Project Title: Measurement and Assessment of Restored and Reference Salt Marsh Structural and Functional Performance Indicators in the Southern Chesapeake Bay.

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Overview – Rationale for Study

A growing population along with associated land use changes and shoreline modifications are primary factors causing and habitat degradation in coastal nearshore systems. The Chesapeake Bay is one of the nation's most populated coastal watersheds with approximately 70 to 90 percent of Virginia's and Maryland's population living within coastal counties, respectively (Crossett et al. 2004). Compounding the stress of a growing population is the sprawl pattern of development within the Bay region with an increase of land consumption per resident and increase in the amount of impervious surfaces.. As a result of regional elevated population growth, sprawl development and the desire to protect waterfront investments through shoreline modifications or erosion control structures, there is a continued degradation, fragmentation and eventual loss of critical nearshore habitats. "Nearshore" estuarine habitats extend over a continuum from upland riparian to intertidal to shallow subtidal areas. Along with degradation or loss of specific habitats, the natural interactions or connectivity between these ecosystems may also be diminished, or in some case, entirely eliminated.

In addition to direct human-induced impacts, threats associated with natural hazards (e.g., sea level rise, climate change, and large episodic storms) further impact of coastal habitats through increased coastal erosion, flooding and changes in ecosystem community type and distribution. It is estimated that one-third of all Bay shorelines are classified as eroding, some areas losing as much as 20-40 cm yr^{-1}. Tidal emergent wetlands and low lying riparian forests are particularly vulnerable to the relatively high rates of sea level rise (3.1 mm yr^{-1} in the northern Bay region to 7.0 mm yr^{-1} near the Bay's mouth; Zervas 2001), increased erosion and the potential for saltwater intrusion. Tidal marshes must have the ability to accrete vertically (e.g., sediment deposition and root mass accumulation) or transgress inland in order reduce continued stress from increased flooding and eventual die-off. According to one study, more than half of the Chesapeake Bay's tidal marsh area shows signs of degradation (Stevenson et al. 2002).

Implementation of sound restoration approaches in nearshore habitats can result in improved water quality, enhancement of critical habitats and a more integrated approach to shoreline management within the Chesapeake Bay region. Many restoration projects unfortunately suffer from a lack of quantitative ecological monitoring, and equally problematic is the general lack of information from reference salt marshes to which data from restoration sites can be compared. The ability to fully evaluate the success or status of salt marsh restoration efforts suffers due to a lack of reference sites and standardized sampling methodologies among projects.

Evaluating the success or status and assessing the response of salt marshes to tidal restoration often relies on comparisons of ecosystem attributes between restored and reference sites (Neckles et al. 2002). The National Ocean and Atmospheric Administration's (NOAA) National Estuarine Research Reserve system (NERRS) and Restoration Center are entering a three-year partnership to evaluate the status of eighteen emergent wetland restoration projects funded with Estuary Restoration Act funds between fiscal years (FY) 2000-2006. The NERRS will be monitoring salt marsh habitats within reserve boundaries to establish reference conditions and will be monitoring a number of nearby restoration projects. Reserves participating in this partnership besides the Chesapeake Bay National Estuarine Research Reserve in Virginia (CBNERRVA) include the Wells NERR (Maine), Narragansett NERR (Rhode Island), North Carolina NERR and Slough Slough NERR (Oregon).

Strong partnerships with key programs within NOAA have help participating Reserves establish vertical control tied to local monitoring infrastructure to enhance the value of reserves as long-term reference sites. This portion of the project, which is currently in progress, will help the Reserve system establish long-term reference sites at each reserve to better evaluate current and future restoration projects. These partnerships between NERRS and other NOAA programs are ultimately intended to provide the spatial framework and training required to establish the reserves as "sentinel sites" to assess and predict marsh-estuarine ecosystem change, especially in response to climate-driven changes in sea level, storms, precipitation, salinity, water temperature and invasive species. It is anticipated that NERRS will be a national leader in monitoring coastal ecosystems in response to climate change and disseminating relevant information to local and regional stakeholders and restoration practitioners.

Partnership projects receive value-added benefits from the science and monitoring data generated by reserves. Data from reference and restored habitats can be submitted to the RC's Restoration Portal for public access. Restoration projects will be evaluated for success using data from reference sites located within the reserves, and pre-and post-restoration monitoring. Restoration practitioners and volunteers will receive information and training that will improve restoration practices for future projects. Both the comprehensive datasets and our monitoring resources are valuable to restoration practitioners.

Overview - Study Design

Chesapeake Bay NERR of Virginia was selected as one of five NERRS to receive funds to establish their Reserves as restoration reference sites by collecting information on salt marsh vegetation, ground water, sediment pore-water, soil properties, and marsh elevation. The data collected from Reserve reference sites will be used to evaluate restoration status on nearby Restoration Projects funded with Estuarine Restoration Act Funds. The monitoring approach applied for this study will follow many of the protocols and procedures adopted by the NERRS for monitoring of emergent wetlands that is found in the technical report "NERRS SWMP Bio-Monitoring Protocol
Long-term Monitoring of Estuarine Submersed and Emergent Vegetation Communities" (Moore, 2009).

Elements of the overall study design included in this report include:

- The collection of wetland structural and functional monitoring data at reference and nearby restoration sites for a duration of three years.
- Development of standardized data templates and data analysis techniques for storage and analysis of collected monitoring data.
- Analysis of collected data from each paired reference site and associated restored sites to compare vegetation, hydrological, and sediment variables between years, marsh zones, and paired reference/restoration sites.
- Discussion of value of indicator variables in ability to track restoration response of local restoration projects.
- Evaluate restoration status for each project, based on observed changes in measured variables relative to reference site values.
- An evaluation of restoration status of local restoration projects and the establishment of local/regional "Sentinel Site" reference marshes.

Elements of the overall study design which will be included in the national level report being completed by Chris Peters (UNH) with the Wells NERR.

- Cumulative three-year evaluation of data across sites with regard to status of projects whose restoration was achieved by restoring natural hydrology and those restored by large-scale grading.
- Development of reference site values from NERRS data sources to populate the NOAA Restoration Planner for emergent marshes (Wells NERRs to administer this
- Identification of most efficient monitoring protocols for restoration center grantees.

Overview – Study Sites

Study sites will be categorized as either reference or restored. Reference sites, representing near pristine, natural marsh systems, will be located within the boundaries of Goodwin and/or Catlett Islands. Restored sites as identified by NOAA's Restoration Center are located within approximately a 40 km (25 mi) radius of CBNERRVA reserve components (Figure 1).

The following restoration sites were monitored by CBNERRVA in this project. All of these restoration projects involved some form of excavation, marsh fill, modifying elevations, and planting with native vegetation.

- Hermitage Living Shorelines Project, Elizabeth River, Hermitage Foundation.
- Naval Weapons Station, York River, U.S. Department of Defense
- Cheatham Annex York, York River, U.S. Department of Defense

The following reference sites were monitored by CBNERRVA in this project.

- Goodwin Islands, York River (Reference Site for Hermitage)
- Taskinas Creek, York River (Reference Site for Naval Weapons and Cheatham).

Overview – Study Sites Descriptions

Restoration Site # 1 – Hermitage Living Museum (information in this section provide through conversations and notes from Walter Priest).

Project Name: Hermitage Living Shorelines Project.
Location: Hampton Roads, Virginia (Figure 1).
Project Partners: Community Based Restoration Joint Project of Restoration Center, National Fish and Wildlife Foundation, and Elizabeth River Project.
Contacts: Melanie Leigh Mathewes (Executive Director of the Hermitage Foundation) and Walter Priest (Restoration Specialist with the NOAA Chesapeake Bay Office)

Purpose of Restoration Project
One of the purposes of the project was to demonstrate the effectiveness of "Living Shorelines" as an alternative shoreline protection strategy that provides protection as well as habitat value. "Living shorelines" are designed to only use structures where necessary to modulate wave energy sufficient to allow natural structures and processes, like beaches and marshes, to be able to provide effective shoreline protection.

Type of Restoration:
This project had three components including a living shorelines component (installation of offshore breakwaters, beach fill, and re-planting – primarily with *Spartina alterniflora*), a non-native replacement component (removing Phragmites and replanting with natives, primarily *Spartina alterniflora*) and a cobble rubble component (remove cobble, fill, grade, and plant with natives – primarily *Spartina alterniflora* and *Spartina patens*) (Figures 2 and 3).

Restoration Details:

- Phase 1: The Living Shoreline segment consisted of approximately 250 linear feet of stone breakwater and marsh toe protection together with approximately 600 cubic yards of sand beach fill and the planting of 7500 square feet of marsh grass, primarily smooth cordgrass, Spartina alterniflora. This protected over 300 linear feet of shoreline including an historic brick wall surrounding the formal garden at the Hermitage. (Figure 4, Top)

- Phase 2: The next phase involved the removal of a stand of invasive Phragmites australis and replacing it with 5000 SF of tidal marsh (Figure 4, Middle)

- Phase 3: The last phase involved the removal of 110 linear feet of riprap and approximately 400 cubic yards of debris to restore approximately 7500 SF of tidal wetlands. These marshes were planted with a combination of smooth cordgrass and saltmeadow hay, Spartina patens, depending on the elevation.(Figure 4, Bottom)

All totaled, the project restored almost ½ acre of wetlands by removing riprap and debris placed in historic wetlands and providing a "softer" approach to shoreline stabilization that provides intrinsic habitat value as well.

Reference Site # 1: Goodwin Islands Research Reserve (information in this section pulled from thee Management Plan for Goodwin Islands Research Reserve, Erdle et al., 2005).

General Location Information:
The Goodwin Islands (37° 13' N; 76° 23' W) component of the CBNERRVA is located on the southern side of the mouth of the York River. The islands are at the northeastern tip of York County approximately 10 km (6 mi) down the York River from Virginia Institute of Marine Science and the Chesapeake National Estuarine Research Reserve. Goodwin Islands are owned by the College of William and Mary. VIMS serves as the on-site manager of the islands and assures consistency with the MOU between VIMS/College of William and Mary and NOAA dated February 6, 1991.

The York River watershed covers approximately 6915 square kilometers (2,670 square miles), and is one of the Bay's fastest growing tributary basins. The York and its tributaries are 226 kilometers (140 miles) long, and its watershed comprises about 12 percent of Virginia's portion of the Chesapeake Bay basin. About 73 percent of the watershed is forested, 19 percent is agricultural, and 8 percent is urban (DCR-Division of Soil and Water Conservation (DSWC) web page, 2005). Approximately half of York County's land area is owned by the federal government (military installations, or national park property), or by adjacent jurisdictions (reservoir watersheds).

Representative Coastal Habitats:
Consisting of an archipelago of salt-marsh islands, the Goodwin Islands component core area is approximately 148 ha (366 ac) in area (Figure 3.10). Primary ecological community groups occurring at Goodwin Islands include tidal meso-polyhaline marshes, maritime dune grasslands, salt scrub, and maritime upland forest (Erdle and Heffernan 2005a). Depauperate salt marsh vegetation occupies approximately 80% of Goodwin Islands. The most abundant and widespread type group contains the "short form" of saltmarsh cordgrass (*Spartina alterniflora*), saltgrass (*Distichlis spicata*) and salt meadow hay (*Spartina patens*). Salt shrubland community, consisting primarily of groundsel tree (*Baccharis halimifolia*) and saltbush (*Iva frutescens*), is irregularly scattered along low dunes and the island perimeter. The higher, interior western portions of the Goodwin Islands support a large stand of loblolly pine (*Pinus taeda*) with some mixed oak. The understory is dominated by southern wax myrtle (*Myrica cerifera*) and to a lesser degree red bay (*Persea palustris*). Vegetation patterns reflect the topography, with forests and upland vegetation on the ridges and marshes in the swales.

Geology and Soils:
Predominant soil types on the Goodwin Islands are classified as Tomotley-Altavista-Dragston. This soil association consists of deep, poorly drained to moderately well drained, to somewhat poorly drained soils that dominantly have a loamy subsoil and are almost level.

Hydrologic Conditions – York River
The York River system is classified as a microtidal, partially mixed estuary. Hydrology within the lower to middle estuarine reaches of the York River system is strongly influenced by tides. The mean tidal range is 0.7 m (2.3 ft) at its mouth, 0.9 m (1.0 ft) at West Point and increases to over 1 m (3.3 ft) in the upper tidal freshwater regions of the Mattaponi and Pamunkey Rivers (Sisson et al. 1997). Historical surface water temperatures range from 5.4º C to 27.4º C and dissolved oxygen concentrations range from 4.2 to 14.0 mg/l (Brooks 1983). These values are indicative of transitional conditions and reflect seasonal freshwater inputs.

Hydrologic Conditions – Goodwin Islands
Tides at the Goodwin Islands are semi-diurnal and display an average range of 0.7 m (2.3 ft). Mean seasonal water temperature values range from 13.7-15.6 °C (56.7-60.1 °F) for spring (March-May), 25.7-27.2 °C (78.3-81.0 °F) for summer (June- August), 18.0-19.2 °C (64.4-66.6 °F) for fall (September-November), and 4.7-8.2 °C (40.5-46.8 °F) for winter (January-February, and December). Located within the polyhaline region of the York River estuary, mean seasonal salinity values range from 13.9-23.0 psu for spring, 17.2-23.0 psu for summer, 16.5-24.0 for fall, and 15.9-23.3 psu for winter.

Actual Reference Site at Goodwin Islands identified for the Hermitage Living Shorelines Project

- CBNERRVA staff identified a section of marsh habitat within a small embayment on the Southern side of Goodwin Islands. This site consists of physical and biological conditions similar to those encountered at the Hermitage Living Shorelines Project (Figure 6).

Restoration Site # 2: Naval Weapons Station (information for this section provided through conversations and notes from Walter Priest of the NOAA Restoration Center and William Friedman, Contractor).

Project Name: Naval Weapons Station Site 6.
Project Location: Located of a tributary of Felgates Creek, off of the York River. (Figures 1 and 7)
Project Partners: US Department of Defense
Contacts: Linda Cole (Linda Cole Remediation Program Manager for Naval Facilities Engineering Command) and Walter Priest (Restoration Specialist with the NOAA Chesapeake Bay Office)

Purpose of Project: This project was a DARRP Project (NOAA's Damage Assessment Remediation and Restoration Program) involving the US Department of Defense. This project, within an area of approximately 1 acre, involved removing and treating contaminated sediments, using new fill material, re-grading on site, and replanting with natives (primarily *Spartina alterniflora* and *Spartina patens*).

Restoration History:
Site 6 is located in the northern portion of WPNSTA Yorktown and consists of three areas: a flume area, an impoundment area, , and an excavated pit. Note: the excavated pit area was not monitored as part of this project (Figure 8).

- The flume area is a network of flumes connected to an impoundment area, where wastewater possibly containing explosives was discharged between 1942 and 1975
- The Site 6 impoundment area is a 3-acre, unlined, surface impoundment adjacent to wetlands along a small tributary to the main branch of Felgates Creek. The surface impoundment was created by building a coffer dam across the headwaters of the small tributary. Wastewater (containing explosives and solvents) was discharged to this area from the flume area between 1942 and 1975.

Restoration Actions:

- Implementation of restoration actions was actually initiated in 1999. The initial phase of remediation consisted of: the construction of a bioremediation cell (bio-cell), excavation of PAH and explosives contaminated soil to approximately 4 feet , disposal of PAH contaminated soil/sediment, transportation of explosives contaminated soil to the bio-cell, flume and drain decontamination, and site restoration (OHM, 1999). To allow for adequate treatment time in the bio-cell, implementation of the remedy (removal of soil and sediment and treatment in the bio-cell) continued into 2006. Approximately 11,800 tons of sediment and soil were treated between 1999 and 2006 in the bio-cell . Restoration probably used mixture of clean and remediated sediments. Re-grading of the site and planting with marsh and upland riparian vegetation took place in late 2006, early 2007 (Figure 9). Some of the native vegetation (especially Typha along edges) was retained and even though was monitored in the sampling effort, was not in the general excavated area.

Restoration Site 3: Cheatham Annex (information for this section provided through conversations and notes from Walter Priest of the NOAA Restoration Center and William Friedman, Contractor).

Project Name: Cheatham Annex Site 1
Project Location: Also located on the York River, slightly upriver from the Naval Weapons Station Site (Figure 1 and 10).
Project Partners: US Department of Defense
Contacts: Linda Cole (Linda Cole Remediation Program Manager for Naval Facilities Engineering Command) and Walter Priest (Restoration Specialist with the NOAA Chesapeake Bay Office)

Purpose of Project: This involved removing contaminants from a contaminated site, adding fill, very accurate grading, re-planting (primarily *Spartina alterniflora* and *Spartina patens* and a riparian buffer) and construction of offshore sills to protect tidal prism at entrance of site. Planting occurred in the fall of 2007 and although the overall size of the restoration area was about 1.3 acres, the actual portion of the project monitored in this study was around 0.6 acres.

Site History:
Site 1 landfill was used for burn residues from 1942 to 1951, and as a general landfill from 1951 to 1972. Site 1 covers approximately 1.3 acres located along the York River behind a former incinerator that was dismantled between 1989 and 1992. The landfill occupied approximately 1 acre; an additional northern area of impacted soils (referred to as the debris pile) occupied approximately three tenths of an acre. The edges of the landfill, along the wetland and the York River, were historically steep (approximately 20 ft high, nearly vertical in areas) and lacking in vegetation. Landfill contents (including metal scrap, wood, drums, containers, and other miscellaneous debris) were exposed along this perimeter. Continued erosion of bluff slopes caused by flooding and wave action may have caused exposure and migration of contaminated soil and debris to the adjacent wetland area.

Remediation Actions:

- In 2000, Geotubes™ were installed to temporarily stabilize the toe of the bank of the erosion area.

- In 2003, two breakwaters were constructed along the shore of Site 1 to reduce the amount of erosion caused by wave action from the York River.
- Removal actions conducted in 2003, 2004, and 2005 eliminated all landfill waste and associated soil from the site.
- Following the 2003 removal action, a "depression pool" was created east of the unnamed tributary that borders the northwest edge of the former landfill.
- A removal action in 2007 excavated contaminated sediment with PAHs, metals, and pesticides from the depression pool and sediment with elevated PCBs in the marsh adjacent to the depression pool. In addition to the most recent removal action, a riparian buffer was constructed adjacent to the depression pool to reduce erosion of the bank.
- In 2007, a removal action of contaminated sediments in the depression pool and marsh area and the installation of a riparian buffer were completed at the site. (Figure 11). Contaminated sediments were removed, clean sediments used as fill, only vegetation planted was Spartina alterniflora and Spartina patens. Also, due to having to cross a beach area through a small tidal inlet, the vegetation was planted at lower elevations.

Reference Site 2: Taskinas Creek Research Reserve (Figure 12) (information in this section pulled from thee Management Plan for Taskinas Creek Research Reserve, Myers et al., 2008).

Location: The Taskinas Creek component (37° 24' N; 76° 42' W) is located within the boundaries of York River State Park (YRSP) near the town of Croaker, in James City County, Virginia. The small subestuary of the York River is located on the southern side of the river, approximately 28 km (17 mi) upriver from VIMS and 38 km (24 mi) from the mouth of the York River.

Ownership and Management: Taskinas Creek encompasses 433 hectares (1070 acres) within the boundaries of York River State Park. Lands within the Taskinas Creek Reserve component of YRSP, identified as the Taskinas Creek Management Unit in the YRSP Resource Management Plan (VaDCR 2000b), are co-managed by the Virginia Department of Conservation and Recreation (VaDCR) and VIMS in a manner consistent with the MOU between VIMS/W&M and the VaDCR dated August 19, 2008

Representative Coastal Habitats:
Tidal wetlands occupy the shore of the York River and the floodplains of Taskinas Creek and its major southern tributary forming the southwestern boundary of the Reserve (Moore 1980). Most of these areas support Tidal Mesohaline / Polyhaline Marsh dominated to varying degrees by Spartina alterniflora (saltmarsh cordgrass), *Spartina patens* (saltmeadow cordgrass), and *Distichlis spicata* (saltgrass). With increasing distance from the York River along Taskinas Creek and its southern tributary, there is a gradual transition toward more oligohaline conditions and the dominance of *Spartina cynosuroides* (big cordgrass) and Scirpus robustus (salt marsh bulrush). Small patches of

Phragmites australis (common reed) occur in this zone. Except for tidal wetlands along the York River and Taskinas Creek, the Reserve is covered by deciduous forest. Individual trees and small patches of *Pinus taeda* (loblolly pine) are scattered through the site. The predominant community type on the moderately steep to steep uplands is the Piedmont / Coastal Plain Oak-Beech / Heath Forest, which is dominated by several *Quercus* spp. (oaks), *Fagus grandifolia* (American beech), and several heath-family shrubs, particularly *Kalmia latifolia* (mountain-laurel). Small patches of forests classified as Mesic Mixed Hardwood Forest and Oak / Heath Forest occur as inclusions within the matrix of Oak-Beech / Heath In addition, small patches of early-successional, forests dominated by *Pinus virginiana* (Virginia pine) occur on the wider crests and divides that were once cleared.

Geology and Soils.

The Taskinas Creek Reserve is a pronounced example of this dissected upland topography, containing more than ten deep ravines, a large number of steep to almost bluff-like slopes, and numerous narrow ridges forming the interfluves. The soils of Taskinas Creek Reserve and surrounding region are weathered from unconsolidated sand, silt, clay, and gravel of Pliocene age. As a rule, most upland soils in the region are highly acidic and very low in available nutrients. Soils on well-drained uplands include Caroline, Craven, and Emporia fine sandy loams. Bohicket muck soils characterize the tidal marshes flanking Taskinas Creek and its tributaries (VIMS 1991).

Hydrologic Conditions:

Taskinas Creek water quality is influenced to a large degree by watershed drainage at low tide and mainstem York River during high tide conditions. Tides are semi-diurnal and display an average range of 1.0 m (3.3 ft). Mean seasonal water temperature values range from 15.2-19.0 °C (59.4-66.2 °F) for spring, 26.8-28.2 °C (80.2-82.8 °F) for summer, 15.7-18.3 °C (60.3- 64.9 °F) for fall, and 3.6-9.0 °C (38.5-48.2 °F) for winter. Located within the meso-polyhaline region of the York River estuary, mean seasonal salinity values range from 4.0-14.0 psu for spring, 7.0-18.2 psu for summer, 6.9-17.0 for fall, and 5.8-15.3 psu for winter.

Actual Site at Taskinas Creek Reserve Identified at the Reference Site for the Naval Weapons Station and Cheatham Annex Site.

- CBNERRVA staff identified a section of marsh habitat within a small cove near the entrance to Taskinas Creek. This site consists of physical and biological conditions similar (and is found in a geographic position near) the two Department of Defense Restoration Sites on the York River (Figures 12 and13).

Methods

Transect Development

As no historical transects were identified at either the Reference or Restoration Sites, appropriate reference sites were selected to allow the best direct comparison with restored sites. Transects were developed based on USGS Salt Marsh Vegetation Monitoring Protocol document (Roman et al. 2001). Although there was some variation in the distance between transects and the distance between quadrants within a particular transects at the five study sites, all projects came close to meeting the minimum sampling requirements of least 3 transects and at least 20 quadrants per restoration or reference site. This threshold was not achieved at the Hermitage Living Museum restoration site due to the unique layout and overall small size of the project site.

Individual transects were no less than 10 m apart to maintain independence and in all cases (except Naval Weapons Station which was an usual situation) ran perpendicular from the primary controlling surface water feature to the upland margin. At each site, one transect (identified as the primary transect) was used for the installation of groundwater wells, pore-water sippers, and for sediment sampling protocols. Due to the very small marsh zone widths at the Hermitage Living Museum restoration site, an second groundwater well/pore-water sipper transect was installed. In additional, a high marsh zone groundwater well in cat-tail vegetation was installed at the Naval Weapons Restoration Site to sample groundwater influences from steep banks along side of restoration site.

Transects and associated sampling stations were geographically located with a Trimble GeoXH Global Positioning System (GPS). Using GPS observations and ArcGIS, the overall marsh size (specifically the monitored area) at both restoration and reference locations were determined. The following is a bulleted list of transect development at each study site.

Hermitage Living Museum (Restoration Site)(Figure 14):

- Initial visit to layout temporary transects – March 19th,' 2008
- Final Location of Vegetation Transects – Determined September 30th, 2008
    - Four Vegetation Transects spaced with plots spaced 5 meters apart.
    - 19 Total Number of Vegetation Plots
- Installation of Groundwater Wells – July 7th and July 29th, 2008 and September 8, 2008.
    - Total of 5 Wells (3 in Low Marsh Zone, 2 in High Marsh Zone)
    - Only site with two different groundwater well transects (along Vegetation Transect 2 and perpendicular to Vegetation Transects 3 and 4).
- Installation of Pore Water Sippers – July 29th, 2008
    - Total of 5 Sippers – 3 in Low Marsh Zone, 2 In High Marsh Zone.

Goodwin Islands (Reference Site)(Figure 15):

- Initial visit to layout primary transect – June 11th, 2008
- Final Location of Vegetation Transects – Determined August 11th, 2008
  - Three Vegetation Transects with plots spaced 5 meters apart
  - 29 Total Vegetation Plots
- Installation of Groundwater Wells – July 15th, 2008
  - Total of 5 Wells (2 in Low Marsh Zone, 2 In High Marsh Zone, 1 in Upland/Forested Zone).
- Installation of Pore Water Sippers – July 18th, 2008
  - Total of 4 Sippers – 2 in Low Marsh Zone, 2 in High Marsh Zone)

Naval Weapons Station (Restoration Site)(Figure 16):

- Initial visit to layout temporary transects – March 24, 2008
- Final Location of Vegetation Transects – Determined September 11th,, 2008
  - Three vegetation transects with plots spaced 10 meters apart
  - 21 total vegetation plots used in study
    - Note: 2 plots located in upland area were not included in final RPI analysis but were included in the Kruskal Wallis tests.
- Installation of Groundwater Wells – June 24, 2008 and July 9th, 2008
  - Total of 5 Wells (2 in Low Marsh Zone, 2 In High Marsh Zone, and 1 in Upland/Riparian Zone
  - One well located off of primary transect
- Installation of Pore Water Sippers – August 7th, 2008
  - 4 Sippers (3 in Low Marsh Zone, 1 in High Marsh Zone)

Cheatham Annex (Restoration Site)(Figure 17):

- Initial visit to layout temporary transects – March 24th,, 2008
- Final Location of Vegetation Transects – September 29th, 2008
  - Four vegetation transects with plots spaced 5 meters apart
  - 16 total vegetation plots used in study
- Installation of Groundwater Wells – June 24, 2008 and July 9th, 2008
  - Total of 4 Wells (2 in Low Marsh Zone, 2 in High Marsh Zone)
- Installation of Pore Water Sippers – August 7th, 2008
  - Total of 4 Sippers (2 in Low Marsh Zone, 2 in High Marsh Zone)

Taskinas Creek (Reference Site)(Figure 18):

- Initial visit to layout primary transect – August 4th,, 2008
- Final Location of Vegetation Transects – August 12th, 2008
  - Three vegetation transects with plots spaced 5 meters apart
  - 34 total vegetation plots (30 used in 2008 and 2009, 34 used in 2010).
- Installation of Groundwater Wells – July 25th, 2008
  - Total of 4 Wells (3 in Low Marsh Zone, 1 in High Marsh Zone)
  - Well closest to upland is actually a low marsh well due to backside depression of marsh surface and presence of low marsh vegetation.
- Installation of Pore Water Sippers – July 25thth, 2008
  - Total of 4 Sippers (3 in Low Marsh Zone, 1 in High Marsh Zone)

Emergent Vegetation Methodology

Non-destructive vegetation sampling was conducted using permanent plots (one meter squared) positioned random-systematically across the entire marsh surface from the marsh/water interface to the upland area. The position of the transects along the marsh/water interface and the position of the first plot along each transect was determined by random and the subsequent plots were spaced at a pre-determined distance (5 meters in most cases) from the first plot along a specific transect. At each site, vegetation sampling occurred once a year and coincided with peak standing biomass (sampled occurred primarily within the August/September time frame). All common species will be identified in the field with unknown or samples in question being taken back to VIMS for identification by trained botanists.

At CBNERRVA, two different measures of vegetation cover were used in this study. The first was the point-intercept method described in Roman et al, 2001. The second method determined basal percent cover for each species through visual inspection and values were recorded based Braun-Blanquet cover-class ranges (i.e., trace, 1-5%; 6-25%, etc.)(Doumlele, 1981). For the purposes of this report (and to maintain consistency with other Reserves), only results from the point-intercept data will be shown in the results section of this report. Stem density for each species was also determined within a subsample (25 cm by 25 cm in most cases, sometimes smaller for species with high abundances) of each meter squared permanent plot. Plant height was determined for each species by taking measurements of the 3 (or up to 3) tallest individuals of each species within the plot. Protocols for species abundance, height and stem density follow those outlined in Neckles et al. (2002) and Moore (2009). A photograph was also taken of each plot to serve as a visual record and assist with species identifications.

Pore Water Measurements

Periodic measurements (5-6 times) of interstitial salinities within the upper root zone (5-20 cm) were determined using pore water samplers (“sippers”) designed to allow for multiple sampling over time without disturbing marsh sediment (Montgomery et al. 1979). Sippers collect pore water through a 15 cm porous PVC window at a depth of 5 to 20 cm below the sediment surface. Water is collected using a syringe from the tubing and measured by a handheld YSI (YSI-85). Placement of sippers was co-located with placement of wells and were chosen to represent the dominant vegetation communities (and marsh zones) within the marsh .

Groundwater Measurements

In order to quantify hydrologic characteristics, tidal regime and water table fluctuations will be measured at all reference and restored marsh sites. Shallow

(1 m depth) monitoring wells will be established using a hand auger along a primary well transects at reference and restoration sites. The number of wells varied at each site, but capture dominant elevation features (e.g., creek bank, levee, low marsh, high marsh) and dominant plant communities (low marsh and high marsh zones at each study site).

Wells will be constructed of 2.5 cm dia. PVC casing and 2 mm slotted screen and follow the basic design of USCOE (2000). Screens will be gravel packed and wells will be fully developed by surging water across the screen and pumping until clean. Over one selected time period each year (attempting to capture a neap-spring cycle), the groundwater wells were equipped with pressure transducers (either Solinst Leveloggers or InSitu Aquatrolls) to continuously measure water table dynamics, water temperature, and specific conductance at a 15 minute sampling rate. During tide cycle studies, a YSI 6600 datalogger will be deployed in surface water to continuously measure surface water levels and salinity. All wells and surface water datalogger platforms will be surveyed to a reference point and depth measurements from unvented sensors will be corrected for variations in barometric pressure.

Efforts were made in 2009 and 2010 to pair well deployments at each reference site/restoration site grouping. Multiple manual spot measurements were collected from groundwater wells during the growing season using a water level probe from Ben Meadows and a YSI 85 as a field check for water levels and well salinity.

Soils Measurements

Physical and hydrophysical properties were determined on surficial (upper 20 cm root zone) sediments to define sediment structure and water transmission characteristics. Due to the relatively small size of our restoration sites, sediment samples were collected only one time at each reference site or restoration site either in the winter of 2008 and spring of 2009 at a location adjacent to each established groundwater well along the primary transect only at each reference and restoration site.

Measured sediment properties included (1) percent organic matter and (2) bulk density. Samples for bulk density and sediment organic matter (i.e loss of organics on ignition) were collected from 20 cm cores sectioned at 1, 3, 7, 10, 15, and (if possible) 20 centimeters. Sediment organic matter and bulk density were determined by combusting dried samples at 500 °C for 5 hrs, followed by reweighing (Dean 1974) and expressed as a percentage weight loss from combustion of the dried sample.

Two other sediment related metrics which were collected during the study to help interpret our monitoring data (but not reported in the results section of this report) were 1) Saturated hydraulic conductivity or sediment permeability (Kh), and 2) sediment grain size. Sediment permeability was determined on a one-time basis from replicate measures at established wells using the Bouwer slug test method (Bouwer 1989). CBNERRVA staff also sampled took deeper cores for sediment grain size (often to depths of 50 cm) to help further characterize study sites but also provide useful sediment information for interpreting the groundwater data.

Elevation Measurements

At a minimum, the agreed upon protocols called for elevation data at just the reference site including an elevation profile along each transect, elevations at the tops of groundwater wells, and elevations at the four corners of vegetation plots; however, there was some variation between Reserves as to how elevation information was collected. CBNERRVA staff did collect elevation information from both reference and restoration sites for each year of the study. At restoration sites, temporary benchmarks were used as control points for surveying efforts while at reference sites, permanent benchmarks (either cement, deep rod, or foundation) were established as control points for surveying efforts. Some of these control points can be observed in Figures 14 to 18.

In 2008, CBNERRVA staff used a Trimble 4800 or Trimble R8 GNSS base station to acquire high accuracy vertical elevation on temporary or permanent benchmarks during 2 hour (or longer) site occupations. These data were processed through the National Geodetic Survey's On-line Positioning User Service (OPUS) (http://www.ngs.noaa.gov/OPUS/). We then used standard leveling techniques (using a TOPCON Automatic Visual Level) to survey in all marsh infrastructure (corners of vegetation quadrants, tops of groundwater wells, and depth port on water quality instruments) based on these permanent (or temporary) benchmarks.

In 2009, CBNERRVA staff collected additional elevation information during year two at all sites using Real-Time Kinematic Global Positioning System (RTK-GPS) techniques. A Trimble R8 Real-Time Kinematic Global Positioning System (RTK-GPS) was used to set site control and acquire marsh elevation data. The R8 receiver utilizes dual-frequency, real-time technology to obtain centimeter accuracy in surveying applications. CBNERRVA staff collected vertical data on groundwater wells (top and bottom), vegetation transects (four corners), and the depth sensor on water quality monitoring instrument. During the 2nd year, we acquired elevation information at all sites during July 31st, 2009 and September 30, 2009.

In 2010, CBNERRVA staff collected additional elevation information at the three restoration sites and two reference sites, this time using a combination of RTK-GPS, static GPS, and digital leveling techniques. The bulleted list below is the list of the dates and equipment used to obtain elevation information (at vegetation plots, groundwater wells, water quality stations) at the study sites during 2010. Note: Due to equipment issues, the only elevation data collected in

2010 from the Naval Weapons Site was at the water quality station (dense and tall marsh vegetation prohibited the use of digital level at this particular location).

- Hermitage Living Museum – RTK on August 5th, 2010.
- Cheatham Annex - Digital Leveling on September 1, 2010.
- Naval Weapons Station – Digital Leveling on September 1, 2010.
- Taskinas Creek- Digital Leveling on July 2nd, 2010.
- Goodwin Island – RTK on August 4th, 2010.

Data Management and Data Analysis

Chris Peter (of the University of New Hampshire) agreed to serve as a subcontractor to assist with analyzing the data across the five participating reserves and taking in the lead in generating a final report for the NOAA Restoration Center. A revised statement of work was developed by Michelle Dionne and sent to the participating Reserves in February of 2010 which included a very detailed workplan and several innovative analysis techniques (i.e. Restoration Performance Indices, regression techniques) designed to use local reference site values as performance benchmarks for key structural and functional parameters against which to evaluate the response of salt marsh ecosystems to restoration.

During the summer/fall of 2010, the five participating Reserves have had several conference calls to discuss and develop standardized data sheets for submitting data to Chris Peters for national level analysis. We used these standardized “data templates” to submit our vegetation, groundwater, pore-water, sediment, and vertical control information for inclusion in a standardized database in November/December of 2010.

