Monitoring of Coastal Wetland Elevation and Vegetation Community Dynamics in the South Atlantic Geography

Accomplishments and FY17 Plan

December 2016

U.S. Department of the Interior
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Southeast Region Inventory & Monitoring Branch

Monitoring of Coastal Wetland Elevation and Vegetation Community Dynamics in the South Atlantic Geography

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Cover photos (clockwise from upper left):

- Installing 10 x 10 m vegetation plots in tidal smooth cordgrass zone of Pinckney Island National Wildlife Refuge (credit: Forbes Boyle/USFWS)
- Installing a rod surface elevation table benchmark at Pinckney Island National Wildlife Refuge (credit: Nicole Rankin/USFWS)
- Using liquid nitrogen to collect a cryogenic core at Ernest F. Hollings ACE Basin National Wildlife Refuge (credit: Theresa Thom/USFWS)
- Installing a 10 x 10 m vegetation plot in black needlerush marsh at Cedar Island National Wildlife Refuge (credit: Forbes Boyle/USFWS)
- Water level station at Bell Island Pier, Swanquarter National Wildlife Refuge (credit: Michelle Moorman/USFWS)
- Measuring surface elevation from rod surface elevation table benchmark installed in oligohaline marsh at Savannah National Wildlife Refuge (credit: Nicole Rankin/USFWS)
- Measuring surface elevation from rod surface elevation table benchmark installed in black needlerush marsh at St. Marks National Wildlife Refuge (credit: Nicole Rankin/USFWS)
- Measuring the accretion of sediment from the feldspar layer to the marsh surface of a cryogenic core collected from Waccamaw National Wildlife Refuge (credit: Theresa Thom/USFWS)
- Setting up a global positioning system receiver to perform a static survey on a surface elevation table benchmark at Waccamaw National Wildlife Refuge (credit: Nicole Rankin/USFWS)

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Project Description

Sea-level rise and its impacts to habitats and species are a concern for the U.S. Fish and Wildlife Service (USFWS) National Wildlife Refuges (NWRs) within the Southeast United States. Rising sea levels threaten coastal wetlands leading to wetland loss, saltwater intrusion, habitat conversion, and inland migration of marsh and forested ecosystems. The mean elevation of these wetland surfaces must increase to keep pace with the annual rise in sea level and subsidence of organic substrates (CCSP 2009; Webb et al. 2013). Understanding rates of wetland elevation change and relative sea-level rise is important to help refuge managers answer critical questions and adjust management techniques of wetlands towards future conditions (Figure 1).

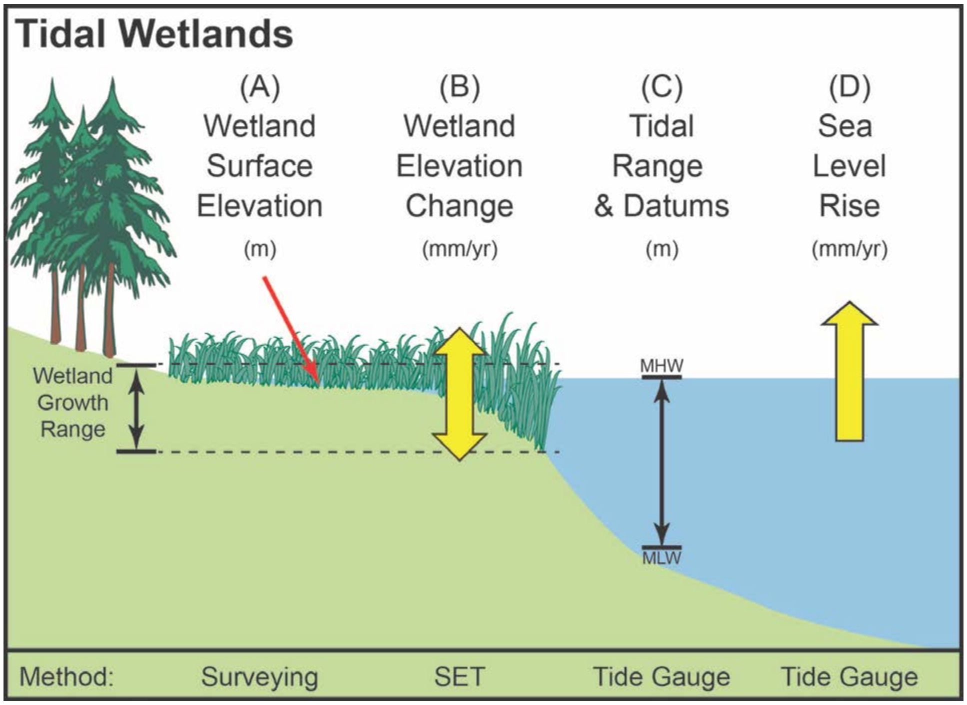

Figure 1. Diagram depicting the relationship among wetland surface elevation (A), wetland elevation change (B), tidal datums (C), and sea- level rise (D) and the measurement method for each, respectively. (Lynch et al 2015).

The USFWS Southeast Region Inventory and Monitoring Branch (I&M) initiated a Coastal Wetland Elevation and Vegetation Community Dynamics Monitoring (CWEM) effort on 18 NWRs within the South Atlantic geography in 2012. This long-term effort collects information on surface elevation, soil accretion, porewater salinity, vegetation composition and structure, soil chemistry, and benchmark elevation at permanent sites established in priority wetland habitats to provide data to managers on the status of and trends in wetland conditions within refuges. Additionally, one water level station was established at Bell Island Pier, Swanquarter NWR in 2013. These data will be combined with other data, tools, and models to better inform decisions on conservation plans and management actions within the coastal zone. Furthermore, these monitoring efforts will provide a new suite of information and products to allow managers greater confidence in their science-based decisions for conservation and management of coastal wetlands on NWRs in the South Atlantic geography.

Study Area

In December 2011 and January 2012, Southeast Region I&M staff, NWR biologists and managers, and partners determined priority habitat types for surface elevation table (SET) benchmarks and associated monitoring stations on 18 coastal NWRs within the South Atlantic Landscape Conservation Cooperative geography (Figure 2). The study area spans the Atlantic coast from North Carolina to north Florida and west into the Florida Panhandle. Twenty CWEM sites were established on 18 NWRs in the spring, summer, and fall of 2012. These sites were established within a prior defined habitat through a spatially balanced random sampling design. In late 2016, two study sites located on Cape Romain NWR were incorporated into project. In total, this monitoring effort is represented by 19 NWRs, 22 sites, and 65 SET benchmarks.

