Salt Marsh Rapid Assessment Method, MarshRAM: Analysis and Application

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

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Thomas E. Kutcher
Rhode Island Natural History Survey

United States Environmental Protection Agency

RHODE ISLAND NATURAL HISTORY SURVEY
Providing Ecosystem Science and Information

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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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Executive Summary

The salt marsh rapid assessment method, MarshRAM, was designed to be a practical and effective method of rapidly documenting information characterizing salt marsh type, setting, ecological value, disturbance, integrity, and opportunity for landward migration at the site scale. The method is intended to be used for gaining perspective on the conditions at individual marshes in reference to conditions at marshes on a broader scale, such as 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 one day per marsh to complete. MarshRAM generates indices of aggregate functions and services, surrounding land use intensity, aggregate in-wetland disturbances, marsh community integrity, and landward migration potential. The indices are designed to be used individually or analyzed in relation to each other to serve various marsh-management objectives. MarshRAM additionally documents qualitative information on several attributes of salt marshes to facilitate categorization for analysis and management, but keeps size, setting, diversity, functions and services, and migration potential information separate from disturbance and integrity scoring, because some of these factors are inherent or can confound the effective assessment of wetland condition.

Findings of this study supersede findings of a pilot study of MarshRAM conducted in 2017 (Kutcher 2018), and although several findings hold from the prior study, insight into the method's properties has improved. MarshRAM's Index of Marsh Integrity (IMI) was designed to reflect inundation stress and anthropogenic disturbances, and a strong additive influence of marsh platform median elevation + MarshRAM's aggregate *Wetland Disturbance* index on IMI indicates its expected function. A strong correlation between IMI components and historic loss suggests that changes in high marsh vegetation may in turn signal salt marsh resilience, concurring with several recent studies. Today's salt marshes diverge from historic accounts in that meadow high marsh species no longer dominate the high marsh zone, the low marsh grass *S. alterniflora* is now the dominant high marsh community, and severe edge erosion, invasion by *Phragmites*, and marsh edge die-back are ubiquitous; these factors are reflected in the IMI score and the *Wetland Disturbance* index. Historic ditches are also widespread, but their apparent support of highly-vulnerable salt marsh-obligate sparrows should be considered in any mitigation efforts. In the context of recent studies implicating sea-level rise in marsh degradation and loss, findings suggest that sea-level rise is more-strongly impacting marsh platform integrity than any other singular or cumulative human disturbances, and that high-marsh vegetation loss is a stronger indicator of degradation and vulnerability than edge die-back or other vegetation shifts. Findings suggest that unassisted landward marsh migration may already be contributing to salt marsh resilience, but without management, existing migration corridors may not be sufficient to replace degraded and lost marsh area, suggesting a need for active management.

A draft management matrix, using MarshRAM data collected during this study, demonstrates how MarshRAM data can provide information for salt marsh management. It is anticipated that MarshRAM will serve as a useful tool to inform restoration and conservation strategies, 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.

Preface

This project builds upon earlier work that piloted and tested a new salt marsh rapid assessment method, MarshRAM, at 11 sites across Narragansett Bay and coastal Rhode Island in 2017 (Kutcher 2018). In 2018, 20 additional Rhode Island salt marshes were assessed, using MarshRAM, to further evaluate its efficiency and effectiveness in reflecting relative intensity of human disturbances and vulnerability to sea-level rise and other stressors, and to begin building a reference gradient of salt marsh conditions in Rhode Island. Because this project is a direct extension of prior work, much of the text in this report is adapted and updated from the Kutcher (2018) report.

1. Introduction

Salt marshes are important to people and wildlife but are highly vulnerable to human disturbances. They are among the most productive ecosystems in the world and provide food and habitat for numerous fishes, shellfish, birds, mammals, reptiles, and invertebrates, including several species that are important for human food production (Nixon 1980, Deegan et al. 2002, Gedan et al. 2009, Barbier et al. 2011). Salt marshes can also absorb floodwater and wave energy, which can protect adjacent and downstream properties from flood damage and erosion (Shepard et al. 2011). Anthropogenic disturbances, such as filling for roads, development, and refuse disposal; impoundment by roads and railways; ditching for mosquito control and salt-hay production; excessive nutrients from waste disposal; and introduction of invasive species, have resulted in widespread salt marsh loss and degradation in Rhode Island (Gedan et al. 2009, 2011, Watson et al. 2017a). Multiple factors associated with climate change and sea-level rise have more recently caused widespread vegetation loss and marsh platform degradation (Donnelly and Bertness 2001, Roman 2017, Watson et al. 2017a). Sea-level rise can work interactively with other anthropogenic stressors to cause rapid marsh degradation in the forms of edge dieback and erosion, platform vegetation dieoff, subsidence, water-logging, drowning, and loss (Donnelly and Bertness 2001, Crotty et al. 2017, Watson et al. 2017a, b, Raposa et al. 2018).

The Rhode Island Coastal Wetland Restoration Strategy (Kutcher et al. 2018) recognizes the critical vulnerability of salt marshes to sea-level rise and other stressors, and recommends conducting monitoring and assessment to inform management of these important systems. Correspondingly, the Rhode Island Salt Marsh Monitoring and Assessment Strategy (Raposa et al. 2016a) details a three-level approach that includes landscape (Level 1, EPA 2006), rapid (EPA Level 2), and intensive (EPA Level 3) monitoring and assessment methods. As part of those strategies, The Rhode Island Natural History Survey (RINHS), under contract with RI Department of Environmental Management (DEM) and in agreement with the RI Coastal Resources Management Council (CRMC), has worked with state, federal, academic, and NGO partners to develop and pilot a rapid assessment method (EPA Level 2) for salt marshes. Wetland rapid assessment methods are typically designed to collect data for characterizing conditions at individual sites in a single visit (Fennessey et al. 2007). Rapid assessment methods are unique among monitoring and assessment approaches in that they can produce reliable site-level data to reflect ecosystem conditions across multiple sites in a single season, allowing sites to be compared against each other or categorized based on condition, value, vulnerability, or other attributes; this makes rapid assessment particularly useful for providing information to support management decisions, such as prioritization for restoration and conservation, or to justify the need for more intensive assessments. The recently-developed Salt Marsh Rapid Assessment Method (MarshRAM) adapts concepts and protocols from prior work to provide users with a single, efficient method designed to document information on salt marsh physical and biological attributes, classification, functions and ecosystem services, geomorphic and landscape setting, human disturbances, vulnerability, and landward migration potential. This report details a project evaluating the properties of MarshRAM and its applications in support of salt marsh management for Rhode Island and other areas.

2. Methods

2.1 MarshRAM structure

MarshRAM builds upon the most effective and useful components from the New England Rapid Assessment Method (NERAM; Carullo et al. 2007), the Rhode Island Salt Marsh Assessment (RISMA; Ekberg et al. 2017), and the Rhode Island Rapid Assessment Method (RIRAM; Kutcher 2011). 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 model, and the fifth is a semi-quantitative model that assesses aspects of landward salt marsh migration potential (Appendix A). MarshRAM was designed to produce metrics and indices characterizing salt marsh disturbances, platform integrity (plants and soils), 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 marsh characteristics, surrounding land use, and wetland disturbances follow RIRAM structure and formatting and draw much of the content 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 (Appendix 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 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, ecosystem services, and habitat use is important for management (USACE 2003, McKinney at al. 2009).

The second section, (B) *Surrounding Land Use*, estimates the occurrence and intensity of human land uses 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), although preliminary analysis suggests that this relationship may not hold for Rhode Island salt marshes (Kutcher 2018).

The third section, (C) *Wetland Disturbances*, estimates, categorizes, and rates the intensity of 30-m buffer disturbances, 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 (Appendix A). *Wetland Disturbances* 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 Disturbances* (i.e., the *Wetland Disturbance* index) is simply the mean of the individual metric scores. The *Wetland Disturbances* section additionally uses checklists to document observed evidence, associated stressors, and general land use categories associated with the stress. These checklists, which closely follow RIRAM formatting and content, allow for analysis of the influences of both specific and categorized 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 (D) has two components, (1) *Marsh Community Composition* and (2) an *Index of Marsh Integrity* (hereafter, IMI). This section adapts elements of RISMA (Ekberg et al. 2017) and floristic quality assessment (FQA, e.g., Kutcher and Forrester 2018), and uses a novel sampling approach to (1) estimate the relative cover of typical salt marsh community cover types and (2) generate a plant-community-based 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 the marsh-upland interface to the subtidal zone. 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 (Section D in Appendix 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 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 were 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 were 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 perceived 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 experienced 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 stressors, and habitat value (Appendix 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, weighted by relative proportion of each type across all transects, was evaluated as an index of marsh integrity (i.e. IMI) (Appendix A).

2.1.3 Migration Potential

The fifth section of MarshRAM, *Migration Potential*, rapidly estimates and characterizes three measures of landward marsh migration potential using a combination of remote-sensing data and field observations. The method uses a worksheet (Appendix A, Section E) to estimate the proportions of various land cover and 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, which characterizes the relative potential of land abutting the wetland to support landward migration. 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) *Migration Area*, defined as the area of surrounding land with moderately-high and high migration potential (land that would require little or no management action to facilitate migration), and the (3) *Replacement Ratio*, which relates *Migration Area* (2) to the area of the existing marsh. These three *Migration Potential* metrics are intended to be used to inform various aspects of salt marsh management and conservation planning.

2.1.4 MarshRAM Scoring

MarshRAM generates two condition indices reflecting *Wetland Disturbances* and *Marsh Integrity* (IMI) (Appendix A); these are intended to be used separately for analysis and decision support. Scores for each metric and index 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* and *Surrounding Land Use* sections do not contribute to MarshRAM condition scores; however, the sum of importance rankings from (A.7) *Ecosystem Functions and Services* may be used as a coarse indicator of the relative ecological and cultural importance of a site. Other attributes from *Marsh Characteristics* are intended to be used for categorization and analysis, but not as indicators of integrity. And, although *Surrounding Land Use* is not incorporated as a scoring metric, it may be used to analyze condition in relation to land-use setting. Similarly, the *Migration Potential* metrics are not incorporated into the MarshRAM condition indices, but are instead designed to be evaluated against the condition scores to inform management decisions. MarshRAM keeps size, setting, diversity, functions and services, and migration potential information separate from disturbance and integrity 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).

Table 1. Salt marsh communities (modified from Ekberg et al. 2017) and coefficients of community integrity (CCI) used to generate indices of marsh integrity (IMI) for 31 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 Habitat	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*; *S. alterniflora* absent
Mixed High Marsh	7	Irregularly flooded emergent high marsh community comprised of any combination of S. patens, *Juncus gerardii*, *Distichlis spicata*; *S. alterniflora* present
Sa High Marsh	5	Irregularly flooded emergent high marsh; typically 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% vascular vegetation cover, or bare decomposing organic soil, typically with remnant roots of emergent vegetation; may have algal mat, filamentous algae, wrack, or flocculent matter present
Low Marsh	8	Regularly flooded, typically sloping emergent community located at the tidal edges of the marsh 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 steep-sided 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

2.2 Field Methods

MarshRAM was conducted at 20 salt marshes (Fig. 1) at the peak of the growing season (mid-July through September) in 2018. Data from these 20 assessments were collected to complement data collected at 11 marshes in 2017 (Kutcher 2018), and the methods used across all 31 combined assessments were fundamentally the same. 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 (Appendix A). Field maps—showing recent (April 2014) high-resolution, leaf-off, true-color, aerial 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

(Appendix C). Maps and buffer delineations were generated using geographic information systems (GIS) software (ESRI ArcMap 10.2). Marsh assessment units comprised the entirety of contiguous marsh area bounded by open water, upland, or a hydrological or functional discontinuity such as a raised road, and were delineated on-screen using aerial photo-interpretation of 2014 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 running from marsh-upland interface to the subtidal zone of a major surface water feature (bay, salt pond, large creek). 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.

2.2.1 Community Composition and IMI Assessment

Vegetation community surveys were conducted first, using transects depicted on the field maps. Transects were navigated 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 was summed following each transect. Transect data were aggregated marsh-wide for IMI scoring and community composition analysis. As a secondary function, transect data can be used separately as replicates to support coarse change-over- time analysis using each transect as a replicate. Tallies and indices were calculated directly on field datasheets and, for quality assurance, were later re-calculated automatically using Excel spreadsheet software upon digital upload.

2.2.2 Observational Assessment

Wetland attributes, disturbances, and evidence of stress were noted during the vegetation community surveys. The perimeter and other inner parts of the marsh were additionally surveyed until the investigator was confident in his/her assessment of all observational metrics and their components. All components of each attribute and metric of the observational parts of MarshRAM (Sections A, B, and C) were filled out completely unless there was no evidence of stress for a *Wetland Disturbance* 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 observed when approaching sections of the marsh for the first time. Marsh-obligate sparrows (*Ammospiza* sp.) flushed during vegetation community transects were also tallied.

2.2.3 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 (Appendix A, Section E). 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 Contour Lines-2011 Statewide LiDAR* (available at www.rigis.org, accessed July-Sept 2018) were overlain and the 5' contour (approximately 1.5m above mean high water) was used to identify low lying lands. The 11 sites previously assessed in 2017 were reassessed using this updated elevation contour (the 3' contour was used in 2017 and was changed by Advisory Committee consensus before field-year 2018). Relative proportions of migration-potential categories (Appendix A, Section E) were estimated using photo-interpretation. Laboratory assessments were ground-truthed during rapid assessment surveys, and adjusted as necessary.

2.3.4 Quality Assurance

To test the accuracy of the vegetation-community sampling methods, the consistency of step-length and its effects on community composition ratios and IMI scoring was tested across *Salt Shrub*, *Mixed High Marsh*, and *Phragmites* community types. Two investigators (T. Kutcher, K. Raposa) each followed a straight transect for 20 steps across each community type, and the distance traversed in the 20 steps was measured. This was replicated across five separate transects in each community type and variability among the replicates and community types was analyzed for each investigator. Traversed distances were further applied to calculate relative proportions of each community type and IMI scores, for comparison against scores from a set of theoretical reference transects using exactly even steps.

Additionally for nine sites, the principal investigator (T. Kutcher) and a second investigator (J. Beck or C. Chaffee) ran the observational sections of MarshRAM separately—without discussing the scoring or process—to assess inter-user variability. In all cases, the secondary investigator had been trained to understand the method and interpretation of all metrics and attributes before the assessment.

2.3 Analysis

Data collected in 2018 (*n*=20) were combined with data collected in 2017 (*n*=11) for analysis, resulting in 31 discrete marsh units for most analyses. Winstat (R. Fitch Software, 2008) was used for statistical analyses, except where noted. Rank-based statistics were used when appropriate to account for the ordinal nature of observational MarshRAM metrics, whereas parametric statistics were otherwise used when assumptions could be met. Spearman rank correlation was used to detect correlations against MarshRAM observational metric (non-aggregated) data, whereas Pearson correlation was used to analyze IMI against tally data and historic loss, elevation, and cover data from prior studies (Berry et al. 2015, Ekberg et al. 2017, Watson et al. 2017b). Kruskal-Wallace H-test, supported by box plots, was used where assumptions could not be met for ANOVA analysis. IBM SPSS Statistics (IBM Corporation) multiple regression analysis was used to test for interactive and additive effects of disturbance and median marsh elevation on IMI.

3. Results

3.1 MarshRAM Logistics

Each MarshRAM assessment took a single field day (8 hours including travel time) or less 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 five hours depending on the size of the site and difficulty in accessing the transects and perimeter of the marsh. Vegetation community transects ranged in length from 10m to 417m (n=248, $\bar{x}$=108) and averaged 861m per eight transects per marsh (range=123 to 2200m), and the number of data points tallied (i.e. the number of steps traversed during transect surveys) averaged 973 per marsh.

3.2 Marsh Characteristics and Disturbances

The study marshes ranged in size from 0.56 to 93 ha (n=31, $\bar{x}$=14.8) and were distributed across Narragansett Bay Upper Bay (14 sites), Mid Bay (6) Lower Bay (3), the Sakonnet River (2), and the Rhode Island South Coast (6) (Figure 1; Appendix D). Geomorphic settings included back-barrier marsh (10 sites), open embayment (8), finger marsh (6), back barrier lagoon (4), and open coast (3). Thirty (30) sites were categorized as platform marshes and one as a fringing marsh, although the fringing marsh also had a narrow high-marsh peat platform. The tidal water of 28 sites was polyhaline (>18 ppt.), one was mesohaline (5-18 ppt.), and two were not measured for salinity. All 31 sites had a high marsh platform, 30 had salt shrub habitat present, 26 contained low marsh, 15 contained brackish marsh habitat, and 6 had overwash fans. All sites were interpreted as having potential or evident value as wildlife habitat, fish and shellfish habitat, and carbon storage, whereas 17 were characterized as having potential or evident value for storm protection of property. Wading birds were detected at 24 sites, marsh-obligate sparrows (*Ammospiza* sp.) at 21 sites (aggregating those flushed during both observational and community-composition surveys), waterfowl at 15 sites, raptors at 13 sites, shorebirds at 12 sites, and gulls at 10 sites.

