**Quality Assurance Project Plan (QAPP) for Nine Salt Marsh Monitoring and Assessment Methods**
**August 8, 2024**

Period of Applicability Generic QAPP - August 2024 through July 2029
Current EPA WPDG # CD00A01323 / EPA QA Tracking # QA24157

**State of Rhode Island**
**Department of Environmental Management**
**Office of Water Resources and**
**Narragansett Bay National Estuarine Research Reserve**

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## A3. Table of Contents

APPENDIX A. MarshRAM User's Guide (Kutcher 2022)
APPENDIX B. Field Methods Manual: US Fish and Wildlife Service (Region 5) Salt Marsh Study (James-Pirri et al. 2002)
APPENDIX C. SMI Avian Point-Count/Callback Survey Protocol (revised 2012)
APPENDIX D. Ecotone Monitoring Protocol (Raposa and Mitchell 2022)
APPENDIX E. The Surface Elevation Table - Marker Horizon Method for Measuring Wetland Accretion and Elevation Dynamics (Callaway et al. 2013)

# A. PROJECT MANAGEMENT

## **<u>A3. Distribution List</u>** (EPA QA/R-5 A3)

- Signatories (Title Page)
- EPA Region 1, New England Wetlands Monitoring Coordinator, Beth Alafat
- EPA Region 1, RI State Wetlands Contact, Erica Sachs-Lambert
- Rhode Island Coastal Resources Management Council (CRMC), Policy Analyst
- Rhode Island Natural History Survey (RINHS), Wetlands Scientist, Thomas Kutcher

## **A4. Project Organization** (EPA QA/R-5 A4)

Henceforth, the Department of Environmental Management (DEM) Office of Water Resources and the Narragansett Bay National Estuarine Research Reserve (NBNERR) will be the lead agencies to co-manage and implement this project. DEM has contracted with the RI Natural History Survey (RINHS) and the RINHS has recruited and hired staff. Qualified and experienced personnel are available to execute the work. The following people will administer and conduct this work as outlined below and depicted in Figure 1.

- Michele McCaughey, Environmental Scientist III, DEM Office of Customer and Technical Assistance (OCTA) - Quality Assurance Manager;
- Anthony Pepe, EPA Region 1 - Quality Assurance Manager and QAPP reviewer;
- Donna Smith-Williams, EPA Region 1 - WPDG Project Officer and primary point of contact;
- Susan Kiernan, Administrator, DEM Office of Water Resources – DEM Program Manager, Responsible for contract agreement and fiscal grant management, and general program oversight;
- Caitlin Chaffee, Manager, NBNERR – Responsible for project management and communication;
- Kenneth Raposa, PhD., Research Coordinator, NBNERR – Project Quality Assurance Officer. Experienced salt marsh research ecologist with over 30 peer-reviewed publications, salary-funded externally to this QAPP. Responsible for data review, quality assurance as described below, report writing, supervision of field staff, and other duties consistent with this QAPP;
- David Gregg, RINHS, Executive Director – Responsible for contract management and supervision of RINHS staff; and
- Thomas Kutcher, Wetland Scientist, RINHS – Responsible for field and office data collection, entry and analysis, QAPP and report writing, and supervision of field staff.

Project Quality Assurance Manager Independence

The Quality Assurance Manager (QAM) is a salaried state employee working independently of the environmental information operations subject to this QAPP. The QAM will not be involved with the program or project management of the Project.

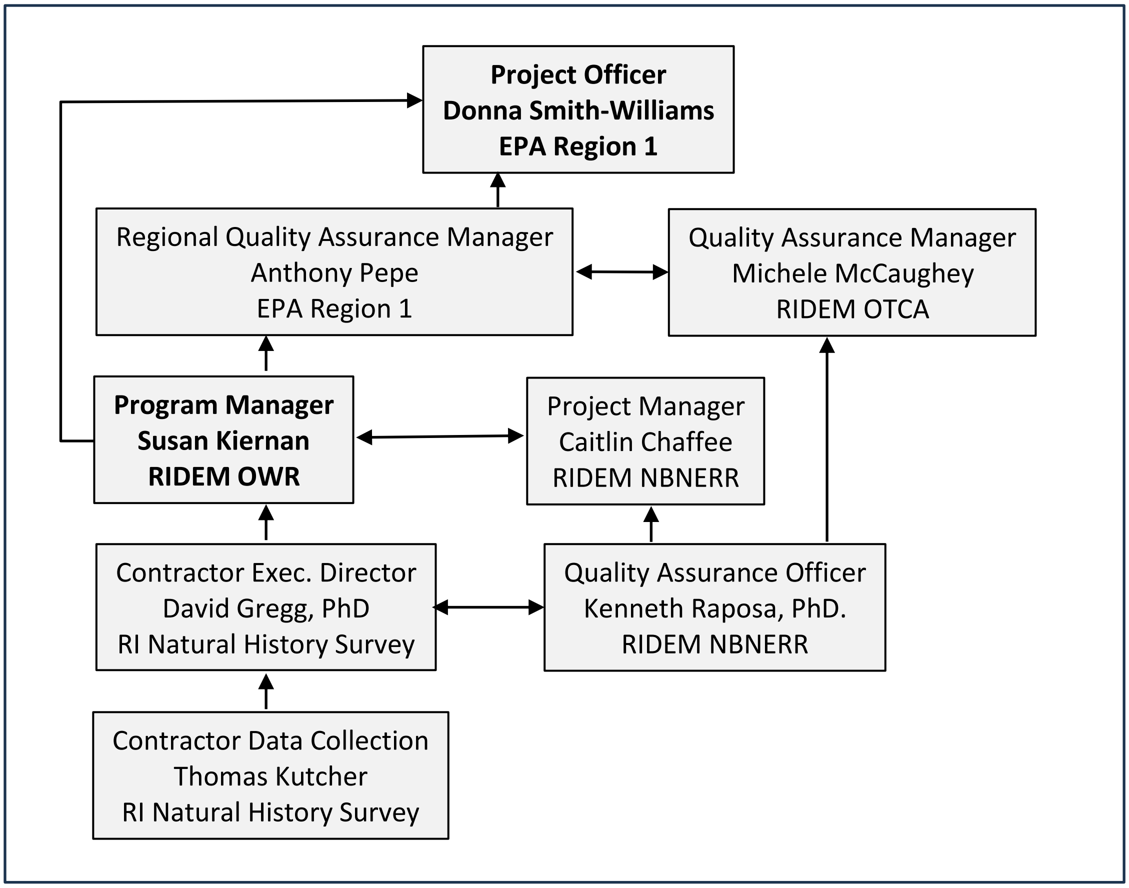


Figure 1. Organizational Chart

## **A5. Problem Definition/Background** (EPA QA/R-5 A5)

*Background*

Salt marshes perform a host of functions that are valuable to people and wildlife, including water pollution filtration and uptake, protection from riverine and coastal flooding, provision of critical habitat for fish and wildlife, and recreation and aesthetics. Salt marshes are at increasing risk of degradation due to stressors caused by human development and other activities, and factors stemming from climate change, such as changing precipitation patterns and sea-level rise. Salt marshes are particularly susceptible to climate change, as they are very sensitive to inundation period, which is expected to increase with sea-level rise. The RI Salt Marsh Monitoring and Assessment Strategy (SMMAS; Raposa et al. 2016) and the RI Coastal Wetlands Restoration Strategy (Kutcher et al. 2018) indicate the need to have methods to monitor and evaluate salt marsh resources as the potential shifts and losses in functions and values of wetlands with human disturbances and climate change become increasingly evident. DEM and NBNERR recognize the importance of monitoring and assessment to inform the management, conservation, and restoration of salt marshes facing these mounting threats.

This QAPP details the quality assurance procedures for nine (9) salt marsh monitoring and assessment methods that have previously been applied and tested in Rhode Island to assess the condition and vulnerability of salt marshes. For each QAPP section, the methods will be addressed together when possible, or separately when necessary, in the order as numbered in Table 1.

Table 1. Sampling parameters covered in this QAPP with references to the methods and procedures.

| # | Sampling Parameter | Method Source | QAPP Section |
|---|---|---|---|
| 1 | MarshRAM rapid assessment | Kutcher 2022a | App. A |
| 2 | Vegetation composition and plant height | James-Pirri et al. 2002 | App. B |
| 3 | Nekton species composition and abundance | James-Pirri et al. 2002 | App. B |
| 4 | Crab burrow density | Raposa et al. 2019 | Sec. B |
| 5 | Avian species composition and abundance | www.tidalmarshbirds.org | App. C |
| 6 | Height and duration of tidal water | James-Pirri et al. 2002 | App. B |
| 7 | Marsh-edge vegetation change | Raposa and Mitchell, unpublished | App. D |
| 8 | Marsh surface elevation and accretion | Callaway et al. 2013 | App. E |
| 9 | Soil shear strength | Turner 2011 | Sec. B |

**A6. Project/Task Description and Schedule** (EPA QA/R-5 A6)

This QAPP covers the quality assurance procedures for the nine salt-marsh monitoring and assessment methods listed in Table 1. The procedures herein apply consistently across all anticipated applications of the listed methods. Specific EPA-funded projects using one or more of these methods will adhere to this "Methods QAPP" and refer to it by name and hyperlink in any project-specific addendum. Project/task descriptions, schedules and site locations will be detailed in the various project addenda.

**A7. Quality Objectives and Criteria for Measurement Data** (EPA QA/R-5 A7)

Measurement data will be collected with the intent of characterizing parameters for analysis against data collected at an earlier time (for change analysis) or against sets of data from other treatments (such as comparing salt marshes to each other). The quality objective is that samples accurately represent actual conditions adequately to run statistically-valid analyses elucidating trends that can inform management (*representativeness*). The methods are either measured or estimated as described in sections below. Quality criteria are that the collection and handling of data ensure *precision* and minimize user *bias* to produce consistent and reliable results. Qualified field personnel will conduct these methods as designed and reported in peer-reviewed literature. Through communications with field personnel and review of the data, the Project Quality Assurance Officer will verify that data were collected properly.

A7.1 Precision, Bias, and Representativeness

*Precision*, *bias*, and *representativeness* are integrated in the sampling designs of each of the nine methods covered in this Methods QAPP, as follows:

1. MarshRAM Rapid Assessment
   *Precision*, *bias*, and *representativeness* of MarshRAM were analyzed in Kutcher et al. (2022). Inter-user variability of the Wetland Disturbances metric scores was <3% of the metric range among trained users, and <1% for across disparate vegetation cover classes applied to the Index of Marsh Integrity (IMI, App. A); it is expected that precision will be similar among trained technicians by following the protocols described in Sec. B1-2-4. *Bias* and *representativeness* are addressed in the application of 8 random-stratified transects for the community cover sampling used for IMI (App. A), where random selection minimizes bias and double-stratification of transect locations maximizes representativeness. Bias will be additionally minimized by having the same person conduct all of the assessments for a given study, when possible. Regarding *representativeness*, Kutcher et al. (2022) reported that 8 random-stratified transects was

sufficient to represent the community composition of salt marshes for comparative analysis.

2. Vegetation composition and plant height
*Precision*, *bias*, and *representativeness* for the vegetation sampling methods are addressed in App. B, James-Pirri et al. (2002), *Vegetation*, pp. 4-11; where plot layout, sampling techniques, and data handling are all designed specifically to ensure adequate precision, reduce user bias, and maximize sample representativeness for analysis. Several prior studies have shown that following these methods results in adequately precise, unbiased, and representative data for conducting meaningful change analysis (e.g., Roman et al. 2002, Raposa et al. 2017).

3. Nekton species composition and abundance
*Precision*, *bias*, and *representativeness* for the nekton sampling methods are addressed in App. B, James-Pirri et al. (2002), *Nekton Sampling in Ponds*, pp. 24-31; where plot location, sampling techniques, and data handling are all designed to ensure adequate precision, reduce user bias, and maximize sample representativeness for analysis. Prior studies have shown that following these methods results in adequately precise, unbiased, and representative data (e.g., Roman et al. 2002, Raposa and Roman 2001).

4. Crab burrow density
Crab burrow counts are straightforward, and *precision* will simply depend on carefully observing and tallying burrows >3mm in diameter (Raposa et al. 2019); a metric ruler will be used to make burrow-size determinations. *Bias* and *representativeness* will be assured by sampling within vegetation plots (see Method 2 of this section) that are systematically located to minimize user bias and provide adequate representativeness (App. B, James-Pirri et al. 2002, *Vegetation*, pp. 4-11).

5. Avian species composition and abundance
*Precision* and *bias* for the avian methods are addressed by using SHARP protocols and SHARP field forms (www.tidalmarshbirds.org; App. C), where data-collection methods are standardized cross users and sites in terms of sampling plot size (100-m radius) and inter-plot distances (>200m); wind and rain noise are accounted for; time of day and month are standardized; a callback sound file is provided; and callback players and speakers are specified. *Representativeness* is addressed in (1) locating two sampling points per marsh, where feasible (Sec. B1-2), (2) sampling three times per field season, (3) aggregating site-level data to improve statistical power, and (4) the large number of existing SHARP sites and data that can be used for reference. It is expected that following the SHARP protocols will produce the quality of data that has been used to monitor salt marsh birds by the longstanding SHARP Program.

6. Height and duration of tidal water
Water levels are recorded using Onset® Hobo® self-contained water-level loggers according to James-Pirri et al. (2002) and manufacturer's directions. Water levels will be monitored at two locations per marsh, in areas selected by a team of qualified salt-marsh ecologists to be *representative* of relatively high- and low-elevation sections of the high-marsh platform per marsh. *Precision* is dependent upon factory calibration of the water-level loggers, which is reported by the manufacturer to be ±0.05% typical and ±0.1% maximum, and careful measuring by the field staff. Only qualified field staff will deploy the loggers and take field measurements.

7. Marsh-edge migration
   *Precision*, *representativeness*, and *bias* for marsh edge migration measurements will be assured through following the methods of Raposa and Mitchell (unpublished method, App D). The method consists of simple measurements from fixed rods placed in the ground to indicator plants. Locations will be selected by best professional judgement of qualified salt-marsh scientists to best represent typical seaward (erosion) and landward (migration) areas in the marsh.

8. Marsh surface elevation and accretion
   *Precision, bias, and representativeness* for measuring surface elevation change and accretion will be assured through following the methods of Callaway et al. (2013, App. E). *Precision* and *bias* are controlled through the number of subsamples per sampling station and calibration of the sampling equipment before each set of measurements, as described in App. E and Sec. B1-2-4 of this QAPP. The locations of the sampling stations will be selected by the best professional judgement of experienced salt-marsh ecologists to *represent* typical higher- and lower-elevation areas of the high marsh platform for each marsh.

9. Soil shear strength
   Soil shear strength will be monitored using a Durham S-162 Hand Vane Tester (shear vane), following Turner (2011). The method will be conducted adjacent to the Vegetation plots as outlined above (A7.1.2) following the plot layout described by James-Pirri et al. (2002), thus assuring *representativeness*. *Precision* and lack of *bias* will be assured by deploying the sampling equipment in a standardized manner according to Turner (2011).

A7.2 Completeness, Comparability, and Sensitivity
All data collection will pursue *complete* application of each method. Data that are deemed to be incomplete and thus unusable or unsuitable for analysis by the Project Quality Assurance Officer will be discarded. Prior applications of each of the methods covered in this QAPP indicate adequate *sensitivity*, and suitable *comparability* with prior data or with data across sampling treatments (such as for MarshRAM, Kutcher et al. 2022; for Vegetation, Roman et al. 2002; for Nekton, Raposa and Roman 2001; for Crab burrows, Raposa et al. 2019; and for SHARP, Wiest et al. 2019, etc.). It is expected that following the methods described in Sec. B1-2-4 will generate data with similar comparability and sensitivity as the data generated using these same methods in prior studies.

## **A8. Special Training Requirements/Certification** (EPA QA/R-5 A8)

Only trained and experienced scientists will conduct the monitoring and assessment methods covered in this Methods QAPP. NBNERR and RINHS monitoring and assessment partners have been instrumental in developing and testing most of the methods detailed in this QAPP, and trained, qualified personnel will conduct the work, as further detailed in specific project addenda.

Tom Kutcher developed and validated the salt marsh rapid assessment method MarshRAM (Kutcher 2022a), and will conduct MarshRAM or train the field investigator conducting it. Kutcher also has nearly two decades of experience conducting the assessment methods covered in this QAPP and will, as needed, provide training to any untrained technicians collecting data. Kenneth Raposa, PhD, has been the Research Coordinator for the Narragansett Bay National Estuarine Research Reserve for over 20 years and has worked to develop and refine the nekton throw trap method (Raposa and Roman 2001), the vegetation point count method (Raposa et al. 2017), crab burrow counts (Raposa et al. 2019), marsh-bird point counts (Raposa et al. 2009), and marsh-migration sampling. Raposa and Kutcher are both experienced and proficient in nekton throw-trap sampling, crab burrow counts, vegetation monitoring, the use of water-level loggers, marsh-migration methods, the use of SETs, and shear-vane sampling, and will, as needed, train any other technicians on conducting methods covered in this QAPP.

## **A9. Documents and Records** (EPA QA/R-5 A9)

The format for all data reporting packages will be consistent with the requirements and procedures used for data validation and data assessment described below. This QAPP will be reviewed annually by the Project Manager and Quality Assurance Officer, to confirm that it remains current and accurate, and is effective at meeting the project and data quality objectives.

### A9.1 QA Project Plan Distribution

This QAPP will be distributed to all appropriate persons within DEM OCTA, Office of Water Resources, NBNERR, CRMC, EPA Region 1, and the RINHS as identified in section A3 of this QAPP. It will also be posted on the DEM web page for Environmental / Quality Assurance Project Plans @ https://dem.ri.gov/data-maps/data.php#quapps and may be posted on the NBNERR web page @ http://www.nbnerr.org.

### A9.2 Field Documentation and Records

Field data will be hand-recorded by completely filling out paper field forms specific to each method, including the date of the field observations and the identity or the person making the observations; waterproof paper will be used in rainy weather. MarshRAM (1) and Avian (5) field data will be housed at the RINHS office until analysis and reporting are complete, whereas vegetation (2), nekton (3), crab (4), water-level (6), marsh-edge (7), marsh elevation (8), and soil shear-strength (9) field data will be housed at NBNERR until analysis and reporting are complete. All field data forms will then be transferred to NBNERR to be held as detailed below. Daily activities (e.g., location, mileage, assessments) of field staff will be documented in diaries, timesheets, and logs as required by EPA grant conditions on relevant OMB circulars cited therein and held by the RINHS.

### A9.3 Laboratory Documentation and Records

Field data will be entered into an electronic spreadsheet (Microsoft Excel) at RINHS or NBNERR, where they will be housed on a hard drive and the "cloud" (Google Drive or similar) until analysis and reporting are complete (see timeline), at which time they will be transferred to NBNERR along with any secondary and derived data. Each project will implement proper document control procedures consistent with DEM's Quality Management Plan (revised Nov. 22, 2022). The NBNERR Project Quality Assurance Officer will have ultimate responsibility for any and all changes to records and documents after submittal to NBNERR and shall be responsible for their retention and storage. The RINHS will copy all final Excel spreadsheet files and GIS shapefiles collected under this QAPP to the DEM Office of Water Resources Program Manager or assigned representative for permanent retention under DEM Record Series 6.13.4.

The DEM Program Manager and the NBNERR Project Quality Assurance Officer shall retain the final approved QAPP and all updated versions and will be responsible for any distribution of the current version. The DEM Program Manager shall retain copies of all contract- and grant-management documents, and the NBNERR Project Quality Assurance Officer shall retain all draft and final reports, memoranda, and technical correspondence between NBNERR and all project personnel. The RINHS will copy all draft and final reports and memorandum produced under the QAPP to the DEM Office of

Water Resources Program Manager or assigned representative for permanent retention under DEM Record Series 6.13.4

Records and documents that will be produced in conjunction with this QAPP may include:

- Completed field forms and site maps
- Excel spreadsheet files for data storage and analysis
- GIS shapefiles of assessment or study areas and their buffers
- This QAPP
- Draft project reports and appendices
- Final project reports and appendices

*Storage of project information*

Files, paper and electronic records, and other media such as incidental photographs will be maintained by the NBNERR for a minimum of three (3) years after the completion of this work and delivery of RINHS products to NBNERR. After three years, some records may be moved to the NBNERR Records Archives for storage in accordance with relevant NBNERR record retention policy. All field data forms will be retained by NBNERR permanently.

The DEM Office of Water Resources shall also retain records of project deliverables and grant management associated with projects funded by EPA to the Office of Water, pursuant to its records retention schedules. As it is anticipated that wetland assessment will continue indefinitely, the time frames stated are the minimum and likely will be exceeded as the information will be needed for the ongoing program.

*Backup of electronic files*

Electronic files will be maintained on the NBNERR network server, as well as periodically backed up locally by the NBNERR Project Quality Assurance Officer on CD's, demountable hard drives, solid state digital storage devices, or the internet "cloud".

A9.4 Quarterly and/or Final Reports

The draft and revised final reports are particular to the specific project, as detailed in the accompanying project addenda. In general, results of data collected will be documented and reported as follows:

- a detailed outline of methods employed;
- data analyses and demonstrations as listed in section 1.6 and detailed below;
- a site map depicting assessment unit locations; and
- tables and figures as necessary to illustrate the work, analyses, and results.

The NBNERR and project participants and partners will provide written comments on a draft report for any given project. A final report, which will be completed by RINHS and/or other project participants, will incorporate responses to revisions based on the NBNERR or other comments.

## B. DATA GENERATION AND ACQUISITION

**B1-2-4 Sampling Design, Methods, and Analysis** (EPA QA/R-5 B1, B2, and B4)

1. MarshRAM Sampling Design and Methods

   MarshRAM field assessments will be conducted by completely filling out one MarshRAM field form at each site according to the MarshRAM User's Guide (Kutcher 2022a, App. A). MarshRAM generates five metrics, four of which are based on observation and one of which (IMI) is based on measurement (App. A). Each metric value is unit-less and is primarily designed to compare conditions at a salt marsh assessment unit to conditions at other marsh units; therefore, statistical power is primarily built by increasing the number of salt marsh units assessed, and statistics are generally run across sites. Secondarily, IMI has been tested to evaluate its capacity to detect changes in habitat cover over time at a single site, and was found to detect 10% change in cover across 8 transects for most community types (R. Martin, unpublished data). MarshRAM has been used to assess conditions at over 60 salt marshes in state applications (Kutcher and Chaffee 2021, Kutcher 2022b) and peer reviewed studies (Kutcher et al. 2022, Kutcher and Raposa 2023).

2. Vegetation Community composition and Abundance Methods
   Vegetation composition and abundance will be measured using methods detailed in James-Pirri et al. (2002), App. B, *Vegetation*, pp. 4-11. The methods have been designed and extensively tested in numerous peer-reviewed publications to be used for measuring vegetation change within a single marsh, and across marshes. Statistical power is assured by following the recommendations of the methods (App. B).

3. Nekton Community composition and Abundance Methods
   Nekton density and composition will be measured using methods detailed in James-Pirri et al. (2002), App. B, *Nekton Sampling in Ponds*, pp. 24-31. The methods have been designed and extensively tested in numerous peer-reviewed publications to be used for measuring nekton community composition and abundance changes within a single marsh, and across marshes. Statistical power is assured by following the recommendations of the methods (App. B).

4. Crab Burrow Density Methods

   Crab burrow counts will roughly follow "burrow count" methods detailed in Raposa et al. (2019) as follows. Using vegetation point-intercept sampling plots, all crab burrows >3mm in diameter, and falling within each $1m^2$ vegetation sampling plot, will be counted. This sampling design will utilize the pre-established stratified-random distribution used for the vegetation sampling (method 2 of this QAPP; App. B, James-Pirri et al. 2002), to characterize the density of crab burrows across the upland-to-open water gradient of salt marsh habitat types. For each plot, a habitat type will be interpreted and assigned in the field as one of the following: bare creekbank, vegetated creekbank, marsh platform, or marsh-upland transition zone (Raposa et al. 2019). The vegetation protocol has been designed and extensively tested in numerous peer-reviewed publications to be used for measuring vegetation species changes across marshes; crab burrow counts conducted within this framework should have similar statistical power to the vegetation data. Statistical power is therefore assured by following the recommendations of the methods.

5. Avian species composition and abundance methods
   Bird point counts will strictly follow SHARP protocols (App. C), and data will be recorded on SHARP field forms. One or two circular, 100-m-radius sampling plots will be located in each marsh as follows. For small marshes, wherein only a single 200-m diameter plot covers the majority of the marsh, the center of the plot (i.e. the sampling point) will be located in the geographic center of the marsh. For medium-sized marshes, wherein two 200-m diameter plots cover the majority of the marsh, the sampling points will be spaced at least 200m apart and

positioned so that the sampling plot covers as much of the marsh as possible. For larger marshes, the sampling points will be placed in a random location on the marsh surface no closer than 80m from any marsh edge and no closer than 200m from the second sampling point. For marshes already containing one or more SHARP sampling point (from the official SHARP study), those existing SHARP sampling points will be used if they meet the above criteria.

Aggregating SHARP data across multiple sites has been shown to reveal important trends in marsh-bird species composition (e.g., Wiest et al. 2019). As the variance of the data is unknown for any particular project, only statistical analysis of the actual project data will determine the statistical power of the data to detect trends. Statistics will be used as needed to reveal these trends.

6. Height and Duration of Tidal Water Methods
Tidal height and duration will be monitored according to James-Pirri et al. (2002). Water levels will be recorded using Onset® Hobo® self-contained water-level loggers according to manufacturer's directions. Two units will be deployed in each marsh during the peak of the growing season for four continuous weeks. Loggers will be lowered into perforated and capped 2" PVC pipe following methods referenced in James-Pirri et al. (2002). Depth of logger in relation to marsh surface will be measured to the nearest mm. Recorded depths will be uploaded to spreadsheet and analytical software directly from the logger at monthly intervals. The depths recorded on the logger will be adjusted to levels relative to the marsh surface, using subtraction, to determine flooding frequencies and water depth.

7. Marsh-edge Migration Methods
Marsh edge change will be measured following the methods of Raposa and Mitchell (App D). The method consists of simple measurements to indicator plants from fixed rods placed in the ground. Repeatability is assured through a set of rules indicating the parts of specific plants within a set transect to be measured for each of several measurements that indicate vegetation migration on the seaward and landward edges of the marsh. Changes in measurements over time are calculated to represent migration of the marsh vegetated edge.

8. Marsh Surface Elevation and Accretion Methods
Surface elevation change and accretion will be measured following the methods of Callaway et al. (2013; App. E). The method uses two sediment elevation tables (SETs) and four feldspar plots per marsh. A SET is an aluminum swingarm that is pinned to the below-marsh bedrock or hardpan using lengths of ½ inch rod driven into the soil to the bedrock or hardpan. The swingarm is leveled before each set of measurements and 9 pins are dropped to the marsh surface to measure changes between the marsh surface and the subterranean hardpan or rock to represent elevation change. This is done in four approximate cardinal directions per sampling station to produce 36 data points (subsamples) per station and 72 points per marsh. To measure accretion, two 0.25-$m^2$ feldspar plots will be established adjacent to each SET. For each plot, 4Kg of feldspar will be spread over a 0.25-$m^2$ area to establish a recognizable artificial soil horizon that can be analyzed for accretion using methods according to Callaway et al. (2013, App. E). A brass elevation benchmark will be surveyed into the concrete base of each SET to serve as a benchmark for further elevation studies using laser surveying equipment.

9. Soil Shear Strength Methods
Soil shear strength will be monitored as an indicator of marsh soil health according to methods

detailed in Turner (2011). The method uses a Durham S-162 Hand Vane Tester (shear vane), rated for 0 to 130 kPa of pressure with a 20 x 40 mm vane, deployed according to manufacturer directions, to assess the shear strength (to the nearest kPa) of soils from the surface to refusal or to 100cm, at 10-cm intervals. This method will indicate soil shear strength, as an indicator of platform integrity, throughout the profile of the marsh platform.

**B3. Sample Handling and Custody** (EPA QA/R-5 B3)

None of the methods covered in this QAPP require sample collection, therefore sample handling and custody are not applicable.

**B5. Quality Control Requirements** (EPA QA/R-5 B5)

RINHS and NBNERR will work together to ensure that all sampling and assessment activities are conducted within the criteria set for the project, specifically as described in the above sections.

**B6. Instrument/Equipment Testing, Inspection, and Maintenance** (EPA QA/R-5 B6)

All equipment will be inspected for proper functionality prior to each use.

**B7. Instrument/Equipment Calibration and Frequency** (EPA QA/R-5 B7)

6. Height and Duration of Tidal Water Methods
Onset® Hobo® self-contained water-level loggers are calibrated by the manufacturer and no user calibration is possible.
8. Marsh Surface Elevation and Accretion
Sediment elevation tables will be calibrated just prior to sampling each arm position, using the manufacturer-supplied bubble level to level the unit arm and pins; the SETs do not otherwise require calibration.
9. Soil Shear Strength
The Durham S-162 Hand Vane Tester is calibrated by the manufacturer and cannot be recalibrated in the field.

Two measurement instruments subject to this QAPP (water-level logger and soil shear vane) are calibrated by the manufacturer. The third, (sediment elevation table) is calibrated by the user prior to every deployment. Other gear, such as the nekton throw traps, could be compromised from wear or breakage and will be inspected by field scientists prior to deployment. The Project QA officer will run quality assurance investigations on all data subject to this QAPP. If the Project QA Officer or Wetland Scientist finds that the data from any method or instrument does not follow prior trends, contains illogical outliers, or otherwise appears erroneous, indicating malfunction or loss of calibration, the QA Officer will discard any erroneous data and immediately take the gear or instrument out of service to be repaired, recalibrated by the manufacturer, or replaced with a new instrument.

**B8. Inspection/Acceptance Requirements for Supplies and Consumables** (EPA QA/R-5 B8)

Not applicable. No critical consumables will be used.

**B9. Data Acquisition Requirements (Non-Direct Measurements)** (EPA QA/R-5 B9)

Geospatial data from the Rhode Island Geographic Information System (RIGIS, available: www.rigis.org) may be used for generating site maps and locating monitoring stations, as detailed in the above sections of this document. RIGIS data are thoroughly quality assured geospatial data, meet FGDC mapping standards, have standardized metadata, and are widely used by State, Federal, and local scientists conducting geospatial analysis in the State of RI.

**B10. Data Management** (EPA QA/R-5 B10)

Field data will be collected and stored in a metal file cabinet in a locked office in the RINHS or at the NBNERR. All data will be transposed to electronic format in the form of Excel spreadsheet files. The Excel files will be coded by date and corrections to the file will be coded by the revision or correction date followed by the suffix *correction*. Duplicate versions of the datasets will be coded specifically for analysis and kept in a separate folder. Analysis versions will also be coded by date with each use. Baseline and analysis data files will be stored in the RINHS laboratory at East Farm, URI, Kingston, RI on a hard drive and on the internet "cloud" (e.g., Google Drive). Any GIS data will be stored in file folders as shapefiles, which will be housed on two separate hard drives within the RINHS.

Field and electronic data will be quality checked for errors by qualified personnel following data collection and following data upload into Excel. Any corrections will be handled as noted above. The Wetland Scientist will be responsible for data management until the data are transferred to NBNERR at the end of the analysis and reporting period, at which time the Project Quality Assurance Officer will be responsible for the data.

## C. ASSESSMENT AND OVERSIGHT

**C1. Assessments/Oversight and Response Actions** (EPA QA/R-5 C1)
Project oversight will be provided through regular correspondence between the NBNERR Project Quality Assurance Officer and RINHS no less than once per month. Correspondence will be in the forms of email and telephone correspondence, review meetings, memoranda, and the exchange of key data and documents according to the schedule of the specific project. Assessment-oversight will involve review of all aspects of the project and its progress. Technical advisors, who may include academic experts, state scientists, EPA scientists, and other expert stakeholders may also be consulted throughout the project. NBNERR and RINHS will respond to input as necessary to ensure the efficient use of project resources in evaluating the effectiveness of salt marsh assessment tools to meet state reporting requirements and SMMAS objectives (Raposa et al. 2016).

The Project Quality Assurance Officer has the authority to issue a stop work order if something is not going right and to document corrective actions that need to be taken. For example, if, upon quality assurance investigations (always done prior to any analysis), the Project QA Officer or Wetland Scientist finds that the data from any instrument (specifically, water-level logger, surface elevation table, or soil shear vane) does not follow prior trends, or otherwise appears erroneous, indicating malfunction or loss of calibration, The QA Officer will discard any erroneous data and immediately take the instrument out of service to be recalibrated by the manufacturer or replaced with a new instrument.

**C2. Reports to Management** (EPA QA/R-5 C2)
For each project, brief quarterly memoranda and final reports will be submitted by the RINHS to the Project Quality Assurance Officer, the Program Manager or assigned representative, and the Project Manager at the following project milestones: (1) the completion of field work and prior to the initiation of data analysis, (2) the completion of data analysis, (3) the draft Report, (4) the Final Report. Memoranda may be appended to or incorporated into the draft and final reports.

## D. DATA REVIEW AND USABILITY

**D1. Data Review, Verification, and Validation Requirements** (EPA QA/R-5 D1)
The validity and utility of data collected in the field is dependent upon (1) the qualifications of the field personnel, (2) the validity of the methodology, and (3) the appropriate analysis and interpretation of the data, which have been addressed in prior sections of this QAPP. Following the methods described in this QAPP and its appendices should assure the quality of the data. Only trained scientists will be able to assess the quality and validity of the data from these methods. The staff analyzing the data are trained to detect errors or inconsistencies in the data through identifying outliers and other unexpected or erroneous behaviors of the data. Data quality will be further assured through the review of data reports submitted to technical peer reviewers from partner academic, state, or federal agencies. The Quality Assurance Officer will ensure that appropriate external peer reviewers review the data outcomes before data reports are finalized.

**D2. Verification and Validation Methods** (EPA QA/R-5 D2)
The salt marsh monitoring and assessment data quality will be verified by the Wetlands Scientist by and other field partners by reviewing field datasheets and electronic data as described above. The Quality Assurance Officer will have the power to require data to be discarded or re-collected, as possible, if it does not meet the requirements detailed in Sec. A7.

1. MarshRAM
The Wetlands Scientist will produce and review scatterplots of metric and index scores against relevant data (such as surrounding land use intensity data). Any data points not fitting within scatters will be reviewed against field datasheets for inconsistencies. Any inconsistencies found will be corrected in the electronic dataset. Any outliers that cannot be corrected through this review process will be discarded prior to analysis, and this action will be documented in the report.

6. Water-level Loggers
Water-level data will be uploaded directly from the loggers to a computer using the internal logger software. The Quality Assurance Officer will produce and review data trends for inconsistencies and outliers. Any data points flagged as inconsistent against expected or typical outcomes will be reviewed and, as necessary, corrected in the electronic dataset. Any inconsistencies that cannot be corrected through this review process will be discarded prior to analysis, and this action will be documented in data reports.

2-5, 7-9. Vegetation, Nekton, Crab burrow, Avian, Elevation, Marsh Migration, and Soil Shear Strength
Measurement data collected will be recorded by qualified personnel. The data will be aggregated and inspected on field datasheets and following upload to electronic spreadsheet software, where the data will be analyzed for validity using statistical software, by reviewing the data for inconsistencies and outliers. Any inconsistencies or discrepancies in outcomes among users or platforms will be investigated

and rectified. Data that cannot be rectified as error-free will be discarded and re-collected, as possible.

**D3. Reconciliation with User Requirements** (EPA QA/R-5 D3)

The goals of Rhode Island wetland program development include testing the applicability of wetland monitoring and assessment methods across a range of conditions, and demonstrating the utility of the methods and resulting data in assessing the conditions of coastal wetlands and evaluating restoration outcomes. Because of the complex nature of the data, it is expected that the interpretation and application of the data will be primarily limited to the wetland professionals who requested the work (the users). As such, the data will be collected specifically for the direct use of the intended users. However, it is anticipated and intended that the data will also be used and interpreted for generating reports, graphics, and other outreach materials aimed at secondary and tertiary consumers of the information.