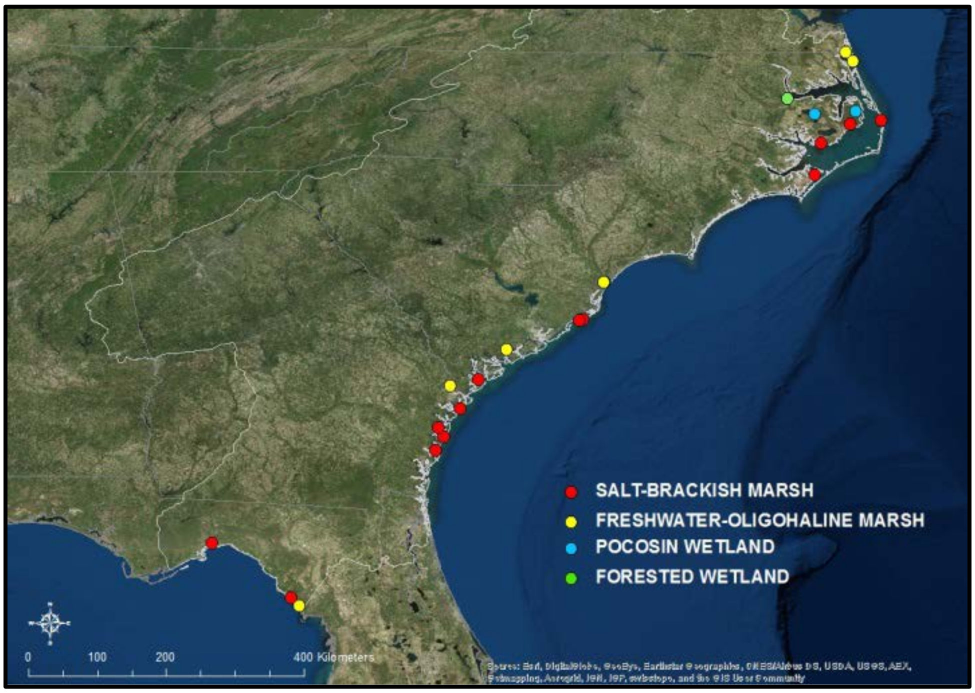

Figure 2. Distribution of the South Atlantic CWEM sites within coastal North Carolina, South Carolina, Georgia, and Florida NWRs.

Nineteen refuges participate in the South Atlantic CWEM effort. From north to south site placement, refuges (and number of sites per refuge) include Mackay Island (1), Currituck (1), Roanoke River (1), Alligator River (2), Pocosin Lakes (1), Pea Island (1), Swanquarter (1), Cedar Island (1), Waccamaw (1), Cape Romain (2), Ernest F. Hollings ACE Basin (1), Pinckney Island (1), Savannah (1), Wassaw (1), Harris Neck (1), Blackbeard Island (1), Wolf Island (1), St. Marks (1), and Lower Suwannee (2; Figure 2).

Broad ecological habitats include salt and brackish marsh, freshwater and oligohaline marsh, pocosin, and forested wetland. Salt marsh sites are located in secluded marsh platforms, embayments, back-barrier, or open coast landforms. Freshwater marsh, oligohaline marsh, and forested wetland sites are located near the mouths of rivers. In 2013, the baseline vegetation inventory was conducted and CWEM study sites were classified into ten vegetation associations and eight Ecological Systems of the United States (Table 1; Boyle et al. 2015).

Table 1. List of NatureServe's Ecological Systems, the number of study sites, and refuges per Ecological System (Comer et al. 2003).

NatureServe Ecological Systems	Number of Sites	Refuges
Atlantic Coastal Plain Embayed Region Tidal Freshwater Marsh	2	Currituck, Mackay Island
Atlantic Coastal Plain Embayed Region Tidal Salt and Brackish Marsh	4	Alligator River, Cedar Island, Pea Island, Swanquarter
Atlantic Coastal Plain Peatland Pocosin and Canebrake	2	Alligator River, Pocosin Lakes
Florida Big Bend Salt and Brackish Tidal Marsh	2	Lower Suwannee, St. Marks
Florida River Floodplain Marsh	1	Lower Suwannee
Southern Atlantic Coastal Plain Fresh and Oligohaline Tidal Marsh	3	ACE Basin, Savannah, Waccamaw
Southern Atlantic Coastal Plain Large River Floodplain Forest	1	Roanoke River
Southern Atlantic Coastal Plain Salt and Brackish Tidal Marsh	7	Blackbeard Island, Cape Romain (2), Harris Neck, Pinckney Island, Wassaw, Wolf Island

Photos: Measuring surface elevation from RSET benchmark in tidal smooth cordgrass zone at Blackbeard Island NWR (credit: Nicole Rankin/USFWS); nested quadrat vegetation sampling within giant cutgrass marsh on Savannah NWR (credit: Forbes Boyle/USFWS); measuring porewater salinity from tidal black needlerush marsh at Lower Suwannee NWR (credit: Nicole Rankin/USFWS).

Project Objectives
The overarching CWEM objective is to observe impacts of sea level rise and change in priority habitats, determine rates of wetland elevation change and relative sea level rise, and forecast longevity of these habitats in refuges within the South Atlantic geography.

National Protocol Framework Objectives
The CWEM efforts in the South Atlantic are based on the following national protocol framework, *The Surface Elevation Table and Marker Horizon Technique, A Protocol for Monitoring Wetland Elevation Dynamics* (Lynch et al. 2015). Specific objectives of this framework include:

A. Quantify elevation change in wetlands with the SET.
B. Understand the processes that influence elevation change, including vertical accretion.
C. Survey the wetland surface and SET mark to a common reference datum (NAVD 88) to allow for comparing sample stations to each other and to local tidal datums.
D. Survey the SET mark to monitor its relative stability.

Multi-Regional Protocol Framework Objectives – Region 4
The national protocol framework will be stepped down to a multi-region protocol framework. Currently, the *Multi-Regional Protocol Framework for Monitoring of Coastal Wetland Elevation and Vegetation Community Dynamics - Regions 2 and 4* is under development. This multi-regional protocol framework provides a structure for monitoring wetlands on coastal refuges in Regions 2 and 4. Specific objectives include:

1. Establish a network of CWEM sites from which to perform monitoring of surface elevation, accretion, porewater salinity, vegetation community, and benchmark elevation on coastal refuges within the South Atlantic geography.
2. Determine the magnitude, rate, and within-site variability of change in ground surface elevation in wetlands on refuges.
3. Determine the status, trends, and within-site variability in surface sediment accretion.
4. Determine the status and trends in soil porewater salinity.
5. Develop a baseline inventory of vegetation species and vegetation community type.
6. Determine the status, trends, and within-site variability in vegetation species composition, vegetation structure (strata height), vegetation cover, and abiotic site conditions (soil nutrients).
7. Compute a baseline vertical height referenced to the National Spatial Reference System on each rod surface elevation table benchmark from which to measure benchmark stability over time.
8. Determine the status and trends in the surveyed elevation of benchmarks relative to the National Spatial Reference System.
9. Develop a local, high accuracy geodetic control network connected to the National Spatial Reference System within each CWEM site.
10. Establish a water level station and two deep-rod benchmarks at Bell Island Pier, Swanquarter NC in order to determine the local water level within the Pamlico Sound and relate the Swanquarter NWR surface elevation (and elevation change) data to the computed tidal datum and associated patterns of inundation.
11. Compute a tidal datum from continuous observations of water level at Bell Island Pier.
12. Determine the status and trends in water level at Bell Island Pier.