The most common stressors in the surrounding landscape within the 150m buffer were residential development (27 of the 31 sites), raised roads (19 sites), trails (11 sites), and recreational development (10 sites). Intensity of cultural encroachment of the vegetated buffer within 30-m of the wetland edge was estimated to be >75% at 2 sites, 51-75% at 1 site, 26-50% at 6 sites, 6-25% at 12 sites, and <5% at 10 sites. Seven sites were at least partly impounded, mainly by roads. Ditching intensity was high at 3 sites, moderate at 15 sites, and low at 9 sites (Appendix A). Potential sources of nutrient input were recorded at 25 sites and nutrient enrichment impacts were assessed as evident at 21 of those sites. Filling was detected at 21 sites, mainly from raised roads and residential development. Edge erosion along marsh creeks and open water edges was assessed as high (>60%) at 18 sites and moderate (>10-60%) at 9 sites, whereas high or moderate crab burrowing damage (e.g., dense, oversized burrows; denuded peat) was observed at 18 sites. Ponding and dieoff was assessed as moderate (10-60% areal cover) at 9 sites and low (1-10% cover) at 17 sites. Vegetation mowing and soil disturbances were assessed as low or absent at all 31 sites. *Phragmites* was present at all 31 sites and cover (as a proportion of the marsh platform) was estimated to be moderate (>10-60%) at 8 sites and high (>60%) at 1 site; residential development and roads were the primary stressors associated with *Phragmites*, overall. Overall, roads were most-often identified as the primary cause of salt marsh disturbances (associated with 34 disturbances in total) followed by known high-nutrient tidal water (12 disturbances) and residential development (10 disturbances; Appendix D).

3.3 MarshRAM Index Values

On average, *Sa High Marsh* was the most common MarshRAM community documented across the study sample (Table 2). *Wetland Disturbance* scores ranged from 4.2 to 8.1 ($\bar{x}$=6.3, *SD*=0.91) and IMI scores ranged from 4.4 to 8.0 ($\bar{x}$=6.2, *SD*=0.96) (Table 3). IMI scores reflect relative community composition as depicted in Figure 2. IMI values were most strongly influenced by the proportion of *Meadow High Marsh* (+), *Salt Shrub* (+), and *Dieoff Bare Depression* (-) (Table 4). Lower-quartile IMI values ranged from 4.5 to 5.5 and upper-quartile values ranged from 6.9 to 8.1 (Fig. 3). *Migration Area* ranged from 0.0 to 12.6 ha (*n*=31, median = 2.5, $\bar{x}$=3.4, *SD*=3.3), and *Replacement Ratio* ranged from 0.0% to 136% (*n*=31, median = 25%, $\bar{x}$=35%, *SD*=34%) (Table 5). Table 5 demonstrates a decision-support matrix showing IMI categories of marsh degradation in relation to observed disturbance intensities and other management information.

Figure 1. Distribution across Rhode Island of 31 salt marshes assessed in 2017 and 2018 using MarshRAM

Table 2. MarshRAM communities and their mean cover across 31 salt marshes in Rhode Island

MarshRAM Community	% Cover
Sa High Marsh	25.7
Meadow High marsh	19.3
Mixed High Marsh	15.4
Phragmites	9.8
Salt Shrub	8.7
Dieback Denuded Peat	6.0
Dieoff Bare Depression	5.2
Low Marsh	3.9
Brackish Marsh Native	2.4
Natural Creek	1.1
Natural Pool	1.1
Ditch	0.8
Bare sediments	0.5
Natural Panne	0.1
Sum	100

Table 3. Locations, MarshRAM index scores, marsh loss, and median elevation of 31 salt marshes in Rhode Island; [1]loss per year of vegetated marsh area from 1981 to 2008 estimated using aerial photo-interpretation, derived from Berry et al. (2015); [2]median elevation in relation to NADV88 from Watson et al. (2017b); ND = no data available. Wetland Disturbance and IMI scores are relative to a 0-10 scale, 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.

Site	Lat	Long	Wetland Disturbance	IMI	% Loss[1]	Median Elevation[2]
Barrington Beach	41.7260	-71.3223	5.9	5.7	ND	0.74
Brush Neck Cove	41.6996	-71.4179	7.5	6.6	ND	0.29
Chase Cove	41.7039	-71.2368	6.4	7.8	ND	0.69
Coggeshall	41.6534	-71.3433	6.6	6.1	ND	0.62
Colt State Park	41.6797	-71.2950	5.3	6.9	ND	0.70
Fox Hill	41.4902	-71.3952	7.7	6.7	5.9	0.45
Galilee	41.3814	-71.5031	6.5	5.9	ND	0.60
Hundred-acre Cove	41.7680	-71.3165	6.0	6.5	8.9	0.59
Island Road North	41.3897	-71.5067	6.1	5.5	ND	0.49
Jacob's Point	41.7126	-71.2878	5.7	7.9	ND	0.70
Jenny	41.6322	-71.3354	6.2	5.9	ND	0.53
Marsh Meadows	41.5460	-71.2063	6.5	6.1	9.3	0.54
Mary Donovan	41.6892	-71.4513	5.9	6.4	ND	0.33
Mary's Creek	41.5852	-71.4521	4.2	5.3	ND	0.54
Mill Creek	41.6283	-71.3206	7.3	7.2	ND	0.53
Nag East	41.6255	-71.3248	5.9	6.0	ND	0.64
Nag West	41.6890	-71.4350	6.4	6.1	ND	0.64
Nausauket	41.3559	-71.6491	7.4	5.9	ND	ND
Ninigret Control	41.1535	-71.3647	7.3	5.6	12.9	0.09
Old Mill Cove	41.7564	-71.2881	5.3	5.3	ND	0.38
Palmer River	41.7456	-71.3902	6.1	6.0	1.7	0.56
Passeonquis	41.6648	-71.3465	6.1	7.1	ND	0.75
Potowomut	41.3364	-71.7169	6.3	6.3	5.5	0.55
Providence Point	41.6570	-71.4120	8.1	7.8	ND	0.64
Quonnie East	41.5081	-71.3733	5.5	4.6	21.2	0.23
Seapowet	41.5089	-71.2009	4.8	4.9	10.6	0.65
Sheffield Cove	41.4931	-71.3828	7.4	8.0	ND	ND
Stillhouse Cove	41.7687	-71.3913	4.9	6.9	ND	0.57
Succotash	40.8454	-71.5218	5.7	5.3	11.3	0.30
Watchemoket	41.8024	-71.3809	5.7	4.4	ND	0.40
Winnapaug	41.3261	-71.7986	7.1	4.7	26.7	0.13

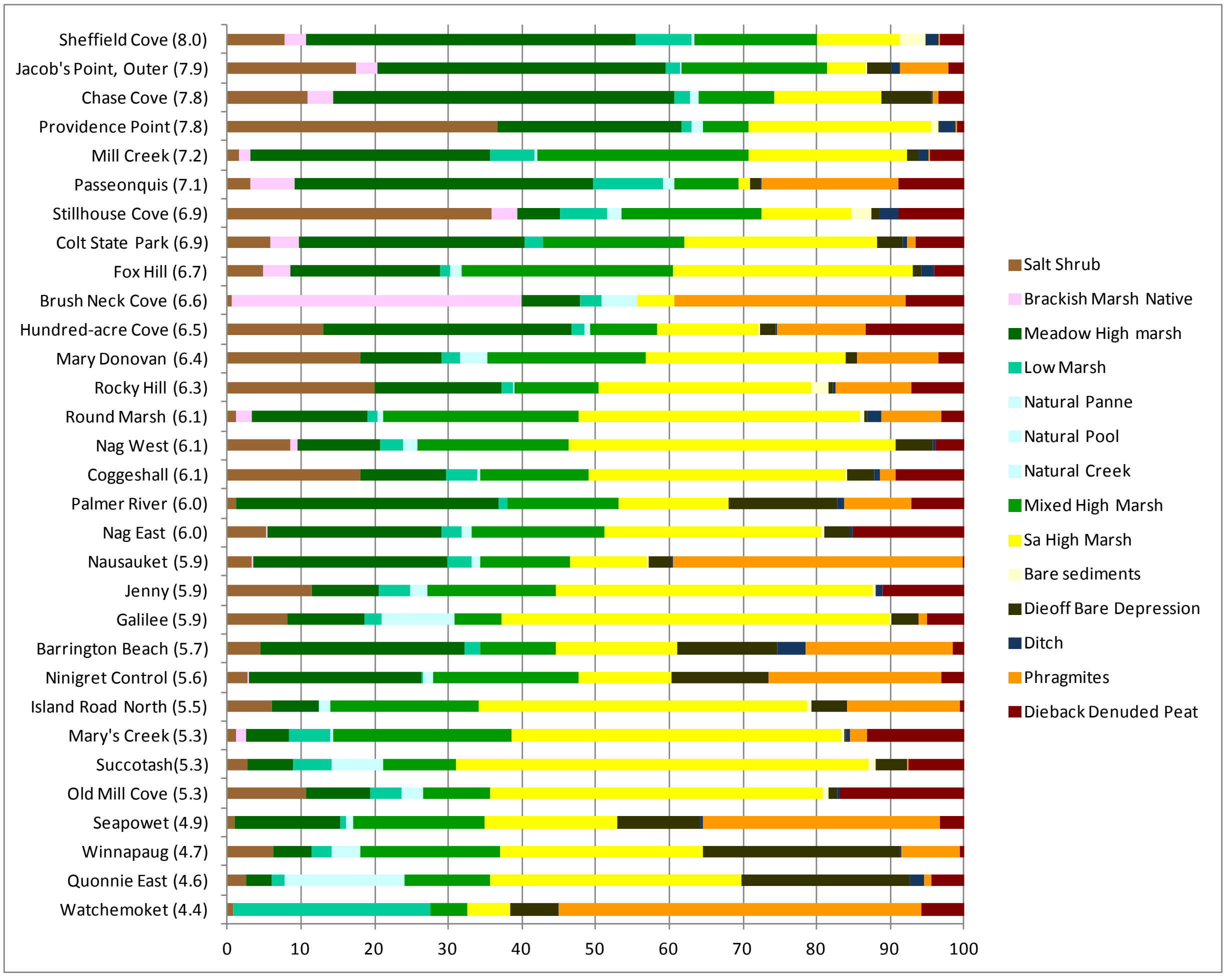


Figure 2. IMI scores (parenthetic) and relative proportions of IMI salt marsh cover types from 31 salt marshes in Rhode Island; salt marshes are listed in descending order of marsh integrity according to IMI scores.

Table 4. Pearson correlation coefficients indicating the relative influence of marsh cover types on IMI values at 31 salt marshes in Rhode Island.

MarshRAM Community	IMI	
	r	*P*
Meadow High Marsh	0.73	<0.01
Salt Shrub	0.46	0.01
Ditch	0.24	0.19
Brackish Native Marsh	0.23	0.22
Mixed High Marsh	0.08	0.66
Dieback Denuded Peat	-0.11	0.54
Natural Creek	-0.11	0.54
Low Marsh	-0.18	0.32
Phragmites	-0.37	0.04
Sa High Marsh	-0.38	0.04
Dieoff Bare Depression	-0.53	<0.01

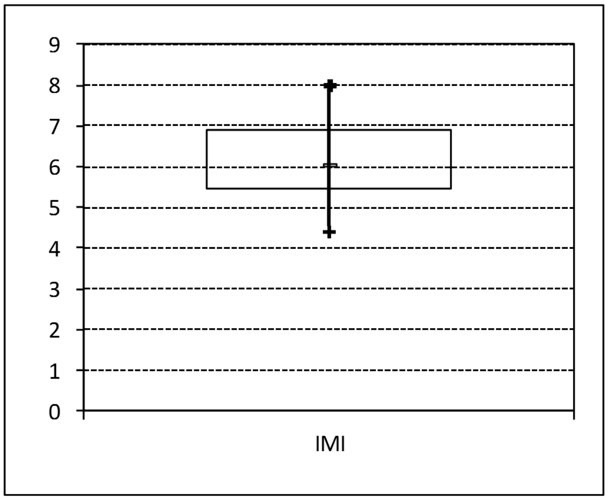


Figure 3. Box plot showing IMI quartiles of IMI values for 31 salt marshes in Rhode Island; the dash represents the median, the boxes represent the inter-quartile range, and the crosses represent upper and lower values.

Table 5. Matrix depicting IMI marsh degradation categories (IMI Bin) in relation to categories of MarshRAM functions and services, marsh migration potential, intensity of human disturbances, and mean elevation from Watson et al. (2017b); MD=most-degraded, ID=intermediately-degraded, LD=least-degraded; AA=above average, A=average, B=below average summed ranks of MarshRAM (A.7) *Ecosystem Functions and Services*; Migration Area=ha of adjacent land with moderately-high migration potential; Replacement Ratio=Migration Area ÷ area of site; disturbance categories: X=low-intensity, XX=moderate-intensity, XXX=high-intensity; green, yellow, and red shading represent, respectively, upper-quartile, moderate, and lower-quartile categories of marsh resiliency or value.

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

3.4 Analysis of MarshRAM Properties

IMI was negatively correlated with historic loss of vegetated marsh area and positively correlated with median marsh platform elevation reported in prior studies, and it was nearly correlated with the *Wetland Disturbance* index (Table 5). Of five MarshRAM community types tested (*Phragmites, Meadow High Marsh, Sa High Marsh, Dieoff Bare Depression, Die-back Denuded Peat*), the cover of *Meadow High Marsh* + *Die-off Bare Depression* most-strongly predicted historic marsh loss values derived from Berry et al. (2015) (stepwise regression, $F(2, 7)=13.09$, $P=0.004$, $R^2=0.73$); additionally adding *Replacement Ratio* to the model did not affect this outcome. *Wetland Disturbance* scores and median marsh elevation had a strong additive effect on IMI (Table 5), and there was no indication of interaction between those two variables ($P=0.781$). *Wetland Disturbance* was not correlated with historic loss values reported in Berry et al. (2015; Pearson, P>0.05). IMI was modestly correlated with the MarshRAM observational metric *ponding and dieoff depressions* (Spearman Rank, r_s=0.52, P=0.002, n=31) but not with any other individual *Wetland Disturbance* metric (P> Bonferroni-adjusted α of 0.005); however, the % cover values of several IMI individual communities were correlated with analogous or functionally-related *Wetland Disturbance* metrics (Table 7).

The % cover of *Meadow High Marsh* decreased with increasing cover of *Sa High Marsh* (r=-0.54, P<0.001, n=31), and both *Meadow High Marsh* and *Sa High Marsh* decreased with increasing cover of *Phragmites* (r=-0.54, P<0.001, n=31 and r=-0.54, P<0.001, n=31, respectively). The cover of *Phragmites* was also correlated with the MarshRAM observational metric *anthropogenic nutrient inputs* (r_s=-0.48, P=0.003, n=31) but not with *filling and dumping*, *buffer encroachment*, or *Surrounding Land Use* (r_s> Bonferroni-adjusted α of 0.007). The observational metric *anthropogenic nutrient inputs* was not correlated with historic loss (Berry et al. 2015); the cover of *Meadow High Marsh*, *Sa High Marsh*, *Die-off Bare Depression*, or *Dieback Denuded Peat*; or with the observational metric *Ponding and Dieoff* (P> Bonferroni-adjusted α of 0.008).

The sum of ranks ascribed to A.7 *Ecosystem Functions and Services* was correlated with marsh area (r_s=0.59, P=0.0003, n=31), but not with the MarshRAM index, aggregate *Wetland Disturbance*, or IMI (P> Bonferroni-adjusted α of 0.013 for all). Marsh area was positively correlated with the number of waterbirds detected during MarshRAM assessments, and with the diversity per marsh of bird cohorts listed in (A.8) *Count of Waterbirds Present at Start* (Appendix A) (Table 8), but not with % historic loss (Berry et al. 2015), median elevation (Watson et al. 2017), MarshRAM (A.5) *natural habitat diversity*, IMI, or *Wetland Disturbance* (P> *Bonferroni*-adjusted α of 0.007).

The aggregate of waterbird tallies by total abundance, cohort richness, and density (birds per ha) per marsh were negatively correlated with IMI but not with *Wetland Disturbance* scores (Table 8). The linear density (sparrows /m) of marsh-obligate sparrows (*Ammospiza* sp.) flushed during IMI transects was not correlated with the *Wetland Disturbance* index, IMI, or any singular observational disturbance metric; a positive association of sparrow linear density with the number of ditch data points tallied along the transects (*Pearson*, r=0.58, P<0.001, n=31) was significant considering a *Bonferonni*-adjusted α of 0.002.

The per-marsh % cover values of MarshRAM communities from MarshRAM transects were correlated with several analogous cover values generated by RISMA line-intercept and point-intercept methods from a prior study (Table 9); IMI values generated using those RISMA data were strongly correlated with MarshRAM IMI values from this current study. Likewise, MarshRAM cover values per marsh were correlated with several *RIGIS Salt Marsh Habitat* (2012) cover values generated by NBNERR through semi-automated classification of aerial imagery in 2012; IMI values generated using those RIGIS data were only modestly correlated with MarshRAM IMI values (Table 10).

Migration Potential was strongly correlated with *Buffer Encroachment* scores (Pearson, n=31, r=0.66, P<0.001) but only qualitatively associated with *Surrounding Land Use* (Pearson, n=31, r=0.35, P=0.056). *Replacement Ratio* was correlated with historic loss values derived from Berry et al. (2015) (*Pearson*, r=-0.66, P=0.039, n=10).