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# Appendix A

## MarshRAM User's Guide

# MarshRAM User's Guide

Detailed instructions on how to conduct and interpret the
Salt Marsh Rapid Assessment Method, MarshRAM

Thomas E. Kutcher
Rhode Island Natural History Survey

Prepared for
Rhode Island Department of Environmental Management, Office of Water
Resources September, 2022

# Table of Contents

# 1. Introduction

## 1.1 Background and Justification

Salt marshes are important to people and wildlife but are susceptible to a range of human disturbances. Salt marshes are highly productive and provide food and habitat for numerous fishes and wildlife species (Nixon 1980, Deegan et al. 2002, Gedan et al. 2009, Barbier et al. 2011), can absorb floodwater and wave energy to protect coastal properties from flood damage and erosion (Shepard et al. 2011), and are valued for recreation, aesthetics, and general enjoyment. Human disturbances, such as filling for roads, development, and refuse disposal; impoundment by roads and railways; ditching for mosquito control and salt-hay production; introduction of excessive nutrients from waste disposal; and introduction of invasive species, have resulted in widespread salt marsh loss and degradation in Rhode Island (RI) and elsewhere (Gedan et al. 2009, 2011, Watson et al. 2017a). Inundation stress associated with sea-level rise has more recently caused widespread vegetation loss and marsh platform degradation (Donnelly and Bertness 2001, Roman 2017, Watson et al. 2017a). Sea-level rise can work interactively with other anthropogenic stressors to cause rapid marsh degradation in the forms of edge dieback and erosion, platform vegetation dieoff, subsidence, water-logging, drowning, and loss (Donnelly and Bertness 2001, Crotty et al. 2017, Watson et al. 2017a, b, Raposa et al. 2018).

In its strategic planning documents (Raposa et al. 2016, Kutcher et al. 2018), the RI Salt Marsh Restoration, Assessment, and Monitoring Program (RAMP) recommends using monitoring and assessment data to inform management of salt marshes following the US Environmental Protection Agency's three-level approach (EPA 2006), which includes landscape (Level 1), rapid (Level 2), and intensive (Level 3) monitoring and assessment methods. As part of this strategy, state, federal, academic, and NGO partners have worked to develop a rapid assessment method (Level 2) for salt marshes. Wetland rapid assessment methods are typically designed to collect data for characterizing conditions at a wetland in a single visit supported by simple remote analysis (Fennessey et al. 2007). Rapid assessment methods are unique among monitoring and assessment approaches in that they can produce reliable site-level data to indicate relative ecosystem condition across multiple sites in a single season, making them particularly useful for developing a multi-wetland reference dataset against-which individual marshes can be assessed for condition, vulnerability, ecosystem functions and services, and other information to support management decisions such as prioritization for restoration and conservation.

The Salt Marsh Rapid Assessment Method (MarshRAM) adapts concepts and protocols from prior work to provide users with a single, efficient method designed to document information on salt marsh physical and biological attributes, classification, relative functions and values, geomorphic and landscape setting, human disturbances, vulnerability, and landward migration potential. MarshRAM is the result of a multi-year development and testing program that included application across Narragansett Bay and coastal Rhode Island, analyses of functionality and subjectivity, demonstrations of applicability, validations against Level 1 data, and input from state, federal, academic, and regional technical advisors and reviewers (Kutcher 2019, Kutcher and Chaffee 2021).

## 1.2 MarshRAM General Description

MarshRAM is a passive salt marsh rapid assessment method designed to inventory ecological data and quantify the relative condition of a user-defined salt marsh assessment unit. In a single site visit supported by simple remote analysis, MarshRAM can be used to generate descriptive and quantitative data that can be applied to address state-identified objectives and establish reference conditions against-which individual marshes can be evaluated across a broad suite of parameters. MarshRAM is organized in a worksheet of attributes, metrics, and indices designed to guide the user through a logical data-collection and scoring process based on estimation and interpretation of field observations and remote-sensed data, and a field survey of community composition (App. 1). Metric scoring culminates in seven indices that can be used separately or together to support management decisions and analysis.

Conducting a MarshRAM assessment entails the identification and evaluation of the evidence and intensity of anthropogenic disturbances and the identification of salt marsh community types by prominent vegetation and other features; this requires that the user holds considerable knowledge of salt marsh ecology. Formal training in the application of MarshRAM is recommended, as this User's Guide cannot fully replace applied field training.

## 2. Overview of MarshRAM Format and Content

MarshRAM draws content from the New England Rapid Assessment Method (NERAM, Carullo et al. 2007) and the Rhode Island Salt Marsh Assessment (RISMA, Ekberg et al. 2017), and formatting from the Rhode Island Rapid Assessment Method (RIRAM, Kutcher 2011). Six sections provide conceptually separate information, as follows.

A. *Marsh Characteristics*: This section documents salt marsh size, setting, type, exposure to tides, natural habitat diversity and connectedness, and tallies birds observed using the marsh. This section is not scored, but is intended to provide context for evaluation and analysis.

B. *Ecosystem Functions and Services*: This section ranks the relative importance of the assessment marsh in providing 12 ecosystem functions and services commonly attributed to salt marshes. The user ranks each function/service by one of four levels of importance. The ranks are summed to provide a coarse metric of relative value.

C. *Surrounding Land Use*: This section comprises a single metric that evaluates the intensity of land use within 150 m of the marsh edge. Scoring ranges from 0 to 10, where buffers with scores approaching 0 are completely developed with high-intensity land use, and those with scores approaching 10 are completely surrounded by natural land.

D. *Wetland Disturbances*: In this section, the user estimates the intensity of 10 influential salt marsh disturbances using coarse, predefined categories organized in a checklist format. Sources of stress and evidence used in the determination are also documented by checklist, where relevant. Each disturbance metric is scored from 1 to 10, where scores approaching 1 indicate high-intensity disturbance and a score of 10 indicates no or low disturbance observed. The metric scores are averaged to generate an index of aggregate disturbance.

E. *Marsh Community Composition and Index of Marsh Integrity*: For this section, the user collects data along eight 'walking transects' to characterize the marsh community composition of the assessment unit according to the proportional cover of pre-defined community types. Each community type has been assigned a coefficient that characterizes its sensitivity to anthropogenic stress (including inundation stress associated with sea-level rise) and, to a lesser extent, habitat value. The average of the coefficients, weighted by the proportion of cover it represents across the marsh, is used as an Index of Marsh Integrity (IMI).

F. *Migration Potential*: This section estimates the site-specific potential of the assessment unit to migrate landward as sea level rises. The user estimates the proportion of predefined land covers that fall into scored categories based on physical, biological, and cultural resistance to migration. Three metrics are derived from the scoring to represent: (1) the relative capacity of the surrounding upland to support migration (*Migration Potential*; range 0 to 10, no units), (2) the area of land where migration will occur without significant intervention (*Migration Area*, in ha), and (3) the ratio of that area to the area of the existing marsh platform (*Replacement Ratio*, expressed as a percentage).

# 3. Conducting the MarshRAM Assessment

## 3.1 General Procedures

### Site Selection

Sites should be selected according to the goals of a given project. The Salt Marsh RAMP has selected salt marsh assessment units throughout Narragansett Bay and coastal Rhode Island to act as a reference dataset against-which to compare individual marshes for management support (Kutcher and Chaffee 2021). An individual site may be selected because there is a particular interest in quickly gaining ecological knowledge about the site, such as for habitat evaluation or management considerations. With certain limitations, an assessment unit can be defined to meet the objectives of the project.

### Defining Assessment Units

Salt marsh assessment units are typically discrete salt marsh platforms separated from other marsh platforms by any combination of upland, open water, or manmade features such as raised roads or railroads. The assessment unit is delineated along the seaward and upland edges, and along any feature that creates a discontinuity in hydrology or habitat. Along the interface of bordering uplands and freshwater wetlands, the unit generally continues until halophytic wetland vegetation ends (Tip 3.1.1), unless the specific project goals dictate otherwise. Any water feature contained within the marsh (surrounded by marsh for >75% of its perimeter) and smaller than the vegetated marsh area is considered part of the assessment unit for some metrics and attributes (including assessment unit delineation), whereas features not contained or larger than the marsh are considered part of the adjacent tidal water.

The user can decide whether a modest manmade or natural feature, such as a dirt road or a large, wide ditch or creek, breaks the marsh into separate assessment units, based on continuity and the goals of the assessment. In many cases, such features can be used to separate marsh assessment units when it is advantageous to the goals of the assessment. In theory, two parts of a marsh platform assessed separately would 'average-out' similarly to the platform assessed as a single unit; therefore, separating larger marshes into smaller, user-defined units should pose no consequences. Still, using existing breaks in marsh continuity is strongly recommended, as it is most consistent with the intended application of the method.

Some rapid assessment methods use assessment units generated by delineating circular plots with predetermined areas around randomly-selected points within wetlands, which has the advantage of being more standardized for probabilistic analysis. This method has not been tested for MarshRAM application. Because MarshRAM was designed to characterize units bounded by existing ecological or physical features, some metrics will not properly apply to a unit delineated around a random point. The point method is therefore not recommended for MarshRAM application at this time.

- Tip 3.1.1: In areas where *Phragmites australis* (hereafter, *Phragmites*) grades from salt marsh to upland or freshwater wetland vegetation, end the unit where either (1) non-halophytic vegetation, such as poison ivy (*Toxicodendron radicans*) or bayberry (*Myrica pensylvanica*) are seen growing among the *Phragmites*, or (2) halophytic plants (such as *Spartina* spp., *Iva frutescens*, or *Schoenoplectus robustus*) are no longer seen growing among the *Phragmites* when heading away from the salt marsh.

## Field Maps

Field maps of each unit should be used for field orientation, determining wetland community and buffer characteristics, locating 'walking transects', and evaluating certain MarshRAM metrics. Ideally, paper maps should be produced using a backdrop of the latest and highest-resolution leaf-off aerial imagery available, at a scale sufficient to illustrate salt marsh features and surrounding land uses. The map should include a delineation of the assessment unit (as defined above), locations of eight 'walking transects', a scale bar, and 150-m and 30-m buffer delineations to facilitate landscape analyses in MarshRAM Sections C and D1 (App. 2). Assessment-unit and buffer delineations can be added to the imagery digitally, using computer software such as a GIS or Google Earth, or manually drawn onto paper printouts of the aerial image (typically 8.5" x 11"). For smaller units, separate maps showing the buffers and the transect lines, each at optimized scales, may be easier to follow.

Walking-transect lines (for community composition and IMI) should also be added digitally to the map image file, or manually on a paper printout of the map. Eight transects should run mainly from the marsh-upland interface to the marsh-open water interface, (ideally) parallel to each other, and evenly spaced across the marsh from a random starting point. This is done to capture both spatial variability and habitat gradation across the marsh. To add the transects to the map, first draw and measure (using any scale) a line (hereafter, 'guideline') across the widest part of the marsh that runs approximately parallel with the marsh-upland and marsh-open water interfaces (see App. 2; see Tip 3.1.2 for variations). Transects will be added perpendicular to the guideline. Divide the guideline length by eight; this will be the 'space' between transects. Select a random number between zero and the length of the 'space' to act as a starting point. Measuring from the left end of the guideline, mark the starting point (at the random length selected) and proceed to add the remaining seven points, each at the distance of the 'space' from the last point (beginning at the starting point). Draw a transect line across the guideline at each mark, running perpendicular to the guideline (Tip 3.1.3, App. 2) and entirely across the marsh surface. Most transects should run across the marsh from upland to open water, but commonly, some may run from upland to upland, barrier beach, or some other feature. A cartographic GPS unit loaded with the same information may be useful (but not necessary) for spatial confirmation and ground-truthing site delineations (Tip 3.1.4).

- Tip 3.1.2: For marshes that surround a major water feature, such as a large cove, creek, or ditch, draw the fewest non-overlapping guidelines that will allow opportunity for perpendicularly-drawn transects to cross any point in the marsh. For example, in a marsh that surrounds a cove, draw the first guideline completely across the marsh on one side of the cove, then a second one on the other side, but extending only as far as the end of the cove (since the first guideline will cover the area beyond the cove). Measure the total length of both guidelines to determine the transect 'space', and proceed following the above guidance.

- Tip 3.1.3: For heavily grid-ditched marshes, where transects may run along or within ditches and mischaracterize the composition of the marsh, transects should be angled to run from (approximately) the 'mouth' of one ditch to the 'head' of the next so that both upland-to-open water and the intra-ditch gradients can be captured.
- Tip 3.1.4: Field maps showing the transects and other information can be uploaded to an electronic device (such as a tablet or cell phone) using data-mapping software, such as Avenza Maps™ (Avenza Systems® Inc.). This is particularly useful for guiding the users along the 'walking transects' described in Section E. If the project aims to capture change in the IMI over time, use an accurate GPS unit to record the start and finish points of each transect, so they can be confidently replicated in future assessments.

### General Assessment Methods

MarshRAM should be conducted using a combination of on-site and remote investigation to complete each assessment. Although MarshRAM could be completed by a single site visit alone, information gained through the interpretation of remote-sensed imagery and investigation of existing geospatial data will result in a more complete and accurate assessment.

#### *Site Investigations*

Each assessment unit must be directly observed by the user. A single MarshRAM datasheet is filled out during the site visit. Assessment units are accessed on foot, or by boat when necessary, to access all parts of the marsh. The entire perimeter and all eight transects of each unit should be assessed when possible, otherwise assessments should be made by accessing as many transects and areas within and around the unit as possible. Particular focus should be given to tidal and surface-water inlets and outlets, and borders adjacent to current and historic cultural activities, since these are areas where condition is most likely to be affected. Because MarshRAM is partly based on the structure and composition of vegetation, units should be assessed during times of peak foliage; in Rhode Island this typically runs from early July through mid-October.

#### *Remote Investigations*

Data obtained during field investigations can be updated, complemented, or completed via GIS analysis. The following GIS operations are recommended. RIGIS data are available on-line at www.rigis.org. If a GIS is unavailable, an on-line software such as Google Earth Pro can be used for remote investigations.

## 3.2 Filling out the MarshRAM Field Datasheet

This section details methods for interpreting, selecting, and scoring attributes and metrics of MarshRAM. It is organized in the order of the field datasheet; refer to the datasheet for clarification (App. 1).

### Header

Fill out the user(s) name, a designated (and exclusive) assessment unit code or name, and the date of the field visit on each page of the datasheet. On the first page, document the longitude and latitude of a point as close to the center of the assessment unit as possible. Longitude and latitude can be determined in the field using a GPS unit, by automating the coordinates of the unit's centroid using GIS, or by approximating the centroid using on-line mapping software.

## A. Marsh Characteristics

This section contains classification and background information on the assessment unit in its current (as observed) state; it is not scored, but the classification can inform scoring and analysis. Fill out all attributes in this section. Completely or accurately answering certain attributes may require remote analysis or research. Some attributes may require the user to apply best professional judgement.

### *A.1 Assessment Unit Area*

This attribute documents the size of the assessment unit in hectares. Determine the unit size using GIS or on-line software, according to the unit delineation (see Sec. 3.1 Defining Assessment Units).

### *A.2 Position in the Watershed*

Position in the watershed can be determined using aerial imagery, and is defined as follows.

- Upper Bay: Waters of Narragansett Bay situated north of Sandy Point, Warwick; Providence Point, Prudence Island; and Bristol Point, Bristol.
- Mid Bay: Waters of Narragansett Bay East and West Passages situated south of Upper Bay and North of Poplar Point, N. Kingstown; Conanicut Point, Jamestown; South Point, Prudence Island; and Carr Point, Middletown.
- Lower Bay: Waters of Narragansett Bay East and West Passages situated south of Mid Bay and north of the Narrow River, Narragansett; Beavertail Point, Jamestown; and Brenton Point.
- Mount Hope Bay: Extends north and east of the Mount Hope Bridge and the Fall River expressway.
- Sakonnet River: Extends south of the Fall River Expressway and North of Sachuest Point, Middletown and Bluff Head, Little Compton.
- South Coast: Waters along the Atlantic Ocean south of the Lower Bay and Sakonnet River.

### *A.3 Marsh Type and Setting*

Marsh type and setting can be determined by interpreting aerial imagery, except as noted.

*Geomorphic Setting*

Categories are defined as follows:

- Open Coast: Greater than 25% of the salt marsh perimeter directly borders a large estuary such as Narragansett Bay, Greenwich Bay, Mount Hope Bay, or the Sakonnet River.
- Open Embayment: Greater than 25% of the salt marsh perimeter directly borders a small estuary or sub-embayment of a larger estuary, such as Point Judith Pond or the Warren River.
- Valley: The marsh is a floodplain or delta surrounding a small tidal river or stream.
- Riverine: The marsh fringes one side of a larger river.
- Back Barrier Marsh: The marsh is largely separated from the ocean or estuary by a tidal spit or barrier beach.
- Back Barrier Lagoon: The marsh surrounds or fringes a coastal lagoon* that is largely separated from the ocean or a larger estuary by a tidal spit or barrier beach.

- Tip 3.2.1: Refer to Sec. 3.1, 'Defining Assessment Units', to determine whether a water feature in a back-barrier system should be included as part of the marsh or as a separate lagoon; this may be useful in differentiating between Back Barrier Marsh and Back Barrier Lagoon.

*Geoform*

Categories are defined as follows:

- Platform: The marsh has developed a level high marsh platform that is intermittently inundated by tides.
- Fringe: The marsh is primarily a regularly-inundated fringing band of low marsh that lacks a developed, level high-marsh platform.

*Adjacent upland*: Select one or two types that best describe the adjacent uplands.

*Tidal Water Salinity*: Use a refractometer to estimate the salinity near the tidal inlet to the marsh.

*Freshwater input*: Using aerial imagery and site observations, determine the main source(s) of freshwater inputs to the marsh. 'Precipitation only' should only be used alone or with 'Groundwater'.

### *A.4 Exposure to Tides*

*For this section, refer to Sec. 3.1, 'Defining Assessment Units', to determine whether a contained water feature qualifies as the tidal water or as part of the assessment unit.

*Exposed Marsh Edge*

Estimate the proportion of the marsh edge exposed to tidal water* as a % of total unit circumference.

*Effective fetch of Tidal Water*

Use GIS or on-line mapping software to determine the distance across tidal water between the exposed edges of the marsh and the nearest significant land mass (large enough to block wave energy) parallel to that exposed edge.

*Tidal Range*

Use any available information or observations to estimate the tidal range for the marsh. For 'open-coast' marshes, the tide range in RI will be >1.5m. Tide information specific to sub-embayments will be needed for other estimations, otherwise, check 'unknown'. The Salt Marsh RAMP has collected tide frame data for over 30 lagoons and sub-embayments of Narragansett Bay in RI; these data are available upon request to the Narragansett Bay National Estuarine Research Reserve (NBNERR).

### *A5. Natural Habitat Diversity*

Indicate the presence of all significant natural habitat types present in the marsh by checking all categories observed. Invasive and manmade habitat types are purposely excluded from this attribute. 'Significant' means it is identifiable and contributes some small or greater functionality at the assessment unit scale. Types are self-explanatory.

### *A6. Connected Natural Habitats*

Use interpretation of aerial imagery and GIS or on-line measuring tools to determine which of the listed or other natural habitats fall within 150m from any edge of the marsh unit. Eelgrass or other SAV can be determined by overlaying the latest RIGIS Eelgrass polygons or viewing the 'RIGIS Eelgrass Locations' on-line mapping tool (available at www.rigis.org). Types are self-explanatory.

### *A7. Count of Waterbirds Present*

Use hash-marks or another system to tally, by listed guild, birds observed when first accessing any part of the marsh. To be counted in the tally, birds must be physically on the marsh, on marsh vegetation, or in waters contained within the marsh (refer to Sec. 3.1 'Defining Assessment Units'), except for swallows, which can also be feeding above the marsh. Songbirds and other common birds are not tallied. For remarkable birds not clearly falling within a guild, write in the species or guild(s) (e.g. 'Owls'), and tally as needed. Listed guilds are defined as follows:

- Wading Birds: Any species of egrets, herons, ibises, bitterns, or storks.
- Shorebirds: Any species of plovers; oystercatchers; avocets; and sandpipers, curlews, and allies.
- Waterfowl: All swans, geese, ducks, loons, grebes, and cormorants.
- Swallows: All species of swallows.
- Raptors: All diurnal raptures, including eagles, osprey, vultures, hawks, falcons, and allies.
- Gulls: All gulls, terns, and their allies.
- Sparrows: Only salt marsh-dependent sparrows from the genus *Ammospiza*. Note: for this section, do not count sparrows flushed during the community composition transects; those are tallied separately on the Community Composition and IMI form (App. 1, Sec. E).

➢ Tip: Identifying sparrows to species may be too time-consuming to allow for efficient assessment of other attributes and metrics (common). Only tally sparrows that are flushed from the marsh grass or low salt shrubs (<0.5m) and land back in the marsh or low shrubs, unless they can be confidently identified as a marsh-obligate sparrow (Genus *Ammospiza*). Other sparrows may use the marsh, but those species are more likely to fly away from the marsh to upland or taller marsh-interface perches (e.g. tall *I. frutescens*) upon being flushed.

## B. Ecosystem Functions and Services

Estimate the importance of 12 ecosystem functions and services commonly attributed to salt marshes, using the pre-defined ranks provided. Sum the ranks as a coarse indicator of salt marsh relative value.

### *Rank definitions*

The MarshRAM *Ecosystem Functions and Services* section uses a four-rank system. The ranking system focuses on the three lower ranks (0, 1, and 2), with *special importance* (rank 3) being reserved for truly unique or critically-important examples of the function or service. Use all available information and best professional judgement to assign one rank to each function and service for each marsh. These general scoring ranks for all categories are defined as follows:

*Not evidently provided* (0): There is no evidence or knowledge of the salt marsh providing the function or service.

*Minor or potential importance* (1): There is evidence or knowledge of the marsh having a minor or potential contribution to providing the function or service.

*Evident or known importance* (2): There is clear evidence or knowledge of the marsh providing or largely contributing to the function or service.

*Special importance* (3): Used sparingly; the evident or known function or service provided by the marsh is uniquely, unusually, or critically important to people or wildlife.

### *Decision processes and breakpoints*

Each of the following *ecosystem functions and services* is ranked according to the above definitions using a combination of geospatial analysis, field investigation, and investigator knowledge for each salt marsh.

1. Storm protection of developed property

Premise: The salt marsh platform and vegetation elevation and roughness provide resistance to the laminar flow of water, interrupting the momentum of tidal surges and causing wave energy to dissipate before reaching adjacent developed properties.

Evidence: The salt marsh lies between tidal waters and low-lying developed property (less than 3m above the marsh surface) vulnerable to damage by tidal flooding or wave action from tides, storm events or boat wakes. The marsh provides the service if it would prevent or mitigate such damage. All ranks are common, except where noted.

*Not evidently provided* (0): There is no vulnerable developed property landward of the marsh.

*Minor or potential importance* (1): There is some evidence or knowledge that the marsh geomorphology or vegetation could lessen the impacts of flooding or wave action on some vulnerable developed property, but it is not clear that the marsh would be effective.

- Examples: The marsh lies between tidal water and low-lying developed property, but:
    - The marsh is narrow (<5m) and unlikely to offer much protection
    - The developed property is somewhat elevated and it's unclear that the property is in danger

*Evident or known importance* (2): There is clear evidence or knowledge that the marsh is providing protection to vulnerable developed properties.

*Special importance* (3): Unlikely; the protection of developed property from tides or waves, which is clearly provided by the marsh, is critically important to many people.

- Example: The marsh clearly protects a municipal water source from exposure or damage from tides or waves.

2. Flood-flow alteration:

Premise: Salt marshes can provide or contribute to water-storage capacity that mitigates downstream flooding from upstream floodwaters. Because gross flood storage along any stretch of river is typically cumulative, each marsh's contribution may be important. With extensive damming of many major tributaries to Narragansett Bay, salt marshes providing this service are uncommon.

Evidence: The marsh lies upstream from low-lying developed land that is vulnerable to flooding from upstream waters.

*Not evidently provided* (0): Common; the marsh does not sit upstream of developed property vulnerable to upstream flooding.

*Minor or potential importance* (1): Uncommon; it is unclear that the marsh provides storage of upstream flooding on vulnerable downstream developed property, or the storage it provides is negligible compared to the volume of flood water.

Example: It is unclear whether the downstream developed property is vulnerable to flooding.

*Evident or known importance* (2): Uncommon; the marsh is situated to provide flood storage upstream of vulnerable developed property.

- ➢ Decision Point: Most marshes situated anywhere upstream of vulnerable developed property should be assigned this rank (2), as all marsh area contributes to cumulative flood storage.

*Special importance* (3): Unlikely; protection of developed property from upstream flooding clearly provided by the marsh is critically important to many people.

- Example: The marsh clearly and largely contributes to the protection of important public infrastructure from upstream flooding.

3. Part of a habitat complex or corridor

Premise: Salt marshes may contribute to larger tracts of wildland, including wildlife corridors, which are important to support biodiversity. All categories are common, except where noted.

Evidence: Investigation of aerial imagery or site visit reveals that the salt marsh is contiguous with other substantial wildlands that together provide a larger continuous wildlife area.

*Not evidently provided* (0): The marsh is not contiguous with any other wildlands (uplands/wetlands).

*Minor or potential importance* (1): The marsh is adjacent to a parcel of wildland that is not substantial or important in the landscape context.

- Example: The marsh is adjacent to small undeveloped woodlands in a developed matrix that may provide additional collective habitat for certain species:

*Evident or known importance* (2): The marsh is contiguous with larger wildlands or is connected by a wildlife corridor to substantial wildlands.

*Special importance* (3): Uncommon; the marsh is part of a larger protected wildlife sanctuary or corridor, or is contiguous with wildlands that are critical to species of special concern.

- Example: Pettaquamscut Marsh is part of a continuous wild riparian system that supports diamond back terrapins, a species of state concern.

4. Sediment / toxin retention

Premise: Salt marshes can trap sediments and toxins from storm water runoff that would otherwise be carried into surface waters. All categories are common, except where noted.

Evidence: The salt marsh is situated between a source of sediments or toxins (such as a farm, highway, quarry, scrapyard) and a vulnerable receiving surface water. Toxins may be pesticides, salts from road salt, or other toxics carried by storm water or adsorbed to sediments carried by storm water.

*Not evidently provided* (0): The marsh is not situated between a significant source of sediments or toxins and a receiving surface water body.

*Minor or potential importance* (1): The marsh is adjacent to a source of toxins or sediments but the input is small, or it is unclear or unlikely that input of the toxins / sediments is present or substantial.

- Example: The marsh is adjacent to a small road that is likely sanded and salted during the winter.

*Evident or known importance* (2): The marsh is adjacent to a substantial source of sediments or toxins that are clearly running off into the marsh.

*Special importance* (3): Unusual; the marsh clearly traps sediments or toxins that pose a human health threat or a direct threat to species of concern.

5. Nutrient uptake

Premise: Salt marshes can intercept anthropogenic nutrients from overland runoff and groundwater from reaching a receiving surface water. All categories are common, except where noted.

Evidence: The salt marsh is situated between a source of nutrients (such as a farm, manicured lawn, unsewered residential development) and a vulnerable receiving surface water. Nutrients may be from fertilizers, human or pet waste, compost, yard debris, or other sources.

*Not evidently provided* (0): The marsh is not set between a source of anthropogenic nutrients and a receiving water.

*Minor or potential importance* (1): The marsh is adjacent to a source of nutrients but the input is small, or it is unclear or unlikely that input of the nutrients is present or substantial.

- Example: The marsh is adjacent to a sewered residential area where yard waste and lawn fertilizers are likely causing some nutrient inputs.

*Evident or known importance* (2): The marsh is adjacent to a substantial source of nutrients that are clearly running off into the marsh.

*Special importance* (3): Unusual; the marsh clearly traps nutrients that pose a human health threat or a direct threat to species of concern.

6. Carbon storage

Premise: Salt marshes can collect and store carbon through plant growth and creation of organic peat soils; this process reduces carbon in the atmosphere.

Evidence: The salt marsh has plants or a peat substrate.

*Not evidently provided* (0): Unlikely; use with discretion.

*Minor or potential importance* (1): The marsh stores little carbon and is actively losing carbon to the atmosphere through decomposition of existing peat.

*Evident or known importance* (2): Common, the marsh is mostly vegetated or has a sound peat substrate.

- Decision Point: Marshes are defined by having plants or peat substrates; therefore, all marshes store at least some carbon, contributing to the collective carbon storage of marshes, worldwide. All marshes are therefore assigned this rank (2) unless they are clearly losing vegetation and peat to erosion and decomposition, in which case a marsh is typically assigned a rank of 1.

*Special importance* (3): Unlikely; use only for large, thriving marshes.

7. Threatened / endangered species habitat:

Premise: Salt marshes can provide important or critical habitat for listed threatened or endangered species.

Evidence: The salt marsh or its immediate buffer (within 30m) supports a known occurrence of a plant or animal species that is threatened or endangered according to official federal or state lists. Evidence is gathered through investigation of geospatial data (Rhode Island Natural Heritage Database, available through the RI Natural History Survey), field observation, or another trustworthy source.

*Not evidently provided* (0): Common, the marsh is not known or likely to support a threatened or endangered species.

*Minor or potential importance* (1): Unusual; the marsh has potential to support obligate species of special concern or has historically supported species of special concern.

- Example: The marsh is large enough and has ample *Spartina* high marsh and buffer to support state-threatened salt marsh sparrows (*Ammospiza* spp.), but there are no records of their presence and none were observed during the assessment.

*Evident or known importance* (2): Common, the marsh is known to support one or more species of high conservation concern (threatened / endangered).

*Special importance* (3): Unusual; the marsh is one of few in the state to support a threatened or endangered species.

- Example: The marsh is in one of the few marsh complexes statewide known to support diamond-back terrapins.

8. Fish and shellfish habitat

Premise: Salt marshes provide important or critical habitat for fish and shellfish, including economically valuable species.

Evidence: The salt marsh has intertidal vegetation, creeks, ponds, or mud flats that support fish and shellfish.

*Not evidently provided* (0): Unlikely; the marsh is highly degraded and situated in an area unlikely to support any fish or shellfish.

*Minor or potential importance* (1): Unusual, the marsh is degraded to a point that it provides little valuable habitat for fish or shellfish.

- Example: A fringing marsh almost entirely dominated by *Phragmites australis* with no geomorphic features that typically support fish and shellfish.

*Evident or known importance* (2): Common, the marsh is mostly vegetated with native plants or has creeks, ponds, pools, mudflats, or other features known to support fish or shellfish.

- Decision Point: Nearly all marshes provide habitat for fish or shellfish, contributing to the collective, broader ecological function of marshes. All marshes are therefore assigned this rank (2) unless the above-listed features are clearly absent, in which case a marsh would be assigned a rank of one (1).

*Special importance* (3): Unusual; the marsh provides uniquely-important habitat for fish or shellfish.

- Example: The salt marsh is part of a fish or shellfish habitat restoration area, such as an active oyster restoration project.

9. Wildlife habitat

Premise: Salt marshes provide important or critical habitat for wildlife beyond fish and shellfish, including birds, mammals, reptiles, and insects.

Evidence: Wildlife are directly observed using the marsh during the assessment, or the salt marsh is known or suspected to support wildlife due to its size, location, adjacency to wildlands, or some other indication of wildlife value.

*Not evidently provided* (0): Unlikely; the marsh is highly degraded and situated in an area unlikely to support any wildlife.

*Minor or potential importance* (1): Common, the marsh is suspected to provide some wildlife habitat or provides a small amount of known habitat (e.g., the marsh is small relative to most marshes).

- Example: A small marsh surrounded by a suburban landscape.

*Evident or known importance* (2): Common, the marsh clearly provides substantial wildlife habitat.

*Special importance* (3): Uncommon; the marsh clearly provides an unusually large amount of wildlife habitat or provides substantial wildlife habitat within a special habitat conservation area or to species of some conservation concern.

- Example: The marsh is part of an active wildlife refuge.

10. Hunting or fishing platform

Premise: Salt marshes can provide a platform for hunting or fishing. All categories are common, except where noted.

Evidence: The salt marsh is accessible and used by hunters or fishermen as evidenced by prior knowledge, direct observation, the presence of hunting blinds, discarded gun shells, fishing litter, worn paths, etc.

*Not evidently provided* (0): The marsh is not easily accessible to hunters or fishermen and there are no signs of use, or hunting and fishing are not permitted on the marsh.

*Minor or potential importance* (1): The marsh is accessible and occasionally or potentially used by hunters or fishermen.

*Evident or known importance* (2): The marsh is accessible and clearly used regularly by hunters or fishermen.

*Special importance* (3): Uncommon; the marsh is clearly an unusually important hunting or fishing platform for many users.

11. Other recreation

Premise: Salt marshes can provide a platform for passive recreation such as bird-watching, sight-seeing, kayaking, or paddle boarding. Common, except where noted

Evidence: The salt marsh is accessible and used by people for recreation as evidenced by prior knowledge, direct observation, worn paths, etc.

*Not evidently provided* (0): The marsh is not easily accessible to recreating and there are no signs of use.

*Minor or potential importance* (1): The marsh is accessible and potentially used for recreation.

*Evident or known importance* (2): The marsh is accessible and clearly used regularly for recreation.

*Special importance* (3): Unusual; the marsh is clearly an unusually important recreation platform for many users.

12. Educational or historical significance

Premise: Salt marshes are culturally important assets that can have historical or educational significance.

Evidence: The salt marsh is known to have cultural significance or is known to be a current or ongoing platform for education. All categories are common, except where noted.

*Not evidently provided* (0): The marsh has no cultural or educational significance beyond its typical intrinsic values.

*Minor or potential importance* (1): The marsh is historically or culturally significant to a small group or is occasionally used for education.

*Evident or known importance* (2): The marsh has unique historical or cultural significance or is regularly used for education.

*Special importance* (3): Unusual; the marsh has unique and broadly-recognized historical or cultural value or is used regularly for wide-reaching education.

## C. Surrounding Land Use

This metric represents the relative intensity of surrounding land use and is generated using a weighted-average model as follows.

- Using the scale bar or buffer delineation on your field map, establish and examine a 150-m buffer zone surrounding the perimeter of the assessment unit.
- The entire surrounding 150-m buffer zone is assessed, including open-water features and other wetlands surrounding the marsh.
- For each intensity class listed, interpret the aerial photography (and field verify) or directly estimate the proportion (to the nearest tenth, i.e. 0, 0.1, 0.2. 1.0) of land and open water within the 150-m buffer zone that falls within the class.
    - Refer to the chart to the lower right of the metric to determine which cover class various land cover types fall into.

- Interpret each intensity class proportion disregarding its position in the buffer. For example, a natural area (*Very Low*) should not be downgraded if it falls behind a cultural feature such as a major road, even if the feature impedes terrestrial access to the area.
- For roads and other linear features, interpret the proportion of the unit the feature covers, including all berms, fill, and bounded catchments associated with them.

- Enter the proportion on the line to the right of the intensity class listed.
    - If total cultural cover is <0.1 but >0.0, enter 0.1 for the most appropriate intensity class and 0.9 for *Very Low*.
- Check that the sum of the proportions is exactly equal to 1.0; otherwise, there is an error in your estimations.
- Multiply each proportion by the predetermined intensity-class coefficient to generate four weighted values.
- Sum the weighted values to generate the *Surrounding Land Use score*. The score should be between 1.0 and 10; otherwise there is an error in calculations or estimation.
- Check all listed land uses identified within the 150-m zone surrounding the assessment unit.

## D. Wetland Disturbances

Ten metrics represent readily-recognizable disturbances that can influence salt marsh condition. Each metric requires the user to assess whether the disturbance is present, estimate the intensity of the disturbance, and when applicable, identify evidence of the disturbance, identify associated stressors, and identify the general source of the stressors. Each metric is scored separately (max 10 points for each); these scores are averaged to generate the Wetland Disturbance Score. The following rules apply for *Wetland Disturbance* metrics:

- Scoring is based on observed or known evidence; therefore a score of 10 is given to the metric if evidence cannot be identified.
- Each metric is assessed as independent of all other metrics, and based on the current status of the marsh.
    - For example, if evidence suggests that the marsh status (e.g. size) has been changed by (e.g.) partial filling, a score is assigned according to (e.g.) D.5 *Filling and dumping…* However, for all other metrics, the remaining wetland (unfilled part) is assessed as the entire unit.
- When indicated, select the *Primary Associated Stressor* that most strongly contributes the given stress type.
- Enter the designation C or H to document the *Source of Stress* associated with the *Primary Associated Stressor*. Source categories are self-explanatory. If the source of stress cannot be determined, check *Undetermined*.
    - When selecting the source for a stressor that is currently in use (e.g. a road currently being used to access a home), write in the designation "C" for *current* (next to e.g. *Private / Residential*).
    - For a stressor that is no longer actively used but still affects the assessment unit (e.g. a historic farm road, no longer being used but still impounding the marsh) write in an "H" for *historic* (next to e.g. *Agricultural*).
- Write the metric score in the box to the left of the metric
- After scoring all *Wetland Disturbances* metrics, add the scores together and average (divide by 10) to generate the **Wetland Disturbance Score** (max = 10).