Methods

The *Multi-Regional Protocol Framework for Monitoring of Coastal Wetland Elevation and Vegetation Community Dynamics - Regions 2 and 4* provides guidance for monitoring surface elevation, benchmark elevation, accretion, porewater salinity, vegetation community, and water level in wetlands on refuges. Specifically, the protocol outlines how to establish and monitor rod surface elevation table (RSET) benchmarks, accretion plots, porewater salinity plots and wells, vegetation plots, and water level stations on coastal NWRs in Regions 2 and 4. The following table and summary outlines the parameters and standardized methods for establishing and collecting data at CWEM sites in the South Atlantic geography (Table 2).

Table 2. List of parameters, methods, scale, and frequency of measurement for CWEM sites and associated objectives from the Multi-Regional Protocol Framework for Monitoring of Coastal Wetland Elevation and Vegetation Community Dynamics.

Parameter	Method	Scale	Frequency	Objectives
Surface Elevation	Rod Surface Elevation Table	Three RSET Benchmarks per site; Four directions per RSET benchmark	Once or twice per year	1, 2
Benchmark Elevation	Simultaneous GNSS GPS and Total Station	Three RSET Benchmarks per site	Every five years	1, 7, 8, 9
Accretion	Mini Macaulay Corer and Cryogenic Coring	Nine accretion 0.25 m^2 plots per site; One core per plot	Once or twice per year	1, 3
Porewater Salinity	10 and 30 cm Sipper Tubes and Porewater Wells	Three porewater 0.25 m^2 plots or wells per site; Three samples per depth	Once or twice per year	1, 4
Vegetation Community	Carolina Vegetation Survey	Three 100 m^2 plots per site	Every three years; growing season	1, 5, 6
Water Level	YSI 600 LS Vented Sensor	One water level station at Bell Island Pier	Every six minutes	10, 11, 12
Water Level Elevation	Laser Level Surveys	Water level sensor, two deep-rod benchmarks and leveling control points	Before and after sensor replacement	10, 11, 12

Surface Elevation

Three RSET benchmarks were established at each CWEM site. For RSET benchmarks, a series of 4-foot stainless steel rods were threaded together and driven through the root zone and underlying substrate until refusal was encountered. A demolition hammer was used to drive the rods to refusal within the sediment. A custom-made, stainless steel receiver was attached to the rod at the surface and stabilized by a six-inch diameter PVC pipe filled with concrete. The RSET receiver provides a constant horizontal reference plane allowing repeated measurements through time of the same patch of sediment surface (Lynch et al. 2015).

Surface elevation is being measured from each RSET benchmark using the RSET technique developed by Cahoon et al. (2002b). This technique provides a non-destructive process that precisely measures the sediment elevation of wetlands over long periods of time relative to a fixed subsurface datum (Cahoon et al. 2002b; Lynch et al. 2015). Measurements are taken by attaching the RSET arm to the RSET benchmark receiver, leveling the RSET arm, and lowering nine fiberglass pins to the wetland surface. The height in millimeters that each pin extends above the arm is measured and used to calculate vertical changes in the wetland surface over time (Cahoon and Lynch 2003; Devivo et al. 2015). The RSET arm is positioned to measure the wetland surface at four 90° angles, resulting in 36 measurements per benchmark. Surface elevation is currently sampled one to two times per year.

Benchmark Elevation
Benchmark elevation is being calculated for each RSET benchmark to determine wetland elevation with respect to the local tidal datums and monitor the stability of the benchmarks overtime. Simultaneous static Global Navigation Satellite System (GNSS) geospatial positioning system (GPS) observations are being conducted using three Trimble R10 GNSS receivers (Trimble Navigation Ltd, Sunnyvale, California), three USGS fixed-dimension GNSS antenna adapters, and one Trimble TSC3 data collector. All available GNSS receivers are set up to simultaneously record observations on each RSET benchmark for a minimum of two, six-hour sessions on each CWEM site. These long, repeated sessions are important to ensure different satellite configurations and atmospheric conditions and allow replication of the survey (Lynch et al. 2015). The data are processed using the Online Positioning User Service (OPUS) and the more robust OPUS projects processing interface. Benchmark elevation will be collected once every five years.

Accretion
Accretion plots were established on the same day of the baseline surface elevation readings (i.e., time zero). Three 0.25 m^2 accretion plots were established in the immediate vicinity of each RSET benchmark. Feldspar clay was evenly sprinkled on the surface of the wetland within each accretion plot upon which sediments naturally settle and accrete. Two corners of the accretion plots were marked with red survey stakes or fiberglass rods. Accretion plots need to be re-established every two-four years.

Accretion is being measured from established accretion plots within each site. Accretion plots are sampled repeatedly over time to determine the rate of soil deposition over the feldspar marker. Depth to feldspar marker is measured in millimeters from cores collected using a mini Macaulay corer and a cryogenic coring technique developed by Cahoon et al. 1996. Accretion is sampled one to two times per year on the same day surface elevation is measured.

Porewater Salinity
Porewater salinity plots were established on the same day of the baseline surface elevation readings. One 0.25 m^2 salinity plot was established in the immediate vicinity of each RSET benchmark at most CWEM sites. Two corners of the salinity plots were marked with red survey stakes or fiberglass rods. At the remaining CWEM sites, one 4-cm diameter porewater salinity well was constructed and installed in the immediate vicinity of each RSET benchmark.

Porewater salinity is being measured from established salinity plots and wells at each CWEM site. Porewater salinity is collected using a sipper tube to extract water from 10 and 30-cm depths within established plots. Temperature (ºC), salinity (ppt), and specific conductance (µS/cm) are measured from the extracted porewater using a handheld salinity meter. For salinity wells, the handheld salinity meter probe is inserted into the well and temperature (ºC), salinity (ppt), and specific conductance (µS/cm) is measured. Porewater salinity is sampled one to two times per year on the same day surface elevation is measured.