Table 6. Pearson correlation coefficients (*r*) and probability values comparing MarshRAM IMI values with loss and elevation estimates from prior studies, and with latitude—Bonferroni adjusted α=0.013; [1]loss per year of vegetated marsh area from 1981 to 2008 estimated using aerial photo-interpretation, derived from Berry et al. (2015); [2]median marsh surface elevation in relation to NADV88, from Watson et al. (2017b); [3]Wetland Disturbance + Median Elevation represents the additive effect of the two prior metrics analyzed against IMI using stepwise regression (*r* reported rather than r^2 for comparison); values from Stillhouse Cove were removed prior to the analyses for this table because a major marsh-platform restoration was recently conducted at the site, which was expected to have affected IMI values in relation to the other metrics.

Reference Indicators	IMI		
	n	*r*	*P*
Historic Loss[1]	10	-0.78	0.008
Latitude	30	0.37	0.044
Median Elevation[2]	28	0.53	0.004
MarshRAM Wetland Disturbance	30	0.44	0.016
Wetland Disturbance + Median Elevation[3]	28	0.75	0.004

Table 7. Spearman rank correlation coefficients and probability values comparing *Wetland Disturbance* scores with the % cover MarshRAM vegetation communiy types for 31 salt marshes in Rhode Island; note that higher *Wetland Disturbance* scores denote less-intense disturbance; Bonferroni adjusted α=0.008.

MarshRAM Disturbance Metric	MarshRAM Vegetation Community	r_s	*P*
C.3 *Ditching and Draining*	*Ditch*	-0.73	<0.001
C.4 *Anthropogenic Nutrients*	*Phragmites*	-0.64	<0.001
C.6 *Edge Erosion*	*Dieback Denuded Peat*	-0.53	0.002
C.7 *Crab Burrows*	*Dieback Denuded Peat*	-0.57	<0.001
C.8 *Ponding and Dieoff*	*Dieoff Bare Depression*	-0.43	0.016
C.10 *Phragmites Score*	*Phragmites*	-0.75	<0.001

Table 8. Pearson correlation coefficients relating MarshRAM waterbird tally metrics to marsh area and MarshRAM sub-indices at 31 salt marshes in Rhode Island, and to [1]historic loss at 10 salt marshes in Rhode Island (from Berry et al. 2015); NA = not applicable; Bonferroni adjusted α=0.017.

	Area		Disturbance		IMI	
	r	*P*	*r*	*P*	*r*	*P*
Waterbird Abundance	0.55	0.001	-0.19	0.297	-0.48	0.006
Waterbird Cohort Richness	0.49	0.005	0.05	0.802	-0.38	0.033
Waterbird Density	NA	NA	-0.08	0.658	-0.45	0.011

Table 9. Pearson correlation coefficients comparing MarshRAM salt marsh community cover values with analogous cover values estimated by RISMA community-based and point-intercept surveys, collected in 2012 from 23 salt marshes in Rhode Island (Ekberg et al. 2017).

MarshRAM Community	RISMA Community	*r*	*P*
Meadow High Marsh	Perennial Turf Grass Type 1	0.81	<0.01
Salt Shrub	Salt Marsh Terrestrial Border	0.79	<0.01
Sa High Marsh	Sa Type 2	0.69	<0.01
Dieoff Bare Depression	Panne	0.65	<0.01
Low Marsh	Low Marsh	0.51	0.01
Mixed High Marsh	Perennial Turf Grass Type 2 + Sa Type 1	0.47	0.03
Brackish Native Marsh	Brackish Marsh Terrestrial Border	0.43	0.04
Dieback Denuded Peat	Eroding Bank	0.42	0.05
Phragmites	Invasives	0.32	0.14
Ditch	Ditch	0.19	0.38
Creek	Natural Creek	-0.11	0.62
IMI	IMI applied to RISMA Community	0.68	<0.01
	RISMA Point Intercept		
Sa High Marsh	*Spartina alterniflora*	0.76	<0.01
Salt Shrub	*Iva frutescens*	0.71	<0.01
Dieoff Bare Depression	*Salicornia sp.*	0.58	<0.01
Meadow High Marsh	*Spartina patens*	0.55	0.01
Phragmites	*Phragmites australis*	0.48	0.02
Brackish Native Marsh	*Schoenoplectus americanus*	-0.11	0.63
IMI	IMI applied to RISMA Point Intercept	0.79	<0.01

Table 10. Pearson correlation coefficients comparing MarshRAM salt marsh community cover values with analogous cover values derived from semi-automated classification of digital aerial imagery generated in 2012 (RIGIS accessed Dec. 2018) for 31 salt marshes in Rhode Island.

MarshRAM Community	RIGIS Salt Marsh Habitats	*r*	*P*
Low Marsh	Low Marsh	0.92	<0.01
Meadow High Marsh	High Marsh; *J. gerardii* (+) *S. patens-D. spicata*	0.78	<0.01
Sa High Marsh	High Marsh; *S. alterniflora*	0.76	<0.01
Salt Shrub	Salt Shrub	0.66	<0.01
Mixed High Marsh	Mixed High Marsh	0.59	<0.01
Dieoff Bare Depression	Dieoff Depression	0.54	<0.01
Dieback Denuded Peat	Mudflat / Bare	0.39	0.04
Phragmites	Invasive *Phragmites australis*	0.32	0.14
Brackish Native Marsh	Brackish Marsh; Native	-0.05	0.39
IMI	IMI applied to RIGIS Salt Marsh Habitats	0.48	0.01

3.5 User Variability Analysis

No differences were detected between the principal and secondary investigators for the aggregate *Wetland Disturbance* sub-index (*dependent T-test*, *n*=9, *T*=-1.2, *P*=0.26), the sum of *Ecosystem Functions and Services* ranks (*n*=9, *T*=-0.13, *P*=0.90), or any of the component metrics/ranks of either index (*dependent T-test*, *P*>0.05 for all that met statistical criteria; those not meeting criteria were identically-scored across sites by users). Average inter-user differences for the *Wetland Disturbance* metric were less than 3% of the potential metric range of 10 and 7% of the range of scores in the study sample (3.7), whereas average differences were 6% of the potential range of 36 for the sum of *Ecosystem Functions and Services* ranks and 13% of the study-sample scoring range of 16 (Table 11).

No differences were detected in the length of steps across three structurally-distinct community types for each of two investigators (*Kruskal-Wallace H-test*, *n*=3x5, *H*=4.2, *P*=0.117 for User 1; *H*=4.1, *P*=0.127 for User 2). Users had different overall step lengths (*Mann-Whitney U-test*, *Z*=-2.6, *P*=0.009), but theoretical IMI values generated using the measured step lengths were within 1% of the IMI range (0-10) between the users (Fig. 4, Table 12).

Table 11. Differences in MarshRAM scores assigned by a principal (P) investigator (T. Kutcher) and secondary (S) investigators (J. Beck, *C. Chaffee) for aggregate metrics of wetland disturbance and the perceived potential for providing ecosystem functions and services (Sum of Function Ranks) at 9 salt marshes in Rhode Island; Abs. Value = absolute value

Site	Wetland Disturbance Score		Difference		Sum of Function Ranks		Difference	
	P	S	Value	Abs. Value	P	S	Value	Abs. Value
Palmer River	6.1	5.8	-0.3	0.3	20	20	0.0	0
Nag East	5.9	6.2	0.3	0.3	21	19	-2.0	2
Coggeshall	6.6	6.1	-0.5	0.5	18	22	4.0	4
Nag West	6.4	5.8	-0.6	0.6	19	22	3.0	3
Chase Cove	6.4	6.4*	0.0	0	16	18*	2.0	2
Jacob's Point	5.7	6.0*	0.3	0.3	18	15*	-3.0	3
Colt State	5.3	4.9	-0.4	0.4	17	17	0.0	0
Passeonquis	6.1	6.1	0.0	0	15	13	-2.0	2
Seapowet	4.8	4.8	0.0	0	20	17	-3.0	3
Mean Value	5.9	5.8	-0.13	0.27	18.2	18.1	-0.11	2.1

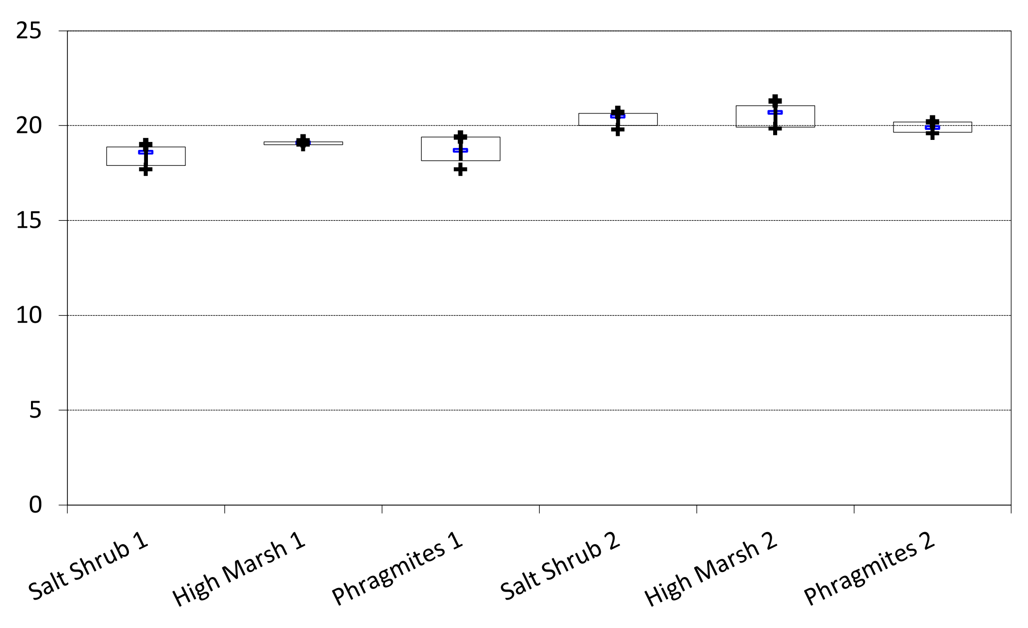


Figure 4. Distributions of distances (m) across five replicates of twenty steps in each of three salt marsh community types for two investigators (1, 2), where label suffixes denote separate investigators, the dash represents the median, the boxes represent the inter-quartile range, and the crosses represent upper and lower values.

	Reference			
	Mean	SD	Cover	Error
Salt Shrub	20.0	0.0	33.3%	0.0%
Mixed High Marsh	20.0	0.0	33.3%	0.0%
Phragmites	20.0	0.0	33.3%	0.0%
IMI	6.3			
	User 1			
	Mean	SD	Cover	Error
Salt Shrub	18.4	0.52	32.7%	-0.6%
Mixed High Marsh	19.1	0.08	33.9%	0.6%
Phragmites	18.8	0.70	33.3%	0.0%
IMI	6.3			
	User 2			
	Mean	SD	Cover	Error
Salt Shrub	20.4	0.36	33.5%	0.1%
Mixed High Marsh	20.5	0.60	33.8%	0.4%
Phragmites	19.9	0.28	32.8%	-0.6%
IMI	6.4			

Table 12. Average distances (m) across five replicates of twenty steps in each of three salt marsh community types for two investigators, compared with a theoretical reference using exactly even intervals. Relative proportions (Cover) and theoretical IMI values were generated using the mean distances and CCI (Table 1).

4. Discussion

4.1 MarshRAM Performance and Utility

4.1.1 Performance as an Indicator of Wetland Condition

MarshRAM sections *Wetland Disturbances* and *Marsh Community Composition and Index of Marsh Integrity* (IMI) were designed to reflect different aspects of salt marsh condition. *Wetland Disturbances* represents individual and aggregate marsh disturbances, whereas *Marsh Community Composition* and IMI were designed to represent marsh-platform vegetative and edaphic response to those disturbances and to increased inundation associated with sea-level rise. In freshwater wetlands, several studies have documented a strong relationship between observational disturbance indices and vegetation integrity indices that are based on sensitivity to disturbances, such as Floristic Quality Assessment, upon-which IMI is partly based (e.g. Miller and Wardrop 2006, Kutcher and Forrester 2014). In contrast, only a weak, qualitative (i.e. nearly significant) relationship between MarshRAM disturbance metrics and IMI was found among the study salt marshes, suggesting that factors other than observable disturbances may be influencing salt marsh integrity.

IMI was designed to weight the influences of increased inundation period (viewed as a result of sea-level rise) equally with the aggregate of other anthropogenic disturbances, both in terms of CCI assignments and the marsh communities assessed (Appendix B). The response of IMI to marsh-platform median elevation, and the markedly-stronger response of IMI to the aggregate of disturbance and elevation, suggest that MarshRAM reflects the cumulative effects of inundation stress (using elevation as a proxy) and other disturbances (nutrient stress, ditching, filling, etc.), as designed. IMI's strong response to disturbance + elevation corresponds to earlier studies that have suggested that the impacts of certain disturbances (nutrient loading, ditching, crab over-grazing of *S. alterniflora*) on marsh integrity can be exacerbated or catalyzed by sea-level rise (Wigand et al. 2003, 2014, Kirwan et al. 2016, Crotty et al. 2017). But the stronger correlation of IMI with elevation than with disturbance suggests that marsh communities may be responding primarily to an increased duration of marsh platform flooding that is associated with accelerating sea level rise (Raposa et al. 2017a, Watson 2017a). A more-precise metric of inundation stress, such as marsh elevation capitol (i.e., elevation in relation to the tide frame), could clarify the relationship between inundation, disturbance, and marsh integrity (Watson et al. 2017b). The University of Rhode Island Environmental Data Center is in the process of collecting local tide-frame data associated with large salt marsh complexes across Rhode Island to provide this clarification and allow a more-accurate assessment of inundation stress at individual marshes.

The significant correlation of IMI with marsh loss suggests that IMI may in-turn reflect overall marsh vulnerability to vegetation loss in the face of sea-level rise. IMI explains 61% of marsh loss among salt marshes assessed by Berry et al. (2015), and the most efficient model, comprising only the cover of *Meadow High Marsh* and *Die-off Bare Depression*, explains 73% of loss among those sites. Although the sample size for this trend is low (*n*=10), this finding suggests that changes in high marsh community types may be a strong indication of marsh vulnerability. The strong combined effect of increased dieoff and decreased *Meadow High Marsh* on explaining historic loss values suggests that loss of high marsh vegetation from ponding and dieoff is a more influential mechanism of marsh loss in Rhode Island than edge dieback, which did not significantly contribute to the model explaining loss. Analysis of MarshRAM community data against rigorous historic loss data across a larger set of wetlands may help clarify these apparent trends.

Meadow High Marsh most-strongly influenced the IMI, indicating that it may be the most sensitive singular community type to human disturbances. *Dieoff Bare Depression* was the strongest negative contributor to IMI, even as its average cover across the sample was only 5.2% of total marsh area, suggesting that even low occurrence of marsh platform die-off may signify broader degradation of marsh platform integrity (as reflected in other community types by IMI). In contrast, *Sa High Marsh*, which was the dominant cover-type overall in the sample (25.7%), only modestly influenced IMI variability (negatively) and did not contribute significantly to the historic loss model, even as it has been shown to be the community type that first displaces *Meadow High Marsh* with marsh platform elevation deficits in relation to the tide frame (Warren and Neiring 1993, Raposa et al. 2017b).

Among individual MarshRAM observational disturbance metrics, only *Ponding and Die-off* (the observational analog to *Dieoff Bare Depression*) was significantly correlated with IMI, even as multiple vegetation community components of IMI were correlated with analogous or functionally-related observation metrics. The lack of significant correlation suggests that, other than inundation stress, no singular type of disturbance overwhelmingly influences marsh community composition at the statewide scale, but that instead varied or combinations of disturbances contribute to the degradation of marsh integrity. Notably, the observational metric *Anthropogenic Nutrient Inputs* was not significantly associated with IMI or the proportion of marsh die-off, even as nutrient loading has been implicated in contributing to marsh subsidence due to its promotion of resource allocation to above-ground biomass over peat-building belowground biomass among high marsh plants (Wigand et al. 2003, 2014). *Anthropogenic Nutrients* is the most subjective MarshRAM metric, requiring interpretation of perceived nutrient sources and apparent vegetative response to nutrient loading, both of which are presumed, whereas most MarshRAM metrics are based on direct observation and estimation. Lack of a detected association may therefore be a result of deficiencies in the method. More reliable nutrient data than MarshRAM provides may be necessary to clarify the potentially interactive effects of nutrient loading and inundation stress on marsh platform integrity.

The negative association between historic loss and *Replacement Ratio* (the proportion of existing marsh that, with minimal or no management, will theoretically replace marsh losses from sea-level rise as marshes migrate inland) suggests that marshes with larger migration corridors (relative to the size of the marsh) are losing vegetated area more slowly than those with smaller corridors; this implies that unassisted marsh migration may already be contributing to marsh sustainability. *Conservation Ratio* does not, however, significantly improve the model fit of *Meadow High Marsh* and *Die-off Bare Depression* in explaining marsh loss, suggesting perhaps that meadow high marsh species are already occupying the front lines of migration, expanding as migration opportunity allows, while succumbing to inundation stress on the seaward edge. The stronger relationship of *Migration Potential* score to *Buffer Encroachment* (30m) than to the *Surrounding Land Use* (150m) at least partly reflects the scale of the *Migration Potential* model, which only assesses migration potential within the surrounding 60m of the wetland. However, the relationship highlights the importance of maintaining broad undeveloped buffers around salt marshes facing increasing threats of degradation from sea-level rise. At the scale of 60m, the median *Replacement Ratio* implies that only about 25% of existing marsh area will be replaced through landward migration as marshes succumb to inundation stress, suggesting that the current state jurisdiction of 200 feet (61m) surrounding wetlands may not be large enough to provide adequate migration opportunity for many salt marshes in the state. Other management mechanisms may therefore be necessary to promote the conservation of these valuable systems.

