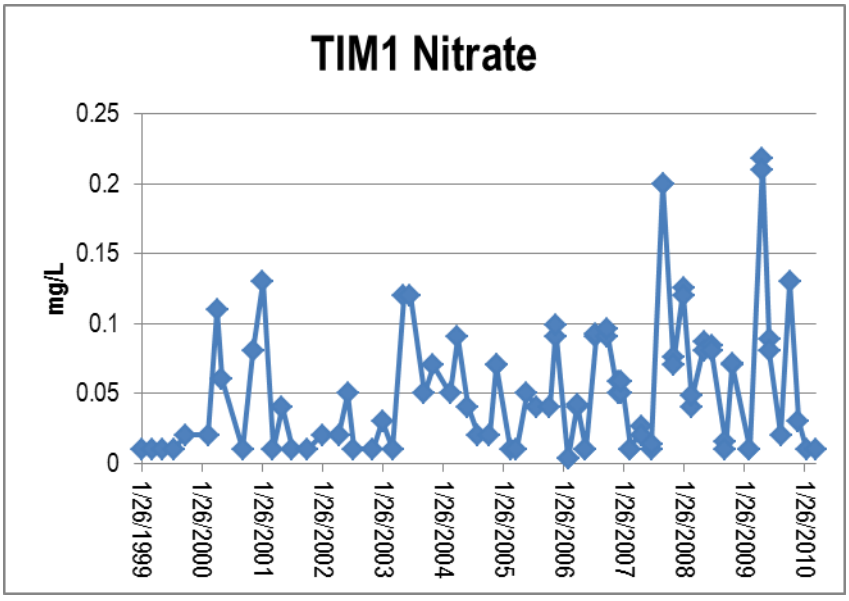


Figure 132. Time series of nitrate at the TIM1 index site located near TIMU.

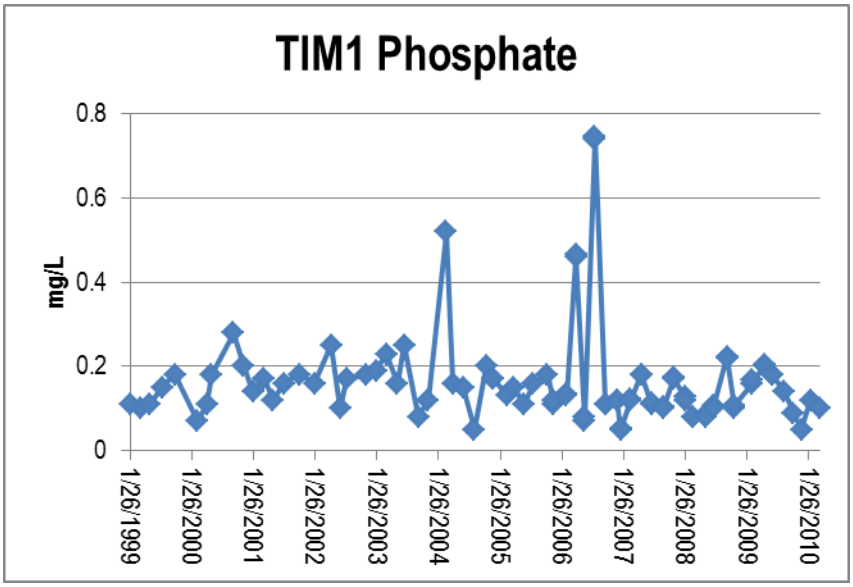


Figure 133. Time series of phosphate at the TIM1 index site located near TIMU.