Vegetation Community

Vegetation plots were established the summer following RSET benchmark installation. One 100 m^2 plot was established adjacent to each RSET benchmark using the Carolina Vegetation Survey (CVS) protocol developed by Peet et al. 1998. Plots were placed no more than a 20 m linear distance from its corresponding RSET benchmark oriented so that they were between the benchmark and nearest open water. Plot corners were monumented using stainless steel conduit driven into the ground, with 3-6" of the top exposed.

Vegetation monitoring is being performed using the CVS protocol (Peet et al. 1998). Monitoring is conducted at established 100 m^2 plots to assess compositional richness (i.e., number of species) across multiple spatial scales (smallest scale = 0.01 m2; largest scale = 100 m2), document tree and shrub density, and describe abiotic conditions (e.g., soil nutrient/texture, disturbance history). Vegetation monitoring is conducted once every three years during the growing season.

Water Level

One water level station and two deep-rod benchmarks were established at Bell Island Pier, Swanquarter NWR in spring 2013. A YSI 600 LS, a vented sensor which collects temperature, salinity, and pressure data, was mounted to the pier. The sensor was deployed inside an inner 2-inch PVC tube and placed into a 4-inch PVC mounting tube attached with saddles bolted to the pier cross beams. A vented field cable is attached to the sensor and to the battery box. Power is supplied using a marine battery housed inside the battery box.

Water level monitoring is being measured at Bell Island Pier, Swanquarter NWR in order to determine the local water level within the Pamlico Sound and relate the Swanquarter NWR surface elevation (and elevation change) data to the computed tidal datum and associated patterns of inundation. The YSI 600 LS sensor is deployed and records date, time, temperature (°C), specific conductance (µS/cm), salinity (ppt), and depth (m) every 6 minutes. Every three months, the sensor is removed for cleaning/post-calibration procedures and replaced with pre-calibrated sensor. The sensor, two deep-rod benchmarks, and other leveling control points are surveyed using a laser level before and after replacement of the sensor. During post-calibration, data is downloaded for quality assurance and quality control.

Roles and Responsibilities

Current roles and responsibilities associated with the *Multi-Regional Protocol Framework for Monitoring of Coastal Wetland Elevation and Vegetation Community Dynamics - Regions 2 and 4* are as follows. The FWS I&M Branch is responsible for technical oversight of protocol implementation and coordinates data collection to ensure consistent data collection at the 19 participating refuges. The FWS I&M Branch is responsible for providing technical support and training to refuges and external agency partners (as appropriate). Participating refuges are responsible for field logistics, data collection and data submission of surface elevation, accretion, and porewater salinity parameters at each CWEM site. The FWS I&M Branch is responsible for coordinating and performing data collection of the vegetation community and benchmark elevation parameters at all CWEM sites. Swanquarter NWR staff is responsible for continued monitoring of water level at Bell Island Pier. The FWS I&M Branch is responsible for ensuring collected data is received, checked for accuracy and completeness, secured, and archived. The FWS I&M Branch is responsible for conducting analysis and synthesis of data and communicating findings in presentations, reports, briefings, and peer-reviewed scientific papers.

Data Collection Chronology
A chronology of CWEM monitoring parameters and data collection efforts from 2012 – 2016 can be found in Appendix A.

Accomplishments and FY17 Plan

Establishing Sites and Collecting Surface Elevation, Accretion, and Porewater Salinity Data
Twenty CWEM Sites (three RSET benchmarks per site) were established on 18 NWRs in the spring, summer, and fall of 2012. In late 2016, two partner study sites located in Cape Romain NWR were incorporated into the CWEM study area. To date, twenty-two sites with 65 SET benchmarks are part of this monitoring effort.

A total of sixteen refuge staff was trained to collect surface elevation, accretion, and porewater salinity data in 2012-2013. Over 50 staff, interns, and volunteers have assisted with logistics and data collection efforts from 2012 – 2016.

In January 2017, four years of surface elevation data will have been collected from 18 CWEM sites. Data collection efforts (three to eleven) have varied among sites. This variance in number of sampling trips results from a variety of factors including storm events, tidal events, logistical constraints, staff turnover, and staff schedules.

For FY17, surface elevation, accretion, and porewater salinity data will be collected during the fall timeframe at each CWEM site. Following CWEM standardized methodologies, this data will also be collected at the Cape Romain NWR sites.

Photos: Installing a rod surface elevation table benchmark at Blackbeard Island NWR (credit: Dave O'Loughlin/Atkins); establishing accretion plots within tidal smooth cordgrass zone on Wolf Island NWR (credit: Nicole Rankin/USFWS); measuring surface elevation from rod surface elevation table benchmark installed in pocosin wetlands at Pocosin Lakes NWR (credit: Nicole Rankin/USFWS).

Benchmark Elevation
Static GNSS GPS surveys were conducted at thirteen CWEM sites in 2015 and 2016 (Table 4). Seven CWEM sites across three states were surveyed in 2015 and six CWEM sites across three states in 2016. This represents the baseline elevation survey for these sites. Over 20 FWS and non-FWS employees assisted with logistics and fieldwork for the 2015 – 2016 survey efforts.

Table 3. List of refuge names, CWEM sites, and the year that static GNSS GPS surveys were conducted.

Refuge Name	CWEM Site	GNSS GPS Survey Year
Alligator River	ALL030	2016
Blackbeard Island	BLB011	2016
Cedar Island	CDR027	2015
Currituck	CRT026	2016
Harris Neck	HSN033	2015
Pinckney Island	PKY008	2015, 2016
Pea Island	PLD010	2015
Pocosin Lakes	POC016	2015
St. Marks	SMK000	2016
Swanquarter	SWQ000	2015
Waccamaw	SAW000	2016
Wassaw	WSW001	2015
Wolf Island	WLF035	2016

FWS I&M continues to work with the National Park Service Southeast Coast Network to post-process the GNSS GPS data collected in 2015. A forthcoming report, *Determining the Elevation of Rod Surface Elevation Table Benchmarks at Seven Coastal Wetland Elevation Monitoring Sites*, will present methods used to process this data and results for each survey in 2015. This report will be completed in the coming year. Another report will be written and completed for GNSS GPS surveys completed in 2016.

For FY17, seven CWEM sites and the Bell Island water level station will need to have the baseline elevation survey completed. The two Lower Suwannee NWR (SWE002 and SWE038) sites were unable to be surveyed in 2016 due to Hurricane Hermine, which made landfall during the scheduled sampling period. The ACE Basin (ABS017), Savannah (SAV004), and Mackay Island (MCI026) NWR sites were unable to be surveyed in 2015 and 2016 due to survey logistics and staff time. Alligator River NWR (ALL005) and Roanoke River NWR (RRV013) require a different survey methodology that proves logistically challenging. FWS I&M and NPS SECN are developing a survey sampling plan for FY17.

