Developing and Piloting the Salt Marsh Rapid Assessment Method, MarshRAM

Technical report prepared for the Rhode Island Department of Environmental Management and the Rhode Island Coastal Resources Management Council

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Acronyms

EPA	U.S. Environmental Protection Agency
CRMC	Rhode Island Coastal Resources Management Council
DEM	Rhode Island Department of Environmental Management
NBNERR	Narragansett Bay National Estuarine Research Reserve
NOAA	National Oceanic and Atmospheric Administration
RINHS	Rhode Island Natural History Survey
URI	University of Rhode Island
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service

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1. Introduction

Salt marshes provide a number of ecosystem functions and services that are important to people and wildlife (Gedan et al. 2009, Barbier et al. 2011). Among the most productive ecosystems in the world, salt marshes provide a base for estuarine food webs and important wildlife habitat for fishes, shellfish, birds, mammals, reptiles, and invertebrates, including several species that depend on salt marshes for their survival (Nixon 1980, Deegan et al. 2002). They can also protect adjacent and downstream properties from riverine and coastal flooding and erosion by slowing and absorbing flood waters and waves (Shepard et al. 2011), and can act as platforms for recreation and provide scenic views.

Salt marshes are highly vulnerable to an array of anthropogenic disturbances. Filling for development and refuse disposal, impoundment of surface water by roads and railways, ditching for mosquito control and salt-hay production, introduction of excessive nutrients from waste products, and introduction of invasive species have resulted in widespread salt marsh loss and degradation in Rhode Island and elsewhere (Gedan et al. 2009, 2011, Watson et al. 2017b). Direct filling for coastal development alone has resulted in a loss of more than half of the historic salt marsh area in Rhode Island (Bromberg and Bertness 2005). More recently, multiple factors associated with climate change and sea-level-rise have caused widespread vegetation loss and marsh platform degradation (Donnelly and Bertness 2001, Roman 2017, Watson et al. 2017a). Several recent studies indicate that sea-level-rise works interactively with other anthropogenic stressors to cause marsh edge dieback, erosion, platform vegetation dieoff, subsidence, water-logging, drowning, and loss (Kutcher et al. 2018 and citations therein). For example, nutrient enrichment can cause a reduction in below-ground biomass and an increased rate of decomposition, causing marsh platform subsidence that may contribute to ponding and subsequent die-off associated with increased inundation from sea-level-rise (Wigand et al. 2003, 2014). The Rhode Island Coastal Wetland Restoration Strategy (CWRS, Kutcher et al. 2018) recommends a state program that uses monitoring and assessment data to manage coastal wetlands facing increased stress from multiple anthropogenic disturbances.

The Rhode Island salt marsh monitoring and assessment strategy (SMMAS, Raposa et al. 2016) outlines a three-level approach to salt marsh monitoring and assessment. The approach uses landscape (Level 1), rapid (L 2), and intensive (L 3) monitoring and assessment methods to provide broad information to managers on the status and trends in salt marsh condition (EPA 2006). Landscape (L 1) assessment is useful to characterize wetland condition across a wide area, but is not generally accurate or detailed enough to be used for assessment at the individual site scale. Intensive (L 3) monitoring is ideal for measuring change over time and identifying long-term trends at a few representative sites, but the typical application of multiple intensive methods is too time-consuming for site-level assessment. Rapid (L 2) assessment is unique in that it can quickly provide fairly detailed and reliable site-level information on salt marsh condition across multiple sites, which would not be effective or practical with landscape or intensive methods. To facilitate data collection across multiple sites in a single year, a rapid assessment method should be logistically efficient enough to conduct during a single site visit (Fennessy et al. 2007). Rapid assessment data across multiple sites can be used to address a variety of management needs, such as categorizing wetlands by relative condition, prioritizing wetland restoration and conservation efforts, and analyzing how human activities affect wetland condition. Rapid assessment is therefore considered to be central to state and tribal wetland assessment programming (EPA 2006). The SMMAS recommends the development of a rapid assessment method based on prior work (Raposa et al. 2016).

Two prior salt marsh rapid assessment methods have been tested in Rhode Island, but neither provides complete information. The New England Rapid Assessment Method (NERAM, Carullo et. al. 2007) focuses on vegetation, soils, site disturbances, and surrounding land use factors, but does not evaluate changes associated with sea-level rise, which is now a dominant influence on salt marsh condition. Conversely, the Rhode Island Salt Marsh Assessment (RISMA, Cole-Ekberg et al. 2017) focuses on vegetation and soil conditions associated with sea-level rise, but does not incorporate information on marsh stressors or classification information on marsh type and setting that can be useful for analysis. To meet the analysis, prioritization, and categorization needs of salt marsh management in Rhode Island, a rapid assessment method needs to evaluate all potential stressors, both direct and indirect, and document relevant classification information (Raposa et al. 2016).

With the impending threat of accelerating sea-level rise, landward migration of salt marshes may be important for their sustainability (Roman 2017, Watson et al. 2017b). The CWRS recommends the development of tools to assess and compare the landward migration potential of salt marshes (Kutcher et al. 2018). CRMC (2015) has worked with partners to develop the Sea-Level Affecting Marsh Migration Model (SLAMM), which uses elevation, predicted sea-level rise rates, estimated marsh accretion rates, and infrastructure data to predict and quantify marsh migration areas throughout Rhode Island, and it has been a useful tool for salt marsh restoration project planning. SLAMM quantifies migration opportunity on a state-wide scale and assumes migration will occur anywhere physical conditions allow; it may therefore over-estimate migration potential (CRMC 2015). State managers have recognized the need for a model that considers migration potential in relation to specific salt marshes, considering biological and cultural opportunity in addition to physical factors.

This report details the development and piloting of a single comprehensive salt marsh rapid assessment method (L 2) that is efficient to conduct, produces a reliable indication of salt marsh condition and vulnerability to sea-level rise, and provides other important information to support salt marsh management, such as classification information and landward migration potential. The development process used components from three existing rapid wetland assessment methods from Rhode Island, NERAM, RISMA, and the Rhode Island Rapid Assessment Method (RIRAM, Kutcher 2011b), to develop the Marsh Rapid Assessment Method (MarshRAM). MarshRAM was developed and field-tested with an interdisciplinary advisory group before being piloted at nine additional salt marshes across Rhode Island. Outcomes of the field test and pilot are analyzed against existing and new data to provide preliminary information on MarshRAM functionality and utility, and to make recommendations on its further development and use. Recommendations in this report will be applied to an upcoming larger analysis of MarshRAM across an additional 20 salt marshes in Rhode Island in 2018.

2. Methods

2.1 MarshRAM design and development

MarshRAM builds upon the most effective and useful components from NERAM, RISMA, and RIRAM. MarshRAM consists of five parts: the first three comprise a typical checklist of observable characteristics and condition indicators, the fourth is a quantitative marsh community-composition survey, and the fifth is a semi-quantitative model that assesses aspects of landward salt marsh migration potential (App. A). MarshRAM was designed to generate metrics and indices characterizing salt marsh relative condition, landward migration potential, and ecological and cultural value to inform salt marsh restoration, conservation, and policy.

2.1.1 Observational checklist

Three sections documenting observable information on (A) marsh characteristics, (B) landscape stress, and (C) in-wetland stress draw directly from RIRAM structure and formatting, although much of the content is adapted from NERAM metrics. The (A) *Marsh Characteristics* section documents, by discrete checklist categories, marsh area, position in the watershed, geomorphic setting and type, tide range, hydrology, exposure, and habitat diversity (App. A); this information facilitates categorization of marshes by type and setting for analysis, as some marsh types or settings may affect how marshes respond to various stressors. This section (A) also estimates and rates the occurrence and relative importance of typical ecosystem functions and services, and tallies waterbirds observed during the assessment. It is widely recognized that information on marsh function/value and habitat use is important for management (USACE 2003, McKinney at al. 2009).

The second section, (B) *Landscape Stress*, estimates the occurrence and intensity of human land uses within a 30-m buffer zone and within 150m of the wetland edge. Several wetland rapid assessment methods incorporate landscape integrity metrics (Fennessy et al. 2007), and prior studies have shown a strong relationship between freshwater wetland condition and landscape condition in Rhode Island (Kutcher and Bried 2014, Kutcher and Forrester 2018).

The third section, (C) *Wetland Stress*, estimates, categorizes, and rates the intensity of tidal restriction, ditching and draining, anthropogenic nutrient inputs, filling and dumping, edge erosion, marsh crab burrowing, platform vegetation die-off, vegetation removal and soil disturbances, and *Phragmites* invasion (App. A). *Wetland Stress* adapts observational NERAM metrics found to be effective in reflecting salt marsh platform condition in Southern New England (Wigand et al. 2011), and adds metrics designed to evaluate observable response to sea-level rise (i.e. edge erosion, crab burrow density). Ranking of intensity is coarse for most metrics, comprising *None*, *Low*, *Moderate*, and *High* intensity categories. Scoring categories are standardized across most metrics and each metric is scored equally. The aggregate score for *Wetland Stress* (i.e., the *Wetland Stress* sub-index) is simply the mean of the individual metric scores. The *Wetland Stress* section additionally uses checklists to document observed evidence, associated stressors, and general sources of stress. These checklists, which closely follow RIRAM formatting and content, allow for analysis of the influences of individual and generalized stressors on wetland condition, to inform management and policy.

2.1.2 Marsh Community Composition and Index of Marsh Integrity

The fourth section of MarshRAM has two components, (1) *Marsh Community Composition* and (2) an *Index of Marsh Integrity* (hereafter, IMI). This section adapts elements of RISMA (Cole-Ekberg et al. 2017) and floristic quality assessment (FQA, e.g., Kutcher and Forrester 2018), and uses a novel sampling approach to generate (1) the relative cover of typical salt marsh community cover types and (2) a biological index of salt marsh integrity. Like the plant community section of RISMA, the relative proportion of typical marsh cover types is quantified using transects traversing the marsh platform from upland to water's edge. MarshRAM condenses RISMA cover types to those that clearly represent stages of salt marsh response to anthropogenic disturbances (Table 1). MarshRAM uses eight transects per marsh distributed evenly across the marsh surface. The investigator walks the transects using repeatable, even paces. For every step across the marsh surface, the cover type traversed is tallied as a single data point (App. A). The relative proportion of each cover type is then derived from the aggregate tallies of each type across all transects. The aim of this novel sampling approach is to efficiently and accurately characterize marsh community composition by quantifying the relative proportions of the various marsh cover types across the marsh surface. Eight transects was chosen to provide adequate spatial resolution to characterize marsh-wide cover, and to serve as replicates for coarse change analysis. R. Martin (unpublished data) found that eight transects of MarshRAM community composition data was adequate to detect 10% change for most cover types.

Applying a functional mechanism similar to FQA, IMI assigns a coefficient to each salt marsh cover type based on its indication of marsh degradation and habitat value. These 'coefficients of community integrity' (hereafter, CCI) were assigned to the cover types through consensus of a team of salt marsh scientists (K. Raposa, NBNERR; C. Roman, URI; C. Wigand, EPA Atlantic Ecology Division; T. Kutcher; RINHS) using a standardized scoring system that rates each cover type by sensitivity to sea-level rise, sensitivity to other stresses, and habitat value (App. B). Cover types with high sensitivity to anthropogenic stress and high habitat value were assigned CCI 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 mean of the coefficients of all cover types documented, weighted by relative proportion across all transects, was evaluated as an index of marsh integrity (i.e. IMI) (App. A). Other metrics based on proportion of cover type were also evaluated.

2.1.3 Migration Potential

The fifth section of MarshRAM, *Migration Potential*, rapidly estimates and characterizes three (3) aspects of landward marsh migration potential using a combination of remote-sensing data and field observations. The method uses a worksheet (App. C) to estimate the proportions of various land cover-elevation types falling within 60m of the marsh edge based on interpretation of aerial imagery overlaid with high-resolution elevation data. Each land-cover type is assigned a coefficient of migration potential ranging from zero (no migration potential) to 10 (high potential). The worksheet aggregates a weighted average of the coefficients to generate a (1) *Migration Potential* score. The area of the marsh and the area of surrounding land within 60m, measured using GIS or Google Earth software, are additionally applied to estimate the (2) *Conservation Area*, defined as the area of surrounding land with moderately-high and high migration potential, and (3) the *Conservation Ratio*, which relates that metric (2) to the area of the existing marsh. The three *Migration Potential* metrics are intended to be used to inform specific aspects of salt marsh management and conservation planning.

Table 1. Salt marsh cover-types (modified from Cole-Ekberg et al. 2017) and coefficients of community integrity (CCI) used to generate indices of marsh integrity (IMI) for 11 salt marshes in Rhode Island. Broad cover-types are listed in approximate order from upland interface to seaward edge, followed by typically-smaller features.

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* , 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% vasuclar vegetation cover, or bare decomposing organic soil, typically with remnant roots of emergent vegetation; may have algal mat, filamentous algaem wrack, or flocculent matter present
Low Marsh	8	Regularly flooded emergent community located at the 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

2.1.4 MarshRAM Scoring

MarshRAM, as tested and piloted, generates three sub-indices reflecting (B) *Landscape Stress*, (C) *Wetland Stress*, and (D) *Marsh Integrity* (IMI); these can be averaged to generate a single MarshRAM index of salt marsh condition (App. A), or used separately for analysis and decision support. Scores for each metric, sub-index, and the aggregate MarshRAM index all range from 0 to 10, where scores approaching 10 indicate no observed indications of disturbance or marsh degradation, and scores approaching zero indicate observation of multiple, strong indications of disturbance and degradation. The *Marsh Characteristics* (A) section does not contribute to MarshRAM condition scores; however, the sum of importance rankings from A.7 *Ecosystem Functions and Services* is tested as an indicator of the relative ecological and cultural importance of a site. Other attributes from A. *Marsh Characteristics* are intended to be used for categorization and analysis, but not as indicators of integrity. Likewise, the *Migration Potential* metrics are not incorporated into the MarshRAM condition index, but are instead designed to be evaluated against the condition scores to inform management decisions. MarshRAM keeps size, setting, diversity, function and value, and migration potential information separate from disturbance and degradation scoring because some of these factors are inherent or can confound the effective assessment of wetland condition (Fennessy et al. 2007, Kutcher and Forrester 2018).

2.2 Field Testing

An early draft of MarshRAM was field tested at two salt marsh sites (Fig. 1). Members of the restoration community (C. Chaffee, CRMC; W. Ferguson, Save The Bay; J. Turek, NOAA Restoration Center; K. Raposa, T. Kutcher) field tested the method at Potowomut Marsh in East Greenwich, RI. Salt marsh research scientists (K. Raposa, C. Roman, C. Wigand, T. Kutcher) field tested the method separately at Nausauket Marsh in Warwick, RI. MarshRAM was conducted approximately as described below (Sec. 2.3.1, 2.3.2). Every metric was discussed jointly by each team before separately scoring the metric, followed by joint discussion of the outcomes. A subset of IMI transects (Sec. 2.1.2) were run jointly, and cover-type ratios were compared in the field among participants. Agreement among ratios was deemed acceptable, although there was discussion over clarifying break points between similar cover classes. All feedback was noted and incorporated into the method prior to the pilot study surveys.