Tips:

- Metric categories are estimates and are not intended to be highly accurate measurements. Select your best judgment of intensity. Studying the field map is often helpful in making proportion determinations based on relative area. Strong-intensity disturbances are usually clearly evident, while some lower-intensity disturbances may be harder to rate or detect. Be sure to base your selection on observed evidence (and document it) or knowledge. Because each metric is scored independently and modestly, scoring consequences of vague proportions and intensities are generally small. Multiple, additive disturbances and their impacts primarily determine final MarshRAM index values.
- For each *Wetland Disturbances* metric, if no evidence of disturbance is detected for any part of the metric, enter *None* (or 10) and move to the next metric, since *evidence*, *associated stressors*, and *sources of stress* sections will not apply. However, all of these sections should be completed if any evidence of the disturbance is detected for any metric.

### *D.1 Buffer Encroachment*

This metric estimates the percentage of cultural land cover within 100 feet of the unit perimeter.

- Using the field map and assessing visually in the field, estimate the percent of *cultural land cover** within the 30m surrounding the outer perimeter of the marsh (or assessment unit) and select the associated cover class from the list. Recovering vegetated lands are not generally considered cultural in this section.
- The entire surrounding 30-m buffer zone is assessed, including open-water features and other wetlands surrounding the marsh. Docks and marinas in the water are considered cultural.
- Write the associated score in the box at the left of the metric.
- **Cultural land cover* is defined as any land that is modified by humans more than once per year (e.g., mowed twice or more), or has been modified in any way that impedes natural succession of vegetation or other natural processes (e.g., any farmed, developed, mowed, paved, etc.).

### *D.2 Impoundment and Tidal Restriction*

This metric documents and scores the intensity and proportion of salt marsh disturbance associated with human activities resulting in impediments to water flow across the marsh. This metric requires the user to identify and evaluate hydrologic and ecological stress caused by the impoundment of freshwater and/or tidal restriction, both of which commonly result from such activities.

- Identify and document evidence of impoundment stress. Select categories from the *Evidence* box that most closely describe any observed evidence of increased water due to impoundment or tidal restriction. Select all that apply.
- Select the highest-intensity category that applies to the restricted part of the marsh. Select only one category.
  - Select *None observed* (10) if there is no evidence of anthropogenic impoundment or tidal restriction within the unit. Move to the next metric.
  - Select *Restriction observed but no change in vegetation or elevation evident* (7) if evidence suggests that a restricting or potentially restricting anthropogenic feature is present but there is no evidence of vegetation or marsh platform change across the restriction. This is common where there is a restriction crossing the marsh, but a bridge or large culvert(s) nullifies or minimizes its effects.

- Select *Restriction observed with change in vegetation elevation evident* (4) if evidence suggests that a restricting anthropogenic feature is present and there is observable vegetation or marsh platform change across the restriction. This is common where there is a restriction crossing the marsh with a culvert that is insufficient to convey the full range of tidal and/or freshwater flow.
- Select *Restriction observed with subsidence, ponding, or dieoff evident* (1) if evidence suggests that a restricting anthropogenic feature is present and there is observable vegetation change and loss due to ponding or marsh platform subsidence. This status is often identified by an increase in the size of a surface water feature upstream of the restriction. It is commonly associated with an undersized, clogged or lacking culvert.

- If less than half of the marsh (or assessment unit) is affected by the restriction, average the selected score with 10; otherwise, the selection dictates the final score.
- Write the resulting score in the box at the left of the metric.

Tips:

- Studying the field map or electronic aerial imagery can help to remotely identify and quantify impounded / restricted areas within the assessment unit. Be sure to field-check remote determinations. An impoundment can often be remotely identified by one of the following:
    - Open water at the upstream part of the unit, often shaped like a cone or semicircle with the flat side against the impoundment
    - Abrupt change to wetter hydrologic regime and associated vegetation upstream of impoundment
    - Abrupt change in wetland width, wider upstream of the impoundment
- To determine vegetation changes, compare restricted vegetation to vegetation downstream of the restriction. For example, the upstream side of a restriction is often dominated by the invasive common reed *Phragmites australis* and the downstream side is dominated by native salt marsh vegetation. This technique assumes that vegetation was originally continuous across the barrier.
- If two or more areas are affected by restriction differently (e.g. partly vegetation change only and partly ponded), select the category that has the highest intensity or affects the greatest proportion of the wetland.

### *D.3 Ditching and Draining Density*

This metric documents and scores the intensity of ditching on the marsh platform. For difficult determinations, select the category based on the total linear length of all ditches in relation to the area of the salt marsh, as indicated in the Key (below and in App. 1). Use the field map and scale bar, GIS, or electronic mapping software to measure the ditch length (m) and marsh area (ha).

- Select *None* if there is no ditching evident.
- Select *Low* if one or more ditches are present but do not strongly affect the hydrology of the marsh, or density is less than 100m/ha.
- Select *Moderate* if one or more ditches are present and strongly affect the hydrology of the marsh, or density is between 100 and 300 m/ha.
- Select *High* if one or more ditches are present and dominate the hydrology of the marsh, or density is greater than 300 m/ha.

### *D.4 Anthropogenic Nutrient Inputs*

This metric requires the user to evaluate the evidence of impacts associated with anthropogenic nutrient loading. Document all evidence and the primary associated stressor and source first; then assign a rank as instructed below.

- Select *No evidence* (10) if there is no evidence of sources or impacts of nutrients.
- Select *Sources observed only* (7) if common sources of nutrients are evident, but there is no evidence of ecological impact.
- Select *Sources observed and some impacts evident* (3) if sources of nutrients are evident and there is minor, localized, or uncertain evidence of ecological impact.
- Select *Strong impact evident* (1) if sources of nutrients are evident and there is strong evidence of significant ecological impact.

<u>Tips:</u>

- ➢ Refer to the *Evidence* section of this metric (App. 1) for examples of evident stressors and impacts for the four fluvial-input categories.
- ➢ Only rank the marsh as having ecological impacts evident when sources of nutrients are also evident or known (e.g., known high-nutrient surrounding waters).
- ➢ Use your best judgement and experience from marshes in different settings to decide whether ecological nutrient impacts are evident.

### *D.5 Filling and dumping within wetland*

This metric documents and scores the intensity and proportion of filling and dumping within the assessment unit. Document all evidence, the primary associated stressor and source, and calculate the score as instructed below.

- Select *No fill observed* (10) if there is no evidence of filling or dumping within or directly abutting the unit.
- Select *Scattered trash in the marsh…*(9) if there is filling or dumping evident that affects the aesthetics of the unit, but there is no evidence of ecological impacts.
- If the fill is substantial, i.e., changes the water regime of a portion of the marsh to upland or interferes with natural hydrology (such as a historic stone wall or farm dike), select the rank that represents the proportion of fill that is within or abutting the perimeter of the marsh.
- If the fill has a hardened edge, check the appropriate box and subtract one point from the rank score.

<u>Tips:</u>

- ➢ Many areas of fill also impound wetlands and should be scored on their contributions to both stress types. For example, a highway that crosses a marsh may both impound/restrict and fill the wetland. Both metrics (D.2 *Impoundment*… and *D.5 Filling*…) should be scored separately and fully for the disturbances caused by the highway.
- ➢ The area (proportion) considered filled in a unit partly bordered by fill that effectively splits the marsh into two separate units should include the entirety of the fill (i.e. to the outermost edge).
- ➢ Using the proportion of the perimeter filled assumes that the marsh originally extended beyond the perimeter-fill line to an unknown degree.

### *D.6 Edge Erosion*

This metric documents and scores the proportion of deep edge erosion along the seaward edges of the marsh, including the banks of major creeks. Only count edges that are clearly eroded deep into thick peat (>0.5m). Shallow erosion along the edge of low marsh is not counted as edge erosion.

- Select *Minimal erosion observed* (10) if there is no evidence of deep erosion along the edges of the unit.
- Select *Low* (7) if <10% of the marsh seaward edge is deeply eroded.
- Select *Moderate* (4) if 10-60% of the marsh seaward edge is deeply eroded.
- Select *High* (1) if >60% of the marsh seaward edge is deeply eroded.

### *D.7 Crab Burrow Intensity*

This metric documents and scores the intensity of crab burrowing and herbivory along the marsh seaward edge, including along the banks of major creeks and ditches. Select the best-fit intensity category and document the evidence of burrowing crab impacts in the provided checklists.

- Select *None* (10) if burrows are limited to the peat edge and are surrounded by dense low-marsh vegetation.
- Select *Low* (7) if <10% of the marsh seaward edge is densely burrowed and partly or fully denuded.
- Select *Moderate* (4) if 10-60% of the marsh seaward edge is densely burrowed and denuded.
- Select *High* (1) if >60% of the marsh seaward edge is densely burrowed and denuded.

### *D.8 Ponding and Dieoff Depressions*

This metric documents and scores the proportion of marsh-ponding and dieoff (defined in Table 1) covering the marsh platform. 'Ponding' is defined as dieoff remaining flooded through the tide cycle. Estimate the proportion of the marsh platform covered by ponding and dieoff, select the associated intensity category, and document the evidence in the provided checklists.

- Select *None* (10) if no ponding or dieoff is observed.
- Select *Low* (7) if <10% of the marsh platform is covered by ponding or dieoff.
- Select *Moderate* (4) if 10-60% of the marsh platform is covered by ponding or dieoff.
- Select *High* (1) if >60% of the marsh platform is covered by ponding or dieoff.

### *D.9 Vegetation Cutting / Removal / Soil Disturbance*

This metric documents and scores the proportion of mowing, cutting, removal, eradication (e.g. via application of herbicides), or other damage to vegetation or marsh peat in the assessment unit, including damage and depression caused by soil disturbances such as driving or regular trampling on the marsh. Document all evidence, the primary associated stressor and source, estimate the cover affected, and select a category and score as instructed below.

- Select *None observed* (10) if no vegetation or soil disturbances are observed.
- Select *Low* (7) if <10% of the marsh platform is covered by disturbed vegetation or soils.
- Select *Moderate* (4) if 10-60% of the marsh platform is covered by disturbed vegetation or soils.
- Select *High* (1) if >60% of the marsh platform is covered by disturbed vegetation or soils.

### *D.10 Phragmites within wetland*

This metric estimates the proportion of the cover of invasive *Phragmites* within the assessment unit. Document all abutting stressors and the primary source of stress, where abutting stressors are defined as: any human disturbances observed adjacent to or within the invasive vegetation incursion. Estimate and select a cover class and score from the list.

- Select *None* (10) if no *Phragmites* is observed.
- Select *Low* (7) if <10% of the marsh platform is covered by *Phragmites*.
- Select *Moderate* (4) if 10-60% of the marsh platform is covered by *Phragmites*.
- Select *High* (1) if >60% of the marsh platform is covered by *Phragmites*.

Tips:

- Count an area as 'covered by *Phragmites*' if *Phragmites* is the tallest marsh plant (not including overhanging trees) that covers at least 30% of the ground.
- Although some stands of native *Phragmites* exist in Rhode Island, the vast majority are non-native; therefore, count all *Phragmites* in the total cover when selecting a cover class. In the rare case where a stand is clearly documented and known to be native, it can be discounted.

## *E.* Marsh Community Composition and Index of Marsh Integrity (IMI)

This section characterizes and rates the integrity of the marsh using the relative proportion of pre-defined cover types (Table 1, App. 3). The relative proportion of typical marsh cover types is quantified using eight transects per marsh distributed evenly across the marsh surface, each traversing from the marsh-upland interface to the subtidal zone, as described in Sec. 3.1 *Field Maps*. The user walks the transects using even, repeatable steps and each step traversing a community type is tallied as a data point for that type. The relative proportion of community types is then estimated by the relative proportion of steps taken in each community type.

The Index of Marsh Integrity (IMI) is calculated using a coefficient of community integrity (CCI) that was assigned to each cover type based on its indication of marsh degradation and habitat value (Kutcher 2019). Cover types with high sensitivity to anthropogenic stress and high habitat value were assigned CCI values approaching or equal to ten (10), whereas cover types sustained by or thriving upon stress with low habitat value were assigned coefficients approaching or equal to zero (0) (Table 1). The IMI is the mean of the coefficients of all cover types documented, each weighted by its relative proportion across all transects (App. 1).

Conduct this section as follows:

- Using the field map as a guide, walk each transect using repeatable, even paces.
- For every step across the marsh surface, tally the cover type traversed as a single data point using the supplied tally form in the datasheet (App. 1, Sec. E).
- On the line provided, also tally any sparrows flushed from the marsh surface and landing back on the marsh surface during the community composition transects. Note: tally sparrows flushed during other parts of the MarshRAM assessment separately on the first page of the datasheet under *Count of Waterbirds Present* (App. 1, Sec. A7).
- At the end of each transect, sum the tallies for each community type in the spaces provided.
- Once all transects have been completed, sum the tallies across all transects for each community type in the worksheet provided on the page following the tally pages.

- Using the worksheet, multiply the total tally (TT) by the coefficient of community integrity (CCI) ascribed to each type and enter in the space provided.
- Using the worksheet, calculate and enter in the space provided, the % cover of each community type, using the formula provided on the sheet.
- **Calculate the Index of Marsh Integrity (IMI)** using the formula provided in the datasheet.

Tips:

- Community cover-types are typically classified by the tallest vegetation with ≥30% aerial cover, even if there is denser cover of other vegetation below (per Cowardin et al. 1979). For example, 30% *P. australis* over 100% *S. patens* would be classified as Phragmites, whereas 20% *P. australis* over 100% *S. patens* would be classified as Meadow High Marsh.
- Starting and endpoints of the walking transects can be located by rectifying landmarks visible on the field map with on-the-ground features. From the starting point of the transect, locate a landmark (e.g., a tree, shrub, house, etc.) in the direction of the transect trajectory and walk toward that landmark to complete the transect.
- Alternatively, coordinates for staring and end points of the transects can be found first using GIS. Starting and end points can then be located using a GPS in the field.
- Another efficient option is to upload the field maps, with transects delineated, to an electronic device (such as a cell phone or tablet) using a data-mapping software such as Avenza Map ™ (Avenza Systems ® Inc.). The walking transects can then be followed in relation to the imagery on the device in real time.
- Only tally sparrows that are flushed from the marsh grass or low shrubs (<0.5m) and land back in the marsh, unless they can be confidently identified as a marsh-obligate sparrow (Genus *Ammospiza*). Other sparrows may feed on the marsh, but those species are more likely to fly away from the marsh to upland or taller marsh-interface (e.g. tall *I. frutescens*) perches upon being flushed.
- For impenetrable thickets of Phragmites or Salt Shrub that are easily identifiable on recent areal imagery, the user may need to replace part of a walking transect with photointerpretation to estimate the number of data points (steps) in that section of the transect. This can be done after the field survey using a GIS measuring tool and the total tally from another transect to determine average step length, then applying average step length to the length of the un-walked section of the transect to generate a tally for the impenetrable community type. Only use remote sensing when the community type can be clearly identified in recent imagery, such as for dense Salt Shrub and Phragmites. Avoid remote sensing whenever possible, because photointerpretation is not consistently effective for most cover types.

Table 1. Salt marsh cover-types (modified from Ekberg et al. 2017) and coefficients of community integrity (CCI) used to generate indices of marsh integrity (IMI). Cover-types are listed in approximate order from upland interface to seaward edge, followed by typically-smaller features (from Kutcher 2019). Refer to App. 3 for representative images of the cover-types.

| Marsh Cover Type | CCI | Description |
|---|---|---|
| Salt Shrub | 9 | Infrequently flooded shrub community (>30% shrub cover) located at higher elevations on the marsh platform and at the upland interface; typically dominated by *Iva frutescens* , *Baccharis halimifolia* |
| Brackish Marsh Native | 10 | Emergent community where freshwater from the watershed dilutes infrequent flooding by seawater; typically dominated by non-halophytic, salt-tolerant vegetation such as *Typha angustifolia* , *Schoenoplectus robustus* , *Spartina pectinata.* |
| Phragmites | 3 | Areas where *Phragmites australis* cover >30%. |
| Meadow High Marsh | 10 | Irregularly flooded emergent high marsh community dominated by any combination of *Spartina patens* , *Juncus gerardii* , *Distichlis spicata* ; *Spartina alterniflora* absent |
| Mixed High Marsh | 7 | Irregularly flooded emergent high marsh community comprised of any combination of *S. patens* , *J. gerardii* , *D. spicata* ; *S. alterniflora* present |
| Sa High Marsh | 5 | Irregularly flooded emergent high marsh; typically a monoculture of *S. alterniflora* (>30% cover), although *Salicornia* sp. may be present. |
| Dieoff Bare Depression | 1 | Shallow gradual depression on marsh platform, irregularly flooded by tides but typically remaining flooded or saturated to the surface throughout the tide cycle; <30% perennial vegetation cover, or bare decomposing organic soil, typically with remnant roots of perennial vegetation; but may have partial or complete cover of annual pioneer vegetation (e.g., *Salicornia* sp., *Sueda* sp.), algal mat, filamentous algae wrack, or flocculent matter. |
| Low Marsh | 8 | Regularly flooded emergent community located at typically-sloping tidal edges of the marsh surface and dominated by tall-form *S. alterniflora* . |
| Dieback Denuded Peat | 0 | Typically non-depressional marsh platform feature; marsh peat is exposed (vegetation <30%) and perforated from grazing, crab burrowing, and erosion; typically at or near tidal edge. |
| Natural Panne | 8 | Shallow depression on marsh platform with clearly defined edge; irregularly flooded, typically dry at low tide; species may include any cover of *Plantago maritima* , *Sueda maritima* , *Salicornia* sp., *J . gerardii* , *Aster* sp. |
| Natural Pool | 6 | Shallow steep-sided depression on marsh platform with clearly defined edge; irregularly flooded by tides but typically remaining flooded throughout the tide cycle; organic or sandy substrate lacking emergent vegetation and roots but may support *Ruppia maritima.* |
| Natural Creek | 8 | Narrow, natural, unvegetated, regularly-flooded or subtidal feature cutting into the marsh surface; typically sinuous. |
| Ditch | 2 | Manmade ditches and associated spoils on the marsh surface; typically linear. |
| Bare Sediments | 4 | Irregularly or infrequently flooded; sandy or gravelly sediments on the marsh surface with <30% vegetation cover; typically from recent washover event or elevation enhancement project. |

## *F.* Migration Potential

This section characterizes three aspects of site-level migration potential using the sum of coefficients that weight the physical, biological, and social resistance to salt marsh landward migration in the areas within 60-m of the marsh edge. By studying aerial imagery overlain with elevation geospatial data, the user estimates, to the nearest tenth (e.g., 0.1, 0.2, etc.), the proportion of each land cover and elevation class described in the worksheet as follows (App. 1, Sec. F). The metrics only assess the proportions of land and inland waters landward of the marsh. The surrounding estuary is not included in the proportions.

- Using a GIS or other electronic mapping software, draw a buffer line or polygon encompassing all land within 60m surrounding the marsh assessment unit.
- Overlay data representing 1.5-m (5-feet) above Mean High Water (MHW). Note: RIGIS provides a shapefile based on LiDAR data called *Inundation Polygons 5ft SLR* (available at rigis.org), which was used on 39 MarshRAM assessments conducted for the State of Rhode Island (Kutcher 2019, Kutcher and Raposa 2021). This is used to determine whether land is low-lying (within the *Inundation Polygons*) or elevated (not within the *Inundation Polygons*).
- Estimate and enter the proportion (to the nearest tenth) of each listed *Landward Surface Waters* class falling within the 60-m buffer; these include only waters that are generally landward of the marsh assessment unit and exclude directly adjacent estuarine and marine waters. Multiply this proportion by zero and enter it in the space provided on the worksheet.
- Estimate and enter the proportion (to the nearest tenth) of each listed *Elevated Land* class falling within the 60-m buffer. For the *No Potential* classes, sum the proportions and multiply the sum by zero. For the *Low Potential* class, multiply the proportion by 2. Enter the products in the spaces provided on the worksheet.
- Estimate and enter the proportion (to the nearest tenth) of each listed *Low-lying Land* class falling within the 60-m buffer. For *No Potential* classes, sum the proportions and multiply the sum by zero. For the *Low, Moderate, Moderately-High, and High Potential* classes, sum the proportions and multiply the sums by the respective numbers assigned in the worksheet (2, 5, 8, or 10). Enter the products in the spaces provided on the worksheet.
- Note: the sum of all collective proportions (across all classes) must be exactly 1.0; otherwise there is an error in estimating the proportions of the classes.
- Sum the products for the **Migration Potential Score**. The value of the Migration Potential Score must be between 0 and 10; otherwise, there is an error in your calculations.
- Calculate the area of the marsh, excluding major areas of open water, and the area of surrounding land within 60m of the marsh edge (excluding adjacent estuarine waters), and enter them in the worksheet in lines *a* and *b*.
- Sum the proportions of *Moderately-High* and *High Potential* classes and enter it on line *c*.
- Multiply lines *b* and *c* to calculate the **Migration Area**. This is the estimated area that the marsh will migrate into with little or no management action.
- Divide *Migration Area* by the area of the marsh (Line *a*) to calculate the **Replacement Ratio**. This is an approximation of the proportion of the marsh that will be replaced through landward migration with little or no management effort.

## 4. Interpreting MarshRAM Data

MarshRAM was designed to generate metrics and indices to support management. Each metric and index value for a particular marsh is intended to be viewed in relation to index values from other marshes in the same timeframe or (less commonly) from another period. IMI serves as a central index of the MarshRAM, as it indicates marsh integrity and vulnerability to inundation stress caused by accelerating sea-level rise (Kutcher 2019), and thus can act as a relative index of marsh health. IMI scores have not been calibrated to any gold standard, but according to historical descriptions, an undisturbed New England salt marsh would produce an IMI score of approximately 9.0 (Kutcher 2019).

A sorted list of IMI scores with community classes depicted as bar graphs can act as a useful reference gradient to investigate marsh condition and variability (Fig. 1). Any single marsh can be compared to other marshes in the list by inserting its data in order with the other marshes by its IMI score. The list can be further applied to categorize marshes by level of degradation using quartiles, where the upper quartile of IMI scores represents 'Least Degraded' condition, the lower quartile represents 'Most Degraded' condition, and the interquartile range represents intermediate condition. IMI scores and categories can then be aligned with other metrics and categories derived from MarshRAM analysis, such as disturbance metrics, marsh migration categories, and ecosystem functions and services categories, as depicted in Table 2, to further support ecological management, such as statewide prioritization for management action (Kutcher and Chaffee 2021).

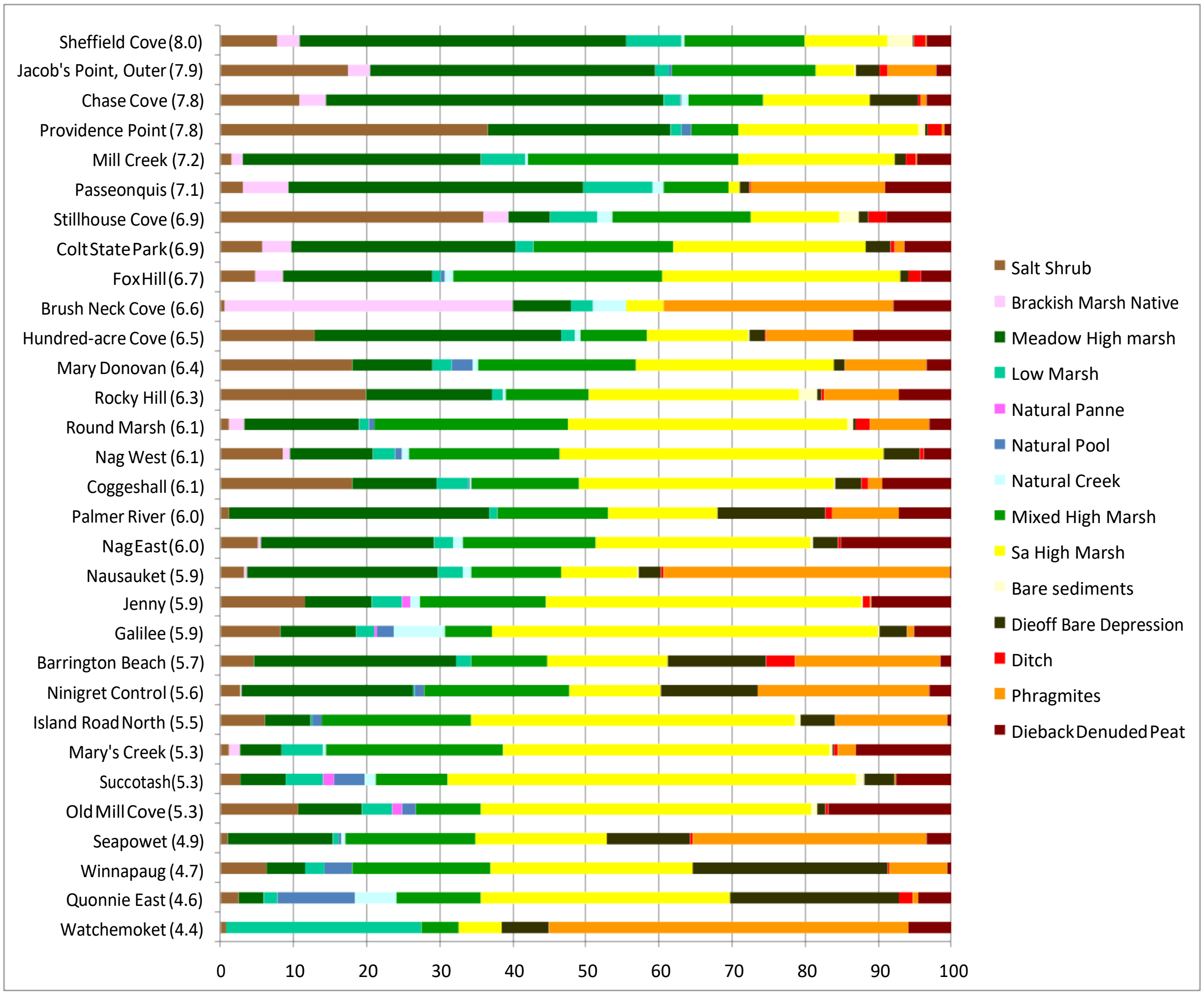


Figure 1: IMI scores (parenthetic) and relative proportions of IMI salt marsh cover types from 31 salt marshes in Rhode Island listed in descending order of marsh integrity according to IMI scores (from Kutcher 2019).

Table 2. Matrix depicting IMI marsh degradation categories (IMI Bin) in relation to categories of MarshRAM functions and services, marsh migration potential, intensity of human disturbances, and mean elevation (from Watson et al. 2017b); MD=most-degraded, ID=intermediately-degraded, LD=least-degraded; AA=above average, A=average, B=below average summed ranks of MarshRAM Ecosystem Functions and Services; Migration Area=ha of adjacent land with moderately-high migration potential; Replacement Ratio=Migration Area/area of site; disturbance categories: X=low-intensity, XX=moderate-intensity, XXX=high-intensity; green, yellow, and red shading represent, respectively, upper-quartile, interquartile range, and lower-quartile categories of marsh resiliency or value (from Kutcher 2019).

| SITECODE | IMI Bin | Disturbance | Elevation | Functions andServices | Migration Potential | Migration Area(ha) | Replacement Ratio | Buffer | Impoundment | Ditching | Nutrients | Fill | Erosion | Crabs | Die-off | Mowing | Phragmites |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sheffield Cove | LD | Low | ND | A | High | 1.5 | 92% | X | | XX | | XX | XXX | | | | X |
| Jacob's Point, Outer | LD | High | High | A | Low | 0.5 | 6% | XX | | XX | XX | XX | XX | XX | X | | XX |
| Chase Cove | LD | Mod | High | A | High | 4.1 | 80% | | X | XX | X | X | XXX | XX | X | | X |
| Providence Point | LD | Low | Med | B | High | 2.5 | 53% | | | XX | | | X | X | X | | X |
| Mill Creek | LD | Low | Med | B | Mod | 1.4 | 29% | | | XX | X | | XXX | XX | | | X |
| Passeonquis | LD | Mod | High | A | Low | 2.3 | 75% | X | | X | XXX | | XXX | XX | | X | XX |
| Stillhouse Cove | LD | High | Med | B | Low | 0.0 | 0% | XXX | | XX | XX | XX | XXX | X | XX | X | X |
| Colt State Park | LD | High | High | A | Mod | 8.2 | 39% | X | | XXX | XX | X | XXX | XXX | X | X | X |
| Fox Hill | ID | Low | Low | A | Mod | 3.9 | 25% | X | | X | | X | XX | X | X | | X |
| Brush Neck Cove | ID | Low | Low | A | Mod | 3.2 | 114% | | | | XXX | | XX | | X | | XX |
| Hundred-acre Cove | ID | Mod | Med | AA | Mod | 1.3 | 20% | | | X | XXX | | XXX | XXX | X | X | X |
| Mary Donovan | ID | Mod | Low | A | Mod | 5.4 | 15% | X | | X | XXX | X | XX | XXX | X | X | X |
| Rocky Hill | ID | Mod | Med | AA | High | 5.0 | 29% | XX | XX | X | XX | X | X | X | X | X | X |
| Round Marsh | ID | Mod | Med | A | High | 11.7 | 37% | X | X | XX | XX | X | XX | X | X | | X |
| Nag West | ID | Mod | Med | AA | Mod | 2.9 | 22% | | | XX | | X | XXX | XXX | X | X | X |
| Coggeshall | ID | Mod | Med | A | Mod | 7.7 | 38% | | | XX | X | | XXX | XXX | X | | X |
| Palmer River | ID | Mod | Med | AA | High | 5.2 | 27% | | | XX | XX | | XXX | XXX | XX | | X |
| Nag East | ID | Mod | Med | AA | Mod | 3.9 | 18% | X | | XX | X | X | XXX | XXX | X | X | X |
| Nausauket | ID | Low | ND | B | Low | 1.0 | 13% | X | | XX | XX | | | X | X | | XX |
| Jenny | ID | Mod | Med | A | Mod | 3.8 | 30% | X | | XXX | | X | XXX | XXX | | X | X |
| Galilee | ID | Mod | Med | B | Low | 1.4 | 13% | XX | | X | | XXX | XXX | | X | X | X |
| Barrington Beach | ID | Mod | High | AA | Mod | 1.1 | 18% | X | X | XX | XXX | XX | | X | XX | | XX |
| Ninigret Control | ID | Low | Low | A | Mod | 0.0 | 0% | | | | XX | | XXX | | XX | | XX |
| Island Road North | MD | Mod | Med | B | Low | 0.4 | 29% | XXX | | | XXX | XX | XX | | X | | XX |
| Mary's Creek | MD | High | Med | B | Low | 0.0 | 0% | XXX | | XX | XX | XXX | XXX | XXX | XX | X | X |
| Succotash | MD | High | Low | A | Mod | 6.5 | 16% | XX | X | X | XX | XX | XX | XXX | X | | X |
| Old Mill Cove | MD | High | Low | B | Mod | 2.0 | 73% | X | | X | XXX | XX | XXX | XXX | XX | | X |
| Seapowet | MD | High | Med | AA | Mod | 12.6 | 14% | XX | X | XX | XX | | XXX | XXX | XX | X | XX |
| Winnapaug | MD | Low | Low | A | Mod | 0.0 | 0% | X | | X | XX | X | XX | | XX | | X |
| Quonnie East | MD | High | Low | AA | High | 5.3 | 19% | | | XXX | XX | XX | XXX | XX | XX | | X |
| Watchemoket | MD | High | Low | B | Low | 0.8 | 136% | XX | X | | XXX | XX | XX | XX | | | XXX |


# Acknowledgements

This user's guide was prepared in partial fulfillment of the contract agreement between the State of Rhode Island Department of Environmental Management (DEM) and the Rhode Island Natural History Survey (RINHS) named Technical Assistance to Support Monitoring and Assessment of Wetlands and Related Work. The agreement was funded in part by federal funds provided by an Environmental Protection Agency (EPA) Clean Water Act Section 104(b)3 Wetland Program Development Grant (FY 19-20, Grant 00A00607). Although the information in this document has been funded in part by the EPA, it may not necessarily reflect the views of the EPA and no official endorsement should be inferred.

Susan Kiernan (DEM), Caitlin Chaffee (NBNERR), Carolyn Murphy (DEM), David Gregg (RINHS), and Kira Stillwell (RINHS) administered this work. Kenneth Raposa (NBNERR), Cathleen Wigand (EPA Atlantic Ecology Division), and Charles Roman (URI) helped develop coefficients of community integrity, field tested the methods, and provided valuable feedback on MarshRAM. Wenley Ferguson (Save The Bay), James Turek (NOAA), and Caitlin Chaffee field tested and provided valuable feedback on MarshRAM methods. RINHS is generously housed by the URI College of the Environment and Life Sciences.

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Appendix 1

MarshRAM Field Datasheet

MarshRAM V.2 Investigators________________________________ Site Code____________ Date________
Longitude (DD) ______________________ Latitude (DD) ______________________

## A. Marsh Characteristics; apply to the *current* state of the marsh. Not Scored.

**1) Assessment Unit Area***__________ha; select one class:

- ÿ <0.5 hectares
- ÿ 0.5 to 2.0 hectares
- ÿ 2.0 to 5.0 hectares
- ÿ 5.0 to 10 hectares
- ÿ 10 to 20 hectares
- ÿ 20 to 30 hectares
- ÿ 30- 40 hectares
- ÿ > 40 hectares

**2) Position in Watershed**

- ÿ Upper Bay
- ÿ Mid Bay
- ÿ Lower Bay
- ÿ South Coast
- ÿ Block Island
- ÿ Mt. Hope Bay
- ÿ Sakonnet River

**3) Marsh Setting and Type**

*Geomorphic Setting*; select primary one or two

- ÿ Open Coast
- ÿ Open Embayment
- ÿ Valley
- ÿ Riverine
- ÿ Back Barrier Marsh
- ÿ Back Barrier Lagoon

*Geoform*; select one

- ÿ Platform
- ÿ Fringe

*Adjacent upland*; select primary one or two

- ÿ Bluff
- ÿ Plain
- ÿ Barrier spit or beach
- ÿ Rock
- ÿ Hardened shoreline

*Tidal water salinity*; select one

- ÿ Fresh............. <0.5 ppt
- ÿ Oligohaline.... 0.5 to <5 ppt
- ÿ Mesohaline... 5 to <18 ppt
- ÿ Polyhaline...... >18 ppt

*Freshwater input*; select primary one or two

- ÿ River or stream
- ÿ Sheet flow
- ÿ Precipitation only
- ÿ Groundwater

**4) Exposure to Tides**

*Exposed Marsh Edge**; estimate exposed edge as a proportion of total unit circumference

- ÿ < 5% no or very low exposure
- ÿ 5 – 25 % low exposure
- ÿ 26 – 50 % moderate exposure
- ÿ > 50 % high exposure

*Effective Fetch of Tidal Water**

- ÿ < 0.5 km
- ÿ 0.5 - 1 km
- ÿ 1 - 2 km
- ÿ 2-3 km
- ÿ > 3 km

*Tidal Range*

- ÿ < 0.4 m
- ÿ 0.4 – 1 m
- ÿ 1 - 1.5 m
- ÿ >1.5 m
- ÿ Unknown

**5) Natural Habitat Diversity**; indicate presence of all significant natural habitat types by checking all present

- ÿ Salt Shrubs
- ÿ Brackish Marsh
- ÿ High Marsh Platform
- ÿ Pools
- ÿ Established Pannes
- ÿ Tall Sa Low Marsh
- ÿ Creeks
- ÿ Ponds
- ÿ Overwash Fan

**6) Connected Natural Habitats**; check all natural habitats that occur within 150 m of the unit.

- ÿ Forested or shrub wetland
- ÿ Freshwater marsh or pond
- ÿ Brackish marsh or pond
- ÿ Other salt marsh
- ÿ Sand or cobble beach
- ÿ Coastal dunes or overwash
- ÿ Intertidal flats
- ÿ Eelgrass or other SAV
- ÿ Upland forest
- ÿ Upland shrubland
- ÿ Upland grassland
- ÿ Other______________________

**7) Count of Waterbirds Present:** Wading Birds ________ Shorebirds ________ Waterfowl ________
Swallows_______ Raptors ________ Gulls ________ Sparrows__________

*If the vegetated marsh area is larger than any open water feature encompassed by the unit, then the water is considered part of the unit. If open water feature is larger, it is considered the tidal water.