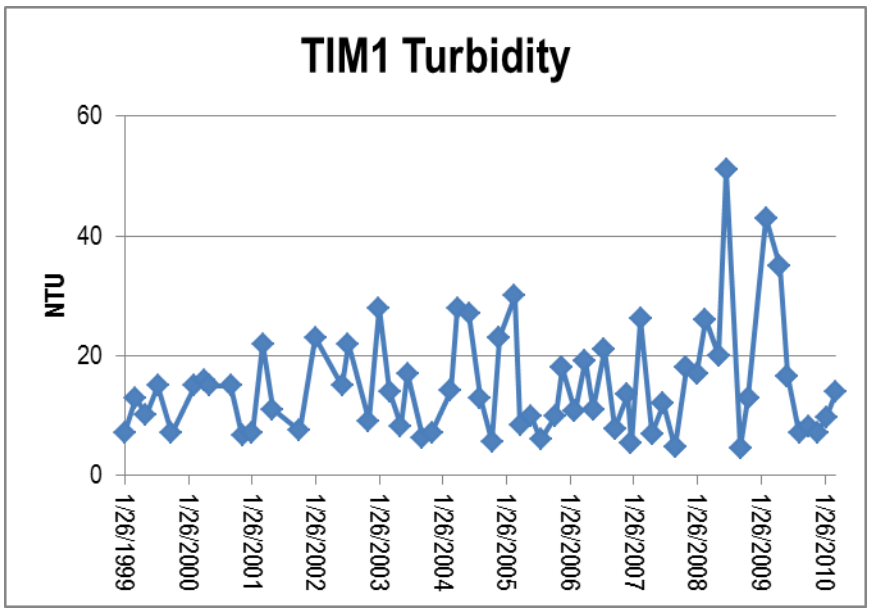


Figure 134. Time series of turbidity at the TIM1 index site located near TIMU.

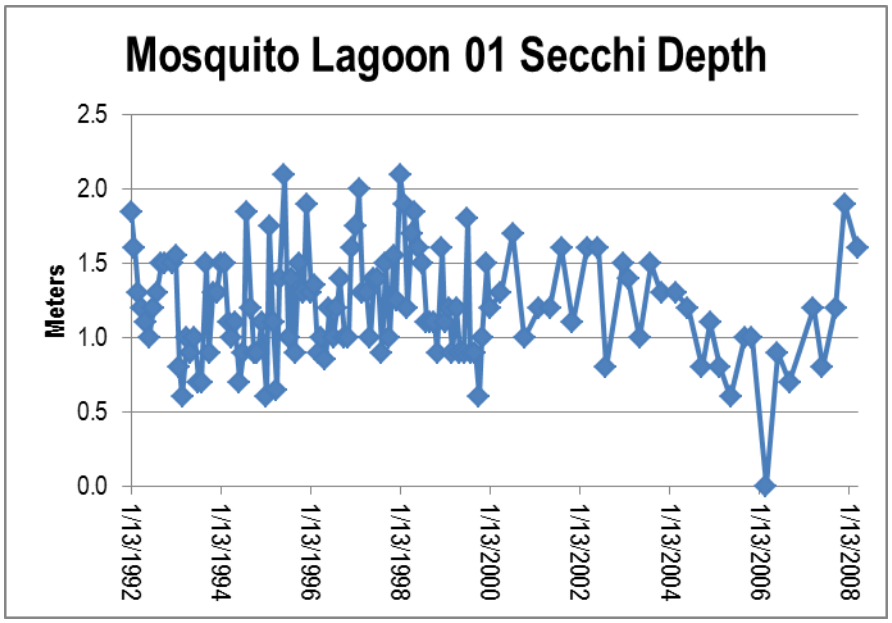


Figure 135. Time series of Secchi depth at the Mosquito Lagoon 01 index site located near CANA.