Figure 1. Locations of two MarshRAM test sites (squares) and nine MarshRAM pilot sites in Rhode Island

2.3 Pilot Study

A revised version of MarshRAM was conducted at nine additional salt marshes (Fig. 1) at the peak of the growing season (mid-July through September 2017). Assessments were conducted at or near low tide for convenience and consistency, although the amplitude of the tide was not considered. Data were recorded on MarshRAM field datasheets (App. A). Field maps—depicting recent high-resolution, leaf-off, true-color, areal imagery of the marsh assessment site; surrounding landscape with 30-m and 150-m buffer delineations; and IMI transects—were taken into the field to facilitate identification of marsh characteristics and estimation of landscape metrics, and to guide transect routes. Maps and buffer delineations were generated using ESRI ArcGIS. Marsh assessment units comprised the entirety of contiguous marsh area bounded by open water or upland, and were delineated on-screen using aerial photo-interpretation of recent leaf-off imagery. Buffers of the assessment unit polygons were drawn automatically using the GIS software buffer tool. Transects were drawn by hand on the paper maps. Transects were located on maps by drawing a guideline across the width of the marsh approximately parallel to the shoreline, locating eight (8) transects evenly-spaced from a random starting point along the guideline, and drawing the transects perpendicular to the guideline. For semi-circular fringing marshes, and marshes surrounding a deep water feature, two or more straight guidelines were used, as needed, and eight transects were evenly spaced along their total length.

2.3.1 Observational Assessment

The perimeter and inner parts of the marsh were walked until the investigator was confident in his assessment of all observational metrics and their components. All components of each attribute and metric of the observational parts were filled out completely unless there was no evidence of stress for a metric, in which case the metric would be scored as 10 and no components needed to be filled out. Waterbirds were counted as they were opportunistically observed when approaching sections of the marsh for the first time.

2.3.2 Community Composition and IMI Assessment

Vegetation community surveys followed transects depicted on the field maps. Transects were followed in the field by identifying landmarks (e.g. evergreen trees, houses, marsh-edge contours, pools, etc.) at each transect end and walking directly from and toward the identified landmarks in a straight line. The investigator walked transects using repeatable, even paces. For each transect, steps traversing each cover type were counted and entered on the field datasheet as individual data points before continuing across the next adjacent type. For example, twelve steps through a salt shrub zone would be tallied as 12 salt shrub data points for analysis. The total number of steps taken across each cover type were summed following each transect. Transect data were (1) tallied separately and (2) aggregated marsh-wide to support (1) future change analysis using each transect as a replicate, and (2) IMI scoring. Coefficients were applied to aggregate tallies to generate the IMI scores. Tallies and index generation were calculated directly on field datasheets and were later re-calculated automatically using Excel spreadsheet software upon digital upload. Marsh sparrows flushed during vegetation community transects were also tallied, and the percentage of *Meadow High Marsh* cover class (aggregated across all transects) was generated as an ancillary metric.

2.3.3 Migration Potential

Migration potential metrics were calculated in the laboratory using GIS software prior to rapid assessment field surveys. MarshRAM uses high-resolution elevation data, estimates of sea-level rise, and photo-interpretation of land cover to estimate and rank biological opportunity (adjacency to existing marsh vegetation), geomorphic, hydrologic, and vegetative resistance (elevation above current tide frame, water features, and vegetation type), and perceived cultural resistance to migration (based on intensity, value, and perceived permanence of land use) within 60m of each salt marsh (App. C). Sixty-meter buffers were generated around the salt marsh assessment units (delineated as described above) using the GIS software buffer tool. The area of land within the buffer was measured using GIS measuring tools. RIGIS elevation data (available at www.rigis.org, accessed July-Sept 2017) were overlain and the 3' contour was used to identify low lying lands (<0.9m above mean high water). Proportions of migration-potential categories were estimated to the nearest tenth through photo-interpretation. Laboratory assessments were checked for ground truth during rapid assessment surveys, and adjusted if necessary.

2.3.4 Analysis

Winstat (R. Fitch Software, 2008) was used for statistical analyses. Rank-based statistics were used to account for the ordinal nature of MarshRAM and any gaps and skews inherent in the small sample. Spearman rank correlation was used to detect correlations among MarshRAM variables and against historic loss and elevation data from a prior study (Watson et al. 2017). To account for the small sample size, single-tailed probability (P) values were applied and reported for all correlation analyses; therefore only expected relationships can be considered valid. Because sample size is low throughout (n=8 to 11), statistical outcomes are used here as preliminary indications of trends that may substantiate or fail under more rigorous study conditions.

3. Results

3.1 MarshRAM Logistics

All MarshRAM assessments took less than a single field day to complete. Office-based preparation of field maps and GIS investigation took less than one hour per site, and field surveys generally took between two and four hours depending on the size of the site and difficulty in accessing the transects. Vegetation community transects (Sec. D) ranged in length from 10m to 264m (n=11, $\overline{x}$=91) and averaged 730m per eight transects per marsh, and the number of data points tallied (i.e. the number of steps traversed during transect surveys) averaged 831 per marsh.

3.2 Marsh Characteristics and Disturbances

The study marshes ranged in size from 0.56 to 41 hectares (n=11, $\overline{x}$=15.3) and were distributed across Narragansett Bay Upper Bay (5 sites), Lower Bay (3), Mid Bay (1), Sakonnet River (1) and the Rhode Island South Coast (1) (App. D). Geomorphic settings represented were back-barrier marsh (7 sites), finger marsh (3), open embayment (2), open coast (1), and back barrier lagoon (1). Ten (10) sites were categorized as platform marshes and one as a fringing marsh, although the fringing marsh also had a narrow high-marsh peat platform. Ten (10) of 11 marshes were polyhaline (>18 ppt.) and one was mesohaline (5-18 ppt.). All 11 sites had a high marsh platform, salt shrub habitat, and *Phragmites* present, 10 contained low marsh, and 6 contained brackish marsh habitat. All sites were interpreted as having potential or evident value for wildlife habitat, fish and shellfish habitat, and carbon storage, whereas 5 were characterized as having value for storm protection of property. Wading birds were detected at 10 sites, marsh sparrows at 7, gulls and shorebirds each at 5, and raptors and waterfowl each at 3.

Intensity of buffer encroachment within 30-m of the wetland edge was estimated as high (51-75%) at 1 site, moderate (26-50%) at 3 sites, and low (6-25%) at 5 sites (App. D). The most common stressors in the surrounding landscape were residential development (10 sites), raised roads (8), and trails (6). Four (4) sites were at least partly impounded, mainly by dirt roads. Ditching intensity was moderate at 6 sites, low at 3 sites, and high at 1 site. Impacts of nutrient enrichment were evident at 6 sites. Filling was detected at 8 sites, mainly from raised roads. High (>60%) or moderate (>10-60%) edge erosion was observed at 8 sites, and high or moderate crab burrowing damage (e.g., dense, oversized burrows; denuded peat) was observed at 6 sites. Ponding/dieoff, vegetation mowing, and soil disturbances were assessed as low or absent at most sites. Phragmites was present at all 11 sites, and cover (as a proportion of the marsh platform) was moderate (>10-60%) or high (>60%) at two sites (Fig. 2). Overall, roads, residential development, and known high-nutrient tidal water were identified as the main causes of salt marsh disturbance among the pilot sites (App. D).


Figure 2. Dense, tall *Phragmites*, a continuous mat of macroalgae, lack of native vegetation, and marsh platform erosion indicate nutrient stress and degraded conditions at Watchemoket salt marsh in East Providence, RI.

3.3 MarshRAM Scores and Analysis

MarshRAM Index scores ranged from 4.8 to 8.5 ($\bar{x}$=6.7), *Landscape Stress* scores ranged from 4.9 to 9.9 ($\bar{x}$=7.6), *Wetland Stress* scores ranged from 4.3 to 7.9 ($\bar{x}$=6.3), and IMI scores ranged from 4.4 to 8.0 ($\bar{x}$=6.2) (Table 2). Several MarshRAM components were correlated with historic loss values from a prior study (Table 3). No significant correlations were found between MarshRAM components and median marsh platform elevation values from that same study. There was no indication that the MarshRAM index, aggregate *Wetland Stress*, or IMI were influenced by marsh area, watershed position, setting, or exposure class (Spearman rank or Kruskal-Wallis, P>0.05). The sum of ranks ascribed to A.7 *Ecosystem Functions and Services* was correlated with marsh area (Spearman rank, r_s=0.69, P=0.01), but not with the MarshRAM index, aggregate *Wetland Stress*, or IMI (P>0.05 for all). Marsh area was also correlated with the number of wading birds, gulls, and all birds detected during MarshRAM assessments, and the diversity per marsh of bird cohorts listed in section A.8 *Count of Waterbirds Present at Start* (r_s = 0.86 to 0.91, P<0.01, n=10). The number of marsh sparrows flushed during IMI transects was correlated with IMI scores (r_s =0.62, P=0.02, n=11). Some MarshRAM observational disturbance metrics were correlated with the Index of Marsh Integrity (IMI) and the proportion of Meadow High Marsh (%MHM) measured per site (Table 4). Table 5 demonstrates IMI categories of marsh degradation in relation to observed disturbance intensities and other management information. IMI scores reflect relative community composition as depicted in Figure 3.

Table 2. MarshRAM index and sub-index scores, marsh loss, and median elevation of 11 salt marshes in Rhode Island; *percent loss of marsh area between 1972-2011 from Watson et al. (2017b); **median elevation in relation to NADV88 from Watson et al. (2017b); ND = no data available

Site	B. Landscape Stress	C. Wetland Stress	D. IMI	MarshRam Index	*% Loss	**Elevation
Providence Point	9.9	7.9	7.8	8.5	7.4	0.64
Mill Creek	9.7	7.0	7.2	8.0	17.0	0.53
Sheffield Cove	8.4	7.3	8.0	7.9	ND	ND
Nausauket	7.8	7.3	5.9	7.0	ND	ND
Jenny	8.7	6.0	5.9	6.9	11.4	0.53
Round Marsh	7.6	6.3	6.1	6.7	1.8	0.54
Rocky Hill	6.8	6.3	6.3	6.5	ND	ND
Mary Donovan	6.1	5.7	6.4	6.0	14.9	0.33
Succotash	6.8	5.7	5.3	5.9	40.8	0.30
Watchemoket	7.1	5.7	4.4	5.7	26.3	0.40
Mary's Creek	4.7	4.3	5.3	4.8	20.7	0.54

Table 3. Spearman Rank correlation coefficients and one-tailed probability values comparing MarshRAM components with loss and elevation estimates from a prior study (n=8); significant correlations are shaded; *loss of vegetated marsh area from 1979 to 2011 estimated by aerial photo-interpretation, from Watson et al. (2017b); **median elevation in relation to NADV88, from Watson et al. (2017b); ***Wetland and Buffer Stress represents aggregate wetland and buffer stress metrics without the Surrounding Landscape metric incorporated

MarshRAM Component	*% Loss		**Elevation	
	r_s	P	r_s	P
B. Landscape Stress	-0.52	0.09	0.45	0.13
C. Wetland Stress	-0.66	0.04	0.48	0.11
D. Marsh Integrity (IMI)	-0.69	0.03	0.49	0.11
B. + C. + D. = MarshRam	-0.67	0.04	0.39	0.16
% Meadow High Marsh	-0.64	0.04	0.38	0.17
***Wetland and Buffer Stress	-0.73	0.02	0.47	0.11

Table 4. Spearman Rank correlation coefficients and one-tailed probability values comparing Index of Marsh Integrity (IMI) and % Meadow High Marsh (%MHM) scores with metrics and sub-indices of MarshRAM from 11 salt marshes in Rhode Island; significant correlations are shaded

MarshRAM Component	Marsh Integrity (IMI)		% MHM	
	r_s	P	r_s	P
Landscape Metric				
B.1 Degradation of Buffers	0.72	0.01	0.78	<0.01
B.2 Surrounding Land Use	0.28	0.20	0.38	0.12
In-wetland Metric				
C.1 Impoundment	0.41	0.11	0.37	0.13
C.2 Ditching and Draining	-0.30	0.18	-0.44	0.09
C.3 Nutrient inputs	0.53	0.05	0.61	0.02
C.4 Filling and Dumping	0.46	0.08	0.60	0.02
C.5 Edge Erosion	-0.01	0.48	0.06	0.43
C.6 Crab Burrows	0.58	0.03	0.72	0.01
C.7 Ponding and Die-off	0.16	0.32	0.24	0.23
C.8 Vegetation/soil disturbance	0.12	0.36	0.42	0.10
C.9 Phragmites	0.47	0.07	0.27	0.21
Combined Metrics				
B. Landscape Stress	0.47	0.07	0.65	0.01
C. Wetland Stress	0.72	0.01	0.89	<0.01
B.1+C. Wetland and Buffer Stress	0.77	<0.01	0.92	<0.01

Table 5. Matrix demonstrating IMI marsh degradation categories in relation to categories of functions and services, marsh migration potential, and intensity of human disturbances; MD=most-degraded, ID=intermediately-degraded, LD=least-degraded; AA=above average, A=average, B=below average summed ranks of MarshRAM A.7 *Ecosystem Functions and Services*; Conservation Area=ha of adjacent land with moderately-high conservation potential; Conservation Ratio=Conservation Area/area of site; disturbance categories: X=low-intensity, XX=moderate-intensity, XXX=high-intensity; green, yellow, and red shading=highest, moderate, and lowest values in the sample, respectively.

Site	Watchemoket	Succotash	Mary's Creek	Jenny	Nausauket	Round Marsh	Rocky Hill	Mary Donovan	Mill Creek	Providence Point	Sheffield Cove
IMI Category	MD	MD	MD	ID	ID	ID	ID	ID	LD	LD	LD
Functions and Values	B	AA	B	A	A	AA	AA	A	B	A	A
Migration Potential	2.2	2.4	0.6	2.2	2.6	4.8	4.4	1.8	3.0	3.2	3.9
Conservation Area (ha)	0.4	3.2	0.0	1.6	1.1	8.5	3.3	1.8	1.0	1.7	0.8
Conservation Ratio	66%	8%	0%	12%	14%	27%	19%	5%	20%	34%	52%
Buffer Loss	XX	XX	XXX	XX	XX	XX	XX	XX			XX
Impoundment	X	X				X	XX				
Ditching		X	XX	XXX	XX	XX	X	X	XX	XX	XX
Nutrients	XXX	XX	XX		XX	XX	XX	XXX	X		
Fill	XX	XX	XXX	X		X	X	X			XX
Edge Erosion	XX	XX	XXX	XXX		XX	X	XX	XXX	X	XXX
Crab Burrows	XX	XXX	XXX	XXX	X	X	X	XXX	XX	X	
Die-off		X	XX		X	X	X	X		X	
Mowing / Soils			X	X			X	X			
Phragmites	XXX	X	X	X	XX	X	X	X	X	X	X

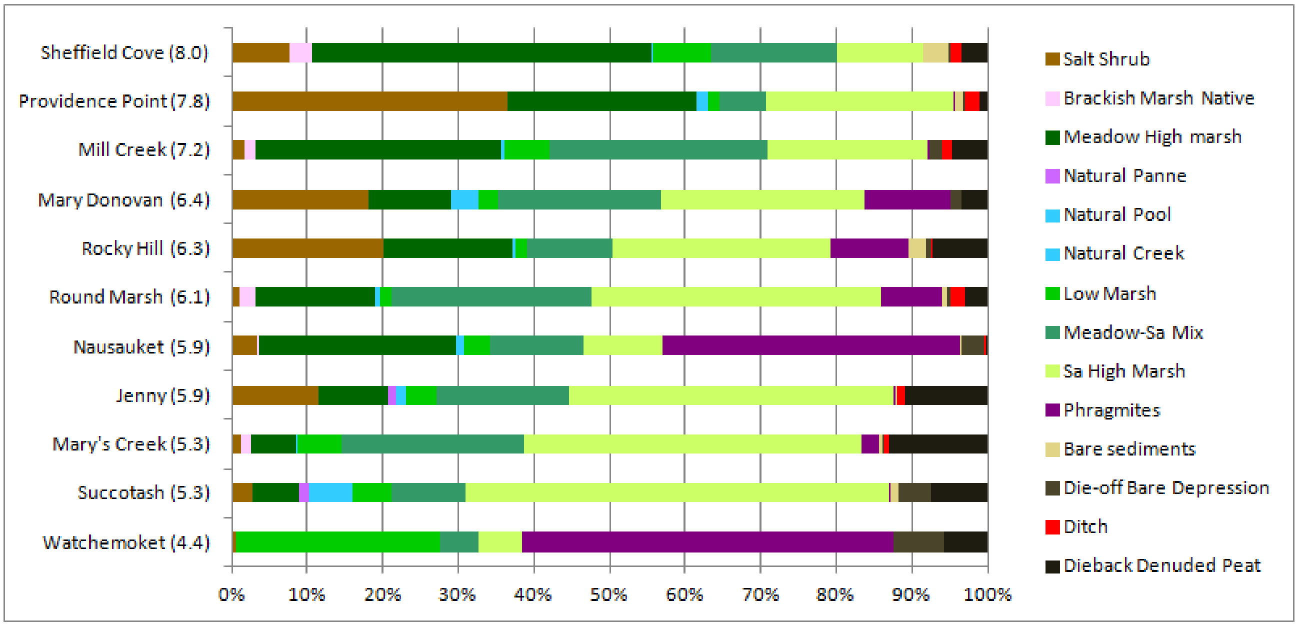

Figure 3. IMI scores (parenthetic) and relative proportions of IMI salt marsh cover types from 11 salt marshes in Rhode Island

4. Discussion

4.1 Preliminary Indications of MarshRAM Performance and Utility

This pilot study was not specifically designed to assess the empirical performance of MarshRAM as an indicator of salt marsh condition, but rather to evaluate its feasibility and identify areas of incompleteness or irrelevance that could be addressed before further testing. However, even as the sample size was small (*n*=11) and statistical power is therefore low, analysis among MarshRAM metrics, components, and existing data revealed some preliminary information about its potential functionality and utility. RINHS and state partners have secured funding to expand this sample by 20 additional salt marsh assessments during the 2018 growing season for a more rigorous evaluation.

