Long-term Salt Marsh Monitoring Site Expansion and Baseline Data Collection in Rhode Island

Prepared for the Rhode Island Department of Environmental Management Office of Water Resources
and the Narragansett Bay National Estuarine Research Reserve

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Contents

Introduction

Salt marshes are highly-productive coastal ecosystems that are valuable to people and wildlife, but they are highly vulnerable to anthropogenic disturbances such as nutrient loading, tidal restriction, impoundment, filling, and the introduction of invasive species. In the last few decades, an increase in tidal inundation associated with sea-level rise and warming climates has exacerbated the impacts of these and other disturbances on salt marshes and has caused marsh degradation and loss across Rhode Island (Watson 2017). Many marsh-degradation processes have been documented using data from long-term monitoring of biological and physical parameters at two "sentinel" marshes located within the Narragansett Bay National Estuarine Research Reserve (NBNERR) on Prudence Island in central Narragansett Bay (e.g., Raposa et al. 2017a, Raposa et al. 2018).

Long-term monitoring is essential to understanding how marshes are responding to changing environmental conditions. Intensive, long-term monitoring of environmental and biological attributes can produce robust quantitative data (hereafter *Tier-3* data) that can be applied to assess changes in a single or set of representative sites over a period of time. Tier-3 data are useful to correlate observed marsh changes with changes in other environmental factors, such as sea-level rise, direct disturbances, or surrounding development. Long-term monitoring in Rhode Island has followed methods from the National Estuarine Research Reserve System's (NERRS) System-Wide Monitoring Program (SWMP), which focuses on biological (i.e., vegetation, nekton, avian), inundation, and edaphic response to sea-level rise at a nationwide suite of sentinel marshes across participating NERRS sites (Buskey et al. 2015). Rhode Island's Salt Marsh Monitoring and Assessment Strategy (Raposa et al. 2016a) recommends expanding on the two existing sentinel marshes to include additional long-term monitoring marshes located across the Narragansett Bay estuary and coastal Rhode Island.

Information from the NBNERR sentinel marshes has been instrumental in understanding the causes of salt marsh degradation in Rhode Island. Our understanding of platform response to relative sea-level rise (Raposa et al. 2017a); vegetation response to inundation stress (Raposa et al. 2017b); top-down interactions among fauna, sea-level-rise, and marsh platform integrity (Raposa et al. 2018); local salt marsh integrity in relation to marshes nationwide (Raposa et al. 2016b); invasive species drivers (Silliman and Bertness 2004); and other valuable information important to salt marsh conservation, has been informed by analysis of long-term sentinel-site data. Rhode Island's salt-marsh rapid assessment method, MarshRAM (Kutcher et al. 2023), incorporates long-term monitoring information into several of its indices and metrics, including the Index of Marsh Integrity (IMI) and metrics on impoundment, nutrient inputs, burrowing crabs, ponding and die-off, and invasive species. Long-term elevation data are also used as a critical component of RI's Sea Level Affecting Marsh Migration (SLAMM) model (CRMC 2015) and are being used to calibrate marsh gain-loss across model scenarios.

Long-term monitoring sites can additionally act as control sites for restoration projects. The BACI (Before, After, Control, Impact) study design (Stewart-Oaten et al. 1986), which compares changes at a restoration (i.e., Impact) site with changes observed in a similar unrestored (i.e., Control) site, is widely used in ecological restoration assessment. RI's Salt-Marsh Restoration, Assessment, and Monitoring Program (RAMP), a collaboration of federal, state, academic, and NGO partners, has worked to standardize the way data are collected among marsh conservation, restoration, and research projects (Raposa et al. 2016a, Kutcher et al. 2018). Restoration monitoring typically follows the sentinel-site protocols; thus, data collected at the sentinel sites can be used as control data for most restoration projects, alleviating data collection burdens for practitioners.

The information gathered at the existing sentinel marshes has informed nearly every management, conservation, and restoration action undertaken by salt marsh managers in Rhode Island. However, because the sentinel marshes have been limited to the two sites in the central estuary, questions remain about how marshes are changing and responding to stressors in the upper and lower parts of the estuary. For example, it is unclear whether marshes are gaining or losing elevation in relation to the tide frame in these other regions; or whether edge-erosion, marsh migration, or vegetation-turnover processes are consistent across the estuary. Expanding these tested and known-effective protocols to the upper and lower reaches of the Narragansett Bay estuary and Rhode Island's coastal lagoons will provide information to answer many of these questions; it is also expected to shed further light on the mechanisms that are causing degradation and loss. This report outlines a Project that expands the number of long-term monitoring sites in Rhode Island to improve the spatial resolution of long-term data.

The Project builds upon existing infrastructure and methodologies already in place at the two sentinel salt marshes, expanding the long-term monitoring program to four additional marshes; one located in the upper Narragansett Bay, one in Mount Hope Bay, one in the lower Narragansett Bay, and one in a coastal lagoon located in coastal Rhode Island (Fig. 1). Two of the expansion sites were partially operational from recent provisional efforts, but incomplete, and two new sites were selected through consensus of the RAMP partners. Infrastructure was installed at these four marshes to support the full suite of intensive monitoring recommended in Raposa et al. (2016a). The Project also includes collecting baseline data for key parameters at selected newly-installed salt-marsh monitoring stations, and developing an electronic filing protocol to archive long-term monitoring station locations and data.

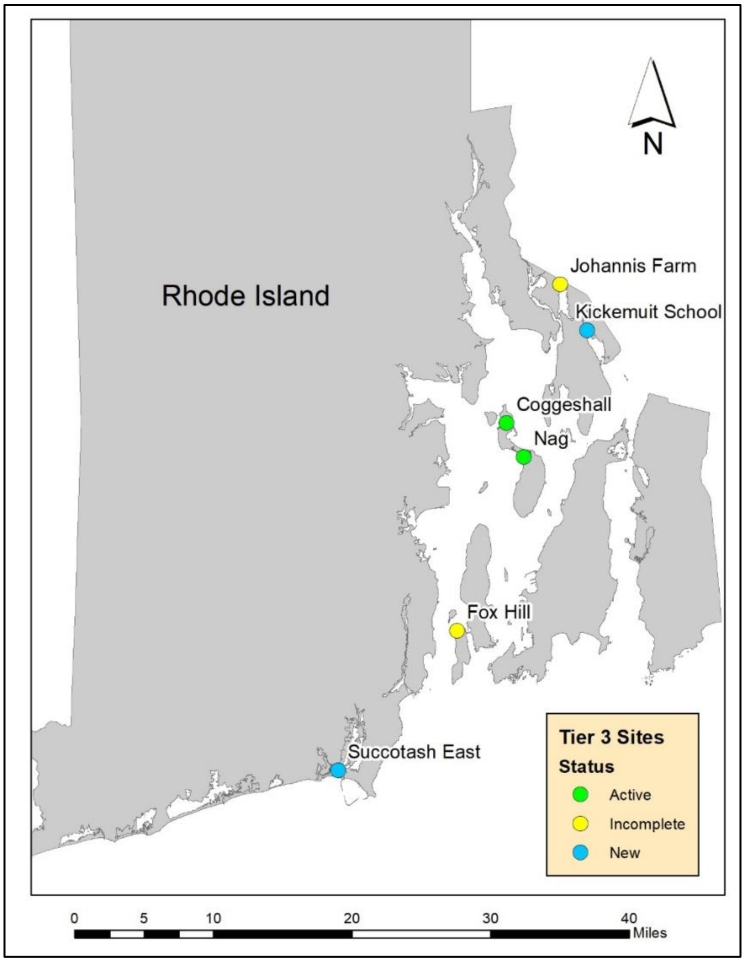

Figure 1. Long-term salt marsh monitoring sites showing the status of each prior to site-expansion by the Project.

2. Methods

Tier-3 (intensive) and Tier-2 (rapid assessment) long-term monitoring infrastructure were installed at the new and incomplete long-term monitoring sites, and baseline monitoring was conducted for key parameters. All build-out and monitoring was conducted from June through October of 2023. Specifics of infrastructure set-up and data collection accomplished in this Project are outlined in Table 1.

Table 1. Locations and installation status in 2023 of monitoring station infrastructure at four long-term salt-marsh monitoring sites in Rhode Island. *Baseline data were collected in 2023.

	Johannis Farm	Fox Hill	Kickemuit School	Succotash East
Latitude	41.7599	41.4902	41.7247	41.3814
Longitude	-71.2885	-71.3952	-71.2594	-71.5186
Starting Status	Incomplete	Incomplete	New	New
Ending Status	Complete	Complete	Complete	Complete
Vegetation	Existing*	Existing*	Installed*	Installed*
Surface Elevation	Existing	Existing	Installed*	Installed*
Edge-ecotone	Existing	Existing	Installed*	Installed*
Nekton	Installed	Installed	Installed	Installed
Water Level	Installed	Installed	Installed*	Installed*
Rapid Assessment	Existing	Existing	Existing	Installed*

2.1 Locating and Installing Monitoring Stations

Monitoring station locations were established according to the MarshRAM User's Guide (Kutcher 2022a), using a stratified random process of locating eight evenly-spaced transects running from the upland to tidal water's edge at each marsh. In each case, the first transect was started at a random location along a guideline paralleling the marsh-upland border, and the remaining 7 transects were evenly spaced from that transect (Figure 2). Most monitoring stations were located along some or all of these transects as detailed below. Locations of all monitoring stations are stored as ESRI shapefiles and as georectified pdf (GeoPDF) files as depicted in Appendices A and B.

Figure 2. An example of a stratified-random transect layout, along-which long-term salt marsh monitoring stations can be distributed, from Kutcher (2022a).

2.1.1 Vegetation Stations

For each new long-term monitoring marsh (Table 1), twenty 1-m × 1-m vegetation plots were located along every other transect (four of the eight) by dividing total selected transect length by 20, and spacing the plots evenly along the transects from a random starting point; this followed James-Perri et al. (2002), except that no bias was given to locating plots in low-marsh zones, as low marsh is no longer a reliable feature in marshes. Stations were established in the field using five ½-inch diameter white PVC stakes per monitoring plot, including one 1-m (0.5m exposed) stake to mark the individual plots and four 0.5-m (10cm exposed) stakes to mark the plot corners.

2.1.2 Surface Elevation Table (SET) Stations

Three SET stations were located and installed in each new marsh according to methods detailed in Callaway et al. 2013. Locations were identified to represent areas of *Meadow High Marsh*, *Mixed High Marsh*, and *Sa High Marsh*, according to Kutcher et al. 2022 (Table 2); these habitats were selected to broadly represent high-marsh conditions. SET stations were delimited using 1-m-long ½" PVC pipe driven into the soil to delineate a 3-m × 3-m square. SETs were installed in the center of the station by driving multiple, connected, four-foot sections of ½-inch stainless steel rod into the marsh soils from an elevated plank to avoid affecting the marsh surface; this was done using an 18-pound ground-rod hammer (see report cover photo) until progress could no longer be made. The SET receiver was bolted to the rod, and the rod and receiver base were encased in a 6-inch × 2-foot PVC pipe filled with concrete to create a stable and permanent reference to solid earth, as depicted in Callaway 2013 (Fig. 3). Rod depth to refusal varied from 12 to 39 feet per SET. Two 0.25m^2 quadrats of 0.5cm-thick feldspar powder were spread at each corner of the SET station to act as *marker horizons* (i.e., indicators of surface deposition), in order to distinguish surface-level changes in elevation from sub-surface changes. Figure 4 shows an example of a newly-installed SET station.