4.1.2 MarshRAM Reliability

Inter-user analysis of observational metrics and attributes suggests that, with careful application, MarshRAM observational data should be consistent across users. *Wetland Disturbance* scores were not different between primary and secondary users, and there were no instances in which the scores across users would have caused a site to fall into a different management category according to quartiles used in Table 5. The sum of *Ecosystem Functions and Services* ranks, which is suggested in Table 5 as a management metric, also was not different between users, although three of the nine sites assessed for user variability would have fallen into different management categories depending on the user. Standardizing the way certain metrics are scored, with a user's guide outlining standard practices and decision points for each MarshRAM observational attribute and metric, perhaps followed by field training, would be helpful for reducing user variability. RINHS will seek funding to author a user's manual to guide further implementation. Although the aggregate *Wetland Disturbance* score and the sum of the functional ranks may be useful for categorization, it is suggested that managers consider the intensity of individual disturbances and the ranks of individual functions and services for each marsh (alone and in the context of other marshes), as well as further investigating the rationale behind each one, when evaluating a salt marsh for management.

Analysis of MarshRAM community-type data against existing vegetation survey data indicates that MarshRAM is consistent in rigor with the other methods. MarshRAM was similar to RISMA vegetation community data (Ekberg et al. 2017) among the categories that most-strongly influence the IMI; this held true for RISMA point intercept data versus MarshRAM, as well, and IMI values generated using both RISMA data types were strongly correlated with IMI values from MarshRAM data. Salt marsh community categories from remote-sensed RIGIS *Salt Marsh Habitats* geospatial dataset were also strongly correlated with several influential community-types from MarshRAM data. Each method has accuracy limitations; RISMA mitigates a labor-intensive method of measurement (using a measuring tape) with fewer transects, which limits spatial coverage and therefore characterization of the marsh, whereas RIGIS uses complete spatial coverage but lacks the accuracy of in-marsh determination of community types (83% accuracy overall). MarshRAM improves spatial coverage over RISMA and identification accuracy over RIGIS, but introduces potential measurement inconsistencies to improve logistical efficiency by using steps rather than measuring tools. However, for each of two users testing MarshRAM step consistency, step length was not significantly inconsistent across community types. Overall step length between users was different, but because IMI is based on relative proportions, step variability across users affected community proportionality and IMI scores less than one percent. There is no way to determine which method (RISMA, RIGIS, or MarshRAM) is most accurate in characterizing marsh-wide vegetation cover without an intensive gold standard against which to compare the methods. Still, these findings indicate that MarshRAM's unique method of tallying footsteps as data points along a walking transect is comparable to more labor-intensive methods and methods using strictly-controlled measuring procedures and better spatial coverage.

4.2 Management Applications

Understanding how sea-level rise and other disturbances are contributing to marsh degradation is critical for restoration planning (Roman 2017, Kutcher et al. 2018), and a decision-support matrix based on MarshRAM and inundation data, such as presented in Table 5, may be a useful tool to help managers interpret this complex information. Table 5 demonstrates how collecting the full suite of MarshRAM data across multiple sites can establish a range (i.e. "reference gradient", Faber-Langendoen et al. 2009) of salt marsh conditions, against which individual wetlands can be evaluated. Assigning three management categories, based on upper and lower quartiles and inter-quartile ranges of metric and attribute values, can be used to clarify the relationships among ecosystem services, human disturbances, elevation, marsh integrity, and migration potential. Using three management categories (e.g. Barbour et al. 1996, Miller et al. 2006), rather than more, simplifies interpretation of each metric (a central purpose of categorization), and reduces the chance of overestimating metric-value precision and meaningfulness (Kutcher and Forrester 2014). Given the broad spatial and hydro-geomorphic representation of marshes in the study sample, it is recommended that categories assigned in Table 5 could presently be used by managers to inform ecological intervention strategies for specific salt marshes. Following quartile-based methods used in Table 5, salt marshes with IMI<5.5 could be classified as most-degraded, marshes with IMI ranging from 5.5 to 6.9 could be classified as intermediately- degraded, and marshes with IMI>6.9 could be classified as least-degraded. However, as more data are collected, expanding and refining this reference gradient to represent more sites (target= 51) would provide a more accurate representation of salt marshes state-wide.

4.3 The Condition of Salt Marshes in Rhode Island

4.3.1 Limitations of the Study Sample

The salt marshes used in this study were selected to represent a wide spatial and hydro-geomorphic distribution across Rhode Island and to correspond with prior studies that could provide data for analysis. Although the study marshes were not randomly selected and are therefore not strictly probabilistic, the selection process aimed at providing a sample that is representative of salt marshes state-wide, and the study sample includes marshes from most of the major salt marsh complexes in Rhode Island. It is acknowledged that a larger set of randomly-selected study marshes would likely increase the accuracy and utility of this dataset in representing marshes across Rhode Island. DEM plans to seek funding for field year 2021 to expand the reference set of marshes to at least 50 sites for future management planning and the ranking and prioritization of salt marshes. This section of the report (4.3) analyzes the sample assessed from 2018 and 2019 (n=31) to represent salt marshes across Rhode Island, recognizing its current limitations.

4.3.2 Marsh Integrity

Recent studies have indicated that salt marshes in southern New England are degrading, are losing vegetated area, and are among the most vulnerable to sea-level rise in the United States (Gedan et al. 2011, Raposa et al. 2016b, Ekberg et al. 2017, Watson et al. 2017a,b); findings of this study support those indications. In their seminal description of the vegetation communities of the southern New England salt marsh, Miller and Egler (1950) detailed vegetation communities at a salt marsh complex surrounding Barn Island at the eastern-most border of Connecticut (directly bordering Rhode Island). The Barn Island marsh was reported to be dominated by *Juncus* and *S. patens* high marsh with fringing bands of low marsh and marsh-upland interface. The authors estimated that "as much as" 20% of the un-ditched portions of the marsh comprised circular or nearly-circular *Pannes and Potholes*; the occurrence of *S. alterniflora* on the high marsh was reported to be restricted to those pannes. Considering (1) 20% cover of *Panne and Pothole* arbitrarily evenly split among the authors' *Pothole* and *Panne* types, (2) a fringing band of *Spartina alterniflora* low marsh (set conservatively at 10%), (3) a fringe of marsh-upland interface (arbitrarily set at 10%), and (4) the remaining 60% split among meadow high marsh *Juncus* and *S. patens* types (both classified as *Meadow High Marsh* by MarshRAM), an un-ditched late 1940s Barn Island marsh without invasive *Phragmites* would have an IMI value of approximately 8.9. Applying that value, as a "reference" value for historic marsh integrity, would suggest that the integrity of marshes in the study sample (*n*=31), as a proxy for Rhode Island marshes statewide (IMI mean=6.1), are considerably degraded on average. There is no way, however, to determine if the study marshes that approach an IMI of 8.9 are within natural variation of an undisturbed marsh, or are in-fact degraded by human activities, including sea-level rise. For example, Sheffield Cove (IMI=8.0) has a nearly-representative distribution of historic communities, except for a moderate occurrence (16.6%) of *Mixed High Marsh* (*S. patens* and *S. alterniflora* mix), which was not a type described by Miller and Egler, and 3.4% representation of *Dieback Denude Peat*, a feature also not described by the authors. *S. alterniflora* was reported as occurring "rarely" in both of Miller and Egler's high marsh communities (*Juncus* and *S. patens* dominated), suggesting that a substantial mixed community did not occur at Barn Island Marsh at that time. Nearly every marsh in this current study had some *Mixed High Marsh* (all except Brushneck Cove, which was mainly a fringe of *Native Brackish* and *Phragmites*), but its occurrence was low (5-10%) at some sites and more subject to user interpretation than other MarshRAM community types; therefore it may be hard to argue with any certainty that Sheffield Cove (or any of the other high-scoring marshes in the study sample with similar community-type distributions; Fig. 2) is any more degraded today than Barn Island was in 1947.

In contrast to Sheffield Cove, several sites in the lower range of IMI scoring are clearly degraded. For example, Quonnie East clearly diverges from Miller and Egler's historic marsh, having only 3.5% cover of *Meadow High Marsh*, 34% *Sa High Marsh*, 11.7% *Mixed High Marsh*, and 23% *Dieoff Denuded Peat*. Medially, several marshes with intermediate IMI values have very little *Dieoff* (<5%), but have low representation of *Meadow High Marsh* (<20%) and high representation *Mixed* and *Sa High Marsh* (>40% combined), indicating a vegetation shift from *S. patens* to *S. alterniflora* that may precede dieoff in the process of marsh drowning (Warren and Niering 1993, Raposa et al. 2017b).

Interestingly, Miller and Egler (1950) described the occurrence of what might now be labeled *Dieoff Bare Depression* in one ditched area of the Barn Island Marsh exhibiting rapid loss of *S. patens* vegetation, which the authors attributed to the incidental plugging of a drainage ditch. They speculated that the area was simply reverting back to a pre-ditched state of mud flat. An even earlier study of Connecticut salt marshes (Nichols 1920) describes shallow "secondary" (i.e., occurring on an already developed high-marsh platform) pannes commonly occurring across the high marsh surface in various degrees of abundance, including apparently substantial coverage (see Fig. 5). Nichols describes various contemporaneous theories of marsh panne formation, which include a theory attributing marsh platform subsidence and dieoff to the ponding of tidal water between the raised levees that can develop along natural creek banks, suggesting that dieoff may be a step in the natural process of panne formation. Later studies have theorized that the same process also commonly occurs between the linear spoils of manmade ditches (Miller and Egler 1950, Smith and Niles 2016, Watson 2017b). This current study found no relationship between the cover of natural creeks or ditching intensity versus IMI or versus the cover of marsh dieoff (even as ditching was observed at 27 of 31 sites), suggesting that the inter-levee panne-formation process is not currently an important driver of marsh degradation at the study marshes, although it may be a factor in other Rhode Island marshes. More recent studies implicate increased rates of sea-level rise and accretion deficits in relation to the tide frame in widespread dieoff of the historic peat platform (Ekberg et al. 2017, Watson et al, 2017a,b); findings from this current study that relatively small amounts of dieoff have a strong negative influence on IMI and historic loss, more-closely support these recent conclusions. The IMI remains a viable indicator of platform degradation and vulnerability to the extent that these recent theories hold true. Documenting changes over time in dieoff features, vegetation shifts, and marsh platform elevation in relation to the tide frame will clarify the role of sea-level rise in the process of marsh degradation and loss.

Figure 5. Historic photograph depicting expansive marsh panne features on a marsh platform in Connecticut (from Nichols 1920).

Phragmites was present at every marsh in the study. *Phragmites* is a disturbance to marsh function in several ways, but is also a vegetative response to other disturbances such as filling, substrate disturbance, and nutrient loading (Silliman and Bertness 2004, Meyerson et al. 2009). *Phragmites* can outcompete and displace native salt marsh vegetation species, lower plant species richness, change soil composition, degrade habitat value, and impede landward migration of marsh vegetation (Benoit and Askins 1999, Meyerson et al. 2000, Smith 2013). The rigorous growth of *Phragmites* promotes accelerates platform accretion over native marsh species, which can support platform elevation relative to sea-level rise (Rooth et al. 2003), but its domination over native species may undermine the value of that benefit. *Phragmites* cover was correlated with indicators of nutrient inputs (although note that presence of tall and robust *Phragmites* was used as one of nine indicators of nutrient stress) but was not correlated with the overall intensity of filling or marsh excavation, even as filling was a common disturbance identified across the sample (occurring at 21 of 31 sites), suggesting that *Phragmites* establishment can occur independent of marsh filling. Residential development and roads were the adjacent land uses most-often associated with *Phragmites* presence across the sample, suggesting that nutrients, filling, and substrate disturbances may in fact be factors in its establishment and success, even as the latter did not show a statistical signal. A larger MarshRAM dataset should help clarify these relationships.

Marsh edge erosion was another pervasive disturbance (29 of 31 sites), assessed as severe (>60% of the marsh edge) at 18 of 31 sites. Minor erosion of the marsh edge is a natural process, and MarshRAM disregards a small amount of natural edge erosion. However, many of the marshes in the study sample were clearly eroded deep into thick peat (>0.5m thick) for the majority of the edge, including along large creeks, leaving some marshes with a minimal vegetated low marsh zone. Coincident occurrence of *Dieback Denuded Peat*, indicating crab damage (Holdridge et al. 2009), at many of these highly-eroded sites suggests a positive interaction between crab overabundance and loss of marsh edge from erosion (Raposa et al. 2018). And because sea-level rise may at least partly facilitate the proliferation of marsh crabs through vegetation shifts and softening of peat deposits (Crotty et al. 2017), the findings of this current study support prior assertions that recent marsh-edge loss at least partly results from sea-level rise (Watson et al. 2017a,b).

4.3.4 MarshRAM Opportunistic Bird Tallies

The MarshRAM method takes advantage of an undemanding opportunity to tally waterbirds, marsh-obligate sparrows, and raptors during MarshRAM assessments. Even though a single survey of birds (rather than several per season) may not be rigorous enough to confidently characterize bird use at a site (Conway 2011), there are signs that these opportunistic tallies may, with little extra effort, provide some useful information on bird use across marshes. First, this study's findings of increased bird abundance and cohort richness with increased marsh area are expected outcomes of the well-established species-area relationship (Connor and McCoy 1979), and imply the ecological benefits of conserving larger salt marshes for birds (Benoit and Askins 2002, Shriver et al. 2004). Next, negative correlations of both bird density and cohort richness with IMI suggest that, as marsh integrity degrades, bird use may increase. This finding supports anecdotal observations of intensive wading bird and shorebird use of marshes with high levels of ponding and marsh dieoff, such as Winnapaug Pond in Westerly, RI. The author and other salt marsh scientists have observed surface ponding that traps nekton on the marsh surface in shallow, sparsely-vegetated dieback pools (Kutcher et al., personal observation), which creates high-quality conditions for attracting wading-birds for foraging (Gawlik 2002). Additionally, dieoff depressions and die-back edges often have exposed areas of decomposing peat, which may hold mud-flat invertebrates and may therefore attract a diversity of shorebirds to the marsh platform (Recher 1966). The finding supports prior conclusions that some functions and values of salt marshes may increase with degrading marsh habitats, as has been demonstrated with nekton use in subsiding marshes in Louisiana, USA (Rozas and Reed 1993). These findings highlight the need to understand the variable persistence of the separate functions and values held by salt marshes facing sea-level rise and other stressors, so that restoration and conservation resources can target preserving or improving imperiled functions and services rather than those which may be stable or even gaining functionality with degrading marsh condition (Kutcher et al. 2018). More study into the sustainability of various salt marsh functions and services seems warranted, given recent trends in salt marsh degradation with accelerating sea-level rise (Roman 2017, Watson et al. 2017a). For example, predicting the trajectory of wading-bird and nekton use as salt marshes degrade through intermediate and severe levels of ponding and degradation may help clarify best management practices in salt marsh restoration and conservation. Rozas and Reed (1993) suggest that, while intermediate degradation enhances nekton use of marshes, more severe degradation may reverse that trend, following intermediate-disturbance theory (Connell 1978).

MarshRAM's opportunistic tallying of marsh-obligate sparrows (*Ammospiza* sp.) flushed during marsh transects may also be useful. Berry et al. (2015) documented a decrease in marsh sparrow abundance in Rhode Island salt marshes from 1982 to 2008, coincident with a general loss of marsh area and condition, suggesting that marsh sparrow density may relate to platform condition. The density of marsh sparrows flushed during IMI transects was not correlated with IMI, but the linear density of marsh sparrows (the number of sparrows per transect length) flushed along the IMI transects increased significantly with the linear density of ditches recorded, suggesting that marsh sparrows may be opportunistically using salt marsh ditches for nesting or foraging. Reinert and Mello (1995) found that salt marsh sparrows in southern New England focus their nesting and foraging activities in the medium-height high-marsh *S. alterniflora* bordering ditches and creeks. Given this current study's findings of net neutral impacts of ditching on salt marsh integrity (according to IMI scores), and their potential support of salt marsh sparrows, management of historic ditches should be considered carefully (Corman et al. 2012). More intensive study into sparrow use of historic ditches may be warranted for clarifying the full ecological effects of ditch remediation, particularly given the recent decline of marsh sparrows and their critical dependence on salt marshes for survival (Correll et al. 2017).

4.4 MarshRAM Efficiency

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 (IMI), and marsh migration sections, and all preparations and travel—took less than a single work day to conduct per marsh, even for the largest marshes in Rhode Island (i.e. Seapowet, Palmer). 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. With total transect length averaging less than one km per site and site surveys planned around the low tide, physical exertion was manageable for this study's researchers. 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.