Using these datasets, Chris Peters conducted statistical comparisons between restoration sites and the corresponding paired reference site which included:

- 2-way ANOVA: For factors of site and year with post-hoc comparisons for the following vegetation community metrics (species richness, percent cover, stem density, and plant height).
- 2-way ANOVA: For factors of site and year with post-hoc comparisons for the following hydrologic metrics (inundation time and pore water salinity).
- 1-way ANOVA: For factor of site with post-hoc comparisons for the following sediment metrics (bulk density, percent sediment organic content).
- Restoration Performance Index Analysis (RPI)

Objectives of using an RPI based analysis include the following: (1) to provide a relative index of restoration performance to date, (2) to provide a means of comparing restoration performance at individual sites and across differing sites for local and regional comparisons, and (3) to provide a basis upon which to demonstrate restoration trajectory and ultimately allow for opportunities to improve restoration outcomes (i.e., adaptive management). The RPI achieves this by incorporating a wide variety of monitoring data into its formulation, regardless of the monitoring protocols used, number of variables, or sampling interval, by using calculated mean values and standardizing along a relative index scale from 0-1. Because the RPI uses reference marsh data as a baseline for comparison, restoration performance is defined as its trajectory leads toward or intercepts the reference condition. The rate at which the trajectory achieves the desired outcome is expected to be widely variable, and dependent upon a variety of factors, including the factors chosen for measurement. The more factors (i.e., measurable parameters) incorporated into the RPI model, the stronger the predictive value of the output.

The RPI is calculated using the following equation (RPI = (Tpresent – T0) / (Tref –T0) where Tpresent is the present value of a parameter at restoration marsh at time zero, TO is the pre-restoration (or oldest post-restoration) value of the same parameter at the restoration marsh and Tref is the present value of the parameter at the reference marsh.

Weighting occurs at 3 different levels for hydrology and 4 levels for vegetation. For hydrology, the RPI weights by (1) marsh zone (low, high, upland transition); (2) parameter (salinity, inundation marsh surface, groundwater level, max high tide level); and (3) core group (hydrology, vegetation) in this order. For vegetation the RPI weights by (1) species; (2) marsh zone (low, high, upland transition); (3) parameter (plant cover, species richness); and (4) core group (hydrology, vegetation) in this order. At each level, the RPI only weights by present items. For example, if salinity was inputted for the low and high marsh, but not the upland transition, it would be weighted by 2 marsh zones. Additionally, if only 1 core group was inputted into the RPI instead of 2, it would be weighted by 1 parameters leading to a maximum score of 1 instead of 0.5. Also, species richness data was used from the high marsh zone only in this analysis.

The following parameters were used in the RPI analysis to calculate an overall RPI score.

<u>Salinity (ppt):</u>

- Means ± SE determined from Shallow Well dataset

<u>Inundation Marsh Surface (%):</u>

- Determined from Groundwater dataset and defined as the percentage of recorded units at or above the marsh surface using the water level ground column

<u>Groundwater Level (m):</u>

- Means ± SE determined from Groundwater dataset using the water level ground column

<u>Max High Tide Level (m):</u>

- Determined from Groundwater dataset by selecting the highest recorded water level using the water level ground column

Plant Cover (%):

- Means ± SE determined from vegetation dataset using converted percent cover data (point intercept * 2). Species chosen are the five most dominant of the paired reference marsh

Species Richness (# m-2):

- Means ± SE determined from Vegetation dataset. Richness is defined as the number of species per plot (in this case, for the high marsh zone only).

CBNERRVA staff also compiled our data into an MS-Access database for data archival and to assist with generating datasets for interpreting our site level comparisons of paired restoration/reference sites.. We also re-analyzed the vegetation, groundwater, pore water, and sediment data using a Kruskal Wallis Rank Sum Test to compare across multiple groups. Where the Kruskal Wallis Rank Sum Test found a significant difference ($p<.05$) among all groups, we used a kruskalmc function to do post-hoc paired analysis between each group. All analysis was performed in R (R-Development Core Team - Krustal Wallis Function, Siegel and Castellan, 1988; Giraudoux, 2011).

Results

Vegetation - Species Richness

A total of 25 different vegetative species were recorded across all sites during the three year study period (Appendix A). Only two species (*Spartina alterniflora* and *Spartina patens*) were recorded from every study marsh site and three additional species (*Scirpus robustus*, *Aster tenuifolium* and *Distichlis spicata* were found in at least three of the study marshes. Twelve species were recorded at only one of the five marsh sites sampled during this project (Appendix B).

There were no significant differences in the number of species per plot by year (Kruskal Wallis Rank Sum Test, p-value = 0.4766); however, there was a significant difference in the number of species per plot in the high marsh zone (2.66) versus the low marsh zone (1.66) over the three year study period (Kruskal Wallis Chi-Squared = 73.8768; p-value < 0.0001). Over the course of the project, a greater number of species per plot were also found in restored sites (2.18) versus reference sites (1.94) which a result of occurrences of some rarer species recorded over the study period, especially in the high marsh zones of Naval Weapons Station and Hermitage (Appendix B).

Species richness was also significantly different at the marsh site level (Kruskal Wallis Rank Sum Test; p-value = <0.0001), although in post-hoc comparisons, the only paired restoration-reference site pair showing significant differences was the reference site Taskinas Creek (2.4 species per plot) and the restoration site Cheatham Annex (1.72 species per plot)(Figure 19). A similar trend was observed when analyzing species richness data across sites in the low marsh zone, but no significant differences were found across sites within the high marsh zone (Figure 19).

Vegetation - Percent Cover (Point Intercept Method).

Mean percent vegetative cover per plot (over all study sites and years) was dominated by three species, *Spartina alterniflora* (41%), *Spartina patens* (30%), and *Distichlis spicata* (18%). Two species within the Genus Scirpus (*S. robustus* and *S. americanus*) also averaged at least 2% cover per plot (Table 1). All other species has mean percent cover less than 1% and three species (*Murdannia keisak*, *Phragmites australis*, and *Sparganium americanum*) were present within plots but never actually recorded using the point-intercept method.

There were no significant differences in percent cover by year (using the point intercept method) for any of the five dominant species, either across all sites and zones, across all sites within the low marsh zone, or across all sites within the high marsh zone (Table 1, Appendix C). There were significant differences; however, in percent cover by marsh zone with *S. alterniflora* having greater percent cover in low marsh plots while *S. patens*, *D. spicata*, and *S. americanus* all had greater percent cover in high marsh plots (Kruskal Wall Rank Sum Test, all p-values < 0.0001) (Table 1, Appendix D).

For two dominant species (*S. patens* and *D. spicata*), mean percent cover per plot was significantly higher across reference sites compared to restored sites (Kruskal Wallis Rank Sum Test, p-values < 0.001). Alternatively, *S. alterniflora* exhibited higher mean percent cover per plot in restored sites compared to reference sites (Kruskal Wallis Rank Sum Test, p-value = 0.0046). Within a marsh zone, only *D. spicata* showed a significant trend in percent cover being significantly higher in references sites in the high marsh (KW Test, p-value < 0.0001)(Table 1, Appendix E).

At the site level, Kruskal Wallis Rank Sum Tests for percent cover were significant (p-value <0.01) for all five dominant species across marsh zones and within marsh zones with the exception of *S. patens* in the high marsh zone only (Table 2, Appendix F). Within the Goodwin Islands (reference site) and Hermitage Living Museum (restoration site) pairing, post-hoc comparisons indicated that the percent cover of *D. spicata* was higher at the reference site, Goodwin Island, across all zones and the percent cover of *S. patens* was significantly greater at Hermitage Living Museum when just examining data from high marsh plots (Figures 20-22). Within Goodwin Islands, mean cover of *S. patens* decreased over the study period which percent cover of *D. spicata* fluctuated but general increased (indicating possibly sampling biases or just natural marsh vegetation change). Percent cover of *D. spicata* was also significantly greater within the Taskinas Creek reference marsh than found at the two paired restoration sites, Naval Weapons Station and Cheatham Annex. This trend was significant across all marsh zones as well as comparisons using only high marsh plots (Figures 23-25). Other significant trends for dominant species included greater percent cover of *S. patens* in the high marsh zone of Taskinas Creek than found at Cheatham Annex and a reverse trend of greater percent cover of *S. americanus* in the high marsh zone of Cheatham Annex than at Taskinas Creek. Also, the Naval Weapons Stations restoration site had percent cover values for *S. alterniflora* which were higher than found at Taskinas Creek, both across all marsh zones and within the low marsh zone only (Figure 23, 24). Another interesting trend was the 40% increase in percent cover of S. patens in the high marsh zone of Naval Weapons Station over the three year study period (Figure 25).

Vegetation - Density

Mean stem density per plot (over all study sites and years) was dominated a couple of high marsh species, S. patens (682 per m^2), *D. spicata* (183 per m^2), a low marsh perennial S. *alterniflora* (85 per m^2), a transitional zone species found only at two sites (*D. spicata* – 30 per m^2), and a upland grass found only in two plots at Naval Weapons Station (Elusine indica – 19 per m^2). All other species from this study had mean stem density counts of less than 5 per meter square (Table 4).

As with other vegetation metrics, there was little to no year to year variation in stem density counts from the dominant species in this study. The only significant exception was for stem density counts for S. alterniflora which decreased in the low marsh zone (across all sites) between 2009 and 2010. The Kruskal Wallis Rank Sum Test was barely significant in this case ($p = 0.007$) although the trend was visible in four of the five sites studied over this time period (Figures 26 and 29 and Table 4). Again, there were significant differences; however, in percent density by marsh zone with *S. alterniflora* having greater stem densities in low marsh plots while *S. patens*, *D. spicata*, and *S. americanus* all had greater stem densities in high marsh plots (Kruskal Wall Rank Sum Test, all p-values < 0.0001) (Table 3, Appendix D).

For the two dominant high marsh species (*S. patens* and *D. spicata*), mean stem density per plot was significantly higher across reference sites compared to restored sites (Kruskal Wallis Rank Sum Test, p-values < 0.0001). This trend was observed across all marsh zones as well as within the high marsh zone only. Also *S. alterniflora* had higher mean stem densities per plot in the low marsh plots of reference sites compared to restored sites (Kruskal Wallis Rank Sum Test, p-value <0.0001) (Table 4, Appendix E).

At the site level, Kruskal Wallis Rank Sum Tests for stem density were significant (p-value <0.01) for all five dominant species across marsh zones and within marsh zones with the exception of *S. robustus* in the low and high marsh zones respectively and *S. patens* in the low marsh zone only (Table 5, Appendix F). Within the Goodwin Islands (reference site) and Hermitage Living Museum (restoration site) pairing, post-hoc comparisons indicated that the percent cover of *D. spicata* was higher at the reference site, Goodwin Island, across all zones and using just data from high marsh plots. In addition, stem densities of *S. alterniflora* were significantly higher in low marsh plots even though *S. alterniflora* stem density generally decreased over the three year study period at Goodwin Islands (Figures 26-28). In similar post-hoc comparisons, stem densities of *Spartina patens* and *D. spicata* were significantly greater within the Taskinas Creek reference marsh than found at the two paired restoration sites, Naval Weapons Station and Cheatham Annex. This trend was significant across all marsh zones as well as comparisons using only high marsh plots (Figures 29-31). Other significant trends for dominant species included greater stem densities of *S. americanus* in the high marsh zone of Cheatham Annex than at Taskinas Creek.

Vegetation - Plant Heights:

Plant height information (representing the 3 tallest individuals from each plot) will only be presented for the five dominant species. Mean values ranged from approximately 1.22 meters for *S. alterniflora* to approximately 0.51 meters for *D. spicata* (Table 6). Although there was some variation in plant height between years at a particular site (Table 6), there was only one significant difference in plant height for any of the five dominant species (*D. spicata*) across sites by sampling year, using data from all marsh zones or by each marsh zone individually (Appendix C). There were significant differences; however, in plant height by marsh zone with *S. alterniflora*, *S. robustus*, and *D. spicata* all having greater plant heights in low marsh plots (Kruskal Wall Rank Sum Test, all p-values < 0.001) (Table 6, Appendix D). For four of the five dominant species, plant heights were significantly greater in restored marshes compared to references marshes (Kruskal Wallis Rank Sum Test, p-value < 0.0001) (Table 6, Appendix E) although this trend was not always consistent within a marsh zone.

At the site level, Kruskal Wallis Rank Sum Tests for plant height were significant (p-value <0.01) for all five dominant species by grouping data across marsh zones with the exception of *S. americanus* (Appendix F). Within the Goodwin Islands (reference site) and Hermitage Living Museum (restoration site) pairing, *S. alterniflora* plants were significantly taller at Hermitage (across all marsh zones and within the low marsh zone only) and *S. patens* plants were also taller at Hermitage (across all marsh zones and within the high marsh zone only)(Figures 32,33). Mean plant heights of *S. alterniflora* across all zones at Naval Weapons Station and within the low marsh zone at Cheatham Annex were found to be significantly greater than observed at the reference site, Taskinas Creek. Mean plant heights of the dominant high marsh species, *S. patens*, were significantly greater at the Naval Weapons Station site compared to Taskinas Creek in the high marsh zone and when pooling data from all zones (Figures 34, 35 and Appendix F). Two other significant differences included greater stem heights of *D. spicata* at Naval Weapons Stations (across all zones) and greater stem heights of *S. americanus* in the high marsh zone of Cheatham Annex when compared to the Taskinas Creek Reference Site (Appendix F).

Soils Data

Soil samples were collected one time at each groundwater well location of each study site during the winter of 2008 or spring of 2009. Average bulk densities per site ranged from 0.19 at Taskinas Creek (reference site) to 2.27 at Naval Weapons Station (a restoration site). Conversely, soil percent organic matter ranged from a low of 2.93 at Cheatham Annex (a restoration site) to a high value of 33.9 at Taskinas Creek (a reference study site). As a result of this sampling methodology, there is no information on yearly trends in soils characteristics. There were no statistical significant differences (KW Rank Sum Test) in either bulk density or percent organic matter in the low marsh versus the high marsh zone (across all sites)(Figure 36, Appendix D). There were significant differences when pooling restoration and reference sites with the two reference sites being characterized by lower bulk densities and higher percent organic matter than observed in the restoration sties (KW Rank Sum Tests, p-values < 0.001)(Figure 36, Appendix E). There were also significant differences in sediment properties between sites (KW Rank Sum Test, p-value < 0.01); however, due to small sample sizes, there were no significant differences between paired reference/restoration sites, although the patterns are clearly evident (Figure 36).

Pore water Data (Spot Data).

Pore water sippers were co-located with groundwater wells and pore water salinity readings were collected multiple times during each sampling year (at least five readings per year at each study site). The lowest pore water salinity values collected (0.4) were from a high marsh site which is adjacent to a riparian upland bank at the restoration site of Cheatham Annex and the highest pore water salinity values collected (28.9) were from an inner low marsh site (with short form *S. alterniflora*) at the Goodwin Islands reference site (Table 7). There was also significant year to year variation in pore water salinity values using data across all sites, especially in the high marsh zone, with data collected in 2009 values being significantly lower than data collected in 2008 and 2010 (Appendix C). Across all sites, mean pore water salinity was also significantly lower in the high marsh zone than observed in low marsh sippers, (KW Rank Sum Test, p-value 0.0002)(Figures 37,38 and Appendix D). Restored sites were characterized by lower pore water salinity values than reference sites (KW Rank Sum Test, p-value = 0.012); however, this trend was primarily driven by pore water salinities at high marsh plots (KW Rank Sum Test, p-value < 0.0001)(Figures 37, 38 and Appendix E).

Comparisons among sites, either across all zones or within a particular zone, were all statistically significant (KW Rank Sum Test, p-value < 0.0001); however, post-hoc multiple comparison revealed significant trends between reference site/restoration site pairs (Appendix F). At Goodwin Islands, pore water salinity values were significantly higher than pore water salinity values at Hermitage in the low marsh plots only (Figure 37, Appendix F). Pore water salinities at Naval Weapons Station were significantly higher than observed at the reference site Taskinas Creek, again, only in low marsh plots. Pore water salinity measurements were also significantly lower at Cheatham Annex, especially in the high marsh plots (Figure 38).

Groundwater Data (Spot Checks)

Spot checks of groundwater wells for well salinity (taken from the bottom of the well) were also collected multiple times during each sampling year (at least five readings per year at each study site). Although readings from groundwater wells were generally lower than salinity readings from pore water sippers (Table 7), as observed with the pore water data, the lowest (0.4) and highest (27.6) groundwater salinity values were obtained from the most upland Cheatham Annex well and the low marsh Goodwin Islands well, respectively. There was less year to year variation in the groundwater salinity data than pore water data across all sites, however, the 2010 groundwater salinity values were still significantly greater than measured in 2009 (Appendix C). Across all sites, mean groundwater salinity was also significantly lower in the high marsh zone (12.2) than observed in low marsh wells (15.7) (Kruskal Wallis Rank Sum Test, p-value 0.0001)(Table 7). As with the pore water data, the groundwater salinity at restored sites was lower than measured at the pooled reference sites, and this trend was significant at both low (p-value = 0.012) and high (p-value < 0.0001) marsh plots (Table 7, Appendix E).

Groundwater salinity was highly variable across sites (p-value < 0.001). Spot checks of salinity at groundwater wells at Goodwin Islands were statistically higher than similar checks at Hermitage across all marsh zones, and within each marsh zone respectively (Figures 37, 38 and Appendix F). Groundwater salinity measurements were also lower at the two restoration sites along the York River, Naval Weapons Station and Cheatham Annex, when compared to their reference site at Taskinas Creek – although this trend was driven by a significant difference in high marsh plots (Figures 37, 38 and Appendix F).

Groundwater Data (Continuous Data)

Using the 15 minute water level data collected by the Solinst and/or Aquatroll continuously monitoring instruments (i.e. transducers), graphs of % inundation, mean groundwater level (relative to ground) and maximum high tide level were calculated for each marsh zone at each study site. One continuous dataset was collected from every study site during every year of the three year study for at least a single two week period to represent a spring-neap tidal cycle, although data collection periods were often for a longer duration. Although there does not appear to be a very strong relationship between the yearly tidal range and percent inundation at a site (calculated using the nearest SWMP or NWLON Station), there does appear to be a very strong relationship between elevation at a particular site (measured as the NAVD88 height at the surface of the ground at the groundwater well) and the percent inundation time (Figures 39 and 40).

The average inundation times within the low marsh zone are about 18 to 20 percent higher at the restoration site at Hermitage than at the Goodwin Islands reference site. However, the average NAVD88 elevation at the low marsh groundwater wells at the Hermitage Living Museum restoration site are also 14 centimeters lower than elevations of low marsh wells at the reference site of Goodwin Islands (Figure 39) which might help explain the different inundation times between the two sites. In the high marsh zone of Hermitage Living Museum (again, defined in a couple of locations by groundwater wells), the average NAVD88 elevation is about 20 centimeters higher than ground elevations in the high marsh zone of Goodwin Islands, but because this particular habitat is infrequently flooded, this difference in elevations has not resulted in substantially different inundation times (Figure 39). It is important to note that the 2008 data from Hermitage was based on a single well placed along a primary transect. The grade from low to high marsh was steeper than in other areas of the marsh and would reflect the disparity in the data from that particular year compared to the other two years at Hermitage in which a second high marsh well as added but at a lower overall NAVD88 elevation in the high marsh zone. In addition 2008 was a year of a large Nor'easter which is reflected by the highest maximum high tide levels at Goodwin Islands (and also deposited large amounts of wrack on the marsh surface).

With a few exceptions, the yearly inundation patterns at the two York River Restoration sites (Cheatham Annex and Naval Weapons Station) are very much in agreement with the yearly inundation patterns observed at the paired reference site, Taskinas Creek (Figure 40). For example, in 2009, the average inundation period at low marsh groundwater wells at all three sites were within 7%. This reflects the very accurate grading of the sediments at the two restoration sites as the average elevation of the earth surface (in NAVD88 heights) at all three sites at low marsh groundwater wells were very similar (Taskinas Creek = 0.44 meters, Naval Weapons Station = .40 meters, and Cheatham Annex = .37 meters). There is some yearly variation within this marsh zone, as the 2010 inundation periods were about 20 percent lower at Taskinas and Cheatham and about 45 percent lower at Naval Weapons Station than measured in 2009.

The very different pattern in the 2008 Naval Weapons Station data from the low marsh zone is a result of the actions of field staff at that particular site. During the 2008 continuous groundwater sampling at the Naval Weapons Station site, the wells were cleaned and tested for permeability on the same day the Solinst leveloggers were also deployed and due to the very low permeability of the sediments used in the restoration of the site, the water levels in these wells never returned to "normal" levers within the wells until after the two week sampling period the leveloggers were deployed.

The disparity in maximum high tide values (with zero representing the level of the marsh surface) between Taskinas and Cheatham in 2008 is simply a function of different sampling times. In the first year of the study (2008) the groundwater sampling was conducted during different time windows for each of the five different sites. As a result, although each site experienced a spring to neap (or neap to spring) sampling period, each site may have experienced different tidal ranges and high tides (for example, due to meteorological forcing). In 2009 and 2010, the groundwater sampling at the sites was conducted to help constrain this particular source of variation by deploying the Aquatrolls/Solinst transducers during the same time period for the Goodwin/Hermitage pairing and the Taskinas/Naval Weapons Station/Cheatham Annex grouping.

Within the high marsh zone, the percent inundation, mean groundwater level, and maximum high tide data from the Naval Weapons Station restoration site and Taskinas Creek reference site were very similar and reflect accurate grading and marsh plantings by restoration professionals at this particular site. The data collected from the high marsh zone of Cheatham Annex exhibit a slightly different pattern. In this particular zone, the elevations of the "high marsh" zone (a mixture of Scirpus americanus/Scirpus robustus in some places and planted Spartina patens in other areas), the ground elevations of the groundwater wells along the primary transect were only slightly higher (by about 2 to 3 centimeters) than the ground elevations of groundwater wells in the low marsh zone and much lower than the ground elevations of groundwater wells in the high marsh zone of Taskinas Creek (difference of about 15 inches)(Table 40). As a result, the high marsh zone of Cheatham Annex experienced longer inundation periods and higher maximum high tides (relative to the marsh surface) than at the reference site of Taskinas Creek. It is important to note; however, that due to limited funding, only one transect line of groundwater wells was sampled at each study site during the study (with the exception of Hermitage and one additional high marsh well at Naval Weapons Station). Although the sampling plan was designed to be representative of the particular site (i.e. restoration site), the data may have been slightly different if the groundwater transect was established in a different location due to the inherent variability in these sites.

Elevation Profiles:

In addition to obtaining elevation information (referenced to NAVD88) at the groundwater wells, we used elevation data collected from the vegetation plots along the transect lines to create elevation profiles at the different study sites. This can be conceptualized by examining the top and bottom graphs of Figure 41 which show elevation profiles from a) Goodwin Islands and the paired restoration site of Hermitage Living Museum and b) elevation profiles from Taskinas Creek and the restoration sties paired with Taskinas Creek which include Cheatham Annex and Naval Weapons Station. The points are symbolized to categorize plots in the low marsh zone versus the high marsh zone of each study site and points represent an average NAVD88 elevation value at each vegetation plot along the primary transects across multiple years and using different methods (please see methods section). Although there is certainly within site variability at all the study sites, using the elevation profiles along these primary transects are useful for discussing elevation patterns between sites.

At Hermitage, there is a much steeper transition between the low marsh and high marsh zone of the wetland community than found at the corresponding reference site of Goodwin Island (Figure 41, top graph). The low marsh areas (characterized by *Spartina alterniflora*) of the Hermitage Restoration site were graded at slightly lower elevations (and the reverse trend was found in the high marsh (dominated by *Spartina patens*) than found on the natural reference marsh of Goodwin Islands. It's also important to note that Hermitage is a much more narrow site overall (transects only extended approximately 20 to 25 meters from water to upper edge of high marsh) than found at Goodwin Island (transect lengths were more in the range of 50 to 55 meters)(Figure 23, top graph).

Marsh elevations along the primary transect in both the low marsh zone and high marsh zone at the restoration site of Cheatham Annex were lower than at the corresponding reference site of Taskinas Creek by an average of 0.15 meters and 0.1 meters respectively. Within the high marsh zone of Cheatham Annex (especially along two of the four transects including the primary transect) there was a slight depression (i.e. lower elevation) along the backside of the marsh close to the transition between high marsh and the upland riparian zone. This would explain the lowest elevation in the high marsh zone occurring at the most upland plot along the primary transect at Cheatham Annex (Figure 41, bottom graph). The most upland plots at Taskinas Creek are also characterized by having lower NAVD88 elevations (and different vegetation) within this zone due to similar depressional areas which occur in the transition between the high marsh zone and the steep upland (Beech-Oak Forest) forested environment. At Taskinas Creek, these "backside" depressional zones are actually characterized by a low marsh vegetation (i.e. dominated by Spartina alterniflora and Scirpus robustus) where at Cheatham Annex, the vegetation in these "backside" depressional areas were composed of a different vegetation community (primarily Scirpus americanus)

Although the zonation patterns were slightly different along the primary transect of the Naval Weapons Station restoration site (i.e. no backside depressional area and a more gradual slope from low marsh to high marsh to forested upland zones), the average elevations at the vegetation plots in the low marsh zone and high marsh zone were very similar to those measured at the Taskinas Creek reference site (see Figure 23, bottom graph).

Restoration Performance Index

As part of this study, standardized datasheets with vegetation, groundwater, pore water, and elevation information were combined to develop a Restoration Performance Index score for each Restoration Site to gauge the restoration "performance" of a given restoration site compared to a nearby reference site. Because the restoration performance index uses data from a reference marsh as a baseline for comparison, the index provides information on the trajectory (over time) of a restoration site towards the hypothetical reference condition. For the purposes of this index, an RPI score of 1.0 is considered to be a equivalent to an ecologically functioning comparable reference site. Due to the lack of pre-restoration monitoring data for all of these study sites, the first year (i.e. 2008) of monitoring data for this study was used as the “pre-restoration” data.

For the Hermitage Restoration Site (using Goodwin Islands as a reference site), an RPI score of 0.57 was calculated based on 2009 monitoring data and an RPI score of 0.54 was calculated based on 2010 monitoring data (Figure 42, top). The slight decrease in scores between 2009 and 2010 was due primarily to differences in mean groundwater levels at the restoration site compared to the reference site of Taskinas Creek during these two years.

At the Naval Weapons Restoration Site (using Taskinas Creek as the reference site), an RPI score of 0.58 was calculated based on 2009 monitoring data and an RPI score of .50 was calculated using 2010 monitoring data (Figure 42, middle). In this case, the decrease in scores between 2009 and 2010 was primarily due to differences in species richness in plots within the high marsh zone only.

At the Cheatham Annex Restoration site (using Taskinas Creek as the reference site) and RPI score of 0.60 was calculated based on the 2009 monitoring data and an RPI score of .47 was calculated using the 2010 monitoring data (Figure 42, bottom). This was the biggest decline between 2009 and 2010 and was primarily due to differences in species richness from plots within the high marsh zone only.

Discussion

Assessing Value of Monitoring Parameters in Evaluation Restoration Status

One of the goals of this project was to determine the value of the various monitoring parameters in their ability to track restoration response of local restoration projects. There was great utility to be gained from a number of the monitoring parameters collected from the very small "excavation, fill, and grade" restoration projects which were part of this study. It appears the most important parameter we measured were marsh elevations at the restoration sites. For many of these restoration projects, restoration practitioners use "biological benchmarks" to guide grading and planting efforts, and the accurate vertical control data collected during this study helped to confirm the accuracy of those plantings. The vegetation parameters (species richness, percent cover, density, height of dominant species) were useful in the short-term in evaluating the "structure" of a site and assessing whether marsh vegetation was planted within the correct elevation range. The hydrological and soils parameters were useful in helping us understand and quantify to some degree whether a restoration site was "functionally" similar to a companion reference site and to identify some potential issues which might be encountered over the long term.

After conducting a thorough analysis of their site-based data, the five Reserves participating in this overall project had a conference call to develop recommendations for core and optional monitoring parameters for Restoration Center funded practitioners to use for evaluating the status of local restoration projects. The following is a list of core and optional monitoring parameters developed through a consensus approach from the research leads on that conference call and is useful as a guide for this discussion.

Core Parameters

- *Vegetation Species Richness* (caveat – should be targeted to restoration goals for that particular site)
- *Vegetation Percent Cover* (caveat - method used should be based on goals of project and required precision of data)
- *Elevation* (correlated with inundation)
- *Surface Inundation* (determined from surface pressure transducers and dependent on accurate elevation measures)
- *Soil Salinity* (caveat - sampling frequency can vary depending on project goals)
- *Soil Characteristics* (important to initially characterize site, frequency of repeating monitoring dependent on project goals and type of restoration).

Optional Parameters

- *Vegetation Stem Density (caveat* - should be monitored if important to project goals or useful for a particular type of restoration)

- *Vegetation Height (*some evidence for being useful (such as *Phragmites* stunting with successful hydrologic restoration), but high variation in this parameter limits usefulness)

- *Groundwater Inundation* (can be useful, but sometime challenging to install and can get same information from surface sensors).

- *Groundwater Salinity* (may be important dependent on project goals)

Vegetation Data

While species richness is usually a very indicative structural parameter when comparing "disturbed" or restored sites to more "natural" or "pristine" sites, the relatively low number of species naturally found at the reference sites (often dominated by one or two species) made this parameter a less useful "indictor" of success when compared to data collected from restoration projects in other regions (i.e. West Coast marshes) or habitats (i.e. freshwater marshes). In this study, both restored and reference sites were composed primarily of *Spartina alterniflora* in the low marsh zones and reference site plots in the high marsh zone were usually a mixture of *S. patens*, *Distichlis spicata*, and maybe one other species (*Scirpus robustus* for example) while the high marsh plots at the restoration sites were primary *Spartina patens* and low occurrences or more "non-native" vines or grasses.

At these "excavate and fill" restoration sites, species should be planted with known tolerances to flooding and inundation times making it critical for restoration practitioners to be able to grade a site to make sure the elevations are adequate for those species. In terms of vegetation parameters, the species planted at the restoration sites (*Spartina alterniflora* in the low marsh zone, *Spartina patens* in the high marsh zone) seemed to do extremely well in terms of percent cover in this study. For example, at the Cheatham Annex and Naval Weapons Station restoration sites, *Spartina patens* was planted in a zone right at or above mean high water and appear to be thriving. However, the *Spartina patens* planted well above mean high water at the Hermitage Living Museum restoration site were also growing well indicating a potentially large range in elevations in which to plant these various species.

In our study, field staff collected vegetation percent cover information using two different methods (i.e. point intercept and visual cover estimate) and found advantages and disadvantages to each approach but (with a few exceptions) very similar results when comparing data across years, marsh zones, or sites (see Appendices C,D,E, and F). Within our larger group (across all participating Reserves), the point-intercept method was chosen as the recommended method due to the potential for less observer bias (less subjective decision making) in a monitoring program stretching across multiple years. However, the point-intercept method is more time-consuming, does tend to underestimate rare species (which are often just marked as present) and in certain habitats (such as a very dense mix of multiple species or when vegetation has fallen over or lying down) can lead to similar problems of observer bias (i.e. determining if plants are touching the rod without altering the natural state). Again, the decision to use a certain sampling method should be based on project goals, available resources, and the desired repeatability of collection efforts in future years.

During this study, the participating group of Reserves questioned the value in collecting stem density information of dominant species and especially for highly dense species such as *Spartina patens* and *Distichlis spicata*. Does this provide the same (or slightly different) information than percent cover? For example, there was a great deal of variation in stem densities at the two reference sites for *S. patens and Distichlis spicata* which may have been the result of sampling methodology (or different field crew) versus any significant change due to natural environmental variation. Stem density; however, might be a good indicator of the "quality" of cover at a restoration site, and when combined with good plant height information, can serve as a non-destructive means of approximating plant biomass and ultimately marsh productivity.

It was also interesting and notable that, in most cases, the dominant planted species at the restoration sites had greater heights than their counterpart at the reference sites. The reasons for this are unknown at this time, but obviously conditions are very favorable for growth, especially for species such as *Spartina alterniflora* and *Spartina patens.* Reasons could include more potential nutrients for uptake (potential for biologically remediated sediments used as fill at NWS having more nutrients in the short term), sediment chemistry (for example less sulfides or differences in sediment oxygen demand), differences in salinity (fresher water at restoration sites), or time along growing season. In addition, it's important to understand other factors influencing plant growth, the various reproductive strategies of the vegetation species and the possible effect of inter-specific and intra-specific competition to better interpret response from vegetative parameters as well as potentially forecast vegetative condition in the future.

It is extremely important to emphasize some caution in making any conclusions using the vegetation parameters due to the very short monitoring time in this study (only 3 years) as well as the time which has passed since remediation actions occurred at the restoration sties (3 to 4 years in most cases). The species which were planted at the restoration sites have done extremely well, but there are also many nuisances at the restoration sites which may ultimately determine success or failure of that site. For example, the tidal inlet at Cheatham Annex will probably need to be maintained in the future to allow water to access the site from the York River. Due to breakwaters causing sediment to be retained on the upstream side, it now has become an issue where water does not completely drain from the Cheatham Annex wetland system, causing ponding, and some loss of *Spartina alterniflora.* This has impacted the tidal range (now has been reduced) and has also raised the MLLW elevation (effectively) as the water remains in the site (and mean high water elevation has not been impacted). This drives the lower limit of *Spartina alterniflora* and has increased the size of the mud flat area at this site. At the Naval Weapons Site, the issue is maintaining a hydrologic connection across the spillway as well as the potential for invasive species encroachment at this particular location (*Phragmites spp.* was found in some of the areas bordering the site mixed in with the native vegetation which included *Typha* spp. and *Scirpus robustus*). Also, when you dry sediments (wetland sediment) and they try to re-hydrate and use in a wetland system, there are potential problems. Remediated sediments were oxidized, sulfides become sulfates, and now have very low ph soils (however did not measure soil PH in this study). In addition, you get a hard, inorganic clay-like material very different from the reference condition. Might have been the reason that certain planted species such as *Panicum virgatum* and *Myrica cerifera* took longer to respond (and grow) in the restored areas. At the Hermitage Living Museum restoration site, shifting sediments (primarily sand) blocked off a small drainage channel in one area of the restoration site causing ponding and visual impacts to the low marsh vegetation

The lack of long-term data impacts our ability to discern long-term vegetation trends from natural variation even at the reference sites. For example, several large winter storms in 2007 and 2008 deposited a large amount of wrack at the Goodwin Islands reference site which might have influenced the relative community composition of *Spartina patens* and *Distichlis spicata* depending on which species was able to colonize open space created by shorter term storm events. At Taskinas Creek, although not significant, we are seeing a gradual loss of high marsh vegetation and a gradual increase in typically low marsh vegetation which may be related to sea level changes at the site. With additional funding and monitoring, especially in the areas of vegetation, water level, and using surface elevation tables (SETS), these are the types of questions we hope to answer through establishing our reference sites as “sentinel sites” for addressing climate change issues as well as potentially understand how our restoration efforts will be impacted by the climate issues such as sea level rise.

Defining marsh zones (especially at the reference sites) was also critically important. For example, the most upland Taskinas Creek vegetation plots were actually classified as low marsh sites based on vegetation and elevation (due to flooding from the creek along the backside of the marsh). At Cheatham Annex, there was also a “high marsh” depressional zone adjacent to the riparian uplands which was composed of natural (not planted) vegetation (such as *Scirpus* *americanus*). This kind of site to site variation makes it critical to obtain information from as many restoration/reference site pairs as possible to make sure the in-site variation (i.e. noise) is not too large as to cloud interpretations between restoration and reference sites. For data analysis, it also really helps to have adequate numbers of samples in each zone.