Table 2. High marsh categories according to Kutcher et al. (2022), modified to only show high-marsh categories targeted for SET placement.

Marsh Habitat	Description
Meadow High Marsh	Irregularly flooded emergent high marsh community dominated by any combination of *Spartina patens*, *Juncus gerardii*, *Distichlis spicata*; *S. alterniflora* absent
Mixed High Marsh	Irregularly flooded emergent high marsh community comprised of any combination of S. patens, *Juncus gerardii*, *Distichlis spicata*; *S. alterniflora* present
Sa High Marsh	Irregularly flooded emergent high marsh; typically monoculture of *S. alterniflora*, although *Salicornia* sp. may be present

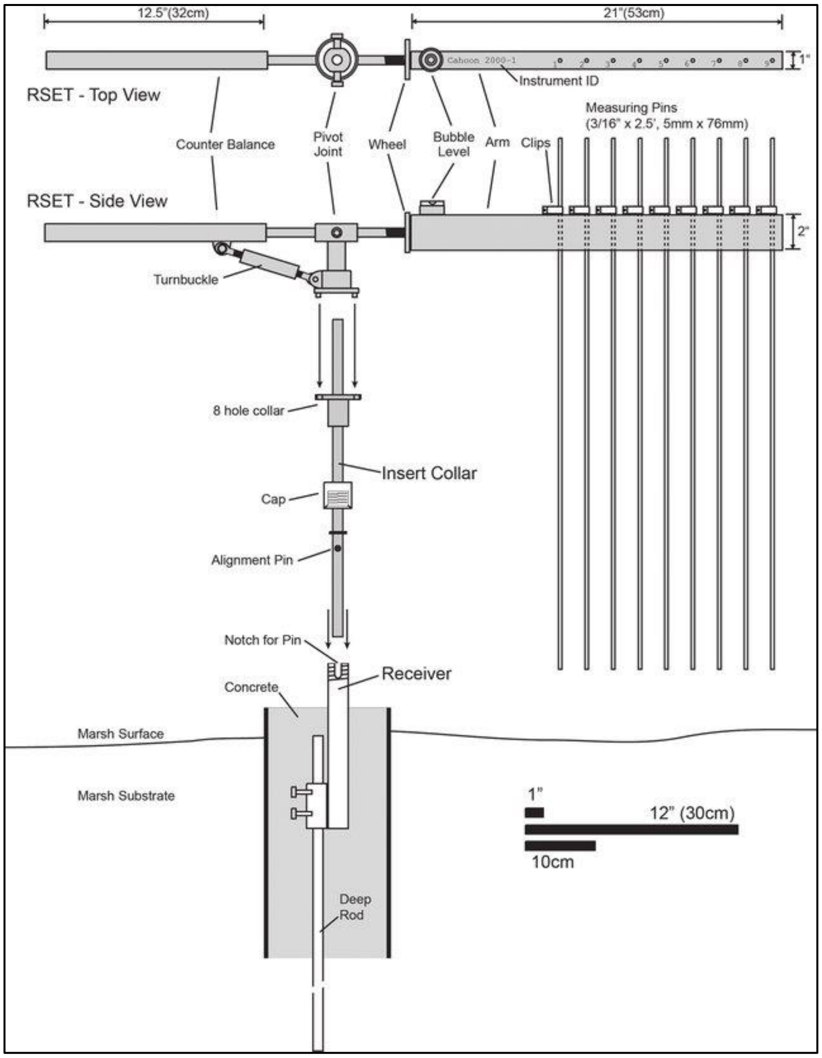

Figure 3. Surface elevation table (SET) sampling apparatus, as installed in new long-term salt marsh monitoring sites in Rhode Island in 2023; from Callaway et al. (2013).

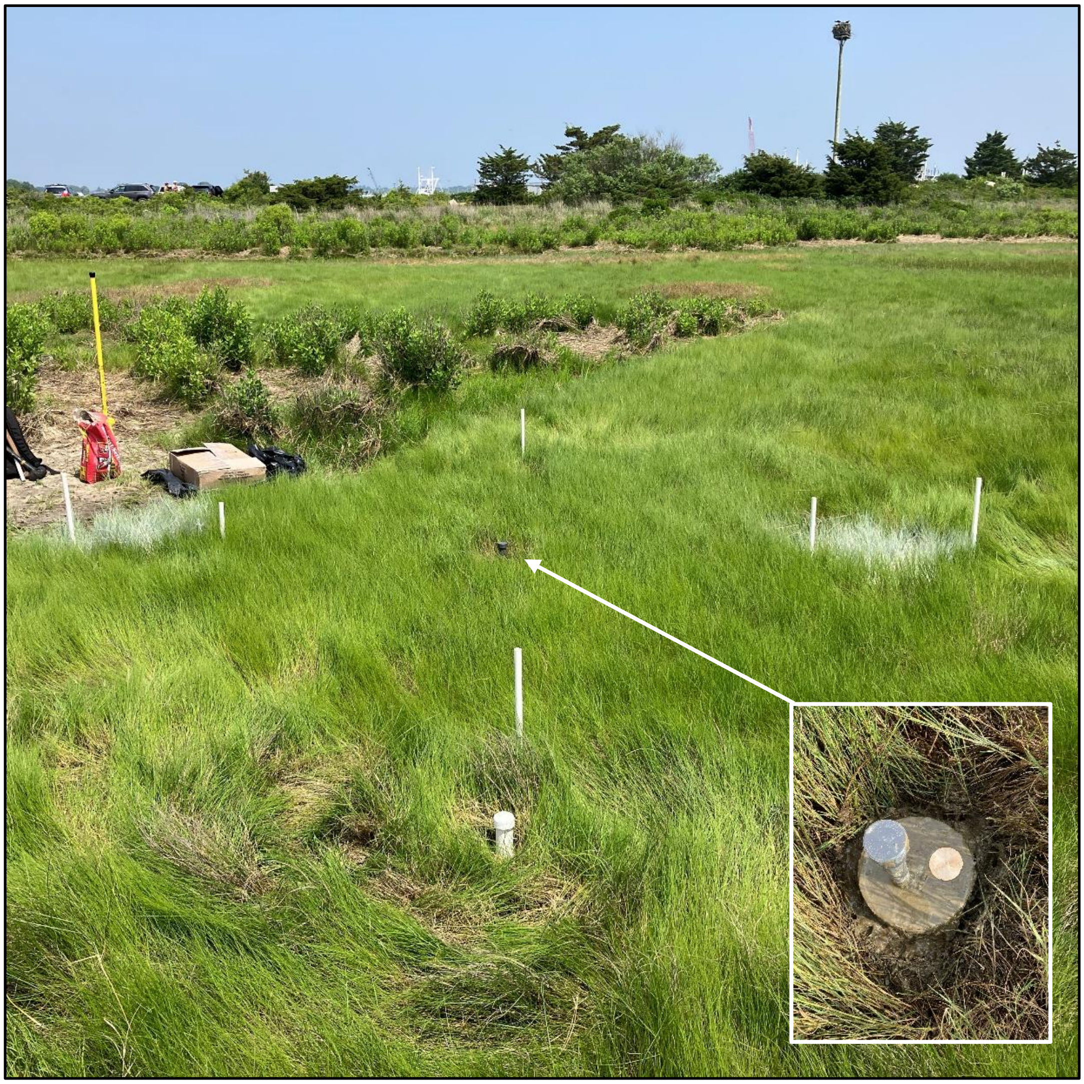

Figure 4. Newly installed surface elevation table (SET) station in the *Meadow High Marsh* at Succotash East marsh in Jerusalem, RI. The SET is in the center of the station, the feldspar marker horizons are evident in the right and left corners, and a water-level well has been installed in proximity to the closest corner. The inset shows the new receiver freshly set in concrete, with a brass marker inserted for SET identification and establishing an elevation datum for surrounding uses.

2.1.3 Edge-ecotone Stations

Edge-ecotone stations were installed to allow monitoring of changes in vegetated marsh edge (mainly loss) and marsh interactions with the adjacent landscape (mainly migration into uplands and shallow freshwater wetlands). Each station establishes a permanent stake from which plant indicators are measured along a 1-m-wide belt transect to characterize changes in vegetation presence and composition, over time, in response to changing climatic and tidal conditions. The stations were located at the seaward and landward ends of each of three (of the eight established) sampling transects (Sec. 2.1) resulting in three edge stations and three ecotone stations. Selection of the particular transects were random-stratified across each marsh. Stations were installed as detailed in the draft Salt Marsh Edge-ecotone Standard Operating Procedure (Raposa et al., in development; Appendix C). An example of monitoring along an edge-ecotone transect is shown in Figure 5.

Figure 5. Measuring plant and edaphic indicators along edge (left) and ecotone (right) transect stations in the Succotash East marsh in Jerusalem, RI in 2023.

2.1.4 Nekton Monitoring Stations

Stations for deploying nekton throw traps were established using GIS mapping tools. One throw-trap station was established at the seaward end of each transect, one station was established in every major tidal creek and large pool, and the remainder of 20 or more total stations was evenly distributed long the seaward shoreline between the transect-end stations. Rather than set physical stakes at each station, we created georeferenced digital (GeoPDF) maps to locate stations; these maps can be loaded onto mapping software (such as Avenza®) to reliably locate the stations in the field. The digital maps are permanently stored and accessible according to Tier-3 data storage protocols (Sec. 2.4). An example of nekton throw-trap sampling-station distribution is shown in Figure 6.