4.5 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.

4.5.1 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 (Appendix 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 Section 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.
- Section 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 (Appendix 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. Because MarshRAM requires transects running from upland interface to the subtidal zone, and an evaluation of the entire marsh platform, large marshes or marshes with deep or wide, mucky creeks may pose a logistical challenge. 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.

4.5.2 MarshRAM Assessment Unit

MarshRAM was designed to characterize and assess entire contiguous salt marshes bounded by uplands, open water, or manmade features that 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 large marshes.

Literature Cited

Barbour, M.T., Gerritsen, J., Griffith, 3., Frydenborg, R., McCarron, E., White, J.S. and Bastian, M.L., 1996. A framework for biological criteria for Florida streams using benthic macroinvertebrates. Journal of the North American Benthological Society, 15(2), pp.185-211.

Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C., and Silliman, B.R., 2011. The value of estuarine and coastal ecosystem services. Ecological monographs 81(2), pp.169-193.

Benoit, L.K. and Askins, R.A., 2002. Relationship between habitat area and the distribution of tidal marsh birds. The Wilson Journal of Ornithology, 114(3), pp.314-324.

Berry, W.J., Reinert, S.E., Gallagher, M.E., Lussier, S.M. and Walsh, E., 2015. Population status of the seaside sparrow in Rhode Island: a 25-year assessment. Northeastern Naturalist, 22(4), pp.658-671.

Bried, J.T., Jog, S.K. and Matthews, J.W., 2013. Floristic quality assessment signals human disturbance over natural variability in a wetland system. Ecological Indicators, 34, pp.260-267.

Carullo, M., Carlisle, B.K. and Smith, J.P., 2007. A New England rapid assessment method for assessing condition of estuarine marshes: A Boston Harbor, Cape Cod and Islands pilot study. Massachusetts Office of Coastal Zone Management, Boston, USA.

Corman, S.S., Roman, C.T., King, J.W., and Appleby, P.G., 2012. Salt marsh mosquito-control ditches: sedimentation, landscape change, and restoration implications. Journal of Coastal Research, 28(4), pp.874-880.

Ekberg, M.L.C., Raposa, K.B., Ferguson, W.S., Ruddock, K. and Watson, E.B., 2017. Development and application of a method to identify salt marsh vulnerability to sea level rise. Estuaries and Coasts, 40(3), pp.694-710.

Connell, J.H., 1978. Diversity in tropical rain forests and coral reefs. Science, 199(4335), pp.1302-1310.

Connor, E.F. and McCoy, E.D., 1979. The statistics and biology of the species-area relationship. The American Naturalist, 113(6), pp.791-833.

Correll, M.D., Wiest, W.A., Hodgman, T.P., Shriver, W.G., Elphick, C.S., McGill, B.J., O'brien, K.M. and Olsen, B.J., 2017. Predictors of specialist avifaunal decline in coastal marshes. Conservation Biology, 31(1), pp.172-182.

Crotty, S., Angelini, C. and Bertness, M.D., 2017. Multiple stressors and the potential for synergistic loss of New England salt marshes. PLoS ONE 12(8):e0183058. https://doi.org/10.1371/journal.pone.0183058

CWMW (California Wetlands Monitoring Workgroup). 2013. California Rapid Assessment Method (CRAM) for Wetlands, Version 6.1, 67pp.

Deegan, L.A., Hughes, J.E. and Rountree, R.A., 2002. Salt marsh ecosystem support of marine transient species. In Concepts and controversies in tidal marsh ecology (pp. 333-365). Springer, Dordrecht.

Donnelly, J.P. and Bertness, M.D., 2001. Rapid shoreward encroachment of salt marsh cordgrass in response to accelerated sea-level rise. Proceedings of the National Academy of Sciences, 98(25), pp.14218-14223.

EPA (U.S. Environmental Protection Agency), 2006. Application of Elements of a State Water Monitoring and Assessment Program for Wetlands. EPA 841-B-03- 003. 12pp.

Faber-Langendoen, D., Lyons, R. and Comer, P., 2009. Developing options for establishing reference conditions for wetlands across the lower 48 states. NatureServe, Arlington, VA, USA.

Fennessy, S.M., Jacobs, A.D. and Kentula, M.E., 2007. An evaluation of rapid methods for assessing the ecological condition of wetlands. Wetlands, 27(3), pp.543-560.

Gawlik, D.E., 2002. The effects of prey availability on the numerical response of wading birds. Ecological monographs, 72(3), pp.329-346.

Gedan, K.B., Altieri, A.H. and Bertness, M.D., 2011. Uncertain future of New England salt marshes. Marine Ecology Progress Series, 434, pp.229-237.

Gedan, K.B., Silliman, B.R. and Bertness, M.D., 2009. Centuries of human-driven change in salt marsh ecosystems. Marine Science, 1.

Holdredge, C., Bertness, M.D. and Altieri, A.H., 2009. Role of crab herbivory in die-off of New England salt marshes. Conservation Biology, 23(3), pp.672-679.

Kirwan, M.L., Temmerman, S., Skeehan, E.E., Guntenspergen, G.R. and Fagherazzi, S., 2016. Overestimation of marsh vulnerability to sea level rise. Nature Climate Change, 6(3), pp.253-260.

Kutcher, T.E., 2011. Rhode Island rapid assessment method user’s guide; RIRAM version 2.10. Rhode Island Department of Environmental Management, Office of Water Resources, Providence, RI.

Kutcher, T.E. and Bried, J.T., 2014. Adult Odonata conservatism as an indicator of freshwater wetland condition. Ecological Indicators, 38, pp.31-39.

Kutcher, T.E., 2018. Developing and piloting the salt marsh rapid assessment method, MarshRAM. Rhode Island Department of Environmental Management, Office of Water Resources, Providence, RI, 25pp. plus appendices.

Kutcher, T.E., Chaffee, C. and Raposa, K.B., 2018. Rhode Island coastal wetland restoration strategy. Rhode Island Coastal Resources Management Council, Wakefield, RI.

Kutcher, T.E. and Forrester, G.E., 2018. Evaluating how variants of floristic quality assessment indicate wetland condition. Journal of Environmental Management, 217, pp.231-239.

McKinney, R.A., Charpentier, M.A. and Wigand, C., 2009. Assessing the wildlife habitat value of New England salt marshes: II. Model testing and validation. Environmental monitoring and assessment, 154(1-4), p.361.

Meyerson, L.A., Saltonstall, K., Chambers, R.M., Silliman, B.R., Bertness, M.D. and Strong, D., 2009. *Phragmites australis* in eastern North America: a historical and ecological perspective. Human impacts on salt marshes: a global perspective. University of California Press, Berkeley, USA, pp.57-82.

Miller, S.J., Wardrop, D.H., Mahaney, W.M. and Brooks, R.P., 2006. A plant-based index of biological integrity (IBI) for headwater wetlands in central Pennsylvania. Ecological Indicators, 6(2), pp.290-312.

Miller, W.R. and Egler, F.E., 1950. Vegetation of the Wequetequock-Pawcatuck tidal-marshes, Connecticut. Ecological Monographs, 20(2), pp.143-172.

Nichols, G.E., 1920. The vegetation of Connecticut VII. The associations of depositing areas along the seacoast. Bull. Torrey Bot. Club, 47, pp.511-548.

Nixon, S.W., 1980. Between coastal marshes and coastal waters—a review of twenty years of speculation and research on the role of salt marshes in estuarine productivity and water chemistry. In Estuarine and wetland processes (pp. 437-525). Springer US.

Raposa, K.B., Ekberg, M.L.C., Burdick, D.M., Ernst, N.T. and Adamowicz, S.C., 2017a. Elevation change and the vulnerability of Rhode Island (USA) salt marshes to sea-level rise. Regional Environmental Change, 17, pp.389-397.

Raposa, K.B., Kutcher T.E., Ferguson W., Ekberg M.C., and Weber R.L. 2016a. A strategy for developing a salt marsh monitoring and assessment program for the State of Rhode Island. A technical report for RICRMC and RIDEM. 23pp.

Raposa, K.B., McKinney, R.A., Wigand, C., Hollister, J.W., Lovall, C., Szura, K., Gurak Jr, J.A., McNamee, J., Raithel, C. and Watson, E.B., 2018. Top-down and bottom-up controls on southern New England salt marsh crab populations. PeerJ, 6, p.e4876.

Raposa, K.B., Weber, R.L., Ekberg, M.C. and Ferguson, W., 2017b. Vegetation dynamics in Rhode Island salt marshes during a period of accelerating sea level rise and extreme sea level events. Estuaries and Coasts, 40, pp. 640-650.

Raposa, K.B., Wasson, K., Smith, E., Crooks, J.A., Delgado, P., Fernald, S.H., Ferner, M.C., Helms, A., Hice, L.A., Mora, J.W. and Puckett, B., 2016b. Assessing tidal marsh resilience to sea-level rise at broad geographic scales with multi-metric indices. Biological Conservation, 204, pp.263-275.

Recher, H.F., 1966. Some aspects of the ecology of migrant shorebirds. Ecology, 47(3), pp.393-407.

Reinert, S.E. and Mello, M.J., 1995. Avian community structure and habitat use in a southern New England estuary. Wetlands, 15(1), pp.9-19.

Roman, C.T. 2017. Salt marsh sustainability: challenges during an uncertain future. Estuaries and Coasts, 40, pp. 711-716.

Rooth, J.E., Stevenson, J., and Cornwell, J.C., 2003. Increased sediment accretion rates following invasion by *Phragmites australis*: the role of litter. Estuaries, 26(2), pp.475-483.

Rozas, L.P. and Reed, D.J., 1993. Nekton use of marsh-surface habitats in Louisiana (USA) deltaic salt marshes undergoing submergence. Marine Ecology-Progress Series, 96, pp.147-147.

Shriver, W.G., Hodgman, T.P., Gibbs, J.P. and Vickery, P.D., 2004. Landscape context influences salt marsh bird diversity and area requirements in New England. Biological Conservation, 119(4), pp.545-553.

Silliman, B.R. and Bertness, M.D., 2004. Shoreline development drives invasion of Phragmites australis and the loss of plant diversity on New England salt marshes. Conservation Biology, 18(5), pp.1424-1434.

Smith, J.A., 2013. The role of Phragmites australis in mediating inland salt marsh migration in a mid-Atlantic estuary. PloS one, 8(5), p.e65091.

Smith, J.A., Niles, L., 2016. Are Salt Marsh Pools Suitable Sites for Restoration? Wetland Science and Practice 33 (4), 102-109.

Shepard, C.C., Crain, C.M., Beck, M.W., 2011. The Protective Role of Coastal Marshes: A Systematic Review and Meta-analysis. PLoS one 6(11), p.e27374.

USACE (U.S. Army Corps of Engineers), 2003. The Highway Methodology Workbook. US Army Corps of Engineers New England Division. NEDEP-360-1-30. 28pp.

Warren, R.S. and Niering, W.A., 1993. Vegetation Change on a Northeast Tidal Marsh: Interaction of Sea-Level Rise and Marsh Accretion. Ecology, 74(1), pp.96-103.

Watson, E.B., Raposa, K.B., Carey, J.C., Wigand, C. and Warren, R.S., 2017a. Anthropocene Survival of Southern New England’s Salt Marshes. Estuaries and Coasts, 40, pp.617-625.

Watson, E.B., Wigand, C., Davey, E.W., Andrews, H.M., Bishop, J. and Raposa, K.B., 2017b. Wetland loss patterns and inundation-productivity relationships prognosticate widespread salt marsh loss for southern New England. Estuaries and Coasts, 40(3), pp.662-681.

Wigand, C., McKinney, R.A., Charpentier, M.A., Chintala, M.M. and Thursby, G.B., 2003. Relationships of nitrogen loadings, residential development, and physical characteristics with plant structure in New England salt marshes. Estuaries, 26(6), pp.1494-1504.

Wigand, C., Carlisle, B., Smith, J., Carullo, M., Fillis, D., Charpentier, M., McKinney, R., Johnson, R., and Heltshe, J., 2011. Development and validation of rapid assessment indices of condition for coastal tidal wetlands in southern New England, USA. Environmental Monitoring and Assessment 182:31–46.

Wigand, C., Roman, C.T., Davey, E., Stolt, M., Johnson, R., Hanson, A., Watson, E.B., Moran, S.B., Cahoon, D.R., Lynch, J.C. and Rafferty, P., 2014. Below the disappearing marshes of an urban estuary: historic nitrogen trends and soil structure. Ecological Applications, 24(4), pp.633-649.

Appendix A

MarshRAM Field Datasheet 2018

MarshRAM V.2 Investigators____ Site Code______________ Date_________

Longitude (DD) ___________________________ Latitude (DD) _____________________________

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

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

- ☐ <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 ________

Swallows_______ Raptors ________ Gulls ________ Sparrows__________

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

MarshRAM V.2 Investigators_______________________________________ Site Code_____________ Date_________

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

Surrounding Land Uses: Check all that apply

- ☐ 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 = _____

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 Associated Stressor; check one:

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

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
- ☐ Raised Trail
- ☐ Railway
- ☐ Dam
- ☐ Dike
- ☐ 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

MarshRAM V.2 Investigators______________________________________ Site Code_____________ Date_________

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 V.2 Investigators____ Site Code_____________ Date_________

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

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

MarshRAM V.2 Investigators____ Site Code_____________ Date_________

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

D. Index of Marsh Integrity

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

$$= \boxed{}$$

Marsh Community Composition:

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

C. Wetland Disturbance Score (max 10) __________

D. Index of Marsh Integrity (max 10) __________

Investigator____ Site ______________________________ Date_________________

E) Migration Potential

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

Landward* Surface Waters

No Potential:

____Ocean
____Estuary
____ Lake/pond
____Other

Sum = ____ x 0 = 0

*separated from marsh by upland

Elevated Land >1.5m above MHW

No Potential:

____Bedrock
____Hardened shoreline
____Developed land
____Landfill
____Other__________________

Sum = ____ x 0 = 0

Low Potential:

____Elevated erodible Land

Sum = ____ x 2 = ____

Low-lying Land <1.5m above MHW

No Potential:

_____Ocean Beach / Dune
_____Estuarine Beach

Sum = ____ x 0 = 0

Low Potential:

____Paved street or lot
____ Residential development (structures present)
____ Industrial / commercial development (structures present)
____Other____________________

Sum Low = ____ x 2 = ____

Moderate Potential:

____ Active farmland
____Golf course
____Sand and gravel operation
____Undeveloped land behind a raised shoreline feature
____Freshwater deep wetland
____Other_____________________

Sum Moderate = ____ x 5 = ____

Moderately High Potential:

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

Sum Mod High = ____ x 8 = ____

High Potential:

____Emergent FW wetland
____Upland field / meadow
____Abandoned farmland
____Other____________________

Sum High = ____ x 10 = ____

Sum weighted values for **Migration Potential score:** ☐

A. Area of Marsh = ________
B. Area of surrounding land to 60m = _______
C. Proportion of Moderately High +High class = _______

D. Migration Area = B X C = ☐

Replacement Ratio = D ÷ A = ☐

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

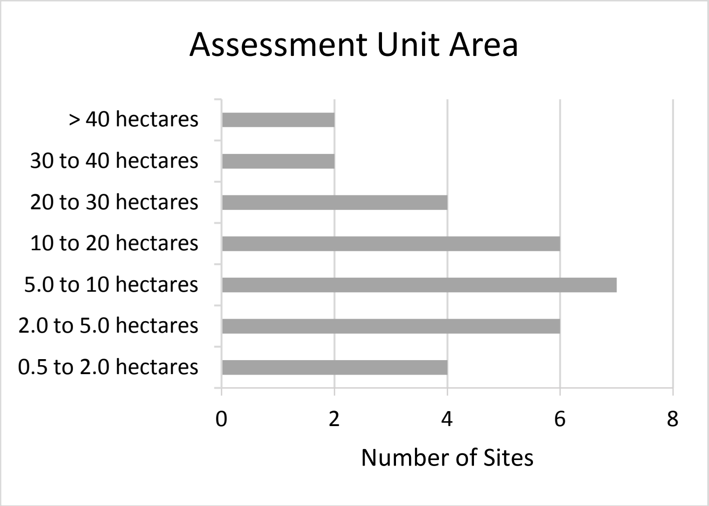
Appendix C

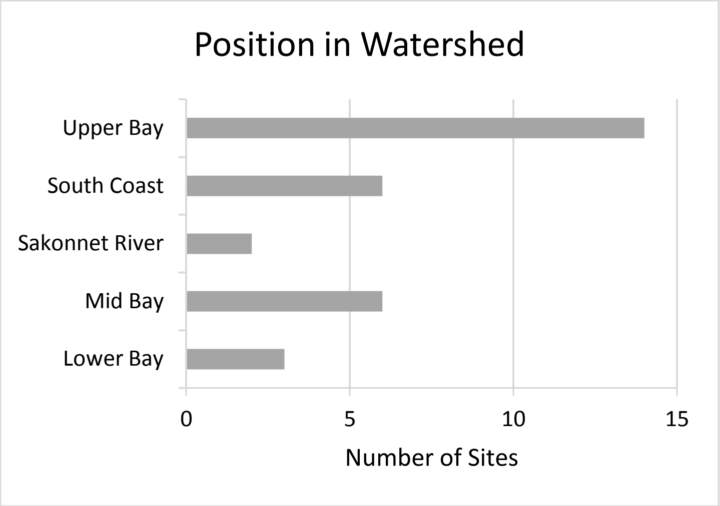
Sample field maps as used for MarshRAM assessment, including a landscape scale map depicting surrounding landscape buffers and a larger-scale map depicting eight hand-drawn marsh-community transects; field maps are typically 8.5" x 11" but have been scaled to fit on this page