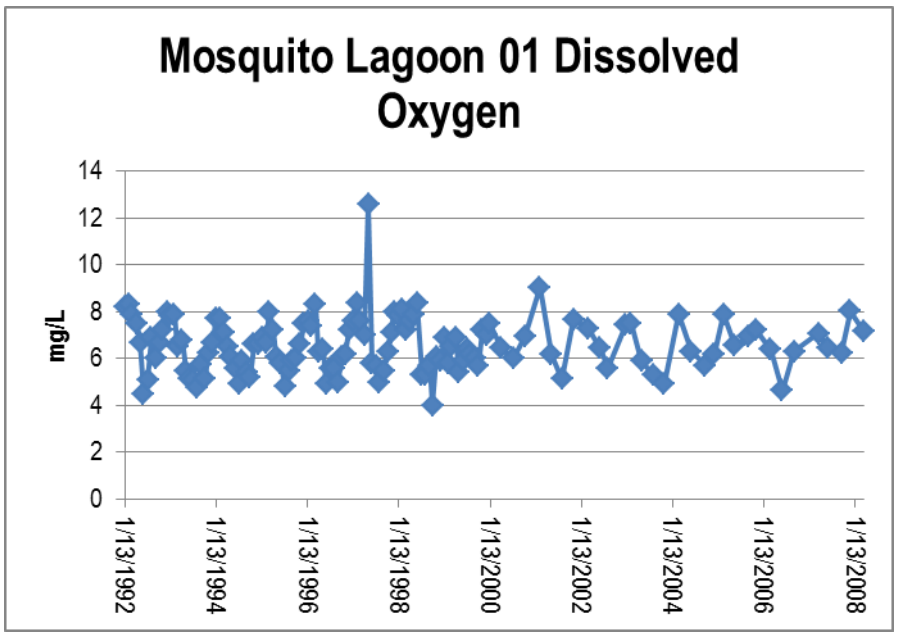


Figure 136. Time series of dissolved oxygen at the Mosquito Lagoon 01 index site located near CANA.

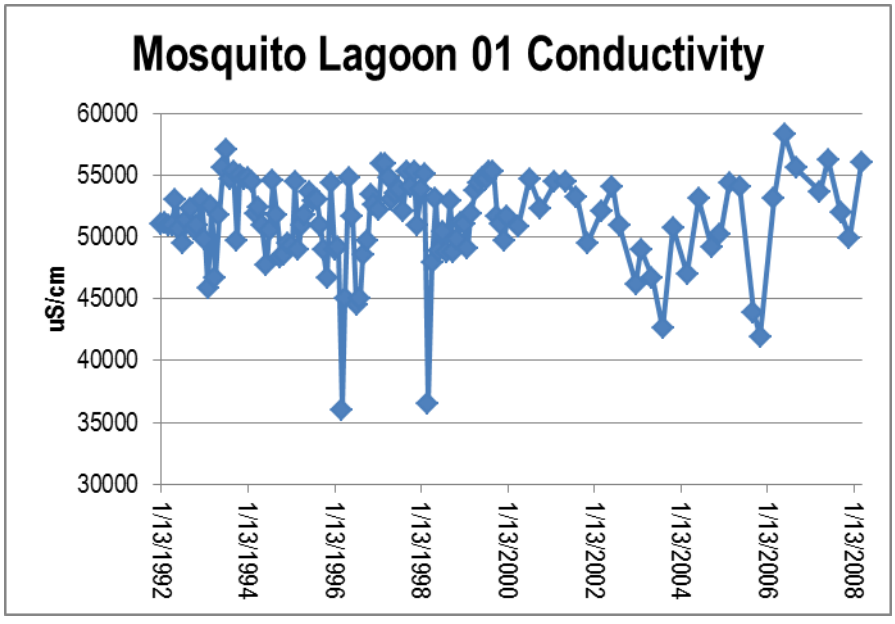


Figure 137. Time series of conductivity at the Mosquito Lagoon 01 index site located near CANA.