Discussion on Soils Information:

In this study, there was a clear difference in soil properties between reference and restoration sites as the former were composed of highly organic and loosely textured soils representative of mature tidal marsh habitats while the latter sites were constructed from either “outside” fill material or bio-treated sediment from the same site (with very different sediment properties due to the treatment process). Fortunately, *Spartina* spp. are well-adapted to sandy, low-nutrient soils, and are relatively easy to propagate upon properly prepared restoration sites and this was observed in the low marsh and high marsh zones of all three restoration sites with fill material which was very low in organic matter and much higher in sediment bulk density compared to restoration sites. Given the opportunity for long-term monitoring, we expect that the soil parameters of the restoration sites to more towards the values expected at a typical reference site (i.e. lower bulk densities, higher sediment organic matter, higher water content). For this reason, we feel information on soils properties would be a useful metric to add to the RPI analysis to help explain the trajectory of a given restoration site towards the more natural conditions of the paired reference site.

Discussion on Elevation Data

This study demonstrated the definite need to have very precise elevation data due to the very shallow grades in these environments and the elevation data was critical for interpreting the inundation data from the groundwater wells as well as some of the vegetation patterns. The elevation data was also very useful in understanding some of the “nuisances” of the reference and restoration sites (i.e. the depressional areas adjacent to the upland area of both Cheatham Annex and Taskinas Creek). As we had access to multiple types of equipment for measuring elevations in this study, we collected elevation information each year using a combination of approaches (standard visual leveling, digital bar code leveling, and real time kinematic (RTK) GPS). While there was some variation in the data collected using the different approaches, all three methods produced reliable results and our recommendation is to determine the level of accuracy need to answer your research questions and (given resources) and think about the costs (i.e. training, field time, processing time) versus the benefits of the different approaches. Other recommendations would include installing a local benchmark network for any long-term restoration monitoring and development a maintenance schedule on which to repeat your elevation surveys.

Discussion on Pore-Water Sampling:

One of the most important indicator variables resulting from this study appears to be the related to hydrology at the site and especially the relationship between pore-water and ground-water salinity. There was some site specific variation in both pore-water and ground-water spot checks most likely due to the unique geologies of the various sites, in all cases there was a much larger difference in overall pore-water salinities (measuring the root zone) versus groundwater salinities (measured from the bottom of the groundwater wells) at restoration sites which may indicate a disconnect between surface waters and groundwater at these sites. It may also reflect whether the groundwater well was sampling (i.e. integrating water) from just within (or both within and below) the fill layers used for restoration. For example, the low pore-water salinity values at the Cheatham Annex restoration site were a function of the consistently low salinity measurements in the two high marsh zone sippers most likely a function of significant freshwater input from the steep riparian hillside adjacent to the restored wetland area. These two sippers were slightly outside of the excavated area and the impact of groundwater was evident at these locations. The effect of the fill material on groundwater patterns could also be observed at the Naval Weapons Restoration Site. There was a small strip of vegetation which ran between the forested hillside (which bounded the study site area) and the area which was excavated and planted. The cat-tail (*Typha*. sp.) dominated the vegetation community in this zone and the upper root zone in this area was clearly impacted by groundwater runoff from the hillside (observations at that site not reported as part of this study).

Some questions restoration practitioners might want to consider when using pore-water sippers are as follows:

- Is it important to sample at a certain depth within the sediment?
- Should we try to standardize the frequency of our data collections?
- Should this be used primarily to characterize site conditions and also look for short or long-term trends or is this information subject to rigorous data analysis methods?

Discussion on Using Groundwater Wells for Inundation Monitoring:

Trying to determine inundation periods using groundwater wells and continuous monitoring units in these very low elevation relief areas required very precise field measurements – including the actual level of the sensor below ground and the distance from sensor to well top. It is important for restoration practitioners who are collecting continuous groundwater data to standardize a process for collecting accurate groundwater well data. It is important to make sure to collect spot measurements of water depth during the time period when the instrument is collecting data as a good field check. A second alternative (which is now recommended by participants in this study) is to use surface water level instruments (rather than groundwater data) and elevation surveys for modeling inundation of various habitats on marsh surface. This does require the use of "on-site" surface water pressure transducers which need to be deployed on a stable platform and should also be able to sample the entire tidal cycle (i.e. should not be placed in a location that is subtidal or water goes below the level of the sensor).

Also, in future work, need to consider different ways to use the groundwater data to reflect not only inundation but also saturation levels within the marsh zone of interest. This could be done examining such factors as the amount of time a certain depth below the sediment surface was inundated (to reflect the area of the root zone) as well as taking into consideration the permeability of the sediment (i.e. soils can be saturated even with mean water levels well below the sediment surface through capillary action). For example, *Spartina patens* seem to thrive in the high marsh zone of the Hermitage and Naval Weapons Station restoration sites even though mean groundwater levels were lower than (or just within) the root zone of the marsh vegetation (defined to be approximately 20 centimeters). Through capillary action, these high marsh areas could still see a saturated root zone environment as observations at the Hermitage Living Museum site in particular indicated a very dry root zone area (i.e. – very limited to no water within the pore-water sippers).

Due to limited funding, only one transect line of groundwater wells was sampled at each study site during the study (with the exception of Hermitage and one additional high marsh well at Naval Weapons Station). Although the sampling plan was designed to be representative of the particular restoration site, the data may have been slightly different if the groundwater transect was established in a different location. In our study, the 2008 data from Hermitage was based on a single well placed along a primary transect. The grade from low to high marsh was steeper than in other areas of the marsh and would reflect the disparity in the data from that particular year compared to the other two years at Hermitage in which a second high marsh well as added but at a lower overall NAVD88 elevation in the high marsh zone. It is important to consider this potential limitation in a sampling design.

Due to the potential variation in hydrologic conditions during different times of the year (and even within the same season), there are probably valid arguments for making sure to collect groundwater data from the reference site and restoration site during the same time period as well as collect groundwater data from different seasons over the course of the year. In the first year of the study (2008) the groundwater sampling was conducted during different time windows for each of the five different sites. In 2008, a large Nor'easter resulted in the highest maximum high tide levels at Goodwin Islands but this was not reflected at the paired restoration site due to data being collected during a different time period. Although each site experienced a spring to neap (or neap to spring) sampling period, each site may have experienced different tidal ranges and high tides (due to meteorological forcing or extreme weather events). In 2009 and 2010, the groundwater sampling at the sites was conducted to help constrain this particular source of variation by deploying the Aquatrolls/Solinst transducers during the same time period at both the reference and paired restoration site(s). One must also consider inter-annual variation in the groundwater data. For example, 2009 was a year of wind forcing keeping water pushed up within the York River Sites which was reflected in the groundwater data (Sweet, 2009). A recommendation from this study is the need for longer sampling runs (as two weeks (the spring-neap cycle) is not enough to capture within-season variability in the data) and multiple runs throughout the year (to attempt to capture data from different seasons).

RPI Discussion

Overall, all three restoration sites visited during this study appear to be on track towards "success", both visually and through examining three years of data collected on a suite of structural and functional monitoring parameters. Although the lack of pre-restoration data is problematic in the RPI analysis (it is difficult to identify restoration progress without knowing the actual original condition of the site), all three sites were at least 50% structurally and functionally equivalent to their paired reference site based on comparing 2008 with 2009 and 2010 monitoring data. It is also important to remember the incorporation of more variables into the RPI will only help strengthen the predictive value of the output (for example, incorporating soils data or stem density information for this particular study).

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Lessons Learned from this Project

- Having pre-restoration data is critical to use the RPI properly.
- Reserve reference sites proved very useful, especially when collecting restoration site data in same time window as reference site data
- Extremely important to have the right reference site/restoration site pairing (i.e. variation due to local site characteristics such as location or geology can potentially mask any attempt to compare monitoring parameters across sites).
- Need to have standardized protocols for all monitoring parameters (for example, consistency in your approach to installing groundwater wells, determining frequency of sampling, paired deployments of units).
- Monitoring needed over a longer time period of time than the 3 years of this study to understand interannual variability at restoration and reference sites.
- Defining marsh zones (especially at the reference sites) was critically important. Important to have adequate sampling size in each zone.

Future Directions of the Reference Site Partnership.

From conversations among the participating group of Reserves, several ideas for future directions for this projects were discussed as new avenues for research. These included:

- Continued monitoring of the current suite of projects for another three to five years to track response over a longer time trajectory with a less frequent monitoring protocol. In addition, there was a recommendation to phase in additional monitoring parameters such as vegetation below ground biomass, invertebrates, and nekton.
- Evaluation of restoration status on a subset of newly funded FY10 restoration projects using the recommended approaches and lessons learned from this study to potentially broaden the evaluation of restoration efforts and suite of reference sites to other regions of the country;
- Evaluation of restoration status in the context of climate change using a subset of projects that are highly vulnerable and resilient to climate change impacts; and
- Post-storm monitoring to evaluate the resiliency of restoration projects
- Development of a web-based portal to deliver NERRs monitoring data as reference data to restoration practitioners.
- Add capability to measure carbon storage through additional long-term monitoring approaches including surface elevation tables (SETS), marker horizons, and soil coring.

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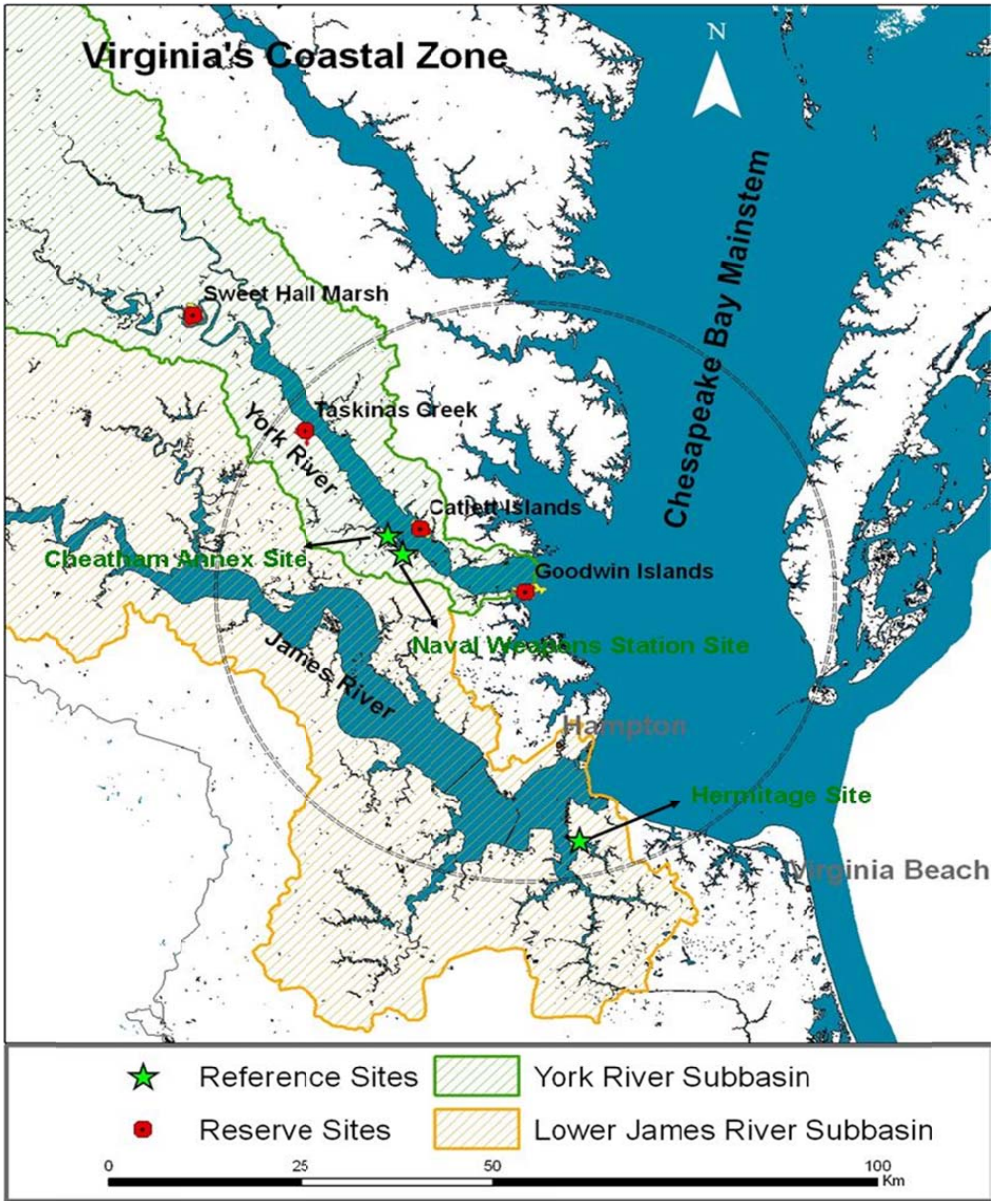


Figure 1: Map of Chesapeake Bay highlighting the general locations of the restored and reference marshes sampling during this study. A marsh on Goodwin Islands served as a Reference Site for the Hermitage Living Museum Restoration Site. A marsh in the Taskinas Creek Reserve served as a reference site for two restoration sites on Department of Defense Lands, including the site at Cheatham Annex and the site at Naval Weapons station.

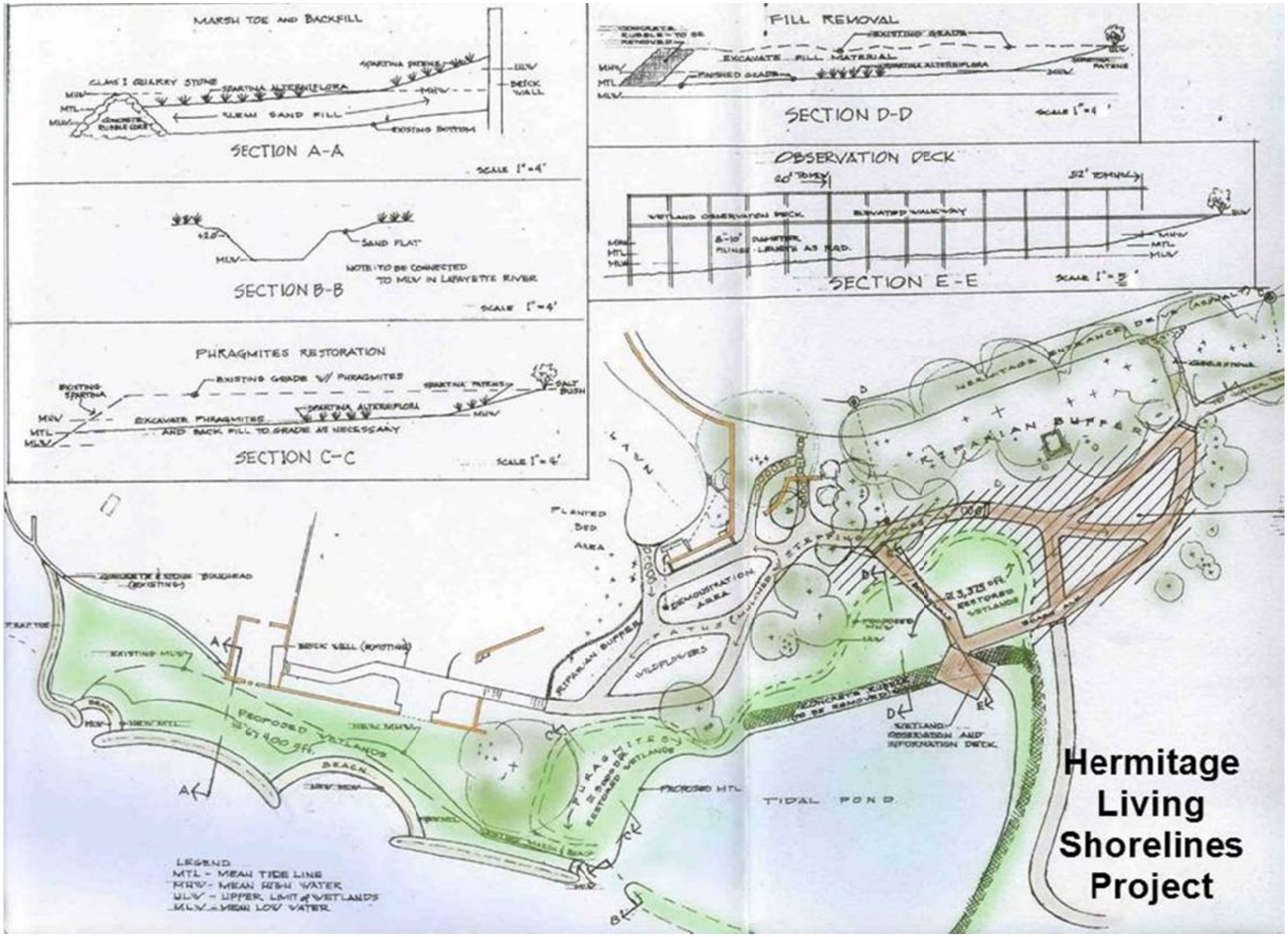


Figure 2: General plan for wetland and riparian restoration as part of the Hermitage Museum Foundation Living Shoreline and Wetland Restoration Project. There were three different phases of this project including creating a living shoreline, removing and replacing a large stand of the invasive reed Phragmites australis with tidal marsh, and removing 400 cubic yards of rubble and debris and replacing with tidal wetlands.

Figure 3: Diagram showing the approximate locations of the different phases of Restoration as part of the Hermitage Living Shorelines Restoration Project. 300 linear feet of shoreline were protected through the creation of a living shoreline at Site A. Removal of an invasive strand of Phragmites and replacement with 5000 SF of tidal marsh took place at Site B. Removal of approximately 400 cubic yard of debris and planting of native plants restored 7500 SF of tidal wetlands at Site C.

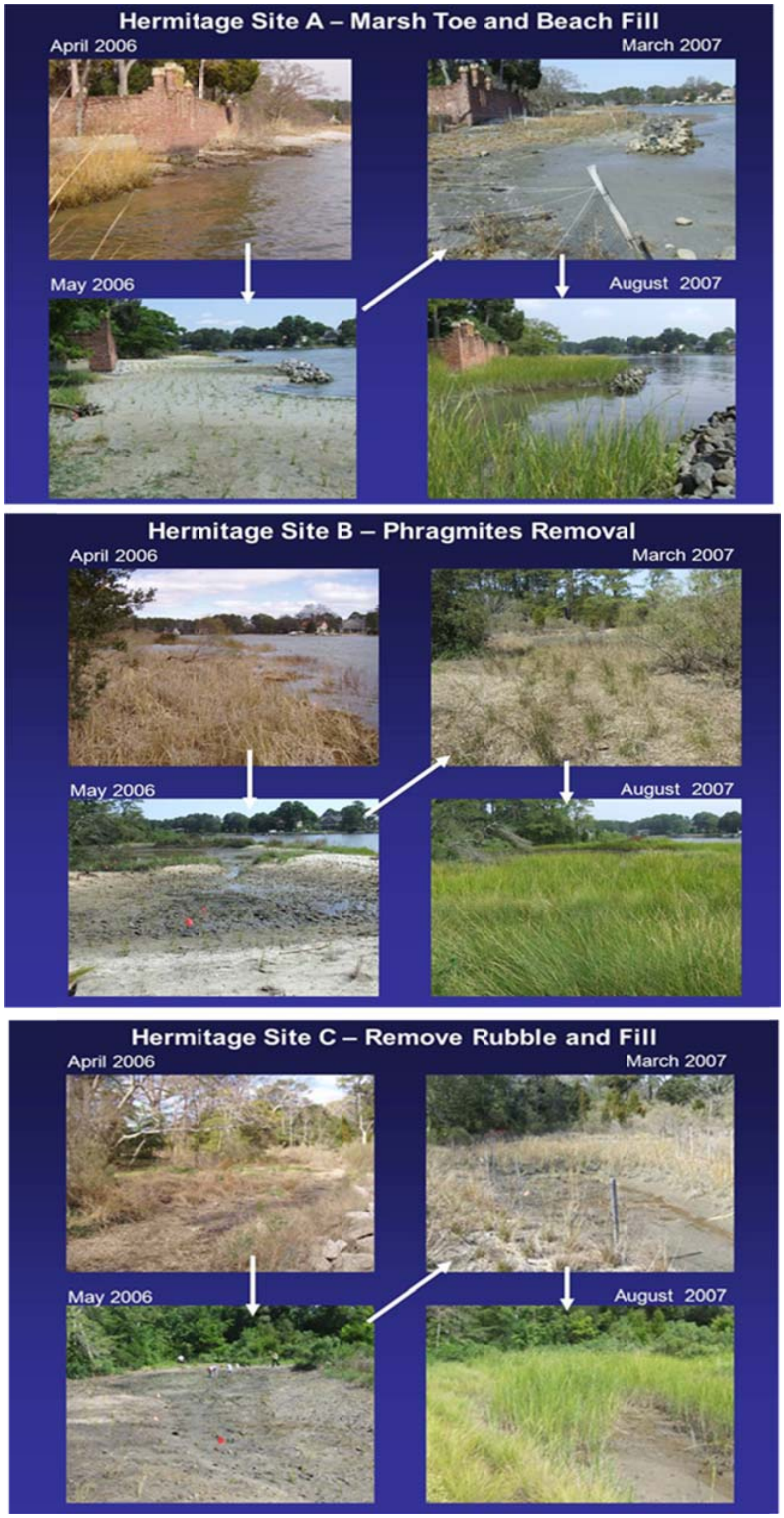


Figure 4. Photos showing the three different types of restoration as part of the Hermitage Living Shoreline and Wetland Restoration Project.

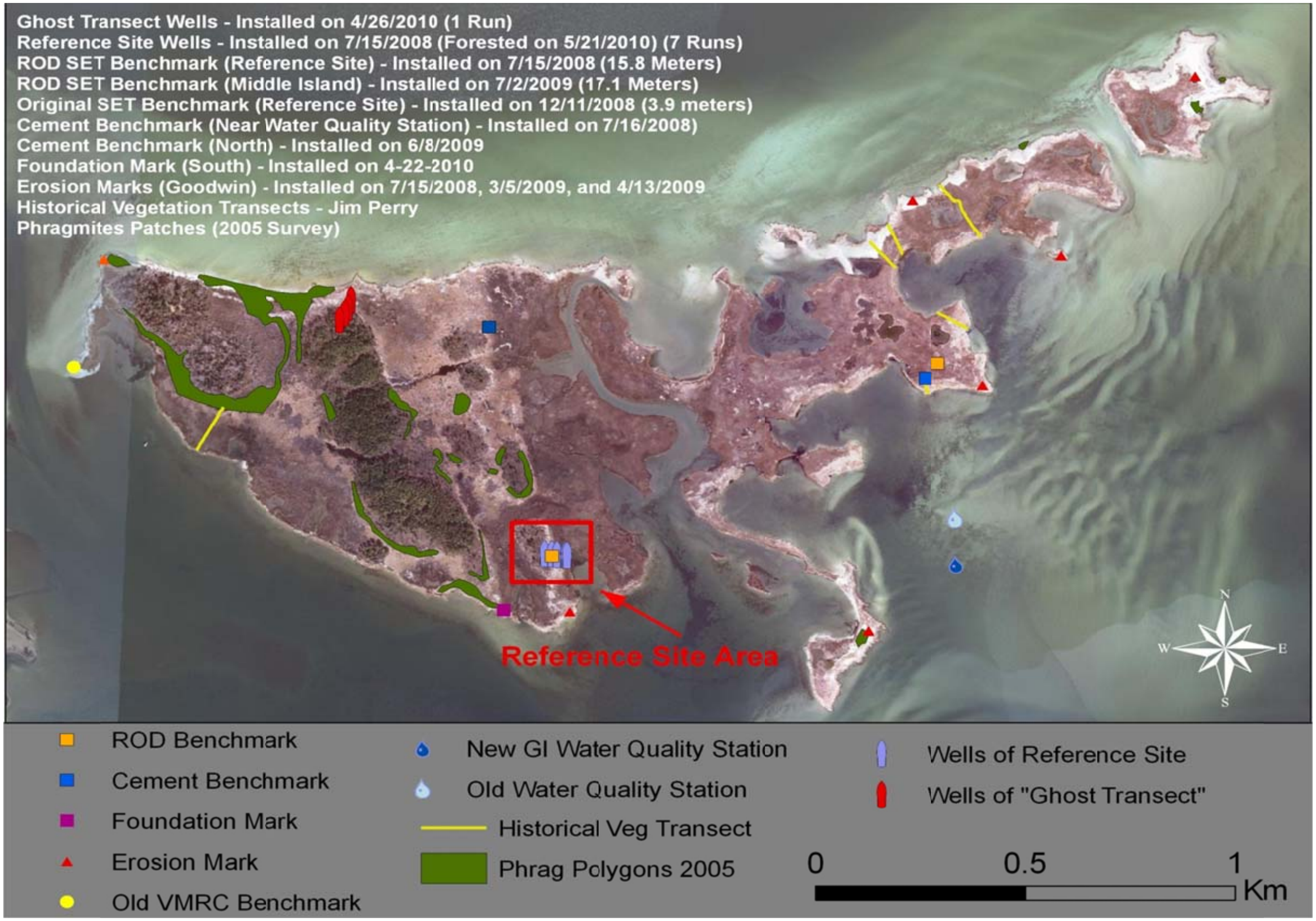


Figure 5. The Goodwin Islands, located near the mouth of the York River, are a 148 ha (366 acres) archipelago of polyhaline salt-marsh islands surrounded by inter-tidal flats, extensive submerged aquatic vegetation beds, and shallow open estuarine waters. CBNERRVA staff used a small tidal marsh area on the southeast corner of the main island to serve as a reference site to evaluate the Hermitage Living Museum Restoration Project.

Figure 6. The Goodwin Island Reference Site represents primary ecological community types including a low marsh dominated by tall and short for Spartina alternflora, a high marsh dominated by Spartina patens and Distichlis spicatata, a shrub scrub community, and upland maritime forest. The top picture was taken in the Spring of 2008 (looking upland) and the bottom picture in the fall of 2007 (looking towards the water).

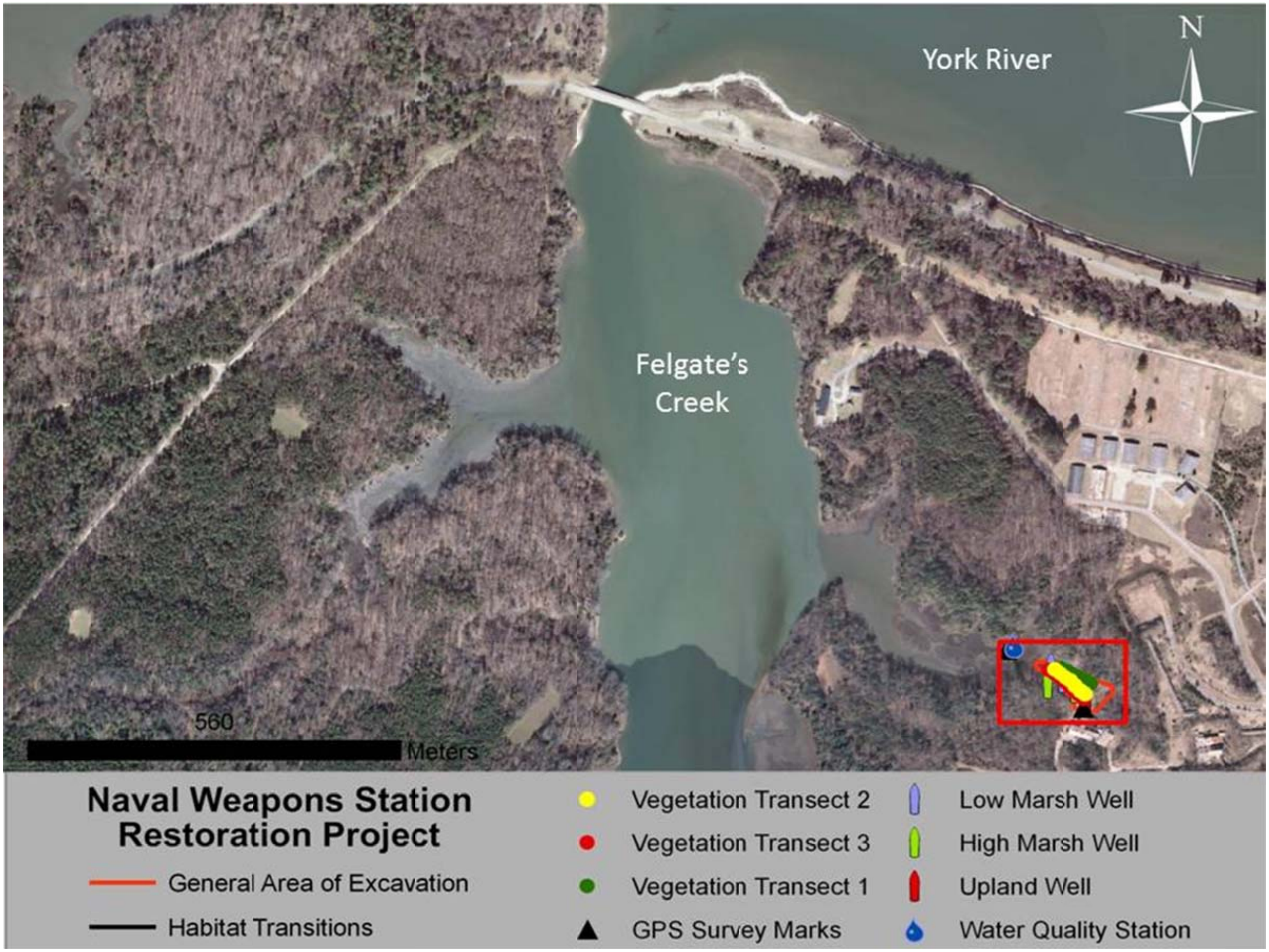


Figure 7. Location of Naval Weapons Station Restoration Project. The Site 6 impoundment area is a 3-acre, unlined, surface impoundment adjacent to wetlands along a small tributary to the main branch of Felgates Creek.

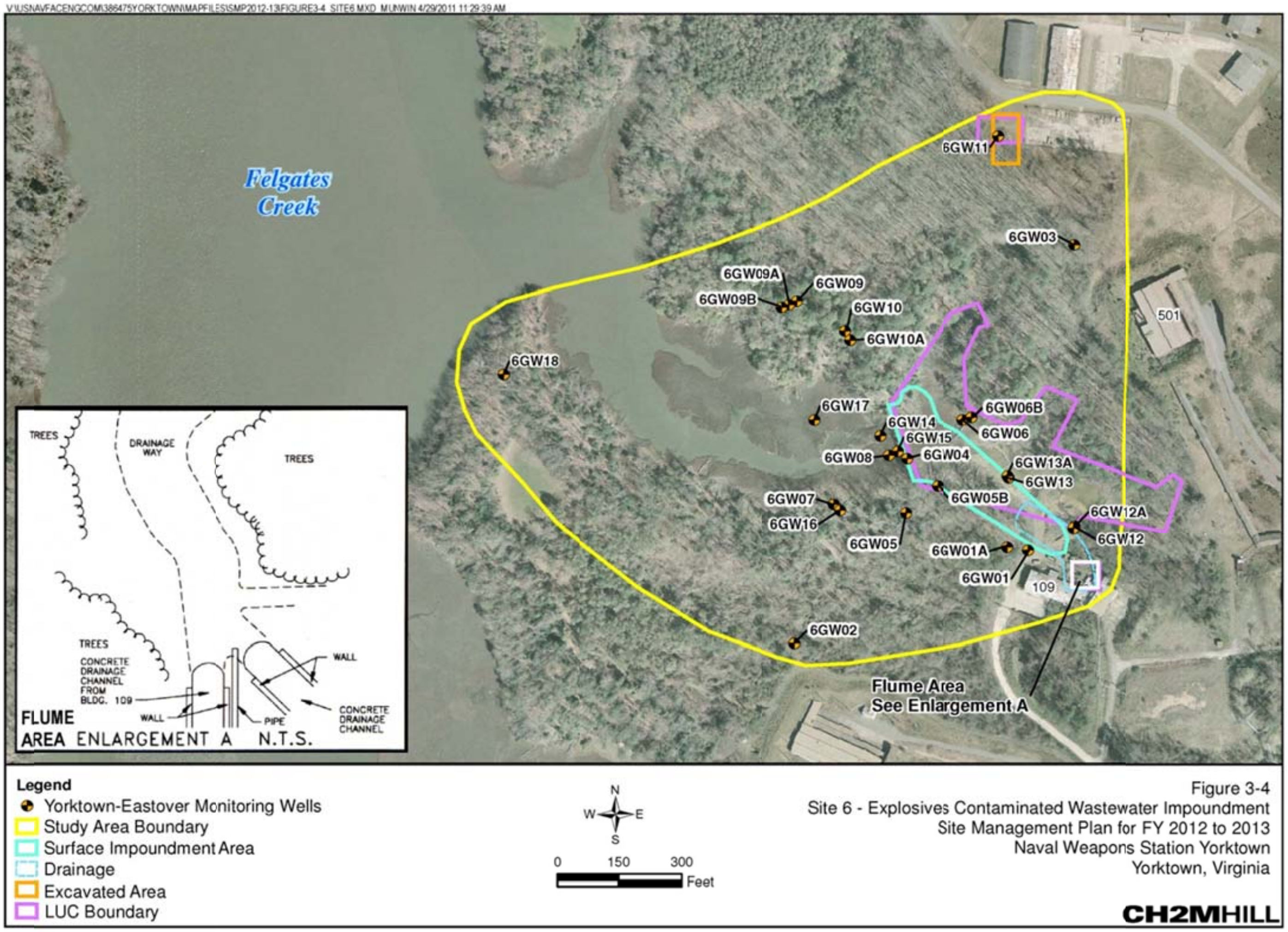


Figure 8. General Site Management Plant for Naval Weapons Area Site 6 in Yorktown, Virginia. The restoration monitoring for this study was focused in the smaller "Surface Impoundment Area" on the map, although other environmental studies (especially for soils monitoring and surface and groundwater testing and remediation)started in 1999 with the restored wetland constructed in 2006.

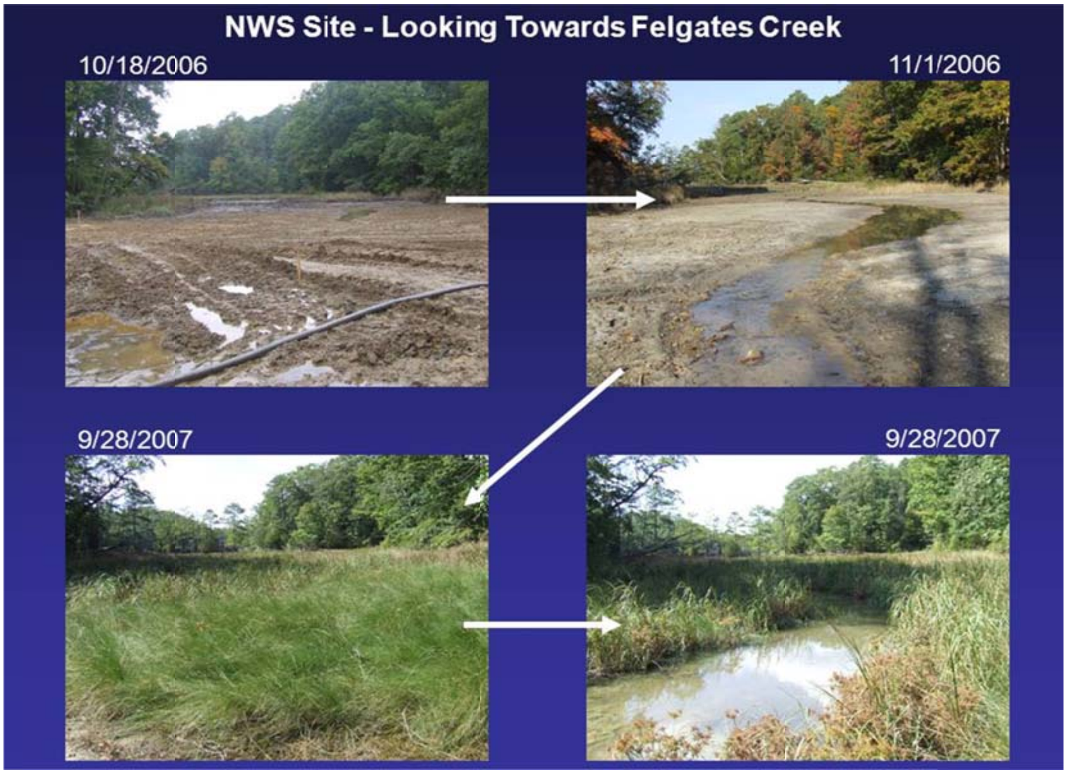


Figure 9. Some depictions of the general restoration within the impoundment area of Naval Weapons Site 6 which included sediment removal, treatment of sediments, fill with decontaminated sediments, re-grading, and planting with a mixture of tidal and riparian vegetation.