Vegetation Community

At each CWEM site, a total of three vegetation plots were established and sampled in 2013 to capture a full vascular species list across multiple spatial scales, areal cover values for each species, stem diameter for woody species, and select environmental attributes. This represented the baseline vegetation inventory for CWEM, and the *Vegetation of Coastal Wetland Elevation Monitoring Sites on National Wildlife Refuges in the South Atlantic Geography – Baseline Inventory Report* was completed in April 2015. Noteworthy findings included:

- Vegetation and environmental data were captured in 60 10x10 m bounded and monumented plots across 20 CWEM sites on 18 NWRs.
- Baseline inventory efforts detected 137 taxonomic concepts, including a potential county record listing for Levy County, Florida (*Eupatorium mikanioides* on Lower Suwannee NWR). The 20 sites were classified into ten vegetation associations, including four with G2 (Imperiled) conservation status (NatureServe 2014), and seven ecological types.
- The most common associations sampled were the *Juncus roemerianus* Herbaceous Vegetation and *Spartina alterniflora* Carolinian Zone Herbaceous Vegetation types.
- The most frequent species found during this survey included *Juncus roemerianus, Sporobolus alterniflora, Schoenoplectus tabernaemontani, Sagittaria lancifolia* var. *media, Peltandra virginica, Zizaniopsis miliacea,* and *Galium tinctorium*.
- Plots located on the Roanoke River NWR site exhibited the highest species richness values (average=34.3) for the full plot-scale (100 m^2); plots located on the Waccamaw NWR site exhibited the highest species richness values (average=17, 9.1, 3.3, and 1.5) for the nested quadrat-scale (10 m^2, 1 m^2, 0.1 m^2, and 0.01 m^2).
- A total of 20 FWS and non-FWS employees assisted with fieldwork for this survey.

In 2016, fifty-seven of the 60 baseline plots were resampled to determine the status of and trends in vascular plant composition and structure. Five new plots were established at Cape Romain NWR to expand monitoring at the site. This represented the second iteration of vegetation sampling for CWEM, and the *Vegetation of Coastal Wetland Elevation Monitoring Sites on National Wildlife Refuges in the South Atlantic Geography – 1st Status Report* will be completed during the coming year. Noteworthy findings included:

- Vegetation and environmental data were captured in 62 10x10 m bounded and monumented plots across 21 Coastal Wetland Elevation Monitoring sites on 19 NWRs.
- Baseline inventory efforts detected 149 taxonomic concepts, including a potential county record listing for Georgetown County, South Carolina (*Ludwigia grandiflora* ssp. *hexapetala* on Waccamaw NWR). The 21 sites were classified into nine vegetation associations, including three with G2 (Imperiled) conservation status (NatureServe 2014), and seven ecological types.
- The most common associations sampled were the *Juncus roemerianus* Herbaceous Vegetation and *Spartina alterniflora* Carolinian Zone Herbaceous Vegetation types.
- The most frequent species found during this survey included *Juncus roemerianus, Sporobolus alterniflorus,* and *Distichlis spicata.*
- Plots located on the Roanoke River NWR site exhibited the highest species richness values (average=36.3) for the full plot-scale (100 m^2); plots located on Waccamaw River NWR exhibited the highest species richness values (average=12.9) for the nested quadrat-scale (10 m^2); and plots located on the Mackay Island NWR site exhibited the highest species richness values (average=8.75, 4.75, 2.75) for the nested quadrat-scale (1 m^2, 0.1 m^2, and 0.01 m^2).
- A total of 16 FWS and non-FWS employees assisted with fieldwork for this survey.
- Cassie Cook, 2016 Directorate Resource Assistant Fellowship Program fellow, lead the vegetation resampling efforts at the 21 CWEM sites.

For FY17, the three plots at the Lower Suwannee NWR (SWE038) marsh site will need to be resampled. SWE038 was unable to be sampled during the 2016 resample effort, due to Hurricane Hermine, which made landfall during the scheduled sampling period. The three plots at Pocosin Lakes NWR (POC016) will need to be resampled due to plot location error encountered during the resampling date in the summer of 2016.

Photos: Resampling a 10 x 10 m vegetation plot in black needlerush marsh at Alligator River NWR (credit: Cassie Cook/USFWS); blackwater swamp forest at Roanoke River NWR (credit: Forbes Boyle/USFWS); freshwater tidal marsh at Waccamaw NWR (credit: Nicole Rankin/USFWS).

Water Level

One water level station and two deep-rod benchmarks were established at Bell Island Pier, Swanquarter NWR in spring 2013. Four FWS staff has been trained to perform laser level surveys and change out the water level station at Bell Island Pier. Over 10 FWS and non-FWS employees have assisted with establishment and data collection efforts from 2013 – 2016.

A pilot deployment of the water level station was conducted and data were collected from May 2, 2013 to July 16, 2014. During this pilot deployment, the water level sonde was removed for cleaning/post-calibration procedures, replaced with pre-calibrated sensor and surveyed on four different occasions resulting in five deployments. All pilot data have been reformatted and entered into an excel spreadsheet for QA/QC and plotting. A first glance of the pilot data shows gaps in data collection from sonde change out and lack of sonde memory. The small gaps from changing out the sonde are unavoidable; however, the large data gap from the full sonde memory will be avoided in the future by erasing the sonde memory following each deployment.

In September 2015, the water level station was redeployed and quarterly change-outs are being conducted by Mattamuskeet NWR staff. These quarterly deployments will continue into the foreseeable future.

In January 2016, FWS partnered with N.C. State University to monitor water level conditions at Bell Island Pier in real-time: http://go.ncsu.edu/bellisland. Through this partnership, Mattamuskeet NWR staff was able to show that high waters in the Pamlico Sound due to Hurricane Joaquin conditions were the cause of Mattamuskeet Lake not being able to drain. This provided valuable data to staff to be able to communicate the drainage problems to stakeholders.

In May 2016, an interactive application was developed to visualize and compare the Bell Island Pier water level station data with the Pungo River and U.S. Coast Guard Station Hatteras water level stations. This tool will be used to complete QA/QC of the pilot data and September 2015 – December 2016 deployments in FY17. Then, the data will be submitted to NOAA Center for Operational Oceanographic Products and Services (CO-OPS) to assess if enough data was collected to compute a tidal datum.

Photos: Installing deep-rod benchmark at Swanquarter NWR (credit: Nicole Rankin/ USFWS); water level station at Bell Island Pier (credit: Larry Boomer/USFWS); using a laser level to determine the elevation of the water level station at Bell Island Pier (credit: Nicole Rankin/USFWS).