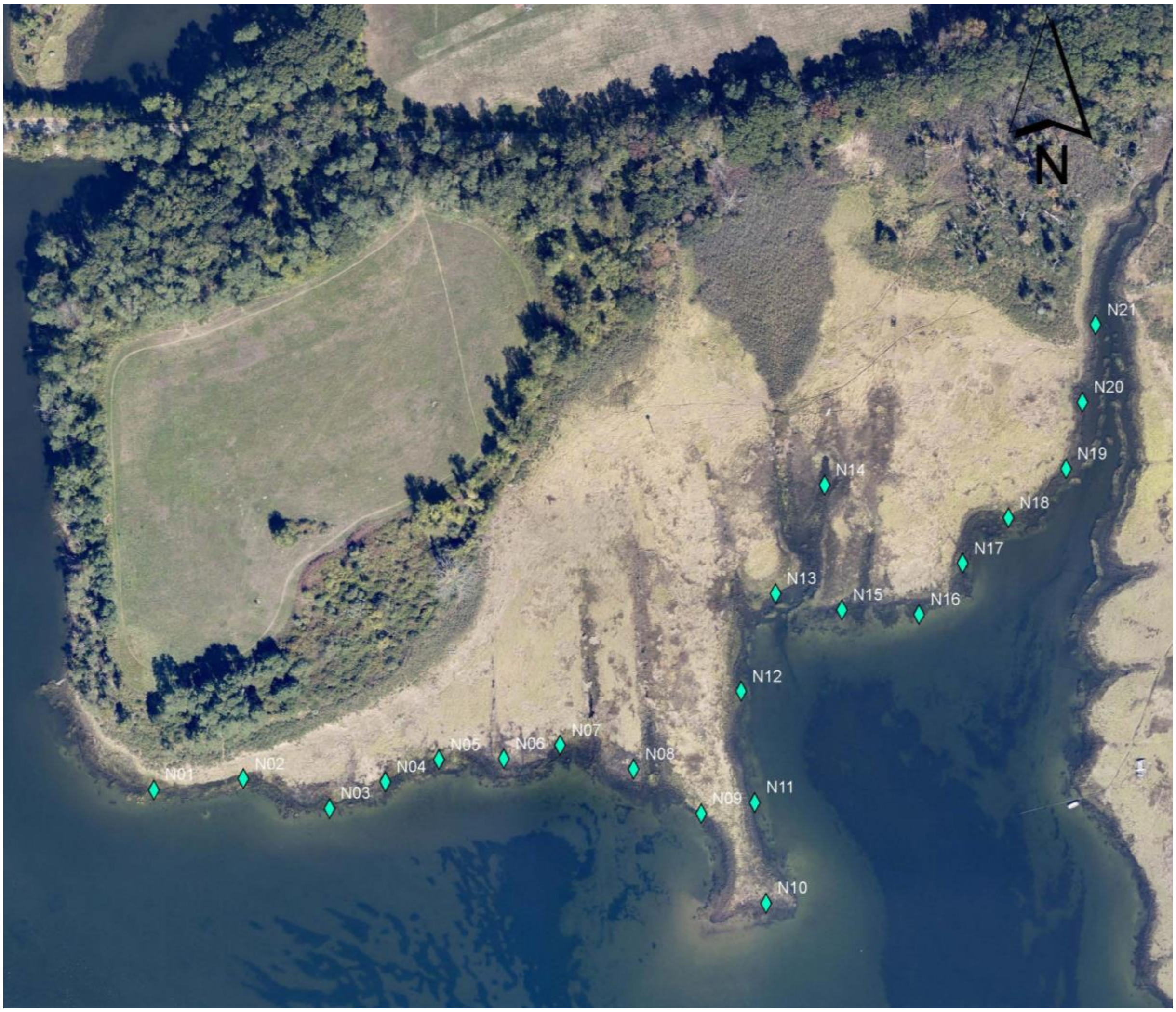

Figure 6. Excerpt from a georeferenced digital map of 21 nekton throw trap monitoring stations established in 2023 at Kickemuit School marsh in Warren, RI.

2.1.5 Water-level Loggers

Wells for monitoring water levels using Hobo™ brand digital loggers were installed in relation to SET stations at each of the new and incomplete long-term monitoring marshes. Specifically, one well was installed 1m outside of the corner of each of three SET stations per marsh (see Figure 4). We installed the well at the corner that was deemed (through best professional judgement) to be most representative of the associated SET location in hydrology and vegetation; typically, it was the corner equidistant to tidal water as the SET. Water-level wells were manufactured and installed according James-Perri et al. (2002) by perforating 70cm of 2-inch PVC pipe and driving it 60cm into the marsh soil with 10cm extending above the marsh surface. A single set screw was installed in the above-ground section of the well from which to hang the digital data logger using braided fishing line. A 2-inch PVC cap, drilled with a single hole to relieve internal pressure while precluding most rainwater, was installed atop each well.

2.1.6 Rapid Assessment Transects

Eight transects were established to guide vegetation surveys as part of the MarshRAM rapid assessment method. The transects were located as detailed in the MarshRAM User's Guide and outlined in Sec. 2.1 (Kutcher 2022a; Figure 2). Rather than set physical stakes at each transect end, georeferenced digital (pdf) maps were created to locate the transects; these maps can be loaded onto mapping software (such as Avenza®) to reliably locate and follow the transects in the field. The digital maps will be permanently stored and accessible according to Tier-3 data storage protocols (Sec 2.2). An example of a MarshRAM transect digital map is shown in Figure 7.

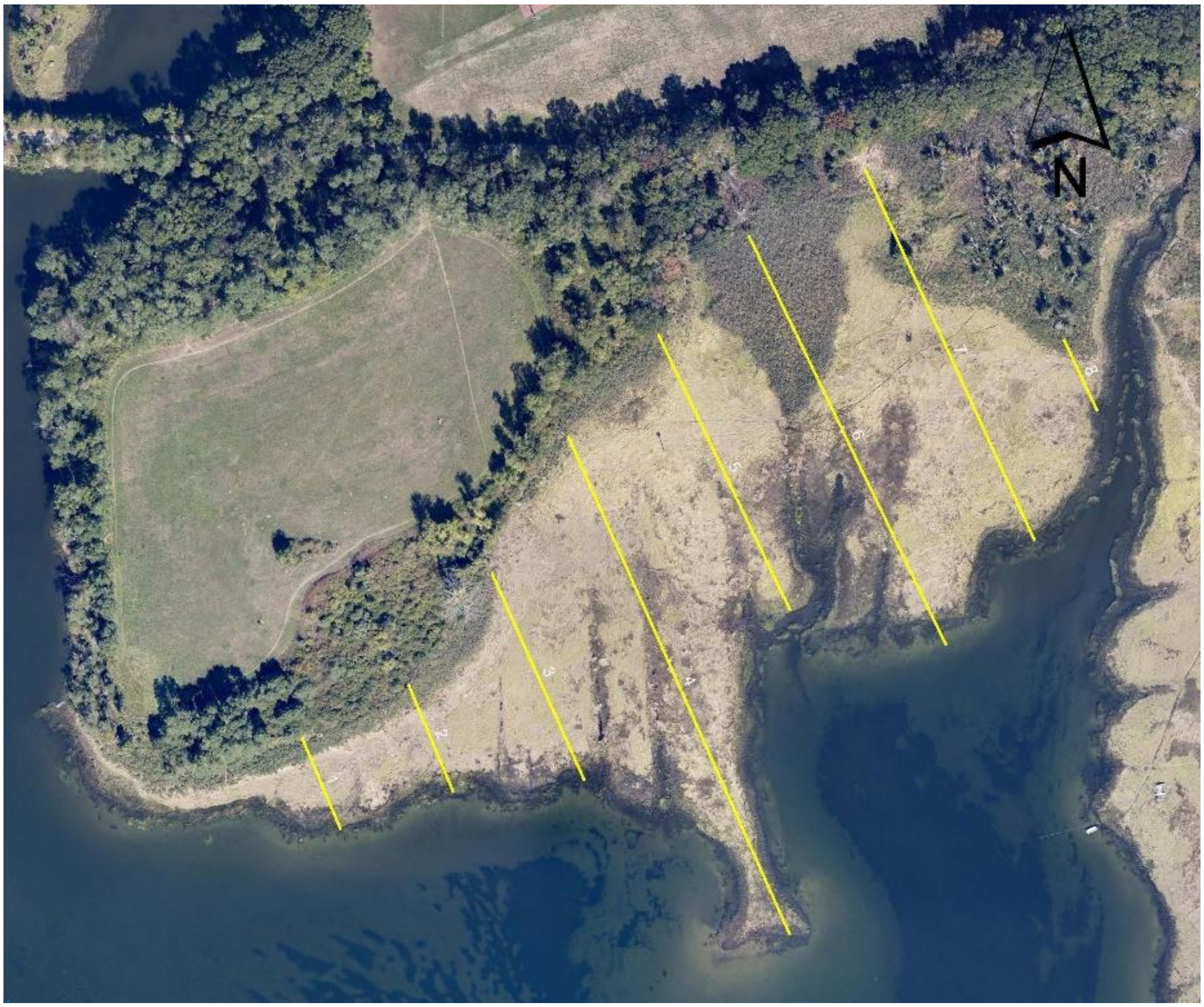

Figure 7. Excerpt from a georeferenced digital map of 8 MarshRAM rapid-assessment transects established in 2023 at Kickemuit School marsh in Warren, RI.

2.2 Digital Documentation for Transect and Station Locations

Transects and all station locations were recorded using ESRI ARCMap geographic information system (GIS) software to create geospatial files (shapefiles) to store the location information. A shapefile was created for the stations of each parameter across all six of the long-term monitoring sites (including new, incomplete, and existing sites). Additionally, georeferenced digital (GeoPDF) maps of stations for all parameters, both combined and individual, were created for each marsh. These maps can be loaded onto mapping software (such as Avenza®) to reliably locate the stations and follow the transects in the field; as such, they are excellent tools for guiding field work. The digital shapefiles and GeoPDF maps are meant to be permanently stored and accessible according to Tier-3 data storage protocols (Sec 2.4). Images of the combined-station GeoPDF maps for all of the Tier-3 salt marshes are shown in Appendices A and B.

2.3 Baseline Monitoring

Data were collected for parameters as outlined in Table 1. Data collection followed sampling methods detailed in the *Quality Assurance Project Plan (QAPP) for Nine Salt Marsh Monitoring and Assessment Methods* (DEM 2023) and its appendices, which is available in the *Methods* folder of the accompanying Database. The resulting data are also delivered to NBNERR and DEM in the Database as part of this project report (Sec. 2.4.1).

Specifically, vegetation data were collected between August and October, 2023 at Johannis Farm, Fox Hill, Kickemuit School, and Succotash East long-term monitoring marshes, according to James-Pirri et al. methods (2002). At Kickemuit School and Succotash East marshes, Onset Hobo™ water-level loggers were deployed for seven months in wells installed at each SET station, SET data were collected according to Callaway et al. (2013), and edge-ecotone data were collected according to the draft Edge-ecotone SOP (Raposa et al., in development; Appendix C). Lastly, MarshRAM was conducted according to Kutcher (2022a) in August, 2023, at the Succotash East site only.

No analyses have been conducted yet to compare new Tier-3 data with existing data among the long-term monitoring marshes. However, MarshRAM data from all six long-term monitoring marshes were set against existing MarshRAM data from 49 other reference marshes in Rhode Island to illustrate the condition gradient the long-term monitoring marshes now span. MarshRAM integrity scores ≥7.0 indicate marshes in least-degraded condition, whereas scores <5.7 indicate marshes in most-degraded condition (Fig. 8).