---

## B. Ecosystem Functions and Services; estimate importance of all evident or known according to ranks provided:

- ___ Storm protection of property
- ___ Floodflow alteration
- ___ Part of a habitat complex or corridor
- ___ Sediment / toxin retention
- ___ Nutrient uptake
- ___ Carbon storage
- ___ T/E species habitat
- ___ Fish and shellfish habitat
- ___ Wildlife habitat
- ___ Hunting or fishing platform
- ___ Other recreation
- ___ Educational or historic significance

0...Not evidently provided
1...Minor or potential importance
2...Evident or known importance
3...Special importance

Sum of ranks = [ ] Explain special importance ______________________________

## C. Surrounding Land Use

Adjacent Land Use Intensity weighted average within 150-m buffer.
Estimate proportion of each class to the ***nearest tenth*** and multiply (max = 10)

| | Proportion | Score | Weighted Value |
|---|---|---|---|
| Very Low | ______ | × 10 = | ______ |
| Low | ______ | × 7 = | ______ |
| Moderately High | ______ | × 4 = | ______ |
| High | ______ | × 0 = | ______ |

Sum weighted values for score = ______

Very Low.......Natural areas, natural open water
Low................Recovering natural lands, passive recreation, low trails, mooring fields
Mod High......Residential, pasture/hay, mowed areas, raised roads, marina docks
High...............Urban, impervious land cover, new construction, row crops, turf crops, mining operations, paved roads > 2-lane, dense marina docks

*Surrounding Land Uses*: Check all that apply

ÿ Commercial or industrial development
ÿ Unsewered Residential development
ÿ Sewered Residential development
ÿ New construction
ÿ Landfill or waste disposal
ÿ Raised road beds
ÿ Foot paths / trails
ÿ Row crops, turf, or nursery plants
ÿ Poultry or livestock operations
ÿ Orchards, hay fields, or pasture
ÿ Piers, docks, or boat ramps
ÿ Golf courses / recreational turf
ÿ Sand and gravel operations
ÿ Railroad bed
ÿ Power lines
ÿ Other____________________

---

## D. Wetland Disturbances. Average metrics D.1 to D.10

### 1) Buffer Encroachment.

Estimate % cultural cover on adjacent land within 30-m buffer.

ÿ <5% (10)
ÿ 6 to 25% (8)
ÿ 26-50% (6)
ÿ 51-75% (3)
ÿ >75% (1)

*Primary Associated Stressor*; check one or two:

ÿ Road
ÿ Railway
ÿ Fill
ÿ Raised Trail
ÿ Power Lines
ÿ Cleared/mowed Land
ÿ Buildings
ÿ Paved Lot
ÿ Dirt Lot
ÿ Dam/dike
ÿ Other________________

*Primary Source of Stress*; indicate as current (C) or historic (H):

__ Private / Residential
__ Commercial
__ Agricultural
__ Public transportation
__ Public utilities
__ Public recreation
__ Undetermined

### 2) Impoundment and Tidal Restriction.

Change in depth or hydroperiod. Select one.
If less than half of the marsh is impounded or restricted, average score with 10.

ÿ None observed (10)
ÿ Restriction observed but no change in vegetation or elevation evident (7)
ÿ Restriction observed with change in vegetation evident (4)
ÿ Restriction observed with subsidence, ponding, or die-off evident (1)

ÿ Less than half the marsh is affected, average with 10 = _____

*Primary Associated Stressor*; check one:

ÿ Road
ÿ Railway
ÿ Weir / Dam
ÿ Raised Trail
ÿ Development Fill
ÿ Other ___________

*Evidence:* check all that apply

ÿ Physical barrier across seaward edge of wetland
ÿ Dam or restricting culvert downstream of wetland
ÿ Ponding or subsidence evident
ÿ Widening of wetland upstream of barrier
ÿ Change in vegetation across barrier
ÿ Dead or dying vegetation

*Primary Source of Stress*; indicate as current (C) or historic (H):

__ Private / Residential
__ Commercial
__ Agricultural
__ Public transportation
__ Public utilities
__ Public recreation
__ Undetermined

### 3) Ditching and draining density.

Estimate the density of ditching and draining. For difficult determinations, use key.

Select one

ÿ None observed (10)
ÿ Low (7)
ÿ Moderate (4)
ÿ High (1)

**Key: density classes of ditches**

| | |
|---|---|
| Low: | < 100 m/Ha |
| Moderate: | 100-300 m/Ha |
| High: | > 300 m/Ha |

**4) Anthropogenic nutrient inputs.**

Select the evidence of sources and impact.

ÿ No evidence (10)
ÿ Sources observed only (7)
ÿ Sources observed and some impacts evident (4)
ÿ Sources and multiple or strong impacts clearly evident (1)

*Evidence:* check all that apply
ÿ Known high-nutrient tidal or fresh waters
ÿ Runoff sources evident
ÿ Point sources evident
ÿ Sewage smell
ÿ Pervasive sulfide smell
ÿ Excessive algae in surface waters
ÿ Unusually tall Sa (≥ 1.5 m)
ÿ Dense and tall Phragmites (≥ 3m) abutting sources
ÿ Obvious plumes or suspended solids

*Primary Associated Stressor*;
Check one or two:
ÿ High-nutrient tidal water
ÿ High-nutrient up-stream water
ÿ Stormwater discharge
ÿ Sheet runoff
ÿ Unsewered residential
ÿ Point effluent discharge
ÿ Organic / yard waste
ÿ Other point ______________
ÿ Multiple / non-point

*Primary Source of Stress*;
indicate as current (C) or historic (H):
__ Private / Residential
__ Commercial
__ Agricultural
__ Public transportation
__ Public utilities
__ Public recreation
__ Multiple / non-point
__ Undetermined

**5) Filling and dumping within wetland.** Select <u>one</u> or two from below. If fill is hardened to the edge subtract 1.

Fill includes typical construction fill, yard waste, and trash.

ÿ No fill observed (10)
ÿ Scattered trash in the marsh, aesthetic impacts only (9)
ÿ Fill covers <10% of the unit area or perimeter (7)
ÿ Fill covers 10-60% of the unit area or perimeter (4)
ÿ Fill covers >60% of the unit area or perimeter (1)
ÿ Fill has hardened edge (subtract 1 from above)

*Evidence:* check all that apply
ÿ Unnaturally abrupt change in ground level
ÿ Abrupt change in soil texture or content
ÿ Unnaturally straight or abrupt wetland edge
ÿ Unnatural items on or within the sediments

*Primary Associated Stressor*;
Check one:
ÿ Road ÿ Dam
ÿ Raised Trail ÿ Dike
ÿ Railway ÿ Trash
ÿ Organic / yard waste
ÿ Fill
ÿ Other

*Primary Source of Stress*;
indicate as current (C) or historic (H):
__ Private / Residential
__ Commercial
__ Agricultural
__ Public transportation
__ Public utilities
__ Public recreation
__ Undetermined

**6) Edge erosion.** Select the appropriate category. Edge includes seaward edge and major creeks.

Intensity of edge erosion

ÿ Minimal erosion observed (10)
ÿ Low (7): <10% of the seaward edge is eroded
ÿ Moderate (4): 10-60% of the seaward edge is eroded
ÿ High (1): >60% of the seaward edge is eroded

*Evidence:* check all that apply
ÿ Vertical marsh edge from platform
ÿ Undercut edge
ÿ Disintegrating unvegetated edge
ÿ Oversized crab burrows

**7) Crab burrow intensity**. Select the appropriate category. Marsh edge includes major creeks.

ÿ None (10): Burrows are limited to the peat edge with dense vegetation
ÿ Low (7): <10% of the marsh edge is densely burrowed and partly or fully denuded
ÿ Moderate (4): 10-60% of the marsh edge is densely burrowed and denuded
ÿ High (1): >60% of the marsh edge is densely burrowed and denuded

*Evidence:* check all observed
ÿ Dense crab burrows
ÿ Eroding or oversized crab burrows
ÿ Abundant fiddler crabs
ÿ Purple marsh crabs
ÿ Clipped vegetation
ÿ Denuded areas of peat

**8) Ponding and Dieoff Depressions.** Estimate the incidence of shallow ponding, dieoff, or sparsely vegetated soft peat on the high marsh platform.

ÿ None observed (10)
ÿ Low: <10% cover (7)
ÿ Moderate: 10-60% cover (4)
ÿ High: >60% cover (1)

*Evidence:* check all observed on the marsh platform
ÿ Shallow ponding
ÿ Shallow unvegetated depressions
ÿ Sparsely vegetated soft peat

**9) Vegetation cutting / removal / soil disturbance.** Select intensity of vegetation or soil disturbance.

ÿ None Observed (10)
ÿ Low: <10% (7)
ÿ Moderate: 10-60% (4)
ÿ High: > 60% (1)

*Primary Associated Stressor*; Check one:
ÿ Power lines
ÿ Grazing
ÿ Crops
ÿ Lawn maintenance
ÿ Development clearing
ÿ View-shed clearing
ÿ Trails / non-raised roads
ÿ Shore access
ÿ Other_____________

*Primary Source of Stress*; indicate as current (C) or historic (H):
__ Private / Residential
__ Commercial
__ Agricultural
__ Public transportation
__ Public utilities
__ Public recreation
__ Undetermined

*Evidence:* check all that apply
ÿ Cut stems or stumps
ÿ Immature vegetation strata
ÿ Missing vegetation strata
ÿ Mowed areas
ÿ Browsing or grazing
ÿ Tire ruts
ÿ Cattle hoof prints / trampling
ÿ Human footprints / trampling
ÿ Excavation evident

**10) Phragmites within wetland.** Select one class for total coverage.

ÿ None noted (10)
ÿ Low: <10% cover (7)
ÿ Moderate: 10-60% cover (4)
ÿ High: >60% cover (1)

*Primary Source of Stress*; indicate as current (C) or historic (H):
__ Private / Residential
__ Commercial
__ Agricultural
__ Undetermined
__ Public transportation
__ Public utilities
__ Public recreation

*Primary Abutting Stressors*; Check one or two:
ÿ Road
ÿ Railway
ÿ Raised Trail
ÿ Footpath
ÿ Dam / Dike
ÿ Organic / yard waste
ÿ Other Fill
ÿ Mowed Lawn
ÿ Crops
ÿ Pasture
ÿ Drainage ditch / tile
ÿ Stormwater input
ÿ Clearing
ÿ Multiple
ÿ Residential Development
ÿ Other

**Sum of D1 to D10 Scores = _________ ÷ 10 = [ ] D. Wetland Disturbance Score**

MarshRAM V.2 Investigators________________________________________ Site Code______________ Date__________

**E. Marsh Community Composition** and **Index of Marsh Integrity.** Walking straight and evenly along each of 8 transects, tally every step traversing the listed community types.

| Zone | T1 | | T2 | |
|---|---|---|---|---|
| Salt Shrub | | | | |
| Brackish Marsh Native | | | | |
| Phragmites | | | | |
| Meadow High Marsh | | | | |
| Mixed High Marsh | | | | |
| Sa High Marsh | | | | |
| Dieoff Bare Depression | | | | |
| Low Marsh | | | | |
| Dieback Denuded Peat | | | | |
| Natural Panne | | | | |
| Natural Pool | | | | |
| Natural Creek | | | | |
| Ditch | | | | |
| Bare Sediments | | | | |
| | Sum: | | Sum: | |
| Sparrow Tally | | | | |

| Zone | T3 | | T4 | |
|---|---|---|---|---|
| Salt Shrub | | | | |
| Brackish Marsh Native | | | | |
| Phragmites | | | | |
| Meadow High Marsh | | | | |
| Mixed High Marsh | | | | |
| Sa High Marsh | | | | |
| Dieoff Bare Depression | | | | |
| Low Marsh | | | | |
| Dieback Denuded Peat | | | | |
| Natural Panne | | | | |
| Natural Pool | | | | |
| Natural Creek | | | | |
| Ditch | | | | |
| Bare Sediments | | | | |
| | Sum: | | Sum: | |
| Sparrow Tally | | | | |

MarshRAM V.2 Investigators________________________________________ Site Code______________ Date__________

| Zone | T5 | | T6 | |
|---|---|---|---|---|
| Salt Shrub | | | | |
| Brackish Marsh Native | | | | |
| Phragmites | | | | |
| Meadow High Marsh | | | | |
| Mixed High Marsh | | | | |
| Sa High Marsh | | | | |
| Dieoff Bare Depression | | | | |
| Low Marsh | | | | |
| Dieback Denuded Peat | | | | |
| Natural Panne | | | | |
| Natural Pool | | | | |
| Natural Creek | | | | |
| Ditch | | | | |
| Bare Sediments | | | | |
| | Sum: | | Sum: | |
| Sparrow Tally | | | | |

| Zone | T7 | | T8 | |
|---|---|---|---|---|
| Salt Shrub | | | | |
| Brackish Marsh Native | | | | |
| Phragmites | | | | |
| Meadow High Marsh | | | | |
| Mixed High Marsh | | | | |
| Sa High Marsh | | | | |
| Dieoff Bare Depression | | | | |
| Low Marsh | | | | |
| Dieback Denuded Peat | | | | |
| Natural Panne | | | | |
| Natural Pool | | | | |
| Natural Creek | | | | |
| Ditch | | | | |
| Bare Sediments | | | | |
| | Sum: | | Sum: | |
| Sparrow Tally | | | | |

MarshRAM V.2 Investigators________________________________________ Site Code_____________ Date_________

| | CCI | Total Tally | CCI X TT | % Cover* |
|---|---|---|---|---|
| Salt Shrub | 9 | | | |
| Brackish Marsh Native | 10 | | | |
| Phragmites | 3 | | | |
| Meadow High Marsh | 10 | | | |
| Mixed High Marsh | 7 | | | |
| Sa High Marsh | 5 | | | |
| Dieoff Bare Depression | 1 | | | |
| Low Marsh | 8 | | | |
| Dieback Denuded Peat | 0 | | | |
| Natural Panne | 8 | | | |
| Natural Pool | 6 | | | |
| Natural Creek | 8 | | | |
| Ditch | 2 | | | |
| Bare Sediments | 4 | | | |
| | **Sums:** | | | |

**E. Index of Marsh Integrity**

$$= \frac{\text{Sum (CCI X TT)}}{\text{Sum (Total Tally)}}$$

=

**Marsh Community Composition:**

*For each cover type, % Cover = $\frac{\text{Total Tally}}{\text{Sum (Total Tally)}}$

**B. Ecosystem Functions and Services (Sum)**

**C. Surrounding Land Use Score (max 10)**

**D. Wetland Disturbance Score (max 10)**

**E. Index of Marsh Integrity (max 10)**

Investigator______________________________________ Site ___________________________ Date_______________

**F. Migration Potential**

Estimate the proportion, to the nearest tenth, of surrounding land within 60m falling into each class, and multiply. Total sum of proportions must = 1.0 and sum of weighted values must = 0.0 to 10.0.

***Landward* Surface Waters***

**No Potential:**

____Ocean
____Estuary
_____Lake/pond
____Other

**Sum =_____x 0 =** _0_

*separated from marsh by upland

***Elevated Land >1.5m above MHW***

**No Potential:**

____Bedrock
____Hardened shoreline
____Developed land
____Landfill
____Other__________________

**Sum =_____x 0 =** _0_

**Low Potential:**

____Elevated erodible Land

**Sum =_____x 2 = _____**

***Low-lying Land <1.5m above MHW***

**No Potential:**

_____Ocean Beach / Dune
_____Estuarine Beach

**Sum =_____x 0 =** _0_

**Low Potential:**

____Paved street or lot
_____Residential development (structures present)
_____ Industrial / commercial development (structures present)
____Other______________________

**Sum Low =_____x 2 = _____**

**Moderate Potential:**

_____Active farmland
____Golf course
____Sand and gravel operation
____Undeveloped land behind a raised shoreline feature
____Freshwater deep wetland
____Other______________________

**Sum Moderate =_____x 5 = _____**

**Moderately High Potential:**

____Forested or shrub wetland
____Phragmites marsh
____Forested or shrub upland
____Mowed land, no structures
____Pasture
____Other___________________

**Sum Mod High =_____x 8 = _____**

**High Potential:**

____Emergent FW wetland
____Upland field / meadow
____Abandoned farmland
____Other____________________

**Sum High =_____x 10 = _____**

Sum weighted values for **Migration Potential score:** [ ]

a. Area of Marsh = _________
b. Area of surrounding land to 60m = ________
c. Proportion of Moderately High +High class = ________

**d. Migration Area = (b x c) =** [ ]

**e. Replacement Ratio = (d ÷ a) =** [ ]

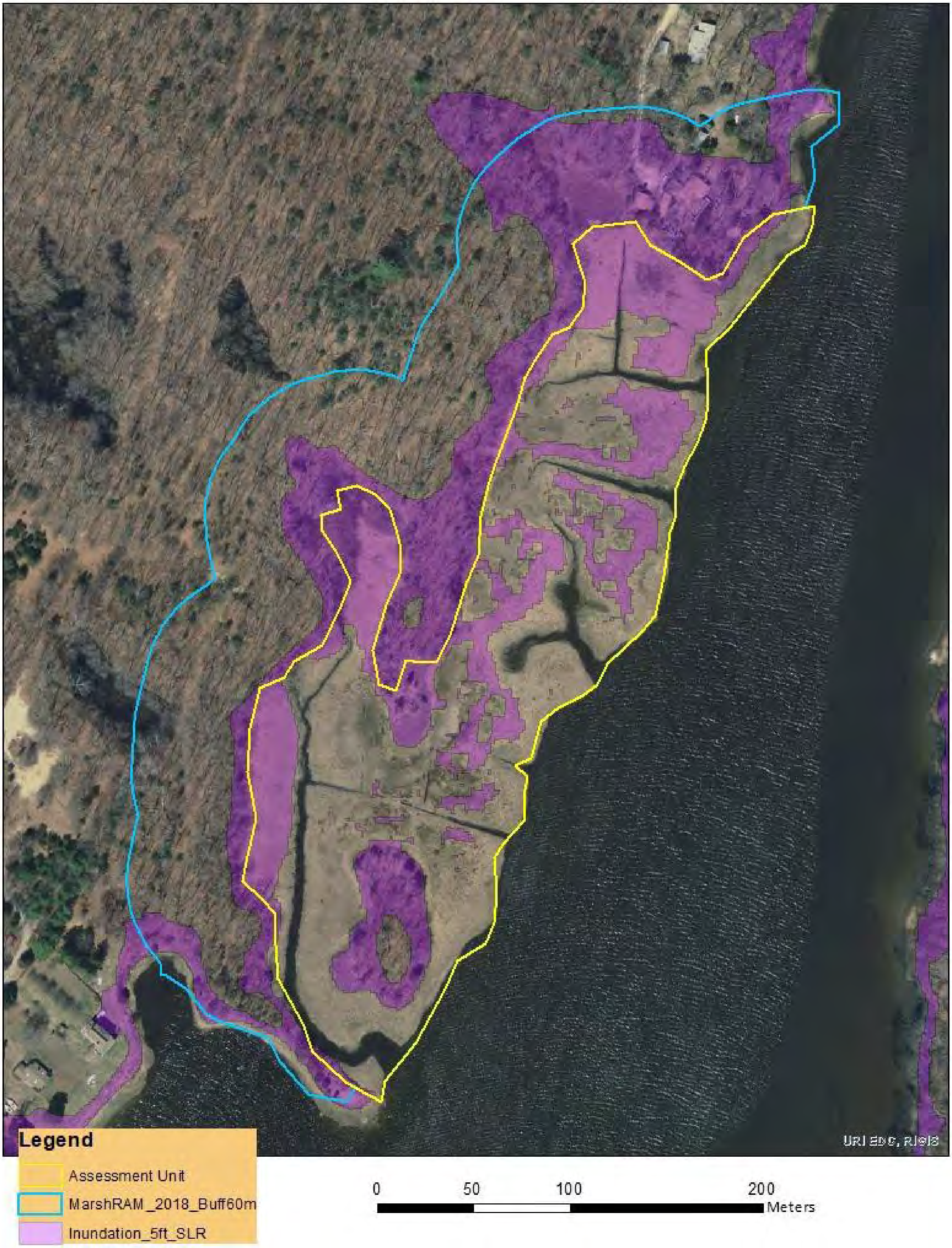
Appendix 2

MarshRAM Field Map Examples

MarshRAM Field Map

Annotated MarshRAM Field Map

Map for Estimating Migration Potential



Appendix 3

Representative images of salt marsh cover-types used in MarshRAM Section E,

Marsh Community Composition and Index of Marsh Integrity

**Salt Shrub** *Iva frutescens* dominant

**Salt Shrub** *Baccharis halimifolia* dominant

**Brackish Marsh Native** (*Schoenoplectus pungens* and *Hibiscus moscheutos* >30%, background) grading into Meadow High Marsh (*S. Pungens* <30% cover, foreground)

**Brackish Marsh Native** with *Bolboschoenus novae-angliae* and *H. moscheutos* co-dominant

**Brackish Marsh Native** *Typha angustifolia* dominant

**Phragmites** (*Phragmites australis* >30%, background) grading into Meadow High Marsh (<30% cover of *P. australis*)

**Phragmites** tall and dense stand (back) grading into Brackish Marsh Native

**Meadow High Marsh** *Spartina patens* dominant

**Meadow High Marsh** *Juncus gerardii* and *Distichlis spicata* co-dominant

**Meadow High Marsh** *D. spicata* dominant

**Mixed High Marsh** *S. patens* dominant with *Spartina alterniflora* present by definition

**Mixed High Marsh** *S. alterniflora* dominant with *S. patens* present

**Sa High Marsh** *S. alterniflora* with *Salicornia europia* present, but salt-meadow species absent by definition

**Sa High Marsh** stunted *S. alterniflora* monoculture on the high marsh platform

**Dieoff Bare Depression** situated in Mixed High Marsh and Meadow High Marsh

**Dieoff Bare Depression** (<30% vegetation cover) interspersed with Sa High Marsh (>30% *S. alterniflora*)

**Low Marsh** >30% cover of tall-form *S. alterniflora* in the regularly-flooded zone

**Low Marsh** (right) tall-form *S. alterniflora* occupying the sloping regularly-flooded zone, typically seaward of the high marsh

**Dieback Denuded Peat** bare peat (<30% vegetation cover) occupying the regularly-flooded zone (typical)

**Dieback Denuded Peat** encroaching onto the high marsh

**Dieback Denuded Peat** along a Natural Creek

**Natural Panne** characterized by a lack of surface water and sparse annual forbs

**Natural Pool** with steep edges and greater depth relative to Dieoff Bare Depression

**Natural Creek** typically sinuous with some Low Marsh fringing

**Ditch** typically linear and steep-sided

**Ditch** running across a degraded high-marsh platform dominated by Dieoff Bare Depression and SA High Marsh

**Bare Sediments** from dune washover among Meadow Salt Marsh and Salt Shrub

**Bare Sediments** in the marsh platform from "thin-layer-placement" salt marsh management

# Appendix B

Field Methods Manual

James-Pirri et al. 2002

# *Field Methods Manual: US Fish and Wildlife Service (Region 5) salt marsh study*

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*April 2002*
*(version 2)*

USGS Patuxent Wildlife Research Center
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## INTRODUCTION

Salt marshes are a common ecosystem type within coastal Refuges of the US Fish and Wildlife Service from Maine to Virginia (Region 5). Most of these marshes have been parallel ditched for mosquito control purposes, and to a lesser extent, to facilitate salt hay farming. Although ditching of salt marshes has occurred since Colonial times, most extensive ditching was in the 1930s, with programs to maintain ditches continuing for three decades or more. Documented impacts of parallel ditching on salt marshes include lowered water table levels, drainage of marsh pools and panes, vegetation changes, and associated impacts on habitat support functions for fish, birds, and other trophic components. Recognizing the detrimental impacts associated with ditching, the practice of Open Marsh Water Management (OMWM), considered a more ecologically appropriate mosquito control method, was introduced in the late 1960s.

OMWM is a common practice on coastal Refuges, especially in New Jersey (Forsythe NWR) and Delaware (Prime Hook NWR). In brief, OMWM involves physical alteration of the parallel ditched marsh, through creation of pools and other hydrologic alterations, to establish a marsh that is unsuitable for mosquito egg deposition and larval development, and that promotes establishment of habitats for larvivorous fishes. Traditional OMWM includes plugging of ditches, creation/excavation of ponds within intense breeding areas, construction of radial ditches to facilitate fish access to breeding areas, and other manipulations. As noted, traditional OMWM practices are common at Forsythe and Prime Hook NWR. At more northern Refuges (Long Island Complex, S.B. McKinney, Parker River, and Rachel Carson) a modification of OMWM is being implemented, which is generally limited to ditch plugging, with limited or no pond excavation and radial ditches. The objective of ditch plugging is to re-establish a hydrologic regime on the ditched marsh that is characterized by permanent water on the marsh surface, thereby restoring fish and wildlife habitat functions while controlling mosquito production.

A cooperative research project of the USGS-Patuxent Wildlife Research Center and US FWS-Region 5 was initiated in 2001 to quantitatively evaluate the response of salt marshes to OMWM and associated practices. The objectives of the three year study are to compare parallel ditched salt marshes with OMWM marshes. Specifically, this study is designed to evaluate the effects of OMWM and/or ditch plugging on marsh hydrology (marsh water table levels, soil salinity, and extent of surface water flooding), sedimentation and marsh development processes, vegetation patterns, utilization by nekton (fish and decapod crustaceans) and birds, and mosquito control. Research study sites were established at Rachel Carson NWR (ME) in 1999. Parker River NWR (MA), Long Island Complex (Wertheim NWR, NY), and Prime Hook NWR (DE) were established in 2001. Research will begin at Forsythe NWR (NJ) in 2002 and at Stewart B. McKinney (CT) in 2002/03.

The purpose of this document is to serve as a ***Field Methods Manual*** for the study. Details are provided on how to collect and record the data on appropriate field data sheets. Guidelines on data management, at least with respect to entering data into spreadsheets, are also provided. This manual does not address data analysis techniques. This document is presented as Version 1 of the Fields Methods Manual. Subsequent versions will include marsh sedimentation methods as well as minor modifications as needed.

## GENERAL STUDY DESIGN

This study employs a BACI study design (before, after, control, impact). At each study Refuge we have (or will) selected pairs of sites that include a ditched marsh and a control marsh. The ditched marsh and control marsh are sampled for one year prior to any OMWM activities (Before). Then in year two, OMWM is performed on the ditched marsh and sampling proceeds (After). In the BACI design, the practice of OMWM is the "impact." With this kind of study design it is possible to evaluate, with a degree of statistical certainty, the initial response of the marsh to OMWM. Continued monitoring in successive years will track the long-term response of the marsh to OMWM. It is important to monitor the control marsh simultaneously with sampling the ditched/OMWM marsh. If after OMWM a particular parameter such as water table level changed, and water level did not change in the control marsh, then it could be suggested with some degree of certainty that the change in water table was due to the OMWM and not some other factors. Inclusion of a control marsh serves to document any changes that are occurring in response to regional or local factors that are independent of OMWM manipulations.

To date, the following study sites have been established. Experimental refers to the OMWM or ditch-plugged marsh. Control and Experimental study areas vary in area, ranging from 0.6ha to 12.2ha.

Rachel Carson NWR
- Granite Point Rd. Marsh (control and experimental)
- Moody Marsh (control and experimental)
- Marshall Point Rd. Marsh (control and experimental)

Parker River NWR
- Control
- Experimental B1
- Experimental B2
- Experimental A

Long Island Complex
- Wertheim East experimental and Smith County Park control
- Flanders (control and experimental)

Forsythe NWR
- Oyster Creek, Atlantic County (control and experimental)
- AT&T, Ocean County (control and experimental)

Prime Hook NWR

- Petersfield Ditch (control and experimental)
- Slaughter Beach (control and experimental)

# VEGETATION

## SUMMARY

The salt marsh vegetation monitoring protocol recommends sampling vegetation community composition and abundance with permanent plots using the point intercept method. At least 20 vegetation plots are required per study area to detect differences in community composition and abundance. Permanent quadrats should be arranged in transects and spaced a minimum of 10-20m apart to maintain independence. Transects should be randomly located within each study area with the first permanent plot randomly located and subsequent plots systematically placed along each transect. Vegetation is sampled once during a season, usually at the end of the growing season (late summer or early fall) when plants are easily identifiable. At least 2 people are required to sample vegetation, one to place the bayonet and the other to record data. It is estimated that 2 people, who are familiar with salt marsh plant identifications, can sample approximately 10-20 plots per day. This does not include time spent re-locating plots that have lost their stakes. Details of the salt marsh vegetation monitoring protocol, including justification of the suggested field method and sample size, are found in Roman *et al.* (2001).

### Materials for Site Selection and Location of Vegetation Plots

- Oak stakes to mark vegetation plots
- Mallet to pound stakes into ground
- Black permanent markers to mark transect and plot number on stakes
- Compass
- Meter tape (preferably 100m long)
- Random number table
- Aerial photos of study sites
- Draft map of study site showing boundaries of study areas and approximate location of transects

### Site Selection and Sample Location

- Define boundaries of the control and experimental areas.
- Systematically divide each study area into segments to adequately sample the marsh. Segmentation is done to insure dispersion of the vegetation plots throughout the study area. Usually, a study area is segmented into 3 or 4 similarly sized areas.
- Randomly locate transects that traverse the main gradient (*e.g.*, elevation) from creek bank to upland edge of the marsh. The starting point for each transect is randomly located along the creek bank. The random location of the starting point for each transect is selected by measuring the total distance of the creek bank (within each segment) and then randomly selecting points along the bank where each transect will start. These measurements are best done from aerial photography.

- There is no definitive number of transects that should be established per marsh segment, however each transect should be at least 10m apart, to maintain independence of the replicate plots. Transects be dispersed throughout the study areas to ensure that the vegetation plots are representative of the entire study area.
- All transects within a marsh segment should be parallel to each other (*i.e.*, should run along the same compass heading) for ease in re-locating plots.
- Locate vegetation plots along each transect. Regardless of the size of the area a minimum of 20 plots are required for each study area.
- The first plot of each transect is randomly located within the low marsh zone. Measure the width of the low marsh and then place the plot at the distance selected by the random number (0 being on the edge of the bank). For example, if the low marsh zone is 5m wide, a random number between 0-5 would be selected. If there is no discernable low marsh zone, or if the vegetation zone at the creek bank is very broad, (*i.e.*, more than 10m), then the first plot should be located by a random number between 0 and 10.
- After the first plot is located, all subsequent plots are then systematically placed, at least 10m apart, along the length of the transect. The spacing of plots along each transect will be variable depending on the area of the marsh. For example, if the marsh is 8-9 hectares in area, then 4 transects, with 40m spacing between plots along each transect would be appropriate. For smaller marshes, 20m spacing between plots may be necessary. However, all plots should be at least 10m apart to maintain independence of the replicate plots. (refer to Fig 1.).
- Each plot should be marked with stakes labeled clearly with transect and plot number. Construction of permanent stakes is at the discretion of the investigator. Our experience suggests that 4 ft oak stakes (1 ft into the marsh sediment, 3 ft above marsh; about $1^2$ inch square) are adequate. Naming convention for vegetation plots is the transect number followed by the distance along the transect where the plot is located. For example, 1-00 would be the first plot on transect 1 (00 meters along the transect), 1-20 would be a plot on transect 1 located 20m from the start of the transect.
- Plot location and distance between plots should be carefully noted on a map so that plots can be re-located in future surveys in the event that the stake is missing. The coordinates (latitude and longitude, UTM coordinates, *etc.*) of all plots should be recorded, preferably with a GPS unit that has sub-meter accuracy.

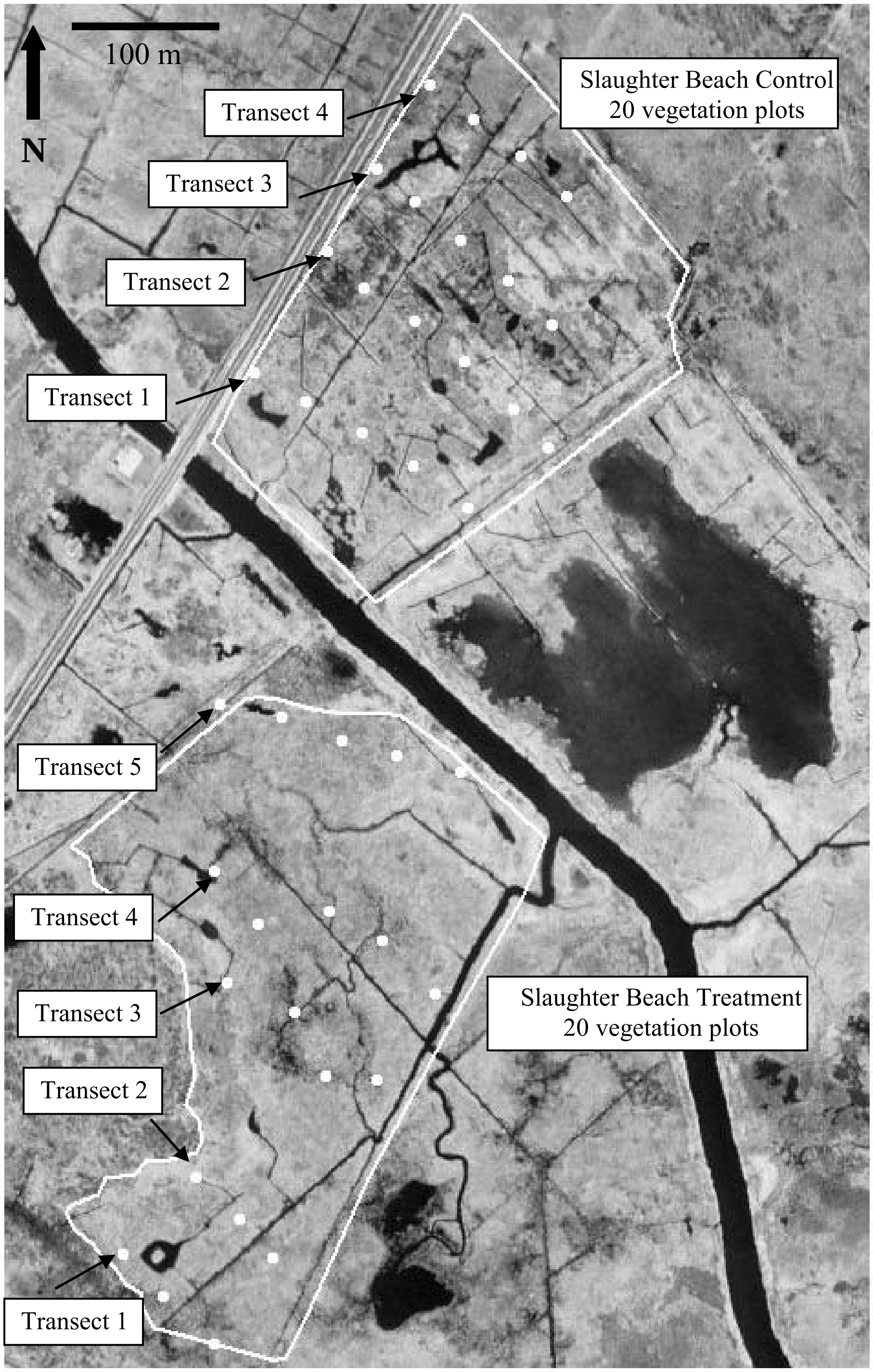



Figure 1. Aerial photo showing location of vegetation plots (white circles) within two study areas at Prime Hook NWR. White line indicates delineation of study areas.