Protocol and Standard Operating Procedures (SOPs)

The CWEM efforts in the South Atlantic are based on the national protocol framework, *The Surface Elevation Table and Marker Horizon Technique, A Protocol for Monitoring Wetland Elevation Dynamics* (Lynch et al. 2015), and the NPS SECN protocol, *Protocol for Monitoring Coastal Salt Marsh Elevation and Vegetation Communities in Southeast Coast Network Parks* (Devivo et al. 2015). The national protocol framework will be stepped down to a multi-region protocol framework. Currently, the *Multi-Regional Protocol Framework for Monitoring of Coastal Wetland Elevation and Vegetation Community Dynamics - Regions 2 and 4* is under development. This multi-regional protocol framework provides a structure for monitoring surface elevation, benchmark elevation accretion, porewater salinity, vegetation community, and water level in wetlands on coastal refuges in Regions 2 and 4. Present protocol development efforts include:

- The NPS Northeast Coast Barrier Network published protocol, *The Surface Elevation Table and Marker Horizon Technique: A Protocol for Monitoring Wetland Elevation Dynamics*, was approved as a National Protocol Framework in March 2016.
- FWS I&M staff listed as coauthor on the NPS Southeast Coast Network published protocol, *Protocol for Monitoring Coastal Salt Marsh Elevation and Vegetation Communities in Southeast Coast Network Parks.*
- Multi-regional protocol framework is drafted.
- Three standard operating procedures have been completed.
  - Generating Spatially-Balanced Random Sampling Locations using ArcGIS 10.3.1
  - Selecting Sample Site Locations
  - Monitoring Vegetation using Carolina Vegetation Survey

- Eleven standard operating procedures are drafted.
    - Installing a Rod Surface Elevation Table Benchmark
    - Monitoring Surface Elevation using Rod Surface Elevation Table
    - Surveying the Rod Surface Elevation Table Benchmark
    - Establishing and Measuring Accretion Plots
    - Establishing and Measuring Porewater Salinity Plots and Wells
    - Calibrating the YSI Pro 30 Salinity Meter
    - Using Porewater Data Loggers to Collect Water Level
    - Establishing a Water Level Station using a YSI 600 LS Vented Sonde
    - Prepping and Calibrating the YSI 600 LS Vented Sonde
    - Deploying and Setting Up the YSI 600 LS Vented Sonde for Unattended Sampling
    - Surveying the Water Level Station, Benchmarks, and Control Points

In FY17, the multi-regional protocol framework and associated standard operating procedures will be completed and sent out for review.

Data Management

The FWS and NPS Natural Resource Program Center divisions are developing an online, centralized database to house data collected from coastal wetland monitoring efforts using surface elevation tables. Multiple FWS regions, NPS networks, and Department of the Interior researchers are involved in the creation of this collaborative database, which will create one application to meet both FWS and NPS data management needs. Currently, the database is in production with anticipated completion within FY17. Present data management efforts include:

- All RSET benchmark install data was entered and QA/QCed into the NPS Southeast Coast Network marsh monitoring database in 2013 – 2014.
- All surface elevation, benchmark elevation, accretion, and porewater salinity datasheets and raw data from 2012 – 2016 are backed up, and housed in two separate locations: CWEM fishnet site and Cape Romain NWR server.
- The 2013 baseline vegetation data was entered into the CVS Microsoft Access data entry tool, archived in the CVS Central Archive Database in 2014, and uploaded to ServCat (reference code: 34503).
- The 2016 resample vegetation data was entered into the CVS Microsoft Access data entry tool and archived in the CVS Central Archive Database in 2016.
- All Bell Island pier water level datasheets and raw data from 2013 – 2016 is backed up and housed in two separate locations: CWEM fishnet site and Cape Romain NWR server.
- ServCat Program Reference Code: 33452
- Fishnet Site: South Atlantic CWEM Monitoring

Upon database completion, all RSET benchmark install data will be imported into the new system. All surface elevation and accretion data will be manually entered into the database. Install, surface elevation, and accretion data will be QA/QCed following import and data entry.

Data Analysis and Project Reporting

Lynch et al. 2015 found that previously-analyzed surface elevation data sets displayed an initial period of rate instability, and more years of data collection resulted in minimized error rates and more consistent averages. Therefore, it is recommended a minimum of five years of surface elevation measurements are collected prior to data analysis and trend reporting (Lynch et al. 2015). After five years of surface elevation data collection, site-specific analyses of monitoring data and trend reporting will be conducted to provide localized information to the individual refuge. As appropriate, FWS I&M will also collaborate with partners including the South Atlantic Landscape Conservation Cooperative to complete a landscape-scale synthesis report. Present CWEM reporting efforts include:

- Published article, *Monitoring Marsh Elevation and Sea-Level Rise*, for the Refuge Update November/December 2012 edition.
- Provided information about the CWEM efforts for the *Water Resource Inventory and Assessment: Lower Suwannee National Wildlife Refuge Dixie and Levy Counties, Florida* technical report, March 2015.
- Published report, *Vegetation of Coastal Wetland Elevation Monitoring Sites on National Wildlife Refuges in the South Atlantic Geography – Baseline Inventory Report,* April 2015.
- Presented poster, *Partnering to leverage scale in coastal wetland monitoring - South Atlantic geography approach*, at the Restore America's Estuaries – The Coastal Society Summit, New Orleans, LA December 2016.
- Drafted report, *Determining elevation of rod surface elevation table benchmarks at seven coastal wetland elevation monitoring sites: baseline report*.
- Drafted report, *Vegetation of coastal wetland elevation monitoring sites on National Wildlife Refuges in the South Atlantic geography: 1st status assessment report*.
- Drafted (coauthored) manuscript, *Measurements of coastal wetland elevation change relative to sea level: the distribution of surface elevation table-marker horizon (SET-MH) stations along the northern Gulf of Mexico*.
- Drafted (coauthored) report, *The Coastal Habitat Integrated Mapping and Monitoring Program Report for the State of Florida*.