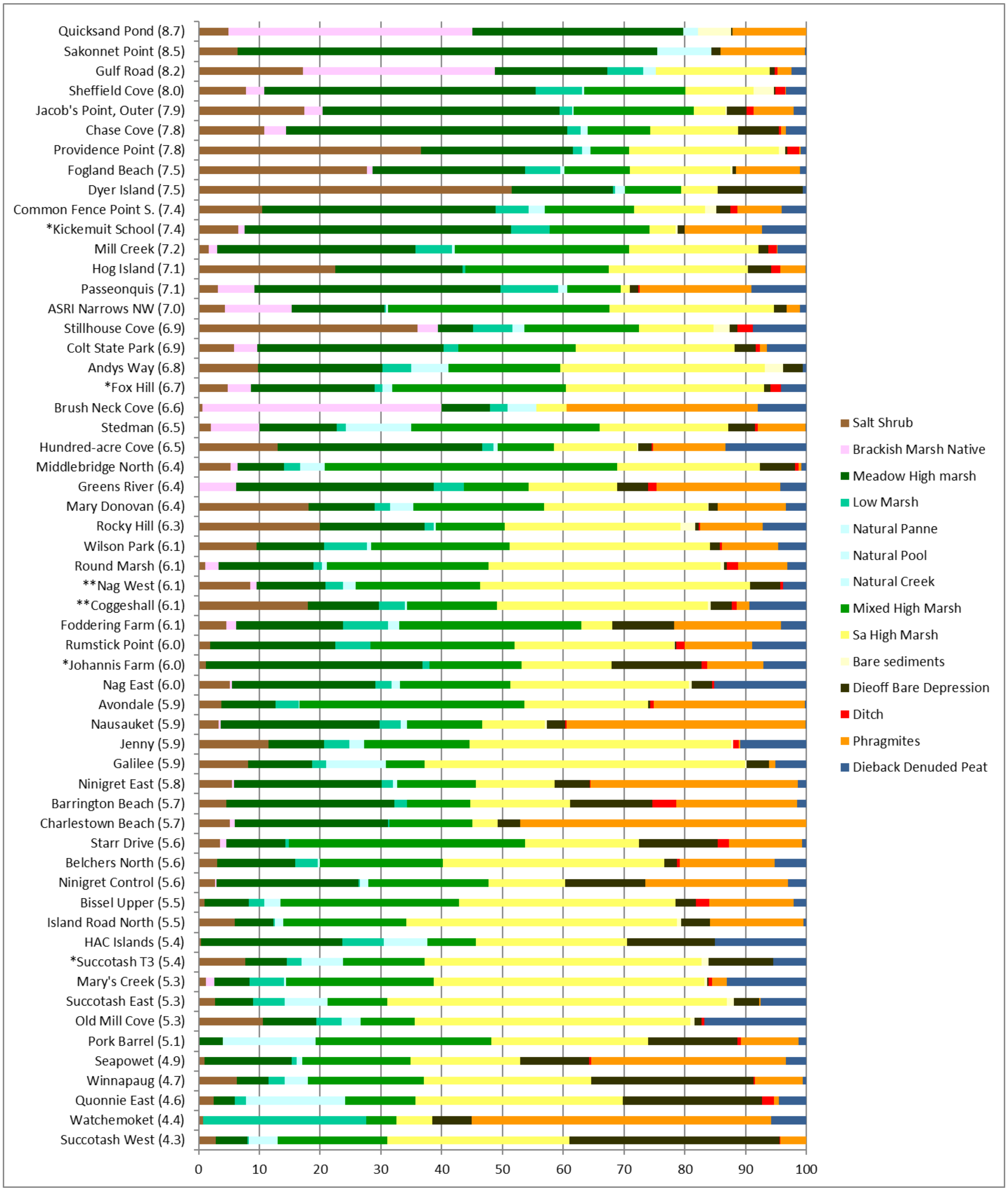

Figure 8. Estimated vegetation composition and Index of Marsh Integrity (IMI) values from 55 reference marshes across Rhode Island, including new* and existing** long-term monitoring marshes; extrapolated from Kutcher (2022b).

2.4 Storage System for Long-term Monitoring Data

This section makes recommendations for a data-filing and storage system for long-term salt marsh monitoring data. It also describes an electronic dataset that is delivered as part of this project to NBNERR and DEM, which contains sampling methods, sampling-station locations, and baseline data collected in 2023 at the long-term monitoring sites. The recommendations and dataset are described below.

2.4.1 Electronic Filing System and Database

An electronic filing system was developed to archive sampling methods, long-term monitoring station locations, and data. Folders and subfolders are organized as described in this section. The complete dataset is contained in the file folder named *Tier 3 Database*. Three subfolders contained within the *Tier 3 Database* folder contain the sampling methods (*Methods*), sampling-station locations (*Sampling Stations*), and collected data (*Tier 3 Data Archive*), as outlined in Table 3.

The *Tier 3 Data Archive* folder contains subfolders holding data collected for each parameter at each marsh. The subfolders are organized by monitoring parameter, then by the year collected (e.g. *2022*, *2023*), then by the sampling site, as needed (Table 3). Data files for each parameter within a year may be grouped to include multiple sites or separated into site folders, as most appropriate. The *T3 z Other Data* folder is meant to hold Tier-3 data that fall outside of the established Tier-3 parameters; this folder can also be organized by date, then by site, as appropriate. The *Data Archive* folder is delivered to DEM and NBNERR containing files for data collected in 2023 at the new long-term monitoring sites; older data from the long-term monitoring marshes can be added to this folder to organize data collected earlier.

The *Methods* folder contains subfolders holding the Tier-3 reference methodologies (*Source Methods*), field forms (*Field Forms*), standard operating procedures (*SOPs*, Section 2.4.3), and relevant quality assurance project plans (*QAPPs*), as available, for the Tier-3 sampling parameters. No further organization for these folders is recommended here. This folder is delivered to DEM and NBNERR containing source methods, field forms, and QAPPs for the common long-term monitoring parameters. A single draft SOP for edge-ecotone monitoring is delivered in the SOP subfolder as a demonstration for future SOPs. Sources, field forms, SOPs, and QAPPs for other methods can be added to the database as relevant and available.

The *Sampling Stations* folder contains two subfolders holding sampling-station location files for all the parameters at each marsh; one file holds georectified PDFs (*T3 GeoPDFs*) and the other holds GIS shapefiles (*T3 Shapefiles*). The GeoPDFs are organized by the site, with each subfolder holding GeoPDF files of each parameter mapped separately and a GeoPDF file of all the parameters mapped together. The shapefiles are organized into separate file folders by parameter (each shapefile is comprised of multiple files that work in GIS together), with each shapefile containing locations of the stations for a single parameter across all sites as shown in Table 3.

Table 3. Electronic file-folder format for the data, methods, and sampling locations for six long-term salt marsh monitoring sites in Rhode Island.

- Tier 3 Database
  - Data Archive
    - MarshRAM Data
    - T3 Edge-Eco Data
    - T3 Nekton Data
    - T3 SET Data
    - T3 Vegetation Data
    - T3 Water Level Data
    - T3 z Other Data
  - Methods
    - Field Forms
    - QAPPs
    - SOPs
    - Source Methods
  - Sampling Stations
    - T3 GeoPDFs
      - Coggeshall
      - Fox Hill
      - Johannis Farm
      - Kickemuit School
      - Nag
      - Succotash T3
    - T3 Shapefiles
      - Benchmarks
      - Eco-Edge
      - GW Wells
      - MarshRAM Trans
      - Nekton
      - SETs
      - Vegetation

2.4.2 Recommended File-naming Conventions

To organize data consistently across years and datasets, a standardized naming convention could be used for data files. File names should reflect the sampling parameter, the site, and the date collected, abbreviated for ease of use. The parameter, site name, and date should be listed, in that order, each separated by an underscore. The year should be listed, followed by the month and then the day to accommodate data that were collected over multiple days; the date can be abbreviated to only include the year or year and month, whichever is more appropriate. If the file contains multiple parameters, they should be hyphenated, with the most important parameter listed first, and if they contain data from multiple monitoring marshes, they should be listed in alphabetical order, separated by hyphens. Recommended abbreviations for parameters are as follows: Vegetation = VEG, Nekton = NEK, Groundwater Level = GWL, Ecotone-edge = ECO, Surface Elevation Table = SET, etc. Recommended abbreviations for the long-term monitoring sites are as follows: Coggeshall = COG, Nag West = NAG, Fox Hill = FOX, Johannis Farm = JOH, Kickemuit School = KIC, Succotash T3 = ST3, and all stations collectively = ALL. So, for example, a file containing nekton data collected at Johannis Farm on July 20, 2023 would be named NEK_JOH_20230720, whereas nekton data collected across multiple days in July would be named NEK_JOH_202307, and nekton data collected across all long-term monitoring marshes across 2023 would be named NEK_ALL_2023.

2.4.3 Standard Operating Procedures

Standard operating procedures (SOPs) are instruction manuals that detail all aspects of implementing a specific task, such as a sampling method. An SOP for ecological sampling typically covers methods for sampling a single parameter (e.g. vegetation) for a particular purpose (e.g. long-term monitoring). A draft SOP for the new Edge-ecotone monitoring method (Raposa et al., in development), formatted according to EPA guidelines (U.S. EPA 2007), is attached as Appendix C to demonstrate the format. This SOP format can be applied for other Tier-3 parameters to improve consistency for Tier-3 monitoring. Although the Tier-3 methods generally follow published methodologies and are well known among current RAMP practitioners, commonly-used modifications to those methodologies have not been well documented; SOPs documenting the methods and their modifications would be helpful for program clarity and continuity. It is therefore recommended that the RAMP program develop detailed SOPs for all of the Tier-3 parameters.