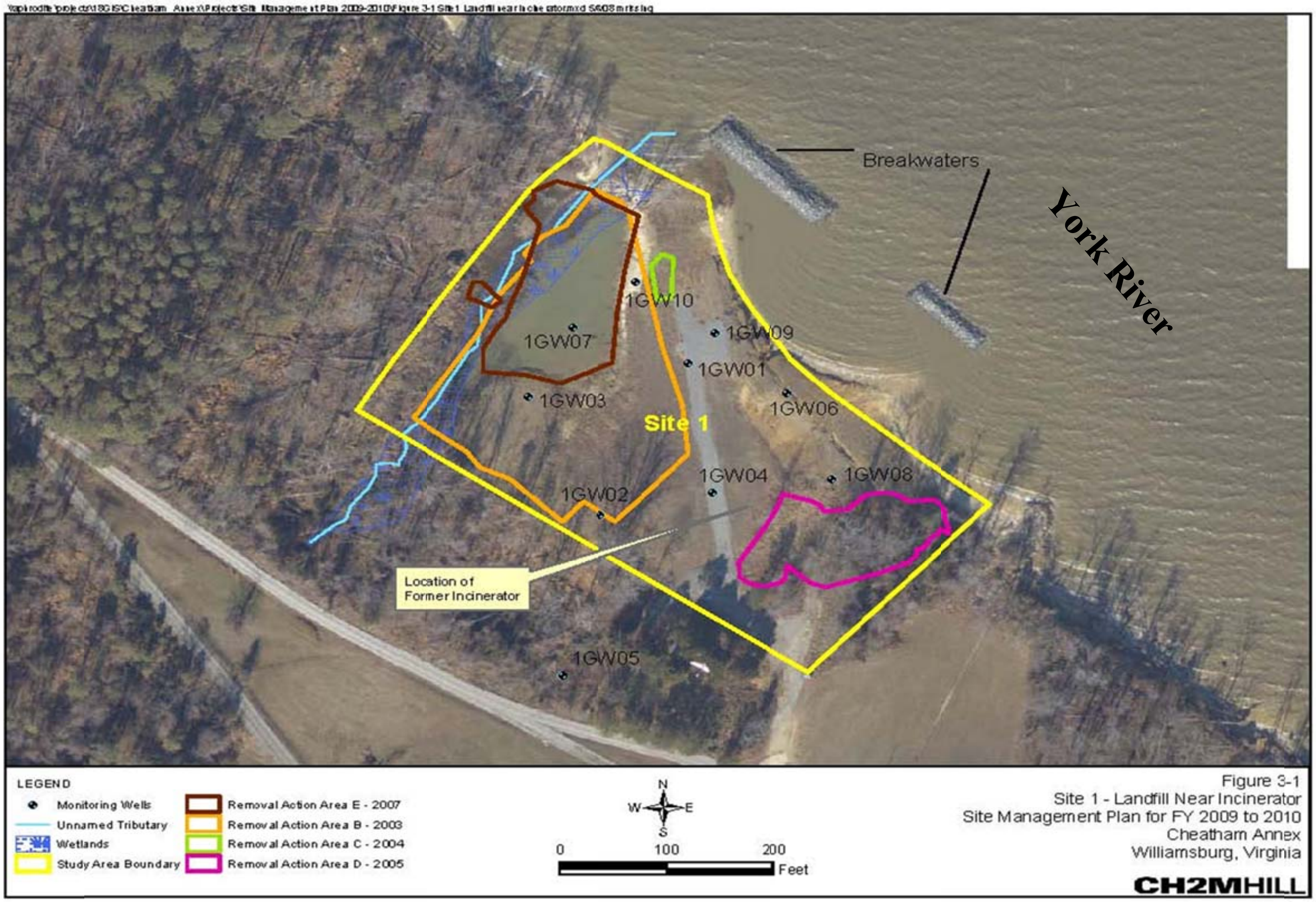


Figure 10. General location of restoration site named Cheatham Annex Site 1. This site, located in the mesholine portion of the York River, was formerly used as a site burn residues and later as a landfill. Due to concerns about landfill contents become exposed due to erosion along the steep banks along the York River, geotubes and a later two breakwaters were constructed to minimize erosion at this site. The area contained by the brown polygon (“Removal Action Area E) was the primary sampling area for this study.

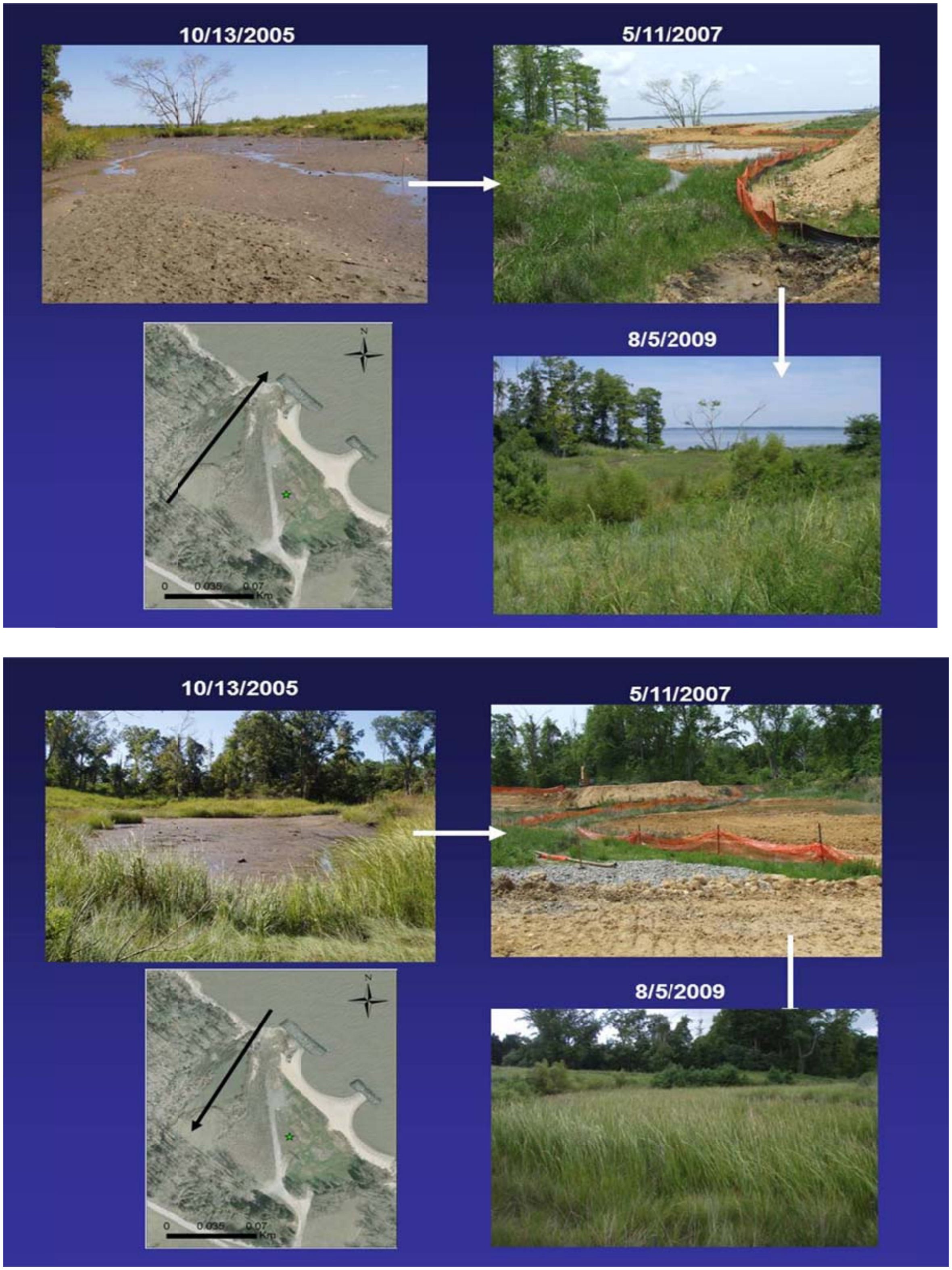


Figure 11. Some depictions of the general restoration within the former “depression pool” adjacent to the former landfill of Cheatham Annex Site 1 which included sediment removal, fill with offsite material, re-grading, and planting with a mixture of tidal and riparian vegetation.

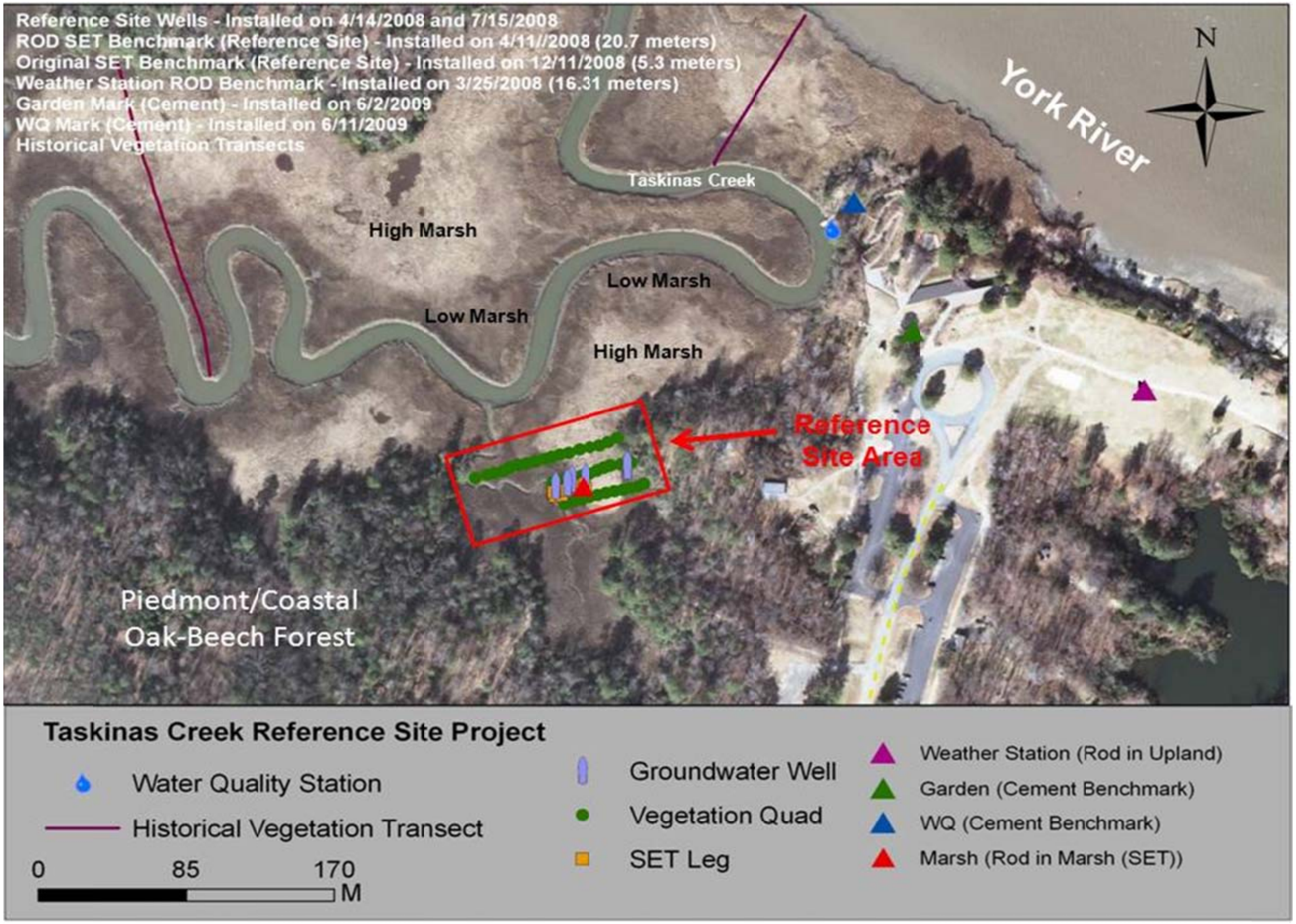


Figure 12. Taskinas Creek encompasses 433 ha (1070 ac) within the boundaries of York River State Park (YRSP). This small subestuary of the York River is located on the southern side of the river, approximately 28 km (17 mi) upriver from VIMS and 38 km (24 mi) from the mouth of the York River. The study area is located in a small pocket tidal mesohaline marsh bounded by a steep upland Beech – Oak forest community.

Figure 13 (a,b). The Taskinas Creek Reference Site represents a transition from a low marsh community dominated by tall and short for Spartina alternflora, a high marsh community dominated by Sparatina patens and Distichlis spicata, and a marsh community adjacent to the upland forest consisting of a misxture of S. alterniflora, Scirpus robustus, and Scripus americanus.

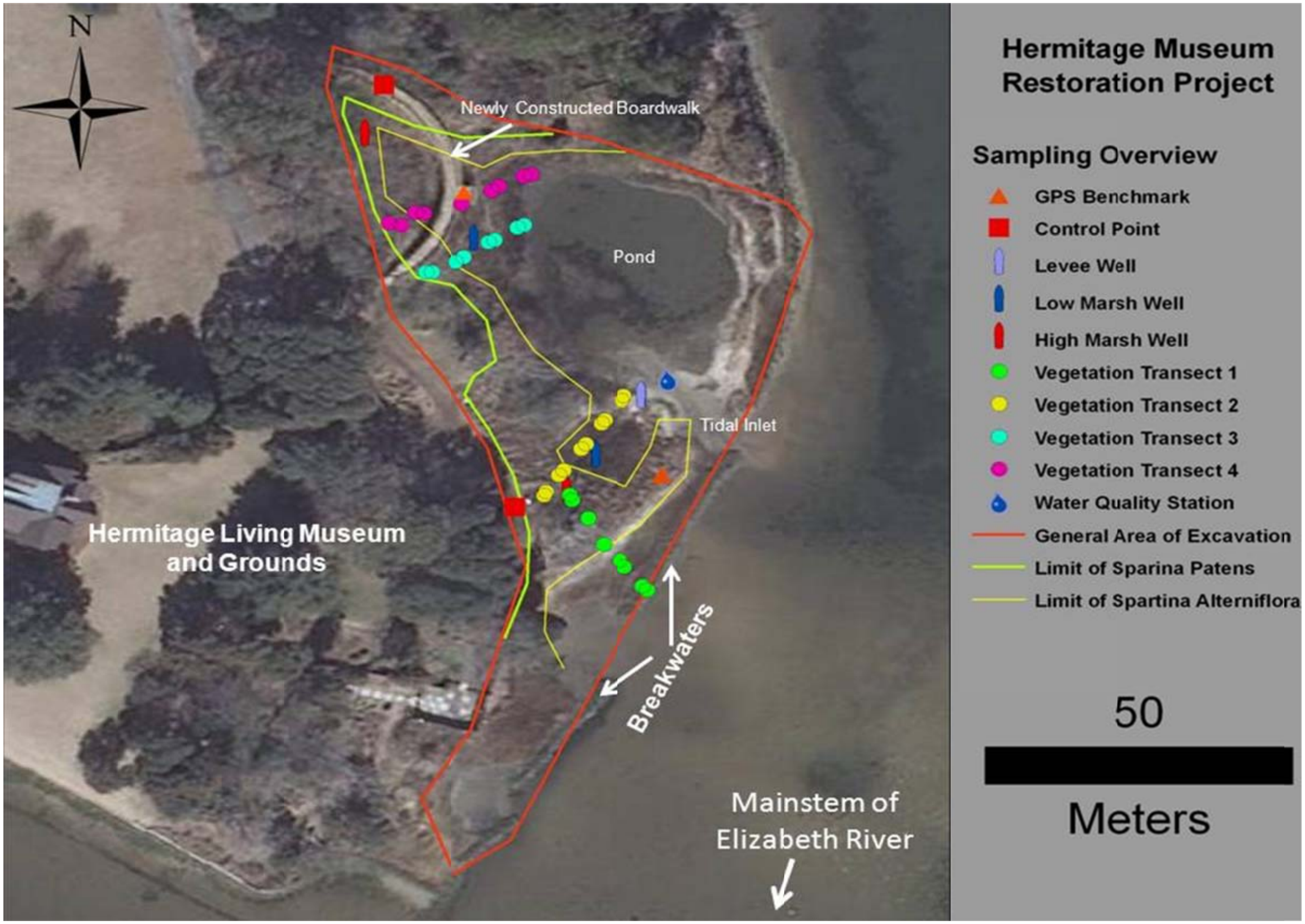


Figure 14. Map showing the locations of vegetation monitoring transects, groundwater wells, and geospatial infrastructure at the Hermitage Living Museum Restoration Project. The general area of restoration as well as major vegetation zones, including a low marsh zone dominated by Spartina alternflora and a high marsh zone dominated by Spartina patens, are also delineated on this map.

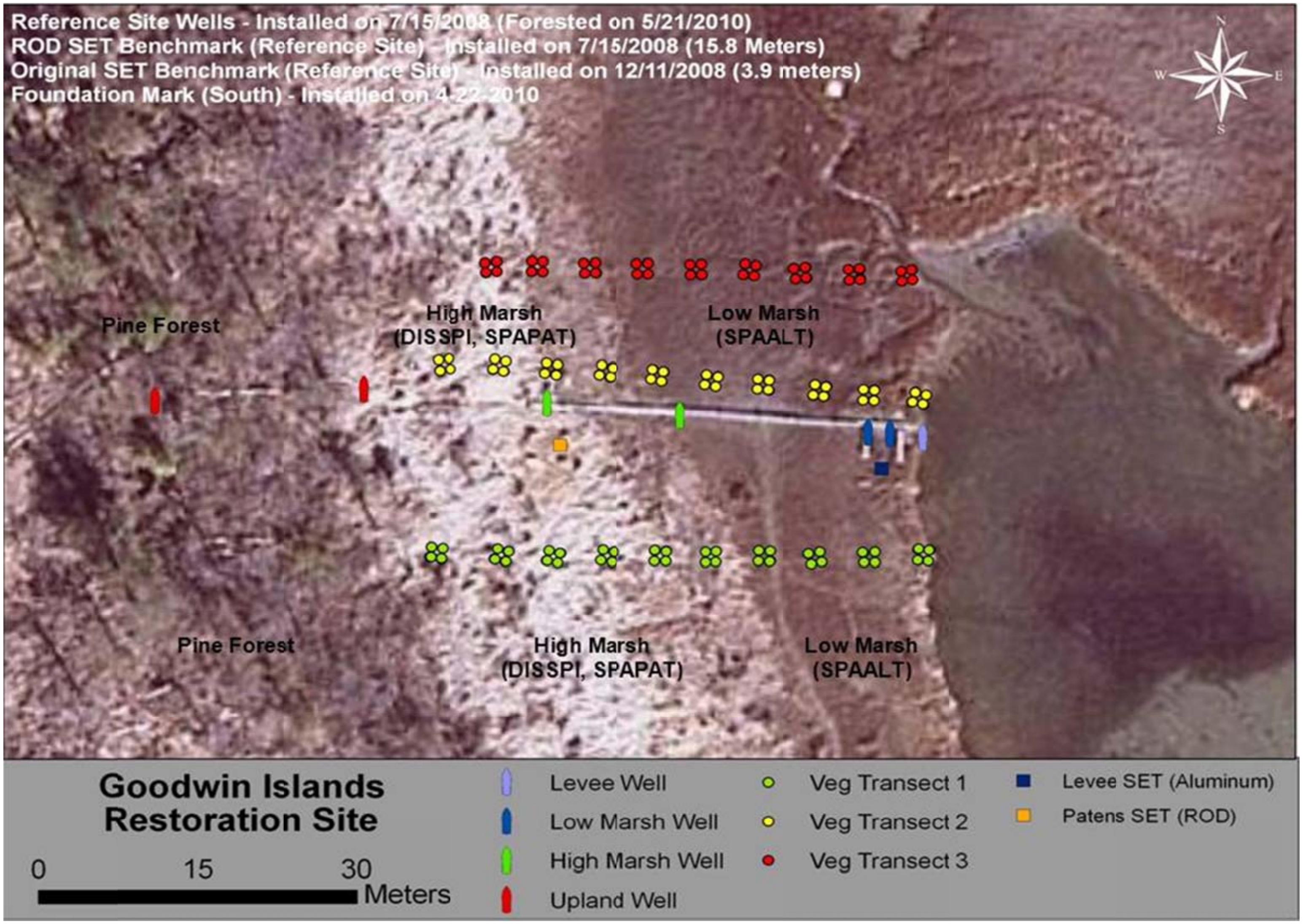


Figure 15. Map showing the locations of vegetation monitoring transects, groundwater wells, and surface elevation tables (SETS) at the Goodwin Islands Reference Site area. The general vegetation zones, including a low marsh zone dominated by Spartina alternflora and a high marsh zone dominated by Spartina patens and Distichlis spicata, are also designated on this map.

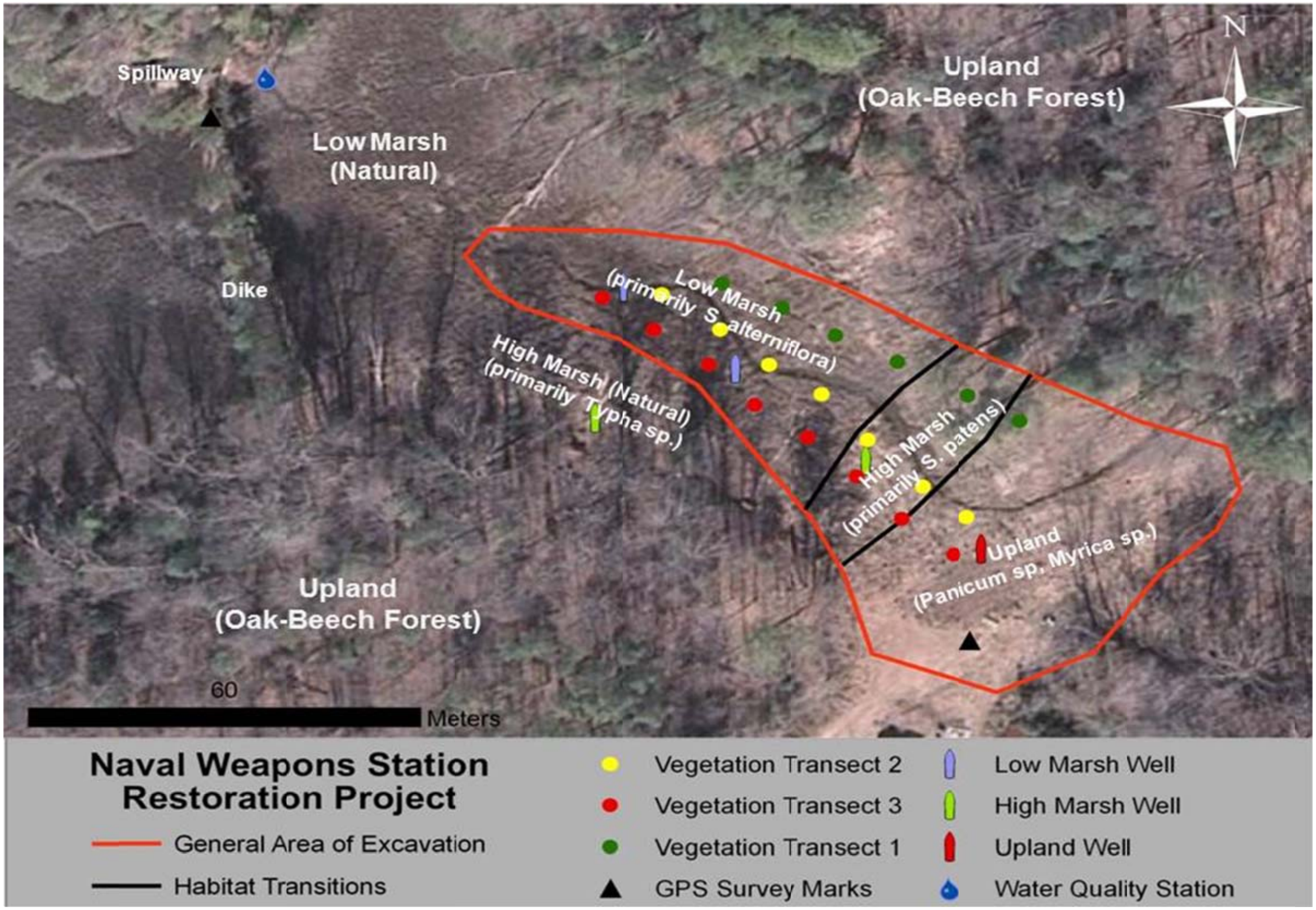


Figure 16. Map showing the locations of vegetation monitoring transects, groundwater wells, and geospatial infrastructure at the Naval Weapons Site 6 Restoration area. The general area of restoration as well as major vegetation zones, including a low marsh zone planted with Spartina alternflora a high marsh zone planted with Spartina patens, and an upland planted with switchgrass and bayberry are also delineated on this map.

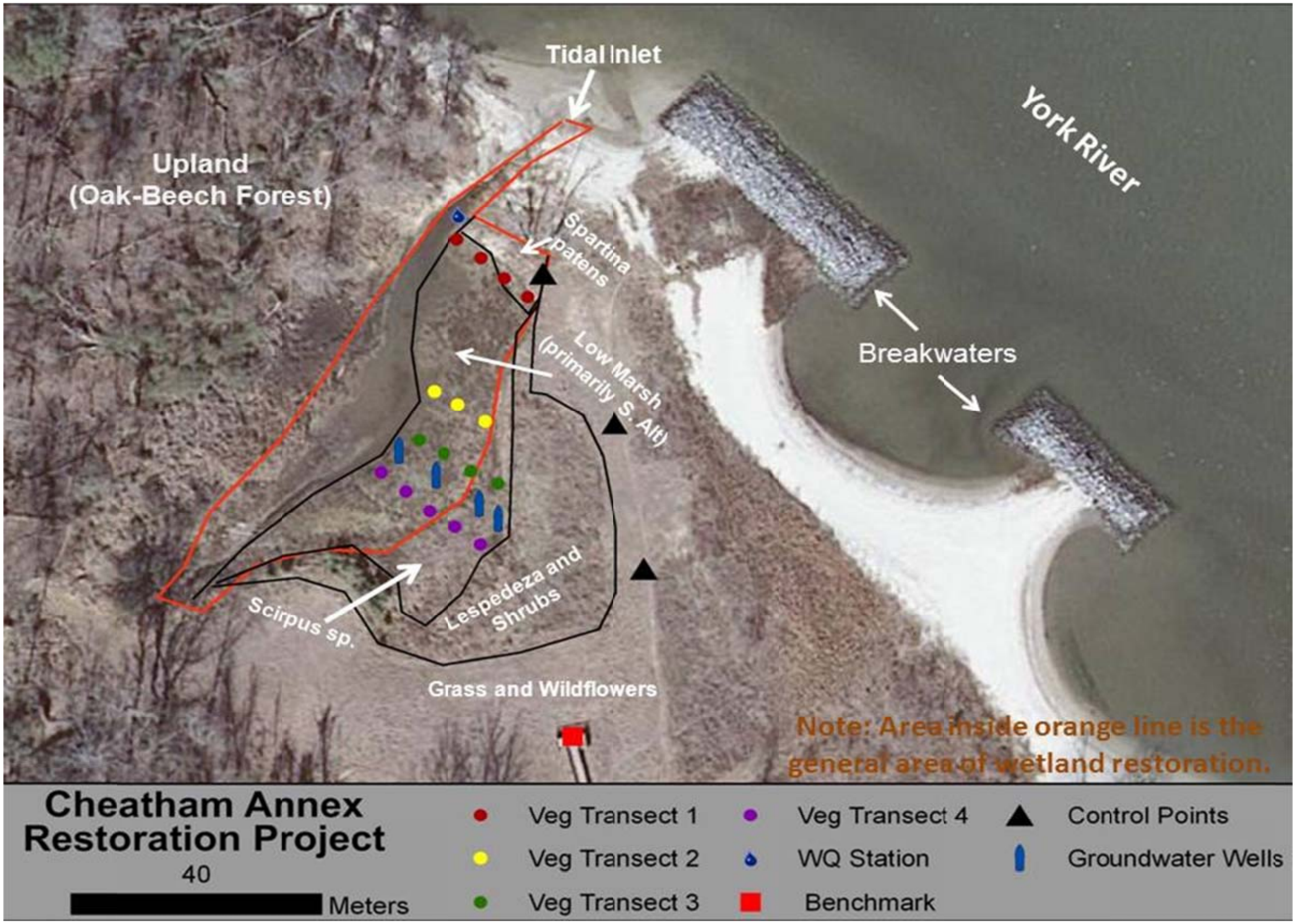


Figure 17. Map showing the locations of vegetation monitoring transects, groundwater wells, and geospatial infrastructure at the Cheatham Annex Site 1 Restoration area. The general area of restoration as well as major vegetation zones, including a low marsh zone planted with Spartina alternflora and a high marsh zone dominated by Scirpus americanus and planted with Spartina patens, are also delineated on this map.

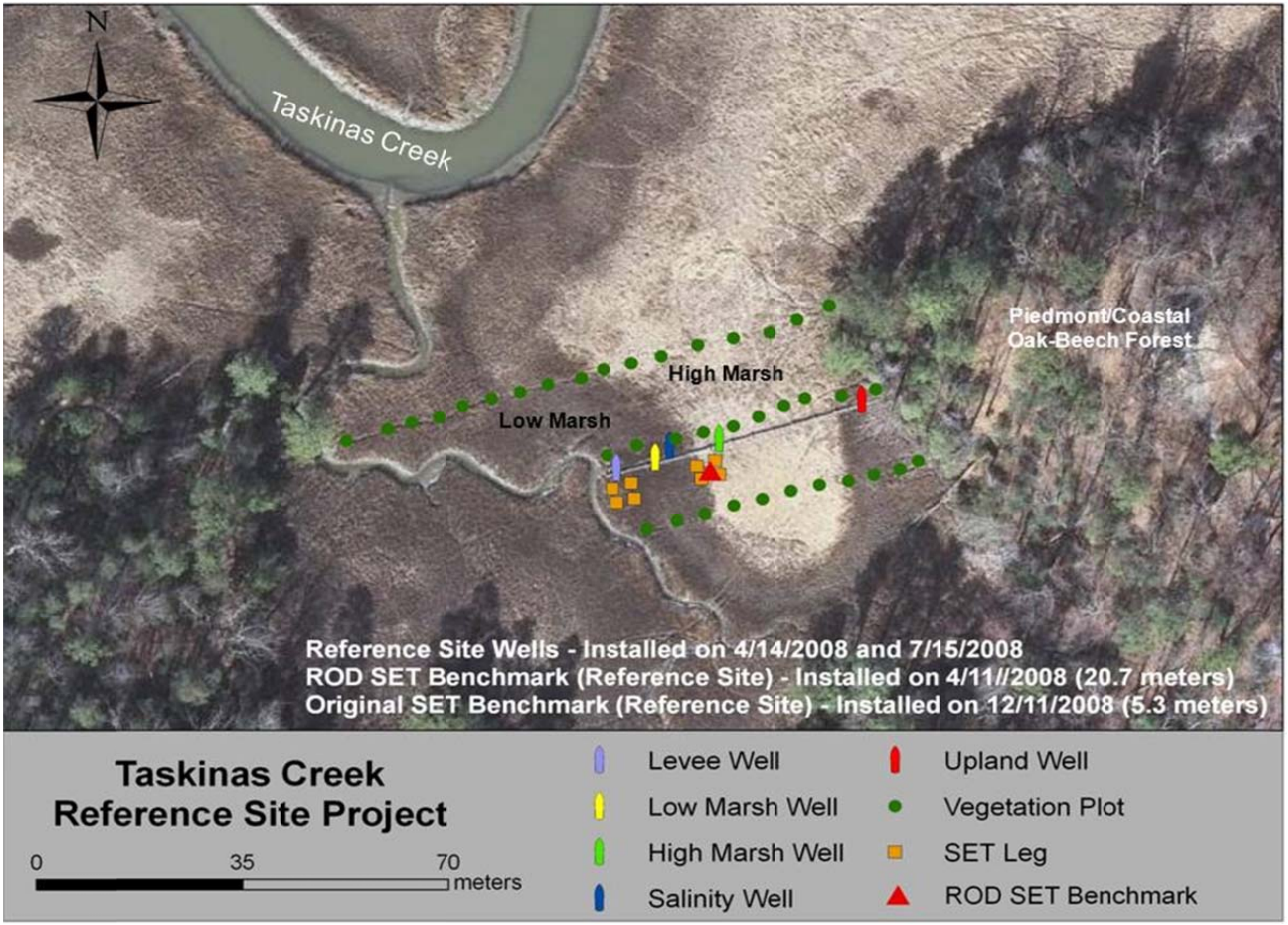


Figure 18. Map showing the locations of vegetation monitoring transects, groundwater wells, and surface elevation tables (SETS) at the Taskinas Creek Reference Site area. The general vegetation zones, including a low marsh zone dominated by Spartina alternflora and a high marsh zone dominated by Spartina patens and Distichlis spicata, are also designated on this map.