4.1.1 Performance as an Indicator of Wetland Condition

Because they were developed separately, based on ecological theory and not on inter-correlation or correlation with any other index, MarshRAM scoring components can be viewed as separate indices. Sections B. *Landscape Stress* and C. *Wetland Stress* can be viewed as individual and aggregate metrics of wetland disturbances, whereas Section D. *Marsh Community Composition* and IMI can be viewed as marsh response to those and other (particularly increased inundation associated with sea-level rise) disturbances. Correlation among marsh community metrics (IMI, % Meadow High Marsh) and individual and aggregate disturbance metrics is therefore expected with a sample of ample statistical power. Even with the small sample size used in this pilot study, the significant relationship of marsh community composition metrics with individual *Wetland Stress* (i.e. disturbance) metrics, coupled with markedly stronger correlations between marsh community composition metrics and the aggregate

Wetland Stress sub-index, indicates that MarshRAM may be reflecting disturbance, aggregate disturbance, and ecological response to disturbance, as designed. Likewise, significant correlations of historic marsh loss with both aggregate disturbance (Sec. B and C) and marsh community composition (Sec. D) metrics suggest that MarshRAM may reflect marsh vulnerability in the face of sea-level rise. The IMI was purposely designed to reflect marsh vulnerability to sea-level rise (App. B), but the observed correlation of marsh loss with aggregate disturbances was less expected and supports prior findings that suggest certain disturbances may interact with sea-level rise, contributing to marsh degradation and vulnerability to loss (Wigand et al. 2003, 2014, Kirwan et al. 2016, Crotty et al. 2017, Watson et al 2017a).

4.1.2 Management Implications

Table 5 demonstrates the potential utility of MarshRAM for supporting management decision-making. IMI categories indicate marsh degradation and vulnerability, and individual wetland disturbance metrics identify what stressors may be contributing most to marsh degradation. Knowing the disturbances that contribute to marsh degradation is critical for restoration planning (Roman 2017, Kutcher et al. 2018), and MarshRAM may be useful to provide this information. Comparative ecosystem functions and values categories may directly help in prioritization or signal managers to look deeper into the MarshRAM data to consider individual functions and values held by a marsh. Additionally, relative values ranking the potential for each marsh to migrate—reflected in metrics estimating opportunity for landward migration (*Migration Potential*), area of surrounding land with moderately-high to high potential (*Conservation Area*), and proportion of the existing marsh that could be replaced as the marsh migrates fully onto that surrounding land (*Conservation Ratio*)—provides managers with information about what types of restoration or other intervention actions (e.g., conservation of surrounding uplands) may be most effective and efficient for a given wetland. This pilot demonstration suggests that collecting the full range of MarshRAM data across multiple sites can establish ranges of metric values (i.e. 'reference gradients') for condition, vulnerability, and migration potential, against which individual wetlands can be evaluated. This information could be used by managers to designate management categories, prioritize salt marsh ecological interventions, and inform intervention strategies for specific salt marshes.

4.2 Method Efficiency and Relevance

4.2.1 General Logistics

Fennessy et al. (2007) suggest that a rapid wetland assessment method should take no more than a day to complete. MarshRAM office and field assessments, including observational, community composition, and marsh migration sections, and all preparations and travel, took less than a single work day to conduct per marsh. Travel time was not a logistical impediment in Rhode Island where travel time rarely exceeds two hours total, but it may be a consideration for collecting MarshRAM data across multiple sites in larger states. Observational data were collected first for the first few assessments, but the order was changed to collecting vegetation community transect data first for the remainder of the sites to improve efficiency, as observations of the marsh interior could be made during the transects.

With total transect length averaging less than one km per site and site surveys planned around the low tide, physical exertion was manageable for researchers in good physical condition. However, following MarshRAM transects can require traversing marsh areas that are mucky, steep, slippery, or dominated by dense thickets of shrubs and tall grasses. Physical condition of the researchers and safety gear (e.g., hip boots, drinking water, first aid kit, cell phone, safety goggles in areas of tall reeds) should therefore be considerations, particularly for large sites, sites with challenging physical conditions, and any assessments conducted on hot summer days when dehydration and over-heating can exacerbate physical exhaustion.

4.2.2 Marsh Characteristics (Section A)

MarshRAM sections categorizing A.1 *Assessment Unit Area*, A.2 *Position in Watershed*, A.3 *Marsh Setting and Type*, A.4 *Exposed Marsh Edge*, and A.4 *Effective Fetch* were found to be complete and relevant for the 11 sites. *Tidal Range* was unknown for most sites, as many marshes in Rhode Island are located in small sub-estuaries where tide-frame data are not monitored or known. Because tidal range may be a key factor influencing salt marsh vulnerability to sea-level rise (Cole-Ekberg et al. 2017, Watson et al. 2017b), state Coastal Wetland Program partners have secured funding to collect tide-frame data in coastal lagoons of Rhode Island and sub-estuaries of Narragansett Bay in 2018 to begin assembling high-resolution tide-frame data across Rhode Island. Evaluating tide-range data in relation to marsh community composition and IMI scores (MarshRAM Sec. D) could help clarify marsh response and vulnerability to expected sea-level rise.

Sections A.6 *Connected Natural Habitats*, A.7 *Ecosystem Functions and Services*, and A.8 *Count of Waterbirds Present at Start* were all found to be complete and relevant across the study sites. A technical advisory group (C. Chaffee, W. Ferguson, K. Raposa, C. Roman, C. Wigand, T. Kutcher) agreed that A.5 *Habitat Diversity* would be more useful if it only reflected natural salt marsh habitats (i.e. without manmade features or invasive species) so that it could be used to categorize marshes by inherent community diversity for analysis. The anthropogenic features are adequately documented in the C. *Wetland Stress* section of the RAM.

Section A.7 *Ecosystem Functions and Services* (modified from USACE 1993) allows categorizing salt marshes by relative value to people and the ecosystem, which may be useful for decision-making (Table 5). Sums of the importance-classes of individual ecosystem functions and services (App. A, Section A.7) could be used to categorize the relative importance of marshes using simple above average (AA), average (A), and below average (B) categories, as demonstrated in Table 5. Although functional assessment is inherently subjective (USACE 1993), the broad importance categories used in MarshRAM may help reduce subjectivity. To further reduce subjectivity, the advisory group recommends standardizing importance-category designations; for example, a rule could require that every marsh be designated as having *evidence of known importance* (score=2) for carbon storage unless it is clearly losing peat to platform dieoff, dieback, or erosion, in which case would be designated as having *minor or potential importance* (score=1). RINHS is funded to expand MarshRAM assessments by an additional 20 sites in 2018; the advisory group recommends analyzing the consistency of *Ecosystem Functions and Services* scoring designations between users to assess inter-user variability (i.e. objectiveness).

4.2.3 Landscape Stress (Section B)

MarshRAM metric B.1 *Degradation of Buffers* was strongly correlated with IMI and the relative proportion of %MHM, suggesting that buffer integrity is important to salt marsh health. In contrast, B.2

Surrounding Land Use Intensity was not correlated with any measure of salt marsh condition or with the closely-related *Degradation of Buffers* metric, suggesting that broader landscape condition is not an important factor in salt marsh condition. This finding is in stark contrast to prior findings in freshwater systems, wherein the same surrounding landscape metric strongly reflects in-wetland condition by several measures (Kutcher and Bried 2014, Kutcher and Forrester 2018). This discrepancy may reflect the strong hydrologic, chemical, physical, and biological interactions of surrounding uplands with freshwater wetlands, in contrast to the dominating hydrologic, chemical, physical, and biological influence of tidal waters on salt marshes (Mitsch and Gosselink 2000). Further testing the *Surrounding Land Use Intensity* metric across a larger sample (scheduled for 2018) may clarify these relationships.

Metric B.2 *Surrounding Land Use Intensity* confounded the empirical performance of B. *Landscape Stress* as an equally-contributing sub-index in MarshRAM (equaling 1/3rd of the MarshRAM Index score). In contrast, *Degradation of Buffers* strongly improved the empirical performance of C. *Wetland Stress* in predicting IMI and historic loss (Tables 4 and 3, respectively). The TAC agreed that *Degradation of Buffers* should therefore be re-assigned as a *Wetland Stress* metric, while *Surrounding Land Use Intensity* should stand alone in Section B. to characterize the relative condition of the surrounding landscape, but will not contribute to the MarshRAM overall score. The MarshRAM score will hereafter be the average of only two sub-indices: C. *Wetland Stress* (renamed *Marsh Disturbances*), which will include *Degradation of Buffers* as one of 10 equally-contributing metrics, and D. IMI (App. E).

4.2.4 Wetland Stress (Section C, renamed Marsh Disturbance)

All marsh disturbances represented by the nine metrics in the B. *Wetland Stress* section of MarshRAM were documented in the pilot study sample (Table 5), and many showed signs of influencing marsh vegetation response according to IMI and % meadow high marsh (%MHM) (Table 4). Every marsh had some *Phragmites* (11 marshes) and nearly every marsh had *ditching/draining*, overabundant *crab burrowing*, and *edge erosion* (10 marshes each), but *edge erosion* and *ditching/draining* did not show signs of positive correlation with the vegetation indices. On the contrary, *ditching/draining* intensity showed a counter-intuitive preliminary tendency toward improving % MHM values, a finding that would suggest that ditching may be beneficial to marsh platform condition. More rigorous study is needed to evaluate this preliminary indication. *Ponding and Dieoff Depressions* were observed at seven (7) marshes, and mostly rated as low-intensity (<10% aerial cover of the marsh platform). MarshRAM defines die-off areas as depressions on the marsh surface having <30% cover of vegetation (Table 1), and this definition was followed for the observational *Ponding and Dieoff Depressions* metric. Many areas showing signs of platform depression and vegetation stress had vegetation cover of ≥30% and therefore did not affect the observational metric; instead, these areas were captured as *Sa High Marsh* during cover-type surveys (Fig. 3), thus influencing the IMI scores.

Importantly, the aggregate of in-wetland disturbance metrics (*Wetland Stress*) was strongly correlated with both vegetation community metrics and with historic wetland loss, suggesting that (1) *Wetland Stress* reflects both cumulative disturbance and vulnerability to loss, and that (2) IMI and % MHM indicate incremental loss of integrity (i.e., degradation) to the intensity of cumulative disturbances, as designed. As discussed in Sec 4.2.3, incorporating *buffer degradation* as an equally-contributing metric in the *Wetland Stress* sub-index improves its correlation with IMI, %MHM, and historic loss. Subsequent iterations of MarshRAM will therefore re-assign the *buffer degradation* metric to *Wetland Stress* and rename the sub-index *Marsh Disturbances* (App. E).

4.2.5 Marsh Community Composition and the Index of Marsh Integrity (IMI) (Section D)

Marsh community composition (represented by %MHM) and IMI were strongly influenced by aggregate disturbance (*Wetland Stress*) and were associated with historic marsh loss, suggesting expected performance as indicators of marsh integrity. The eight-transect method was logistically practical and correlations with measures of disturbance and loss suggest that it generates an effective estimation of relative marsh community composition. The method—employing evenly-spaced, continuous transects, each traversing the entire gradient of the marsh (elevation-hydrologic-vegetation)—was designed to accurately characterize salt marsh cover more efficiently than other available methods, such as the popular Roman et al. (2001) method, which uses 20 or more separate 1-m^2 plots, usually along fewer transects. But unlike the more precise and intensive plot-based methods, MarshRAM sampling is not designed to detect subtle changes in vegetation cover over time (although an analysis of statistical power suggests that the eight transects employed as statistical replicates should detect 10% change in cover for most cover types, R. Martin, unpublished data). Instead, the MarshRAM vegetation survey methods are designed to compare multiple sites to each other and facilitate the development of a reference gradient against which individual sites can be compared. Setting condition or vulnerability categories along such a gradient can be useful for prioritizing sites for management action and for evaluating restoration or conservation success (Stoddard et al. 2006; Faber-Langendoen et al. 2009, Kutcher 2011a).

IMI was designed to detect degradation from cumulative disturbances, including sea-level rise and direct disturbances (App. B); thus a strong correlation with the *Wetland Stress* sub-index suggests proper function as designed. Strong negative correlation of IMI with historic marsh loss suggests that IMI may additionally capture vulnerability to sea-level rise. The equally-strong correlation between historic loss and aggregate *Wetland* (and buffer) *Stress* brings to question whether vulnerability and degradation can be cleanly differentiated. Studies have suggested that wetland disturbances such as nutrients (Wigand et al. 2014), ditching (Kirwan et al. 2016), and crab overabundance (Crotty et al. 2017) can increase salt marsh vulnerability to degradation and loss stemming from sea-level rise. More rigorous study will be needed to determine whether differentiating between (1) degradation from disturbance and (2) vulnerability to sea-level rise are meaningfully distinguishable, particularly from a practical (applied) standpoint.

Interestingly, the proportion of meadow high marsh (%MHM) was generally more-strongly correlated with individual and aggregate disturbance measures than IMI. The small sample size used in this pilot study lends little confidence to the meaningfulness of this outcome, but the consistency of %MHM outperforming IMI versus disturbance raises interest in the potential mechanism of the outcome. This outcome may preliminarily suggest that meadow high marsh is among the most sensitive marsh community types (as expected—it was designated the highest-possible coefficient of 10) and its response to disturbances may be moderated by the weaker response of less-sensitive community types in IMI. IMI did respond marginally higher to historic marsh loss than did %MHM. Analysis across a larger sample may clarify the performance characteristics of IMI versus %MHM.