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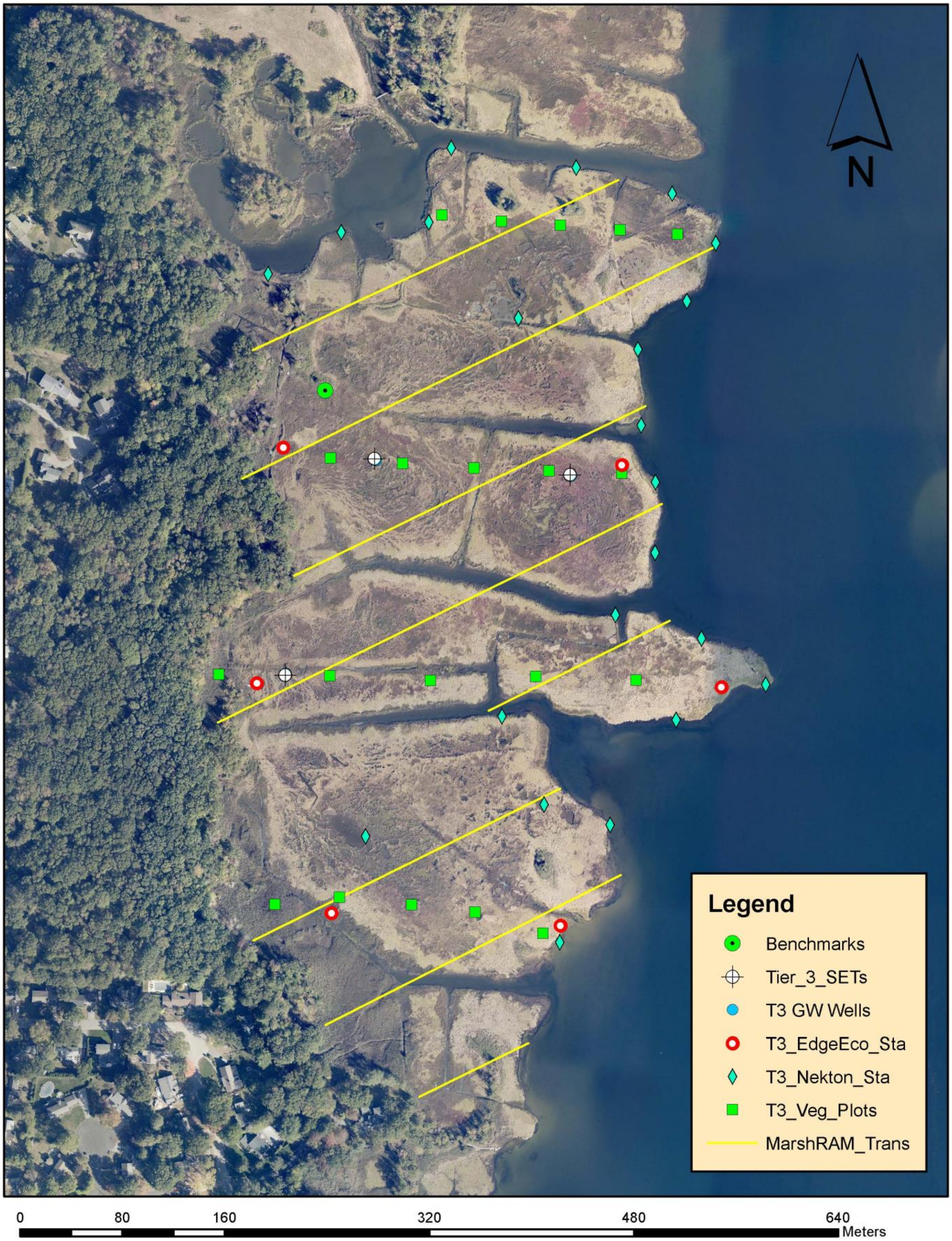
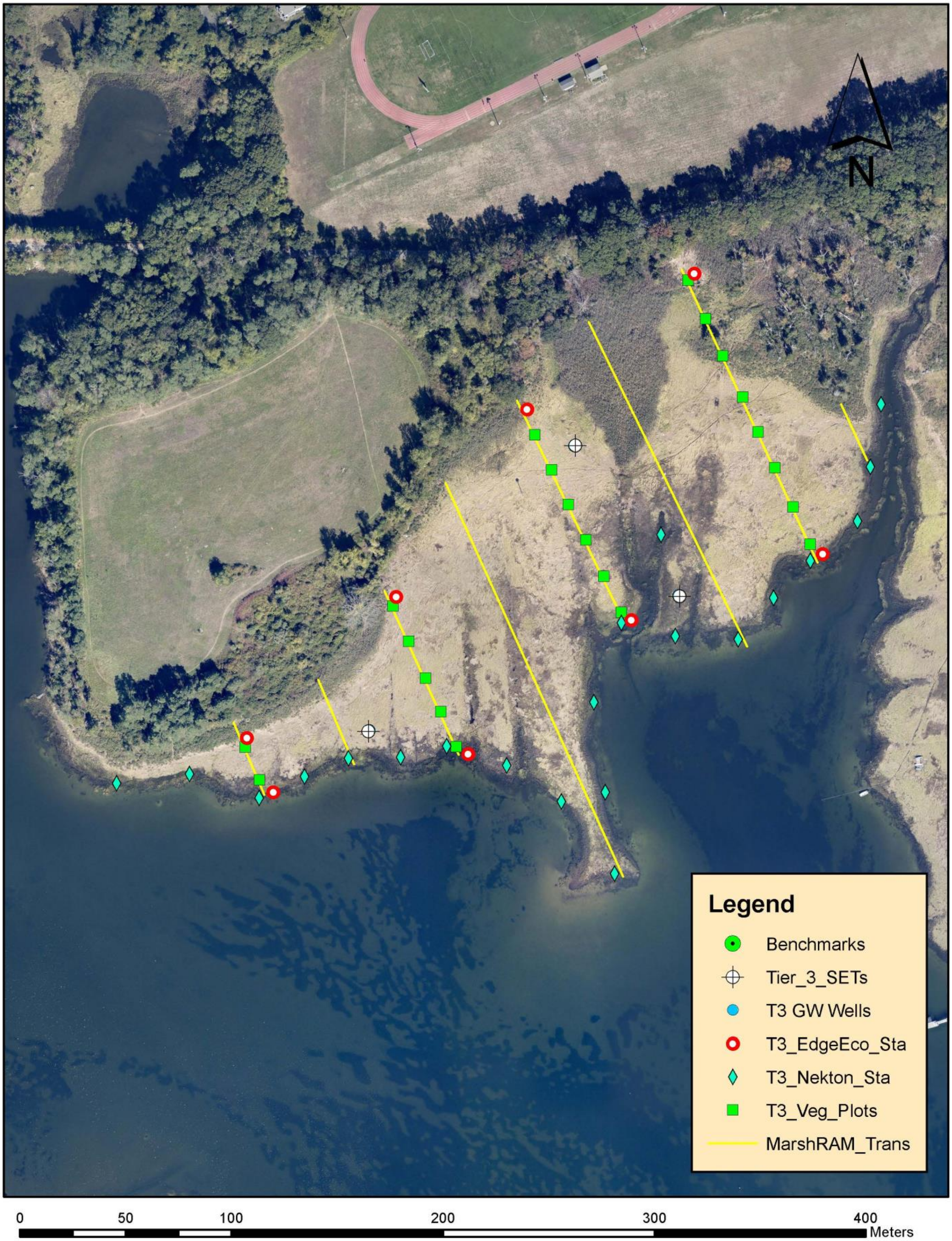
Appendix A

Monitoring station locations at four long-term salt-marsh monitoring sites in Rhode Island established in 2023

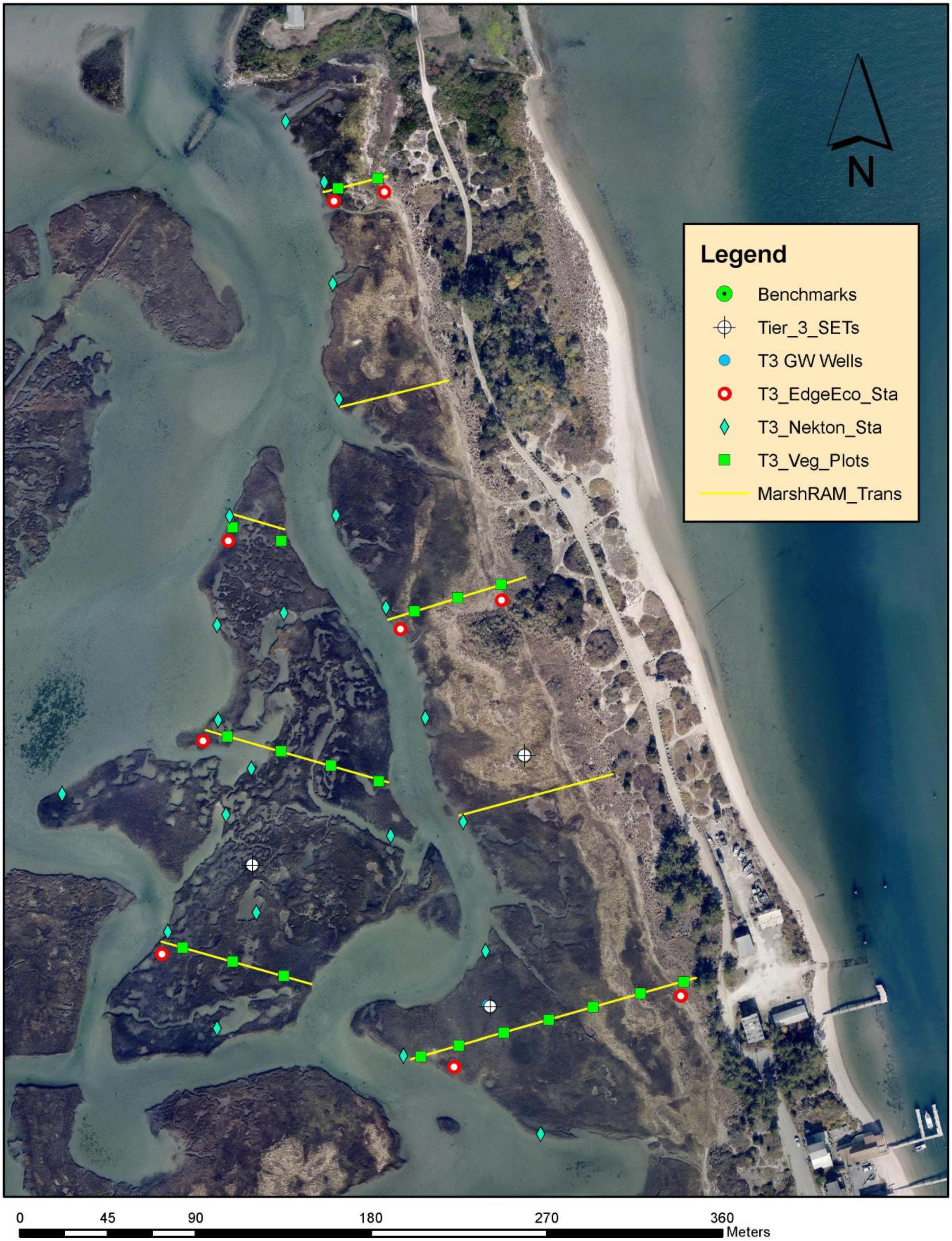
Monitoring locations for Fox Hill Marsh long-term monitoring site; 41.4902 N, 71.3952 W



Monitoring locations for Johannis Farm Marsh long-term monitoring site; 41.7599 N, 71.2885 W