<u>Materials for Sampling Permanent Vegetation Plots</u>

- 1 $m^2$ quadrat. The quadrat can be made from four 1m lengths of thin diameter (3-5mm) doweling. Dowels should be marked with 10 evenly spaced (11.1 cm apart) increments
- Bayonet or thin rod for point intercept method (less than 3mm diameter).
- Meter stick
- Map of vegetation plots
- Plant identification book
- Plastic bags for voucher specimens
- Data sheet and pencils (Table 1)

<u>Sampling Procedure</u>

- Locate permanent stake marking the vegetation plot.
- In order to sample vegetation that has not been trampled during the establishment of transects, the quadrat is offset 1m from the stake.
- Facing the direction of the transect (from the first plot towards the remaining plots of the transect) set the quadrat 1m to the right of the stake and orient the plot towards the direction of the transect. Be sure to maintain the same offset for all plots and record a detailed description of the offset (Fig. 2). Note: if existing plots are oriented differently that is acceptable. Continue with the existing layout, but be certain to carefully document the orientation with a schematic such as that shown in Fig. 2.

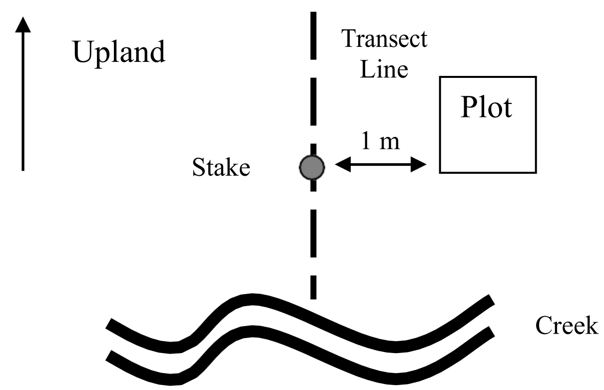
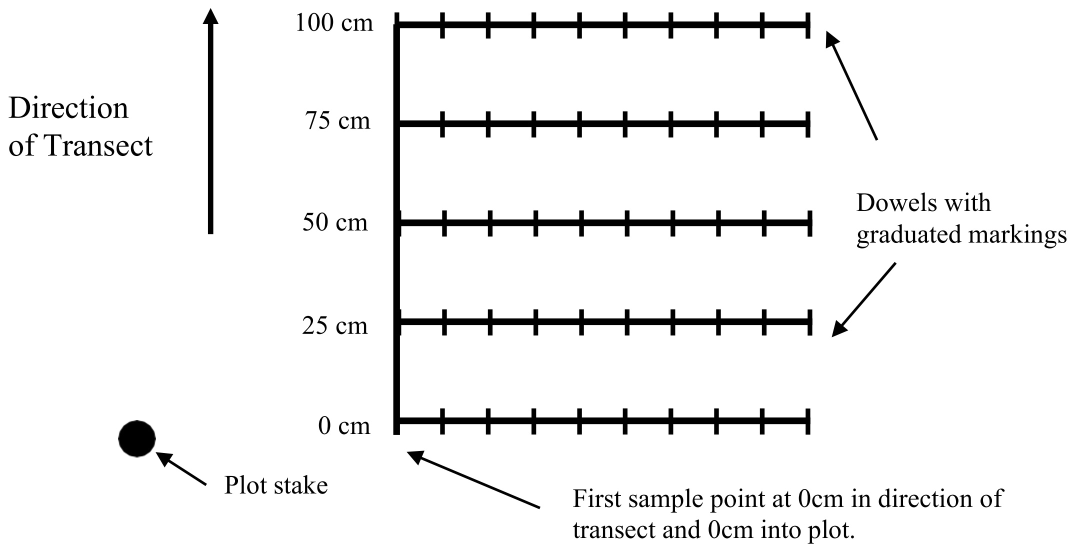



Figure 2. A schematic of the orientation of the sampling quadrat relative to plot stake.

- A meter stick is placed on the marsh surface and then at 0, 25, 50, 75, and 100cm intervals along the meter stick, dowels ($\leq$3mm in diameter) are placed perpendicular to the meter stick. Each dowel is 1m in length and has a total of 10 marks, each spaced 11.1cm apart (Fig. 3). Thus, the 1m$^2$ quadrat is divided into a grid of 50 evenly spaced points. In dense vegetation it may be necessary to weave the dowels through the vegetation.
- List all species that are present within the sample quadrat on the data sheet for that plot (a sample data sheet is presented in Table 1).
- Hold a thin rod ($\leq$3mm in diameter) vertical to the first sampling point and lower the rod through the vegetation canopy to the sample point on the ground.
- All species that touch the rod are recorded as a "hit" on the data sheet for that point. Categories other than plant species, such as "water", "bare ground", "wrack or litter," and others are also recorded if they are "hit" by the rod. Table 2 provides definitions of cover type categories that should be included.
- More than one cover type category can touch the rod at each point, and thus multiple hits for each sample point should be recorded if appropriate. However, it is not necessary to count the number of hits for each individual species. For example, if *S. alterniflora* touches the rod in 3 places, it is recorded as one hit of *S. alterniflora* for that point. At least one cover type should be recorded for each point (*i.e.* if there is no vegetation, "bare ground" or "water" may be the appropriate cover type).
- After the first point is completed, the process is repeated for all remaining points on the sampling quadrat until all 50 points have been sampled.
- Tally the total number of hits per species for each plot on the data sheet (Table 1). This can be done after returning to the laboratory.
- All marsh study areas should be sampled within the same time frame (within 1-2 weeks of each other) and occur when the marsh surface is not flooded so that tidal waters do not conceal vegetation.
- This method can also be successfully used in marshes with taller vegetation canopies, like *Phragmites* and *Typha* marshes, or marshes dominated by shrubs (*e.g.*, *Iva*). The observer needs to be careful to use a long rod and to look up to determine if higher vegetation touches the rod.



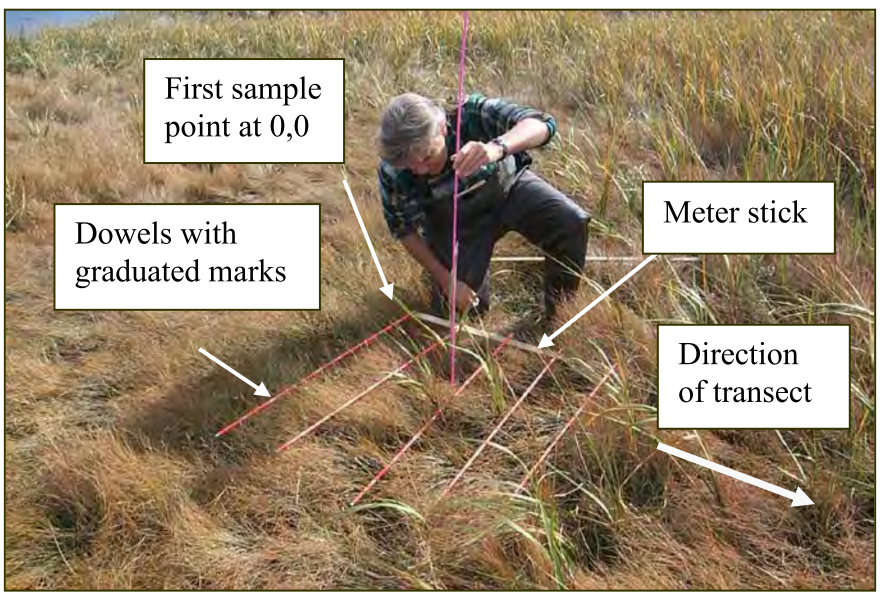




Figure 3. Schematic and photo of the sample quadrat and arrangement of dowels used in the point intercept method.

Table 1. Example of a field data sheet for the point intercept method.

Marsh ____________________ Field Crew _____________________ Date _________________________

Transect & Plot number ____________________ GPS Coordinates N:_____________________ E:_____________________

Record species, first row is for points 1-25, second row is for points 26-50.

Point

| SPECIES | Total Tally | 1<br>26 | 2 | 3 | 4 | 5<br>30 | 6 | 7 | 8 | 9 | 10<br>35 | 11 | 12 | 13 | 14 | 15<br>40 | 16 | 17 | 18 | 19 | 20<br>45 | 21 | 22 | 23 | 24 | 25<br>50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Species # 1 -- pts. 26-50 | XXXX | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Species # 2 -- pts. 26-50 | XXXX | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Species # 3 -- pts. 26-50 | XXXX | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Species # 4 -- pts. 26-50 | XXXX | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Species # 5 -- pts. 26-50 | XXXX | | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Species # 6 -- pts. 26-50 | XXXX | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Species # 7 -- pts. 26-50 | XXXX | | | | | | | | | | | | | | | | | | | | | | | | | |
| 8. | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Species # 8 -- pts. 26-50 | XXXX | | | | | | | | | | | | | | | | | | | | | | | | | |
| 9. | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Species # 9 -- pts. 26-50 | XXXX | | | | | | | | | | | | | | | | | | | | | | | | | |

Table 2. Cover type categories to be included in the point-intercept salt marsh vegetation program.

Live vascular plants (herbaceous and shrubs) identified by species

Standing dead vascular plants identified by species (*e.g., S. alterniflora* dead). This category only includes standing dead (attached) plants that are from a previous year's growth. There may be some dead leaves from this year's growth (*e.g.,* the ends of leaves or leaves that are being replaced by new growth, *etc.*). If you are sure these dead leaves are from the current growing season, then record as live. Dead plant material from a previous growing season is recorded as "liter" (see below).

Macroalgae identified by species. This category generally includes the rockweeds (*e.g.*, *Fucus*, *Ascophyllum*). Microalgae (*e.g.*, diatom mats) and fine filamentous algae are not included in this category.

Bare. Includes mud, sand, microalgae cover, *etc*. These are areas that are not flooded with water and are devoid of standing live, standing dead, or macroalgae. There can be a thin film of surface water within the bare category.

Water. Permanent standing water is identified in plots that are partly within a creek, ditch, marsh pool, or flooded panne.

Wrack/Litter. Wrack is material that has floated into the plot. This is generally dead (not attached) plant material, but could also be trash. Litter is dead plant material that is highly decomposed, if from a previous years growing season, and may or may not be attached. It is not identified to species, as is standing dead (see above).

Trash. Items such as logs, old piers, tires, etc.

Rock. Boulders or rocks can be found on the surface of northern New England marshes.

NOTES:

- If an intercept point has standing water that is covering a bare mud bottom, this point should be recorded as standing water. It is assumed that the bottom is bare and there is no need to record this.
- If macroalgae or submerged aquatic vegetation are hit at the intercept point in a standing water habitat, then both the plant and water should be recorded.
- If a plot is at the edge of a marsh pool (water), *Spartina* overhangs the water, and the intercept point hits the *Spartina* and water, then both *Spartina* and water should be recorded.

# WATER TABLE LEVEL

## SUMMARY

Water table level provides information on the amount of waterlogging or drainage that is occurring in a marsh. Water table level is an important parameter to use when attempting to understand why vegetation is changing. Water table level is measured using ground water wells. It is recommended that a water table level well be placed in association with each vegetation sampling plot.

For water table level and soil salinity, approximately 20-30 sample stations could be visited within a low tide period. Sampling can be accomplished by one person, but teams of people are always recommended when conducting field work. More details on water table monitoring are found in Roman *et al.* (2001)

Construction and installation of the wells is outlined below. Wells can also be purchased, pre-made, from hydrological supply companies.

Materials for Groundwater Wells

- 1.5 inch (4 cm) interior diameter, schedule 40, PVC Tubes (comes in 10ft lengths and can be purchased at home goods stores)
- PVC caps to fit the tubes. Two caps (rounded preferably) are required for each well
- ¼ inch drill bit
- Meter sticks
- Black permanent markers to mark well number on caps
- Mallets to pound wells into ground and blocks of wood to place on well top when wells are pounded
- All weather copier paper for field data sheets.

Groundwater Well Fabrication

- Cut PVC into 70 cm lengths (4 wells per 10 ft of tube), 10 cm will be aboveground, 60cm will be belowground.
- Drill ¼ inch holes in the belowground section of the well (along the 10–60cm length of the well). Drill enough holes to allow water to percolate into the well. The top of the well is the 0-10cm section that has no drill holes; the bottom of the well is the section with the drill holes. To prevent surface water from entering the well the top 0-10cm section of the well is left intact.
- Place a cap on the bottom of each well. Well bottoms should fit snugly, but do not need to be glued.
- Draw a line 10cm down from the top of the well. In the field, this line will serve as a guide for how deep the well should be driven into the peat.

- The remaining caps are for the top of the wells.
- Drill a ¼ inch hole in the center of the remaining top well caps. These caps are used to prevent rainwater from entering the well. A hole is drilled in the center of the top cap for venting.
- Well top caps are installed in the field.

Well Installation (refer to Fig. 4)

- Locate vegetation plot stake.
- Place groundwater well 1m away from the plot stake in the direction of the transect and pound well into the marsh.
- Pound well until only 10cm of well is above ground and all drill holes are below the marsh surface. Use 10cm mark on well as a guide.
- Label top cap (cap with center drill hole) with plot identification number. The well number will be the same as the vegetation plot number.
- Place top cap loosely on well top. Do not jam the cap onto the well top. These caps must be removed to measure the water table level.

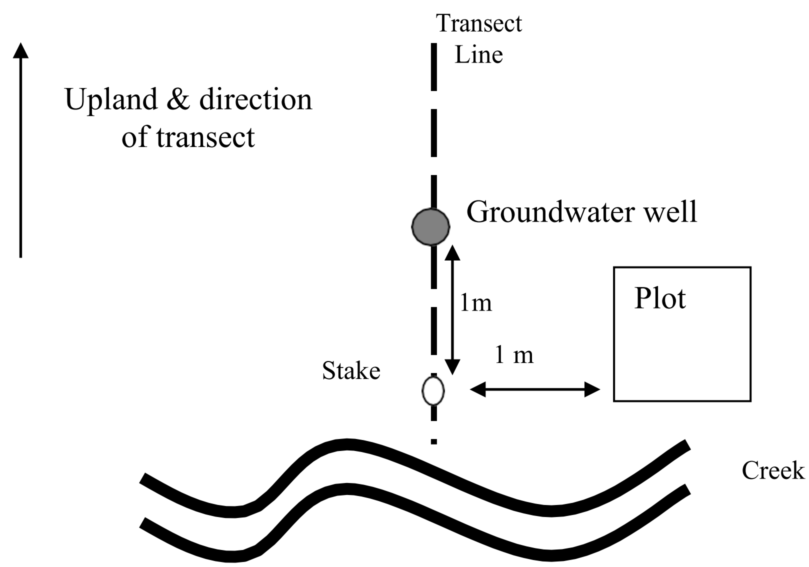



Figure 4. Schematic showing the location of groundwater well relative to stake and vegetation plot.

Materials for Sampling Ground Water Wells

- Meter stick
- Map of ground water well station locations
- Datasheet and pencils (Table 3)

<u>Sampling Procedure (refer to Fig. 5)</u>

- Water table level should be measured within 2 hours of low tide.
- Sampling should occur throughout the growing season, 10-14 intervals.
- Record well number.
- Remove well cap.
- Insert the meter stick into well (0mm end first) until the meter stick barely touches the water surface. By peering into the well as the meter stick is lowered you will be able to see the surface tension of the water break as the meter stick reaches the water surface.
- Record the measurement off the meter stick at the top of the well (Measurement A in Fig. 5 and Table 3).
- Record the height of the well from the marsh surface (Measurement B in Fig. 5 and Table 3). This measurement is important because the well could move from freezing/thawing, trampling, vandalism, *etc*.
- The height of the well from the marsh surface is subtracted from the total distance of the top of the well to the water level. This will give the distance of the water level below the marsh surface. This calculation will be done back in the office and should not be done in the field. The above two numbers are all that is required to be recorded in the field.
- If the well is dry (no water in the well at all), record "dry" on the data sheet
- If the marsh surface is flooded, measure the depth of the water from the marsh surface to the water surface. Be sure to write "surface" on the data sheet next to this measurement.
- Replace the top cap. Be sure not to jam the cap onto the well top.

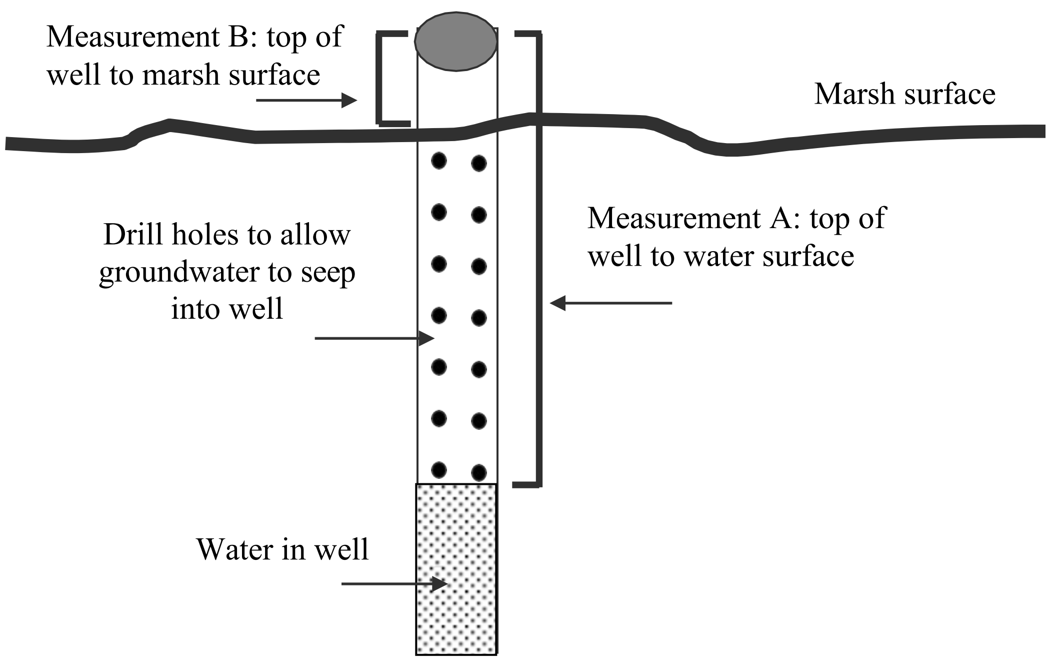



Figure 5. Schematic of groundwater well in place in the marsh

# SOIL SALINITY

## SUMMARY

In addition to water table level, soil water salinity is an important factor controlling the patterns of salt marsh vegetation. It is not appropriate to sample soil water salinity from water within the groundwater wells for several reasons. First, most useful measurements will be from the portion of sediment that has the most active roots and rhizomes. This is generally from the marsh surface to 10-15cm deep. The groundwater wells are integrating soil water from the surface to a greater depth (60cm). Second, water collected within the groundwater wells tends to stratify over-time, with denser high salinity water near the bottom of the well and fresher water near the surface of the well. The well could be pumped dry before each sampling event, allowed to fill, and then the water in the well sampled for salinity; however, the process of filling could take several hours (although filling is quite rapid for some wells, depending on soil porosity). To avoid these problems with sampling water from the groundwater wells, a soil probe in recommended for collecting soil water.

In conjunction with water table level measurements, sampling of soil water salinity with a soil probe is recommended as follows.

<u>Materials for Soil Salinity</u>

- Soil probe, constructed of stainless steel tubing, 1/16 inch (1.6mm) inner diameter, 1/8 inch (3.2mm) outer diameter, wall thickness 1/32 inch (0.8mm) (e.g., gas chromatography tubing), cut to about 70 cm length, with one end crimped and slotted to allow entry of soil water. Any rigid tubing that approximates these dimensions is satisfactory to use (Fig. 6).
- 10-15cc plastic syringe, or larger volume syringe up to 50cc
- 5cm length of plastic tubing to attach the soil probe to the syringe
- Salinity hand-held refractometer
- Filter paper (cut-up coffee filters are fine)
- Plastic squeeze bottle with freshwater to rinse and calibrate refractometer
- Data sheets and pencils (Table 3)

<u>Soil Probe Fabrication</u>

- Make 3 – 4 slits approximately 5mm apart and 2.5cm from one end of the metal tubing. The slits can be made with a roto-tool or a fine blade hacksaw. The slits are to allow water to be drawn up into the tube (Fig 6).
- Close the end of the metal tube (nearest to the slits) by crimping with pliers.
- Attach a short length of plastic tubing to the uncrimped end of the metal tubing.
- Attach the syringe to the other end of the plastic tubing.

- Make sure that water can be drawn up into the tubing by pulling the plunger on the syringe.
- Mark increments of 15cm, 30cm, and 45cm on the metal tube with tape so that depth of the soil salinity sample can easily be determined.

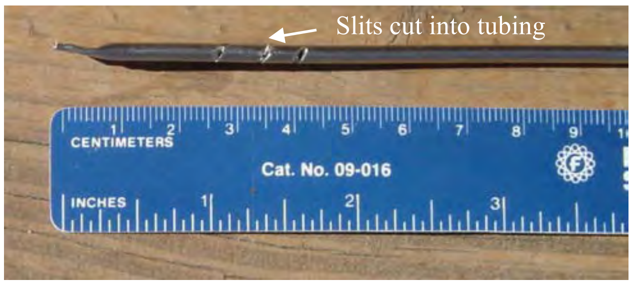




Figure 6. Photograph of a soil probe used to sample soil water salinity.

<u>Sampling Procedure</u>

- Sampling should coincide with groundwater well sampling. Always measured within 2hrs of low tide.
- Calibrate (zero) hand-held salinity refractometer with fresh water (tap is okay) before EACH field day.
- At a location near the groundwater well, insert the soil salinity probe (crimped end downward) 15cm into the sediment (Tape can be used to mark 15cm). The plastic syringe is attached to the top of the probe. Carefully withdraw the plunger to collect soil water.
- Once several milliliters (just a few drops) of water have been withdrawn into the syringe, detach it from the probe. If the marsh is dry at 15cm, then insert the probe deeper (30cm, then 45cm) until soil water is collected. Record the depth that soil water was collected. Record dry if no soil water was collected at 45cm.
- Place a piece of filter paper over the nozzle of the syringe. Depress the syringe plunger and let the water pass through the filter paper and onto the glass plate of the refractometer.
- Read and record the soil water salinity (Table 3). The station location for the soil salinity is the same as the water table level station and vegetation plot.

- Clean-up. Discard (never re-use) the filter paper. Using water from the groundwater well or a nearby creek, rinse silt and sediment from the probe by drawing up water into the syringe. Discard all the water in the syringe and probe before sampling the next station. Rinse refractometer with freshwater; dry refractometer.
- SAMPLING FREQUENCY: Soil salinity should be sampled in conjunction with groundwater sampling (10-14 day intervals during the growing season).

Table 3. Example of a field data sheet for water table level and soil salinity monitoring.

***Water Table Level & Soil Salinity Monitoring***

**SITE______________________ DATE _____________**

**Data Collector(s) __________________________**

**Note:** *If water is below marsh surface indicate water table level with a negative sign in "Depth Column". If water is on the marsh surface, write "surface" in Column A, measure water depth and record depth with a positive sign in "Depth" column. If water is below marsh surface than water table depth will be negative. If water is on marsh surface than depth will be positive.*

| Plot No. | Time | A. Top of Well to Water (cm) | B. Top of Well to Marsh (cm) | Depth to Water Table (B-A)[1] | Salinity (ppt) | Depth if other than 15 cm |
|---|---|---|---|---|---|---|
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[1] calculate in lab.

# SOIL SULFIDES (An Optional Monitoring Variable)

## SUMMARY

Under waterlogged and anaerobic soil conditions sulfide concentrations can rise to levels that are toxic to root metabolism, often inhibiting nitrogen uptake and plant growth (Howes et al 1986, Koch *et al.* 1990). When restoring salt marshes by re-introducing tidal flow it is suggested that soil porewater sulfide be monitored as a measure to help understand why vegetation patterns are changing. For example, if tidal flow is re-introduced to a wetland site and the soils become waterlogged then high sulfide levels could result. Sulfide toxicity from waterlogged soils can stress *Phragmites* growth, while *Spartina alterniflora* is more tolerant of high sulfide (Chambers *et al.* 1998).

Field and laboratory methods for total sulfides in salt marsh porewaters are described in detail by Portnoy and Giblin (1997) and will only be summarized here.

Materials for Sampling Soil Sulfides

- Soil probe (same probe as used for salinity as described above), constructed of stainless steel tubing,1/16 inch (1.6mm) inner diameter, 1/8 inch (3.2mm) outer diameter, wall thickness 1/32 inch (0.8mm) (e.g., gas chromatography tubing), cut to about 70 cm length, with one end crimped and slotted to allow entry of soil water. Any rigid tubing that approximates these dimensions is satisfactory to use. See Soil Salinity section for fabrication instructions.
- 10-15cc plastic syringe, or larger volume syringe up to 50cc
- Small volume pipette

Sampling Procedures for Soil Sulfides (Field and Lab)

- Sampling should coincide with groundwater well and soil salinity sampling. Always measured within 2hrs of low tide.
- At a location near the groundwater well, insert the soil salinity probe (crimped end downward) 15cm into the sediment (tape can be used to mark 15cm). The plastic syringe is attached to the top of the probe. Carefully withdraw the plunger to collect soil water. Be certain that air is purged from the probe and syringe prior to sampling using a three-way valve.
- Once several milliliters of water have been withdrawn into the syringe, detach it from the probe. If the marsh is dry at 15cm, insert the probe deeper until soil water is collected. Record the depth that soil water was collected.
- In the field, the porewater sample is collected from the syringe with a pipette and discharged into 2% zinc acetate and stored on ice. Volume of the pipette depends on expected sulfide concentration, but 0.1 ml is often appropriate.
- Sulfide is determined colorimetrically after Cline (1969).
- SAMPLING FREQUENCY: Soil sulfide should be sampled at least monthly during the growing season in conjunction with groundwater and soil salinity sampling.

# MOSQUITO LARVAL SAMPLING

## SUMMARY

Mosquito larvae will be sampled using the standard “dip count” method along the established vegetation transects. Mosquito larvae should be sampled 4 to 5 days after a tide that has flooded the surface of the marsh. This is usually a full or new moon high tide, but can also be associated with rainfall events and storms. This time frame corresponds to the period when mosquito larvae are present on the marsh. Adult mosquitoes deposit their eggs on moist soil or stems of grasses where the eggs must dry for at least 24 hours. The eggs hatch when flooded by the monthly high tides or a rainfall event. After hatching, the larvae pass through five developmental stages, or instars, that reside in small, stagnant pools before emerging in one to two weeks as adult mosquitoes. Larval sampling is conducted during this development period. Larvae will be sampled at approximately every 15-20 m along the transect, this corresponds to samples in the vicinity of every vegetation plot and in between each vegetation plot.

Materials for Sampling Mosquito Larvae

- Mosquito dipper
- Sample vials for mosquito larvae
- Labels for sample vials
- Map of vegetation transect locations
- Datasheet and pencils (Table 4)

Sampling Procedure for Mosquito Larvae

- Sample for mosquito larvae 4 to 5 days after a tide has flooded the marsh surface. This could be after new or full moon high tide, storm surge, or a rainfall event that floods the marsh. Four to five days after flooding, larvae should be in the 3$^{rd}$ or 4$^{th}$ instar and are therefore easier to count and identify.
- Optimal sampling time will not always be as predictable as the full and new moon tides. Investigators should be ready to sample 4 to 5 days after major rainfall events as well.
- Sample larvae at least once per month from May to October (twice per month is better).
- Mosquito larvae sampling stations are located at approximately 15m to 20m intervals along each vegetation transect. This should correspond to sampling in the vicinity of each vegetation plot as well as in between each plot. A meter tape should be used to measure the distance between vegetation plots to locate stations between each vegetation plot. To ensure that the same approximate location is sampled each time, sample stations could be marked with flags or another identifying marker.
- Mosquito sampling stations located at vegetation plots should be identified as the vegetation plot ID. Those stations in between plots should be identified as the meter distance along the vegetation transect. For example, a mosquito sampling

station located at vegetation plot 1-120 (transect 1, distance 120m along the transect) would be identified as 1-120, a mosquito sampling station located between vegetation plots 1-120 and 1-140 would be identified as 1-130.

- When walking the vegetation transect for mosquito sampling be sure not to walk in the permanent vegetation plots. Offset the mosquito larvae sampling transect several meters to the left or right of the plot stake.
- Transects should be walked facing the sun, so the sampler's shadow is not cast onto the standing water that is sampled. Mosquito larvae will quickly disperse if a shadow is cast over them.
- Once at a sampling location (a permanent vegetation plot or in between 2 adjacent plots) locate the nearest standing water within a 3m radius. If no standing water is present record "dry" on the data sheet. Record the type of water that was sampled on the data sheet using the following categories:
    - creek
    - pool
    - panne
    - SW: standing water in vegetation
    - Other: be sure to define what "Other" represents
- If standing water is present, sample the edges of the standing water with a standard mosquito dipper. Attempt to get a full dipper of water. If this is not possible, estimate the amount of water using the following coded categories and record the amount on the data sheet:
    - 5: full dipper
    - 4: ¾ full
    - 3: ½ full
    - 2: ¼ full
    - 1:less than ¼ full
    - 0: no water in dipper

  Some mosquito dippers have volume increments on the inside of the dipper than can be used to estimate the water volume.
- Count all larvae up to 100 in the dipper. Larvae are be counted by letting the water in the dipper slowly flow out of the dipper lip and back on to the marsh surface. If there are more than 100 larvae estimate the number using the following categories:
    - 100 to 200 larvae
    - 200 to 300 larvae
    - 300 to 500 larvae
    - > 500 larvae
- In the field, save a sub-sample of the larvae (approximately 5 individuals from each sample station) and place them in a vial with water from the dipper. Record the sample location on the vial. These larvae will be brought back alive to the lab for species identification.

<u>Method to Preserve Mosquito Larvae for Identification</u>

- If the mosquito larvae are not identified immediately they must be preserved for later identification upon return to the laboratory.
- First the mosquito larvae should be killed in hot water. Boil a small amount of water and let it cool until it stops bubbling. Then put the mosquito larvae in the water and remove them after about 50 seconds. This heating is necessary to maintain taxonomic characteristics for identification.
- Remove larvae from water either by straining or individually with forceps.
- After heating the larvae should be preserved in either a Dietrich's solution or an AGA solution, both are described below.
- Dietrich's solution: The formula for Dietrich's solution is:
    - 30 parts distilled water (=58%)
    - 15 parts 95% ethanol (=29%)
    - 6 parts formaldehyde (=11%)
    - 1 part glacial acetic acid (=2%)

  Specimens should be transferred from Dietrich's solution to a long-term preservative (*e.g.*, 75% ethanol) after 24 hours. However, they can be left in Dietrich's solution for months before transferring them, if necessary.
- AGA solution: AGA solution is a 1:1:8 solution (by volume) of glacial acetic acid:glycerin:75%ethanol. The formula for AGA solution is:
    - 1 part glacial acetic acid (=10%)
    - 1 part glycerin (=10%)
    - 8 parts 75%ethanol (=80%)
- Record sample date, site, and station location on vial.

Table 4. Example of a field data sheet for mosquito larvae monitoring.

## ***Mosquito Larvae Sampling Data Sheet***

**Site__________________________ Date____________ Sampler __________**

Dipper volume codes: 0=no water, 1= < ¼ full, 2=¼ full, 3= ½, 4=¾, 5=full

| Station # | # Mosquito Larvae | Water volume in Dipper | Area dipped<br>(dry, pool, panne, standing water in vegetation) | Larvae saved for ID?<br>(yes or no) |
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# NEKTON SAMPLING IN PONDS


## SUMMARY

This estuarine nekton protocol recommends sampling exclusively with $1m^2$ throw traps in shallow salt marsh ponds. The species composition and abundance (density) of nekton (fish and decapod crustaceans) is measured with a $1m^2$ enclosure trap in shallow water (< 1m) habitats such as marsh ponds. Enclosure traps provide a repeatable, quantitative estimate of nekton utilization of specific habitats. Beach seines are useful for determining species composition and relative abundance, but provide a less repeatable method. Raposa and Roman (2000 and 2001) provide details on the method, sample size requirements, and information on data analyses. There should be two daytime sampling efforts per year; one in early summer (June-July) and another in late summer-early fall (August-October), unless there are species or processes unique to other seasons that are of interest. The number of throw trap samples required depends on the habitat under examination, but generally between 25 and 50 samples should be collected from each sampled habitat during each sample period. This protocol recommends sampling twice in summer and is presented as a minimum for nekton monitoring.


Materials for Identifying Station Locations

- Oak stakes to mark station locations
- Mallet to pound stakes into ground
- Black permanent markers to mark transect and plot number on stakes
- Colored flagging (optional) to tie to oak stakes
- Compass
- Random number table (to determine specific station location at each pond)
- Aerial photos of study sites
- Draft map of study site showing boundaries of study areas and approximate location of ponds

Nekton Pond Station Location Procedure

All pond sampling stations should be randomly selected prior to monitoring. The best method is to obtain either an aerial photo or GIS map of the study area and randomly selecting pond sampling stations using the procedure outlined below.

- Obtain an aerial map of the study area.
- Identify all ponds within the study area.
- If there are more than 25 ponds, sequentially number each pond within the study area. Random numbers between one and the total of number of ponds are then generated using a random number generator found in several spreadsheet

programs. The first 25 random numbers from the generated list are chosen, each of these random numbers correspond to a pond that will be sampled.
- If there are 25 or fewer ponds, all ponds will be sampled.
- Locate the pond in the field.
- Pace the perimeter of the pond to estimate the length of the perimeter.
- Select a random number between one and length of the perimeter.
- Locate the station (point where the throw trap will be released from) by pacing the distance of the random number. For example, if the pond perimeter is 25 meters, and the random number is 17, the station location will be 17m around the perimeter.
- Alternatively, a random compass bearing (between 0 and 360) can be chosen to location the station location on the pond.
- Locate the station in the field and mark with a 1m oak stake.
- Label the oak stake with the station number. The naming convention should be "P" for pond and the station number, one through the total number of stations sampled in that area (*e.g.* P1, P2, *etc.*).
- If a pond is large, more than one station may be located at the pond if additional stations are needed. However, stations located on the same pond should not be sampled at the same time and sampling time should be spaced apart by at least 30min. If two stations are located on the same pond, the naming convention is the same as explained above. For example, P1 and P2 can be on the same pond.

Materials for 1m$^2$ Throw Trap Construction

- The throw trap measures 1m wide x 0.5m high. The bottom and top of the trap are open
- Eight, 1m long by 2.5cm aluminum bars
- Four, 0.5 m long by 2.5cm angle aluminum bars
- Nuts, bolts and lock washers to attach aluminum bars to angle bars
- 3mm hardware cloth (when reporting results from this method, investigators should cite a 3-mm mesh size, the mesh size of the throw trap)
- thin gauge wire or cable ties to attach hardware cloth to aluminum frame
- Nylon netting, 3mm mesh, 4m long by 0.5m width (for skirt)
- 4m of float cord (for skirt)

Materials for Dip Net Construction

- The dip net measures 1m long x 0.5m wide, and fits snugly within the throw trap (Fig 7).
- Approximately 4m of 1.25cm diameter aluminum rod that can be bent into the shape of the dip net with a 0.5m handle.
- 0.5m length of 2.5-5.0cm diameter steel pipe (to fits over the aluminum rod to strengthen the handle).
- Cable ties or sewing thread.

<u>Throw Trap and Dip Net Fabrication</u>

- The throw trap measures 1m$^2$ x 0.5m high (Fig. 7).
- Construct the frame of the throw trap by attaching the 0.5m long 2.5cm angle aluminum angle bars (forms the corners of the trap) to the 1m long 2.5cm straight aluminum bars (forms the sides of the trap) with nuts, bolts, and lock-washers.
- Once the frame is built, the four sides of the trap are surrounded by 3mm mesh hardware cloth that is attached to the horizontal frame bars with thin gauge wire. Attach hardware cloth (with thin gauge wire or cable ties) to the 4 sides of the trap, leaving the top and bottom of the trap open.
- If water depths are expected to exceed 0.5m, the height of the trap can be extended to 1 m by attaching a skirt (3mm mesh nylon netting) to the top of the trap. The skirt is equipped with float-cord along the top edge to ensure that the top of the skirt floats at the waters surface.
- Bend the aluminum rod into the shape of the dip net (1m long by 0.5m wide) with a 0.5m handle.
- 0.5m length of 2.5-5.0cm diameter steel pipe can be fit over the aluminum rod handle of the dip net to strengthen the handle.
- Attach the 1mm mesh nylon netting (1.25m by 0.75m), to the dip net frame either with numerous small cable ties, or by sewing with twine or wire cable ties. Use of a 1mm mesh dip net facilitates collection of all nekton within the 1m$^2$ frame.
- When reporting results from this method, investigators should cite a 3-mm mesh size, the mesh size of the hardware cloth.