External Reporting

Managing data and reporting requests from external partners has been an important component of CWEM reporting. Most data requests have been for CWEM site location and project information. These external partner requests include:

- Surface Elevation Table (SET) Inventory for the Northern Gulf of Mexico – NOAA Northern Gulf of Mexico Sentinel Site and USGS National Wetlands Research Center, 2012, 2015 – 2016. http://oceanservice.noaa.gov/sentinelsites/pdf/set-inventory-summary.pdf; https://gcpolcc.databasin.org/datasets/6a71b8fb60224720b903c770b8a93929
- Estuarine Monitoring Programs in the Albemarle Sound Study Area, North Carolina – USGS Water Science Center, 2013 – 2014. https://pubs.usgs.gov/of/2014/1110/
- Surface Elevation Table (SET) Inventory for the North Carolina Sentinel Site – NOAA National Centers for Coastal Ocean Science, 2013 – 2016. http://oceanservice.noaa.gov/sentinelsites/pdf/set-inventory-summary.pdf

- Global Change Monitoring Portal – N.C. State University and DOI Southeast Climate Science Center, 2013- 2016. https://my.usgs.gov/gcmp/program/show/844288
- North Carolina Sentinel Site Cooperative Clearinghouse – NOAA National Centers for Coastal Ocean Science and East Carolina University Coastal Atlas, 2013, 2016. https://www.nccoastalatlas.org/explore?map=161
- Hydrology Restoration and Carbon Sequestration project at Pocosin Lakes NWR – USGS National Wetlands Center and The Nature Conservancy, 2014.
- Surface Elevation Table (SET) Inventory and Distribution along the Georgia Coast - Georgia Department of Natural Resources, 2014

Partnerships

FWS I&M is working with many partners to implement a regional network of CWEM sites on refuge lands in the South Atlantic geography. Partners have been engaged since the beginning of this project and have continued to provide guidance in planning, sample design, site selection, field techniques, equipment, logistics, data management and analysis, and reporting. The South Atlantic CWEM efforts relies on collaborating closely with refuges where the study sites are located, other FWS regions, NPS I&M networks (chiefly, Southeast Coast Network), USGS National Wetlands Center, USGS Patuxent Wildlife Research Center, National Oceanic and Atmospheric Administration, North Inlet-Winyah Bay National Estuarine Research Reserve, South Atlanta Landscape Conservation Cooperative, and The Nature Conservancy. Detailed partnering benefits and efforts include:

- Provided guidance in planning and sample design phase – USGS, TNC, NPS SECN
- Trained FWS staff and contractors to install RSET benchmarks – USGS
- Trained FWS staff to perform SET readings, take accretion cores, and collect porewater salinity – USGS, NPS SECN
- Shared knowledge and documented methods regarding RSET benchmark installs and CWEM data collection procedures – USGS, NPS SECN, NOAA, North Inlet- Winyah Bay NERR, FWS Regions 2 and 5
- Develop consistent monitoring protocol and SOPs being used by NPS SECN and FWS Regions 2 and 4 – NPS, USGS, NOAA, FWS Region 2
- Share equipment: corers, liquid nitrogen dewars, GNSS GPS receivers, survey adapters – NPS SECN, USGS, FWS Region 5
- Troubleshoot methods, site issues and logistics, equipment, and technology – USGS, NPS SECN, NOAA, FWS refuge staff
- Develop an online, centralized database – FWS and NPS NRPC
- Develop data analysis tools and R code – FWS Region 5
- Develop post-processing methods for GNSS survey data – NPS SECN
- Assist with water level station analysis and tidal datum determination – NOAA
- Actively monitored partner sites in South Atlantic geography:
    - 12 sites located on refuge lands – USGS
    - 12 sites located on park lands – NPS SECN
    - 1 site located at Alligator River refuge – TNC

Student Funded Opportunities

Student assistantships are a resource utilized to accomplish and expand CWEM monitoring efforts. Students have been used to perform field work, enter and analyze data, write SOPs, and solve technical problems. The FWS Directorate Fellowship Program and NPS SECN contracts with the University of Georgia have provided opportunities to move forward different monitoring aspects, most recently benchmark elevation surveying, from which both FWS I&M and NPS SECN benefit.

The FWS Directorate Fellowship Program has funded two proposals for DFP fellow projects:

1. Establishing Vertical Control at Coastal Wetland Elevation Monitoring Sites in the South Atlantic Geography – 2015
2. Assessing Vegetation Change at Coastal Wetland Monitoring Sites in the South Atlantic Geography – 2016

A third DFP fellow project proposal, *Improving Data Management for Coastal Wetland Elevation Monitoring*, is currently under review.

Future Data Collection Efforts

A six-year timeline for future data collection efforts of each CWEM monitoring parameter can be found in Appendix B.

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Appendix A. Chronology of parameters and data collection efforts conducted at CWEM sites on 18 refuges within the South Atlantic geography.

	Fall 2012	Winter 2013	Spring 2013	Summer 2013	Fall 2013	Winter 2014	Spring 2014	Fall 2014	Spring 2015	Summer 2015	Fall 2015	Spring 2016	Summer 2016	Fall 2016
ACE Basin (ABS017)														
Surface Elevation	X	X	X				X		X					X
Benchmark Elevation														
Accretion	X		X				X							X
Porewater Salinity	X	X					X		X					X
Vegetation				X									X	
Alligator River (ALL005)														
Surface Elevation		X	X					X	X		X			X
Benchmark Elevation														
Accretion		X						X	X		X			X
Porewater Salinity		X	X					X	X		X			X
Vegetation				X									X	
Alligator River (ALL030)														
Surface Elevation		X	X	X				X	X		X			X
Benchmark Elevation													X	
Accretion		X						X	X		X			X
Porewater Salinity		X	X	X				X	X		X			X
Vegetation				X									X	

	Fall 2012	Winter 2013	Spring 2013	Summer 2013	Fall 2013	Winter 2014	Spring 2014	Fall 2014	Spring 2015	Summer 2015	Fall 2015	Spring 2016	Summer 2016	Fall 2016
Blackbeard Island (BLB011)														
Surface Elevation	X		X	X	X			X	X		X			X
Benchmark Elevation													X	
Accretion	X		X	X	X			X	X		X			
Porewater Salinity	X		X	X	X			X	X		X			X
Vegetation				X									X	
Cedar Island (CDR027)														
Surface Elevation		X	X	X	X	X		X	X			X		X
Benchmark Elevation										X				
Accretion		X				X		X	X					X
Porewater Salinity		X	X	X	X	X		X	X			X		X
Vegetation				X									X	
Currituck (CRT026)														
Surface Elevation		X	X	X	X		X	X			X			X
Benchmark Elevation													X	
Accretion		X						X						
Porewater Salinity		X	X	X	X		X	X			X			X
Vegetation				X									X	

	Fall 2012	Winter 2013	Spring 2013	Summer 2013	Fall 2013	Winter 2014	Spring 2014	Fall 2014	Spring 2015	Summer 2015	Fall 2015	Spring 2016	Summer 2016	Fall 2016
Harris Neck (HSN033)														
Surface Elevation	X		X	X	X			X		X	X			X
Benchmark Elevation										X				
Accretion	X		X	X	X			X		X	X			
Porewater Salinity	X		X	X	X			X		X	X			X
Vegetation				X									X	
Lower Suwannee (SWE002)														
Surface Elevation	X	X		X				X						
Benchmark Elevation														
Accretion	X													
Porewater Salinity	X			X				X						
Vegetation				X									X	
Lower Suwannee (038)														
Surface Elevation			X	X				X						
Benchmark Elevation														
Accretion			X											
Porewater Salinity			X	X				X						
Vegetation				X										