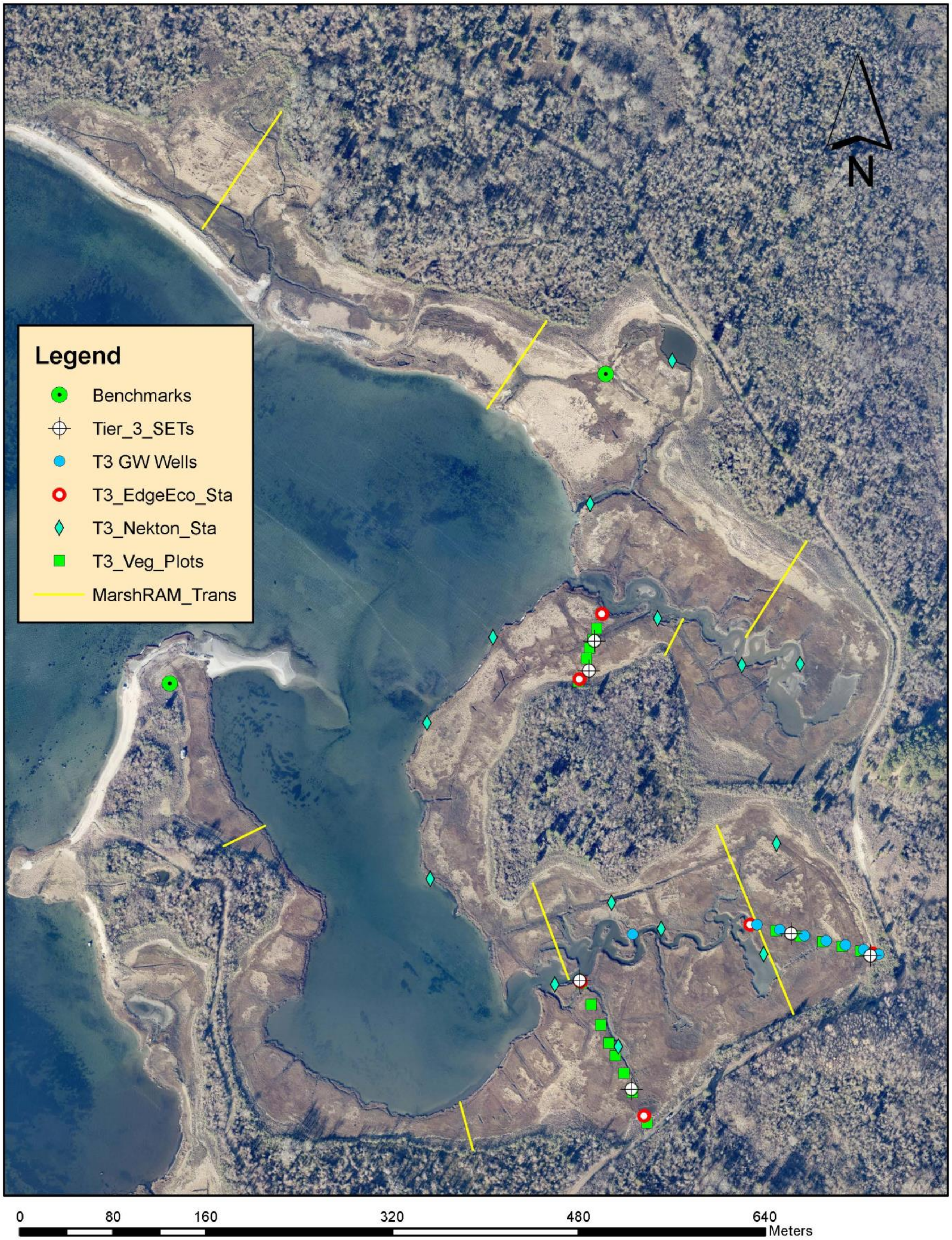
Monitoring locations for Kickemuit School Marsh long-term monitoring site; 41.7247 N, 71.2594 W



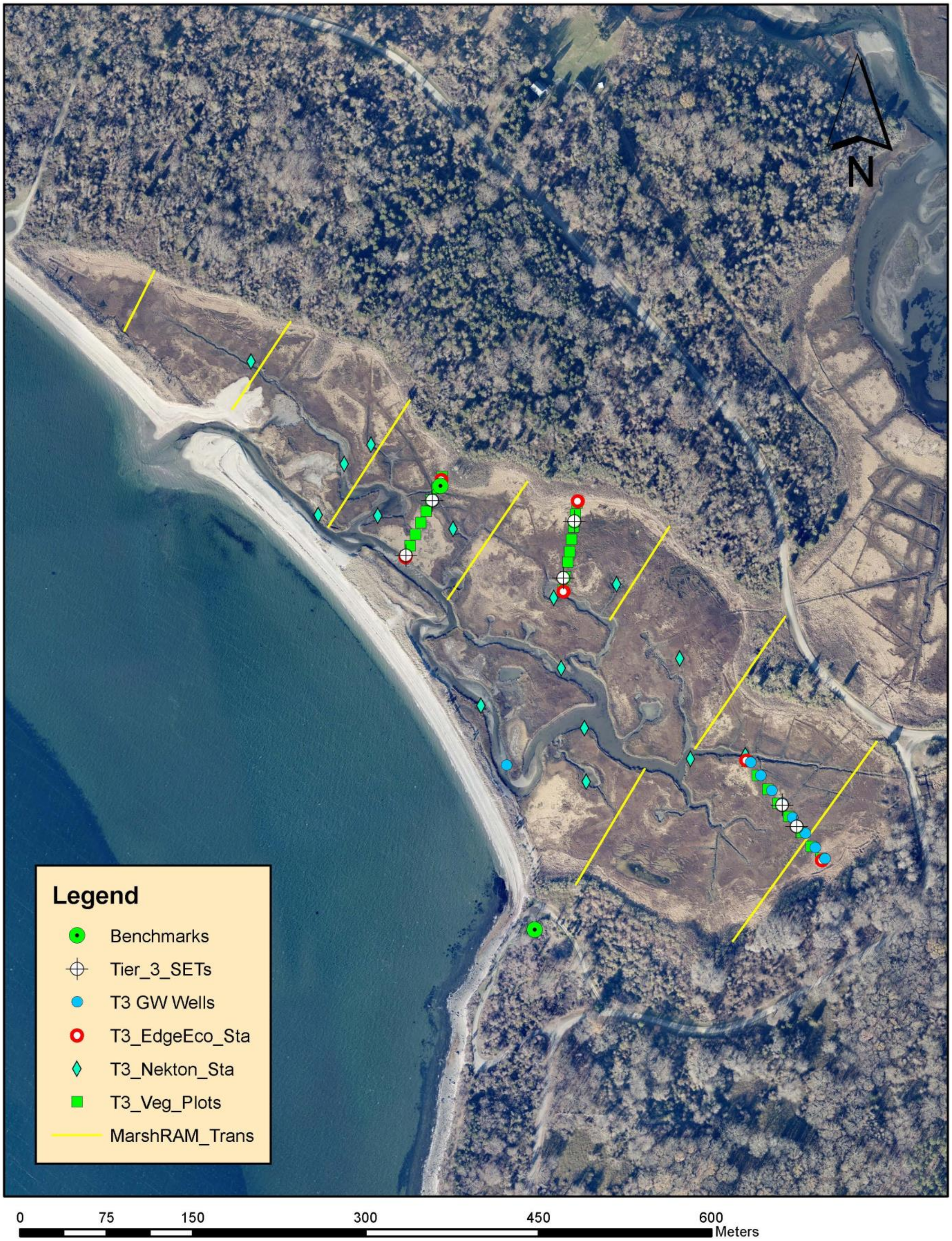
Monitoring locations for Succotash T-3 long-term monitoring site; 41.3814 N, 71.5186 W

Appendix B

Monitoring station locations at two long-term salt-marsh monitoring sites located in the Narragansett Bay National Estuarine Research Reserve on Prudence Island, RI



Monitoring locations for Coggeshall Marsh long-term monitoring site; 41.6528 N, 71.3433 W



Monitoring locations for Nag West Marsh long-term monitoring site; 41.6255 N, 71.3248 W

Appendix C

Standard Operating Procedure for Edge Ecotone Monitoring in Rhode Island
Draft in Development

Standard Operating Procedure

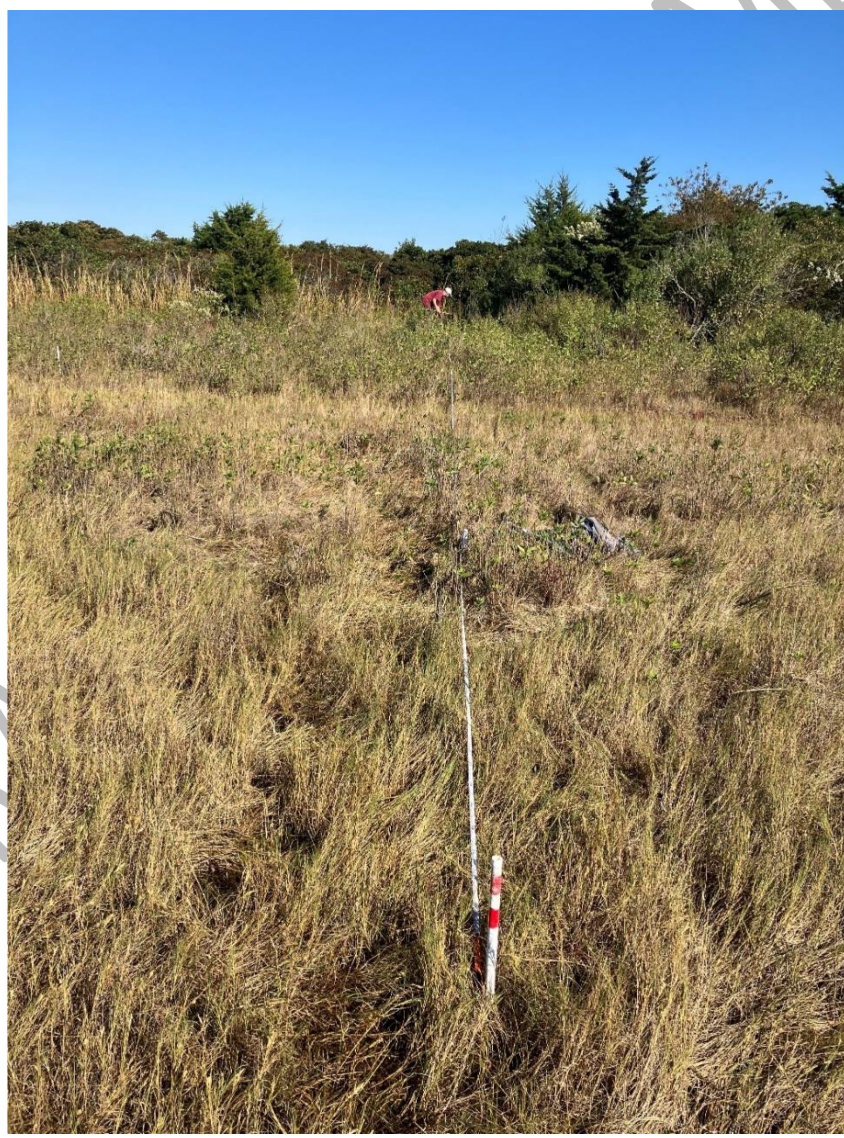
Salt Marsh Seaward-Edge and Landward-Ecotone Monitoring

DRAFT IN DEVELOPMENT

Prepared by Kenneth B Raposa, Jonathan Mitchell, and Thomas E. Kutcher for

Narragansett Bay National Estuarine Research Reserve

March 2024



1. Background

Salt marshes are important coastal wetlands that are critically threatened by rapidly accelerating sea-level rise. In the past five decades, salt marshes in Rhode Island have lost 12% of their vegetated area from tidal edges and the marsh surface, caused by inundation stress to the vegetation and soil. As sea-level rises, salt marshes can also gain area vegetated through landward migration into uplands and shallow freshwater wetlands if physical and biological conditions allow, but combinations of conditions may impede or facilitate marsh migration to various degrees. Managers can make more informed decisions to conserve marsh area by monitoring rates of edge loss and landward migration and identifying the physical and biological factors that affect those rates. This document details the standard operating procedures (SOP) for monitoring changes in the seaward edge and the marsh-upland ecotone of salt marshes for the State of Rhode Island. Following this SOP helps ensure quality and comparability of data across projects, space, and time.