4.2.6 Marsh Migration Potential

The marsh migration section generates three metrics intended to inform marsh management. The (1) *Migration Potential* score is designed for coarse categorization by relative migration potential, disregarding wetland size, which may be useful for certain management decisions. For example, marshes found to be in poor condition with high migration potential might be targeted for conservation of adjacent lands, whereas those with poor migration potential may be better candidates for restoration. The (2) *Conservation Area* metric estimates the area of land adjacent to a salt marsh that is likely to support marsh migration without extensive management or cultural resistance, independent of the size of the associated marsh. This is intended to identify parcels of migration opportunity associated with large marshes that may have low overall *Migration Potential* values, but offer good opportunity for conservation of a large area of potential marsh, nonetheless. (3) *Conservation Ratio* characterizes the potential for landward migration to preserve the area of the assessed marsh (size), as existing marsh area is lost to sea-level rise. A *Conservation Ratio* of 100% would indicate that adjacent lands with moderately-high and high migration potential are just as large as the marsh itself, suggesting that with no or little management, marsh area could remain relatively unchanged as the marsh migrates landward while it is lost at the seaward edges. Conversely, a *Conservation Ratio* of 5% would indicate that the surrounding landscape with good migration potential is only capable of replacing 5% of existing marsh area; therefore, without manipulation of the landscape or infrastructure, the marsh is unlikely to migrate and will need restoration or intervention action to conserve its functions and values.

In its current form, SLAMM does not incorporate biological opportunity (i.e. adjacency to existing marsh vegetation) or vegetative and cultural resistance (other than presence of buildings), which may contribute to its apparent over-estimation of migration potential. MarshRAM works at the individual-salt-marsh scale and uses SLAMM elevation data to create a “bathtub” inundation model similar to SLAMM, but instead incorporates biological opportunity, vegetation resistance, and cultural resistance to estimate migration opportunities specific to the marsh under assessment. MarshRAM does not consider marsh accretion rate (i.e. the ability of the marsh to sustain under sea-level rise rate scenarios) and therefore only estimates potential for marsh gain, but not for marsh loss or net change, as SLAMM predicts. MarshRAM assumes that migration potential is always beneficial, regardless of the actual rate of sea-level rise or marsh loss. However, MarshRAM does implicitly assume inevitable loss of existing marsh area—an assumption informed by consensus forecasts of accelerating sea-level rise (NOAA: https://www.climate.gov, accessed April 2018), recent findings of a current deficit in marsh-platform elevation gain (Raposa 2017a), historic marsh losses (Watson 2017b), and predictions of marsh drowning and loss based on ecological monitoring (Raposa 2017b, Watson 2017a). If these broad predictions of rapid salt marsh loss are realized, marsh migration may be the most practical and sustainable way to conserve salt marsh ecosystem functions and services for the future (Donnelly and Bertness 2001, CRMC 2015, Watson et al. 2017b), highlighting the need for increasingly more accurate and comprehensive predictive tools (Raposa et al. 2016, Roman 2017, Kutcher et al. 2018).

4.3 MarshRAM Updates

Based on feedback and findings of the 2017 field test and pilot study of MarshRAM, changes were made to the original datasheet (App. A) to increase its performance and clarify terminology, as summarized below. The changes are incorporated in the updated MarshRAM datasheet (App. E), which will be used for an expanded study at 20 additional sites in 2018.

- Sec. A.4 *Exposed Marsh Edge* 0% category is changed to <5% to reduce confusion over how to categorize back barrier systems with small openings.
- Sec. A.5 *Habitat Diversity* is changed to *Natural Habitat Diversity* as discussed in Sec. 4.2.2 of this report.
- The sparrow tally is removed in Sec. A.8 *Count of Waterbirds* because it was cumbersome to conduct and redundant with more-standardized sparrow tallies recorded in Sec. D.
- *Degradation of Buffers* is moved from Sec. B to an equally-weighted metric of Sec. C. and renamed *Buffer Encroachment*. Sec. B. becomes *Surrounding Land Use*, a standalone metric that does not contribute to the MarshRAM index, as discussed in Sec. 4.2.3 and 4.2.4 of this report.
- Sec. C. *Wetland Stresses* is renamed *Wetland Disturbances* for improved accuracy of terminology. The associated sub-index is now the average of ten rather than nine metrics due to the addition of *Buffer Encroachment* metric.
- Sec. D is renamed *Marsh Community Composition and Index of Marsh Integrity* to more accurately reflect its function. The tally and index table is modified to reflect the heading for *Coefficients of Community Integrity* (CCI) and a column is added for documenting the % cover of each community type. These changes are also reflected in the formulae for the indices.
- The RIRAM Condition Index is changed to the average of sub-indices C and D only, as Sec. B. *Surrounding Land Use* is no longer averaged in.

4.4 Transferability across Regions

The content of MarshRAM could be modified for application in other states, across regions, or across multiple regions, such as nationwide. Although rapid assessment methods for estuarine wetlands in other states exist (Jacobs 2003, Carullo et al. 2007, CWMW 2013), MarshRAM may offer benefits not provided by others, such as: broad setting and classification information; a ranking method for functions and values; opportunistic waterbird and marsh bird tallies; a tested surrounding-landscape evaluation model (Bried et al. 2013, Kutcher and Forrester 2018); disturbance metrics with evidence and causation associations for policy analysis; vegetation community composition information that can generate metrics of degradation/vulnerability; and site-level information characterizing landward migration potential. Also, MarshRAM keeps inherent function and value information separate from disturbance and degradation information, which is important for effective assessment of wetland condition (Fennessy et al. 2007), analysis, and decision support (Table 5). The inclusive, yet rapid framework of MarshRAM may be attractive to applied scientists and managers beyond Rhode Island because, with a single visit per marsh, it provides information that may be useful for: characterizations of condition and value, cause-and-effect analysis, prioritization for restoration and conservation, and assessment of restoration success.

4.4.1 Recommendations for MarshRAM Transferability

Some MarshRAM attributes and metrics may need to be modified for application of MarshRAM across regions, but the utility of the RAM— e.g., categorizing marshes by attributes for analysis, identifying specific disturbances and their individual and aggregate influences on marsh integrity, comparing individual marshes against a "reference gradient" of condition for management planning—can be preserved. Following are recommendations to facilitate MarshRAM interoperability across regions (App. E).

- A.1 *Assessment Unit Area* could be expanded to include categories covering larger marshes as necessary.
- A.2 *Position in Watershed* could be modified to reflect ecologically-meaningful sub-regions for another region, or standardized for use across regions.
- Sub-attributes under A.3 *Marsh Setting and Type* could remain or be modified as needed to cover small or large regions.
- A.4 *Exposure to Tides* / *Tidal Range* could be expanded to accommodate larger tides.
- A.5 *Natural Habitat Diversity* and A.6 *Connected Natural Habitats* could be modified or expanded to cover habitat types in other regions.
- A.8 *Count of Waterbirds* could be expanded or modified as needed to characterize waterbirds in other regions.
- B. *Surrounding Land Use* should be applicable across regions.
- Metrics in Sec. C. *Wetland Disturbances* could be evaluated for relevance in other regions or across broad regions. Region-specific metrics such as C.7 *Crab Burrow Intensity* and C. 10 *Phragmites within Wetland* could be replaced with other similar biological disturbances (e.g. invasive and nuisance species known to degrade marsh structure or function) or omitted from the *Wetland Disturbances* model. Other, more-universal metrics could remain or be modified as needed to better reflect regional or more-universal conditions. The *Wetland Disturbances* index would remain as the average of the metrics.
- Sec. D. *Marsh Community Composition* and *Index of Marsh Integrity* could be modified, as needed, to reflect regional marsh community cover-types. Regional experts could use the same criteria as used in Rhode Island (App. B) to assign 'coefficients of community integrity' (CCI) to clearly-discernible tidal wetland cover-types that reflect meaningful vegetation response to individual, cumulative, and interactive disturbances. Formulae would remain the same to characterize community composition and generate the IMI index. IMI index scores may need to be standardized for comparisons across regions, but the utility of the index (categorization by condition and vulnerability, and analysis) would remain the same. For very large marshes, the number of transects running from upland to water's edge could be reduced to save time and effort, at the expenses of accuracy in characterizing community composition and degradation, and capacity for change analysis.

4.4.2 MarshRAM Assessment Unit

MarshRAM was designed to characterize and assess entire contiguous salt marshes bounded by uplands, open water, or manmade features that clearly isolate the hydrology or function of a marsh. Other rapid methods have used one or more plots to represent a marsh (Carullo et al. 2007, CWMW 2013), but several MarshRAM attributes and metrics would not transfer effectively into plot-based methods because they rely on estimating attributes or proportions in relation to the entire unit. It is therefore recommended that MarshRAM be conducted across the entire marsh, even if time or logistical concessions need to be made for very large marshes.

4.5 Conclusion

MarshRAM is designed to be a practical and effective method of rapidly documenting information characterizing salt marsh type, setting, value, condition, vulnerability, and opportunity for landward migration. The method is intended to be used for gaining perspective on the conditions at individual marshes in reference to conditions at marshes statewide, and to analyze the relative effects of individual and aggregate disturbances on wetland integrity and vulnerability. MarshRAM collects categorical and semi-quantitative observational information, and quantitative community composition data, from aerial imagery and a single site survey, taking less than a day per marsh to complete. MarshRAM generates indices of relative aggregate functions and values, surrounding land use intensity, wetland aggregate disturbances, marsh community integrity, and landward migration potential. The indices can be used individually, analyzed in relation to each other, or aggregated to serve various marsh-management objectives. MarshRAM additionally documents qualitative information on several attributes of salt marshes to facilitate categorization for analysis and management.

Preliminary analysis suggests that, as designed, MarshRAM may reflect individual, cumulative, and interactive disturbances; incremental degradation of marsh integrity; and vulnerability to loss from sea-level rise and other disturbances. A draft management matrix, using MarshRAM data collected during this pilot study, demonstrates how MarshRAM data can provide information for salt marsh management. It is anticipated that MarshRAM will serve as a useful tool to prioritize salt marsh management opportunities, inform restoration and conservation methods, assess restoration outcomes, and inform policy decision-making. The format of MarshRAM allows for adjustments to meet the needs of other regions or broader applications. A more-rigorous, upcoming study evaluating MarshRAM performance may clarify the preliminary findings of this study.

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Appendix A

MarshRAM datasheet used to assess 11 salt marshes in 2017

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

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

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

2) Position in Watershed

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

3) Marsh Setting and Type

Geomorphic Setting; select primary one or two

- ☐ Open Coast
- ☐ Open Embayment
- ☐ Finger
- ☐ Riverine
- ☐ Back Barrier Marsh
- ☐ Back Barrier Lagoon

Geoform; select one

- ☐ Platform
- ☐ Fringe

Adjacent upland; select primary one or two

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

Tidal water salinity; select one

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

Freshwater input; select primary one or two

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

4) Exposed Marsh Edge*

Estimate exposed edge by dividing length of exposed wetland edge by unit total circumference.

- ☐ 0 % no or intermittent exposure
- ☐ 1 – 25 % low exposure
- ☐ 26 – 50 % moderate exposure
- ☐ > 50 % high exposure

*Effective Fetch of Tidal Water**

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

Tidal Range

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

5) Habitat Diversity; Indicate presence of all significant habitat types by checking all present

- ☐ Salt Shrubs
- ☐ Brackish Marsh
- ☐ High Marsh Platform
- ☐ Pools
- ☐ Established Pannes
- ☐ Tall Sa Low Marsh
- ☐ Creeks and Ponds
- ☐ Phragmites
- ☐ Ditches

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

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

7) Ecosystem Functions and Services; Estimate importance of all evident or known according to classes at right:

___ 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

Explain special importance ____

8) Count of Waterbirds Present at Start: Wading Birds ________ Shorebirds ________ Waterfowl ________ Raptors ________ Gulls ________ Salt Marsh 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. Landscape Stresses. Sum metrics 1 and 2

Associated Stressors: Check all that apply

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

1) Degradation of Buffers

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

- ☐ <5% (5)
- ☐ 6 to 25% (4)
- ☐ 26-50% (3)
- ☐ 51-75% (2)
- ☐ >75% (1)

2) Intensity of Surrounding Land Use (max = 5)

Adjacent Land Use Intensity weighted average within 150-m buffer.
Estimate proportion of <u>each</u> class to the ***nearest tenth*** and <u>multiply</u>.

	Proportion	Score	Weighted Value
Very Low	______	× 5 =	______
Low	______	× 4 =	______
Moderately High	______	× 2 =	______
High	______	× 0 =	______

Sum weighted values for score = ______

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

Sum of Metrics 1 and 2 = ☐ **B. Landscape Stress Score**

C. Wetland Stresses. Average metrics C.1 to C.9.

1) Impoundment and Tidal Restriction. Change in depth or hydroperiod. Select <u>one</u>.
If less than half of the marsh is impounded or restricted, average score with 10.

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

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

Primary Associated Stressor; check one:

- ☐ Road
- ☐ Railway
- ☐ Weir / Dam
- ☐ Raised Trail
- ☐ Development Fill
- ☐ Other ___________

Evidence: check all that apply

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

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

Select one

- ☐ None observed (10)
- ☐ Low (7)
- ☐ Moderate (4)
- ☐ High (1)

<u>Key: density of ditches</u>

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

3) Anthropogenic nutrient inputs.

Select the evidence of sources and impact.

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

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

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

4) 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.

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

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

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

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

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

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

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

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

6) Crab burrow intensity. Select the appropriate category. Marsh edge includes major creeks.
- ☐ None (10): Burrows are limited to the peat edge with dense vegetation
- ☐ Low (7): <10% of the marsh edge is densely burrowed and partly or fully denuded
- ☐ Moderate (4): 10-60% of the marsh edge is densely burrowed and denuded
- ☐ High (1): >60% of the marsh edge is densely burrowed and denuded

Evidence: check all observed
- ☐ Dense crab burrows
- ☐ Eroding or oversized crab burrows
- ☐ Burrowing crabs
- ☐ Clipped vegetation
- ☐ Denuded areas of peat

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

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

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

8) Vegetation mowing / removal / soil disturbance. Select intensity of vegetation or soil disturbance.

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

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

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

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

9) Phragmites within wetland. Select one class for total coverage.

- ☐ None noted (10)
- ☐ Low: <10% cover (7)
- ☐ Moderate: 10-60% cover (4)
- ☐ 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:
- ☐ Road
- ☐ Railway
- ☐ Raised Trail
- ☐ Footpath
- ☐ Dam / Dike
- ☐ Organic / yard waste
- ☐ Other Fill
- ☐ Mowed Lawn
- ☐ Crops
- ☐ Pasture
- ☐ Drainage ditch / tile
- ☐ Stormwater input
- ☐ Clearing
- ☐ Multiple
- ☐ Residential Development
- ☐ Other

Sum of C1 to C9 Scores = _________ ÷ 9 = ☐ C. Wetland Stress Score

D. Marsh Habitat 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				
Meadow-Sa Mix				
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				
Meadow-Sa Mix				
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.1S Investigators____ Site Code_____________ Date_________

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

	CC	Total Tally	CC X TT
Salt Shrub	9		
Brackish Marsh Native	10		
Phragmites	3		
Meadow High Marsh	10		
Meadow-Sa Mix	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:		

D. Habitat Integrity Score $= \frac{\text{Sum (CC X TT)}}{\text{Sum (Total Tally)}}$

= [ ]

B. Landscape Stress Score (max 10) __________

C. Wetland Stress Score (max 10) __________

D. Habitat Integrity Score (max 10) __________

MarshRam Condition Index
Average of B, C, and D

Appendix B

MarshRAM Coefficient of Community Integrity Designation Worksheet

Zone	Sensitivity to SLR (0-4)	Sensitivity to other Stress (0-4)	Habitat Value (0-2)	Sum
Salt Shrub				
Brackish Marsh Native				
Phragmites				
Meadow High Marsh				
Meadow-Sa Mix				
Stunted Sa Marsh				
Dieoff Bare Depression				
Low Marsh				
Dieback Denuded Peat				
Natural Panne				
Natural Pool				
Creek				
Ditch				
Bare Sediments				
Sensitivity	0	Thrives on or end result of stress		
	1	Sustained or increased by stress		
	2	Neutral to stress		
	3	Affected or decreased by stress		
	4	Sensitive to stress		
Habitat Value	0	Low		
	1	Med		
	2	High		

Appendix C

MarshRAM Migration Potential Metric

1) Migration Potential V 3.0

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 weighted value score must be within 0.0 to 10.0.