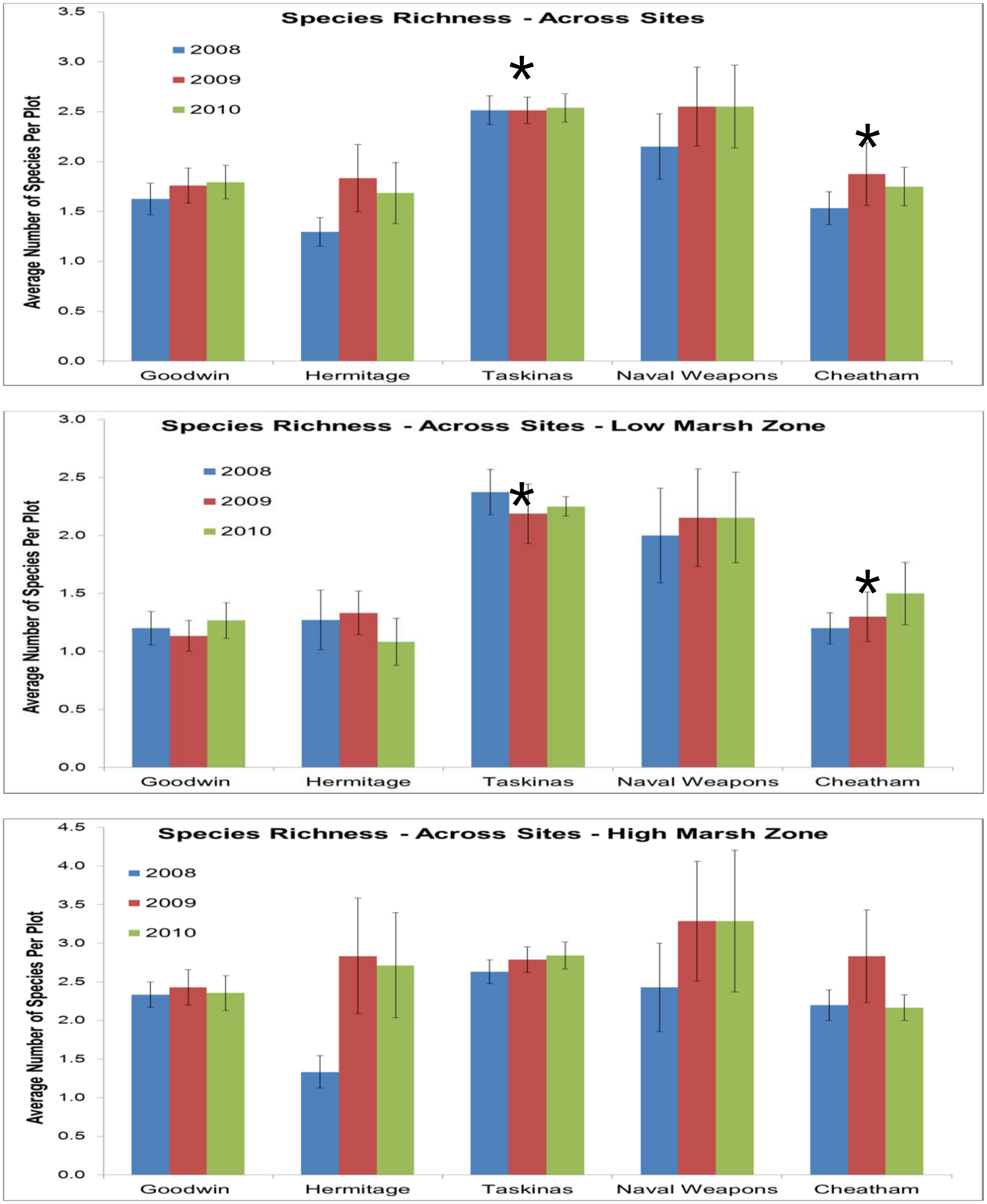


Figure 19. Mean species richness (+/- SE) across study sites for all three years for all data (marsh zones combined), for the low marsh zone only, and for the high marsh zone only. Asterisks denote significant differences between a paired restoration and reference site. Goodwin (reference) is paired with Hermitage (restoration) and Taskinas (reference) is paired with Naval Weapons and Cheatham (restoration).

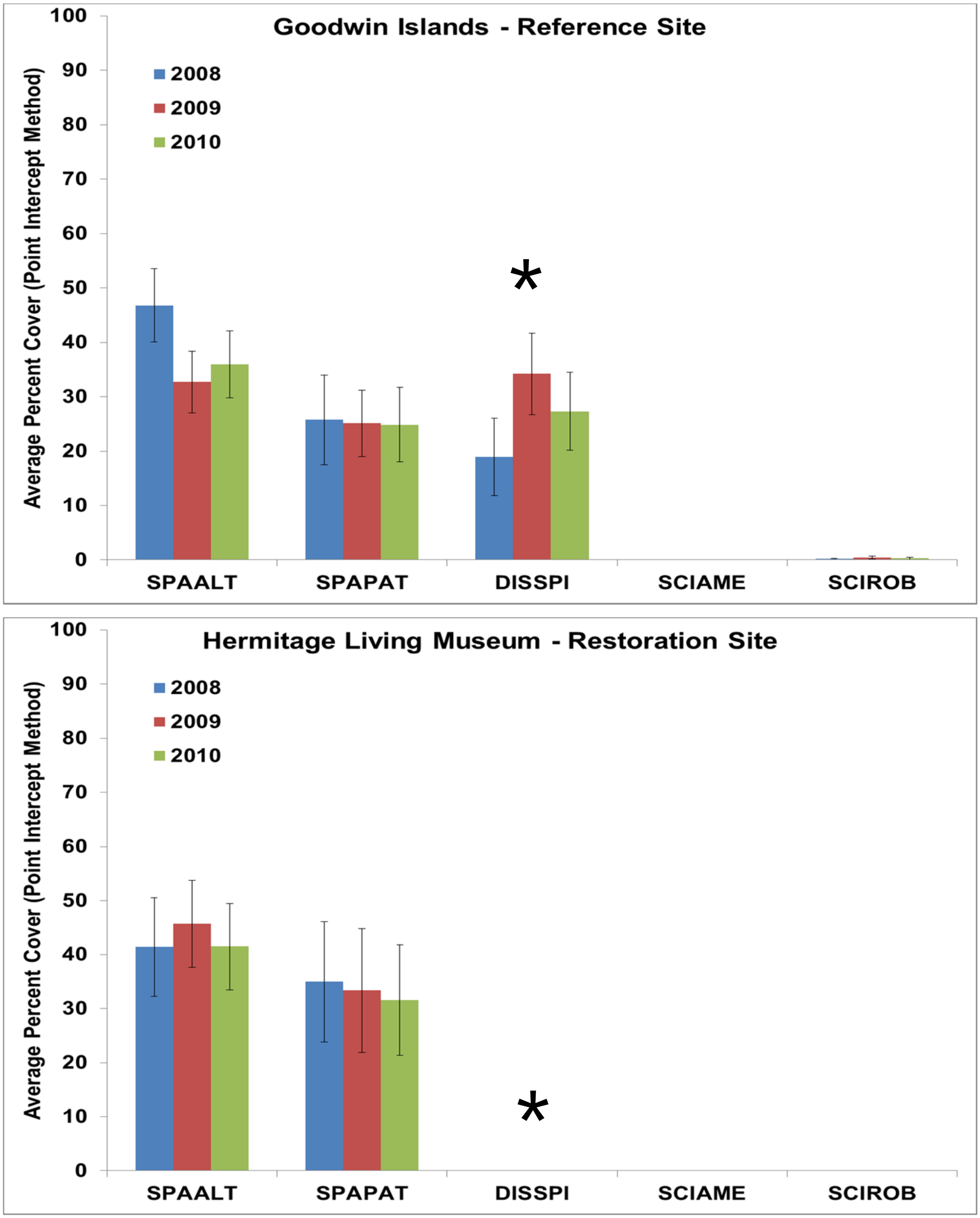
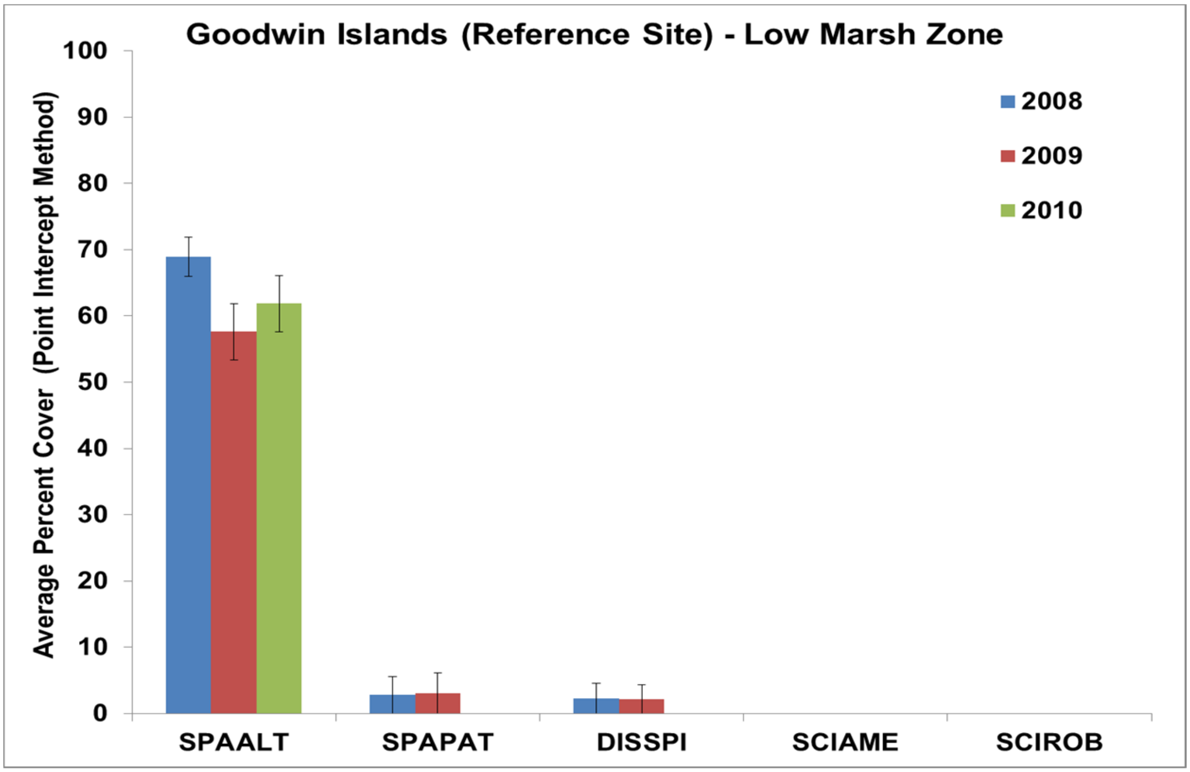


Figure 20. Mean percent cover (+/- SE) for the five dominant species for all three years at the paired Goodwin Islands (reference) and Hermitage Living Museum (restoration) study sites. Asterisks denote significant differences for a particular species between a paired restoration and reference site.



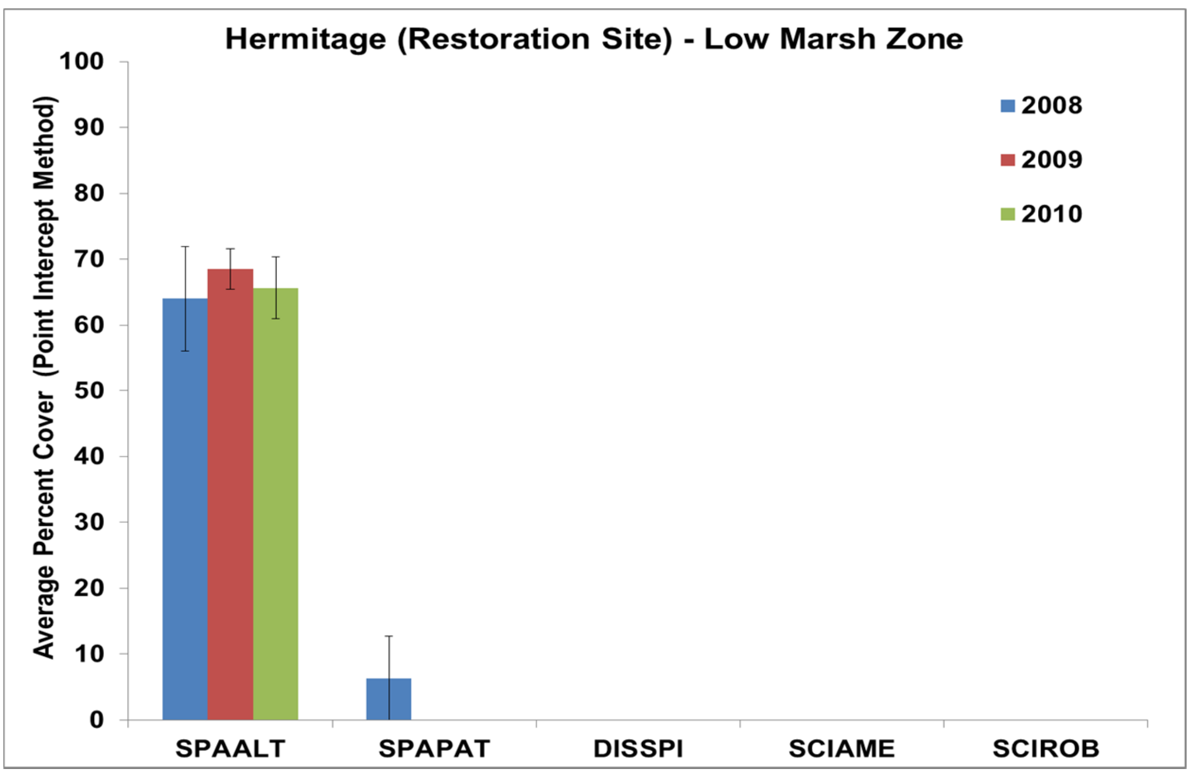
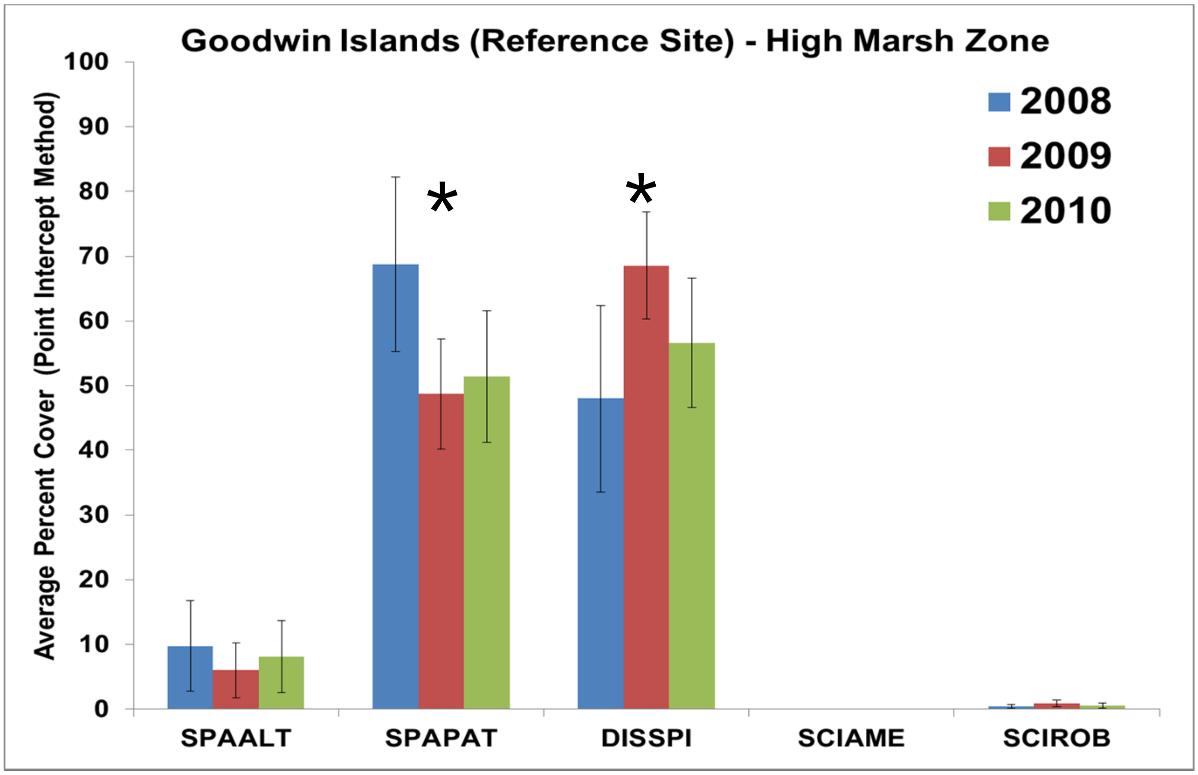


Figure 21. Mean percent cover (+/- SE) for the five dominant species for all three years within the low marsh zone at the paired Goodwin Islands (reference) and Hermitage Living Museum (restoration) study sites. Asterisks denote significant differences for a particular species between a paired restoration and reference site.



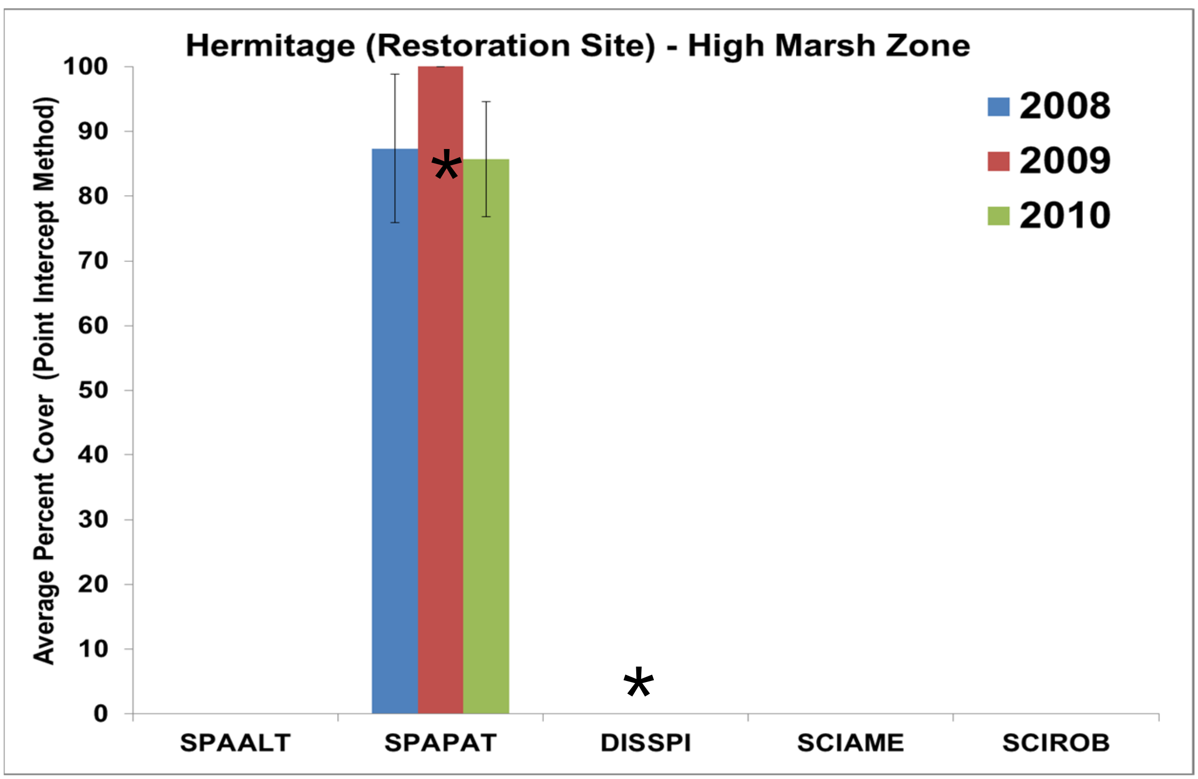


Figure 22. Mean percent cover (+/- SE) for the five dominant species for all three years within the high marsh zone at the paired Goodwin Islands (reference) and Hermitage Living Museum (restoration) study sites. Asterisks denote significant differences for a particular species between a paired restoration and reference site.

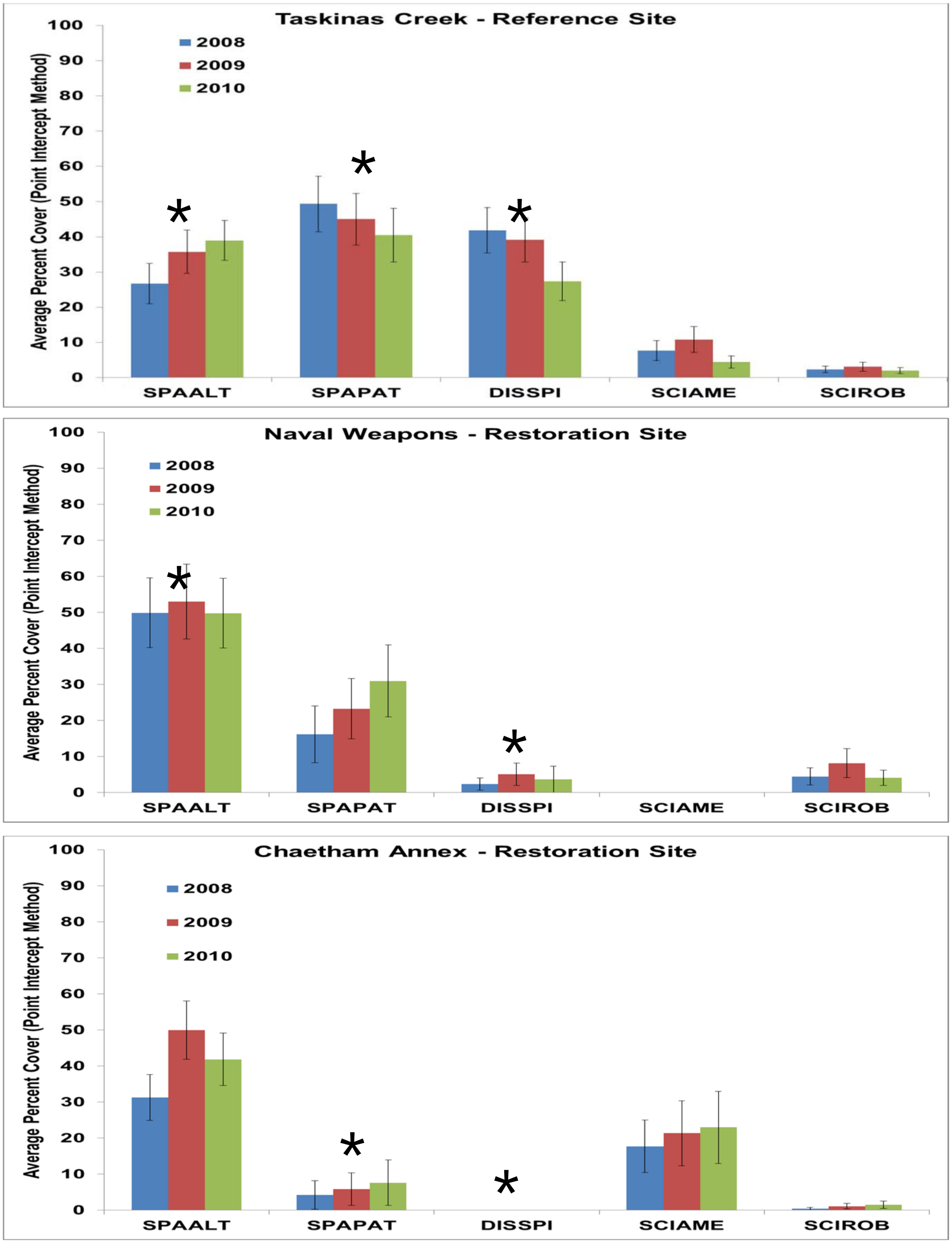


Figure 23. Mean percent cover (+/- SE) for the five dominant species for all three years at the paired Taskinas (reference) and Cheatham Annex and Naval Weapons Station (restoration) study sites. Asterisks denote significant differences for a particular species between a paired restoration and reference site.

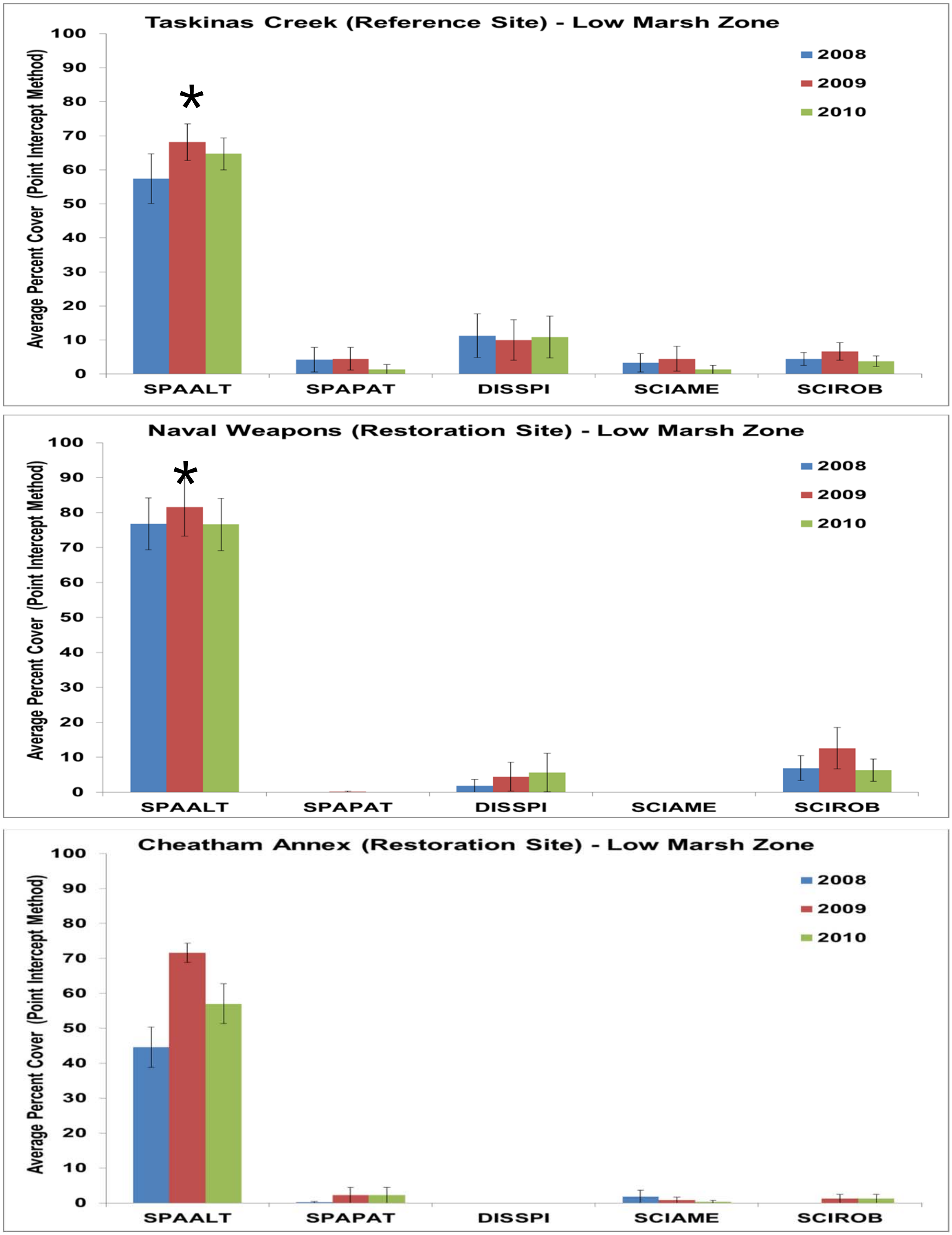


Figure 24. Mean percent cover (+/- SE) for the five dominant species for all three years within the low marsh zone at the paired Taskinas (reference) and Cheatham Annex and Naval Weapons Station (restoration) study sites. Asterisks denote significant differences for a particular species between a paired restoration and reference site.

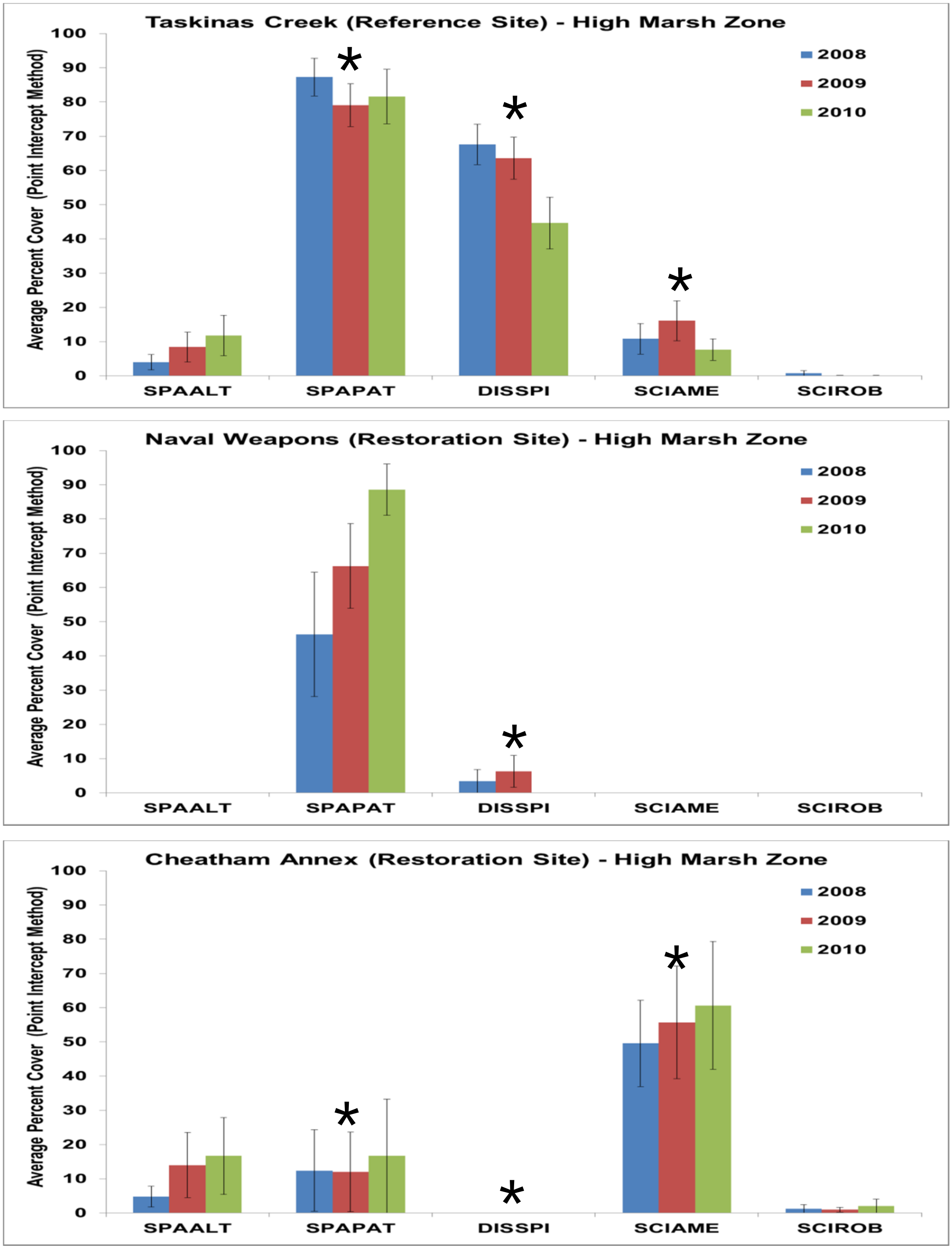


Figure 25. Mean percent cover (+/- SE) for the five dominant species for all three years within the high marsh zone at the paired Taskinas (reference) and Cheatham Annex and Naval Weapons Station (restoration) study sites. Asterisks denote significant differences for a particular species between a paired restoration and reference site.

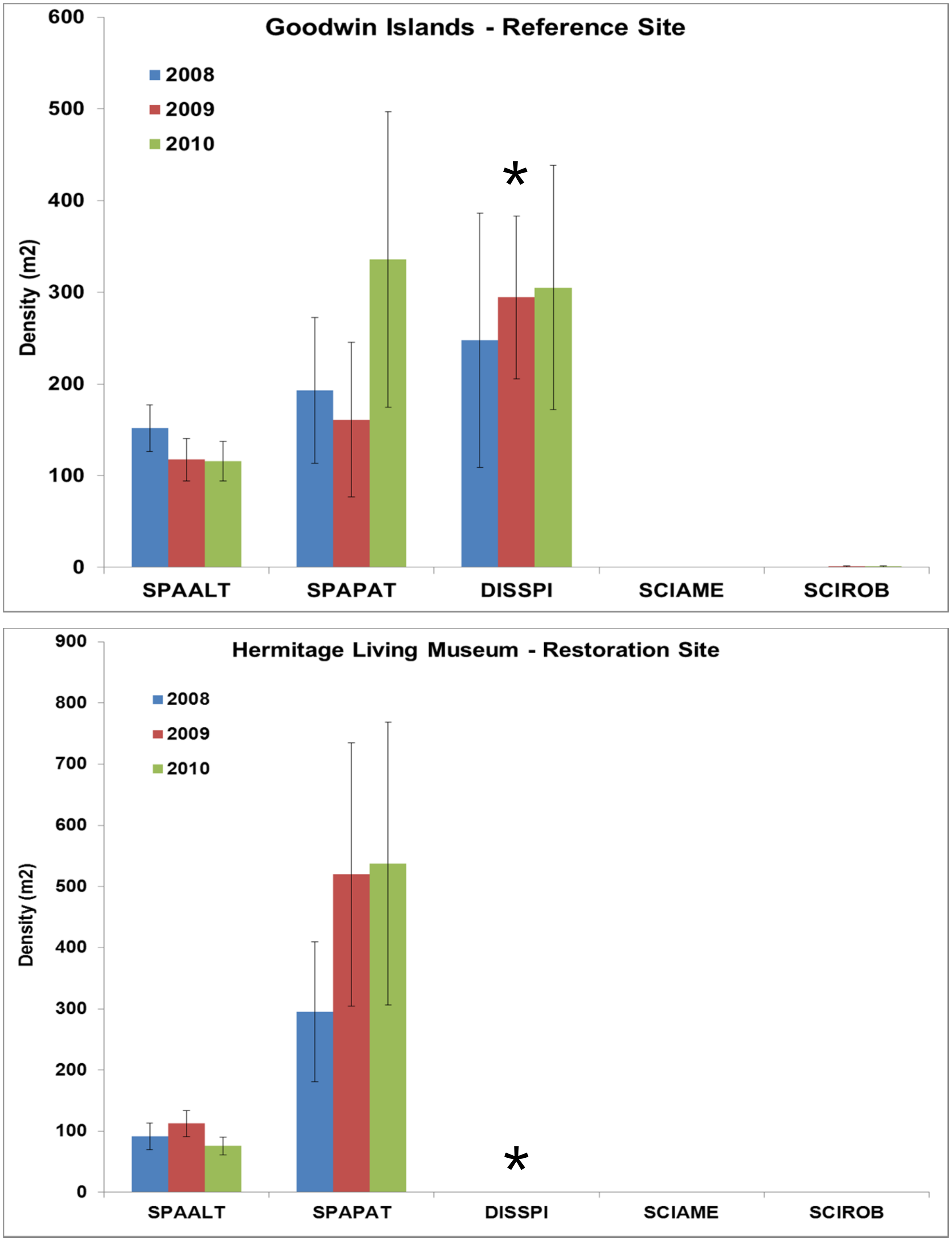


Figure 26. Mean stem density (+/- SE) for the five dominant species for all three years at the paired Goodwin Islands (reference) and Hermitage Living Museum (restoration) study sites. Asterisks denote significant differences for a particular species between a paired restoration and reference site.