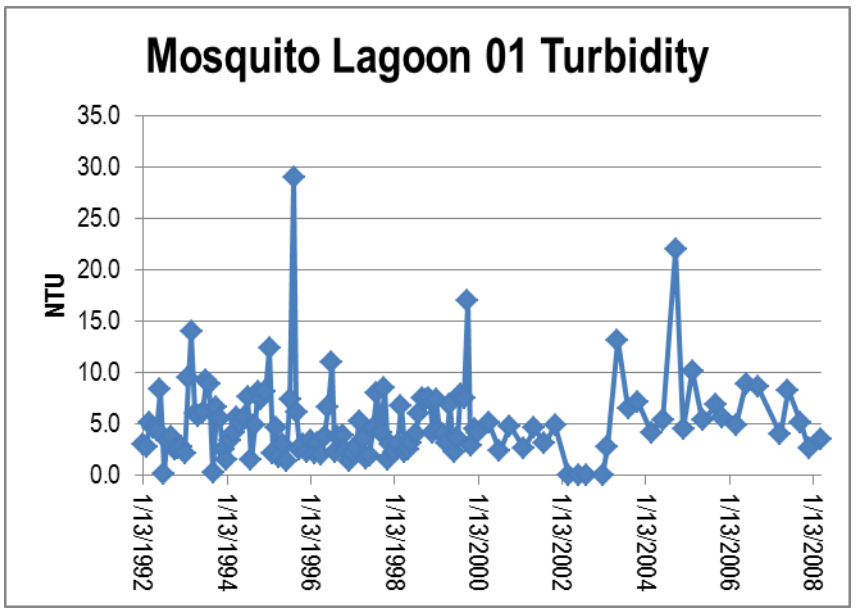


Figure 138. Time series of turbidity at the Mosquito Lagoon 01 index site located near CANA.

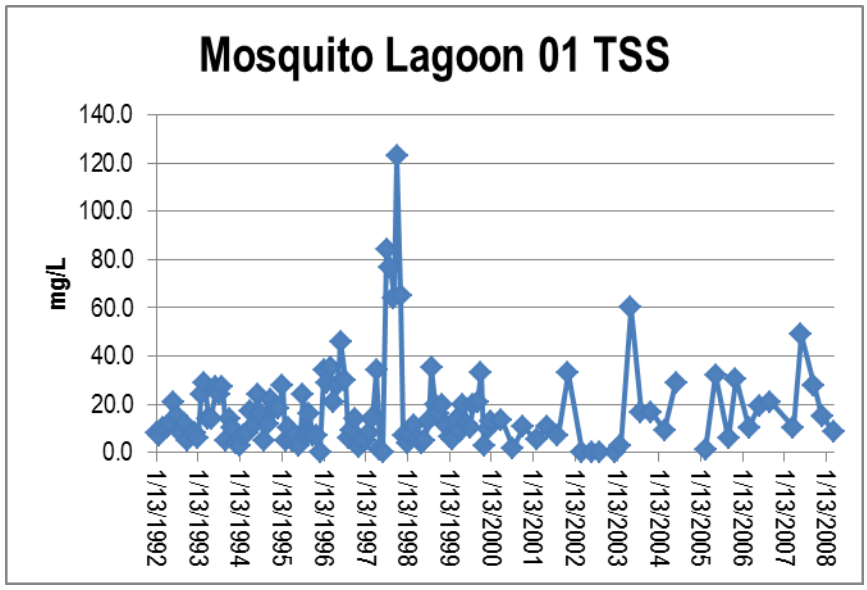


Figure 139. Time series of TSS at the Mosquito Lagoon 01 index site located near CANA.

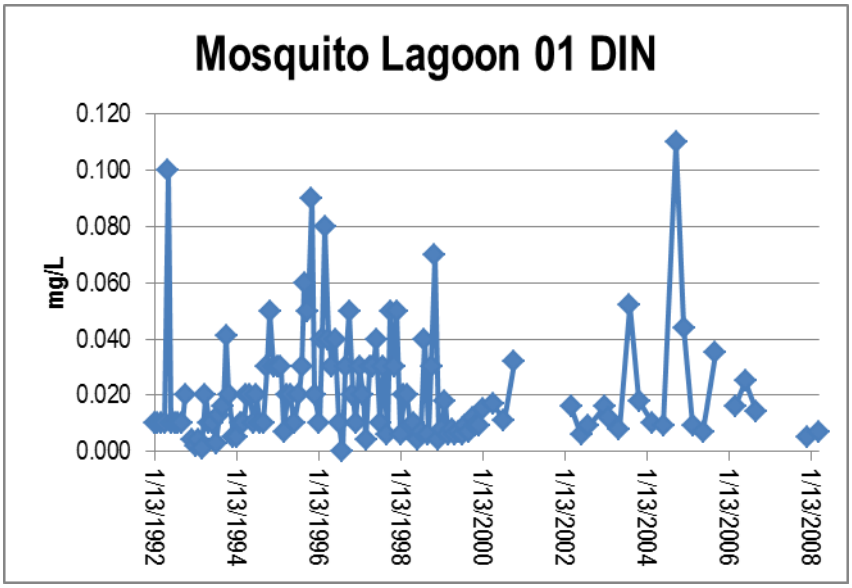


Figure 140. Time series of DIN at the Mosquito Lagoon 01 index site located near CANA.