Landward* Surface Waters

No Potential:

____ Lake/pond
____Ocean
____Estuary
____Other

Sum = ____ x 0 = __0__

*separated from marsh by upland

Elevated Land >0.9m 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 <0.9m 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 = ____

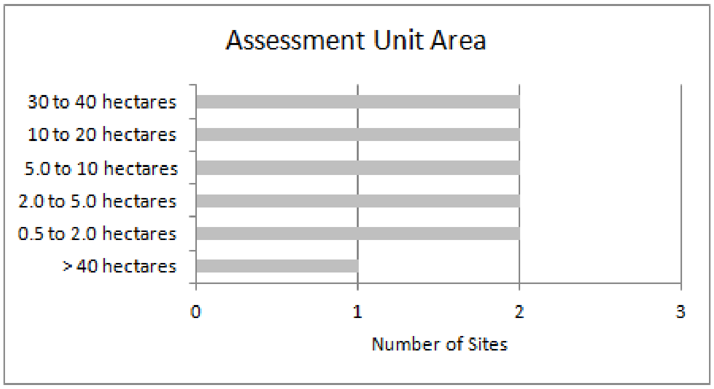
Sum weighted values for Migration Potential score: [ ]

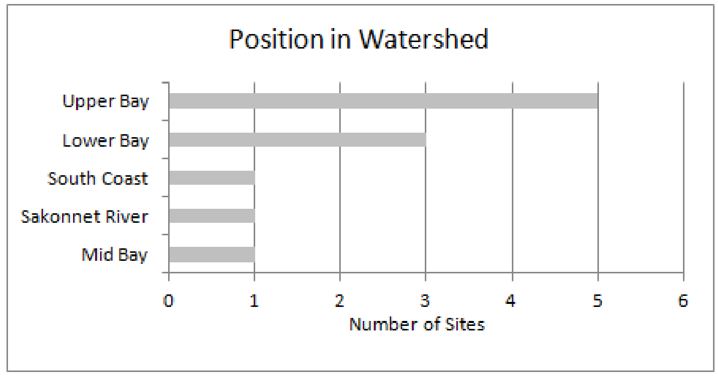
A. Area of Marsh = _________
B. Area of surrounding land to 60m = ________
C. Proportion of Moderately High +High class = ________
D. Area of Moderately High and High potential = B X C = ________
E. Conservation Ratio = D ÷ A = _________

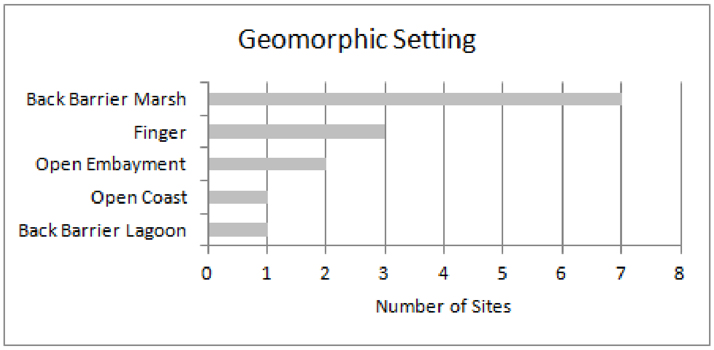
Appendix D

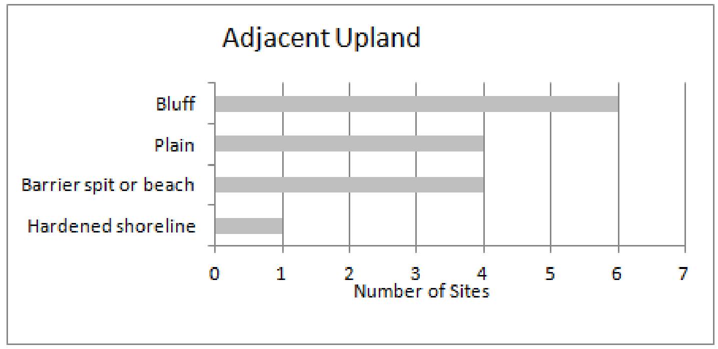
Graphs of MarshRAM Attributes and Metric Scores at 11 Salt Marshes Assessed 2017

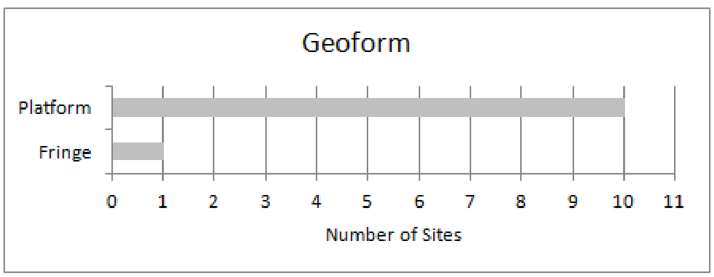
A. Marsh Characteristics

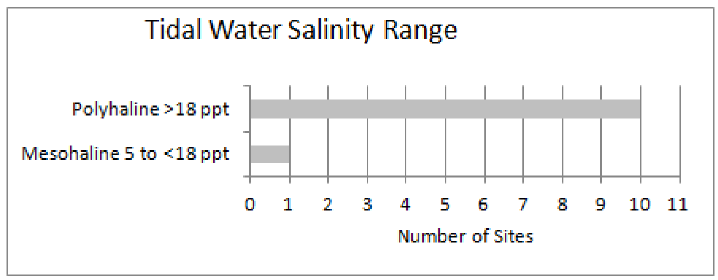


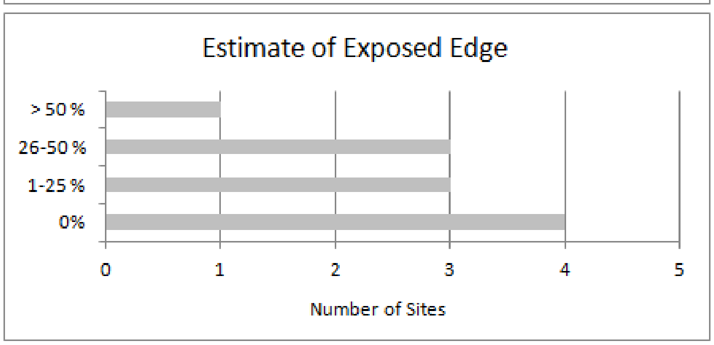


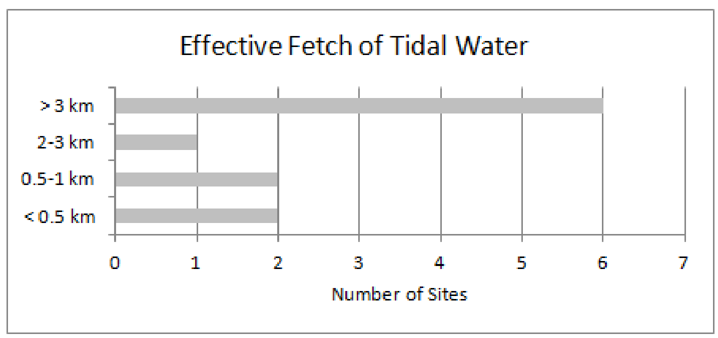


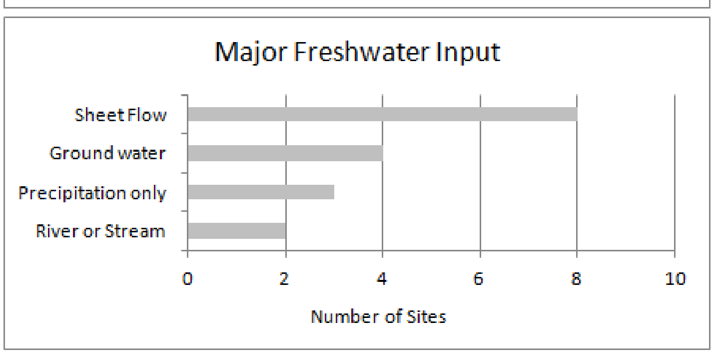


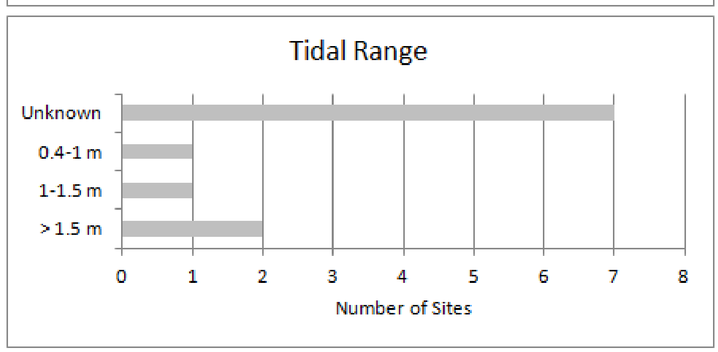


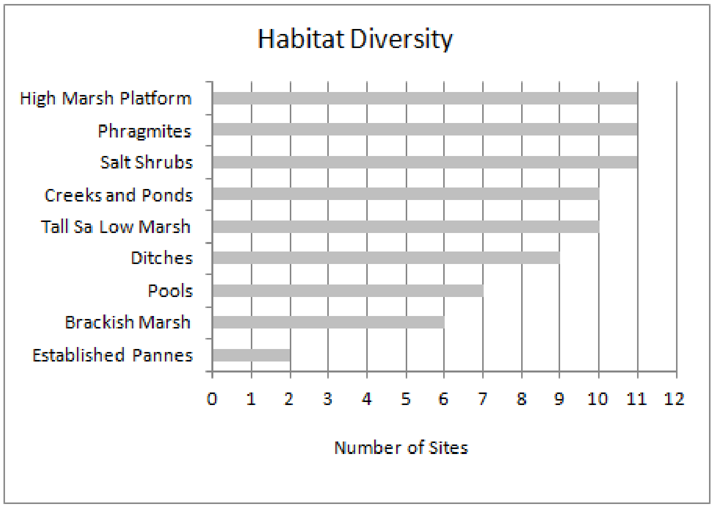


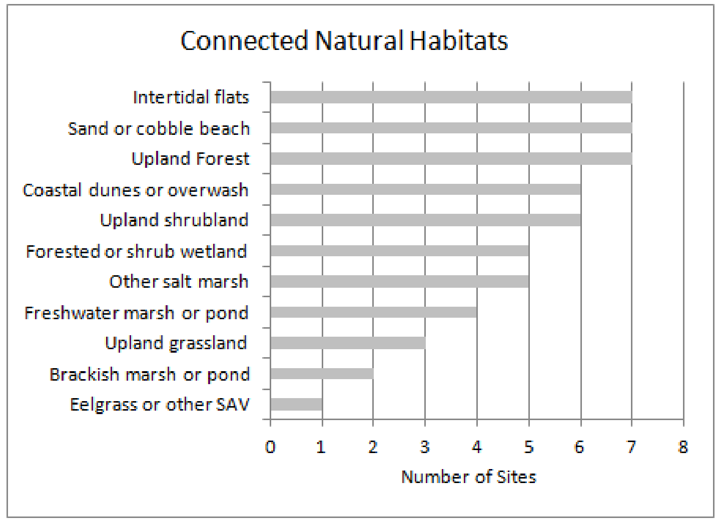


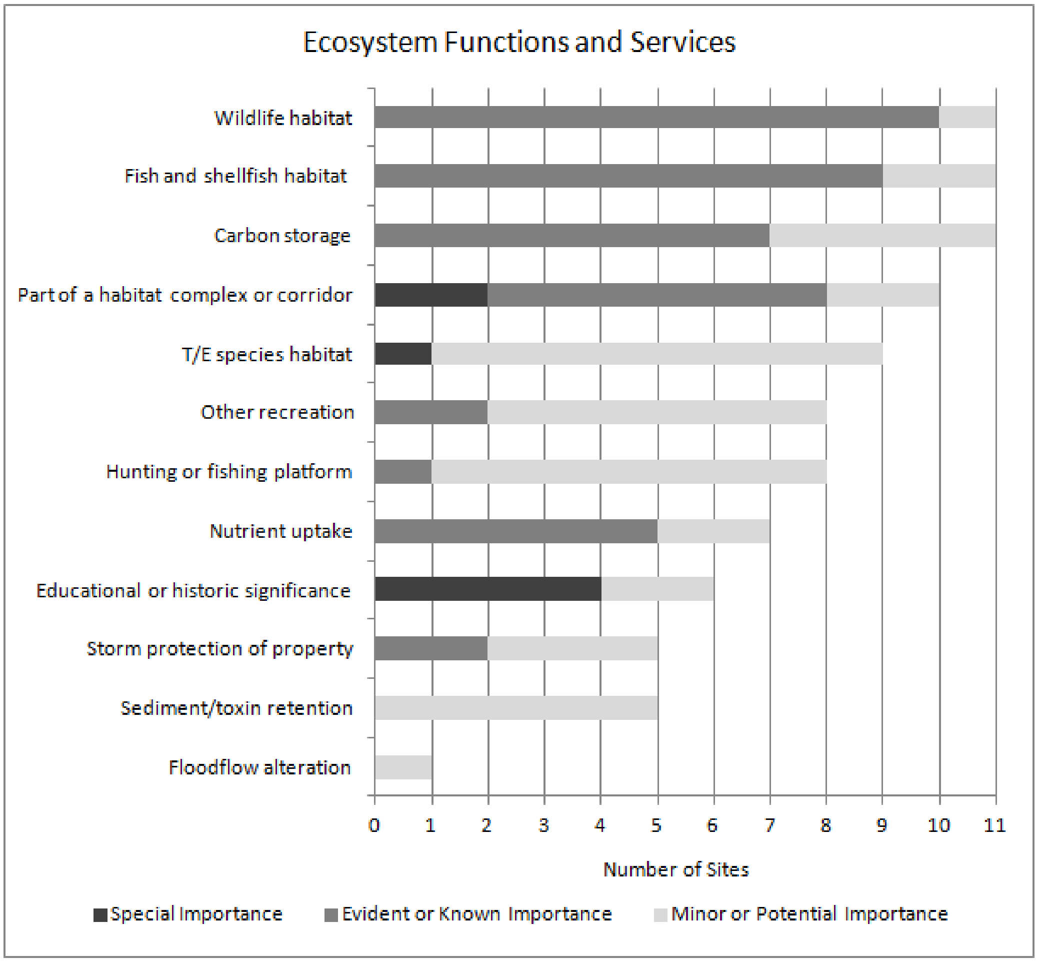


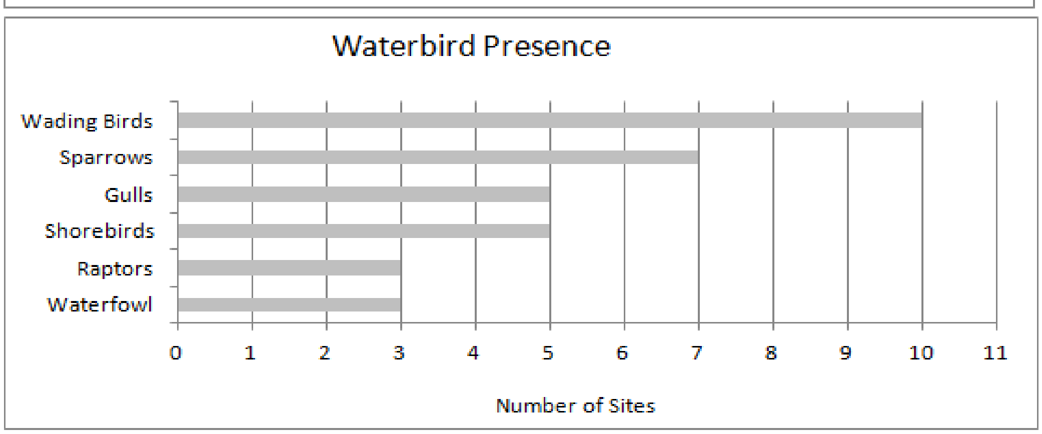




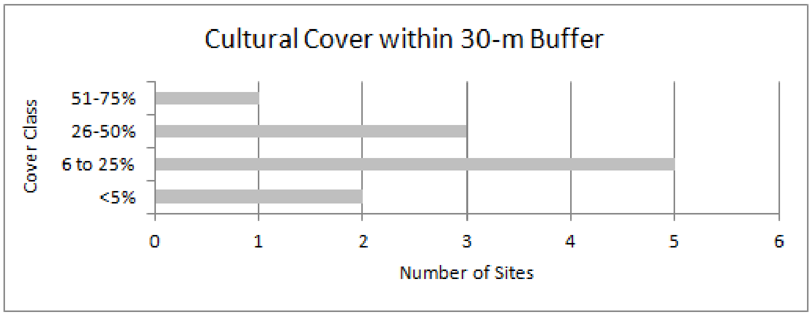

Habitat Diversity
High Marsh Platform
Phragmites
Salt Shrubs
Creeks and Ponds
Tall Sa Low Marsh
Ditches
Pools
Brackish Marsh
Established Pannes
0 1 2 3 4 5 6 7 8 9 10 11 12
Number of Sites