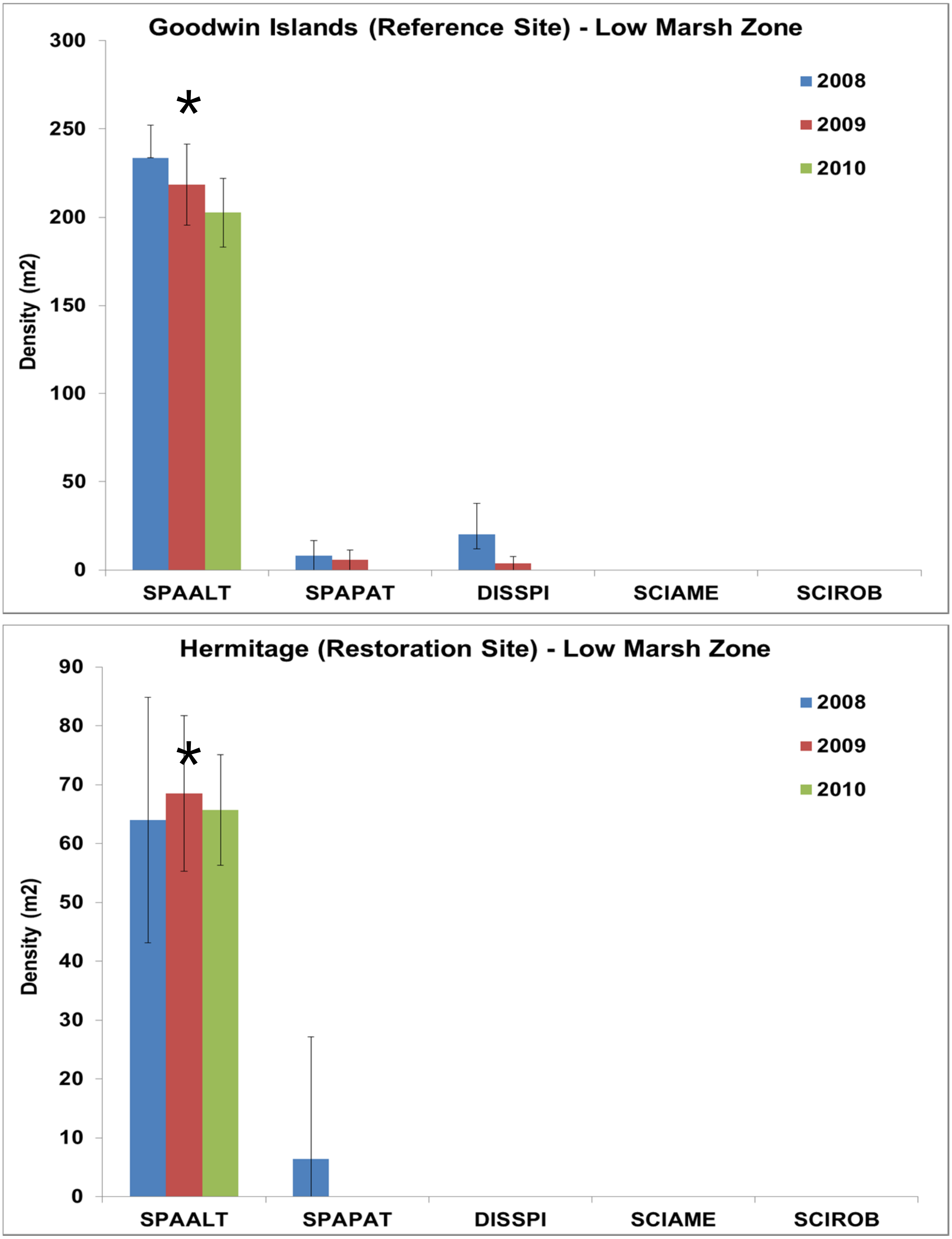


Figure 27. Mean stem density (+/- SE) for the five dominant species for all three years within the low marsh zone at the paired Goodwin Islands (reference) and Hermitage Living Museum (restoration) study sites. Asterisks denote significant differences for a particular species between a paired restoration and reference site.

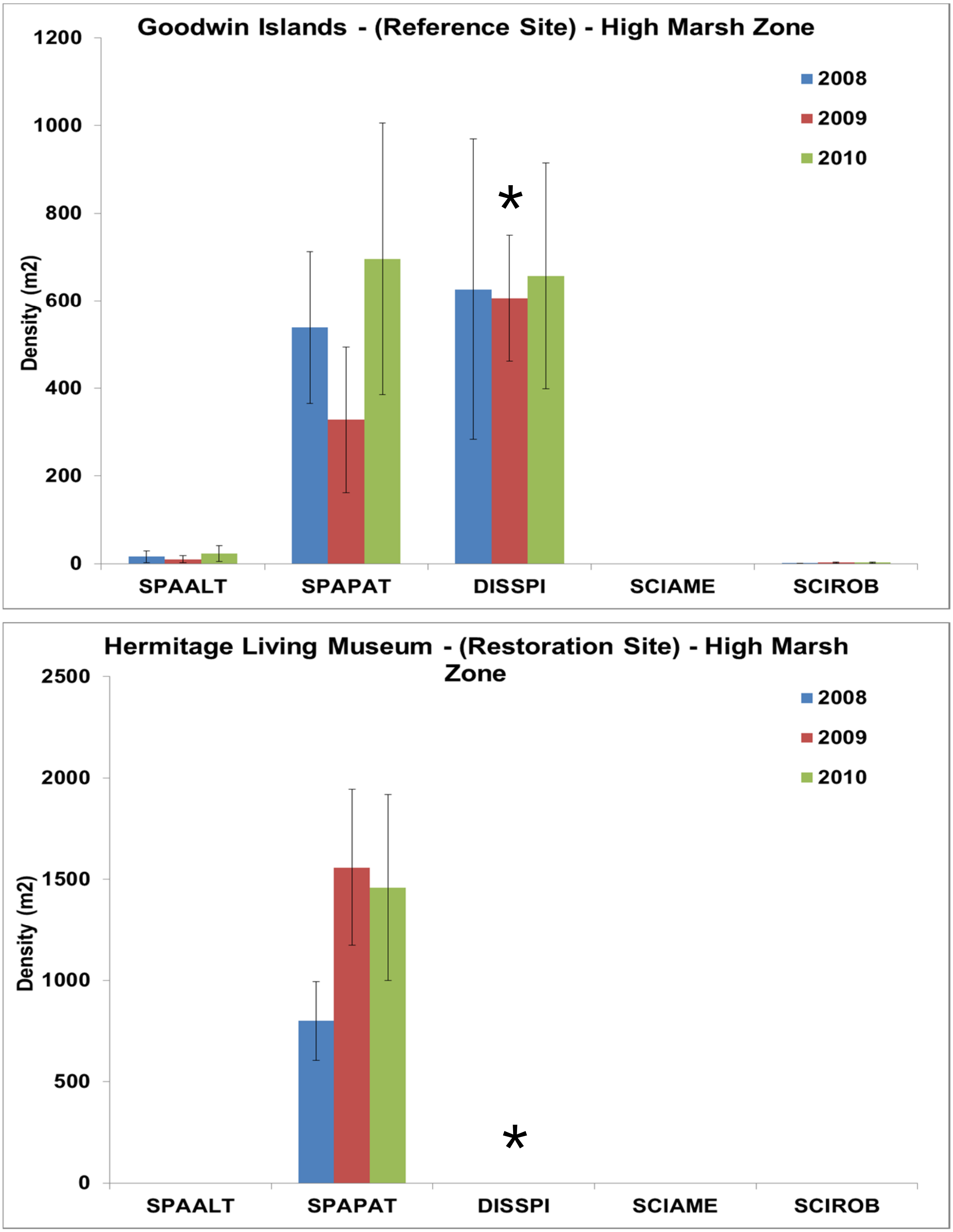


Figure 28. Mean stem density (+/- SE) for the five dominant species for all three years within the high marsh zone at the paired Goodwin Islands (reference) and Hermitage Living Museum (restoration) study sites. Asterisks denote significant differences for a particular species between a paired restoration and reference site.

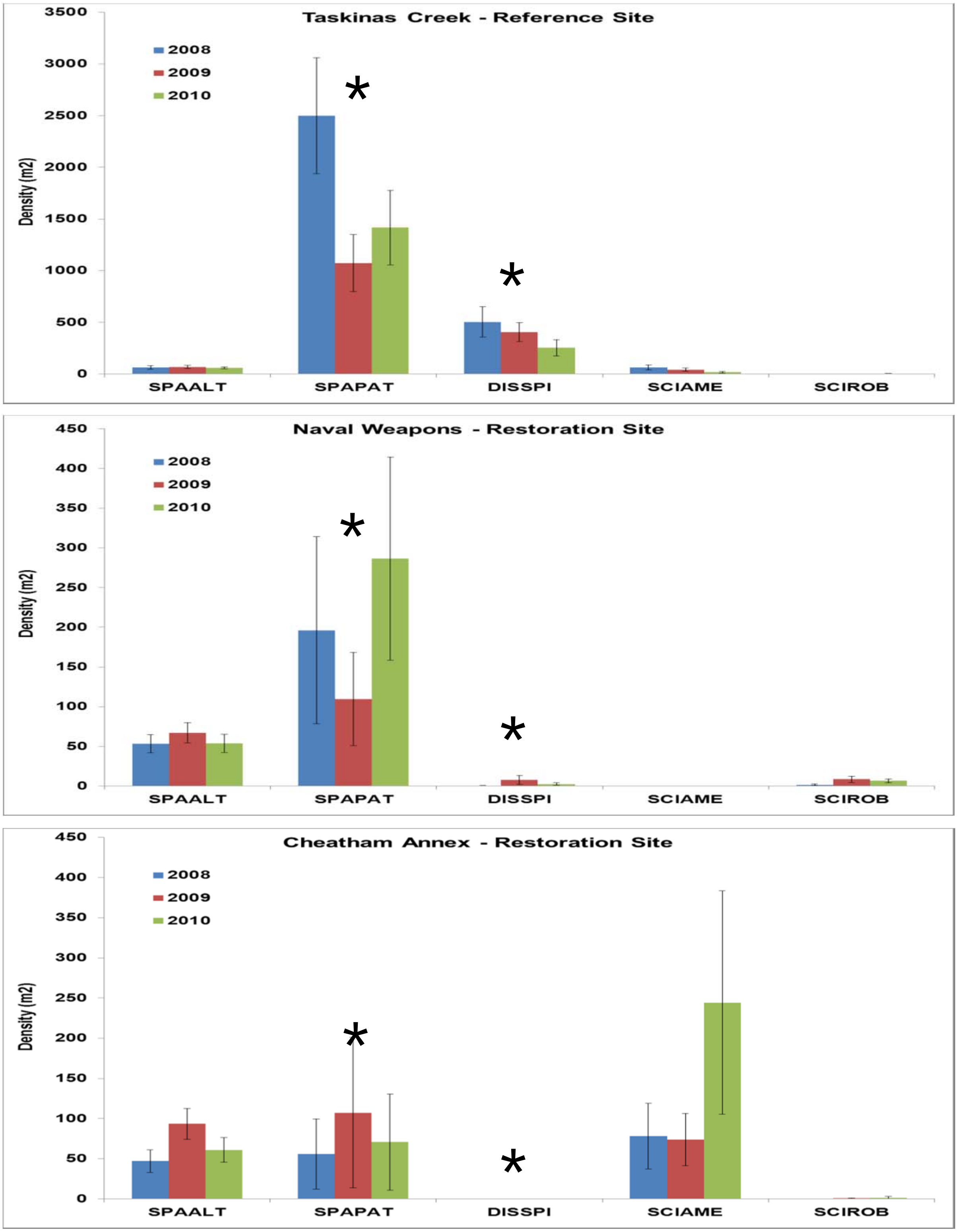


Figure 29. Mean stem density (+/- SE) for the five dominant species for all three years at the paired Taskinas (reference) and Cheatham Annex and Naval Weapons Station (restoration) study sites. Asterisks denote significant differences for a particular species between a paired restoration and reference site.

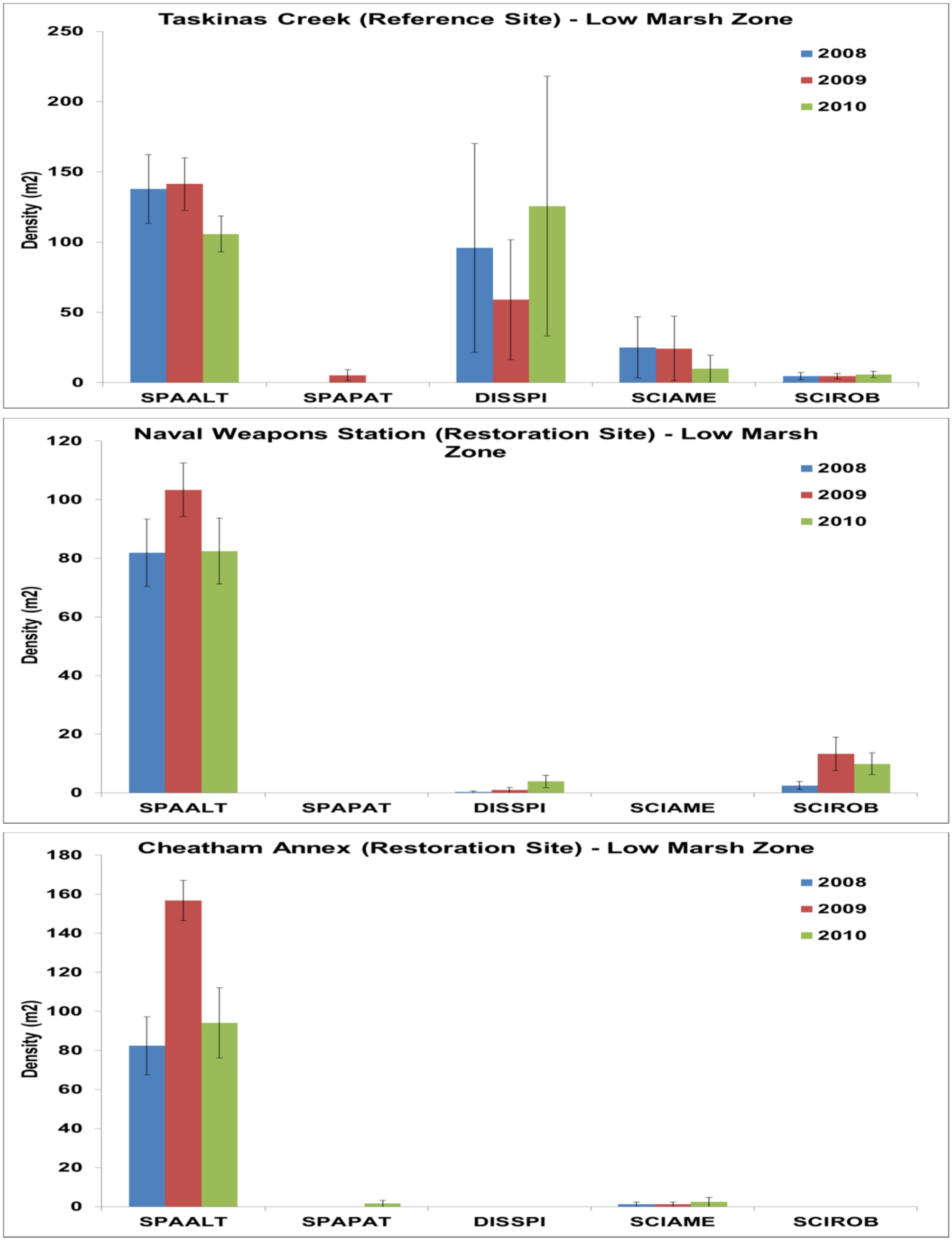


Figure 30. Mean stem density (+/- SE) for the five dominant species for all three years within the low marsh zone at the paired Taskinas (reference) and Cheatham Annex and Naval Weapons Station (restoration) study sites. Asterisks denote significant differences for a particular species between a paired restoration and reference site.

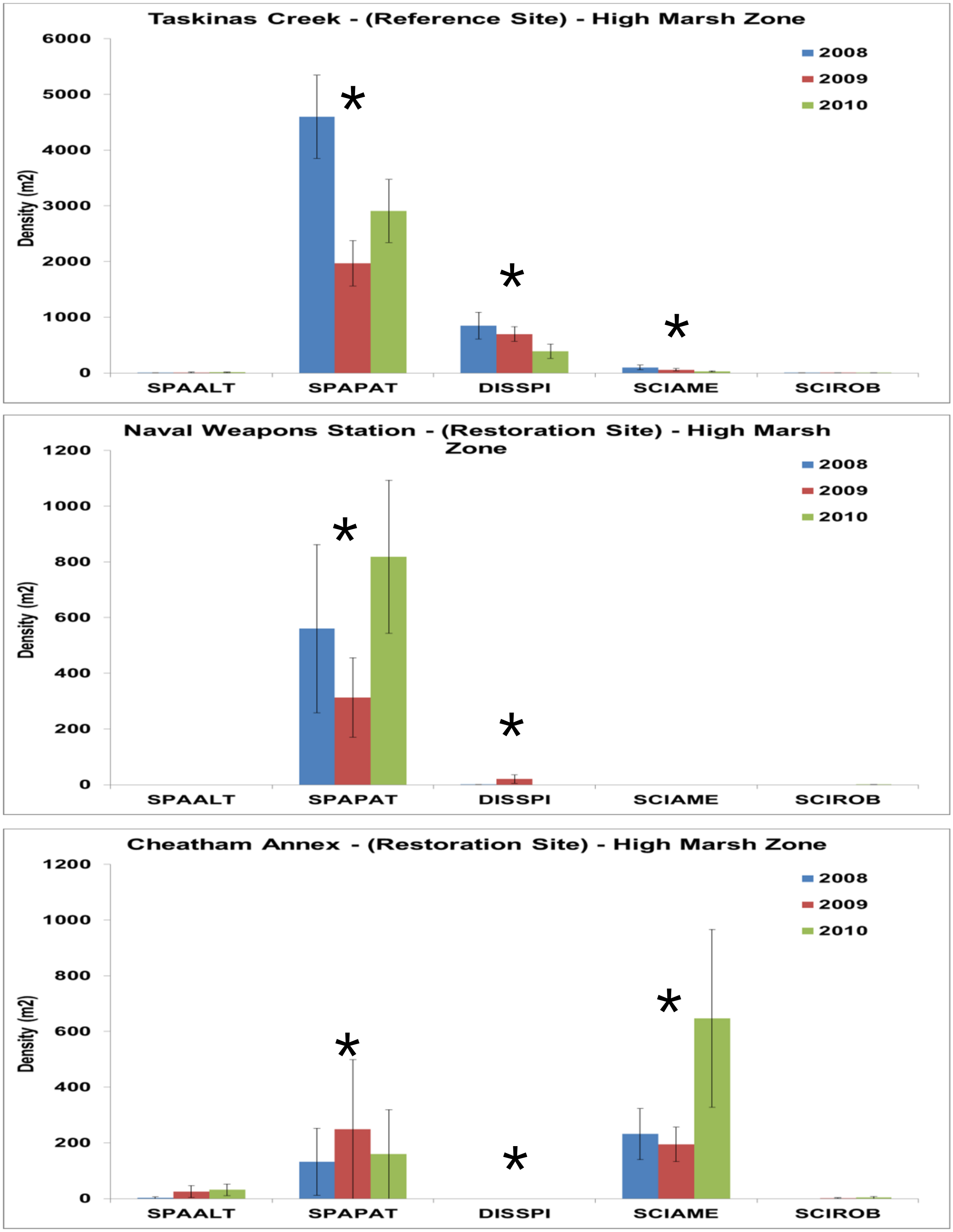


Figure 31. Mean stem density (+/- SE) for the five dominant species for all three years within the high marsh zone at the paired Taskinas (reference) and Cheatham Annex and Naval Weapons Station (restoration) study sites. Asterisks denote significant differences for a particular species between a paired restoration and reference site.

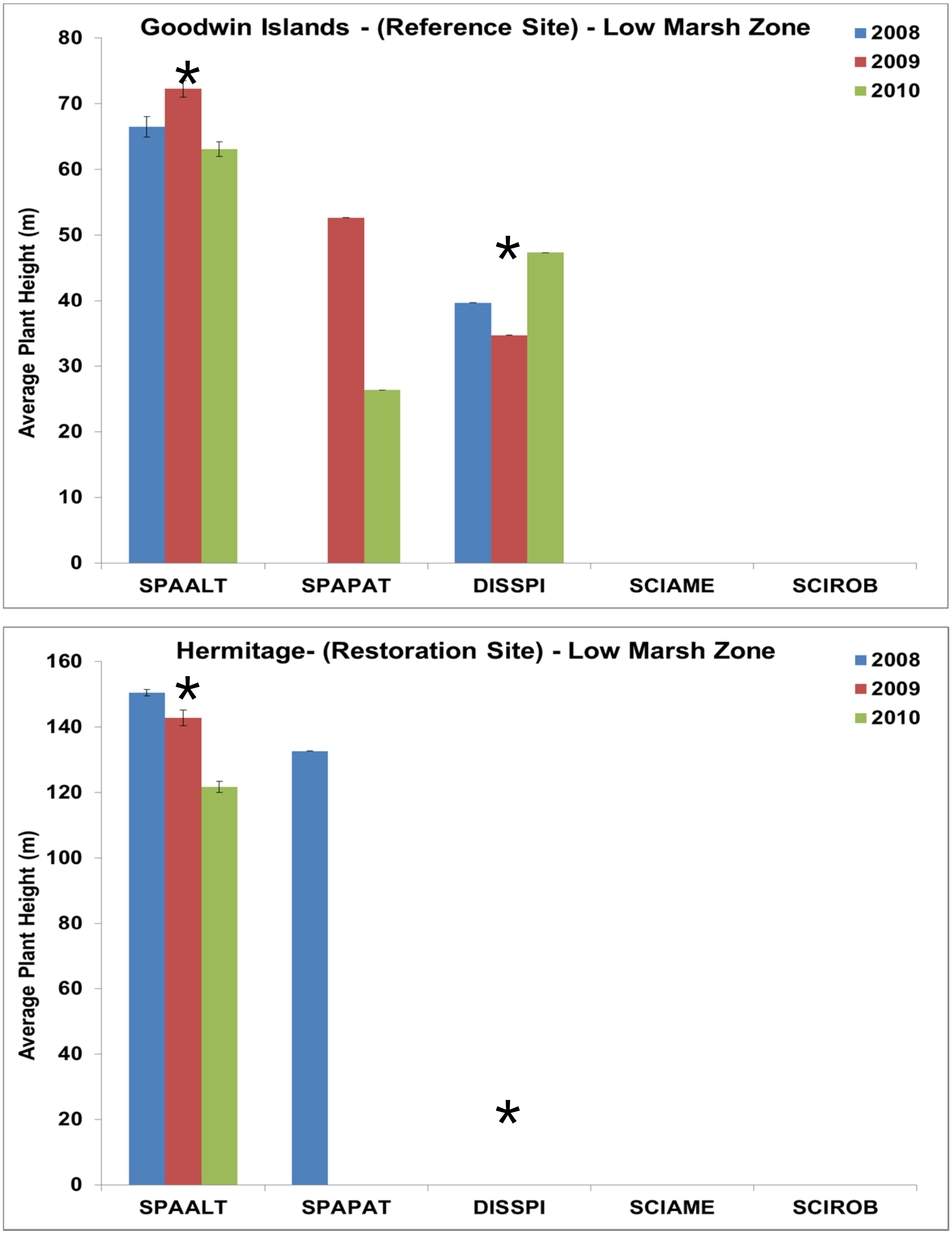
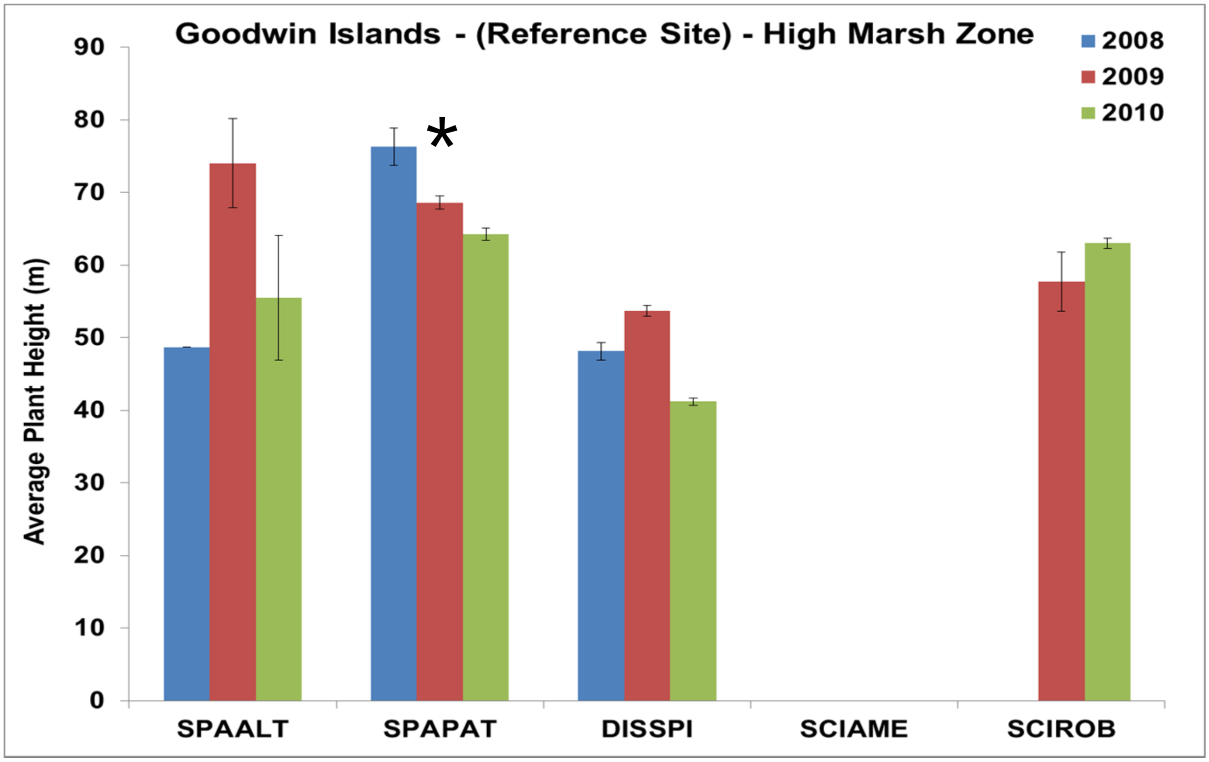


Figure 32. Mean plant height (+/- SE) for the five dominant species for all three years within the low marsh zone only of the paired Goodwin Islands (reference) and Hermitage Living Museum (restoration) study sites. Asterisks denote significant differences for a particular species between a paired restoration and reference site.



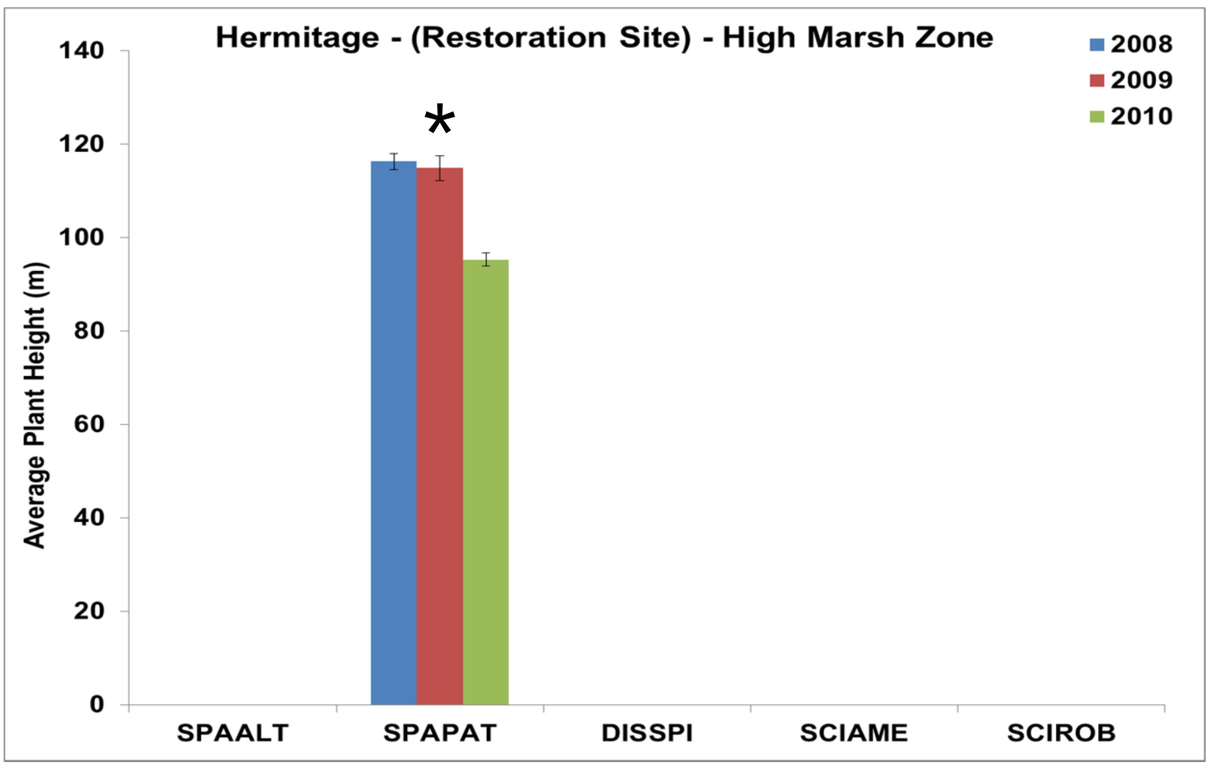


Figure 33. Mean plant height (+/- SE) for the five dominant species for all three years within the high marsh zone only of the paired Goodwin Islands (reference) and Hermitage Living Museum (restoration) study sites. Asterisks denote significant differences for a particular species between a paired restoration and reference site.

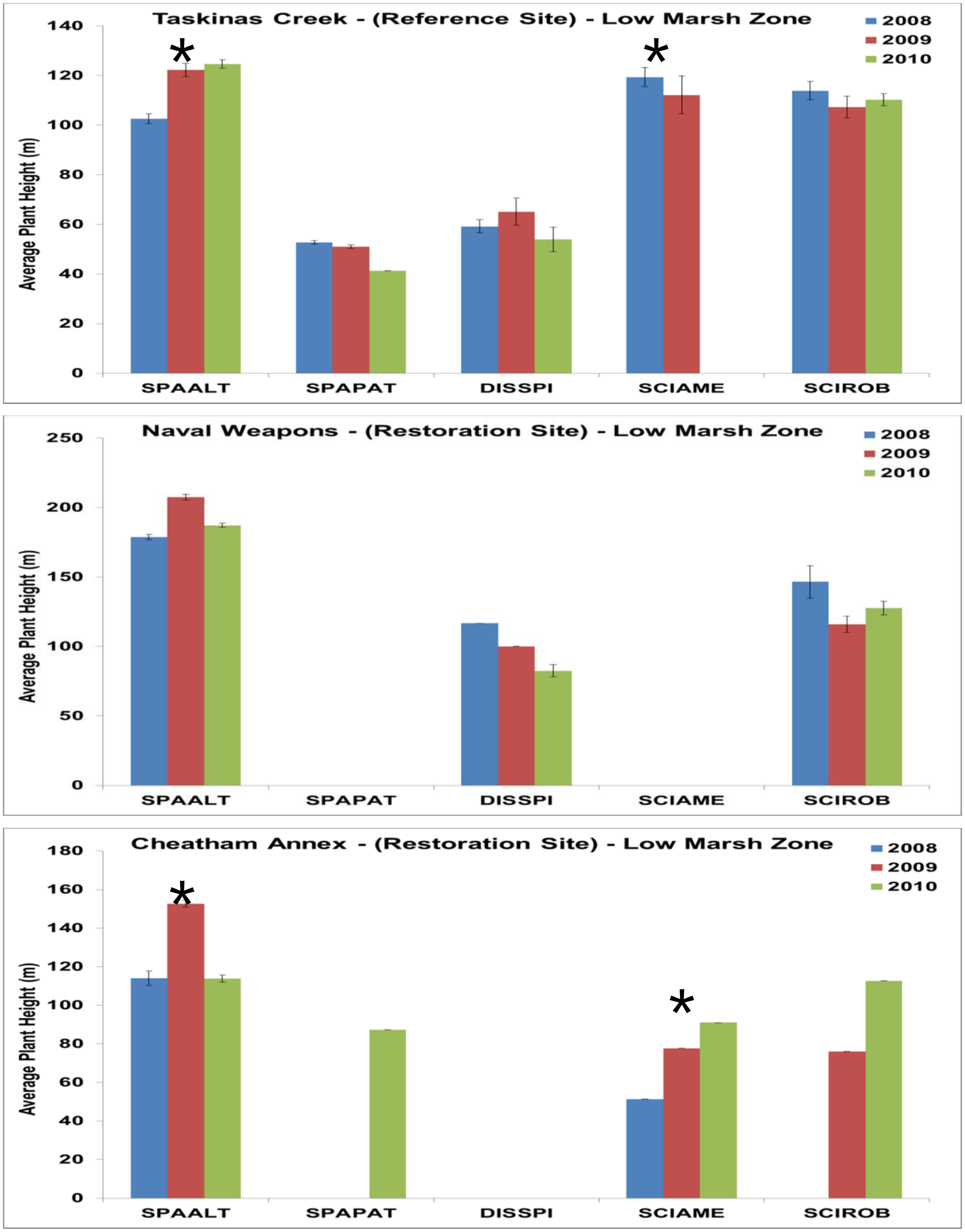


Figure 34. Mean plant height (+/- SE) for the five dominant species for all three years in the low marsh zone only for the paired Taskinas (reference) and Cheatham Annex and Naval Weapons Station (restoration) study sites. Asterisks denote significant differences for a particular species between a paired restoration and reference site.

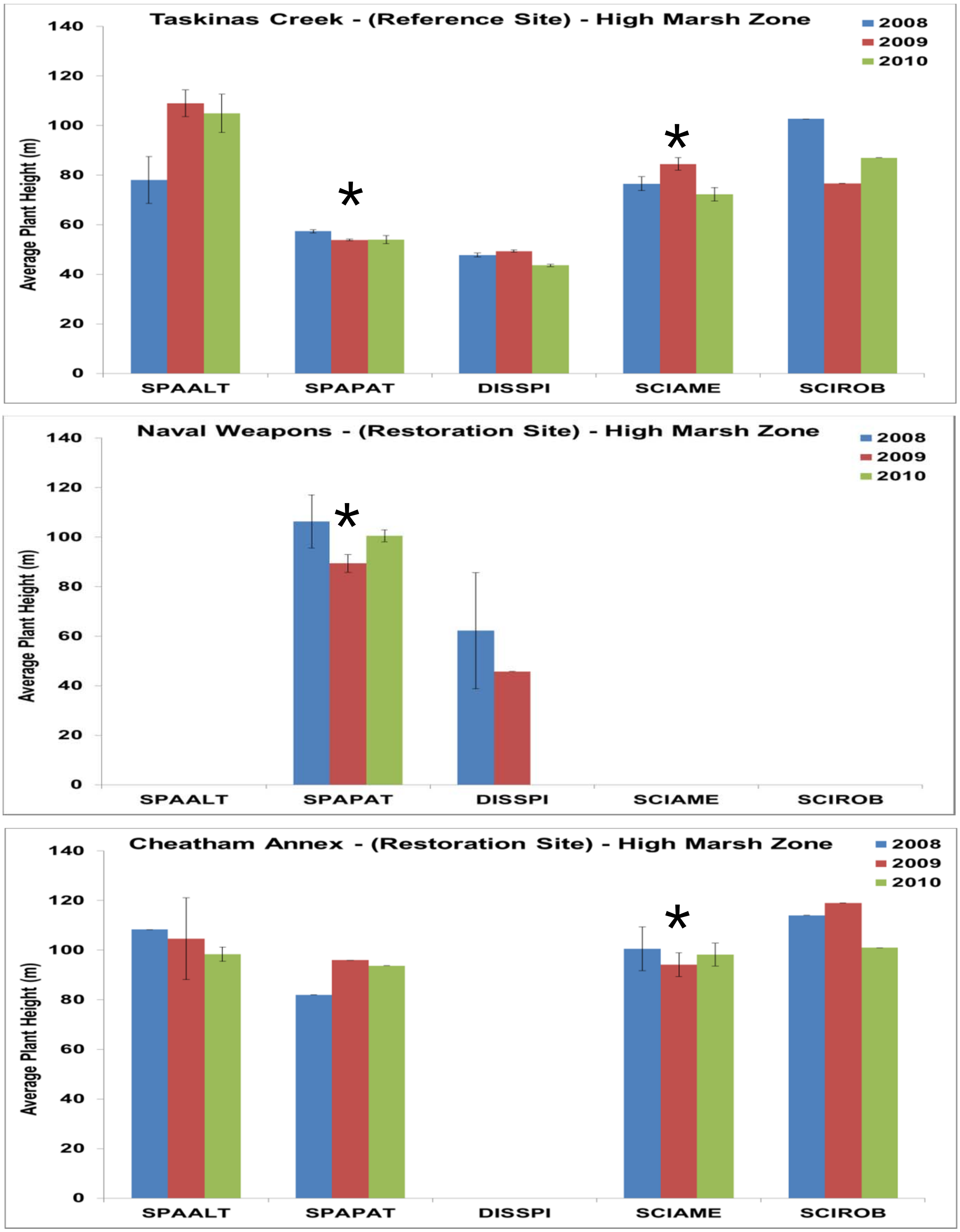


Figure 35 . Mean plant height (+/- SE) for the five dominant species for all three years in the high marsh zone only for the paired Taskinas (reference) and Cheatham Annex and Naval Weapons Station (restoration) study sites. Asterisks denote significant differences for a particular species between a paired restoration and reference site.