2. Definitions

Ecotone: The transition zone where one ecosystem overlaps an adjacent ecosystem. For salt marshes, the upland ecotone contains species characteristic of both salt marshes and adjacent uplands.

3. Method Overview

Salt marsh edge erosion and landward migration are monitored in the field by using a surveyor's tape to measure the lateral movement of vegetation **indicators** along representative 1.0-m-wide linear transects in relation to permanent PVC stakes. Transects traverse the salt marsh from the upland to the tidal water's edge. Two sampling stations are located along each transect; a seaward station to characterize vegetation movement and erosion along the marsh tidal edge (hereafter, **tidal edge** station), and a landward station to characterize vegetation movement and changes in the marsh-upland ecotone (hereafter, **ecotone** station). At each station, all measurements to the indicators are taken in relation to a **base stake**, which is secured with steel rebar driven deep into the marsh soil. The direction of the sampling transect is guided by **guide stakes**, situated centrally along each transect, as needed to guide the investigator in maintaining a consistent straight line when sampling. Other physical and biological conditions of the marsh edges, such as slope, soil type, and dominant vegetation cover are documented when each transect is established. Changes in the distance and composition of the various indicators, in relation to the base stakes, are analyzed over time to characterize the rates of marsh erosion and landward migration under various documented conditions.

4. Site Selection

Sites should be selected according to the objectives of the project. For example, for characterizing the migration patterns of marshes across a geographic area, sites would be selected to broadly represent environmental conditions of the region, such as marsh hydrogeomorphology and adjacent physical, biological, and cultural conditions of the migration corridor. An individual salt marsh sampling site is typically selected based on full or partial geographic or hydrologic isolation from other marshes by any combination of upland, surface water, or manmade features. In contrast, for some projects, the characteristics of a marsh site as a whole will be less important than the characteristics of the individual transects, such as when studying certain physical aspects of migration such as slope, soils, or vegetation cover; in these cases, sites can be selected based on containing areas representative of the conditions needed for the project (see Sec. 6.1).

5. Equipment

5.1 Sampling Station Installation Equipment

1. Base stakes: **3' of ½" PVC pipe and 4' of ½" rebar per stake** x 1 stake per station (x 2 stations per transect)
2. **Bright red exterior paint** and **masking tape** to mark the Base Stakes
3. Guide stakes: **3' of ½" PVC pipe per stake** x 1 or more stakes per station
4. **Dremel® tool** and **fine-tip permanent markers** for etching and labeling the stakes
5. **50-meter measuring tape** to locate stakes along the transect
6. **3-lb sledge hammer** or similar to drive stakes into the marsh soil
7. **Field map of transect locations** (see Sec. 6.2)
8. **Surveyor's transit and rod** for collecting slope and elevation data (Sec. XX)
9. **Soil sampling kit:** spade, zip-lock bags, marker

5.2 Sampling Equipment

1. **50-meter measuring tape**, survey quality, for making field measurements
2. **Meter stick** for delimiting transect width and making fine measurements
3. **Chaining Pin**
4. **Flagging tape** for highlighting the locations of base and guide stakes
5. **Plastic plant labels**
6. **Field map of transect locations** (see Sec. 6.2)
7. **Field Datasheets** (Appendix X), **pencil, and clipboard** for recording data; one datasheet per transect
8. **Datasheet from a prior year** to act as a reference
9. **Camera**

6. Sampling Setup

6.1. Establish the Transect Locations

Choose the transect-location method that best serves the objective of the project. For projects aimed at characterizing changes to marsh edges at an individual marsh or a group of representative marshes, use Method 1; for projects aimed at characterizing edge changes under certain conditions, use Method 2.

6.1.1. Method 1. Characterizing a Marsh

The objective is to establish at least 3 randomly-located, yet evenly-spaced transects running from the upland to the seaward edges of the marsh. Use the transect method from Kutcher (2022), modified for the number of transects desired, to locate the transects as needed (Appendix 1). For practical purposes, and where they are already in place, existing vegetation or rapid assessment transects can be used to locate the tidal edge and ecotone stations.

6.1.2. Method 2. Characterizing Certain Conditions

Use any combination of prior knowledge, photointerpretation of recent imagery, and field inspections to identify the range of conditions identified for characterization or comparison in the project. For example, the sampling may investigate the rate of landward migration across shallow-sloped coastal shrubland versus shallow-sloped coastal grasslands. Locate at least two transects in each set of conditions. The paired transects need not be within the same marsh and should not be closely adjacent to each other, so they can act as replicates.

6.2. Create a Digital or Paper Field Map

Locating transects and sampling stations for installation and sampling requires a field map. The field map can be displayed in paper or digital format and should depict the transects and sampling stations, including stake locations, overlaying high-resolution aerial photography. A paper map can be used to locate the transects and stations in relation to recognizable natural or manmade features on or near the marsh, such as pools, creeks, ditches, trees, etc., whereas a digital map can be loaded onto a GPS device, smart phone, or tablet to display the location of the user in relation to the sampling stations, which makes finding the sampling locations more efficient. Use of a digital map is highly recommended.

6.3. Stake Placement and Installation

6.3.1. Tidal Edge Stake Location

Locate the tidal edge stakes along the transect on a grassy part of the high marsh platform. Locate and install the base stake 10m from the seaward extent of vegetation (>30% cover of marsh grass) closest to the transect. Locate and install the first guide stake halfway between the Base Stake and the edge of the marsh grass directly perpendicular to the marsh edge; the guide stake does not need to run along the transect.

6.3.2. Ecotone Stake Location

Locate the ecotone base stake along the transect in the high marsh, ~2 m from the start of the ecotone zone. Locate the first guide stake at the seaward edge of the ecotone directly perpendicular to the edge. Install additional guide stakes directly in line with the base stake and the primary guide stake, as needed to act as a visible guide for the direction of the measuring tape. As needed, adjust the guide stake length and height to be visible to the investigator in the vegetation being sampled. A terminal guide stake is placed beyond the ecotone edge, in the upland; the terminal stake may be easiest to install in the winter, when the vegetation is thinner.

6.3.3. Installing the Stakes

Use a small sledge hammer to drive the stakes into the marsh soil as plumb as possible in all directions. Install the Base Stake by inserting the rebar into the PVC stake and driving them in together until the top of the stakes are located 0.5m above the marsh surface. If needed to facilitate measuring in dense vegetation, additional Guide Stakes can be installed by driving them into the marsh soil until the top of the stakes are located 0.3m above the marsh surface or as tall as surrounding vegetation, and used as listed below.

1. Run out a tape measure, keeping it taut so there is no slack (ideally the tape will be extended flush with the marsh surface, but it can also be extended at height, as long at the tape is taut), and sink additional PVC stakes into the marsh at intervals to facilitate accurate measurement of indicators
2. Intervals can be regular (e.g., every 3 m) or at other distances, as long as the tape measure can be easily extended and kept taut between two sequential stakes (e.g., the interval could be 5 m or more if going across a road or grassy habitat; conversely it might need to be <3 m in very thick or shrubby vegetation)
3. Use the cordless dremel to etch the distance (in meters, out to two decimal places; e.g., "2.46") from the starting stake on each subsequent stake
4. The starting stake will be etched with the name of the transect and "0.00"

6.3.4. Moving the Tidal Edge Stakes

As the tidal marsh edge erodes, the guide stake, and eventually the base stake, may need to be moved away from the eroded edge before erosion undermines the setup. The guide stake can be moved directly toward the base stake until it is within 2m of the base stake, beyond which, the base stake should also be moved. If the base stake needs to be moved, it should be moved exactly 10m away from its original location directly in line with the original sampling transect. Distances between the new base stake location and the seaward edge will need to be adjusted by 10m in the datasheet so that vegetation loss or movement values will remain continuous in the data.

6.4 Characterize the Landward Migration Corridor Under development at the time of this draft

6.4.1 Determine Slope and Elevation

Use a surveyor's transit and rod to characterize the slope elevation at 5, 10, 20, 30, 40m
for xx meters
Calculate slope to XX m

6.4.2. Characterize the Vegetation

Cover type and dominant species of canopy and understory vegetation

6.4.3. Characterize the Soils

Use a soils map or dig a few pits ourselves?

6.4.4. Characterize any land use that may affect migration

Land use type and distance to it. Roads, mowed areas, buildings.