Figure 7. 1$m^2$ throw trap. The investigator is sweeping the trap with the 1m x 0.5m dip net. Note the skirt of 3mm nylon mesh net attached to the top of the trap for sampling in deeper water.

<u>Materials for Sampling Nekton in Ponds</u>

- $1m^2$ throw trap
- small ruler (to measure nekton)
- Map of pond station locations
- Data sheet and pencils (Table 5)
- Identification keys
- Any other equipment necessary for taking environmental variables (*e.g.* refractometer, oxygen probe, thermometer)

<u>Sampling Procedure for Nekton Using $1m^2$ Throw Trap</u>

- Nekton sampling should occur at the same relative tide stage.
- Sampling salt marsh ponds should occur only after the marsh surface is drained of tidal water. We generally begin sampling in seaward habitats where the marsh surface drains first, and then proceed to landward areas following the tidal prism. This method ensures that samples are collected at similar water depths throughout the marsh, and is thus one way to control for the effects of tide stage.
- Samples are collected by approaching to within 4 to 5m of a marked station with the throw trap. Approach the station quietly so as not to not disturb or startle the nekton. Only the person throwing the throw trap should approach the station, all others should remain at a distance (>10m) from the station to avoid startling the nekton. Pond stations are approached by crouching low and walking over the marsh surface, then waiting about 2 minutes before throwing the trap.
- The trap is thrown into the water by tossing it from the hip like a giant Frisbee (Fig. 8). The trap is then quickly pushed into the sediment to prevent escape of nekton from under the trap. In order to minimize disturbance, replicates are never taken from the same station in a single sampling period.
- Once the sample is secured, nekton is removed by the large dip net.
- The net is slid downward into the trap, flush against the side of the trap nearest the researcher. The net is then moved across the trap with the forward edge of the net always remaining flush against the sediment until the opposite side of the trap is reached. In muddy sediments the dip net often goes through a thin layer of surface sediment, capturing buried nekton. The net is then moved upward out of the trap, again keeping the leading edge flush against the far wall of the trap.
- The dip net should be used from at least three sides of the trap because nekton may be hiding in the trap corners.
- The dip-netting procedure is repeated until three consecutive dips do not capture any animals or if the first four dips come up empty. At this point the trap is considered empty.
- Animals are processed as they are captured. All animals are identified to species in the field and immediately released at the same station.
- In each sample, up to fifteen individuals of every species are measured to the nearest mm for total length (from the tip of the snout to the tip of the caudal fin for fishes; from the tip of the rostrum to the tip of the telson for shrimp) or carapace width for crabs (the distance between the two furthest points across the

carapace). Generally, dominant fish species (*i.e.* the mummichog, *Fundulus heteroclitus*) is counted and measured as two categories, juveniles (<45mm) and adults (>45mm). Juveniles and adults can be entered on the data sheets under separate species (Table 5).

- Nekton may be identified using any number of guides that are specific to the Atlantic coast and New England regions, including Bigelow and Schroeder (1953), Gosner (1978), and Robins *et al.* (1986), Eddy and Underhill (1978).
- Individuals that are difficult to identify may be humanely sacrificed by a strong blow to the head, preserved in 70% ethanol, and returned to the laboratory for identification.
- Any associated environmental variables should be measured at this time (see section entitled "Other Environmental Variables Monitored During Nekton Sampling").

Figure 8. Sampling technique for $1m^2$ throw trap. The trap is tossed like a frisbee into the pond that is being sampled.

Table 5. Sample nekton throw trap field data sheet.

## THROW TRAP DATA SHEET

SITE:_________________________ DATE:____________________TIME:__________

STATION #:___________ SAMPLING CREW: _________________________

GPS Coordinates: N__________________________E______________________________

Water temp: __________ Salinity: __________ DO: ___________

Water Depth:____________Tide (circle one): Flood Ebb Vegetation (circle one): Yes No

Vegetation Species #2_________________Veg. % Cover: <1% 1-5% 5-25% 50-75% >75%

## NEKTON SPECIES & MEASUREMENTS

SPECIES #1_________________________ Total # of individuals: ________________

Talley (include measured fish): ____________________________________________________________

LENGTHS:___________________________________________________________________________
(15)

SPECIES #2_________________________ Total # of individuals: ________________

Talley (include measured fish): ____________________________________________________________

LENGTHS:___________________________________________________________________________
(15)

SPECIES #3_________________________ Total # of individuals: ________________

Talley (include measured fish): ____________________________________________________________

LENGTHS:___________________________________________________________________________
(15)

SPECIES #4_________________________ Total # of individuals: ________________

Talley (include measured fish): ____________________________________________________________

LENGTHS:___________________________________________________________________________
(15)

SPECIES #5_________________________ Total # of individuals: ________________

Talley (include measured fish): ____________________________________________________________

LENGTHS:___________________________________________________________________________
(15)

# NEKTON SAMPLING IN DITCHES and SMALLER TIDAL CREEKS

## SUMMARY

Common features on salt marshes are grid ditches that were created for mosquito control purposes in the 1940's. These ditches vary in width, (usually 45cm and 100cm in wide) and on some marshes, especially those in the southern New England, are the only water habitat within the marsh. The throw trap is not a good sampling gear for the grid ditch habitat, as the trap is too large. Even smaller versions of a throw trap would not sample these areas as the trap would have to land precisely in the ditch in order to enclose the nekton. This protocol outlines an enclosure sampling gear, the ditch net, that we have designed to sample these narrow tidal channels. The center body of the net lines the sides and bottom of 1 linear meter (approximately) of ditch. There are two doors on the open ends of the net, which when pulled, rise up to close off the ends of the net, enclosing an area of water that is 1m long and as wide as the ditch. This sampling gear is designed to sample mosquito ditches and smaller tidal creeks up to 1m wide and 1m deep. There should be two daytime sampling efforts per year; one in early summer (June-July) and another in late summer-early fall (August-October), unless there are species or processes unique to other seasons that are of interest. The number of ditch net samples required depends on the habitat under examination, but initially we recommend at least 10 samples should be collected from each sampled habitat during each sample period.

Materials for Identifying Ditch Station Locations

- Oak stakes to mark station locations
- Mallet to pound stakes into ground
- Black permanent markers to mark transect and plot number on stakes
- Colored flagging (optional) to tie to oak stakes
- Random number table (to determine specific station location along ditches)
- Aerial photos of study sites
- Map of study site showing boundaries of study areas and approximate location of ditches

Nekton Ditch Station Location Procedure

All sampling stations should be randomly selected prior to monitoring. This is best accomplished by obtaining an aerial photograph of the study location to identify the ditches and smaller tidal creeks (<1m wide).

- Estimate length of ditch.
- Choose a random number (from a random number table) between zero and the total ditch length.

- Locate station location at the random number and mark with a 1m oak stake and colored flagging. For example, if the ditch is 120m long and the random number is 33, the station would be located at 33m along the ditch.
- Label stake with ditch net station ID. The naming convention for ditch stations is "D" for ditch and the station number, one through the total number of stations sampled in that area (*e.g.* D1, D2, *etc*.).
- Establish at least 10 ditch net stations per study area.
- Generally, only one station is located per ditch.
- If there are few ditches, more than one station can be located on the same ditch, but the station should be at least 20m apart.
- Record geographic coordinates (UTM, latitude/longitude) of all station locations using a sub-meter accurate GPS unit.

<u>Materials for Ditch Net Construction (for 1 net)</u>

- NYLON netting (24lb test), 1/8in mesh, at least 1m deep. Each net takes 5 meters of netting – a 1m X 3m section for the center of the net (sides & bottom) and two 1m X 1m sections the doors
- 20m of nylon rope, 3/16in diameter. Each net takes 20m of line – four 4m lengths for rip cords and four 1m lengths for runner lines of the doors
- 5m of leadcore line; m for the top of each door (total 2m) and 3m for the floor of the net
- 4 eye-hooks with 1in eyes
- 4 oak stakes – 1.5 to 2m long, 2.5cm square
- Staple gun and 3/8 in stainless steel staples
- D-ring hand pliers and 9/16 in C-ring fasteners
- 25 to 30 plastic rings or rubber O rings, approximately 2.5cm diameter

<u>Ditch Net Fabrication</u>

- Cut a 1m by 3m section of the nylon netting for the center of the net.
- Cut two 1m by 1m sections of nylon netting for the doors of the net.
- Attach the doors of the net to the center section. The doors should be centered on the main body of the net along the 3m length (Fig 9a). To attach the doors take a 1m length of leadcore line and wrap the nylon netting from the leading edge of the door and the center 1m middle section of the net body around the leadcore and fasten the two pieces of nylon netting to the leadcore line with the D-ring pliers and 9/16 in C-ring fasteners.
- Attach 5 to 7 nylon rings or rubber O-rings to sides of the doors (side A in Fig 9a). Use the D-ring pliers to attach the rings to the nylon netting. The rings should be attached to the edge of the netting so the center of the ring is clear of the netting. The draw cord that pulls the doors up passes through these rings.

- Attach 3 to 5 plastic rings to the top of the door (side B in Fig. 9a). Use the D-ring pliers to attach the rings to the nylon netting. The rings should be attached to the edge of the netting so the center of the ring is clear of the netting.
- Attach a short length of lead core line to the top of each door (Fig. 9a, side B) using either cable ties or the D-ring pliers and C-ring fasteners. This is to weigh down the top of the net so it does not float up, and impede the passage of fish through the net.
- Attach a length (approximately 1m) of leadcore line to the bottom center of the net (Fig. 9b) on the outside of the net using either cable ties or the D-ring pliers and C-ring fasteners. This is to weigh down the center of the net so it does not float up when placed in the ditch.
- Attach the net to the four oak stakes using a staple gun and stainless steel staples. The free edges of the net (Fig 9a, side C, and Fig. 9b between points 1 and 2) are stapled to the oak stakes. The portion of the net closest to the doors should be stapled starting at approximately 30cm (1 ft) from the bottom of the oak stake, and continue up towards the top of the stake. The bottom 1ft of the stake should be free of the net so that the stake can be pushed into the ground to hold the net in place while it is deployed.
- The runner lines are attached next. The runner lines hold the plastic rings close to the stake, so when the door is pulled up the net remains close to the stake.
- Attach the bottom of runner lines to the interior of the stakes (on top of the stapled netting). The runner lines are approximately 1m in length. The bottom of the runner line should be attached at the intersection of the doors and main body of the net. Tie a few knots in the end of the line and staple the line to the stakes using several staples close together on each side of the knot so the line will not pull loose.
- Pass the free end of the runner line through the 5 plastic rings that are attached to side A (Fig. 9a) of the door closest to the stake (Fig. 9b, runner line (3) and plastic rings (4)). The bottom most ring is added first, then the next ring, until all rings for that door side are on the runner line. The runner line is then pulled taut against the stake and the free end is stapled approximately 5 to 8cm above the end of the net. After stapling a knot should be tied in the free end of the line and stapled again on either side of the knot to ensure the runner line does not come loose.
- Attach the rip cord to the center ring on the top of the door, and pass the rip cord through one of the rings on the corner of the door. Then pass the rip cord through the top ring of the door that is attached to the runner line. Attach another rip cord to the same center ring, and pass it through the other corner ring, and the top ring on the other side of the door. When these lines are pulled, they will pull on the top rings attached to the doors, which in turn will pull the sides of the doors up the stakes to enclose the sides of the net.
- Attach the rip cords to the other side of the net as described above.
- Attach the eye-hook to the oak stake. When the net is held upright, with the 4 stakes sticking into the ground, the eye-hook should be placed on the outside of the stake. The free end of rip cord is passed through the eye-hook. When the rip

Fig. 9a

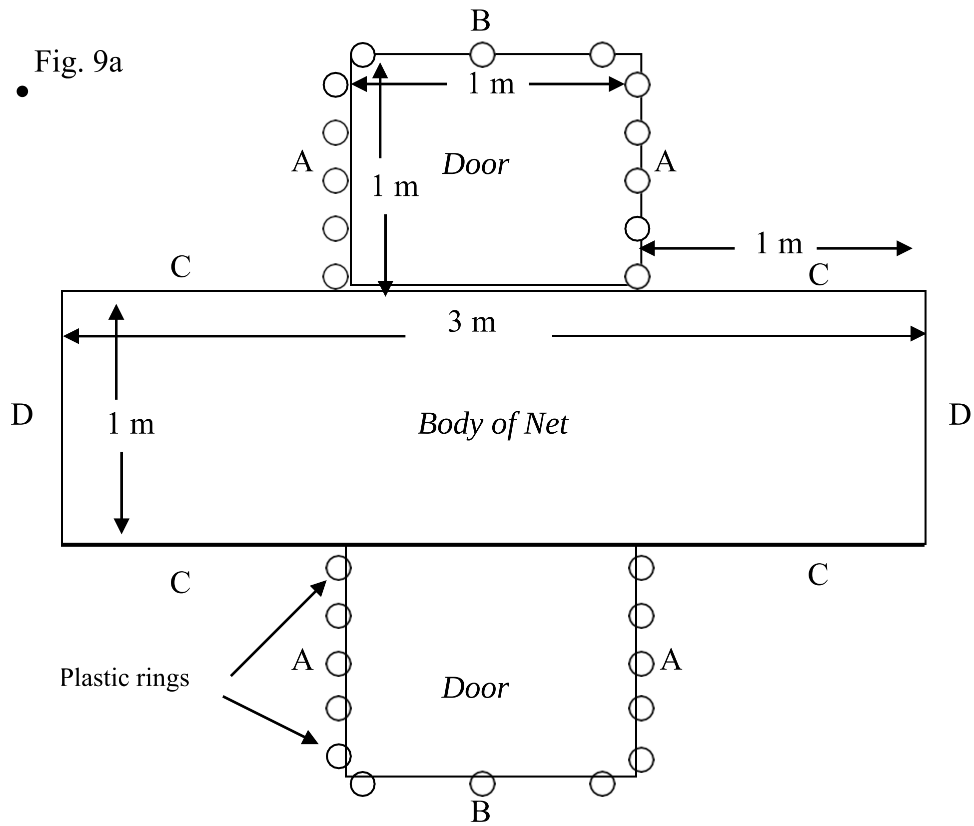



Fig. 9b.

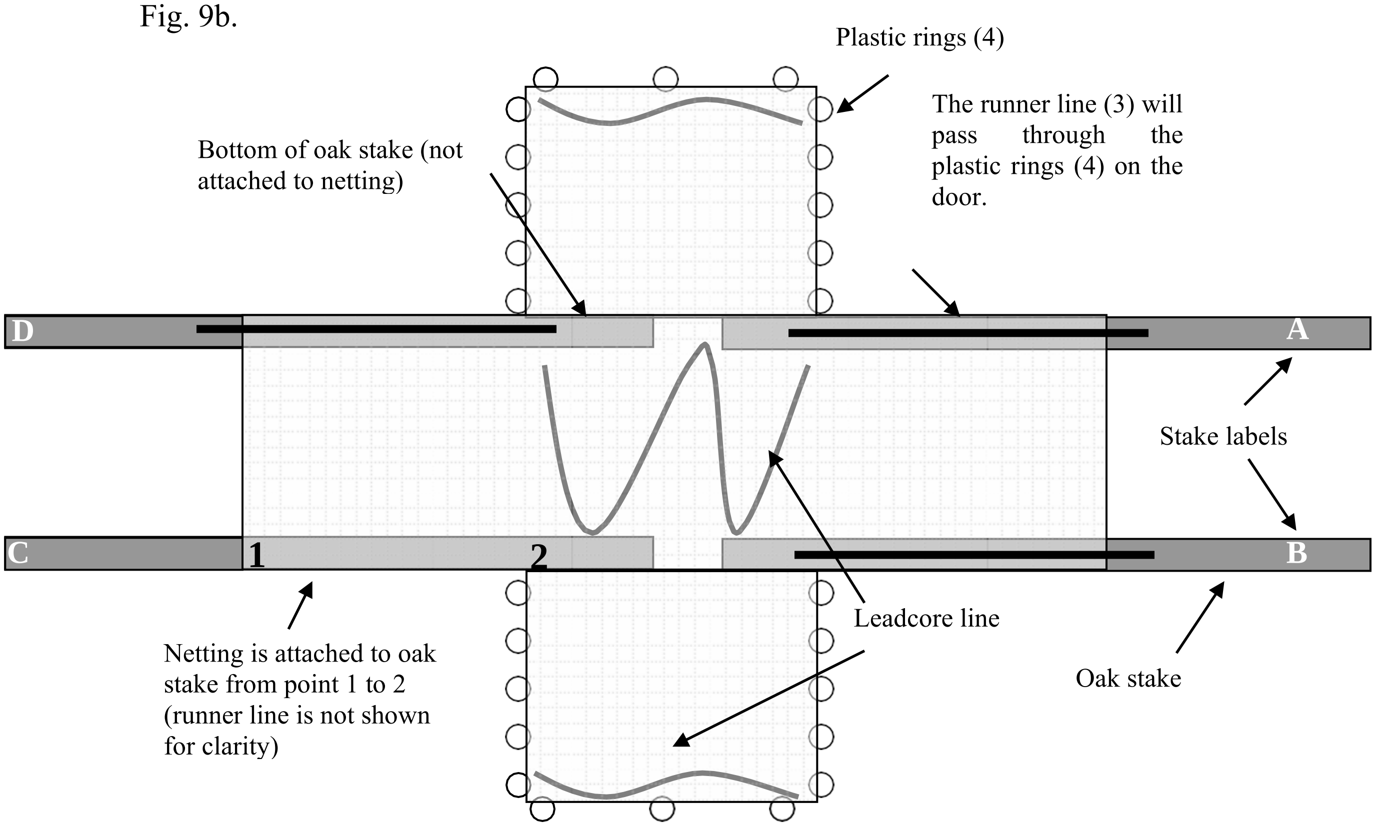



Figure 9a and b. Schematic of ditch net showing dimensions of nylon netting and attachment points for leadcore line, plastic rings, runner lines, and oak stakes. Fig. 9b is looking down into the interior of the net.

is pulled the line should pass easily through the eye-hook, so the doors are pulled up smoothly.

- Label the stakes. We usually label the stakes A, B, C, and D. Be sure to label each net exactly the same. The labels are used to set the net correctly in the ditch and to measure the distance between the stakes in order to determine the area of the water that the net was fishing (refer to data sheet). For example, stakes A and B are place on one side of the ditch and stakes C and D are place on the opposite side of the ditch (Fig. 9b).
- Test each net to be sure that the rip cords pull up the doors smoothly and quickly.

<u>Materials for Sampling Nekton in Ditches</u>

- Ditch nets
- small ruler (to measure nekton)
- meter stick (to measure net, creek and water depths)
- Map of ditch station locations
- Data sheet and pencils (Table 6)
- Identification keys
- Any other equipment necessary for taking environmental variables (*e.g.* refractometer, oxygen probe, thermometer)

<u>Sampling Procedure for Nekton Ditch Net</u>

- Nekton sampling in ditches should occur at the same relative tide stage. Sampling salt marsh ditches should occur only after the marsh surface is drained of tidal water. Sampling should occur on a high slack or ebb tide, when the marsh surface has drained.
- Nets are placed at the station locations in the ditches at least 30min before sampling. This usually means that the nets are placed at flood or slack tide.
- Set up a ditch net usually requires 2 people, each standing on opposite sides of the ditch. One person will take stakes labeled “A” and “B” and place the stakes into the bottom of the ditch close to the side of the ditch. The other person will take stakes labeled “C” and “D” and place them on the opposite side of the ditch. The net should be stretched tight between stakes “A” and “B” and stakes “C” and “D” so that approximately a 1m section of ditch is sampled. (Fig 10a).
- The rip cords should be pulled to make sure that the lines are not fouled and that the doors will pull up smoothly and quickly.
- Push the doors and the center of the net down into the bottom of the ditch with the meter stick. Make sure that the net lays down on the bottom of the ditch, so that fish passage through the net is not impeded.
- Measure the distance between all the stakes (*e.g.* “A” to “B”, “B” to “C”, “C” to “D”, and “D” to “A”) and the diagonal distance between stakes “A” and “C” and record these on the datasheet (Table 6). These distances are measured when the

net is placed in the ditch and are necessary to calculate the area of water that is sampled.

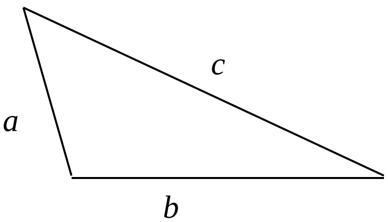
- Lay the rip cords out on the marsh surface as far from the net as possible without pulling on the doors.
- Note the time that the net is deployed on the data sheet.
- Ditch nets should not be sampled until they have been deployed for at least 30min. This time period is necessary to minimize any disturbance to nekton caused by placing the net in the ditch.
- At high slack or ebb tide, the ditch nets are pulled. Two people are required to pull the ditch nets. The nets are quietly approached from opposite sides of the ditch, one person on each side. Upon reaching the rip cords, each person kneels and waits quietly for approximately 2min. The rip cords should not be handled during this time, as the vibrations on the cords can be transmitted to the stakes and possibly disturb nekton that are in the net. At a pre-determined signal, both people quickly pull on the rip cords and run towards the net. The doors of the net will pull up, enclosing nekton within the net (Fig. 10b and 10c).
- The net is then quickly lifted out of the ditch and onto the marsh surface. The best way to do this is to have both people pull the stakes out simultaneously (while still maintaining pressure on the rip cords). All four stakes are then handed to one person who will lift the net out of the ditch and onto the marsh surface. It is important to quickly pull the stakes and net out of the ditch, since this creates a bag of netting in the center of the net where the fish are trapped.
- The net is then laid out on the marsh surface and the nekton are identified, counted, and measured.
- The collection time should be recorded.
- In each sample, up to fifteen individuals of every species are measured to the nearest mm for total length (from the tip of the snout to the tip of the caudal fin for fishes; from the tip of the rostrum to the tip of the telson for shrimp) or carapace width for crabs (the distance between the two furthest points across the carapace). Generally, dominant fish species (*i.e.* mummichog, *Fundulus heteroclitus*) is counted and measured as two categories, juveniles (<45mm) and adults (>45mm). Juveniles and adults can be entered on the data sheets under separate species.
- Nekton may be identified using any number of guides that are specific to the Atlantic coast and New England regions, including Bigelow and Schroeder (1953), Gosner (1978), and Robins *et al.* (1986), Eddy and Underhill (1978).
- Any associated environmental variables should be measured at this time (see section entitled "Other Environmental Variables Monitored During Nekton Sampling").

Calculating the Area of a Ditch Net

- The area of a ditch net is calculated as the sum of two irregular triangles.
- The areas of the 2 irregular triangles are calculated from the 5 distances measured in the field.
- The formula for an irregular triangle is:

$$\sqrt{[s*(s-a)(s-b)(s-c)]}$$

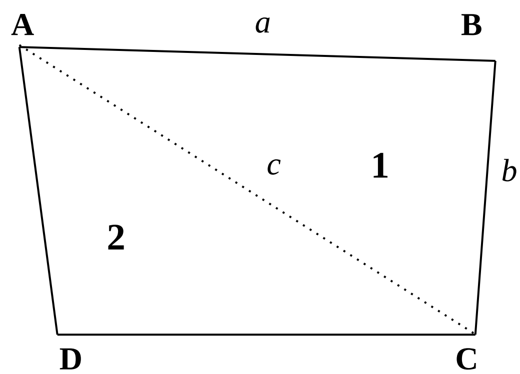
Where: $s = \frac{(a+b+c)}{2}$




- For example, a net with the following dimensions:

Where:

A to B = 81cm
B to C = 73cm
C to D = 71cm
D to A = 76cm
A to C (diagonal) = 109cm




s for Triangle 1: $s = \frac{(81 + 73 + 109)}{2} = 131.5$

The area of Triangle 1:

$$\sqrt{[131.5 * (131.5 - 81)(131.5 - 73)(131.5 - 109)]} = 2684.9\text{cm}^2$$

s for Triangle 2: $s = \frac{(71 + 76 + 109)}{2} = 128$

The area of Triangle 2:

$$\sqrt{[128 * (128 - 71)(128 - 76)(128 - 109)]} = 2956.5\text{cm}^2$$

The total area of the net would be: $2956.5\text{cm}^2 + 2684.9\text{cm}^2 = 5641.4\text{cm}^2$ or $0.56\text{m}^2$




Figure 10a-c. Photos of ditch net in the field showing correct deployment (Fig 10a), doors being pulled up (Fig. 10b), and the net once the doors have been pulled (Fig 10c).

Table 6. Sample nekton ditch net field data sheet.

## Nekton Ditch Sampler Data Sheet

SITE:__________________________ DATE: ____________________

STATION #:___________ SAMPLING CREW: ________________________

GPS Coordinates: N_____________________________E__________________________

Habitat Type: Tidal Creek (TC) Open Ditch (OD) Plugged Ditch (PD)

Deployment Time:____________ Collection Time: ______________________

Net Distance Measurements:

A to B:_______B to C:________C to D:________D to A:________ A to C (diagonal): _______

Water temp: __________ Salinity: __________ DO: ___________

Water Depth:_____________Creek/Ditch Depth:_____________Tide: Flood or Ebb

### NEKTON SPECIES & MEASUREMENTS

SPECIES #1__________________________ Total # of individuals: ________________

Talley (include measured fish): ______________________________________________________________

LENGTHS: ____________________________________________________________________________

SPECIES #2__________________________ Total # of individuals: ________________

Talley (include measured fish): ______________________________________________________________

LENGTHS: ____________________________________________________________________________

SPECIES #3__________________________ Total # of individuals: ________________

Talley (include measured fish): ______________________________________________________________

LENGTHS: ____________________________________________________________________________

SPECIES #4__________________________ Total # of individuals: ________________

Talley (include measured fish): ______________________________________________________________

LENGTHS: ____________________________________________________________________________

SPECIES #5__________________________ Total # of individuals: ________________

Talley (include measured fish): ______________________________________________________________

LENGTHS: ____________________________________________________________________________

# BIRD SURVEYS

## SUMMARY

The bird guilds using salt marsh areas within Region 5 that may be affected by OMWM practices include: (1) cryptic marsh passerine species such as marsh wrens and salt marsh sparrows (Seaside, Coastal Plain, Swamp, and Sharp-tailed primarily) and non-passerine rails and bitterns; (2) conspicuous, large waterbirds such as waterfowl (ducks, geese, and swans), colonial species such as herons and egrets, gulls, terns, Black Skimmers, and Double-crested Cormorants; and (3) migrating and wintering shorebirds, including sandpipers, plovers, and relatives. Many of these species are of high priority in state and national bird conservation plans, Partners in Flight, and Region 5 FWS. These groups however require different survey methods.

Because previous work on breeding salt marsh sparrows had begun in New England in 1998, the same protocol used then, developed by James Gibbs and Greg Shriver, SUNY-Syracuse, should continue at the northern refuges, Parker River and Rachel Carson NWRs. It is probably necessary to add points specifically in the OMWM study areas at these northern refuges, although usually only one point could fit into each treatment area (points have a 100m radius, and adjacent points must be 300 m apart, according to the Shriver protocol). At ALL refuges, starting in 2002 or 2003, the marsh sparrow surveys will be combined with those for the other bird groups. The surveys will be conducted both in the breeding and non-breeding seasons. Although the same fixed walking route (see details below) can be used as with the Group 2 and 3 species, the bird survey method varies somewhat.

<u>Methods: Group 1 Species:</u>

- A *trained* observer should conduct the survey (see Training section below). If possible, having a second person as a recorder is desirable.
- The observer should maintain a slow pace following a flagged walking route, recording all *passerine bird species* (sparrows, wrens) seen (flushed or perched) or heard within a 25 m distance from the survey line.
- Detections that are visual (V) or auditory (A) should be recorded on the form. Auditory detections will be the most critical for a few of the marsh passerines as well as the rails and bitterns.
- For birds that flush, try to mentally record their new location to avoid double-counting individuals. This method will certainly underestimate Sharp-tailed Sparrows which are not vocal (except during periods after spring tides) and are non-territorial, however it should be more effective for Seaside and Swamp sparrows.
- Because the surveys will be conducted with the larger Group 2-3 species and will focus on low-tide periods, time of day will vary from morning to afternoon. (Again, this is not optimal for passerine surveys, but Seaside and Swamp sparrows are very vocal species in the breeding season).

- The order of visitation of the treatment and control areas should be varied each survey, so that no systematic time bias results; *e.g.*, avoid going to only controls early, treatments late in the day.

Methods Groups 2 and 3 Species:

- A four-season survey design is desired.
- At least 5 replicates for each season should be performed: Spring/breeding (May 10 – June 30), late Summer (July 20 – September 10), late fall (October 15 – December 10) and Winter (January 10 – March 10).
- For these groups, detailed maps of the study area (2 + ha plot) should be used to set up the survey route and discrete habitats (creek segment, panne, pond, OMWM ditch) should be marked.
- Later, data analyses will require converting bird estimates to densities using both water (or basin) area and total plot area.
- Surveys should be timed to coincide with falling (>3hrs past high tide) or low tide (2hr before to 2hr after low), during daylight hours between 1hr after sunrise to 1 h before sunset.
- A fixed point should be established along one side of the area, preferably elevated (blind or scaffolding), that will allow the observer to use a spotting scope (15-20 X) and scan the entire area.
- All birds seen or heard are recorded, including those flying over the area *that are feeding in the area, not simply transiting over* (includes northern harriers, tree swallows, peregrine falcon, *etc*.).
- Birds should be assigned to one of the habitats listed on the form.
    - Water bodies without daily tidal influence are considered "nontidal," therefore plugged ditches would be nontidal.
    - Unplugged ditches would be tidal.
    - For the aerial feeders, the habitat should be "Air".
- It is easiest to cover different sectors of the plot in sequence (*e.g.*, N to S) recording all species by habitat use.
- We recommend using tick marks in the field form block as sectors accumulate, then in each block, at the end of the survey (10min minimum to 15min maximum) total the ticks and circle the number (see field sheet example).
- The notation of "FP" should be used in the left-hand column for all birds detected (A or V) from the fixed point observation.
- At the end of the 15min, draw a line across the form under the line for the last species entered. This will prevent confusion between entries for the FP and the walking route parts of the survey.
- A walking route (WR) transect marked with wire flagging (different colors than those used for marking nekton stations and vegetation plots) should be followed to survey each water body, panne, ditch, or creek as potential habitat.
- At regular intervals along the WR, GPS locations should be recorded in case flags disappear.

- Water levels in ditches and ponds should be crudely estimated and averaged for the entire plot area, not each water body (scores of 1-4, where 1=<25% basin full, 2=25-50% *etc*.); this will allow more refined analyses of bird densities.
- The observer should maintain a slow, steady pace, but should stop at larger water bodies to record, or at long tidal ditches to inspect for rails, and cryptic birds with binoculars.
- The observer should record the number of individuals of each species within a given habitat, with careful attention noted of species movements; *i.e*., avoid double counting birds that flush ahead and land in the next location visited.
- As before, we recommend using tick marks in each habitat block as one walks along, then totaling and circling the number in each habitat block after the transect is completed.
- Because the surveys are conducted around low tides, most birds are expected to be using ditches, creek banks, or pools/pannes.
- Also recorded should be those species that feed aerially (Habitat = Air), such as harriers, terns, falcons. (NOTE: We no longer recommend recording behavior during the surveys).
- The data should be recorded on field forms (Table 7) and if possible entered the same day in electronic format.
- A second individual should cross check the field forms and electronic database. The data should be maintained in a Microsoft Access database format that is being developed by PWRC personnel in consultation with other personnel involved with the OMWM project.

<u>Training</u>

- Observers need to be able to identify all species of waterbirds and marsh birds by sight and sound. If necessary, they may need to listen to tape recordings of certain species (rails, sparrows) or may require field reinforcement with an expert. Tapes can be provided by the USGS Patuxent Wildlife Research Center if necessary.
- Ideally, at the beginning of each refuge study, a local expert should be used to conduct a series of 20-30 point counts (radius 25m) at marsh pannes, tidal creeks, impoundments, and emergent marsh plots. Accompanying the expert should be the refuge biologist and field technicians expected to conduct the bird surveys.
- They should record on field forms all the birds seen or heard during 10min point counts, keeping records independently and not talking during the sessions.
- After the sessions, a tally of total species and numbers should be compared among the observers.
- A "qualified" field observer must have identified > 90% of the total species correctly, and > 80% of the total numbers of individuals compared to the "expert."
- If not, that individual should receive more training and be retested, or not used.
- We prefer this method to the much more time-consuming alternative of the double-observer method where two observers are required on every survey and where a rigorous data collection protocol is required using primary and secondary observers.

- We *strongly* encourage that data collection for birds be conducted by the *same observer at all the sites* and that the same individuals be used between years to reduce observer variability, a major source of variation.
- Observers should be reinforced using markers at 10, 20, 25, …up to 50m distances so that they may accurately determine bird detections within 25m of the transect.
- Stakes should be set out at these fixed intervals in one field site.
- During training, objects can be placed at varying distances for observers to estimate. After estimating each distance, they are then told the actual distance, and the two distances recorded for side by side comparison.
- If the observer can consistently (> 90% of occurrences) estimate within 5 m of the 20-30 distances, he/she should be considered qualified.

Instructions for Filling Out Bird Survey Field Data Sheet

These instructions are to be used for the OMWM waterbird data surveys. For continuation of the special marsh sparrow surveys at Rachel Carson and Parker River, Greg Shriver has provided the protocol for those, begun in 1999, and data for New England is being compiled by Greg Shriver.

OMWM WATERBIRD DATA: We have set up the field data forms in a manner that will be most efficient when entering into Microsoft Access. We plan on creating a data entry form in Access that will look very much like your field datasheets. Many of the fields on the Access data entry form will contain bound dropdown lists (for example, when you enter your bird species codes, there will be a set list that you must choose from) and automated calculations (total survey minutes will be calculated; bird totals will be summed across the habitat types and compared with your bird totals as a data check). Migration from the field datasheets to electronic form (Access) will be done at each refuge, and then forwarded to Mike Erwin's group.

TOP SECTION OF OMWM DATA FORM – Survey Description

- Refuge Name and Site Code: This is a combination of Refuge Code and Site Code. For example, Prime Hook Petersfield Treatment would be PHPT. Refer to Table 8 in the section entitled "Data Headers for Spreadsheets" for site codes.
- Date: two digit month and day, four digit year (e.g. 05/24/2001)
- Observer: Use 3 initials.
- Time: First conduct a Fixed Point (FP) survey at each unit where one vantage point can cover the entire unit (elevated if possible). We decided to allow a 10-15 min window depending on numbers of birds and location. Do not exceed 15min. Time of day is not being standardized, but tide is. Use military time (*i.e.,* 1:00 pm = 1300h). For walking surveys, try to stay within about 30 minutes. This will vary among survey units, but keep a slow, steady pace. The emphasis is on WATERBIRDS using ditches and waterbodies; other birds using marsh grasses

are to be recorded within 25m of the transect. Total survey times will be calculated by Access, based on the times that you enter in these fields.

- Time of Low Tide: Record the predicted time of low tide. Of course, factors may differ for each survey, depending on local conditions (wind, *etc*.). It is beneficial to note water levels on the main data form (Water Level column, second from the right edge of the form) at each waterbody surveyed (see Water Level below).
- Temperature: in degree F.
- Wind speed: Check with nearest weather station, USCG, or military airport if possible. Windspeed codes are listed on the datasheet: L(<5mph), M(6-12mph), S(>12mph).