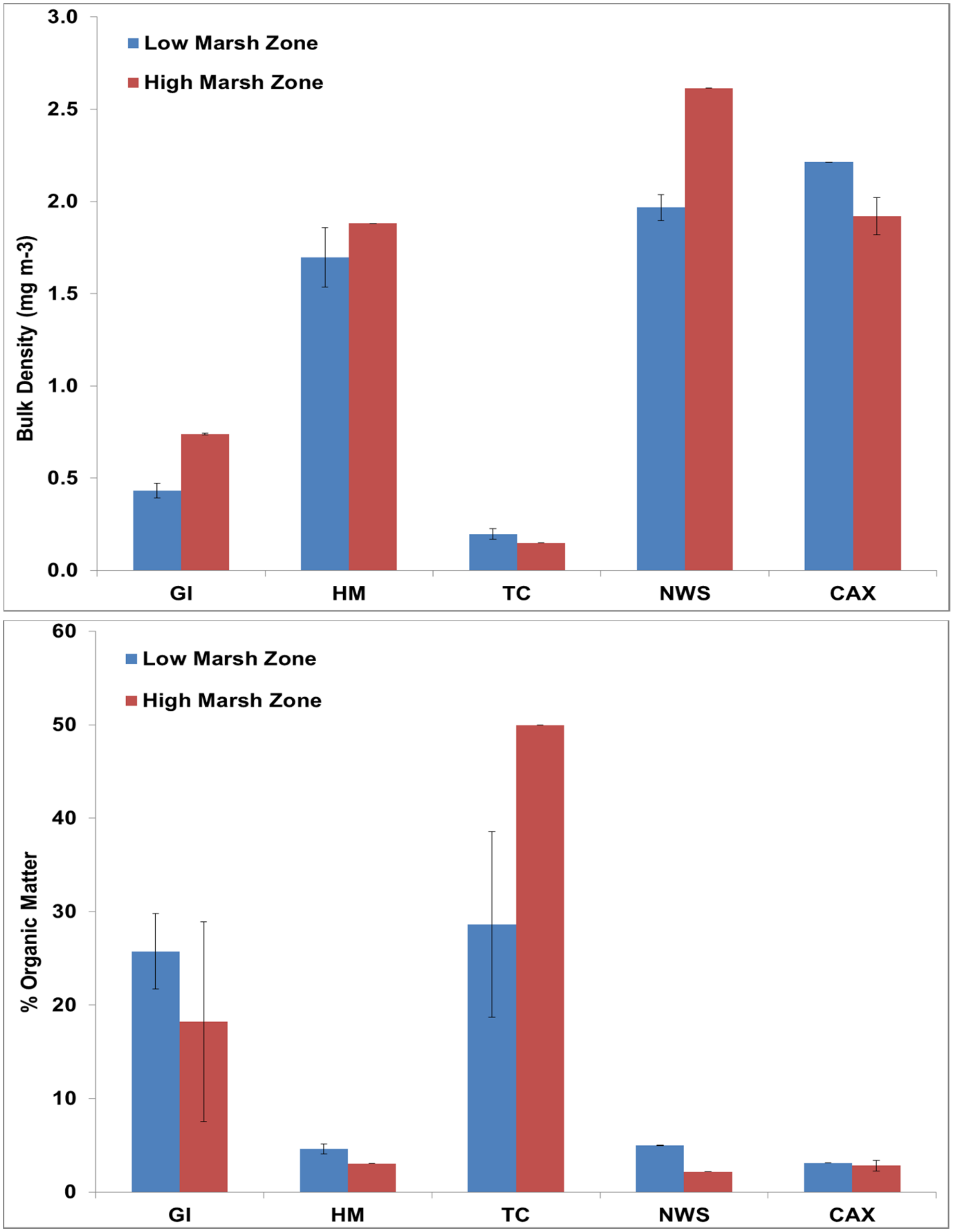
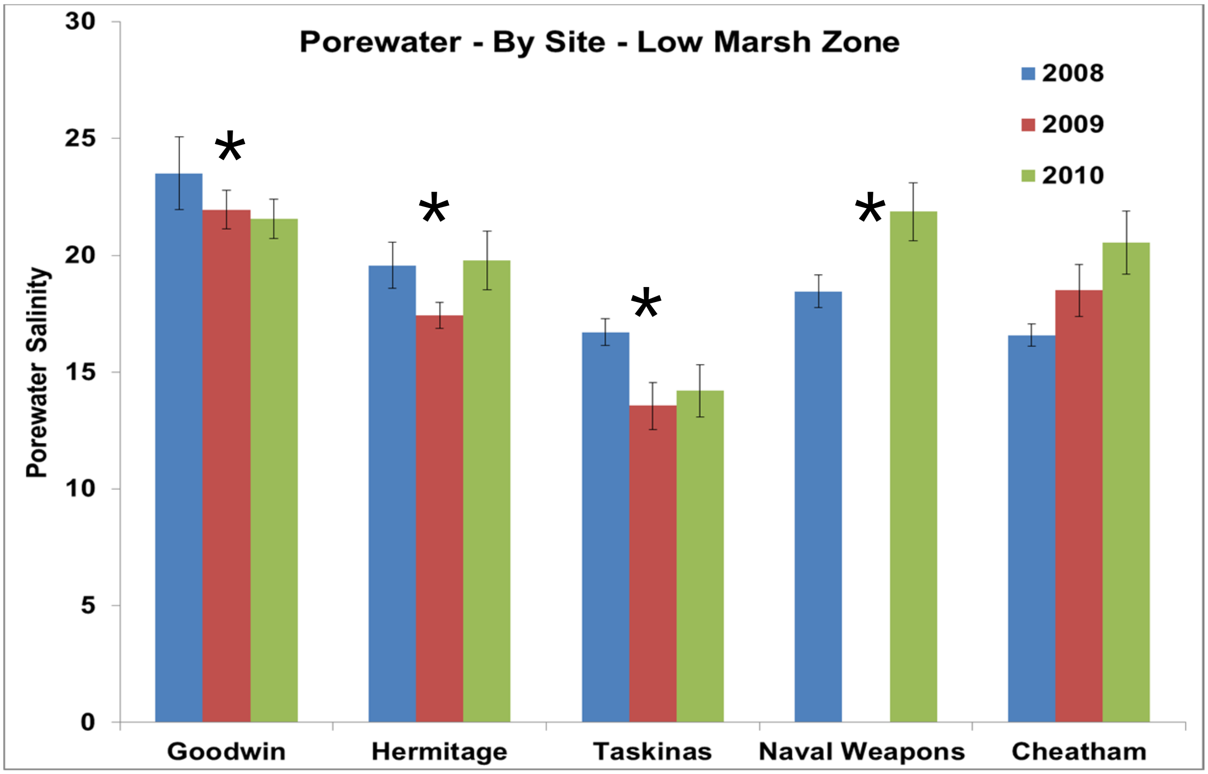


Figure 36. Mean sediment bulk density (top graph) and sediment organic matter (bottom graph) (+/- SE) grouped by marsh zone across study sites for all three project years. Asterisks denote significant differences between a paired restoration and reference site. Goodwin (reference) is paired with Hermitage (restoration) and Taskinas (reference) is paired with Naval Weapons and Cheatham (restoration).



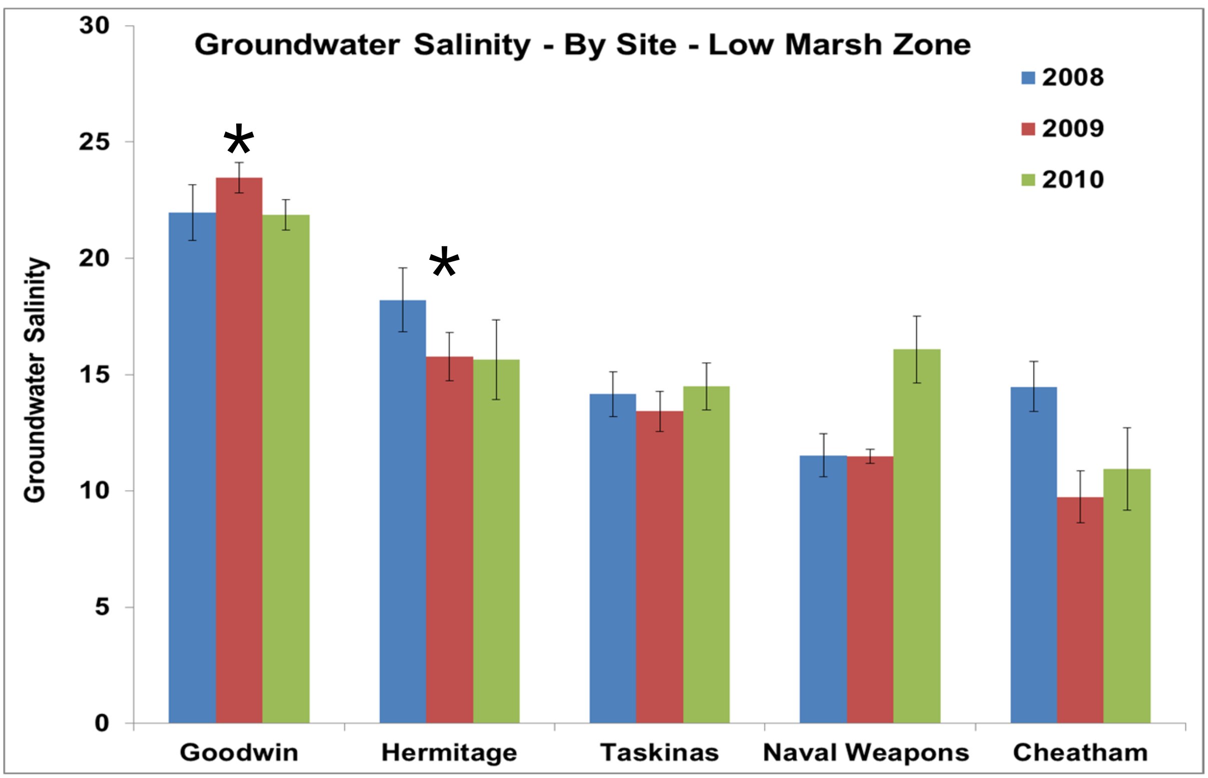


Figure 37. Mean porewater (top graph) and groundwater (bottom graph) (+/- SE) across study sites for all three years for all data within the low marsh zone only. Asterisks denote significant differences between a paired restoration and reference site. Goodwin (reference) is paired with Hermitage (restoration) and Taskinas (reference) is paired with Naval Weapons and Cheatham (restoration).

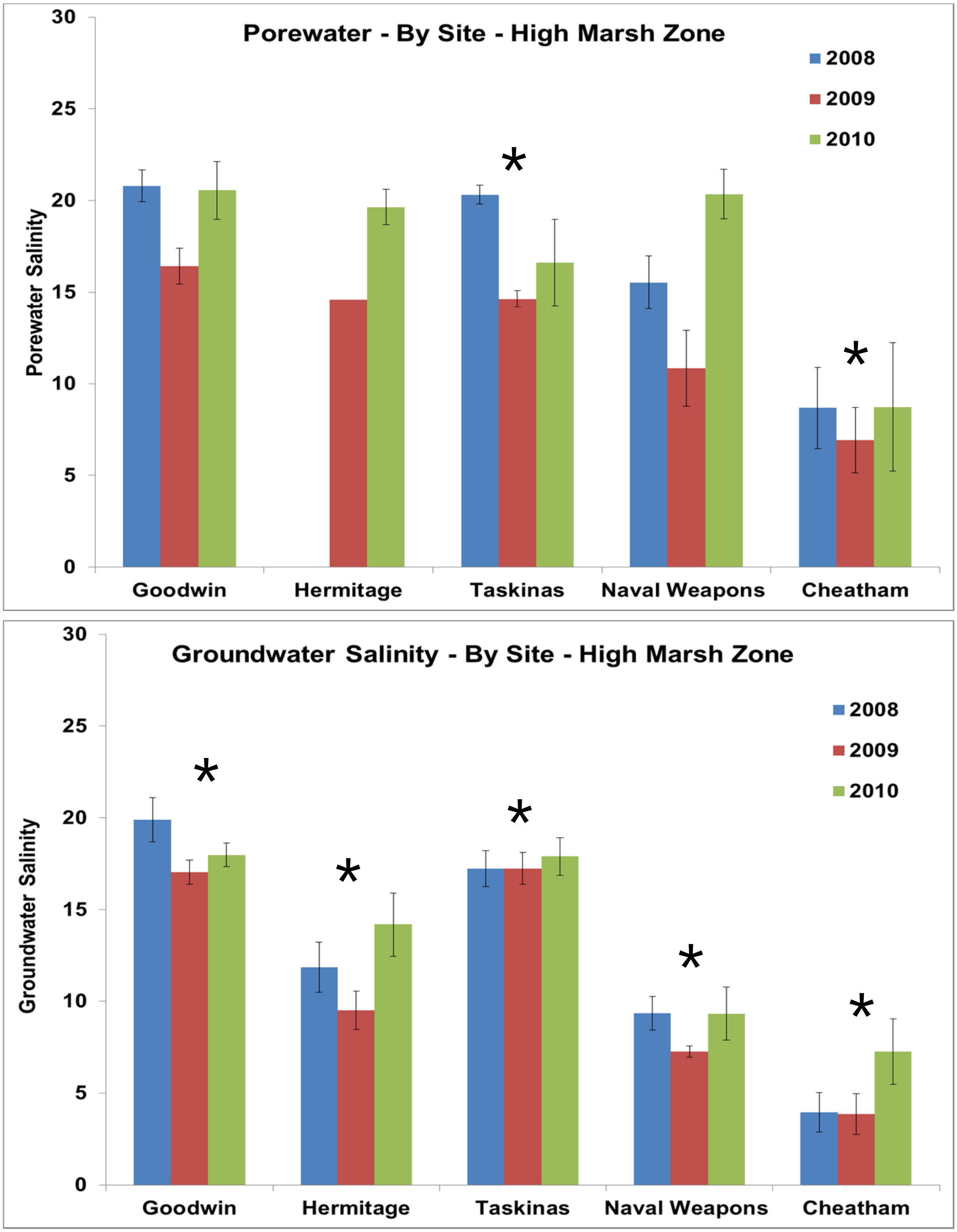


Figure 38. Mean porewater (top graph) and groundwater (bottom graph) (+/- SE) across study sites for all three years for all data within the high marsh zone only. Asterisks denote significant differences between a paired restoration and reference site. Goodwin (reference) is paired with Hermitage (restoration) and Taskinas (reference) is paired with Naval Weapons and Cheatham (restoration).

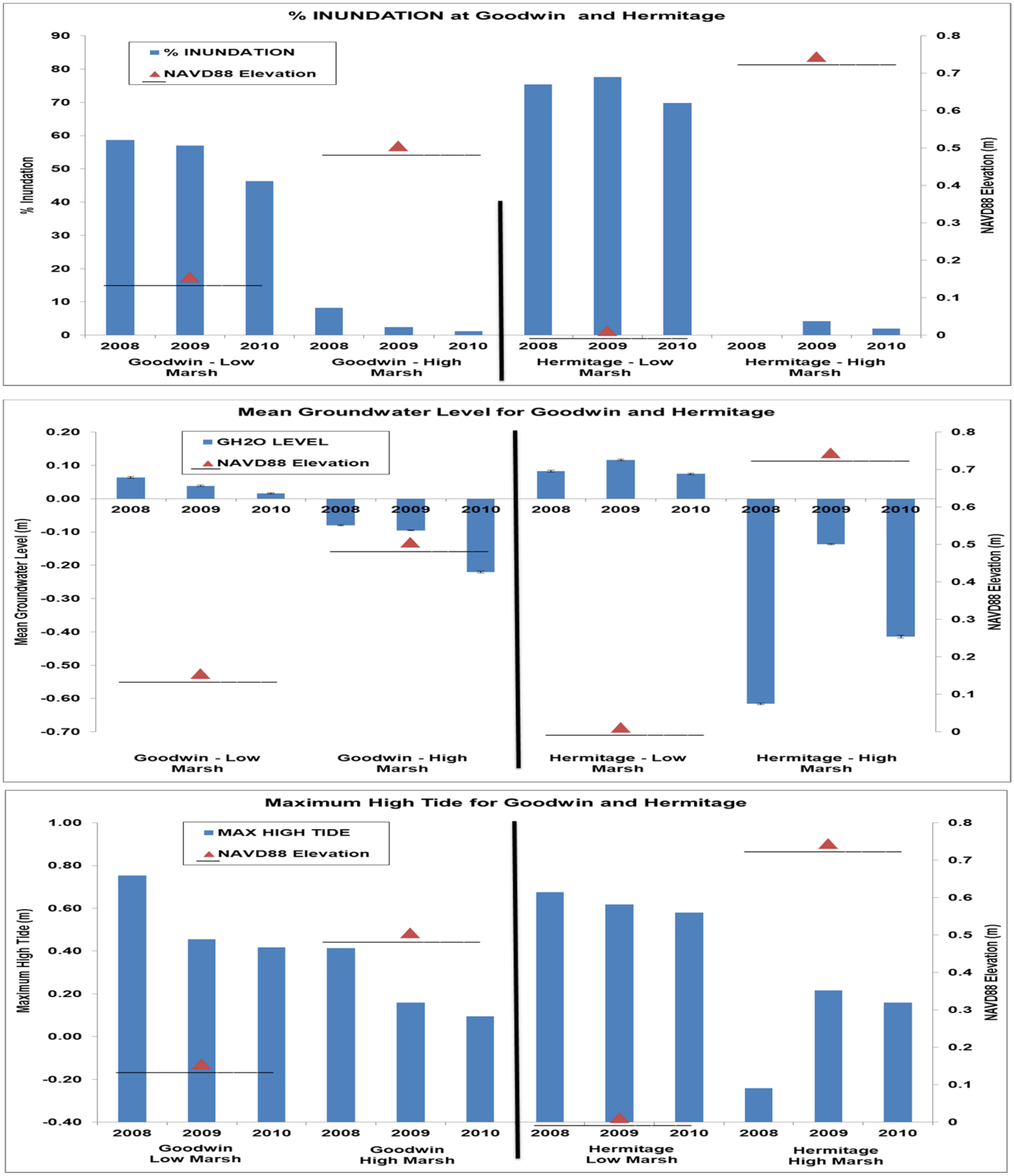


Figure 39. Data collected from continuous monitoring instrument deployments in groundwater wells for three years at Goodwin Islands (reference site) and Hermitage Living Museum (restoration site). Data are also further grouped by marsh zone. The top graph displays percent inundation, the second graph displays mean groundwater level (relative to the ground surface which is zero), and the third graph displays the maximum high tide level during the deployment. In each graph, the elevation (relative toNAVD88) of the surface of the ground at each well location has also been displayed.

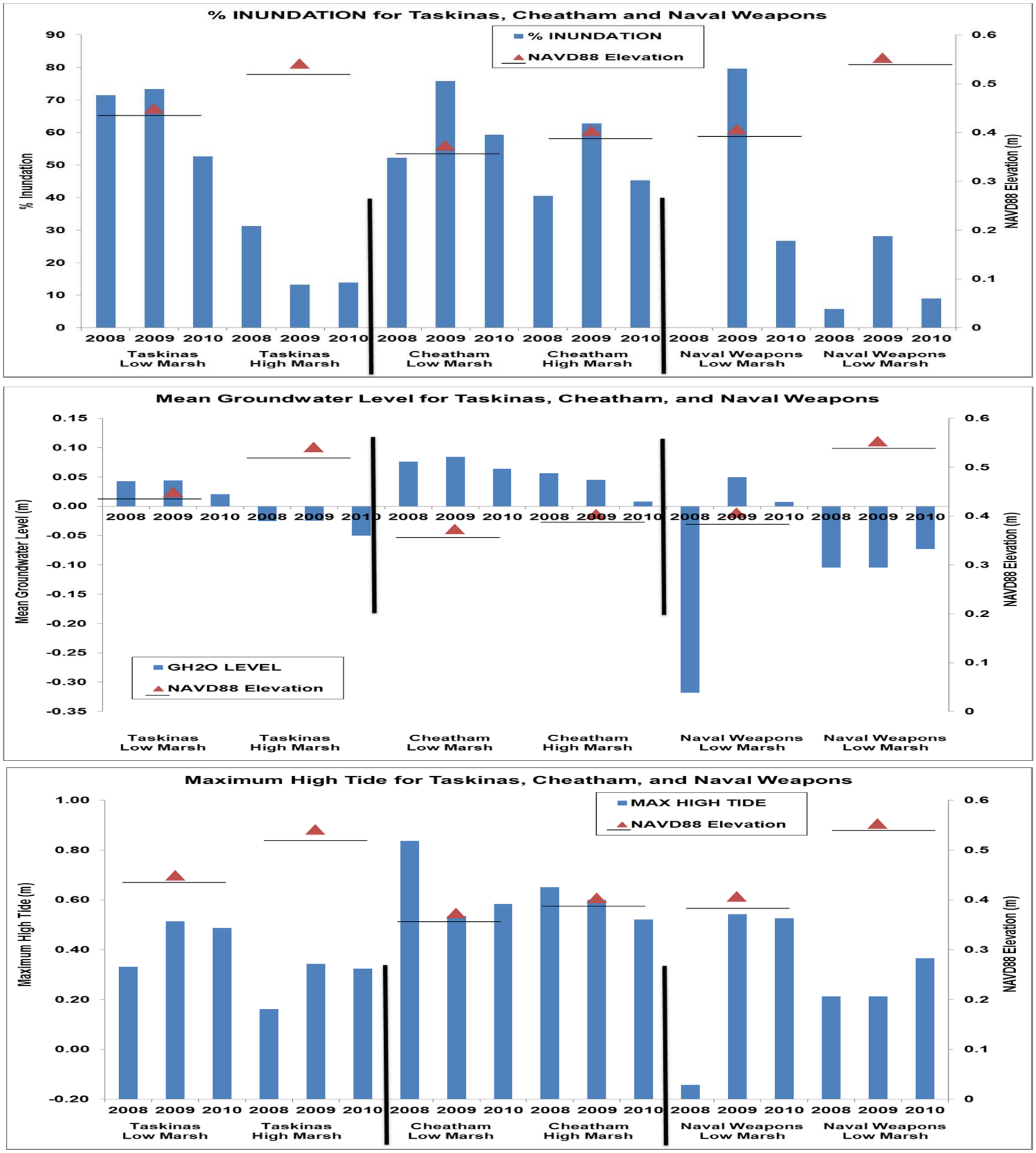
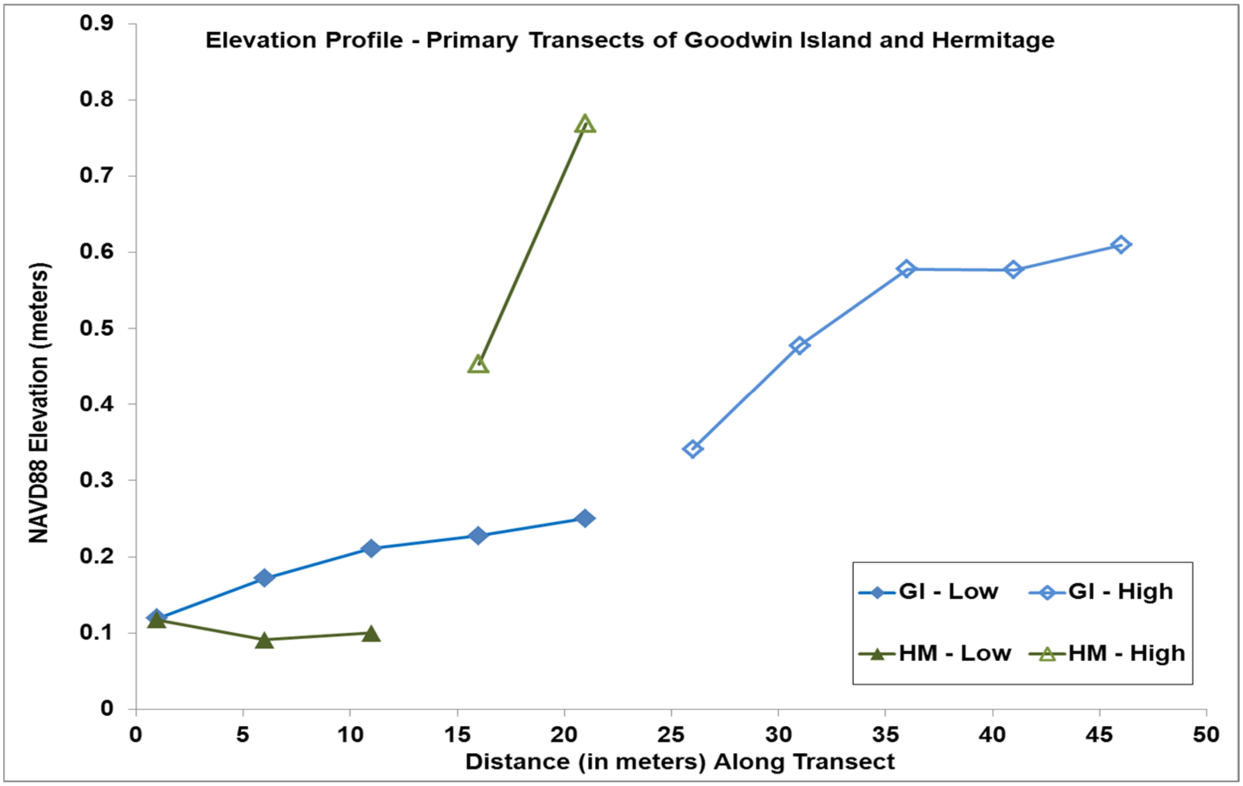


Figure 40. Data collected from continuous monitoring instrument deployments in groundwater wells for three years at Taskinas Creek (reference site) and Cheatham Annex and Naval Weapons Station (restoration sites). Data are also further grouped by marsh zone. The top graph displays percent inundation, the second graph displays mean groundwater level (relative to the ground surface which is zero), and the third graph displays the maximum high tide level during the deployment. In each graph, the elevation (relative toNAVD88) of the surface of the ground at each well location has also been displayed.



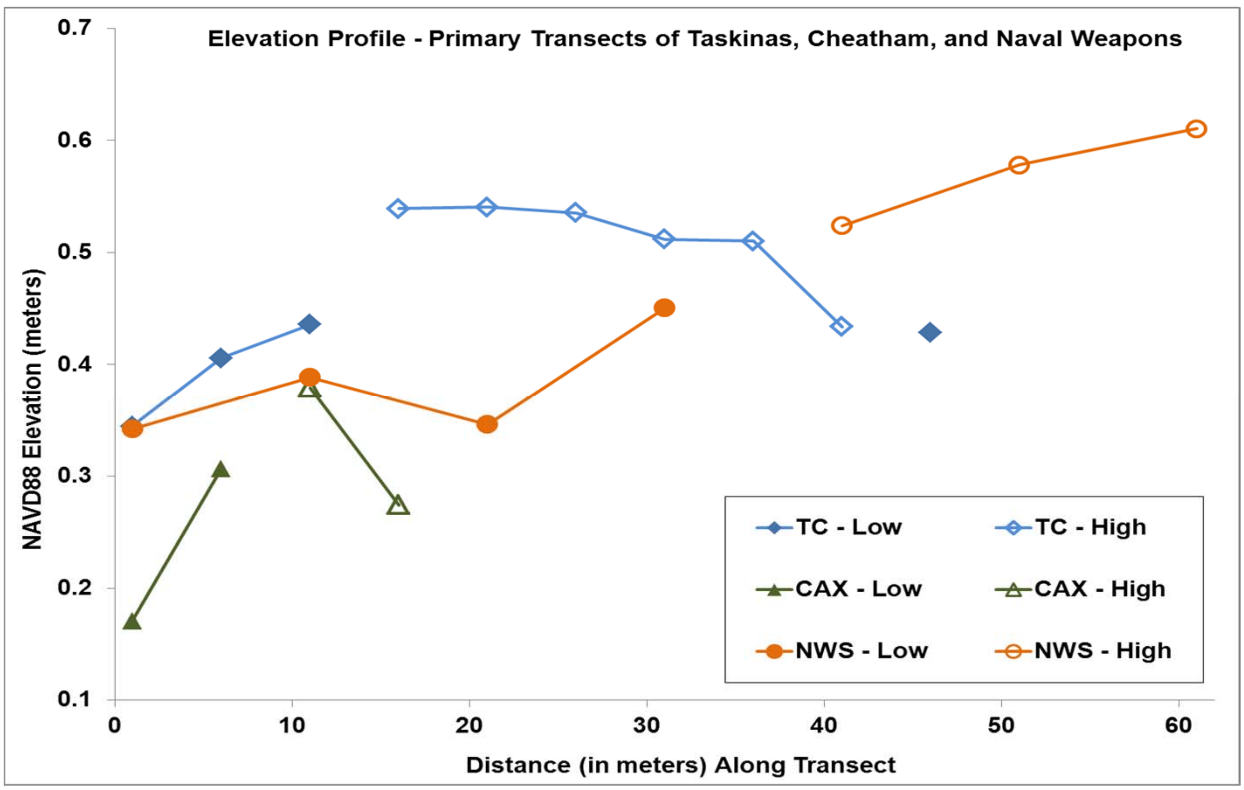


Figure 41. Elevations at each vegetation plot along the primary sampling transect of each study site. The data are also further categorized by marsh zone. The top graph displays data from Goodwin Islands (reference site) and Hermitage Living Museum (paired restoration site). The bottom graph displays data from Taskinas Creek (reference site) and two paired restoration sites (Cheatham Annex and Naval Weapons Station).

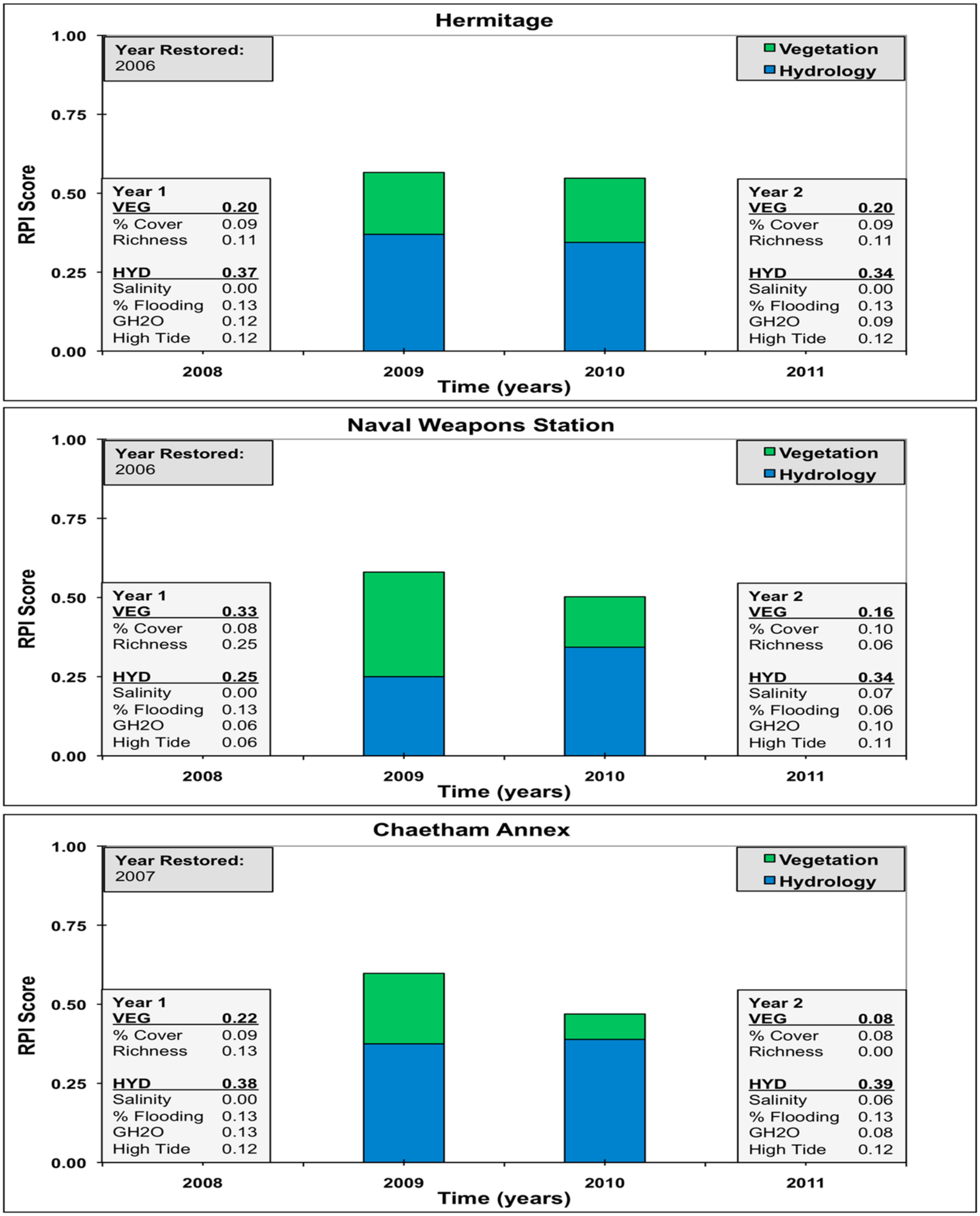


Figure 42. Restoration Performance Index for the three restoration sites sampled in this study. Due to lack of pre-restoration monitoring, the first sampling year of this study was used as the “pre-restoration” dataset.

Table 1: Mean percent cover (using point intercept method) of emergent vegetation collected during this study. Data are grouped into various categories which includes an overall category (across all sites and years), grouped by year (across all sites), grouped by restoration or reference category (across years), and grouped by marsh zone (across sites and years). See Appendix A for a comple list of scientic names and common names for species codes.