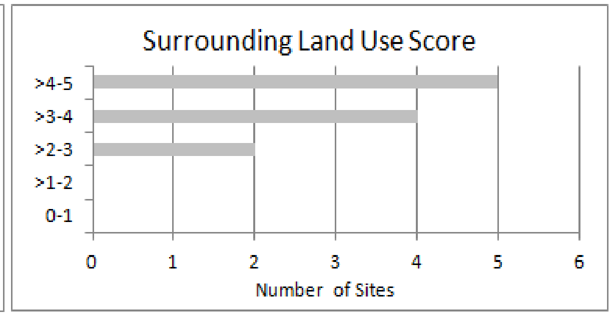

Connected Natural Habitats
Intertidal flats
Sand or cobble beach
Upland Forest
Coastal dunes or overwash
Upland shrubland
Forested or shrub wetland
Other salt marsh
Freshwater marsh or pond
Upland grassland
Brackish marsh or pond
Eelgrass or other SAV
0 1 2 3 4 5 6 7 8
Number of Sites

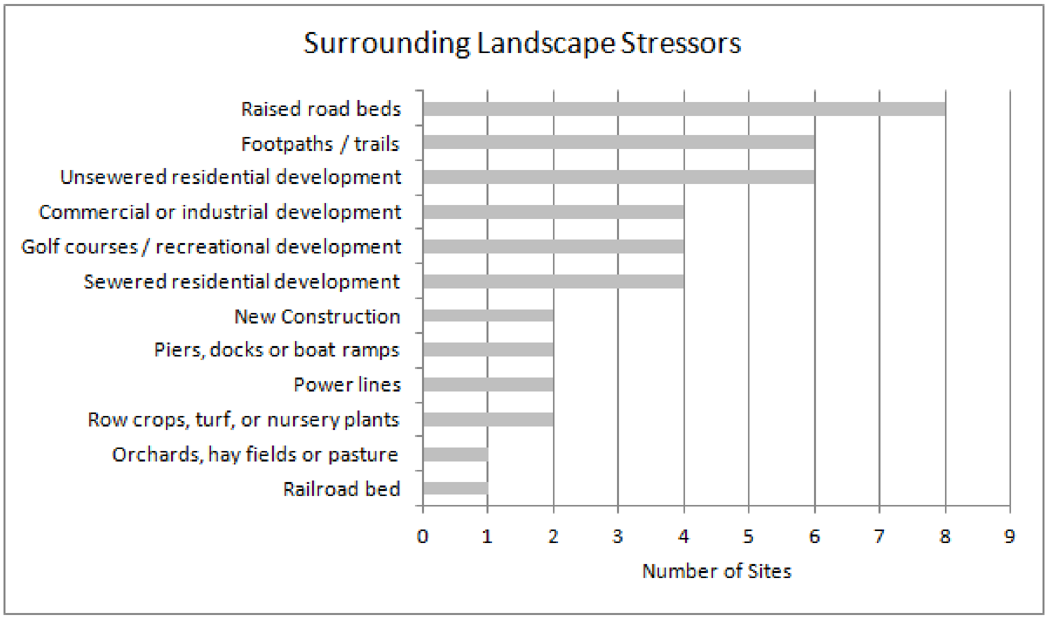

Ecosystem Functions and Services
Wildlife habitat
Fish and shellfish habitat
Carbon storage
Part of a habitat complex or corridor
T/E species habitat
Other recreation
Hunting or fishing platform
Nutrient uptake
Educational or historic significance
Storm protection of property
Sediment/toxin retention
Floodflow alteration
0 1 2 3 4 5 6 7 8 9 10 11
Number of Sites
Special Importance
Evident or Known Importance
Minor or Potential Importance

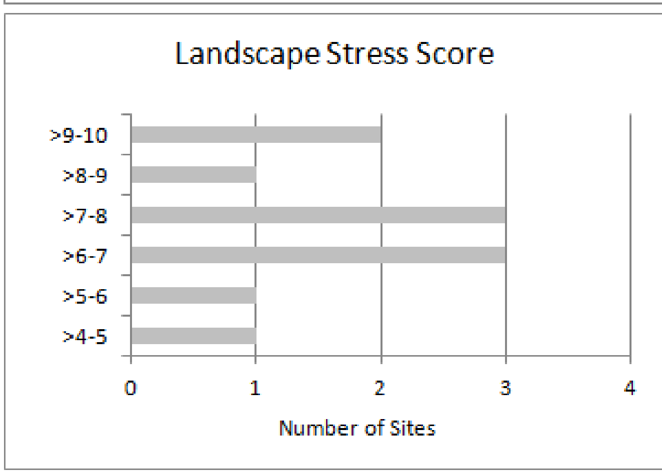

Waterbird Presence
Wading Birds
Sparrows
Gulls
Shorebirds
Raptors
Waterfowl
0 1 2 3 4 5 6 7 8 9 10 11
Number of Sites