	Fall 2012	Winter 2013	Spring 2013	Summer 2013	Fall 2013	Winter 2014	Spring 2014	Fall 2014	Spring 2015	Summer 2015	Fall 2015	Spring 2016	Summer 2016	Fall 2016
Mackay Island (MCI026)														
Surface Elevation		X	X	X	X		X	X			X			X
Benchmark Elevation														
Accretion		X						X						
Porewater Salinity		X	X	X	X		X	X			X			X
Vegetation				X									X	
Pea Island (PLD010)														
Surface Elevation		X	X					X	X		X			X
Benchmark Elevation										X				
Accretion		X						X	X		X			X
Porewater Salinity		X	X					X	X		X			X
Vegetation				X									X	
Pinckney Island (PKY008)														
Surface Elevation	X		X	X	X			X	X		X			X
Benchmark Elevation										X		X		
Accretion	X		X	X				X			X			
Porewater Salinity	X		X					X	X		X			X
Vegetation				X									X	

	Fall 2012	Winter 2013	Spring 2013	Summer 2013	Fall 2013	Winter 2014	Spring 2014	Fall 2014	Spring 2015	Summer 2015	Fall 2015	Spring 2016	Summer 2016	Fall 2016
Pocosin Lakes (POC016)														
Surface Elevation		X	X	X	X	X	X	X	X		X			X
Benchmark Elevation										X				
Accretion		X				X	X	X	X		X			X
Porewater Salinity		X	X	X	X	X	X	X	X		X			X
Vegetation				X									X	
Roanoke River (RRV013)														
Surface Elevation		X	X	X	X	X	X	X	X		X			X
Benchmark Elevation														
Accretion		X				X		X	X		X			X
Porewater Salinity		X	X	X	X	X	X	X	X		X			X
Vegetation				X									X	
Savannah (SAV004)														
Surface Elevation	X		X	X		X		X		X	X			X
Benchmark Elevation												X	X	
Accretion	X		X	X		X		X		X	X			X
Porewater Salinity	X		X	X		X		X		X	X			X
Vegetation				X									X	

	Fall 2012	Winter 2013	Spring 2013	Summer 2013	Fall 2013	Winter 2014	Spring 2014	Fall 2014	Spring 2015	Summer 2015	Fall 2015	Spring 2016	Summer 2016	Fall 2016
St. Marks (SMK000)														
Surface Elevation	X	X	X	X	X		X	XX	X		X			X
Benchmark Elevation													X	
Accretion	X		X		X		X	X						X
Porewater Salinity	X	X	X	X	X		X	XX	X		X			X
Vegetation				X									X	
Swanquarter (SWQ000)														
Surface Elevation		X	X	X	X	X		X	X		X			X
Benchmark Elevation										X				
Accretion		X				X								X
Porewater Salinity		X	X	X	X	X		X	X		X			X
Vegetation				X									X	
Water Level			←				→				←			→
Waccamaw (WAW000)														
Surface Elevation	X	X	X	X	X		X	X				X		X
Benchmark Elevation													X	
Accretion	X		X		X		X	X						X
Porewater Salinity	X	X	X	X	X		X	X				X		X
Vegetation				X									X	

	Fall 2012	Winter 2013	Spring 2013	Summer 2013	Fall 2013	Winter 2014	Spring 2014	Fall 2014	Spring 2015	Summer 2015	Fall 2015	Spring 2016	Summer 2016	Fall 2016
Wassaw (WSW001)														
Surface Elevation	X		X	X	X			X		X	X			X
Benchmark Elevation										X				
Accretion	X		X	X	X			X		X	X			
Porewater Salinity	X		X	X	X			X		X	X			X
Vegetation				X									X	
Wolf Island (WLF035)														
Surface Elevation	X		X	X	X			X		X	X			X
Benchmark Elevation													X	
Accretion	X		X	X	X			X		X	X			
Porewater Salinity	X		X	X	X			X			X			X
Vegetation				X									X	

Appendix B. Future data collection efforts for each parameter collected for the time period of 2017 – 2022 at CWEM sites on 18 refuges within the South Atlantic geography. Data Analysis and Reporting parameter is listed for time period of 2017 – 2023.

Refuge Name	CWEM Site	Surface Elevation, Accretion, Porewater Salinity						Benchmark Elevation						Vegetation						Data Analysis and Reporting						
		2017	2018	2019	2020	2021	2022	2017	2018	2019	2020	2021	2022	2017	2018	2019	2020	2021	2022	2017	2018	2019	2020	2021	2022	2023
Ace Basin	ABS017	X	X	X	X	X	X	X					X			X			X		X					X
Alligator River	ALL005	X	X	X	X	X	X	X					X			X			X		X					X
Alligator River	ALL030	X	X	X	X	X	X					X				X			X		X					X
Blackbeard Island	BLB011	X	X	X	X	X	X					X				X			X		X					X
Cedar Island	CDR027	X	X	X	X	X	X				X					X			X		X					X
Currituck	CRT026	X	X	X	X	X	X					X				X			X		X					X
Harris Neck	HSN033	X	X	X	X	X	X				X					X			X		X					X
Lower Suwannee	SWE002	X	X	X	X	X	X	X					X			X			X		X					X
Lower Suwannee	SWE038	X	X	X	X	X	X	X					X	X		X			X		X					X
Mackay Island	MCI026	X	X	X	X	X	X	X					X			X			X		X					X
Pea Island	PLD010	X	X	X	X	X	X				X					X			X		X					X
Pinckney Island	PKY008	X	X	X	X	X	X				X					X			X		X					X
Pocosin Lakes	POC016	X	X	X	X	X	X				X			X		X			X		X					X
Roanoke River	RRV013	X	X	X	X	X	X	X					X			X			X		X					X

Refuge Name	CWEM Site	Surface Elevation, Accretion, Porewater Salinity						Benchmark Elevation						Vegetation						Data Analysis and Reporting						
		2017	2018	2019	2020	2021	2022	2017	2018	2019	2020	2021	2022	2017	2018	2019	2020	2021	2022	2017	2018	2019	2020	2021	2022	2023
Savannah	SAV004	X	X	X	X	X	X	X					X			X			X		X					X
St. Marks	SMK000	X	X	X	X	X	X					X				X			X		X					X
Swanquarter	SWQ000	X	X	X	X	X	X				X					X			X		X					X
Swanquarter	Bell Island	X	X	X	X	X	X	X					X			X			X		X					X
Waccamaw	SAW000	X	X	X	X	X	X					X				X			X		X					X
Wassaw	WSW001	X	X	X	X	X	X				X					X			X		X					X
Wolf Island	WLF035	X	X	X	X	X	X					X				X			X		X					X