MAIN SECTION OF OMWM DATA SHEET – Bird Data

- Survey type: Use abbreviations FP for Fixed Point and WR for Walking Route. When transitioning from conducting the Fixed Point to the Walking Route, draw a line sectioning off all FP data, and below the line write WR to start the WR section of data.
- Species: On your field datasheets, you may record the bird species in whatever way is best for you, although we recommend using the ABA 4-letter codes. When the data is entered in Access, a drop down list containing 4 letter codes and the species common name will be provided in this field so that all refuges will be using the same 4-letter codes. Abbreviation conventions are as follows: For common names with one word, take the first 4 letters, example: Dunlin = DUNL; common names with 2 words, take the first 2 letters from each word, example: Greater Yellowlegs = GRYE; For multiple species confusion, use the following conventions: For small unidentified sandpipers (the Least, Semipalmated, Western complex), use "PEEP"; for small terns (Forster's or Common), use TERN, for unidentified dowitchers, use DOWI; for Greater or Lesser Yellowlegs, use YELL; for unidentified sparrow, use SPAR; for unidentified (usually immature) gulls, use GULL.
- Total Number of Birds: Tally this up at the end of the session. We suggest using tick marks in pencil as you count birds by species in each habitat type. After the survey is complete, add up the ticks in each cell, write the total in the cell, and circle it. The sum of all cells in a row is what you should write in the Total Number of Birds Column. We will use this column as a data check (it will be compared with a sum that Access calculates for each row).
- Habitat types: Self explanatory. To avoid double counting of individuals, record individuals in the first habitat that they were seen in ONLY (if a dunlin moves from a tidal pond to a ditch, record it in the tidal pond only). For analysis, we will create GIS layers and each habitat type will be measured for area. When analyses are underway, we will convert total numbers of birds by habitat type into density values. **For birds seen in the air, only list species that are aerially feeding or hunting, not those obviously flying over. For example, you may list a northern harrier that is hovering**.

- A or V: Record whether a bird was observed audially or visually. You don't need to do this for the waterbirds, but please be sure to distinguish for the sparrows and secretive species such as rails and bitterns.
- Water Level: Note water levels in each waterbody (ditch, tidal pool, panne, *etc*.) using the codes provided on the sheet (1=25% full, 2=25-50%, *etc*.).
- Notes: Record any anomalies such as disturbances, use of heavy equipment, *etc*. Because the cell is pretty small, you might have to write over a couple of cells; be sure to demarcate which record the note refers to.

PAGE 2 - MAIN SECTION OF OMWM DATA SHEET – Bird Data
Use this if you fill up the first sheet. Be sure to fill in the page number and the total number of pages for that survey in the top right corner (*e.g.*, page 2 of 2).

Table 7. Sample bird survey field data sheets. The second data sheet is to be used if the first sheet is filled.

## OMWM WATERBIRD DATA FORM

page____of _____

Refuge Name and Site Code ____________________________ Time of Low Tide __________________________

Date (mo/da/yr ) ____________________________________ Temperature (F) __________________________

Observer Initials ____________________________________ Wind Speed ___________L(<5mph), M(6-12mph), S(>12mph)

Time(military) **Fixed Point:** Start___________End________________ **Walking Route:** Start_____________ End __________________

| Survey Type Fixed Point (FP) or Walking Route (WR) | SPECIES (4 letters) | Total # Birds | HABITAT TYPE | | | | | | | | | | | A or V (Audial or Visual Detection) | Water Level 1=<25% 2=25-50% 3=50-75% 4=75-100% | Notes (Disturbance, etc.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Tidal pool | Non Tidal Pool-panne | Creek (natural) | Ditch (Open) | Ditch (Plugged) | Low Marsh (S.altern.) | High Marsh (S.patens) | Phrag-mites | Woody Veg. | Air | Other: | | | |
| | | | *** To avoid double counting of individuals, record numbers within habitat where they were first observed ONLY. | | | | | | | | | | | | | |
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Table 7. continued.

**OMWM WATERBIRD DATA FORM**

Page____of _____

Refuge Name and Site Code ____________________ Date (mo/da/yr ) ____________________________ Temp.(F)___________

| | | | HABITAT TYPE | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Survey Type<br>Fixed Point (FP) or Walking Route (WR) | SPECIES (4 letters) | Total # Birds | Tidal pool | Non Tidal Pool-panne | Creek (natural) | Ditch (Open) | Ditch (Plugged) | Low Marsh (S.altern.) | High Marsh (S.patens) | Phrag-mites | Woody Veg. | Air | Other: | A or V (Audial or Visual Detection) | Water Level 1=<25% 2=25-50% 3=50-75% 4=75-100% | Notes (Disturbance, etc.) |
| | | | *** To avoid double counting of individuals, record numbers within habitat where they were first observed ONLY. | | | | | | | | | | | | | |
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## OTHER ENVIRONMENTAL VARIABLES MONITORED DURING NEKTON SAMPLING

Once nekton is removed from a trap or ditch net sample, environmental variables can be measured. Measures of water temperature, salinity, water depth, and plant cover are essential environmental data to collect in conjunction with each throw trap and ditch net sample. Some investigators may elect to also collect other variables. Sediment composition (*e.g.* grain sizes and organic content) can be measured by extracting sediment cores and then processing according to Dean (1974). This information helps describe the habitat available to the nekton. Other variables such as creek width, creek order (*e.g.*, 1$^{st}$ order, 2$^{nd}$ order), pond size, adjacent shoreline type, distance of seagrass bed to shoreline, are easy measures and can enhance interpretation of the nekton data.

The following water quality measurements should be taken from an area of the pond or ditch that has not been disturbed (*e.g.* sediment re-suspension) from the throw trap or ditch net activity.

- Water temperature, to the nearest degree C, is measured using a stick thermometer or temperature probe.
- Salinity is measured, to the nearest part per thousand, using either a refractometer or water quality probe.
- Dissolved oxygen is measured using a dissolved oxygen probe.
- Water depth within the trap is measured to the nearest cm using a meter stick. Alternatively, the sides of the trap can be marked off in centimeters and readings taken directly from the trap. The trap is often located on an uneven bottom, and thus, depth should be measured near each corner of the trap to obtain a mean depth value. Water depth is a simple measure and is useful for documenting changes in water depth over time. When monitoring restoration sites, where hydrology has been altered, this is a particularly important measure.
- Water depth in the ditch is measured after the net is removed from the ditch. The depth of the ditch is also measured.
- If macroalgae, marsh grass, or eelgrass are present within the trap, cover and species composition should be quantified. **Prior to dip netting for nekton**, the percent cover of each plant species should be visually estimated according to the following cover class categories (<1% cover, 1-5%, 5-25%, 25-50%, 50-75%, >75%). These data provide a measure of the complexity of habitat available to the estuarine nekton. If sampling in regions with turbid waters and the vegetation can not be seen, then vegetation should be quantified by a biomass technique after Raposa and Oviatt (2000).

## DATA MANAGEMENT AND QUALITY ASSURANCE AND QUALITY CONTROL

Field data should be recorded in waterproof notebooks or on datasheets that are previously developed and printed on waterproof paper. Datasheets can be organized to the preference of individual researchers, but should include all information described previously in these protocols (*e.g.,* study site, date, station identification, habitat, species name, total number of individuals captured by species, lengths, comments, and environmental parameters). Examples of sample datasheets are provided after each protocol.

- Be sure to write legibly on the datasheet.
- Make sure that all sections of the data sheet are filled out before moving on to the next sampling station.
- If a variable cannot or was not measured (*e.g.* instrument failure, fish escaped) explain on the data sheet for that station the reason for missing data. Record the reason/explanation in the field. Do not wait until you return to the office to record the reason or explanation.
- All field data should be transferred to digital format soon after sampling. Field data are easily incorporated into common spreadsheet programs that are designed for comprehensive data management.
- After the data are entered it is important to carefully check the data for typos and mis-entries to insure the data are correct and to maintain quality assurance and quality control of the data.

## DATA HEADERS FOR SPREADSHEETS

The following are the suggested column headers for entering data into computer spreadsheets. Column headers should be limited to 8 characters in length. Refuge and site codes given in Table 8 should be used for all data types. The usual naming convention for species (except for birds, see section entitled "Instructions for Filling Out Bird Survey Field Data Sheet") is to use the first 3 letters of the species, an underscore for the 4$^{th}$ character, and the first 4 letters of the genus. A separate key to all species codes should be kept (preferably in another spread sheet page) with the electronic data.

Table 8. Site codes for Refuges and study areas. Note: Some codes are not yet available (n/a).

| Refuge | Refuge/Site Code | Site Name |
|---|---|---|
| Rachel Carson | n/a | n/a |
| Parker River | PR_A | Parker River Area A (plugged) |
| | PR_B1 | Parker River Area B1 |
| | PR_B2 | Parker River Area B2 |
| | PR_C | Parker River Area C |
| S.B. McKinney | n/a | n/a |
| Long Island Complex | LI_FT1 | Long Island, Flanders Site 1, Treatment |
| | LI_FT2 | Long Island, Flanders Site 3, Treatment |
| | LI_FC | Long Island, Flanders Site 2, Control |
| | LI_WTE | Long Island, Wertheim East, Treatment |
| | LI_WTW | Long Island, Wertheim West, Treatment |
| | LI_WC | Long Island, Smith Point, Wertheim Control |
| E.B. Forsythe | F_OC | Forsythe, Oyster Creek Control |
| | F_OT | Forsythe, Oyster Creek Treatment |
| | F_ATTC | Forsythe, AT&T Control |
| | F_ATTT | Forsythe, AT&T Treatment |
| Cape May | n/a | n/a |
| Prime Hook | PH_PC | Prime Hook, Petersfield Control |
| | PH_PT | Prime Hook, Petersfield Treatment |
| | PH_SC | Prime Hook, Slaughter Control |
| | PH_ST | Prime Hook, Slaughter Treatment |

Vegetation Data Headers

All vegetation data for a refuge should be entered into a single spread sheet (*i.e*., do not use separate spreadsheets for each study area). The first and second columns identify the study area and the vegetation plot. The remaining columns are for the vegetation cover types that were observed at all study locations. It is helpful to first make a master list of all vegetation cover types that were observed within the Refuge study areas. Be sure to make a list of all vegetation cover type codes used and what they represent, so that others can interpret the codes. In each cell under the appropriate cover type for that plot, the total tally of "hits" would be entered. Table 9 shows an example of vegetation data entered for study sites at Prime Hook NWR for Slaughter Control (PH_SC) plot 2-40 and Petersfield Treatment (PH_PT), plot 1-100. At Slaughter Control, plot 2-40, *S. alterniflora* (Spa_alte) had 14 hits, *S. patens* (Spa_pate) had 45 hits, and bare ground had 3 hits, while at Petersfield Treatment, plot 1-100 had 50 hits of *Phragmites australis* (Phr_aust) and 15 hits on bare ground. Note that since all vegetation data for a refuge are entered into one spreadsheet, entries of "0" are entered if that species was not present at a particular plot. Only four species are shown in this example, however there will be more species for any particular Refuge.

Table 9. Example of vegetation data entry.

| **Study Site** | **Plot ID** | **Spa_alte** | **Phr_aust** | **Spa_pate** | **Bare** |
|---|---|---|---|---|---|
| PH_SC | 2-40 | 14 | 0 | 45 | 3 |
| PH_PT | 1-100 | 0 | 50 | 0 | 15 |

Water Table Level and Soil Salinity Data Headers

Headers for data entry are shown in Table 10. Calculations can be done by hand and entered on the spreadsheet or can be entered as additional columns and the spreadsheet program can perform the calculation. For example, water table level is calculated as the top of the well measurement (A) minus the top of the well to the marsh surface (B). In the example below only the finished calculation is shown. Note that at Flanders treatment 1 (LI_FT1), stations 1-00 and 1-30, the water table depth was negative since the water table was below the surface, but at Wertheim control (LI_WC), station 1-60, there was water on the surface of the marsh and therefore the water table level was positive number. Missing data are entered as a "." as at LI_WC, station 1-90.

Table 10. Example of water table level and soil salinity data entry.

| **Date** | **Site** | **Station #** | **Water Table Depth (cm)** | **Soil Salinity (ppt)** | **Depth of Soil Salinity (cm)** |
|---|---|---|---|---|---|
| 7/5/2001 | LI_FT1 | 1-00 | -2.8 | 25 | 15 |
| 7/5/2001 | LI_FT1 | 1-30 | -14.9 | 26 | 45 |
| 7/5/2001 | LI_WC | 1-60 | 3.7 | 20 | 15 |
| 7/5/2001 | LI_WC | 1-90 | . | . | . |

Mosquito Larvae Data Headers

Mosquito data headers are shown in Table 11. If the station is dry, then a missing value represented by "." should be entered as the number of larvae observed. If water was present at the station, but no larvae were in the dipper, then "0" is entered for the number of larvae observed. For example, at Forsyth NWR's Oyster Creek control site (F_OC), station 4-120, the station was dry and since there was no water present the number of larvae is entered as ".". At the AT&T control site (station 1-40) water was present, but no larvae were in the dipper, so a "0" is entered. Missing values are entered for dry stations so as not to bias the counts by including habitats that are not appropriate for larval mosquitoes. If larvae were present, then enter "yes" or "no" in the appropriate species column indicating what species were found. This information will be entered after the larval samples have been identified. Be sure to keep information on species identification with the appropriate Mosquito Larvae Sampling Data Sheet. Only two mosquito species are shown for example purposes, it may be necessary to add more species columns. Note that codes for the amount of water volume in the dipper are entered instead of the actual volume.

Nekton Data Headers

Nekton data from both collection methods (throw trap and ditch net) are entered on the same spread sheet. Nekton data require two different spreadsheets since one data type deal with station information and the other with individual nekton (length) information. Table 12 illustrates the header information for example data from Parker River NWR. Note that the station ID also identifies the type of gear. For example, P1 stands for Pond 1 which is sampled with a throw trap, whereas D2 is a ditch net station which is sampled with a ditch net. Environmental variables such as water depth, creek depth, tide phase, water temperature, salinity, and DO are also entered. For throw trap samples, a missing value represented by "." is entered for the creek depth since only the water depth of the pond is measured. Habitat type for ditch nets should be entered as TC (tidal creek), OD (open ditch) or PD (plugged ditch). Habitat type for throw traps is always "pond". The area of the ditch net is from the measurements of the net (refer to section "Calculating the Area of a Ditch Net"). The area of throw trap samples is always $1m^2$. The remaining columns are for the nekton species that were observed at all study locations. The total count of individuals for that station is entered under each appropriate species. Note that species names are coded into an 8 letter code. Be sure to include a key to the codes with the database. If a nekton species was not present, represent that by a "." not "0" as this will influence the final density calculation. Density is calculated as the sum total number of individuals per trap or ditch net divided by the area of the trap or net.

The individual nekton (fish and decapods) data are entered in another spreadsheet. Headers for individual nekton data are shown in Table 13. In this database there is one "species" column and the species coded name is entered and the corresponding length of that fish is entered in the corresponding cell under "length". Carapace width (for crabs) and total length (for shrimps) are also entered under the length. Note that *Fundulus heteroclitus* adults (Fun_hetA) and juveniles (Fun_hetJ) are given separate species codes. Be sure to include a key to the codes with the database.

Bird Survey Data Headers

An Access Database with drop down menus has been designed for bird survey data entry by Diann Prosser, USGS, Patuxent Wildlife Research Center. All refuges will receive a copy of this database for bird survey data entry.

Table 11. Example of mosquito data entry. Note that the Och_soli and Och_cant stand for *Ochlerotatus sollicitans* and *O. cantator* which were formally *Aedes sollicitans* and *A. cantator*.

| Date | Site | Station # | Total # of larvae | Dipper volume | Area dipped | Larvae ID'ed? | Och_soli | Och_cant |
|---|---|---|---|---|---|---|---|---|
| 7/02/02 | F_OC | 4-120 | . | . | dry | no | . | . |
| 7/05/02 | F_OT | 3-40 | 72 | 3 | panne | yes | yes | no |
| 7/06/02 | F_ATTC | 1-40 | 0 | 2 | pool | no | . | . |

Table 12. Example of nekton data entry.

| Date | Site | station | Water depth (cm) | Creek depth (cm) | tide | habitat | Area (m^2) | Water Temp | Salinity (ppt) | DO (mg/L) | Fun_hete | Cyp_vari | Men_bery |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6/1/01 | PR_B1 | P1 | 50 | . | ebb | pond | 1 | 26.9 | 29.8 | 7.36 | 1 | . | . |
| 8/15/01 | PR_A | D2 | 46 | 48 | ebb | OD | 0.409954 | 25.8 | 27.8 | 5.10 | . | . | . |

Table 13. Example of individual nekton data entry.

| Date | Location | Station | Species | Length (mm) |
|---|---|---|---|---|
| 9/28/01 | PR_C | P6 | Fun_hetA | 50 |
| 9/28/01 | PR_C | P6 | Fun_hetA | 50 |
| 9/28/01 | PR_C | P6 | Fun_hetJ | 45 |
| 9/28/01 | PR_C | D3 | Fun_hetA | 79 |
| 9/28/01 | PR_C | D3 | Fun_hetA | 76 |
| 7/12/01 | PR_B2 | D5 | Car_maen | 15 |
| 7/12/01 | PR_B2 | D5 | Pun_pung | 40 |

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# Appendix C

SMI Avian Point-Count/Callback Survey Protocol (revised 2012)

## SMI Avian Point-Count/Callback Survey Protocol
## (revised November 2012)

## Summary of the Standardized North American Marsh Bird Monitoring Protocols

### Modified From Courtney Conway Wildlife Research Report #2007-04

**Objectives:**

1. Determine distribution of marsh birds within an area.
2. Estimate / compare density of marsh birds among management units, wetlands, or regions.
3. Estimate population trend for marsh birds at local or regional scale.
4. Evaluate incidental effects of management actions on marsh birds.
5. Document habitat types / conditions that may influence marsh bird abundance or occupancy.

**Survey Overview:**

Each survey consists of a 5-minute passive period point count and a broadcast sequence where all birds seen and/or heard using habitat are recorded. The passive period is followed by a broadcasting of a series of secretive marsh birds calls, in which a 30-second call is broadcast into the marsh, followed by a 30-second window of silence. This broadcast process is repeated for each secretive marsh bird species included on the broadcast sequence. Broadcast sequences vary from area to area.

**Required Equipment:**

Binoculars, data sheet, mp3 player and speaker, clip board, GPS, compass, pencil, & extra batteries

**General Survey Guidelines**

- One survey (consisting of both a passive period and series of broadcast calls) should be conducted within each survey period:
    - May 1 – May 31 (exceptions: Virginia portion of Regions 7, 8, and 9 start April 15, Region 1 starts May 15 and ends June 15)
    - June 1 – June 25 (exceptions: Region 1 – June 16 – July 5)
    - June 26 – July 15 (exceptions: Region 1 – July 6 – July 31)

- Surveys should be conducted in the morning, starting 30 minutes before sunrise and ending between 10 and 11 am.

- Once a survey has begun, the observer should remain next to the mp3 player and speakers until the survey has ended. Observers should change the direction in which they are facing several times during both the passive and broadcast periods to ensure detection of the maximum possible number of birds.

- Observers should stand 2 meters to one side of the speakers to avoid detection interference. Speakers should face the same direction, be positioned ***toward the center of the marsh***, and should not be moved during the survey. Please note the direction of the speakers so that future observers can remain consistent.

- Surveys should be conducted when wind speed is <20 km/hr (12 mph) and not during sustained rain or heavy fog.

- Cell phones and other devices with an audible notification should be turned to "off" or "vibrate" during the survey period.

- Conduct surveys in the same chronology when possible. **There should be a minimum of ten days between surveys at each point.**

# The Survey

**When you arrive at a point:**

1. **Record basic survey information:**

   1) Record the date in the format of the example provided; circle the appropriate state, region, visit number, and survey window; and record the hexagon and point id.

   2) For main observer, record the person who surveyed the birds. Additional observers are those who recorded the data, but did not survey the birds.

2. **Record survey conditions:**

   1) Circle the tide and stage of tide using the following guidelines:

   High - within 1 hr of high tide
   High/Falling - >1 hr after high tide, but less than half of the tidal cycle from high tide
   Low/Falling - >1 hr before low tide, but less than half of the tidal cycle from low tide
   Low - within 1 hr of low tide
   Low/Rising - >1 hr after low tide, but less than half of the tidal cycle from low tide
   High/Rising - >1 hr before high tide, but less than half of the tidal cycle from high tide

   2) Record how the survey was conducted. It is important to record type of boat used for a survey because it may affect vocalization probability. Use the following guidelines:

   Foot – survey conducted while standing on the ground
   Boat – survey conducted while standing in a motorized boat, engine off
   Kayak – survey conducted while standing in a kayak/canoe
   Boat/foot – survey conducted while standing on the ground, but motorized boat is <100m away
   Kayak/foot – survey conducted while standing on the ground, but kayak/canoe is <100m away
   Vehicle – survey conducted while standing immediately next to a vehicle, on the road

   3) Record ambient temperature using a thermometer, background noise (see codes), wind speed (see Beaufort numbers), wind direction, and sky condition (see U.S. Weather Bureau codes). Record these in the first row of the data sheet – these measurements do NOT need to be repeated for each bird detected.

   **Background Noise Codes**

   0 – no noise
   1 – faint noise
   2 – moderate noise (probably can not hear birds beyond 100m)
   3 – loud noise (probably can not hear birds beyond 50m)

4 – intense noise (probably can not hear birds beyond 25m)

**Wind Speed Codes (use Beaufort Number on Data Sheet)**

| Beaufort Number | Wind speed indicators | Wind Speed mph / kmph |
|---|---|---|
| 0 | Smoke rises vertically | < 1 / < 2 |
| 1 | Wind direction shown by smoke drift | 1-3 / 2-5 |
| 2 | Wind felt on face; leaves rustle | 4-7 / 6-12 |
| 3 | Leaves, small twigs in constant motion; light flag extended | 8-12 / 13-19 |
| 4 | Raises dust and loose paper; small branches are moved | 13-18 / 20-29 |
| 5 | Small trees in leaf sway; crested waves lets on inland waters | 19-24 / 30-38 |

**Sky Condition Codes – U.S. Weather Bureau Codes**

0 – Clear or a few clouds
1 – Partly cloudy (scattered) or variable sky
2 – Cloudy (broken) or overcast
4 – Fog or smoke
5 – Drizzle
7 – Snow
8 – Showers

**3. Begin bird survey:**

1) Turn on speakers.

2) Press play on the mp3 player, making sure to check the mp3 file is playing from the beginning. Record Start Time as the time you pressed the start button of the mp3 player. The mp3 file includes a 5-minute passive period followed by a series of primary species broadcast calls, with 30 seconds of broadcasted vocalizations followed by 30 seconds of silence for each species. Each minute in the passive period is marked with a “Minute 1”, “Minute 2”, etc., vocal cue from a woman’s voice on the mp3 file. This eliminates the need to look at a watch during the survey. There are corresponding columns on the data sheet for each time interval in the passive period as well as each broadcast call.

3) For the duration of the mp3 file, **record any bird that you see and/or hear using the marsh and the immediate terrestrial edge habitat, as well as the number of individuals of each species.** This includes any bird actively foraging from the air, observed on vegetation or on the ground, or birds swooping at you. Do NOT record

fly-overs of birds not using the habitat. This sometimes boils down to a judgment call on behalf of the observer.

Bird detections are recorded on the data sheet differently for Primary Species and Secondary Species. A list of both sets of species can be found at the end of this protocol. This species division is NOT the same as SHARP focal/non-focal species, so be sure to understand the difference! Follow the following protocol for each type of species:

a. **Primary Species** – Each time a Primary Species individual is detected, record the 4-letter code for that species in a new line on the data sheet. Mark an "X" in the appropriate distance band. Mark an X in the column for each time interval in which the individual is detected.

   When a Primary Species is detected, additional information is collected about the first detection of each individual. The columns for these data are located at the far right side of the data sheet. In the *Call Type* column record the type of call heard. A description of these calls can be found at:

   http://www.cals.arizona.edu/research/azfwru/NationalMarshBird/

   Finally, estimate the exact distance in meters between you and the detected bird and record this in the *Distance* column.

   **Example:** If a Virginia Rail was heard 75 meters away doing the *kicker* call during the BLRA call sequence, the observer would record VIRA in the *Species* column, an "X" in the 50-100 column, an "X" in the *BLRA* column, "kicker" in the *Call Type* column, and "75" in the *Distance* column. If the same individual VIRA calls during the CLRA vocalization and then flew, then record an "X" in the *CLRA* column on the same line. If the bird called constantly throughout the survey, all columns would have an "X". If an unknown species is detected, write unknown in the *Species* column and take notes regarding the vocalization. If too many individuals of a species are calling at once, estimate the number and note the number is an estimate in the *Comments* column. Record any ancillary information that may have influenced bird detection in the *Comments* column.

b. **Secondary Species** – Each time a Secondary Species is detected, record the 4-letter code in the *Species* column, along with how many birds of that species were present. Mark an "X" in the appropriate distance band column. Each species should be listed on a separate line on the data sheet. Within each species, individuals detected in different distance bands are recorded on different rows.

**Example:** If a Seaside Sparrow was seen/heard 70 meters away during minute 2, record SESP in the *Species* column, an “X” in the *50 – 100* column, and a tic mark or a dot in the *Min 2* column. If additional Seaside Sparrow individuals are detected within 50 – 100m, record the number of individuals on the same row in the appropriate *Responded During* column(s). If a Seaside Sparrow is detected 0 – 50m or 100+m away, record the data in a new row. *Only record the first time a Secondary Species is detected. This is different from how Primary Species detections are recorded.* The *Call Type*, *Direction*, and *Distance* (meters) columns are not used for Secondary Species detections.

**Primary Species and 4-letter AOU codes**

Each individual of the following species gets recorded on a separate line on the data sheet

SORA - Sora
VIRA - Virginia rail
CLRA - Clapper rail
KIRA - King rail
BLRA - Black rail
YERA - Yellow rail
AMCO - American coot
COMO - Common moorhen (Common gallinule)
PUGA - Purple gallinule
LIMP - Limpkin
PBGR - Pied-billed grebe
AMBI - American bittern
LEBI - Least bittern

**Selected Secondary Species**

All species observed utilizing tidal marsh or the immediate terrestrial border of the marsh *that are not on the primary species list* are considered secondary species.

SHARP Point-Count/Callback Survey Data Sheet

Page___of___

**Date** *(e.g. 10-May-12)* **:**__________________ **Region (circle one):** 2 Cape Cod - Casco Bay **Hexagon/Unit:** ________________________

**Main Observer:** ______________________ **Add'l Observer(s):** _________________________ **Survey Point ID(s):** ____________________

**Tide (circle one):** (High) (High/Rising) (High/Falling) **State (circle one):** ME NH MA **Survey method (if by boat, include type):**____________________________________

(Low) (Low/Rising) (Low/Falling) **Visit Number (circle one) :** 1 2 3 **Survey Window (circle one)** : 1 (May 1 - May 31) 2 (June 1 - June 25) 3 (June 26 - July 15)

| | | | | | | | Distance Band | | | Responded During | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point ID | Start Time (military) | Temp (F) | Sky | Wind (Beaufort) | Background noise | Species Code | 0 - 50m | 51 - 100m | >100m | Min 1 | Min 2 | Min 3 | Min 4 | Min 5 | Min 6 (BLRA) | Min 7 (LEBI) | Min 8 (SORA) | Min 9 (VIRA) | Min 10 (CLRA) | Outside survey period | Call Type(s) | Distance (meters) | Comments |
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**Sky:** 0 clear or a few clouds, 1 partly cloud or variable sky, 2 cloudy or overcast, 4 fog or smoke, 5 drizzle, 7 snow, 8 showers

**Wind - Beaufort scale:** 0 smoke rises vertically, 1 wind direction shown by smoke drift, 2 wind felt on face; leaves rustle 3 leaves, small twigs in constant motion; light flag extended, 4 raises dust and loose paper; small branches are m
5 small trees with leaves sway; crested wavelets on inland waters

**Background noise:** 0 no noise, 1 faint noise, 2 moderate noise (probably can't hear some birds beyond 100m), 3 loud noise (probably can't hear some birds beyond 50m), 4 intense noise (probably can't hear some birds beyond 25m)

# Appendix D

Ecotone Monitoring Protocol

Raposa and Mitchell (2022)

Updated July 2021

**Field protocol for elevation surveys using the line-levelling BF method with the Sprinter**

Basics: This is the field protocol to follow when monitoring creekbank erosion and upland ecotone migration rates. At each transect that has been established, there will be PVC pipes near the water for creekbank measures and a second set of pipes near the upland border for measuring marsh and ecotone migration into the upland. The method is a simple belt transect. At each location, the end of a measuring tape is attached to the rear pipe, with the adjacent front pipe used as a bearing guide when running out the tape. Then, a suite of simple indicators is measured along the transect by moving a meter stick perpendicular along the tape, until hitting each indicator.

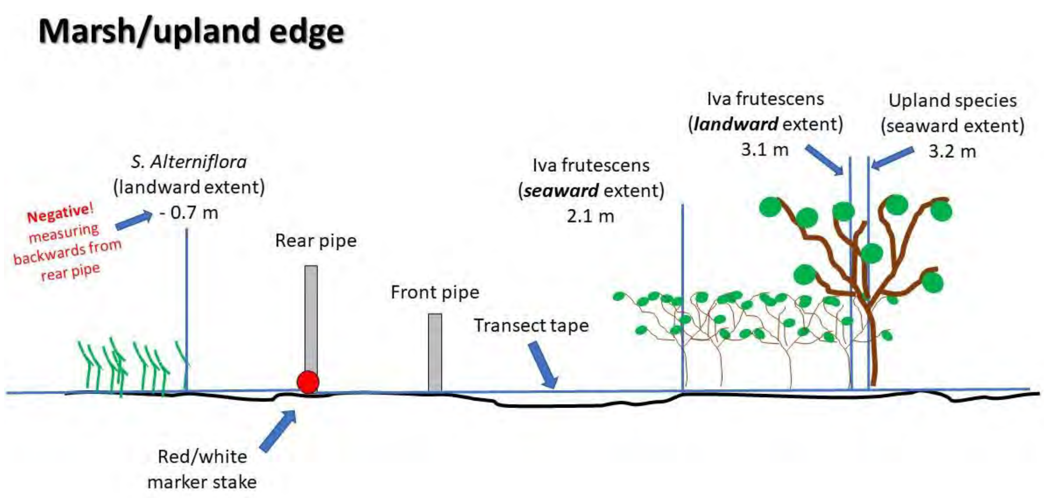
To bring to the field:

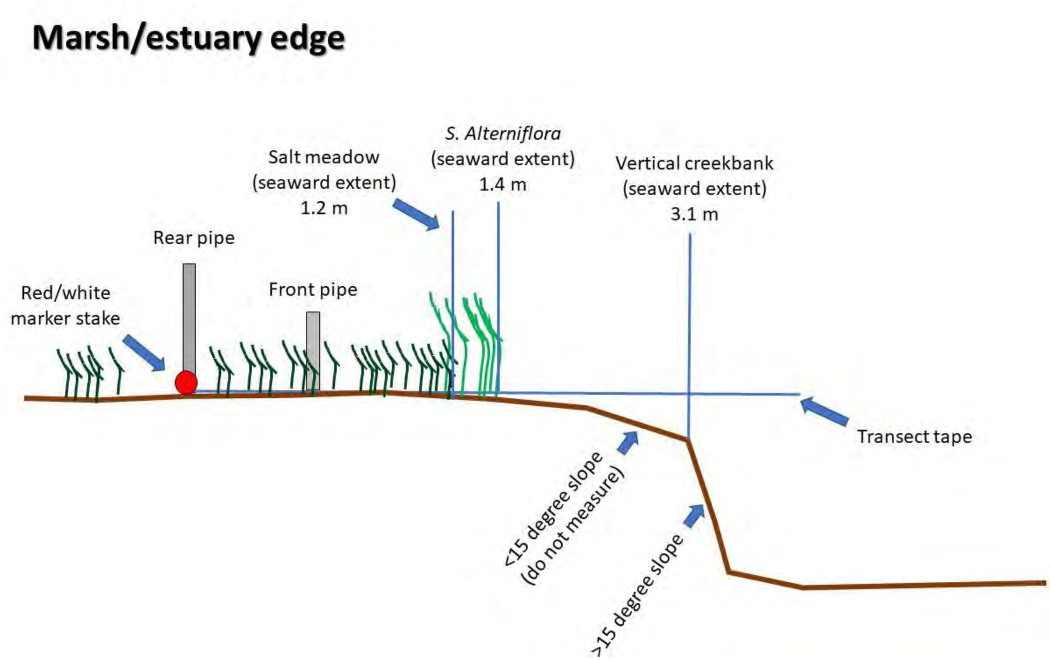
- **100m field transect tape**
- **Meter stick**
- **Red/white stake**
- Hardcopy field **ecotone monitoring protocol**
- Hardcopy or Avenza **map of transect locations**
- Hardcopy of **x/y coordinates of all transects, seaward and landward**
- Hardcopy field **ecotone monitoring datasheet (one per transect)**
- Hardcopy of **data from prior years to use as reference**
- **Clipboard, pencils**

1) Establishing the transect tape:
    a. Upon reaching a transect, start with the seaward portion, then do the upland portion after
    b. Place the end of the transect tape over the tip of the red/white marker stake
    c. Place the marker stake into the marsh, directly adjacent to the rear pipe
        i) The rear pipe is ALWAYS higher than the front stake (**Fig. 1**; at the seaward edge, the rear pipe is closer to the upland; at the upland end, the rear pipe is closer to the water)
    d. Run the transect tape as far as possible (i.e., ideally, until reaching into the upland), using the forward pipe as a guide to ensure you establish the transect in the right direction
2. Moving along the belt transect
    **a.** Return to the start of the transect tape, **being careful to walk around the transect and not through it**
    b. Using the meter stick, move along the transect towards the upland, keeping the meter stick centered on the tape (e.g., 50 cm is on the tape)
    c. Keep moving until you hit one of the indicators for that transect (**Table 1**)
3. Measuring a migration indicator
    a. Once the meter stick encounters the first plant of any of the indicators (within the 1-m wide band), stop and measure the distance along the transect
    b. Record distance on the field sheet
    **c. Note that a 'hit' only counts if it's a stem; leaves/flowers/etc. do NOT count (Fig. 2)**
        i) And only count live plants; ignore dead
    d. Continue along the transect until all indicators for that transect have been recorded
        i) Note that it is probable that all of the possible indicators on the master list will not be present on a given transect

4. Measuring indicators behind the rear stake
   a. For indictors that fall in the opposite direction from the rear stake (i.e., behind the stake, backwards into the marsh (**Fig. 1**), simply turn the tape 180 degrees (pivoting on the red/white stake) and measure as described above.
      i) **Record value as a negative number** (e.g., -1.23 m for landward extant of S. alterniflora near the upland edge)

**Figure 1**. Schematic of the layout of an ecotone monitoring transect for the marsh/upland border (top) and the marsh/estuary border (bottom).




Updated July 2021

**Figure 2**. Hitting and measuring a migration indicator

**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 grey 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 upland species (seaward extent) | X | X | X | X | X | X |
| | Any other indicator relevant to that transect | | | | | | |

* a vertical creekbank edge is one that is less than ~15 degrees away from vertical (90 degrees)
** salt meadow species include *S. patens* , *Distichlis spicata* , and *J. gerardii*
*** example brackish species include *Schoenoplectus* spp., *Typha* spp., *Eleocharis* , etc

# Appendix E

The Surface Elevation Table–

Marker Horizon Method for Measuring Wetland Accretion and Elevation Dynamics

Callaway et al. 2014

Published 2013



# The Surface Elevation Table–Marker Horizon Method for Measuring Wetland Accretion and Elevation Dynamics

**John C. Callaway,* Donald R. Cahoon, and James C. Lynch**

**Abstract**

Tidal wetlands are highly sensitive to processes that affect their elevation relative to sea level. The surface elevation table–marker horizon (SET–MH) method has been used to successfully measure these processes, including sediment accretion, changes in relative elevation, and shallow soil processes (subsidence and expansion due to root production). The SET–MH method is capable of measuring changes at very high resolution (±millimeters) and has been used worldwide both in natural wetlands and under experimental conditions. Marker horizons are typically deployed using feldspar over 50- by 50-cm plots, with replicate plots at each sampling location. Plots are sampled using a liquid $N_2$ cryocorer that freezes a small sample, allowing the handling and measurement of soft and easily compressed soils with minimal compaction. The SET instrument is a portable device that is attached to a permanent benchmark to make high-precision measurements of wetland surface elevation. The SET instrument has evolved substantially in recent decades, and the current rod SET (RSET) is widely used. For the RSET, a 15-mm-diameter stainless steel rod is pounded into the ground until substantial resistance is achieved to establish a benchmark. The SET instrument is attached to the benchmark and leveled such that it reoccupies the same reference plane in space, and pins lowered from the instrument repeatedly measure the same point on the soil surface. Changes in the height of the lowered pins reflect changes in the soil surface. Permanent or temporary platforms provide access to SET and MH locations without disturbing the wetland surface.