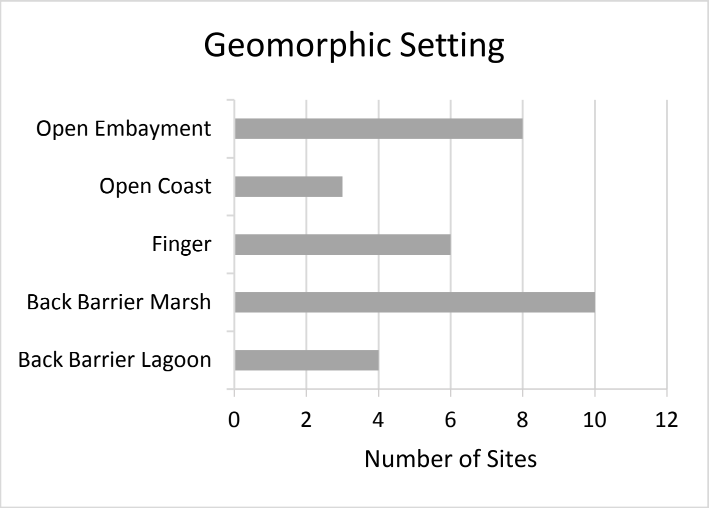
Appendix D

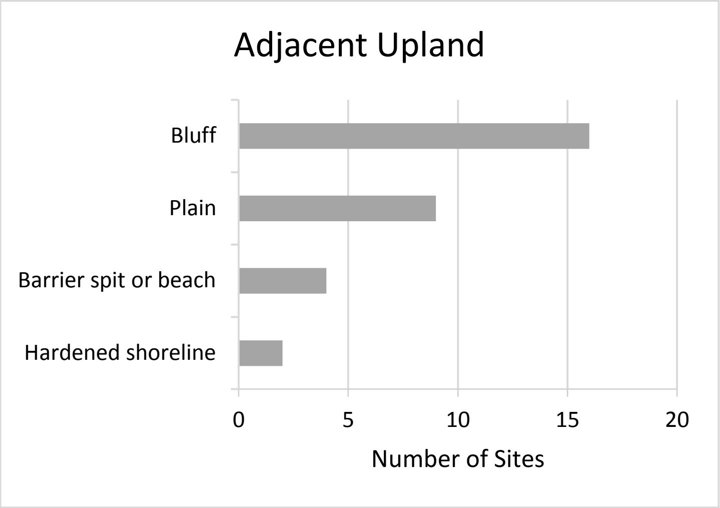
Graphs of MarshRAM Attributes and Metric Scores at 11 Salt Marshes Assessed in 2017 and 2018 Combined

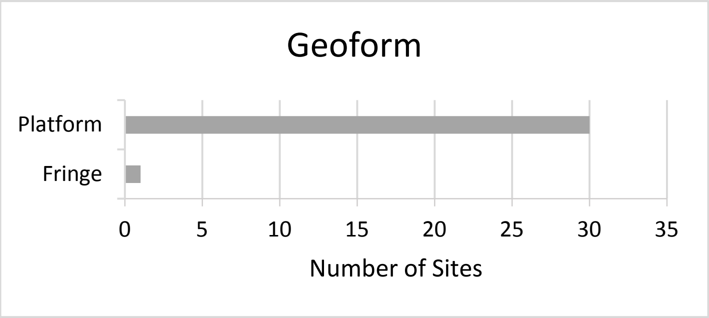
A. Marsh Characteristics

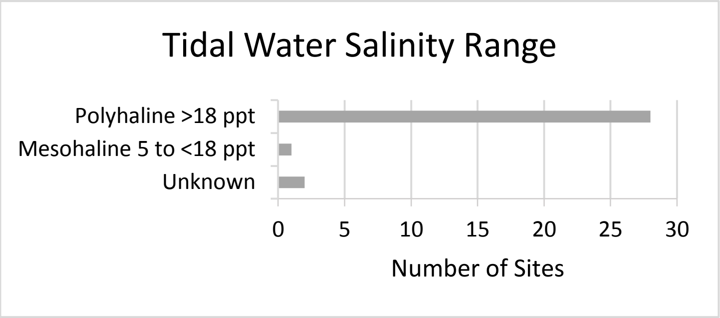


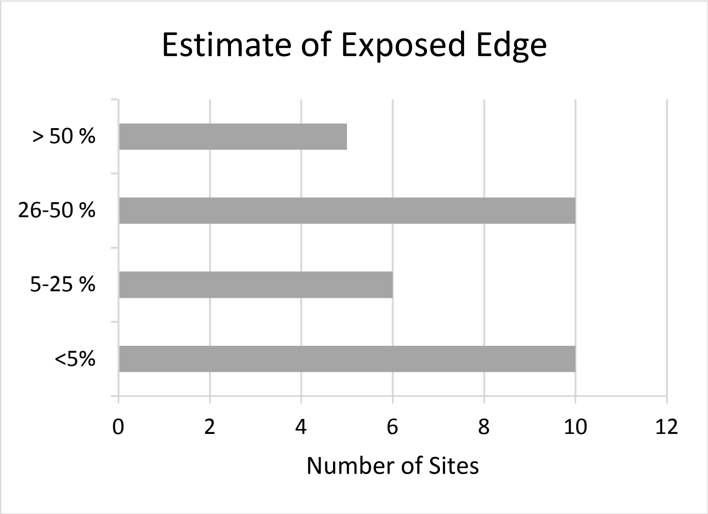


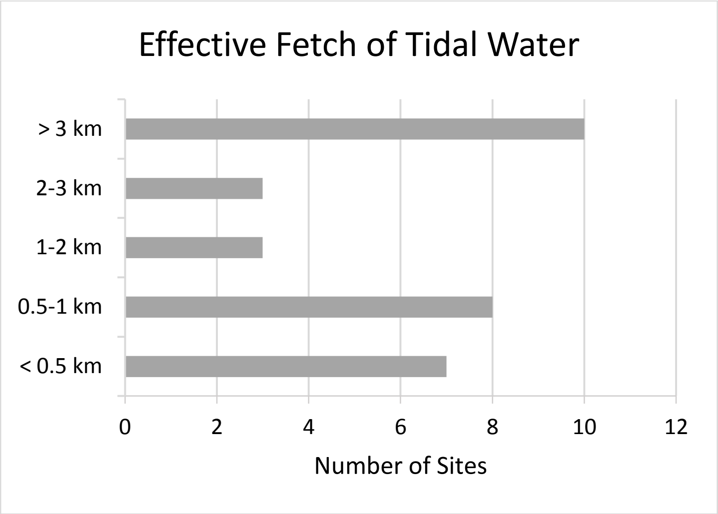


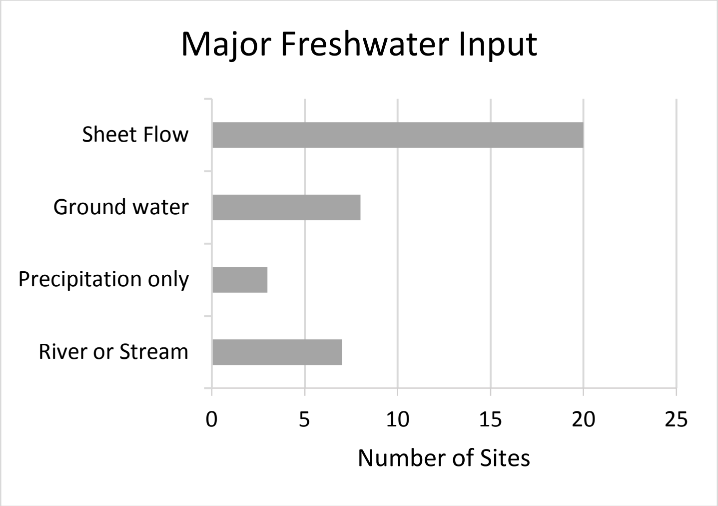


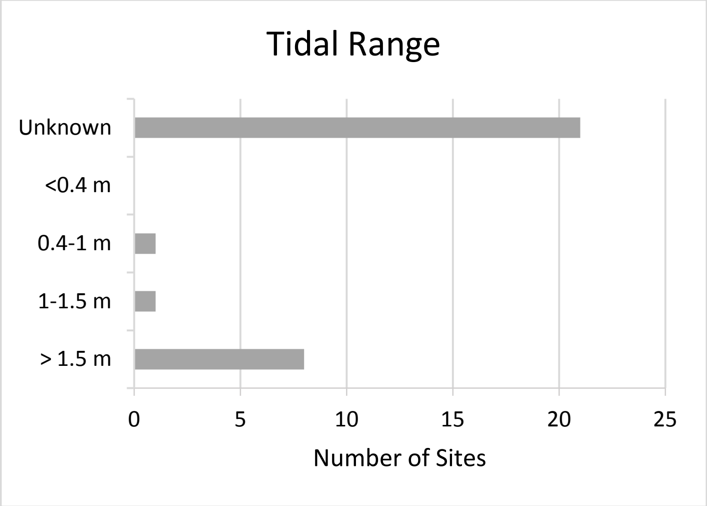


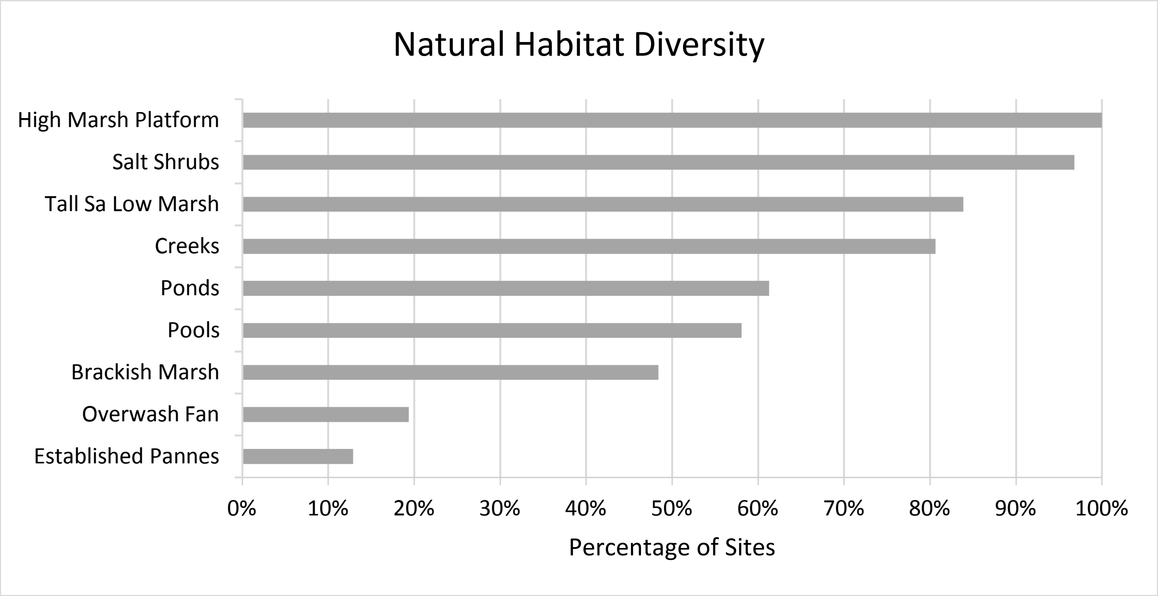


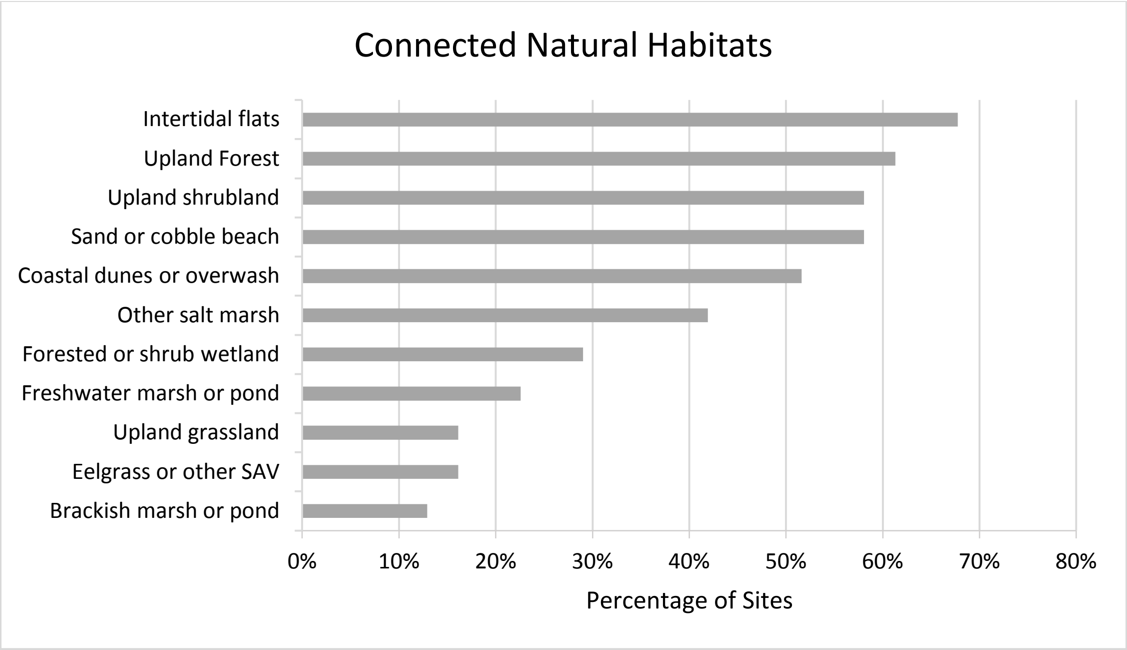

Estimate of Exposed Edge
> 50 %
26-50 %
5-25 %
<5%
0
2
4
6
8
10
12
Number of Sites

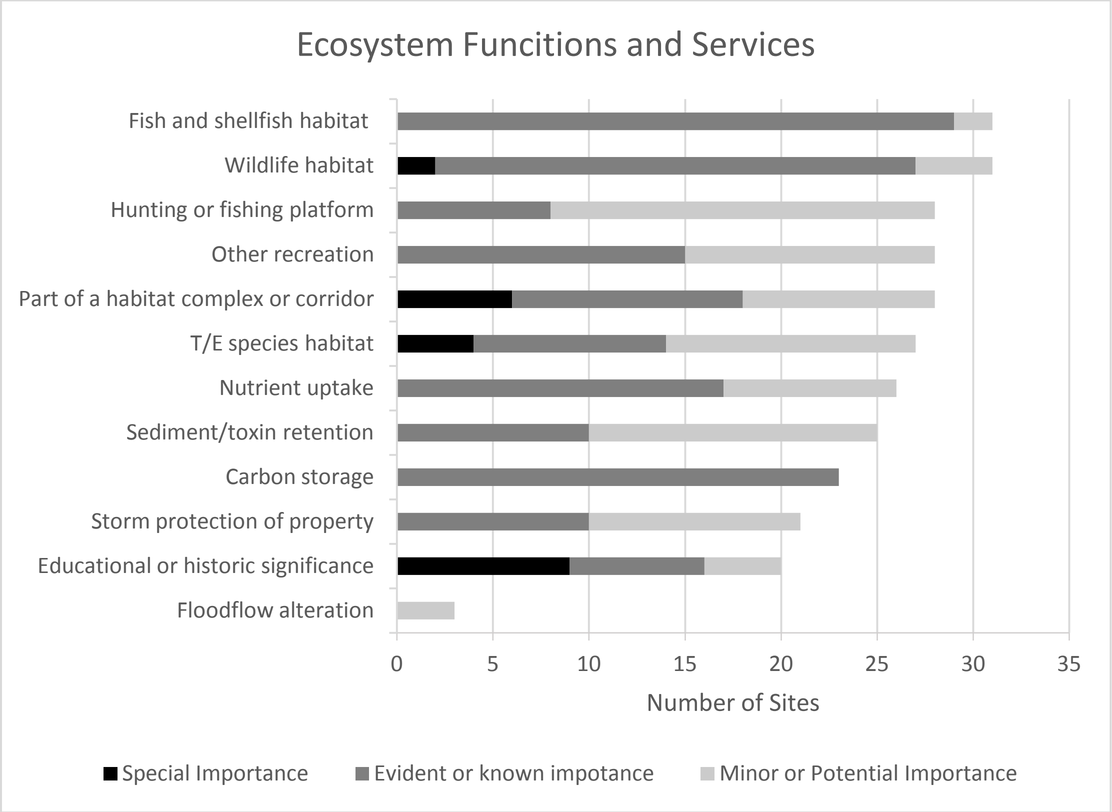

Effective Fetch of Tidal Water
> 3 km
2-3 km
1-2 km
0.5-1 km
< 0.5 km
0
2
4
6
8
10
12
Number of Sites