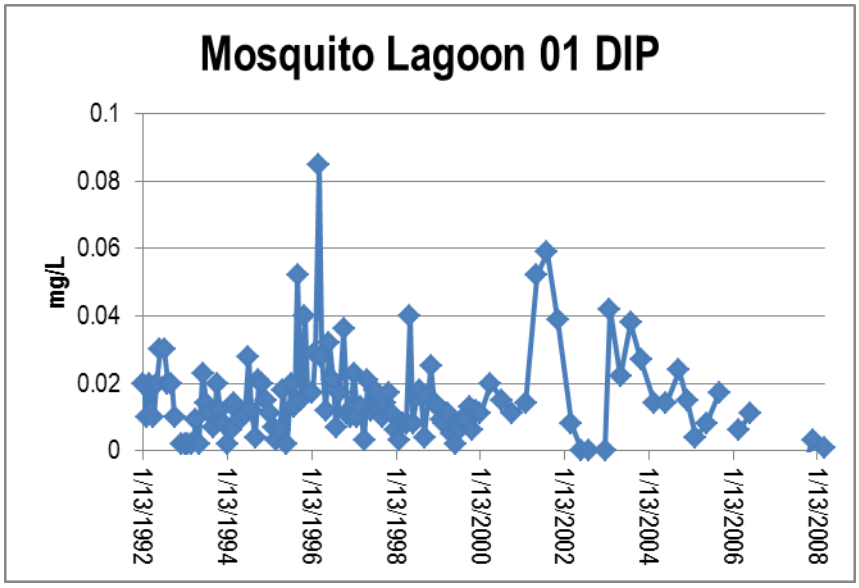


Figure 141. Time series of DIP at the Mosquito Lagoon 01 index site located near CANA.

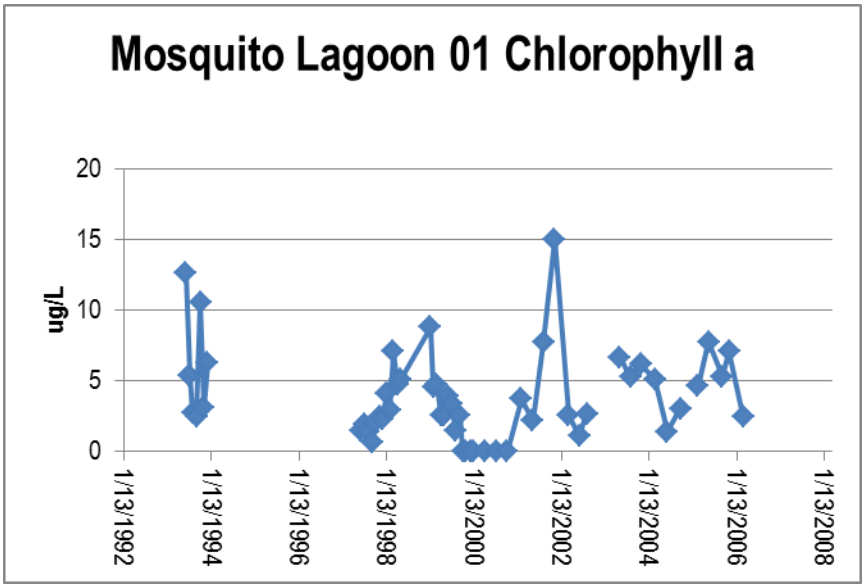


Figure 142. Time series of Chlorophyll a at the Mosquito Lagoon 01 index site located near CANA.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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U.S. Department of the Interior

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