B. Landscape Metrics



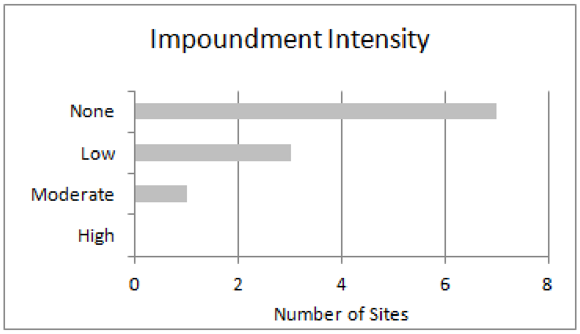


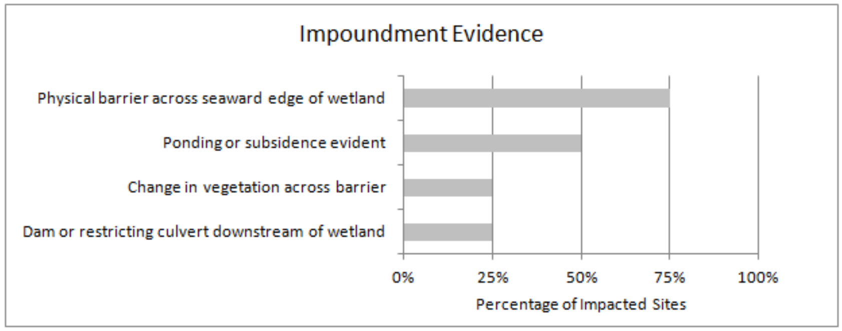


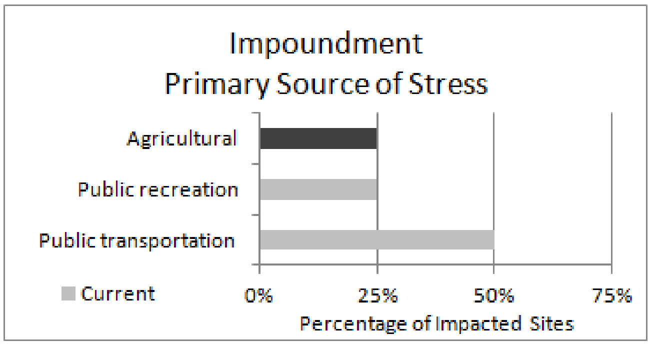


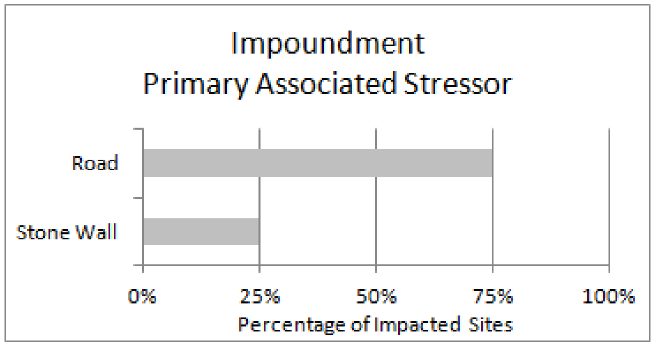
C. Wetland Stresses

1. Impoundment

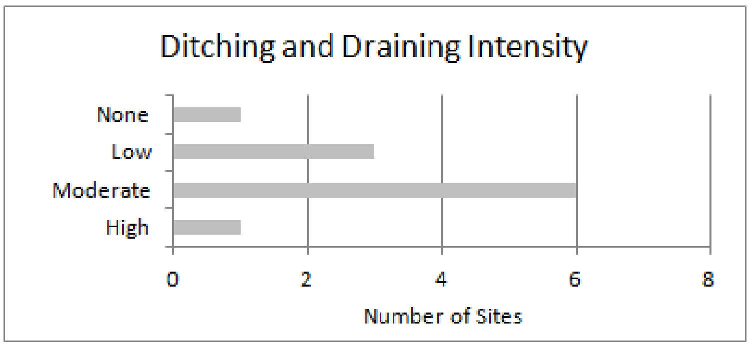




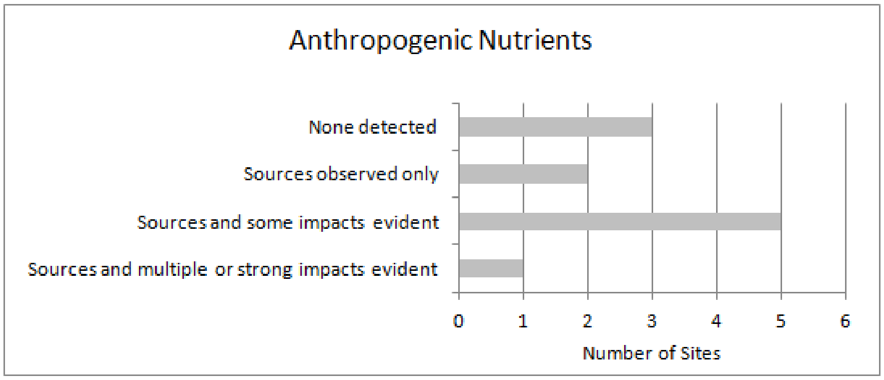


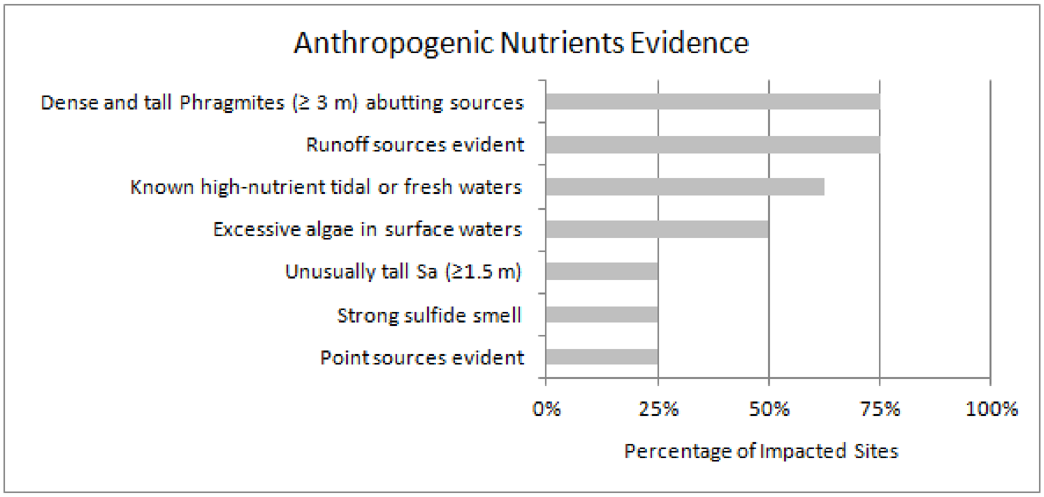


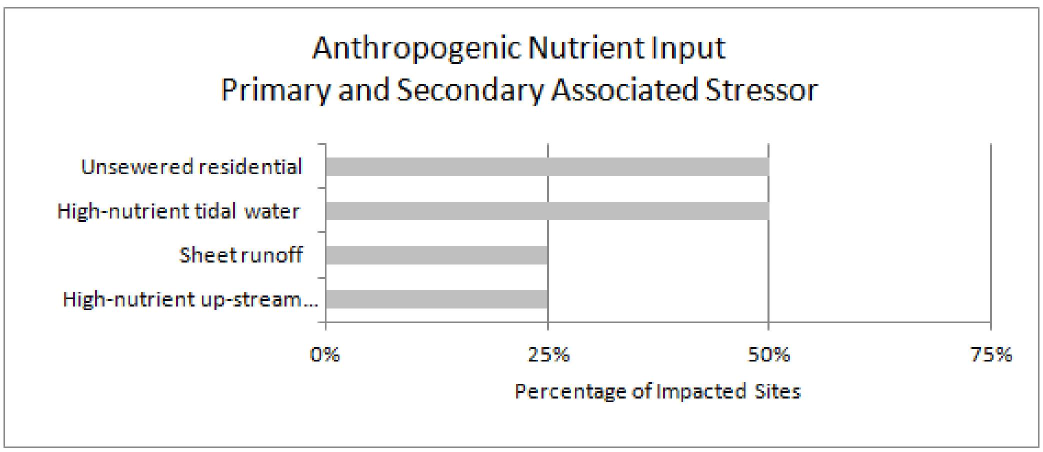
2. Ditching and Draining

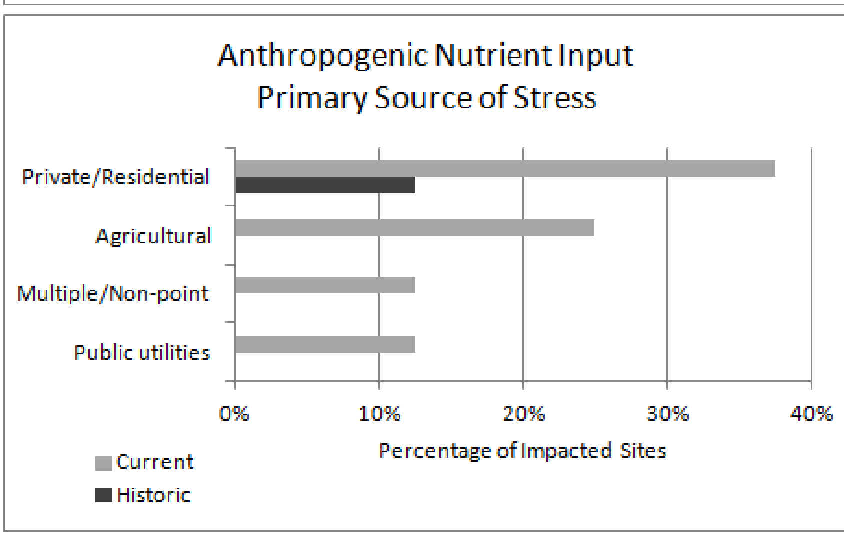


3. Anthropogenic Nutrients

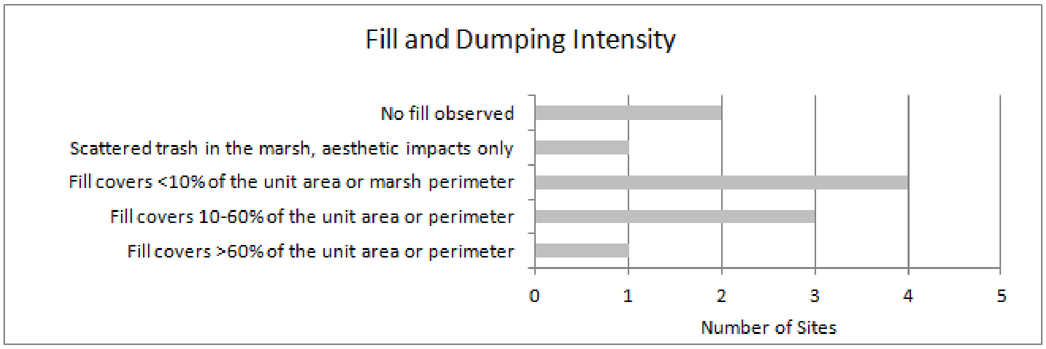


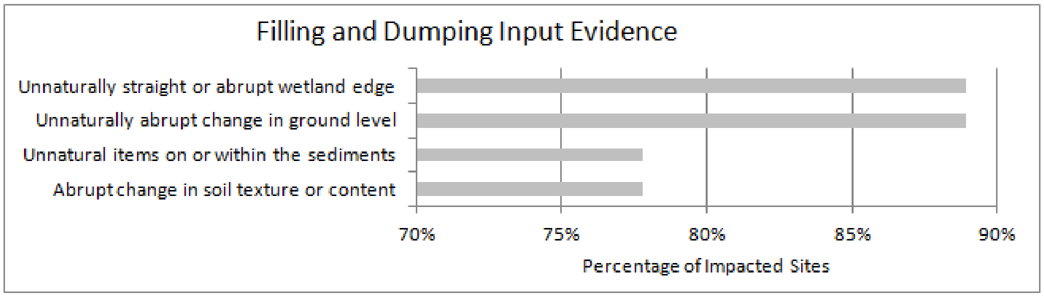


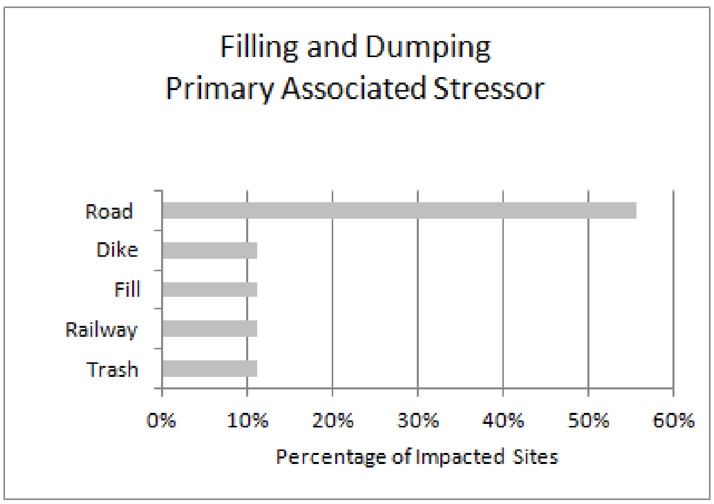


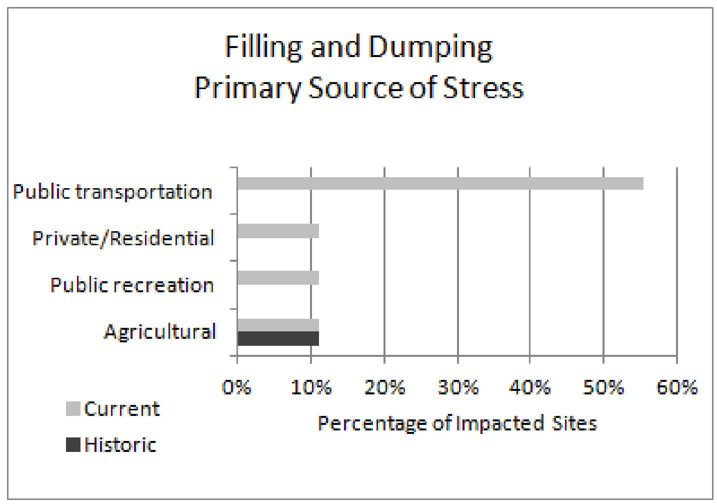


4. Filling and Dumping

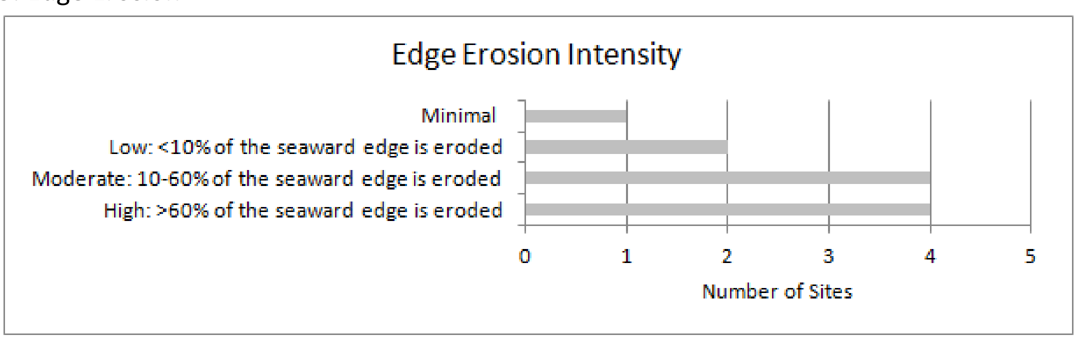


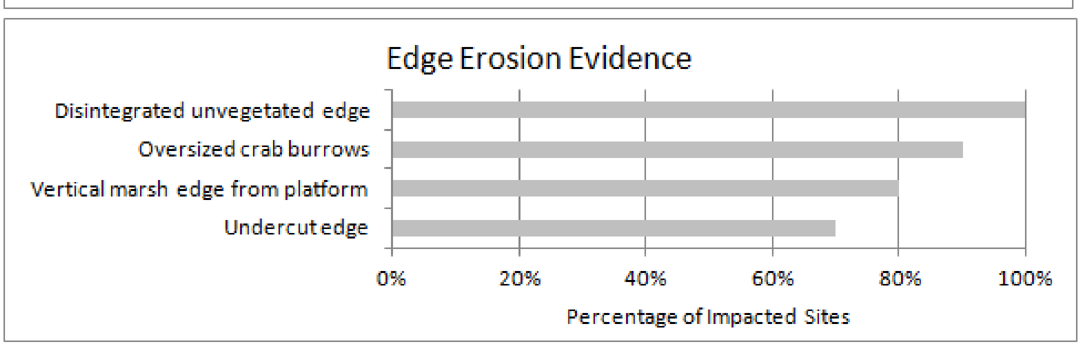




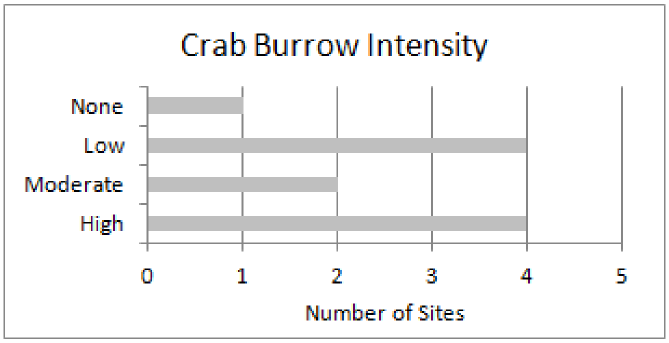


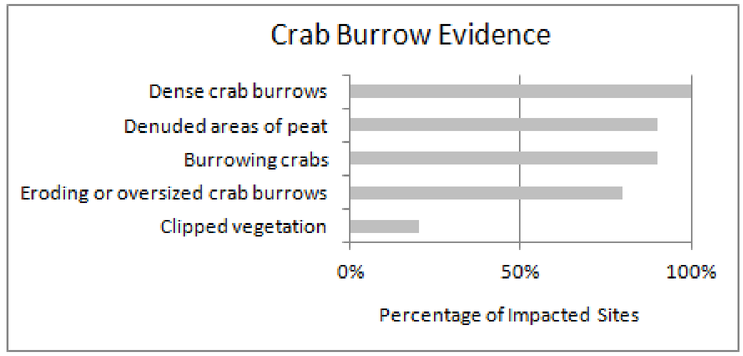
5. Edge Erosion



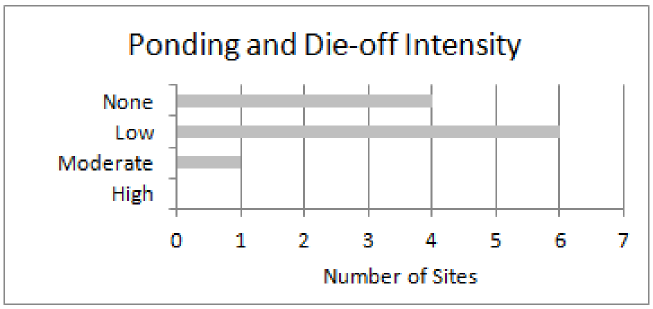


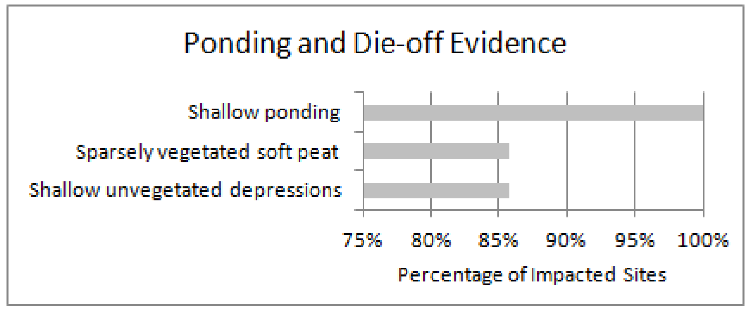
6. Crab Burrow Intensity



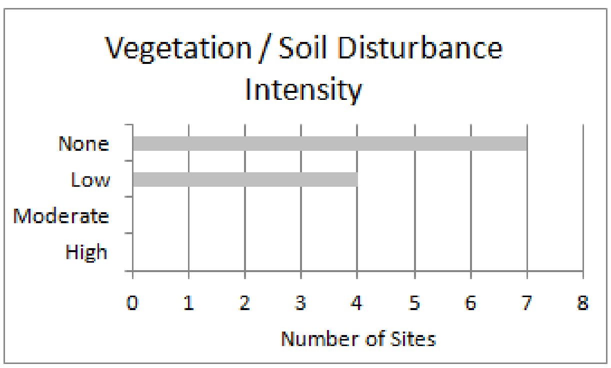


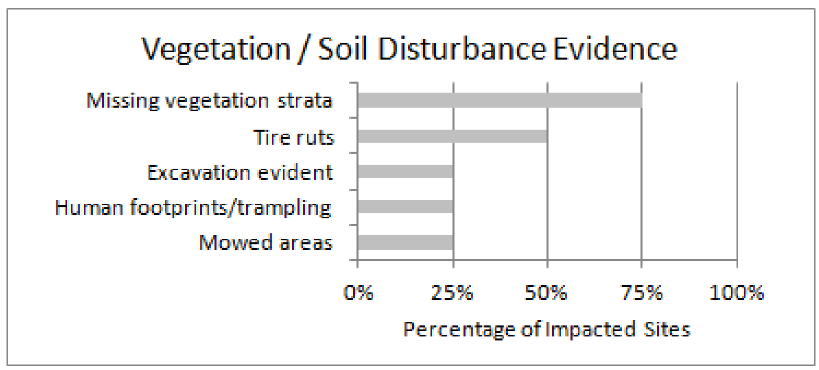
7. Ponding and Die-off

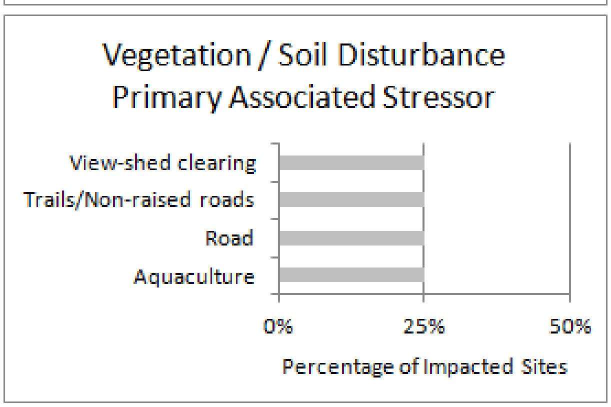


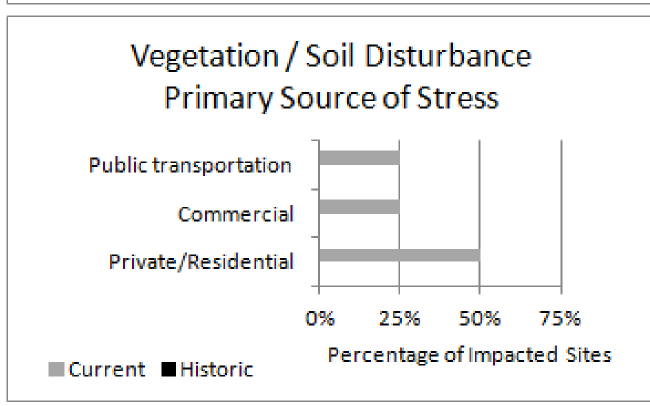


8. Vegetation / Soil Disturbances

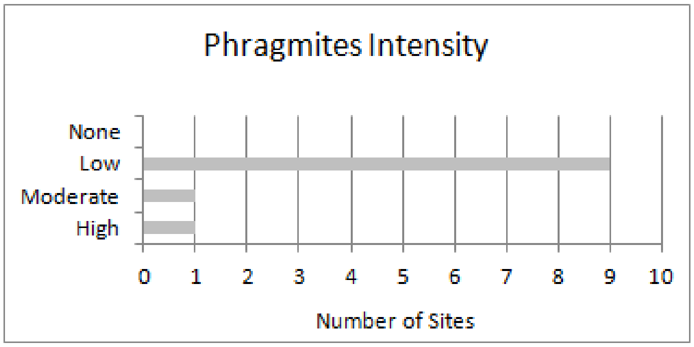


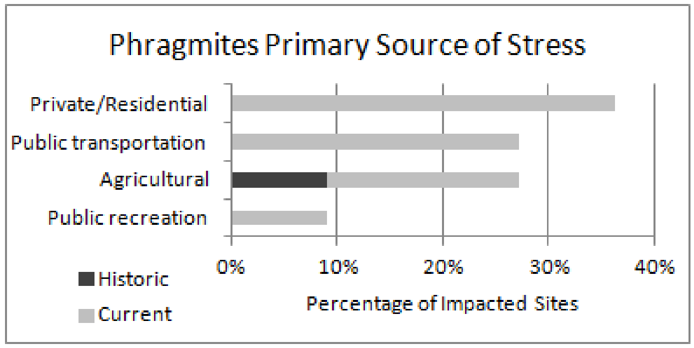


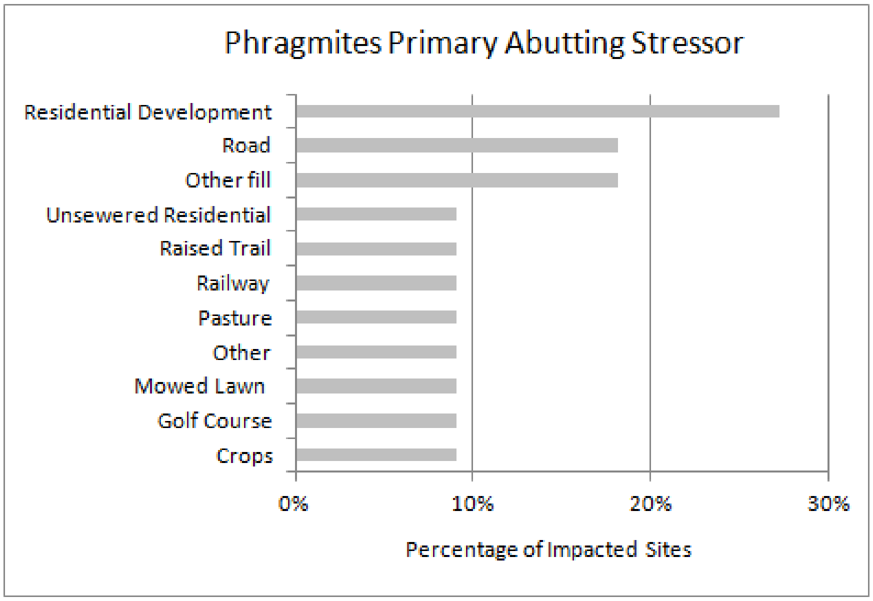




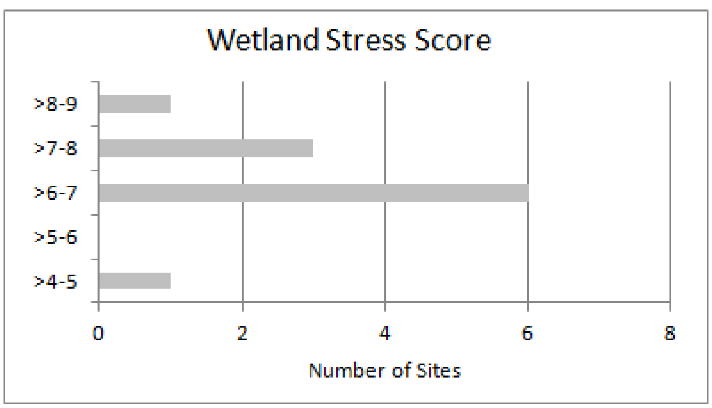
9. Phragmites

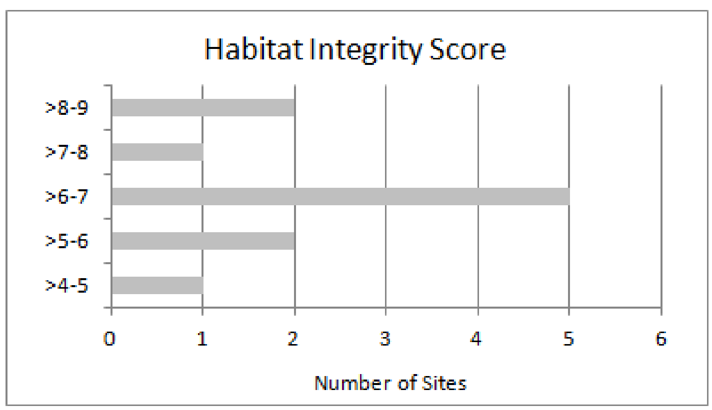


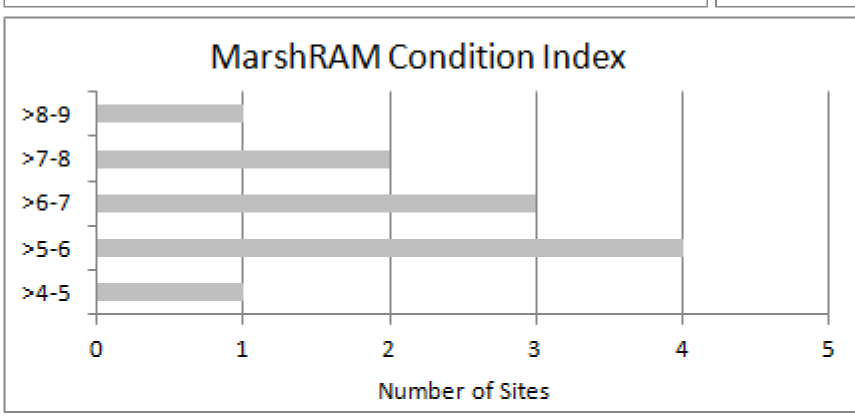




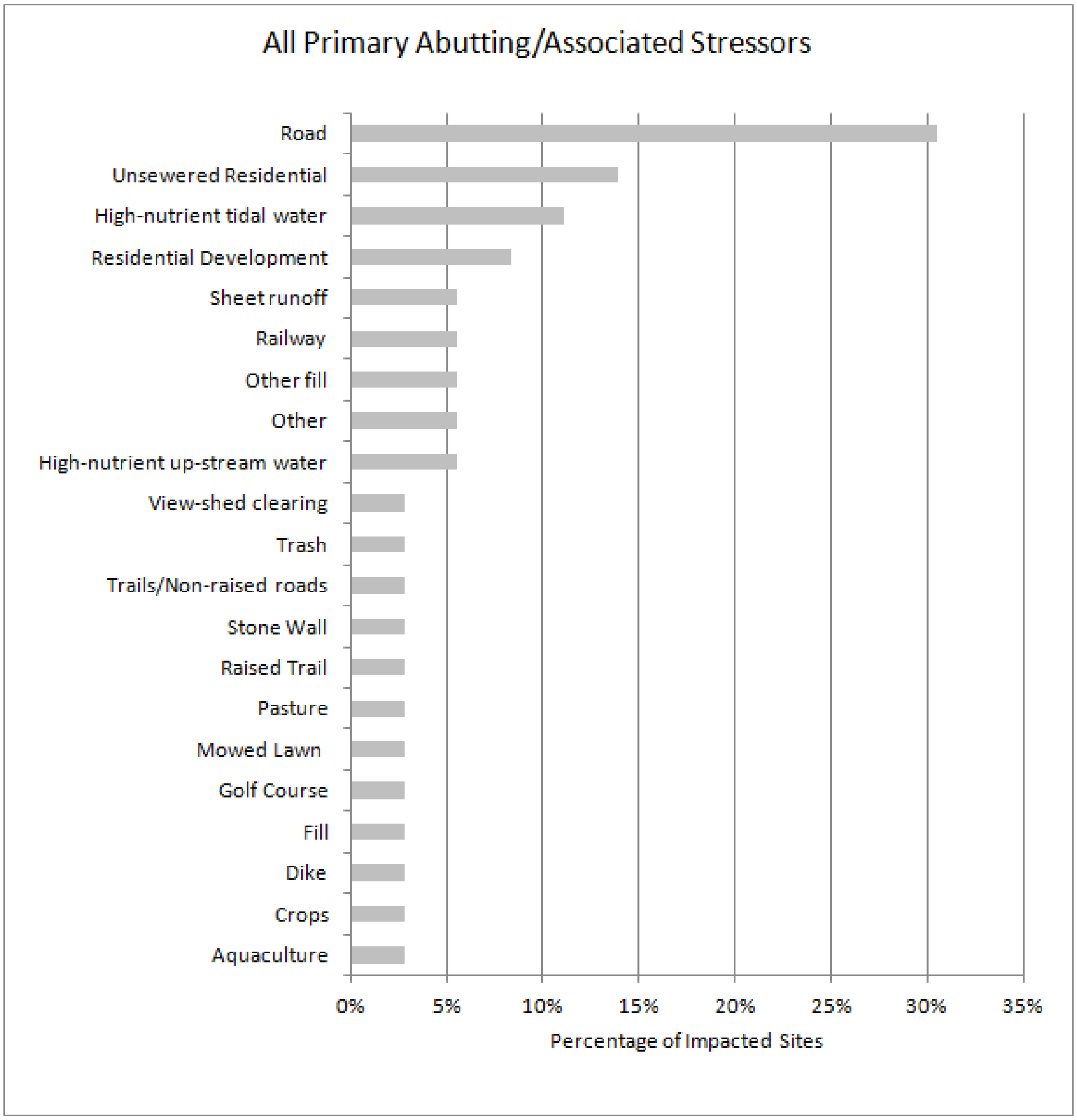
Sub-Index and Index Scores

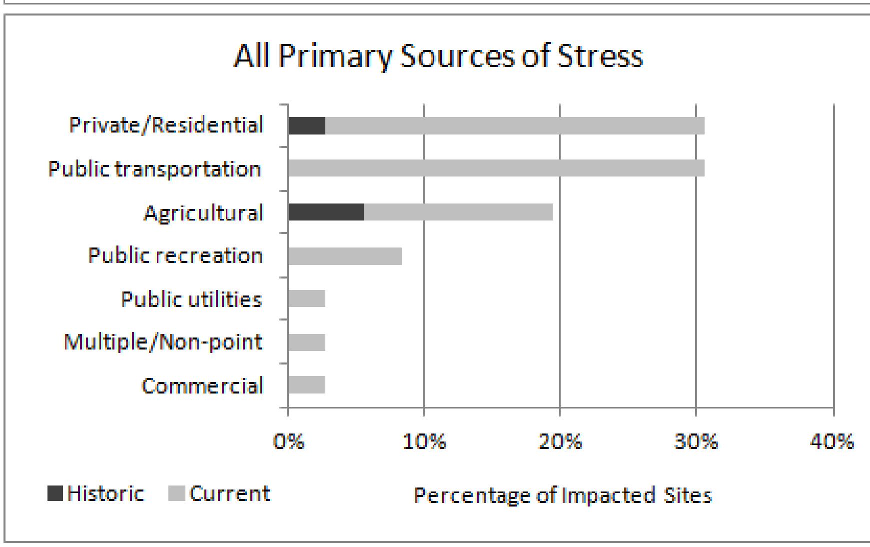






Stressor information aggregated across sites





Appendix E

Revised MarshRAM Datasheet

MarshRAM Investigators____ Site Code_____________ Date_________

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

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

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

2) Position in Watershed

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

3) Marsh Setting and Type

Geomorphic Setting; select primary one or two

- ☐ Open Coast
- ☐ Open Embayment
- ☐ Finger
- ☐ Riverine
- ☐ Back Barrier Marsh
- ☐ Back Barrier Lagoon

Geoform; select one

- ☐ Platform
- ☐ Fringe

Adjacent upland; select primary one or two

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

Tidal water salinity; select one

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

Freshwater input; select primary one or two

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

4) Exposure to Tides

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

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

*Effective Fetch of Tidal Water**

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

Tidal Range

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

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

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

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

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

7) Ecosystem Functions and Services; estimate importance of all evident or known according to classes at right:

___ 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

Explain special importance ____

8) Count of Waterbirds Present: Wading Birds ________ Shorebirds ________ Waterfowl ________ Raptors ________ Gulls ________

*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. 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, open water
Low................Recovering natural lands, passive recreation, low trails/dirt roads
Mod High......Residential, pasture/hay, mowed areas, raised roads to 2-lane
High................Urban, impervious land cover, new construction, row crops, turf crops, mining operations, paved roads > 2-lane