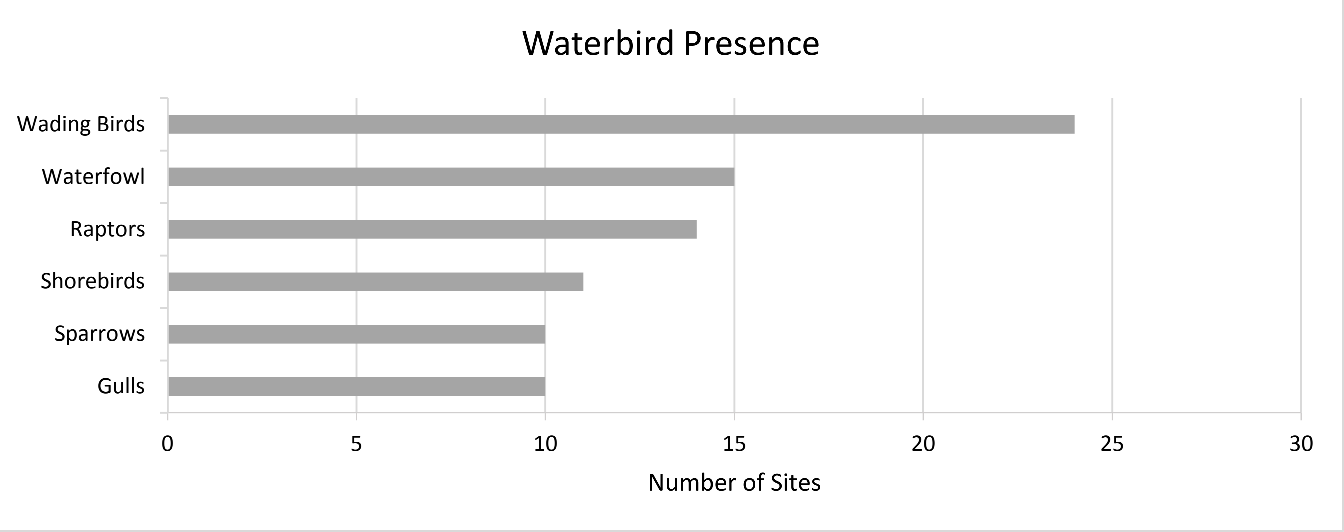

Major Freshwater Input
Sheet Flow
Ground water
Precipitation only
River or Stream
0
5
10
15
20
25
Number of Sites


Tidal Range
Unknown
<0.4 m
0.4-1 m
1-1.5 m
> 1.5 m
0
5
10
15
20
25
Number of Sites

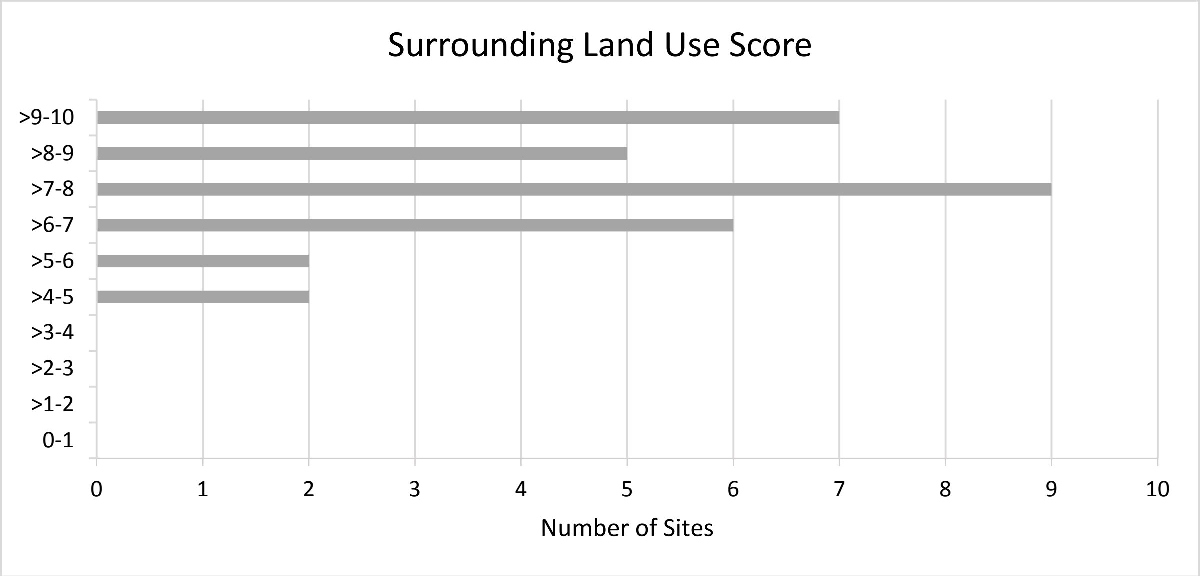

Natural Habitat Diversity
High Marsh Platform
Salt Shrubs
Tall Sa Low Marsh
Creeks
Ponds
Pools
Brackish Marsh
Overwash Fan
Established Pannes
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percentage of Sites

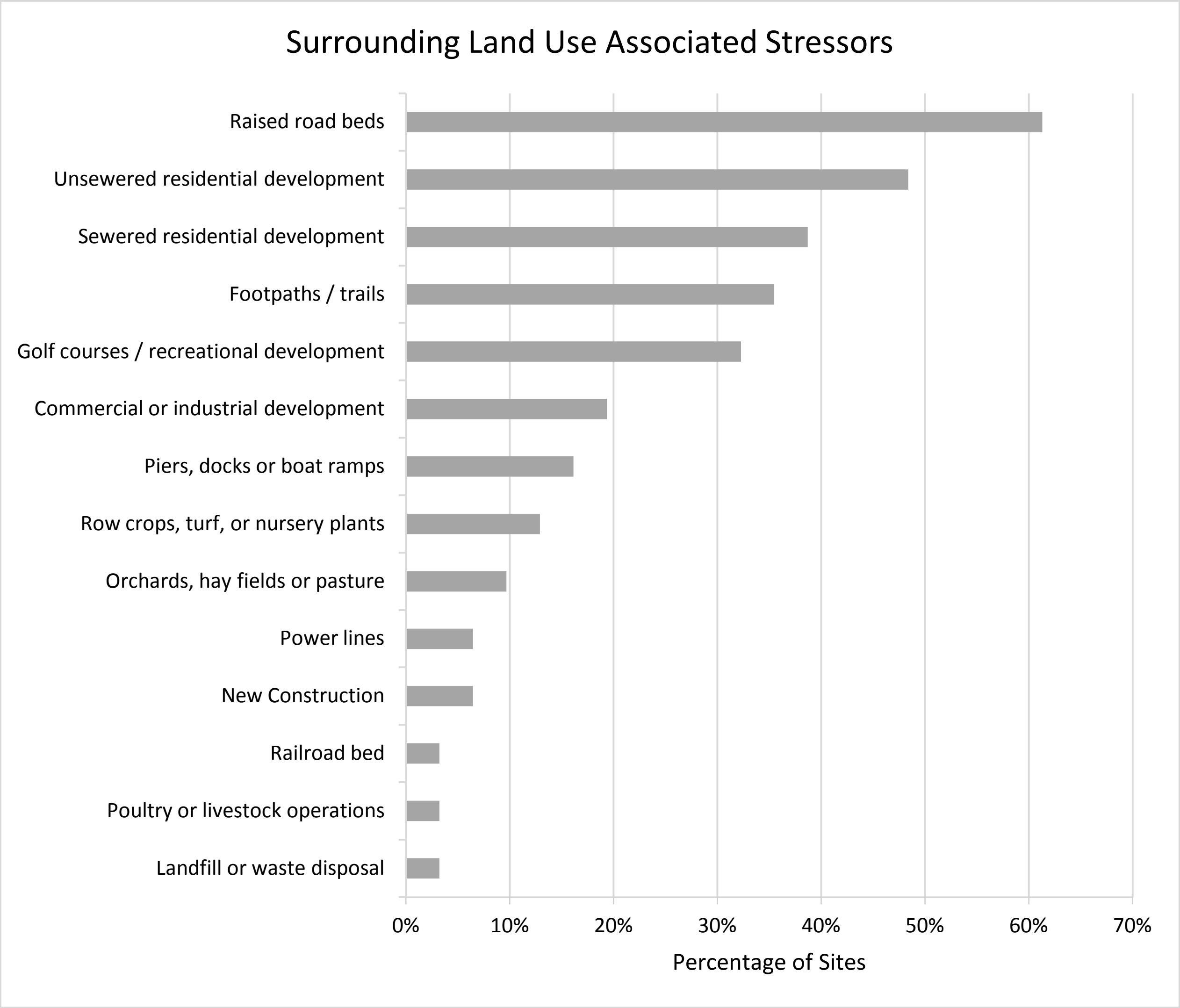

Connected Natural Habitats
Intertidal flats
Upland Forest
Upland shrubland
Sand or cobble beach
Coastal dunes or overwash
Other salt marsh
Forested or shrub wetland
Freshwater marsh or pond
Upland grassland
Eelgrass or other SAV
Brackish marsh or pond
0%
10%
20%
30%
40%
50%
60%
70%
80%
Percentage of Sites


Ecosystem Funcitions and Services
Fish and shellfish habitat
Wildlife habitat
Hunting or fishing platform
Other recreation
Part of a habitat complex or corridor
T/E species habitat
Nutrient uptake
Sediment/toxin retention
Carbon storage
Storm protection of property
Educational or historic significance
Floodflow alteration
0
5
10
15
20
25
30
35
Number of Sites
Special Importance
Evident or known impotance
Minor or Potential Importance


Waterbird Presence
Wading Birds
Waterfowl
Raptors
Shorebirds
Sparrows
Gulls
0
5
10
15
20
25
30
Number of Sites