7. Sampling Methods

7.1. Moving along the belt transect

1. Upon reaching a transect, start with the tidal edge station, then proceed to the ecotone station.
2. Before running out the tape measure, slowly move along the transect, starting from the beginning, and try to determine the general location of the first indicator to measure
3. Once identified, place the end of the transect tape over the tip of the chaining pin
4. Place the chaining pin into the marsh, directly adjacent to stake that is closest to the indicator at the marsh-ward (back) edge of the stake.
5. Run the tape measure out to the base of the next stake and slowly wrap it around the pipe to keep it taut
6. Return to the start of the tape measure, **being careful to walk around the transect and not through it**
7. Using the meter stick, now move along the transect towards marsh edge or ecotone, keeping the meter stick perpendicular to and centered on the tape (e.g., 50 cm mark is centered on the tape) to create a 1-m wide sampling transect.
8. Keep moving along the sampling transect until the meter stick encounters the first indicator for that transect according to **Table 1.**

7.2. Measuring a migration indicator

1. Once the meter stick hits the main stem of any of the plant indicators within the 1-m wide sampling transect, use the measuring tape to record the distance, in meters, out to two decimal places (e.g., "5.34"). **Note that only the living main stem of an indicator counts as a "hit"; leaves/flowers/etc. and dead plants do NOT count as indicators (Fig. 2)**
2. Add the measured distance to the distance etched into the stake at the start of the tape measure
3. Record distance from the start of the base stake to the indicator on the field sheet (= distance from base stake to guide stake + distance to indicator).
4. Place a color-coded plant label (**Table 2**) directly adjacent to the stem of the indicator plant to mark for the next round of monitoring

5. Continue along the transect until all indicators for that transect have been recorded, moving the chaining pin and start of the transect tape to the next appropriate stake to ensure the tape is always extended taut
6. Note that it is probable that all of the possible indicators on the master list will not be present on a given transect

7.3. Measuring indicators behind the starting stake

1. For indicators that fall in the opposite direction from the starting stake (i.e., behind the stake, backwards into the marsh (**Fig. 1**), simply turn the tape 180 degrees (pivoting on the chaining pin) and measure as described above.
2. **Record the value as a negative number in relation to the base stake** (e.g., -1.23 m for landward extent of *S. alterniflora* near the upland edge)

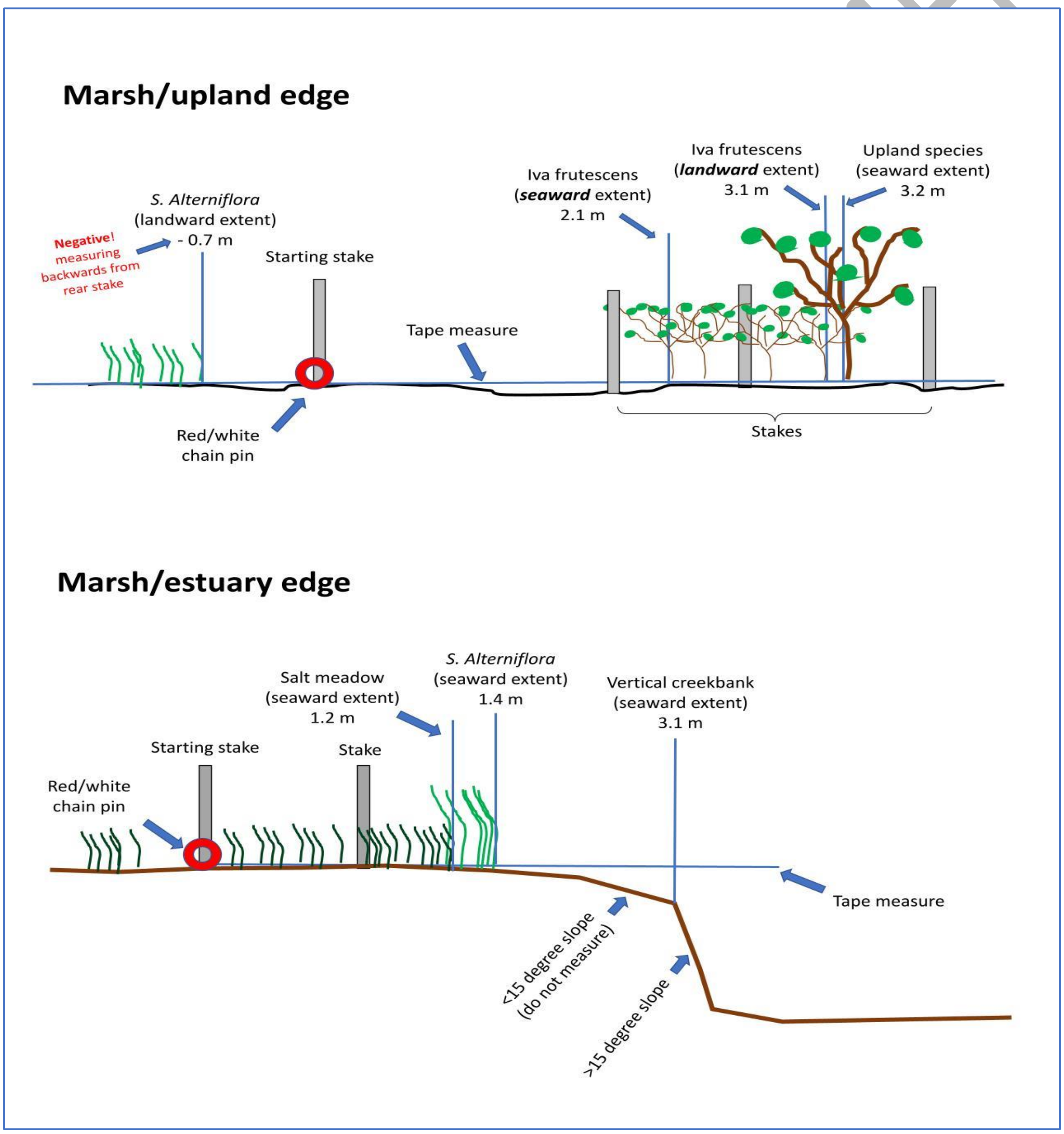


Figure 1. Schematic of an ecotone monitoring transect at the marsh/upland border (top) and the marsh/estuary border (bottom). Note that stakes are placed closer together in the shrubs near the upland edge, and that only two stakes might be needed near the water. See Table 1 for explanation of how to measure the seaward extent of vertical creekbank edges.

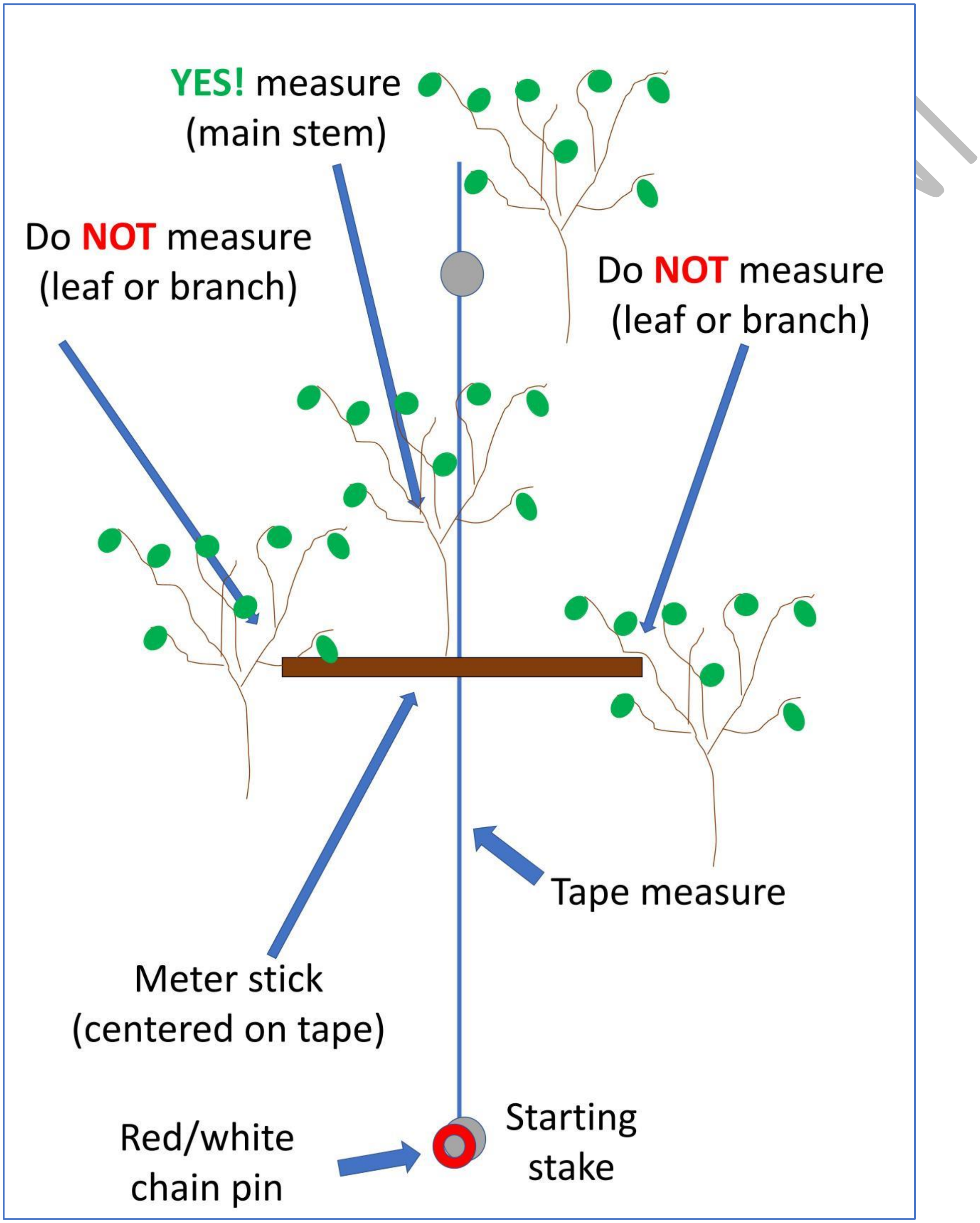


Figure 2. Hitting and measuring a vegetation indicator. This example shows a transect run from the base

stake toward the marsh/upland border, with *Iva frutescens* within the sampling transect area. To measure **seaward extent** of *I. frutescens*, note that the first plants are not measured because only leaves or branches fall within the belt transect. The measurement is ONLY taken when hitting the first stem within the transect.

Table 1. Master list of migration indicators, including subsets (marked with an 'X') that are used at existing monitoring transects in Coggeshall and Nag West sentinel sites marshes. **Note** that metrics shaded gray have not been successfully measured in Coggeshall or Nag, but they could be in the future (typically, it has been near impossible to reach far enough into the upland ecotone to get to the end of the *S. patens/J. gerardii* zone due to extremely heavy invasives and brush cover).

		Coggeshall			Nag West		
		T1	T2	T3	T1	T2	T3
Marsh/estuary edge	Vertical* creekbank (seaward extent)	X	X	X	X	X	X
	Spartina alterniflora (seaward extent)	X	X	X	X	X	
	Any salt meadow species** (seaward extent)						X
Marsh/upland edge	*Spartina alterniflora* (landward extent)	X	X	X	X	X	X
	Spartina patens (landward extent)	?	?	?	?	?	?
	Juncus gerardii (landward extent)	?	?	?	?	?	?
	Iva frustesens (seaward extent)	X	X	X	X	X	X
	Iva frustesens (landward extent)	X	X	X	X		
	Baccharis halimifolia (seaward extent)	X		X	X	X	X
	Baccharis halimifolia (landward extent)	X		X			
	Any brackish species*** (seaward extent)				X		
	Any brackish species*** (landward extent)				X		
	Phragmites australis (seaward extent*)*		X				
	Any woody upland species**** (seaward extent)						
	Any non-woody upland species**** (seaward extent)	X	X	X	X	X	X
	Any other indicator relevant to that transect						

* a vertical creekbank edge is one that slopes more than ~15 degrees away from the horizontal platform plane

** salt meadow species include *S. patens*, *Distichlis spicata*, and *J. gerardii*

*** example brackish species include *Schoenoplectus* spp., *Typha*, *Eleocharis*, etc

**** measure and record the name of the first non-woody (e.g., grass, fern, yearling shrub) AND woody (e.g., mature shrub, tree) upland species hit on the trans