	Overall		2008		2009		2010		Reference		Restored		Low Marsh		High Marsh	
Species	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
SPAALT	40.19	1.90	38.29	3.40	41.36	3.35	40.76	3.16	35.77	2.46	45.39	2.92	65.90	1.55	6.32	1.37
SPAPAT	29.64	2.21	30.00	4.05	29.34	3.66	29.59	3.83	36.41	3.10	21.64	3.03	1.86	0.64	66.85	3.15
DISSPI	18.06	1.70	17.69	3.04	20.86	3.09	15.71	2.73	32.26	2.71	1.39	0.63	3.89	1.08	36.96	3.10
SCIAME	5.08	0.91	4.75	1.42	6.10	1.76	4.39	1.53	4.24	0.96	6.06	1.64	0.87	0.39	10.62	1.97
SCIROB	1.91	0.36	1.61	0.55	2.56	0.83	1.56	0.47	1.51	0.35	2.39	0.68	3.04	0.62	0.44	0.14
ELEIND	0.90	0.45	1.32	0.99	0.81	0.81	0.62	0.54	0.00	0.00	1.98	0.99	0.00	0.00	2.11	1.05
SPACYN	0.78	0.33	0.90	0.64	0.41	0.39	1.02	0.66	1.43	0.61	0.00	0.00	1.36	0.58	0.00	0.00
TYPANG	0.73	0.31	1.12	0.68	0.95	0.63	0.18	0.13	0.00	0.00	1.60	0.66	1.13	0.53	0.20	0.12
ASTTEN	0.63	0.20	0.79	0.39	0.68	0.37	0.44	0.32	0.37	0.24	0.94	0.35	0.31	0.16	1.06	0.42
PANVIR	0.55	0.30	0.59	0.48	0.68	0.68	0.37	0.37	0.00	0.00	1.19	0.66	0.00	0.00	1.27	0.70
ATRPAT	0.44	0.21	0.36	0.36	0.14	0.11	0.80	0.50	0.00	0.00	0.96	0.46	0.08	0.06	0.91	0.48
BACHAL	0.23	0.12	0.11	0.08	0.59	0.34	0.00	0.00	0.17	0.13	0.31	0.20	0.00	0.00	0.55	0.27
SORHAL	0.22	0.15	0.29	0.27	0.37	0.36	0.02	0.02	0.00	0.00	0.48	0.32	0.00	0.00	0.52	0.34
IVAFRU	0.22	0.13	0.02	0.02	0.34	0.32	0.28	0.20	0.00	0.00	0.47	0.28	0.02	0.01	0.48	0.30
PLUCAM	0.20	0.10	0.02	0.02	0.51	0.30	0.08	0.04	0.00	0.00	0.45	0.22	0.03	0.02	0.44	0.24
ELYVIR	0.11	0.11	0.00	0.00	0.00	0.00	0.31	0.31	0.00	0.00	0.24	0.24	0.00	0.00	0.25	0.25
MYRCER	0.10	0.06	0.07	0.05	0.08	0.08	0.13	0.13	0.02	0.02	0.19	0.12	0.02	0.02	0.20	0.13
CYPSP	0.02	0.01	0.02	0.02	0.03	0.02	0.00	0.00	0.00	0.00	0.04	0.02	0.00	0.00	0.04	0.02
LEEVIR	0.02	0.02	0.00	0.00	0.05	0.05	0.00	0.00	0.00	0.00	0.04	0.04	0.00	0.00	0.04	0.04
ASTSUB	0.01	0.01	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00
LONSP	0.01	0.01	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01
SALSP	0.01	0.01	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00
MURKEI	P	P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PHRAUS	P	P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SPAAME	P	P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2: Mean percent cover (using point intercept method) of emergent vegetation collected during this study. Data are categorized by restoration or reference site and data are grouped across years. Goodwin Islands is the reference site for the Hermitage Living Museum. Taskinas Creek is the reference site for the Cheatham Annex and Naval Weaspons Station restoration projects. See Appendix A for a comple list of scientic names and common names for species codes.

	Reference Site Goodwin		Restoration Site Hermitage	
Species	Mean	SE	Mean	SE
SPAALT	37.95	3.57	42.85	4.77
DISSPI	27.50	4.23	0.00	0.00
SPAPAT	25.19	3.99	33.22	6.19
BACHAL	0.39	0.31	0.94	0.61
SCIROB	0.29	0.12	0.00	0.00
ATRPAT	0.00	0.00	2.56	1.33
IVAFRU	0.00	0.00	1.41	0.82
ASTTEN	0.00	0.00	1.04	0.60
ELYVIR	0.00	0.00	0.70	0.70
LEEVIR	0.00	0.00	0.11	0.11
ASTSUB	0.00	0.00	0.04	0.04
LONSP	0.00	0.00	0.04	0.04
CYPSP	0.00	0.00	0.00	0.00
ELEIND	0.00	0.00	0.00	0.00
MYRCER	0.00	0.00	0.00	0.00
PANVIR	0.00	0.00	0.00	0.00
PLUCAM	0.00	0.00	0.00	0.00
SCIAME	0.00	0.00	0.00	0.00
SORHAL	0.00	0.00	0.00	0.00
SPAAME	0.00	0.00	0.00	0.00
TYPANG	0.00	0.00	0.00	0.00
SPACYN	0.00	0.00	0.00	0.00
PHRAUS	P	P	P	P
SALSP	P	P	0.00	0.00
MURKEI	0.00	0.00	P	P

	Reference Site Taskinas		Restoration Site Naval Weapons		Restoration Site Cheatham	
Species	Mean	SE	Mean	SE	Mean	SE
SPAPAT	44.75	4.36	23.50	5.05	5.96	2.87
DISSPI	35.76	3.51	3.73	1.65	0.00	0.00
SPAALT	34.09	3.37	50.90	5.62	41.28	4.29
SCIAME	7.50	1.62	0.00	0.00	20.77	5.04
SPACYN	2.51	1.06	0.00	0.00	0.00	0.00
SCIROB	2.45	0.59	5.60	1.72	1.02	0.45
ASTTEN	0.64	0.42	1.60	0.75	P	P
MYRCER	0.04	0.04	0.50	0.32	0.00	0.00
ELEIND	0.00	0.00	5.30	2.61	0.00	0.00
TYPANG	0.00	0.00	4.30	1.73	0.00	0.00
PANVIR	0.00	0.00	3.20	1.75	0.00	0.00
SORHAL	0.00	0.00	1.30	0.85	0.00	0.00
PLUCAM	0.00	0.00	1.13	0.59	0.09	0.09
CYPSP	0.00	0.00	0.07	0.05	0.04	0.04
ATRPAT	P	P	0.07	0.07	0.26	0.26
SALSP	0.00	0.00	0.00	0.00	0.04	0.04
SPAAME	0.00	0.00	0.00	0.00	P	P
ASTSUB	0.00	0.00	0.00	0.00	0.00	0.00
BACHAL	0.00	0.00	0.00	0.00	0.00	0.00
ELYVIR	0.00	0.00	0.00	0.00	0.00	0.00
IVAFRU	0.00	0.00	0.00	0.00	0.00	0.00
LEEVIR	0.00	0.00	0.00	0.00	0.00	0.00
LONSP	0.00	0.00	0.00	0.00	0.00	0.00
MURKEI	0.00	0.00	0.00	0.00	0.00	0.00
PHRAUS	0.00	0.00	0.00	0.00	0.00	0.00

Table 3: Mean percent cover (using the Braun Blanquet method) of emergent vegetation collected during this study. Data are grouped into various categories which includes an overall category (across all sites and years), grouped by year (across all sites), grouped by restoration or reference category (across years), and grouped by marsh zone (across sites and years). See Appendix A for a comple list of scientic names and common names for species codes.

	Overall		2008		2009		2010		Reference		Restored		Low Marsh		High Marsh	
Species	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
SPAALT	3.00	0.13	2.92	0.23	3.01	0.23	3.06	0.22	2.68	0.17	3.38	0.19	4.83	0.08	0.56	0.10
SPAPAT	1.88	0.14	1.98	0.26	1.89	0.22	1.79	0.22	2.21	0.18	1.49	0.20	0.17	0.05	4.17	0.19
DISSPI	1.22	0.10	1.15	0.18	1.35	0.19	1.15	0.17	2.12	0.15	0.15	0.05	0.34	0.08	2.38	0.17
SCIROB	0.40	0.05	0.34	0.08	0.40	0.08	0.46	0.08	0.46	0.06	0.34	0.07	0.51	0.07	0.26	0.05
SCIAME	0.39	0.06	0.46	0.12	0.37	0.10	0.36	0.10	0.36	0.07	0.43	0.11	0.11	0.04	0.77	0.13
ASTTEN	0.13	0.03	0.13	0.05	0.16	0.05	0.11	0.04	0.06	0.02	0.22	0.05	0.09	0.03	0.18	0.05
TYPANG	0.10	0.03	0.13	0.06	0.09	0.06	0.07	0.04	0.00	0.00	0.21	0.06	0.12	0.05	0.06	0.03
SPACYN	0.09	0.03	0.07	0.05	0.04	0.03	0.14	0.07	0.16	0.05	0.00	0.00	0.15	0.05	0.00	0.00
ELEIND	0.08	0.03	0.11	0.08	0.05	0.05	0.07	0.05	0.00	0.00	0.17	0.07	0.00	0.00	0.18	0.08
ATRPAT	0.07	0.02	0.03	0.03	0.05	0.03	0.12	0.05	0.01	0.01	0.14	0.05	0.03	0.02	0.12	0.05
PLUCAM	0.07	0.02	0.02	0.01	0.13	0.05	0.06	0.03	0.00	0.00	0.15	0.05	0.03	0.02	0.11	0.04
BACHAL	0.05	0.02	0.04	0.03	0.08	0.04	0.05	0.03	0.03	0.02	0.09	0.04	0.00	0.00	0.13	0.04
PANVIR	0.04	0.02	0.06	0.04	0.03	0.03	0.02	0.02	0.00	0.00	0.09	0.04	0.00	0.00	0.09	0.05
IVAFRU	0.03	0.01	0.02	0.02	0.04	0.03	0.03	0.03	0.00	0.00	0.07	0.03	0.02	0.01	0.05	0.03
SORHAL	0.03	0.01	0.04	0.03	0.04	0.03	0.02	0.02	0.00	0.00	0.07	0.03	0.00	0.00	0.07	0.03
MYRCER	0.03	0.01	0.04	0.03	0.03	0.03	0.02	0.02	0.01	0.01	0.05	0.03	0.01	0.01	0.05	0.03
PHRAUS	0.02	0.01	0.00	0.00	0.03	0.01	0.03	0.02	0.01	0.01	0.04	0.01	0.00	0.00	0.04	0.02
CYPSP	0.01	0.01	0.02	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.03	0.02
ELYVIR	0.01	0.01	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.02	0.02	0.00	0.00	0.02	0.02
LONSP	0.01	0.01	0.00	0.00	0.01	0.01	0.02	0.02	0.00	0.00	0.02	0.01	0.00	0.00	0.02	0.01
SALSP	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00
ASTSUB	0.01	0.01	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00
MURKEI	0.01	0.01	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01
LEEVIR	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01
SPAAME	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01

Table 4: Stem density (per meter squared) of the emergent vegetation collected during this study. Data are grouped into various categories which includes an overall category (across all sites and years), grouped by year (across all sites), grouped by restoration or reference category (across years), and grouped by marsh zone (across sites and years). See Appendix A for a comple list of scientic names and common names for species codes.

	Overall		2008		2009		2010		Reference		Restored		Low Marsh		High Marsh	
Species	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
SPAPAT	681.90	87.20	930.95	209.07	468.24	98.66	666.16	134.89	1047.94	151.25	247.23	47.33	2.68	1.39	1587.52	179.34
DISSPI	185.25	26.59	212.65	58.44	194.14	38.17	151.73	41.20	341.10	46.32	1.33	0.72	26.95	11.65	397.38	55.91
SPAALT	84.07	4.81	84.31	9.18	92.41	8.66	75.93	7.24	91.17	7.59	75.70	5.43	140.46	5.53	9.39	2.61
SCIAME	30.41	7.73	31.01	10.00	22.54	6.81	37.43	19.17	23.28	5.86	38.88	15.42	5.14	2.70	64.05	17.32
ELEIND	19.13	11.77	30.95	30.95	11.90	11.90	15.51	15.51	0.00	0.00	41.98	25.79	0.00	0.00	44.77	27.50
SCIROB	2.07	0.37	1.01	0.43	2.58	0.79	2.54	0.65	1.86	0.42	2.31	0.65	2.95	0.61	0.90	0.28
PANVIR	1.27	0.77	0.83	0.83	1.29	1.29	1.66	1.66	0.00	0.00	2.78	1.67	0.00	0.00	2.97	1.78
ASTTEN	1.26	0.75	2.32	2.25	0.51	0.32	1.01	0.58	1.62	1.33	0.82	0.43	0.10	0.05	2.79	1.73
PLUCAM	1.19	0.86	0.00	0.00	3.42	2.56	0.13	0.10	0.00	0.00	2.61	1.88	0.00	0.00	2.78	2.00
SPACYN	0.93	0.38	1.15	0.89	0.44	0.38	1.20	0.66	1.72	0.70	0.00	0.00	1.63	0.67	0.00	0.00
TYPANG	0.80	0.28	1.23	0.69	0.71	0.43	0.49	0.29	0.00	0.00	1.74	0.61	0.94	0.41	0.61	0.36
ATRPAT	0.28	0.14	0.00	0.00	0.20	0.12	0.62	0.40	0.00	0.00	0.63	0.32	0.16	0.14	0.45	0.28
SORHAL	0.28	0.17	0.32	0.32	0.54	0.41	0.00	0.00	0.00	0.00	0.62	0.37	0.00	0.00	0.66	0.40
BACHAL	0.17	0.11	0.00	0.00	0.27	0.21	0.23	0.23	0.00	0.00	0.37	0.23	0.00	0.00	0.40	0.25
ELYVIR	0.13	0.13	0.00	0.00	0.00	0.00	0.36	0.36	0.00	0.00	0.27	0.27	0.00	0.00	0.29	0.29
ASTSUB	0.08	0.08	0.00	0.00	0.24	0.24	0.00	0.00	0.00	0.00	0.17	0.17	0.14	0.14	0.00	0.00
IVAFRU	0.07	0.07	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00	0.15	0.15	0.00	0.00	0.16	0.16
SALSP	0.06	0.04	0.00	0.00	0.00	0.00	0.16	0.11	0.08	0.07	0.02	0.02	0.10	0.07	0.00	0.00
MYRCER	0.05	0.02	0.07	0.05	0.03	0.03	0.03	0.03	0.02	0.02	0.07	0.04	0.02	0.02	0.08	0.05
CYPSP	0.01	0.01	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.03	0.03
LONSP	0.01	0.01	0.00	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.03	0.03
PHRAUS	0.01	0.01	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.00	0.02	0.02	0.00	0.00	0.03	0.03
LEEVIR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MURKEI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SPAAME	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5: Mean stem density (per meter squared) of emergent vegetation collected during this study. Data are categorized by restoration or reference site and data are grouped across years. Goodwin Islands is the reference site for the Hermitage Living Museum. Taskinas Creek is the reference site for the Cheatham Annex and Naval Weaspons Station restoration projects. See Appendix A for a comple list of scientic names and common names for species codes.

	Reference Site Goodwin		Restoration Site Hermitage	
Species	**Mean**	**SE**	**Mean**	**SE**
DISSPI	284.17	68.58	0.00	0.00
SPAPAT	232.67	68.57	455.19	113.11
SPAALT	126.88	13.36	92.96	11.06
SCIROB	0.83	0.36	0.00	0.00
SALSP	0.20	0.15	0.00	0.00
ASTSUB	0.00	0.00	1.13	0.79
ASTTEN	0.00	0.00	1.11	0.69
ATRPAT	0.00	0.00	0.81	0.81
BACHAL	0.00	0.00	0.52	0.52
CYPSP	0.00	0.00	0.44	0.44
ELEIND	0.00	0.00	0.22	0.16
ELYVIR	0.00	0.00	0.07	0.07
IVAFRU	0.00	0.00	0.07	0.07
LEEVIR	0.00	0.00	0.00	0.00
LONSP	0.00	0.00	0.00	0.00
MURKEI	0.00	0.00	0.00	0.00
MYRCER	0.00	0.00	0.00	0.00
PANVIR	0.00	0.00	0.00	0.00
PHRAUS	0.00	0.00	0.00	0.00
PLUCAM	0.00	0.00	0.00	0.00
SCIAME	0.00	0.00	0.00	0.00
SORHAL	0.00	0.00	0.00	0.00
SPAAME	0.00	0.00	0.00	0.00
SPACYN	0.00	0.00	0.00	0.00
TYPANG	0.00	0.00	0.00	0.00

	Reference Site Taskinas		Restoration Site Naval Weapons		Restoration Site Cheatham	
Species	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
SPAPAT	1653.78	243.36	197.40	60.83	68.09	40.07
DISSPI	383.40	62.58	3.57	1.90	0.00	0.00
SPAALT	64.06	7.78	58.00	6.84	78.47	9.82
SCIAME	40.79	9.96	0.00	0.00	133.19	50.59
SPACYN	3.01	1.22	0.00	0.00	0.00	0.00
ASTTEN	2.84	2.32	2.00	1.14	0.00	0.00
SCIROB	2.64	0.67	5.60	1.62	0.77	0.54
MYRCER	0.04	0.04	0.20	0.11	0.00	0.00
ELEIND	0.00	0.00	113.83	69.30	0.00	0.00
PANVIR	0.00	0.00	7.47	4.44	0.00	0.00
PLUCAM	0.00	0.00	7.00	5.01	0.00	0.00
TYPANG	0.00	0.00	4.67	1.56	0.00	0.00
SORHAL	0.00	0.00	1.67	0.99	0.00	0.00
ATRPAT	0.00	0.00	0.20	0.11	0.60	0.60
CYPSP	0.00	0.00	0.07	0.07	0.00	0.00
SALSP	0.00	0.00	0.00	0.00	0.09	0.09
ASTSUB	0.00	0.00	0.00	0.00	0.00	0.00
BACHAL	0.00	0.00	0.00	0.00	0.00	0.00
ELYVIR	0.00	0.00	0.00	0.00	0.00	0.00
IVAFRU	0.00	0.00	0.00	0.00	0.00	0.00
LEEVIR	0.00	0.00	0.00	0.00	0.00	0.00
LONSP	0.00	0.00	0.00	0.00	0.00	0.00
MURKEI	0.00	0.00	0.00	0.00	0.00	0.00
PHRAUS	0.00	0.00	0.00	0.00	0.00	0.00
SPAAME	0.00	0.00	0.00	0.00	0.00	0.00

Table 6: Mean plant height in meters (using the three tallest species at each plot) of selected species sampled during this study. Data are grouped into various categories which includes an overall category (across all sites and years), grouped by year (across all sites), grouped by restoration or reference category (across years), and grouped by marsh zone (across sites and years). See Appendix A for a comple list of scientic names and common names for species codes.

	Overall		2008		2009		2010		Reference		Restored		Low Marsh		High Marsh	
Species	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
SPAALT	121.95	3.30	116.48	5.80	131.49	6.15	117.59	5.09	92.77	3.51	151.14	3.93	125.29	3.52	92.56	6.32
SCIROB	105.89	4.20	119.30	7.50	94.95	7.57	107.00	6.03	98.80	5.14	119.55	5.92	114.73	4.03	81.76	7.40
SCIAME	89.60	3.64	92.10	7.37	91.40	5.24	84.58	6.38	87.54	4.73	92.69	5.81	102.41	8.86	85.88	3.76
SPAPAT	72.42	2.42	76.67	4.94	71.45	3.58	70.14	4.24	58.77	1.87	102.05	3.35	60.85	10.43	73.28	2.48
DISSPI	50.57	1.49	52.55	3.35	52.89	2.13	46.84	2.31	48.30	1.13	79.25	10.47	64.62	5.16	47.42	1.19

Table 7: Mean porewater and groundwater salinities for sites visited during during the three year study period.

Site	Porewater Sipper Salinity Mean	Porewater Sipper Salinity SE	Groundwater Well Salinity Mean	Groundwater Well Salinity SE
Goodwin Islands	20.7	0.52	19.7	0.38
Hermitage	18.6	0.49	14.8	0.76
Taskinas Creek	16.0	0.45	14.9	0.46
Naval Weapons Station	17.9	0.95	9.3	0.62
Chaetham Annex	12.1	1.15	8.1	0.78

Year	Porewater Sipper Salinity Mean	Porewater Sipper Salinity SE	Groundwater Well Salinity Mean	Groundwater Well Salinity SE
2008	17.8	0.53	14.5	0.66
2009	15.5	0.64	12.9	0.55
2010	18.6	0.72	14.7	0.61

Marsh_Zone	Porewater Sipper Salinity Mean	Porewater Sipper Salinity SE	Groundwater Well Salinity Mean	Groundwater Well Salinity SE
Low Marsh Zone	18.6	0.34	15.7	0.40
High Marsh Zone	15.0	0.72	12.2	0.61

Restoration Type	Porewater Sipper Salinity Mean	Porewater Sipper Salinity SE	Groundwater Well Salinity Mean	Groundwater Well Salinity SE
Reference	18.4	0.41	17.7	0.35
Restored	15.7	0.63	10.7	0.46

Appendix A. Species list for emergent vegetation collected during this study.

Species Code	Species Name	Common Name
ASTSUB	Aster subulatus	eastern annual saltmarsh aster
ASTTEN	Aster tenuifolium	perennial saltmarsh aster
ATRPAT	Atriplex patula	fat hen/marsh orach/spear saltbush
BACHAL	Baccharis hamlimifolia	groundsel bush/cotton bush
CYPSP	Cyperus strigosus	strawcolored flatsedge
DISSPI	Distichlis spicata	salt grass/spike grass
ELEIND	Eleusine indica	Indian goosegrass
ELYVIR	Elymus virginicus	Virginia wildrye
IVAFRU	Iva frutescens	Jesuit's bark
LEEVIR	Leersia virginica	whitegrass
LONSP	Lonerica sp.	honeysuckle species
MURKEI	Murdannia keisak	marsh dayflower
MYRCER	Myrica cerifera	southern wax myrtle
PANVIR	Panicum virgatum	switchgrass
PHRAUS	Phragmites australis	common reed
PLUCAM	Pluchea camphorata	camphorweed
SALSP	Salicornia sp.	salicornia sp.
SCIAME	Scirpus americanus	olney three square
SCIROB	Scirpus robustus	saltmarsh bulrush
SORHAL	Sorghum halepense	Johnsongrass
SPAALT	Spartina alterniflora	saltwater cordgrass/smooth cordgrass
SPAAME	Sparganium americanum	lesser bur-reed
SPACYN	Spartina cynosuroides	big cordgrass
SPAPAT	Spartina patens	salt hay grass/salt meadow cordgrass
TYPANG	Typha angustifolia	narrowleaf cattail

Appendix B: Occurances of vegetation species at each study site within each study year.

	Goodwin			Hermitage			Taskinas			Chaetham Annex			Naval Weapons			
Species	2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010	**Totals:**
ASTSUB					X											**1**
ASTTEN				X	X		X	X	X		X		X	X	X	**9**
ATRPAT				X	X	X						X		X	X	**6**
BACHAL	X	X	X	X	X	X										**6**
CYPSP											X		X	X	X	**4**
DISSPI	X	X	X				X	X	X				X	X	X	**9**
ELEIND													X	X	X	**3**
ELYVIR						X										**1**
IVAFRU				X	X	X										**3**
LEEVIR					X											**1**
LONSP					X	X										**2**
MURKEI						X										**1**
MYRCER							X						X	X	X	**4**
PANVIR													X	X	X	**3**
PHRAUS		X			X	X										**3**
PLUCAM											X	X	X	X	X	**5**
SALSP			X									X				**2**
SCIAME							X	X	X	X	X	X				**6**
SCIROB	X	X	X				X	X	X	X	X	X	X	X	X	**12**
SORHAL													X	X	X	**3**
SPAALT	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	**15**
SPAAME											X					**1**
SPACYN							X	X	X							**3**
SPAPAT	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	**15**
TYPANG													X	X	X	**3**
Totals:	**5**	**6**	**6**	**6**	**9**	**9**	**8**	**7**	**7**	**4**	**8**	**7**	**12**	**13**	**13**	

Appendix C. Results of Krustal-Wallis Rank Sum Tests. The five dominant species in the study were grouped by sampling year for the following metics (percent cover using point intercept method, percent cover using cover class method, stem density, and plant height). The Krustal Wallis Rank Sum Test was also used to test for differences in groundwater salinity, porewater salinity, soil organic matter, soil bulk density, and species richness. Thes K-W tests were first run using the entire dataset (across all sites and zones) and these same tests were repeated using only data from the low marsh zone (across sites) and the high marsh zone (across sites), respectively (with the exception of the soils metic and species richness community metric). If the Kruskal Wallis test found a significant difference among groups (p<0.05), then a kruskalmc function was used to do post-hoc paired compasions between groups. A Yes indicates significant differences between data collected from different years. The reference sites were Goodwin Islands and Taskinas Creek and the restoration sites were Hermitage Living Museum, Cheatham Annex, and Naval Weapons Station.

Individual Species Comparisons		PI Overall	CC Overall	Density Overall	Height Overall	PI Low	CC Low	Density Low	Height Low	PI High	CC High	Density High	Height High
Species (SPAALT)	Test P-Value	0.8956	0.8613	0.4661	0.1965	0.2657	0.2864	0.0078	0.163	0.986	0.9843	0.482	0.548
Year - 2008	Year - 2009	no	no	no	no	no	no	no	no	no	no	no	no
Year - 2008	Year - 2010	no	no	no	no	no	no	no	no	no	no	no	no
Year - 2009	Year - 2010	no	no	no	no	no	no	**yes**	no	no	no	no	no
Species (SPAPAT)	Test P-Value	0.9634	0.8335	0.9509	0.5029	0.401	0.3998	0.7644	0.3932	0.5514	0.4026	0.2393	0.6232
Year - 2008	Year - 2009	no	no	no	no	no	no	no	no	no	no	no	no
Year - 2008	Year - 2010	no	no	no	no	no	no	no	no	no	no	no	no
Year - 2009	Year - 2010	no	no	no	no	no	no	no	no	no	no	no	no
Species (DISSPI)	Test P-Value	0.5785	0.7647	0.6858	0.049	0.9014	0.9913	0.801	0.9622	0.3576	0.5757	0.4199	0.0046
Year - 2008	Year - 2009	no	no	no	no	no	no	no	no	no	no	no	no
Year - 2008	Year - 2010	no	no	no	no	no	no	no	no	no	no	no	no
Year - 2009	Year - 2010	no	no	no	**yes**	no	no	no	no	no	no	no	**yes**
Species (SCIAME)	Test P-Value	0.8473	0.6845	0.7735	0.7001	0.818	0.4115	0.4466	0.6644	0.927	0.9488	0.9503	0.7917
Year - 2008	Year - 2009	no	no	no	no	no	no	no	no	no	no	no	no
Year - 2008	Year - 2010	no	no	no	no	no	no	no	no	no	no	no	no
Year - 2009	Year - 2010	no	no	no	no	no	no	no	no	no	no	no	no
Species (SCIROB)	Test P-Value	0.8979	0.21	0.2106	0.1319	0.958	0.5581	0.446	0.3591	0.7961	0.1895	0.3545	0.2563
Year - 2008	Year - 2009	no	no	no	no	no	no	no	no	no	no	no	no
Year - 2008	Year - 2010	no	no	no	no	no	no	no	no	no	no	no	no
Year - 2009	Year - 2010	no	no	no	no	no	no	no	no	no	no	no	no

Physical and Community Metrics		GW Sal Overall	GW- Sal Low	GW - Sal High	PW Sal Overall	PW Sal Low	PW Sal High	Richness Overall
	Overall P-Value	0.024	0.2842	0.082	0.0002	0.1467	0.0004	0.4766
Year - 2008	Year - 2009	no	no	no	**yes**	no	**yes**	no
Year - 2008	Year - 2010	no	no	no	no	no	no	no
Year - 2009	Year - 2010	**yes**	no	no	**yes**	no	**yes**	no

Appendix D. Results of Krustal-Wallis Rank Sum Tests. The five dominant species in the study were grouped by marsh zone (low marsh versus high marsh) for the following metics (percent cover using point intercept method, percent cover using cover class method, stem density, and plant height). The Krustal Wallis Rank Sum Test was also used to test for differences in groundwater salinity, porewater salinity, soil organic matter, soil bulk density, and species richness. Thes K-W tests were first run using the entire dataset (across all sites and years). If the Kruskal Wallis test found a significant difference among groups (p<0.05), then a kruskalmc function was used to do post-hoc paired compasions between groups. A Yes indicates significant differences between data collected from different years. The reference sites were Goodwin Islands and Taskinas Creek and the restoration sites were Hermitage Living Museum, Cheatham Annex, and Naval Weapons Station.

Individual Species Comparisons		PI Overall	CC Overall	Density Overall	Height Overall
Species (SPAALT)	Test P-Value	<.0001	<.0001	<.0001	0.002
Low Marsh	High Marsh	yes	yes	yes	yes
Species (SPAPAT)	Test P-Value	<.0001	<.0001	<.0001	0.097
Low Marsh	High Marsh	yes	yes	yes	no
Species (DISSPI)	Test P-Value	<.0001	<.0001	<.0001	0.001
Low Marsh	High Marsh	yes	yes	yes	yes
Species (SCIAME)	Test P-Value	<.0001	<.0001	<.0001	0.069
Low Marsh	High Marsh	yes	yes	yes	no
Species (SCIROB)	Test P-Value	0.006	0.031	0.027	0.0014
Low Marsh	High Marsh	no	no	no	yes

Physical and Community Metrics		GW Sal Overall	PW Sal Overall	Soils OM	Soils BD	Richness Overall
	Overall P-Value	<.0001	0.0002	0.2998	0.1589	<.0001
Low Marsh	High Marsh	yes	yes	no	no	yes

Appendix E. Results of Krustal-Wallis Rank Sum Tests. The five dominant species in the study were grouped by the restoration/reference site category for the following metics (percent cover using point intercept method, percent cover using cover class method, stem density, and plant height). The Krustal Wallis Rank Sum Test was also used to test for differences in groundwater salinity, porewater salinity, soil organic matter, soil bulk density, and species richness. Thes K-W tests were first run using the entire dataset (all years and all zones) and these same tests were repeated using only data from the low marsh zone (across years) and the high marsh zone (across years), respectively (with the exception of the soils metics and species richness community metric). If the Kruskal Wallis test found a significant difference among groups ($p<0.05$), then a kruskalmc function was used to do post-hoc paired compasions between groups. A Yes indicates significant differences between data collected from restoration sites with data collected from reference sites. The reference sites were Goodwin Islands and Taskinas Creek and the restoration sites were Hermitage Living Museum, Cheatham Annex, and Naval Weapons Station.

Individual Species Comparisons		PI Overall	CC Overall	Density Overall	Height Overall	PI Low	CC Low	Density Low	Height Low	PI High	CC High	Density High	Height High
Species (SPAALT)	Test P-Value	0.0046	0.004	0.8204	<.0001	0.0702	0.0902	<.0001	<.0001	0.258	0.3397	0.2694	0.2174
Restored	Reference	yes	yes	no	yes	no	no	yes	yes	no	no	no	no
Species (SPAPAT)	Test P-Value	0.0011	0.003	<.0001	<.0001	0.4227	0.4403	0.5785	0.0404	0.5496	0.7247	0.0005	<.0001
Restored	Reference	yes	yes	yes	yes	no	no	no	yes	no	no	yes	yes
Species (DISSPI)	Test P-Value	<.0001	<.0001	<.0001	0.004	0.0086	0.0187	0.1607	0.004	<.0001	<.0001	<.0001	0.991
Restored	Reference	yes	yes	yes	yes	no	no	no	yes	yes	yes	yes	no
Species (SCIAME)	Test P-Value	0.648	0.4425	0.4343	0.4476	0.3499	0.1391	0.1331	0.0204	0.2459	0.2551	0.3231	0.0082
Restored	Reference	no	no	no	no	no	no	no	yes	no	no	no	yes
Species (SCIROB)	Test P-Value	0.4692	0.04889	0.4934	0.0212	0.3599	0.0205	0.452	0.1618	0.526	0.5072	0.4899	0.0247
Restored	Reference	no	no	no	yes	no	no	no	no	no	no	no	yes

Physical and Community Metrics		GW Sal Overall	GW- Sal Low	GW - Sal High	PW Sal Overall	PW Sal Low	PW Sal High	Soils OM	Soils BD	Richness Overall
	Overall P-Value	<.0001	0.012	<.0001	0.012	0.5137	<.0001	0.0003	0.0003	<.0001
Restored	Reference	yes	yes	yes	yes	no	yes	yes	yes	yes

Appendix F. Results of Krustal-Wallis Rank Sum Tests. The five dominant species in the study were compared across study sites for the following metics (percent cover using point intercept method, percent cover using cover class method, stem density, and plant height). The Krustal Wallis Rank Sum Test was also used to test for differences in groundwater salinity, porewater salinity, soil organic matter, soil bulk density, and species richness between sites. Thes K-W tests were first run using the entire dataset (all years and all zones) and these same tests were repeated using only data from the low marsh zone (across years) and the high marsh zone (across years), respectively (with the exception of the soils metics and species richness community metric). If the Kruskal Wallis test found a significant difference among groups (p<0.05), then a kruskalmc function was used to do post-hoc paired compasions between groups. A Yes indicates significant differences between the paired groups. Goodwin serves as the reference site for the Hermitage restoration project and Taskinas serves as the reference site for the Cheatham Annex and Naval Weapons Station restorstion projects.

Individual Species Comparisons		PI Overall	CC Overall	Density Overall	Height Overall	PI Low	CC Low	Density Low	Height Low	PI High	CC High	Density High	Height High
Species (SPAALT)	Test P-Value	0.017	ns	0.001	<0.0001	<.0001	<.0001	0.007	<.0001	0.0006	< .001	0.003	0.02
Goodwin	Hermitage	no	no	no	yes	no	no	yes	yes	no	no	no	no
Taskinas	Naval Weapons	yes	no	no	yes	yes	no	no	yes	no	no	no	no
Taskinas	Cheatham	no	no	no	no	no	no	no	no	no	no	no	no
Species (SPAPAT)	Test P-Value	<.0001	0.0001	<.0001	<.0001	0.2046	0.197	0.833	0.225	<.0001	<.0001	<.0001	<.0001
Goodwin	Hermitage	no	no	no	yes	no	no	no	no	yes	yes	no	yes
Taskinas	Naval Weapons	no	no	yes	yes	no	no	no	no	no	no	yes	yes
Taskinas	Cheatham	yes	yes	yes	yes	no	no	no	no	yes	yes	yes	no
Species (DISSPI)	Test P-Value	<.0001	<.0001	<.0001	0.014	<.0001	<.0001	0.007	0.006	<.0001	<.0001	<.0001	0.055
Goodwin	Hermitage	yes	yes	yes	no	no	no	no	no	yes	yes	yes	no
Taskinas	Naval Weapons	yes	yes	yes	yes	no	no	no	no	yes	yes	yes	no
Taskinas	Cheatham	yes	yes	yes	no	no	no	no	no	yes	yes	yes	no
Species (SCIAME)	Test P-Value	<.0001	<.0001	<.0001	0.4476	0.017	0.004	0.003	0.02	<.0001	<.0001	<.0001	0.008
Goodwin	Hermitage	no	no	no	no	no	no	no	no	no	no	no	no
Taskinas	Naval Weapons	no	no	no	no	no	no	no	no	no	no	no	no
Taskinas	Cheatham	no	no	no	no	no	no	no	yes	yes	yes	yes	yes
Species (SCIROB)	Test P-Value	0.0002	<.0001	<.0001	<.0001	<.0001	<.0001	0.007	0.062	0.012	0.0002	ns	0.016
Goodwin	Hermitage	no	no	no	no	no	no	no	no	no	no	no	no
Taskinas	Naval Weapons	no	no	no	no	no	no	no	no	no	no	no	no
Taskinas	Cheatham	no	no	no	no	no	yes	no	no	no	no	no	no

Physical and Community Metrics		GW Sal Overall	GW- Sal Low	GW - Sal High	PW Sal Overall	PW Sal Low	PW Sal High	Soils OM	Soils BD	Richness Overall
	Overall P-Value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.003	0.007	<.0001
Goodwin	Hermitage	yes	yes	yes	no	yes	no	no	no	no
Taskinas	Naval Weapons	yes	no	yes	no	yes	no	no	no	no
Taskinas	Cheatham	yes	no	yes	yes	no	yes	no	no	yes