Surrounding Land Uses: Check all that apply

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

C. Wetland Disturbances. Average metrics C.1 to C.10

1) Buffer Encroachment.

☐

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

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

Primary Associated Stressor; check one or two:

- ☐ Road
- ☐ Railway
- ☐ Fill
- ☐ Raised Trail
- ☐ Power Lines
- ☐ Cleared/mowed Land
- ☐ Buildings
- ☐ Paved Lot
- ☐ Dirt Lot
- ☐ Dam/dike
- ☐ 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.

☐

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

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

Primary Associated Stressor; check one:

- ☐ Road
- ☐ Railway
- ☐ Weir / Dam
- ☐ Raised Trail
- ☐ Development Fill
- ☐ Other ___________

Evidence: check all that apply

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

- ☐ None observed (10)
- ☐ Low (7)
- ☐ Moderate (4)
- ☐ 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.

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

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

Primary Associated Stressor; Check one or two:
- ☐ High-nutrient tidal water
- ☐ High-nutrient up-stream water
- ☐ Stormwater discharge
- ☐ Sheet runoff
- ☐ Unsewered residential
- ☐ Point effluent discharge
- ☐ Organic / yard waste
- ☐ Other point ________________
- ☐ 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.

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

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

Primary Associated Stressor; Check one:
- ☐ Road ☐ Dam
- ☐ Raised Trail ☐ Dike
- ☐ Railway ☐ Trash
- ☐ Organic / yard waste
- ☐ Fill
- ☐ 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
- ☐ Minimal erosion observed (10)
- ☐ Low (7): <10% of the seaward edge is eroded
- ☐ Moderate (4): 10-60% of the seaward edge is eroded
- ☐ High (1): >60% of the seaward edge is eroded

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

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

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

Evidence: check all observed
- ☐ Dense crab burrows
- ☐ Eroding or oversized crab burrows
- ☐ Abundant fiddler crabs
- ☐ Purple marsh crabs
- ☐ Clipped vegetation
- ☐ 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.

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

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

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

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

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

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

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

10) Phragmites within wetland. Select <u>one</u> class for total coverage.

- ☐ None noted (10)
- ☐ Low: <10% cover (7)
- ☐ Moderate: 10-60% cover (4)
- ☐ 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:
- ☐ Road
- ☐ Railway
- ☐ Raised Trail
- ☐ Footpath
- ☐ Dam / Dike
- ☐ Organic / yard waste
- ☐ Other Fill
- ☐ Mowed Lawn
- ☐ Crops
- ☐ Pasture
- ☐ Drainage ditch / tile
- ☐ Stormwater input
- ☐ Clearing
- ☐ Multiple
- ☐ Residential Development
- ☐ Other

Sum of C1 to C10 Scores = _________ ÷ 10 = ☐ C. Wetland Disturbance Score

D. 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 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 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:			

D. Index of Marsh Integrity

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

= ☐

Marsh Community Composition:

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

C. Wetland Disturbance Score (max 10) __________

D. Index of Marsh Integrity (max 10) __________

MarshRam Condition Index =

Average of C and D

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