**Abbreviations:** MH, marker horizon; PVC, polyvinyl chloride; RSET, rod surface elevation table; SET, surface elevation table.

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doi:10.2136/sssabookser10.c46



Methods in Biogeochemistry of Wetlands. R.D. DeLaune, K.R. Reddy, C.J. Richardson, and J.P. Megonigal, editors. SSSA Book Series, no. 10.

Tidal wetlands are found across a relatively narrow band of elevation within the tidal frame, typically occurring from somewhere above mean sea level at the low end to mean high water or mean higher high water at the high end. Dual feedbacks drive tidal wetlands to develop at these elevations. First, inputs of allochthonous mineral sediment promote increases in elevation; however, inputs decrease as elevations build over time (Krone, 1987). Second, wetland plants contribute organic matter that also promotes elevation increases, but wetland plants cannot tolerate the extremely frequent rates of inundation that are found at lower elevations and are outcompeted by terrestrial vegetation at higher elevations (Morris, 2006).

Given these relationships, tidal wetlands are highly sensitive to processes that affect their relative elevation (i.e., elevation relative to sea level), such as sea-level rise, regional subsidence (Hatton et al., 1983; Baumann et al., 1984), tectonic activity (Thilenius, 1990), compaction of shallow sediments (Cahoon et al., 1995), allochthonous mineral sediment inputs, and autochthonous organic matter accumulation (Callaway et al., 1997; Turner et al., 2000). Large-scale shifts in elevation will gradually lead to conversion of wetlands to either unvegetated tidal mudflats at lower elevations or terrestrial vegetation at higher elevations (DeLaune et al., 1994); smaller scale shifts in relative elevation can lead to shifts in the dominant plant species, as well as changes in productivity, soil biogeochemistry, and other processes (Warren and Niering, 1993).

A number of different methods have been developed to evaluate sediment accumulation and the belowground dynamics that affect the rates of sediment processes and subsequent changes in relative wetland elevation (Thomas and Ridd, 2004). Various methods focus on one or more of the components that affect accretion (the vertical accumulation of material on the sediment surface), belowground dynamics, and elevation change, and these methods also span a range of time scales (e.g., see Ch. 45, Brenner and Kenney, 2013, this volume). The simple approach of "marking" the sediment surface at a particular time and following surface sediment accretion on top of the marker over time has been used for decades. A variety of substances have been used as marker horizons, including colored sand (Carey and Oliver, 1918), sand (Steers, 1938), brick dust (Stearns and MacCreary, 1957), glitter (Richard, 1978), feldspar clay (Cahoon and Turner, 1989), a solid layer of polyester resin (Letzsch and Frey, 1980), and filter paper (Reed, 1989). In general, feldspar marker horizons have been the most widely used method to measure surface sediment accretion, given the relatively fine texture of most tidal wetland soils, the colloidal properties of feldspar, and the ease of identifying the bright white layer it establishes. Sediment pins or rods have also been used to measure surface sediment accretion by simply following the burial of pins over time (Ranwell, 1964; Reed, 1988; Krauss et al., 2003), but there are potential artifacts associated with the use of pins—their presence can affect flow patterns and cause localized enhanced sedimentation as well as scouring around the pin base. In addition, the change in sediment surface height relative to the pin height is influenced not only by surficial processes of sediment deposition and erosion but also by subsurface processes occurring between the sediment surface and the buried base of the pin. Thus, results from this method should be reported as elevation change rather than accretion or erosion (Krauss et al., 2003). Tiles or plates made of metal and ceramic (Pasternack and Brush, 1998; Neubauer et al., 2002) also can be buried below the sediment surface to provide a reference point; however, the installation of these requires some impact to the vegetation, and they are more typically used in unvegetated mudflats in high-energy settings where marker horizons would erode away.

While marker horizons are widely used, they only provide information on rates of sediment accretion on the surface of the wetland. Accretion is clearly an important process, but the sustainability of wetland vegetation communities is controlled in large part by the local inundation regime, which is immediately affected by the relative elevation of the wetland. Changes in elevation and inundation are directly affected by sediment accretion but are also influenced by sea-level rise, regional subsidence, shallow compaction, belowground inputs of roots, and decomposition (Cahoon et al., 1995; Callaway et al., 1996). Surface elevation tables (formerly known as sedimentation-erosion tables) or SETs were developed to provide insight into changes in wetland relative elevation. When SETs are used in conjunction with marker horizons, the SET–marker horizon (SET–MH) method provides data on sediment accretion, changes in relative elevation, and shallow soil processes, including subsidence and expansion due to root production (Fig. 46-1; Cahoon et al., 1995). Surface elevation tables provide very high resolution measures of changes in relative elevation (in millimeters). Over time there have been a number of improvements to SET design (Boumans and Day, 1993; Cahoon et al., 2002a), including the use of a stainless steel rod for the benchmark of the RSET (Cahoon et al., 2002b) and the use of shallow benchmarks to quantify the relative depth of process influences on wetland elevation.

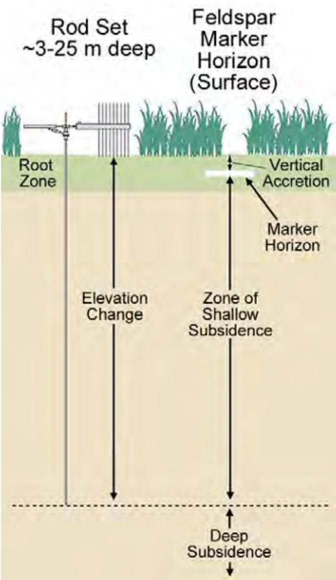


**Fig. 46-1.** Processes measured by feldspar marker horizons and surface elevation tables (SETs), including vertical accretion, shallow subsidence, and elevation change of the wetland surface (from the USGS SET web page: http://www.pwrc.usgs.gov/set/).

## PREVIOUS USES

Feldspar marker horizons and SETs have been used to measure accretion and elevation dynamics in a wide range of salt marsh and mangrove settings around the world, including locations with high rates of local subsidence, as well as very stable sites (Cahoon et al., 2006). Feldspar and other marker horizons have been used for many decades as the simplest way to measure the surface accumulation of sediment (Carey and Oliver, 1918; Steers, 1938; Stearns and MacCreary, 1957; Richard, 1978; Cahoon and Turner, 1989). Although similar elevation monitoring instruments were developed earlier, e.g., the Sedi-Eros Table used by Schoot and de Jong (1982) and van Eerdt (1985), the SET was developed by Boumans and Day (1993) in the late 1980s to measure the elevation change of shallow water bottoms in the Mississippi River delta, Louisiana. Cahoon et al. (2002a) modified the Boumans and Day SET to improve its efficiency and resolution in measuring the elevation of vegetated marsh and mangrove soil surfaces. Cahoon et al. (1995) clearly demonstrated how marker horizons and SETs could be used simultaneously to estimate shallow subsidence or expansion in tidal wetlands and to quantify the influence of subsurface processes on wetland elevation.

For example, the SET–MH method has been used to quantify the varying importance of shallow subsidence across a range of sites in Louisiana, Florida, and North Carolina (Cahoon et al., 1995) and in salt marshes and mangroves around the globe (Cahoon et al., 2006). Water levels, associated with tidal cycles, short-term evapotranspiration, or long-term droughts can lead to substantial changes in wetland surface elevation (Paquette et al., 2004; Cahoon et al., 2011), with short-term changes of as much as five times the long-term trends due to severe drought events (Cahoon et al., 2011). Differences in sediment processes between vegetated wetlands and adjacent ponds were highlighted by Erwin et al. (2006). Marion et al. (2009) also evaluated sediment dynamics across wetlands and adjacent unvegetated mudflats using a mix of techniques, including RSETS, at a macro-tidal site in France. Ibáñez et al. (2010) used marker horizons, SETs, and dated sediment cores (using $^{210}$Pb) to illustrate the importance of subsidence in the Ebro River delta; they also found that inputs of freshwater and inorganic sediments from the river resulted in significantly higher rates of sediment accretion. Cahoon et al. (2003) reported rapid subsidence (peat collapse) in a Honduran mangrove forest destroyed by Hurricane Mitch. Whelan et al. (2005) and Rogers and Saintilan (2008) demonstrated the shrink–swell capacity of mangrove soils, and McKee et al. (2007) and McKee (2011) quantified shallow expansion in oceanic mangroves in the Caribbean. Krauss et al. (2010) reported high rates of shallow subsidence in sediment-rich, high island mangroves in the Pacific Ocean.

The SET–MH method has not been used as widely in brackish and freshwater tidal marshes, although it has been used successfully in these ecosystems (Childers and Day, 1990; Darke and Megonigal, 2003; Baldwin et al., 2009; Ibáñez et al., 2010). It is unlikely that these methods would be as successful in higher energy wetlands, such as riparian ecosystems, which are much more dynamic in terms of sediment processes. In these cases, feldspar marker horizons are likely to be washed out, and the high level of precision in elevation measurements that can be obtained with SETs is not necessary.

More recently, marker horizons and SETS have been used to specifically evaluate sediment dynamics under experimental conditions. For example, Langley et al. (2009) used SETs to demonstrate that elevated $CO_2$ stimulated gains in elevation in a field experiment using brackish wetland species from the Chesapeake Bay. Nitrogen additions were also incorporated into this experiment, although there were no significant effects of N on the sediment elevation (Langley and Megonigal, 2010). In addition to their use in manipulative experiments, results from these methods have been used to inform the ongoing development of simulation models that evaluate the long-term sustainability of tidal wetlands in the face of probable increases in sea-level rise (Morris et al., 2002; Kirwan et al., 2010).

## EQUIPMENT AND INSTRUMENTATION

The field equipment required for coring feldspar marker horizons is a liquid $N_2$ cryocorer, especially in soft sediments or under wet or flooded conditions. If the sediments are firm and dry, a knife can be used to cut a core. A SET instrument is required for measuring changes in relative elevation. In addition, permanent or temporary sampling platforms and boardwalks are needed to reduce disturbance to the soil and vegetation when accessing sites for installation and measurements.

### Liquid Nitrogen Cryocorer

The cryocorer is a portable dewar and sediment cryoprobe ("bullet") that is used for transporting and dispensing liquid $N_2$ into wetland soils to freeze a small volume of soil (Fig. 46-2; Cahoon et al., 1996). Freezing of the soil allows the handling and measurement of soft and easily compressed soils with minimal compaction. The typical cryocorer consists of a 15-L dewar, a flexible stainless steel hose, and a hollow Cu probe that can be inserted into wetland soils through which the liquid $N_2$ is pumped. Stainless steel, self-pressurized dewars are used so that no additional equipment is needed to deliver the liquid $N_2$ in the field. Details on the dewar and cryoprobes are available at http://www.pwrc.usgs.gov/set/readmarkers.html.

### Surface Elevation Table

The SET is a high-precision instrument for measuring small-scale changes in wetland surface elevation. It is a portable device that is attached to a permanent benchmark to make field measurements (see below for installation and measurement procedures) and then removed from the benchmark when measurements are completed. Surface elevation table design has evolved over time, and detailed descriptions of each SET design were provided by Boumans and Day (1993) and Cahoon et al. (2002a, 2002b). The original SET design was based on an earlier instrument used in the Netherlands called the Sedi-Eros Table (Schoot and de Jong, 1982; van Eerdt, 1985). A brief description of significant changes in SET design is included here, and more detailed information is available at the USGS SET web page (http://www.pwrc.usgs.gov/set/). Regardless of the type of SET that is used,

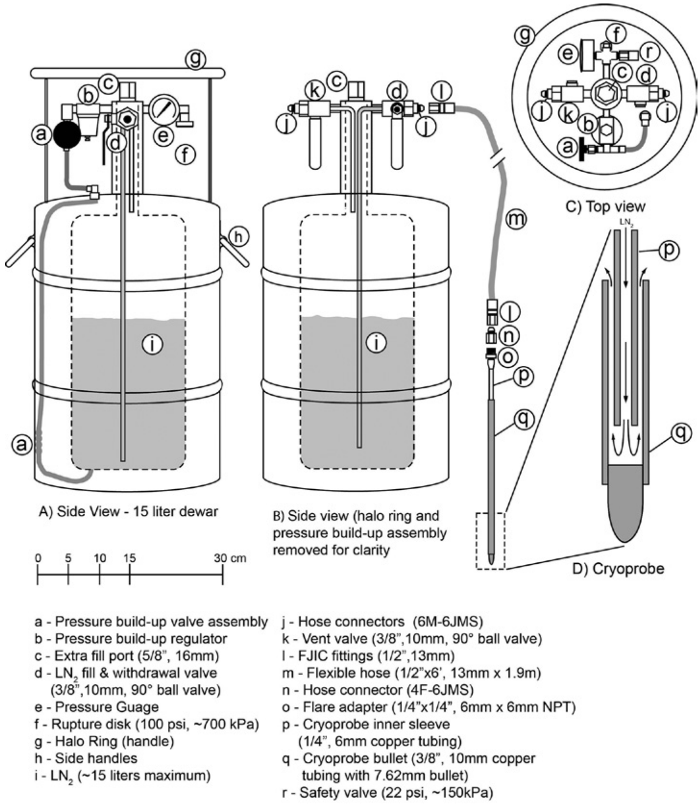


**Fig. 46-2.** Diagram of liquid $N_2$ cryocorer, including (A) side view, (B) side view rotated 90°, (C) top view, and (D) close-up of the cryoprobe (modified from Cahoon et al., 1996).

the SET consists of (i) a permanent benchmark that is established at the location of interest (benchmark supplies are discussed below), (ii) a fitting or "receiver" that couples the benchmark to the SET instrument, and (iii) the SET instrument, including both vertical and horizontal arms, with moveable pins that are used to measure the surface elevation relative to the benchmark.

The SET instrument attaches to the appropriate benchmark using a coupling device that is designed to attach in the exact same position each time. This coupling ensures that the SET reoccupies the same reference plane in space and that each labeled pin of the horizontal arm measures the same point on the wetland surface each time the SET is deployed. The device thus provides repeated measures of the wetland surface. For the original SET, the coupling device is a collar and insert pipe with machined grooves that fit a stainless steel pin on the SET instrument, while for the RSET it is a grooved receiver on the benchmark and a matching fitting on the RSET instrument. The horizontal arm of the SET can rotate and has a turnbuckle and bubble level so that it can be leveled in all directions.

In the original SET design, the horizontal arm attaches to a 25- by 30-cm plate that holds nine pins that can be lowered to the sediment surface. Early SETs were improved by better fittings to stabilize the pins and reduce measurement error (Cahoon et al., 2002a). The pins on the RSET are lowered from a 53-cm linear arm rather than a plate, and the arm is counterbalanced to reduce torque on the benchmark (Fig. 46-3). Each SET device is custom made based on designs available from the USGS (http://www.pwrc.usgs.gov/set/) and in Cahoon et al. (2002b).

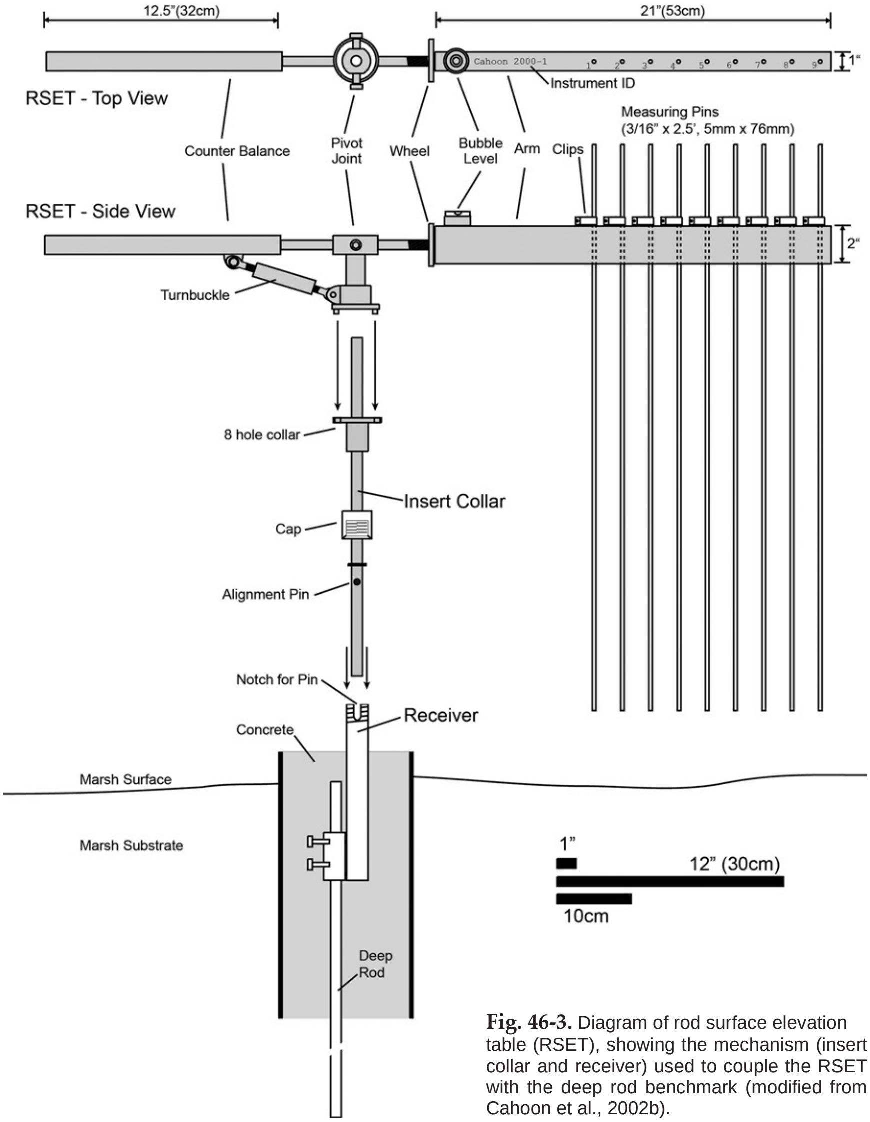


**Fig. 46-3.** Diagram of rod surface elevation table (RSET), showing the mechanism (insert collar and receiver) used to couple the RSET with the deep rod benchmark (modified from Cahoon et al., 2002b).

### Sampling Platforms and Boardwalks

Because of the potential for impacting local elevation and vegetation through trampling, sampling platforms and boardwalks, permanent or temporary, are used to provide access to SET and marker horizon locations. Permanent platforms and boardwalks are typically constructed of treated lumber. Individual supports consist of two legs, made with 2 by 4″ boards (actually 3.8 by 8.9 cm), and a cross-piece, made with a 2 by 6″ board (actually 3.8 by 14.0 cm), which is bolted to the legs. The legs are pounded into the wetland soil using a sledgehammer. Supports are typically 2 to 2.4 m apart, and a 2 by 10″ board (actually 3.8 by 23.5 cm), typically 2.4 m (8 ft) long, is laid across the supports to provide an elevated walkway. Walkways can be bolted in place or brought to the location when sampling. Four supports around the SET location can provide a platform for accessing both the SET and adjacent marker horizons (Fig. 46-4), while individual supports in a line can provide a boardwalk for access to the platform. The design of the platform and the extent of the boardwalk will depend on the firmness of the substrate and local concerns about the use of permanent structures within wetlands. In cases where permanent platforms or boardwalks cannot be used, temporary platforms can be used. Temporary platforms are typically made out of wood or aluminum planks that are attached to plastic step stools on each end. The step stools have boards bolted to their bottom legs that distribute weight on the wetland surface and reduce local impacts. Specifics on the design of platforms are included at the USGS web page (http://www.pwrc.usgs.gov/set/installation/platforms.html).

## MATERIALS AND REAGENTS

Specifics on the SET and MH materials are included at the USGS web page (http://www.pwrc.usgs.gov/set).

Feldspar is most commonly used to establish marker horizons, although other materials can be used as long as they are similar in texture to the local soil and will provide an easily distinguishable layer or marker in the soil. Feldspar is typically available from ceramic supply shops in 22.7-kg (50-lb) bags. Short sections of polyvinyl chloride (PVC) pipe or 1.3-cm (0.5-inch) fiberglass rod are used

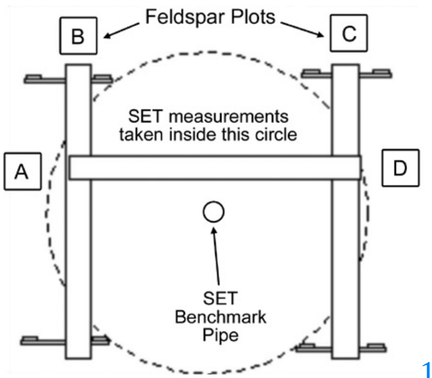


**Fig. 46-4.** Typical layout of surface elevation table (SET) benchmark and feldspar marker horizon plots around a sampling platform (from the USGS SET web page: http://www.pwrc.usgs.gov/set/).

to mark the corners of individual feldspar plots, as well as the broader sampling location. Liquid $N_2$ is used with the cryocorer and is widely available from commercial gas suppliers and most university chemical stock rooms.

For each SET station that is established in the field, materials are needed to construct the permanent benchmark. For the original SET, the benchmark consists of 7.6-cm (3-inch) diameter aluminum pipe (typically a 6.1-m [20-ft] section of irrigation pipe). Deep benchmarks for the RSET are established using 15-mm (9/16-inch) stainless steel rods, which typically come in 1.2-m (4-ft) threaded sections that can be easily coupled in the field and are driven in to depths ranging from 3 to 25 m or more. Shallow RSETs can also be used to measure near-surface dynamics (Cahoon et al., 2002b), and in this case the benchmark typically is established at depths of 30 to 60 cm. The shallow RSET benchmark consists of a custom-made platform that holds four 7.6-cm (3-inch) diameter aluminum pipes, which are cut to length depending on the depth of insertion. For the original SET pipe benchmark, a specially machined insert pipe is needed to receive the SET device. Mortar is used to secure the insert pipe into the larger thin-walled aluminum pipe. For the RSET benchmark, a specially machined receiver is needed to receive the SET device, which is bolted to the rod benchmark. A short section of 15.2-cm (6-inch) diameter PVC pipe is pushed into the substrate around the benchmark and filled with mortar to stabilize the receiver for the deep RSET. The shallow RSET benchmark does not require cement to fix it into place.

## PROCEDURE

At each sampling station, feldspar marker horizons are typically established adjacent to the SET benchmark (Fig. 46-4) to allow simultaneous measurements of sediment accretion and surface elevation change from the same marsh area. Because marker horizons are inexpensive and simple to establish, at least three marker horizon plots usually are established around each SET benchmark, but more can be used if accretion rates are highly variable. Extreme care should be taken to minimize trampling or other impacts to the sampling station during both installation and subsequent sampling visits. Repeated sampling can create paths that will impact vegetation and soils and may affect the local hydrology and cause unnatural draining or impoundment of tidal water. The use of sampling platforms and boardwalks will reduce impacts to the site. Other precautions include carefully marking feldspar plots and other sampling locations and keeping accurate drawings of the site to minimize searching for stations and trampling during sampling visits.

### Feldspar Marker Horizons

Feldspar marker horizons are typically established in 50- by 50-cm plots; larger plots make access difficult, and smaller plots are likely to have substantial edge effects. Three or four plots are typically established per station to get an esti- mate of the local variation in accretion rates at a given location. Plots are located adjacent to the SET sampling platforms and boardwalks, or in a grid using 2- to 3-m spacing in locations without an SET station. At the plot location, feldspar is sprinkled evenly across the plot to provide a uniform, thin layer over the entire area. A 50- by 50-cm quadrat (PVC or wire) allows rapid determination of the plot boundaries in spreading feldspar. Ideally, feldspar should be applied when the vegetation is dry so that the feldspar will not stick to plant stems and leaves. Any feldspar that does stay on plants should be worked through the vegetation by gently shaking the vegetation. A 22.7-kg (50-lb) bag of feldspar typically will cover six to eight 50- by 50-cm plots to a depth of 0.5 cm. The corners of all feldspar plots should be marked with PVC posts or other permanent stakes so that they can be easily relocated. Painting the top of posts or stakes or using some colored flagging tape can allow quicker relocation of plots in densely vegetated wetlands, especially if they are not near a sampling platform. Plots should also be marked with a GPS unit to facilitate relocation.

Feldspar plots should be established at the same time that initial SET measurements are made so that direct comparisons between accretion and elevation can be made. If feldspar establishment and initial SET readings are not simultaneous, there will be difficulty in interpreting processes affecting the wetland relative elevation, including shallow subsidence or expansion. The feldspar plots can be sampled any time after establishment and should be sampled each time the SET is read. This can be done monthly, seasonally, annually, or less frequently depending on the specific research question of interest. Often sampling is done at more frequent intervals in the first year or two of sampling to evaluate seasonal dynamics in sediment accumulation, and the sampling frequency is reduced once finer scale dynamics have been established (e.g., quarterly in Years 1 and 2, annually in Years 3–5, and biannually in subsequent years).

Whatever the frequency of sampling, the goal of feldspar marker sampling is to collect a surface sample without compacting or otherwise disturbing the sediment. Typically, a single core is randomly sampled within each plot, and up to four measurements of the soil depth are made if the feldspar marker is visible. Additional cores can be collected if the layer is not found in the first core or if there is large variability at this location. The cryocorer freezes the soil in place and allows highly accurate measurement of the depth of soil above the marker horizon, with no compaction from sampling. The cryoprobe or bullet is inserted into the sediment at the random location to a depth below the expected location of the marker based on prior sampling or other data from the site (if no prior knowledge of the probable marker depth is available, insert 7 to 10 cm). Flow of liquid $N_2$ from the dewar is started until the soil around the bullet is frozen. The bullet and surrounding frozen soil is then removed. The frozen soil is scraped with a knife to more clearly identify the feldspar marker, and the depth from the sediment surface to the top of the feldspar layer is measured on up to four sides of the frozen sample, using a caliper or ruler. Standing water on the marsh surface is frozen during cryocoring, with suspended sediments trapped in the ice, so care should be taken not to measure the frozen flocculum but rather the same sediment surface that is being measured by the SET. If possible, the frozen sample is returned to the origi- nal sampling location, and as it thaws it will fall off the cryoprobe.

If soils are soft and easily compacted during sampling, the cryocorer is essential to minimize soil disturbances due to sampling; however, in cases where soils are firm and free from standing water, it may be simpler to collect small square or triangular plugs with a knife or a very sharp coring device. In sampling plugs, the same approach is used as with the cryocorer: random locations are sampled per plot, three to four measurements of the sediment depth above the marker are completed for each plug using a caliper, and the plug is returned to the original sampling location, if possible. Core collection through the feldspar plot can also be used if the cores are not extracted first but frozen in the laboratory before handling (Cahoon and Turner, 1989), although this is likely to create a larger disturbance within the feldspar plot.

If sites are highly erosive, feldspar marker horizons (or other marker horizons) will not be effective because they are likely to be washed away shortly after being established. Similarly, high rates of bioturbation can mix the feldspar layer into the existing sediments and reduce the effectiveness and precision of marker horizons. Very coarse sediments can also be problematic because the fine feldspar clay may sink into deeper sediments; in these cases, a coarser marker material should be used. Most wetland environments tend to be primarily depositional, however, with minimal bioturbation and fine, cohesive sediments, so these problems are the exception in typical tidal wetlands. Even under ideal conditions, however, marker horizons will become dispersed and more difficult to relocate over time. Eventually new marker horizons may need to be established in long-term studies, and new plots should be established adjacent to, not on top of, the existing plots. In cases where feldspar does not work (e.g., soils with very coarse texture), other materials, such as sand or glitter, should be evaluated for potential use as marker horizons. Care should be taken to note “misses” when coring for marker horizons. Excessive misses can indicate that the marker has effectively disappeared due to the factors listed above, including erosion.

## Surface Elevation Table

Surface elevation table measurements require the establishment of a stable benchmark at the desired sampling location. Before establishing a benchmark, a sampling platform must be installed to eliminate trampling when pounding in the benchmark or completing measurements (see above for details on sampling platform and boardwalk designs). Depending on the SET, a 7.6-cm (3-inch) diameter, thin-walled aluminum pipe or 15-mm (9/16-inch) stainless steel rod is pounded into the ground until substantial resistance is achieved. A custom-made pipe pounder (similar to a fence post driver) or a vibra-corer is used to pound the aluminum pipe into the soil. For the deep RSET, a 15.2-cm (6-inch) diameter hole is dug 30 to 50 cm deep, and a sledgehammer, custom-made rod pounder (also similar to a fence post driver), demolition hammer, or jack hammer is used to drive in the stainless steel rod in the center of this hole. A short piece of rod should be used as a driving head to avoid deforming the rod during installation. For the shallow RSET, a custom-made aluminum platform is used that attaches directly to four 7.6- cm (3-inch) diameter aluminum pipes, which serve as legs for the platform. The four pipes are pushed into the ground by hand to the same depth (typically 30–60 cm). Once they are in place, the platform is attached using self-tapping machine screws. Rod SET benchmarks can be established at a range of soil depths at a particular location to identify the depth where shallow compaction or expansion is occurring.

Once the benchmark has been established, the appropriate fittings are attached to the benchmark to connect the benchmark to the SET. In the case of the original SET, this entails cementing a 5.1-cm (2-inch) diameter, thick-walled insert pipe into the 7.6-cm (3-inch) diameter pipe. The insert pipe fits within the 7.6-cm-diameter pipe and is cemented in place using mortar mix; the insert pipe is held in place in the correct orientation using duct tape while the mortar sets. For the deep RSET, a 15.2-cm (6-inch) diameter PVC pipe is pounded approximately 15 to 20 cm below the 30-cm-deep hole that has been dug, with the top 5 to 10 cm above the wetland surface. A custom-made stainless steel receiver is attached to the rod within the PVC pipe, and the entire pipe is then filled with concrete or mortar. The receiver is designed to attach directly to the insert collar of the RSET. For the shallow RSET, the platform includes fittings for attaching the RSET instrument. In case there is any initial movement of the pipe or rod following establishment, it is best to wait at least 3 to 4 wk after establishing the benchmark before taking the initial SET measurements.

Although the benchmark remains permanently in the wetland, the SET instrument is brought in the field only for measurements. The SET is attached to the benchmark in the appropriate direction. For both the original SET and the RSET, there are eight potential orientations for the attachment of the SET to the benchmark. Typically, measurements are made for four of the eight potential orientations, and a compass is used to identify the orientations or directions of the SET arm for measurement. For the original SET, the orientations can also be confirmed by the numbered notches in the insert collar. It is critical that the SET be relocated to these same exact locations each time. The orientations for the initial measurements must be recorded and brought into the field for future measurements. Small lengths of PVC pipe or fiberglass rods can also be used to mark the orientation of the SET. Measurement pins are placed in their proper holes on the SET (holes are numbered, as are the pins, to ensure that the same pin–hole combinations are always used).

When the SET is in the proper orientation, it must be leveled in two directions using the bubble level that is attached to all SETs. The pins are then carefully lowered through the vegetation until they just touch the soil surface. Where necessary, the vegetation is gently moved to allow the pins to reach the soil surface. Pins are secured in place, and the height of each pin above the SET plate or RSET arm is recorded with a metric ruler. Any irregularities in the sediment surface should be noted for each pin, e.g., root, burrow, etc. It is advisable to double-check pin heights to minimize the likelihood of errors in reading and recording data. As above, care is necessary to minimize any impacts to the vegetation and soil in com- pleting sampling. In very soft sediments, small disks that increase the surface area of the pin bottom, or "feet", can be attached to the bottom of each pin to ensure that the pins do not penetrate the soft sediments.

To maintain the high level of precision that is desired in measuring changes in wetland surface elevation, the same SET instrument must be used each time because of slight differences in SET components. If it is necessary to switch to a new instrument or investigator reading the SET, simultaneous measurements must be completed with both the new and old instruments and investigators to convert readings across instruments and people.

## CALCULATIONS

### Feldspar Marker Horizons

The data for the depth of sediment above the marker horizon are averaged within each marker plot, first by averaging the multiple measurements for each core or plug and then averaging across cores or plugs if multiple samples are collected within a marker plot. Averages from replicate plots at a sampling location (typically a SET benchmark location) are used for the estimate of the mean and variation (standard deviation or standard error) for that location, i.e., $n$ = the number of plots at the location, not the number of individual measurements. These data reflect the cumulative change in sediment accretion since the time of marker deployment. No estimate of erosion is possible unless measurable sediment has already accumulated; however, buried tiles or plates could be used to estimate erosion (Pasternack and Brush, 1998; Neubauer et al., 2002). If the marker horizon data are used in broader statistical analyses, the replicate marker plots within a sampling location are generally treated as subsamples in the experimental design (the true replicates would be the sampling locations, which should be chosen at random and be representative of the local environmental conditions being tested). If the statistical model of interest includes temporal effects (such as seasonality or wet vs. dry years), the cumulative marker horizon data would have to be converted to incremental data reflecting the appropriate temporal periods.

### Surface Elevation Table

Changes in relative elevation are calculated by comparing changes in individual pin heights across sampling periods. Assuming verification that there was no vertical motion in the SET benchmark itself, an increase in pin height during a particular time interval corresponds to an increase in wetland surface elevation during that interval. Changes in individual pin heights can be calculated for specific intervals or cumulatively for longer periods. Typically, interval data are used to run quality control and quality assurance on the data because outliers are more easily detected than with data expressed as cumulative change. Suspect data, including sediment disturbance by biota or other surface features not corresponding to the representative sediment surface (e.g., a branch lying on the sediment surface) are generally excluded from the larger trend analysis. Once the data are reviewed for quality control, they are formatted for statistical analysis. This typically means expressing the data either as incremental change data during

specified time intervals (e.g., seasons or specific years) or as linear rates of change across the entire data set. The former is used when the study addresses temporally related "treatment" effects, such as seasonality or wet vs. dry years; if the study addresses nontemporal effects, such as wetland type, location along the intertidal gradient, fertilization, or burn treatments, then linear rates of change are used. In either case, the generally accepted experimental unit is the SET benchmark plot itself. Typically, then, these methods result in an experimental design with very low replication (often $n = 3$). For analyses focusing on cumulative changes, linear regression is used either at the pin or position level across the entire time series to generate linear rates of change, and these are averaged across the SET location.

### Comparison of Marker Horizon and Surface Elevation Table Data

Shallow subsidence is indicated as the difference between vertical accretion and elevation change (i.e., shallow subsidence = accretion − elevation increase). Care must therefore be taken to express both data sources at the SET plot level and across the exact same time intervals (whether incremental or cumulative). As with accretion and elevation change data, subsidence data are typically calculated across multiple years to provide an annual rate of subsidence. Linear rates of change from separate regression analyses for accretion (marker horizons) and elevation change (SETs) can be compared in an analysis of variance model, which can also test for other explanatory variables, or the cumulative data from both data sources can be combined in an analysis of covariance. In some cases, the marker and SET data may show very similar patterns, indicating that no shallow subsidence is occurring at that site; more frequently, however, the elevation change rate indicated by the SET is less than the surface sediment accumulation rate indicated by the marker horizons. On some occasions, the elevation change rate is greater than accretion, indicating shallow expansion, which is the opposite of shallow subsidence. The RSETs that are deployed at multiple depths at a given location can be used to evaluate the depth where subsurface vertical movement is occurring at sites where subsurface processes are important.

### Acknowledgments

Philippe Hensel provided critical comments on the calculations and statistical analyses section. The use of trade or product names is for descriptive purposes only and does not represent endorsement by the U.S. Government.

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Investigators: Date:

Site:

| SET# | Pin Height | | | | Vegetation | | | |
|---|---|---|---|---|---|---|---|---|
| Direction | N | S | E | W | N | S | E | W |
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| Pin 2 | | | | | | | | |
| Pin 3 | | | | | | | | |
| Pin 4 | | | | | | | | |
| Pin 5 | | | | | | | | |
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| SET# | Pin Height | | | | Vegetation | | | |
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| SET# | Pin Height | | | | Vegetation | | | |
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