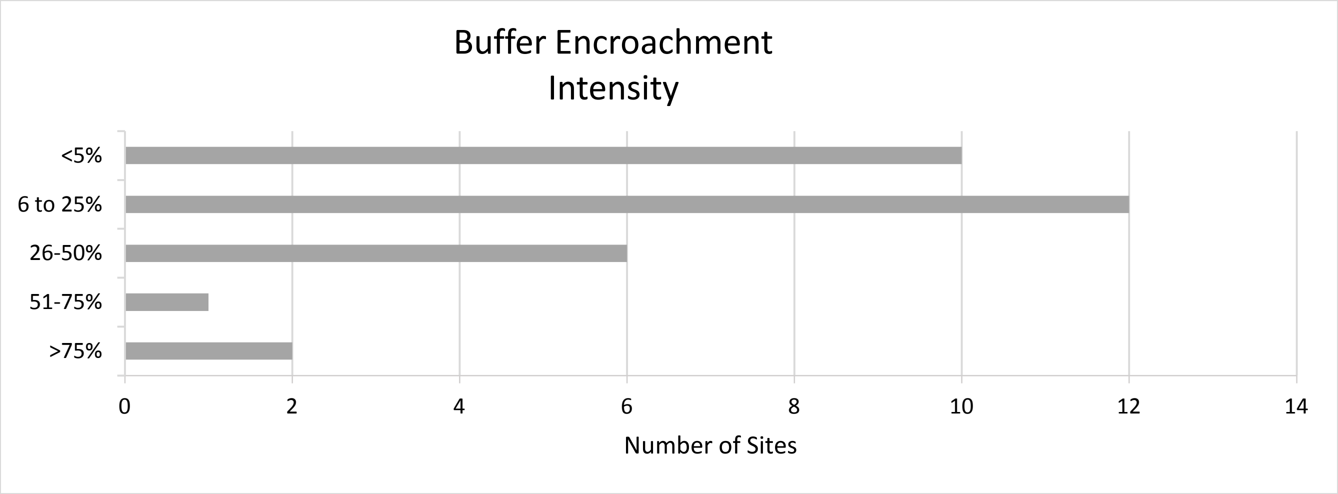
B. Surrounding Landscape Metrics



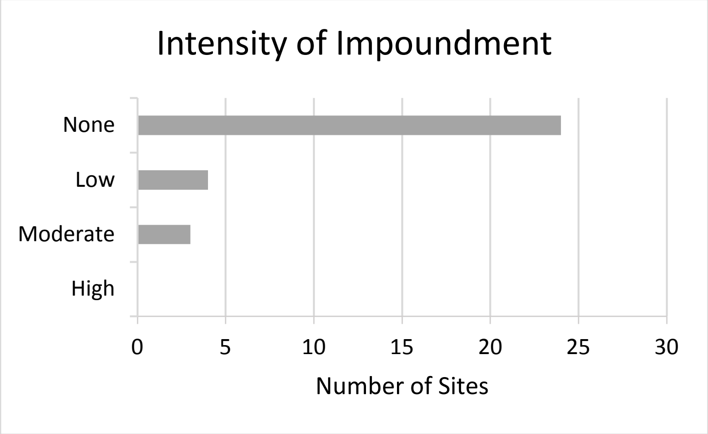


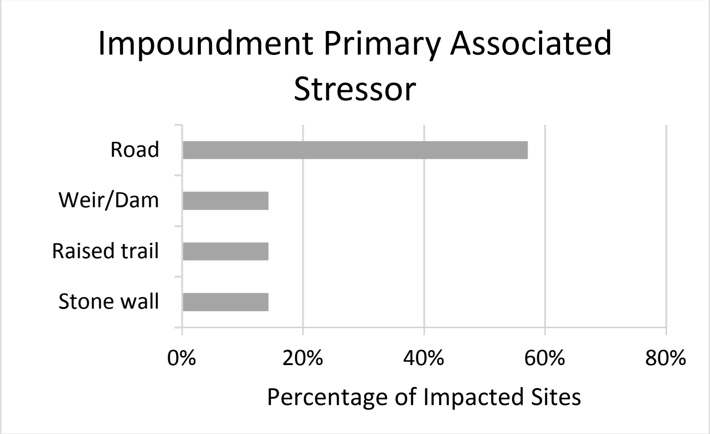
C. Wetland Stresses

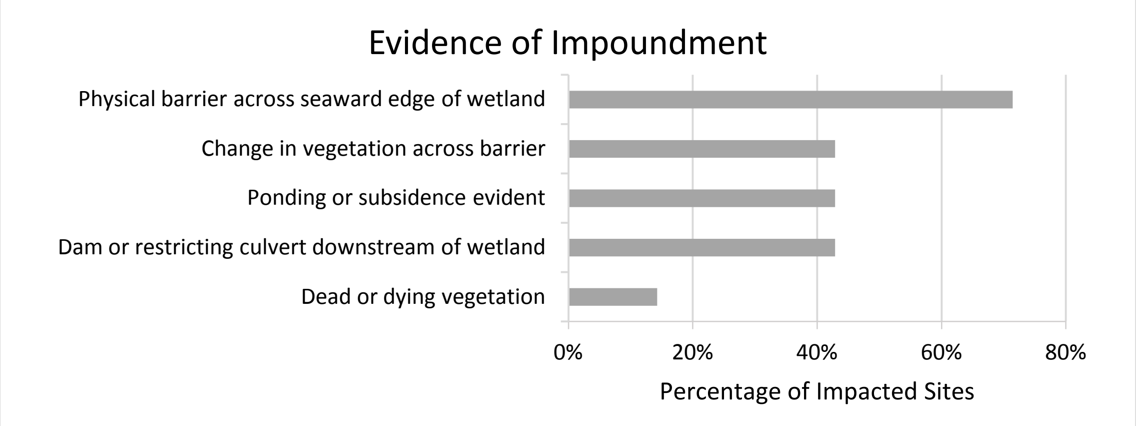
1. Cultural Cover within 30-m Buffer

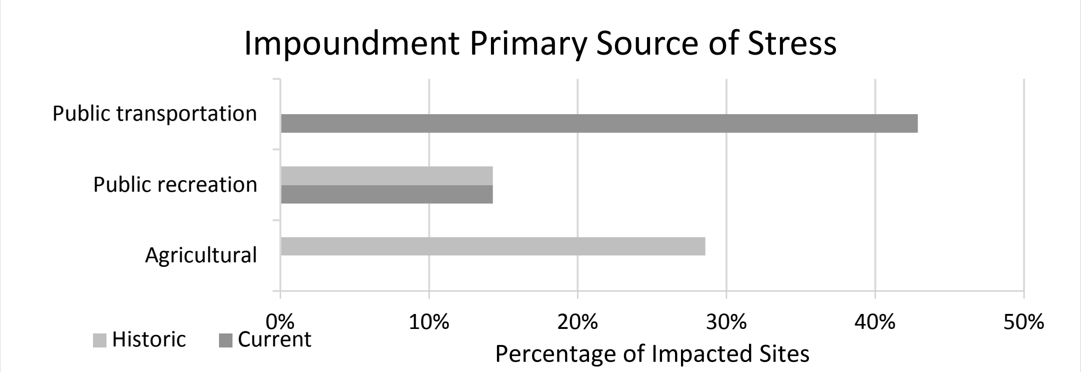


2. Impoundment

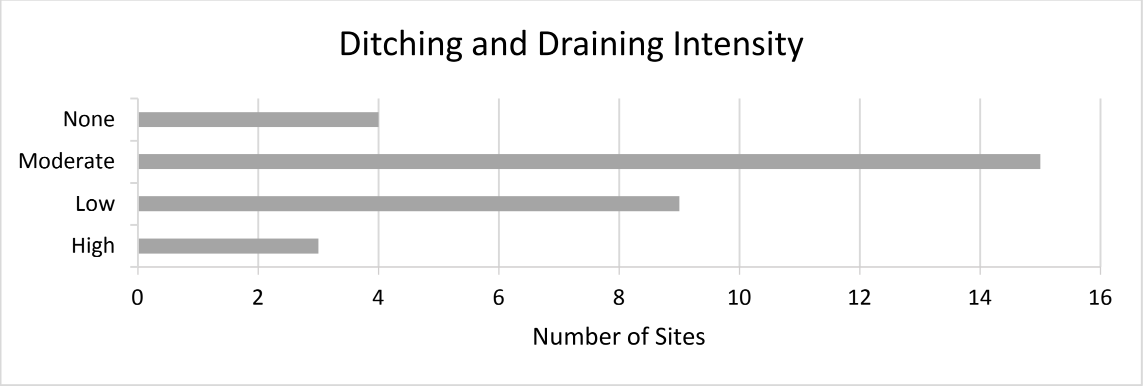




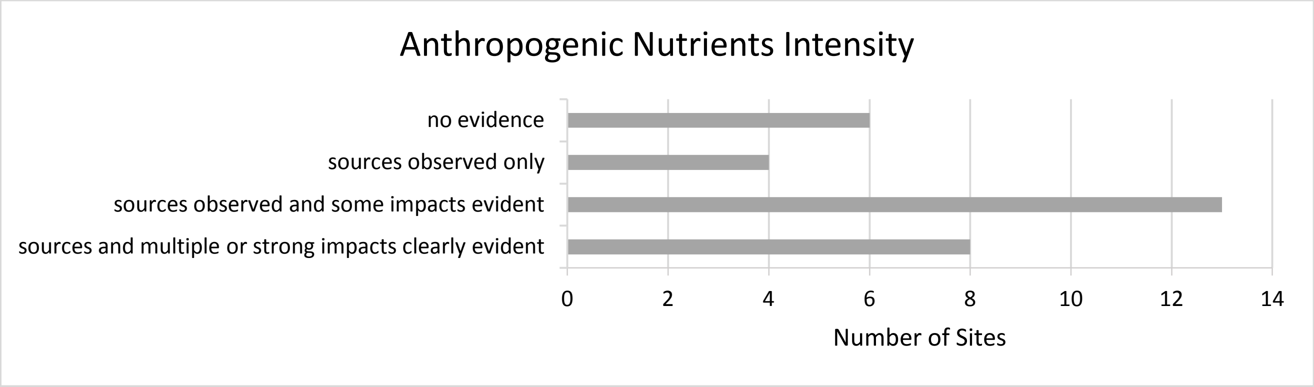


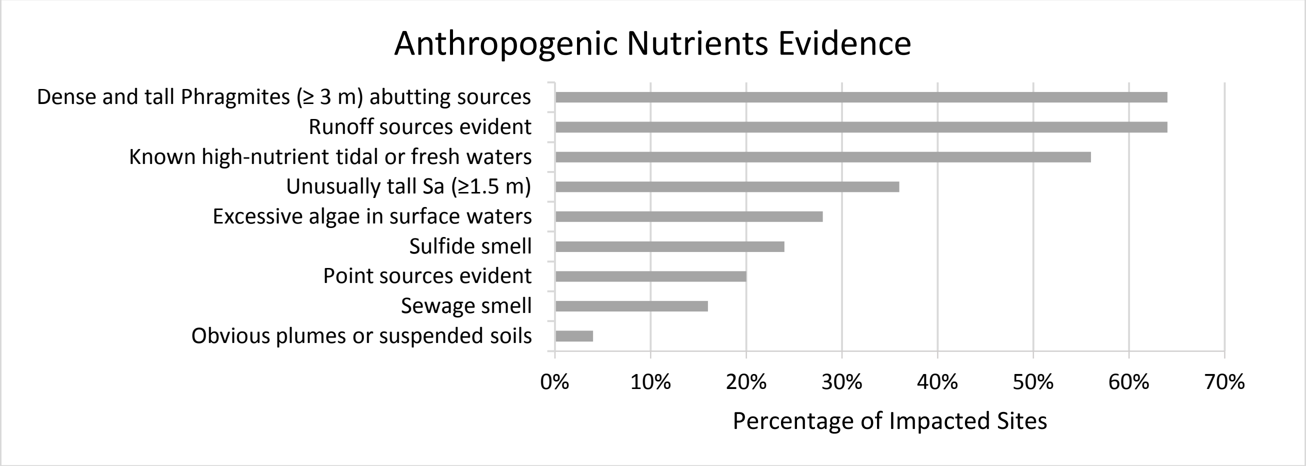


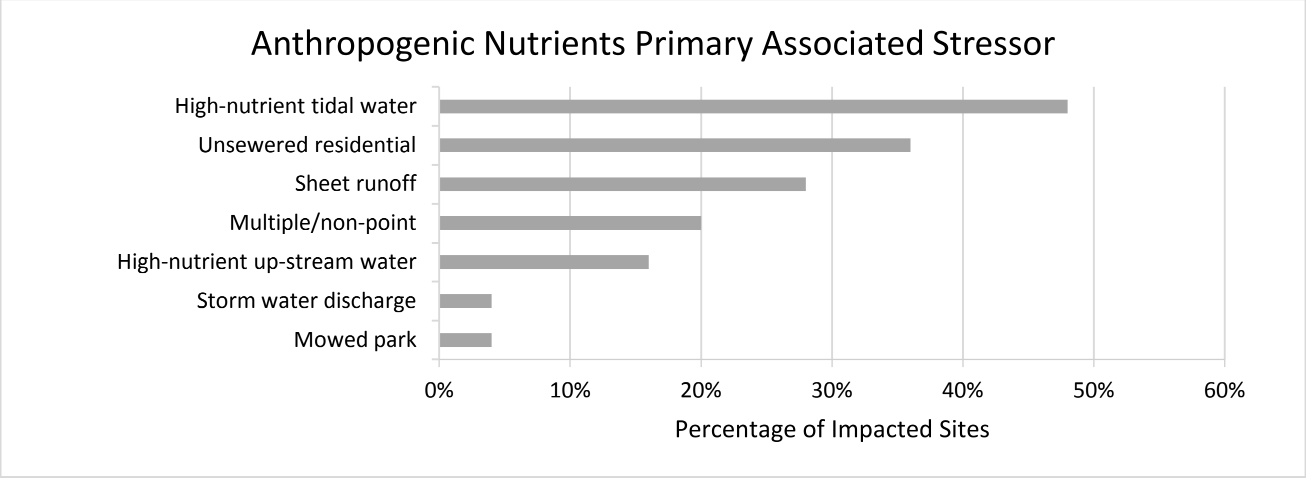
3. Ditching and Draining

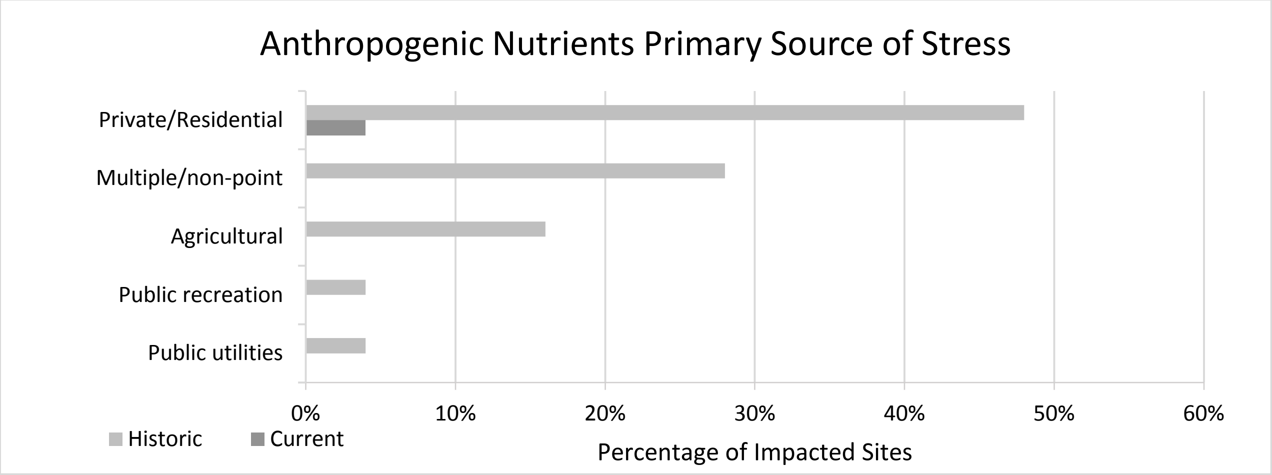


4. Anthropogenic Nutrients

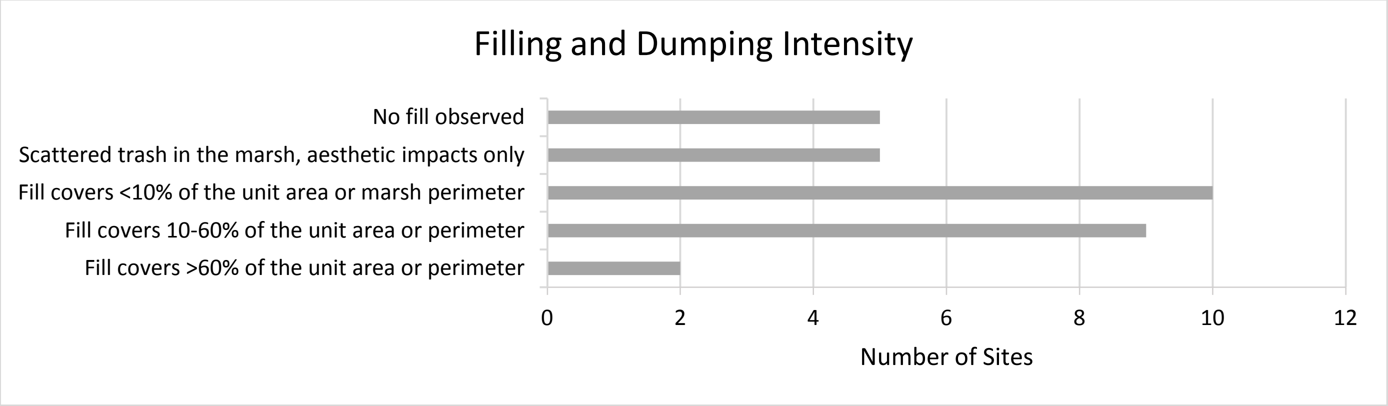


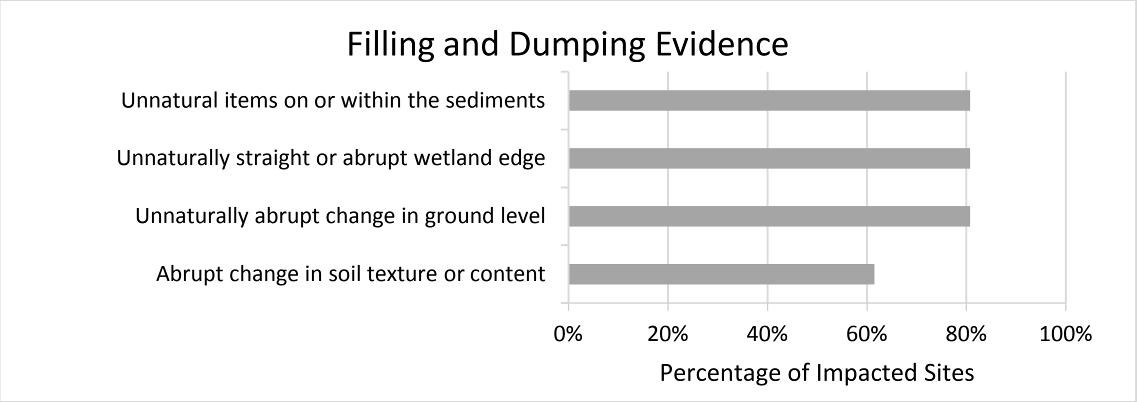


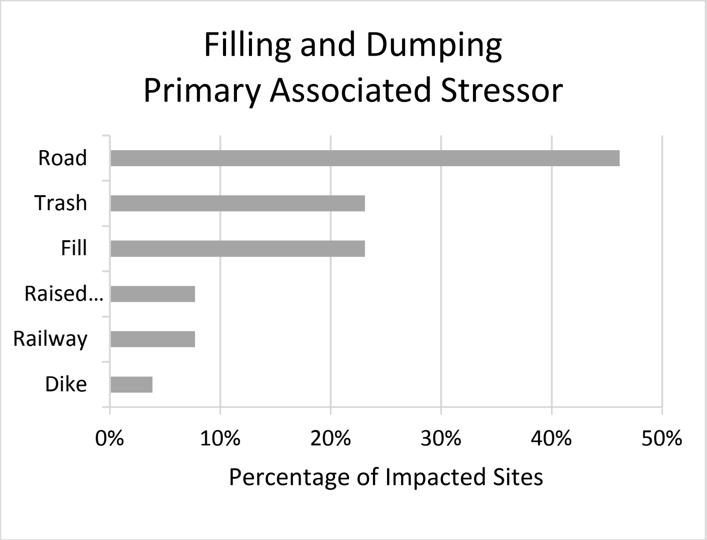


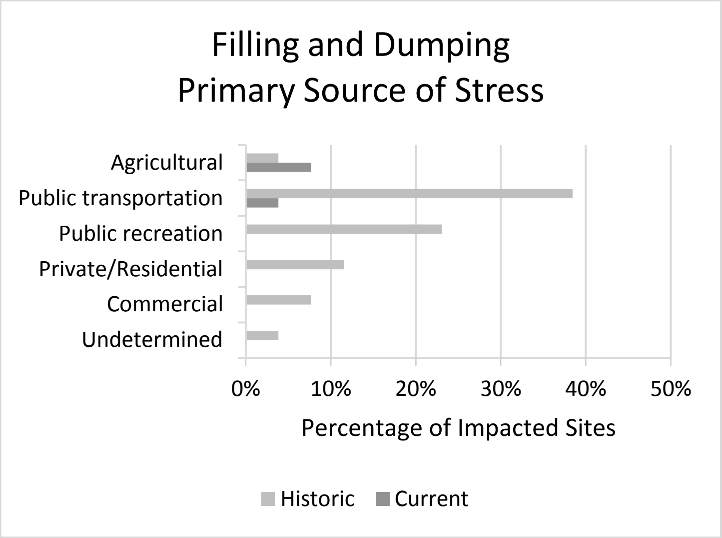


5. Filling and Dumping

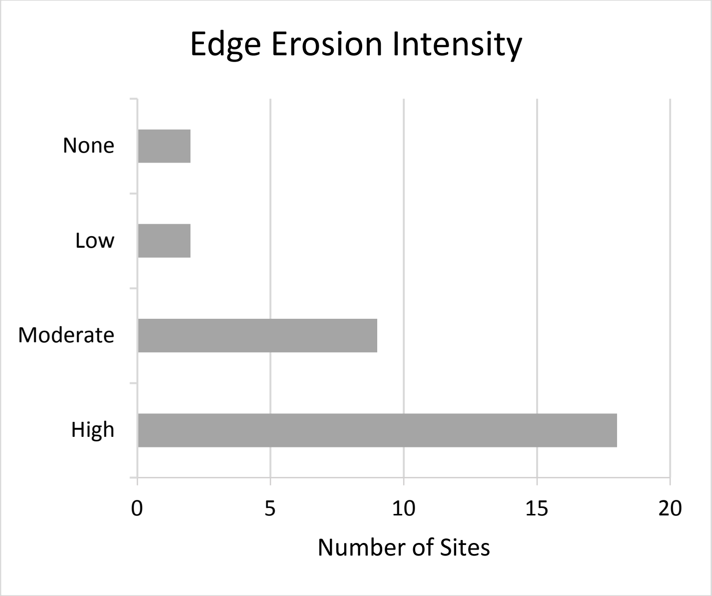


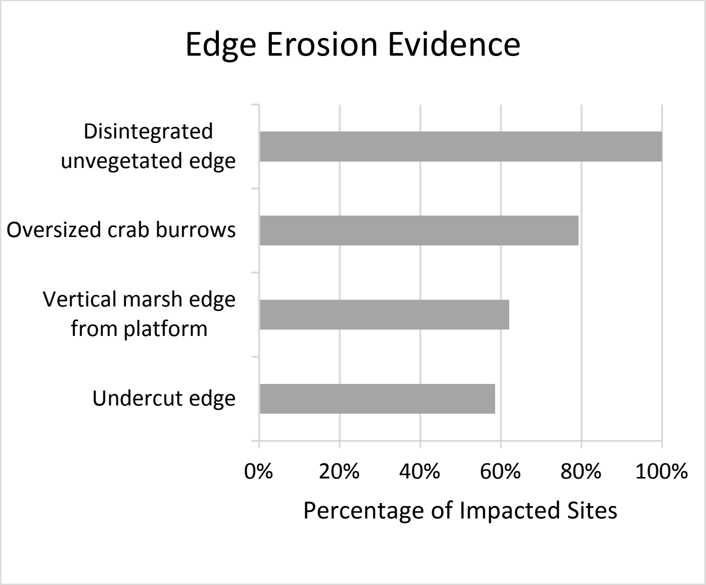




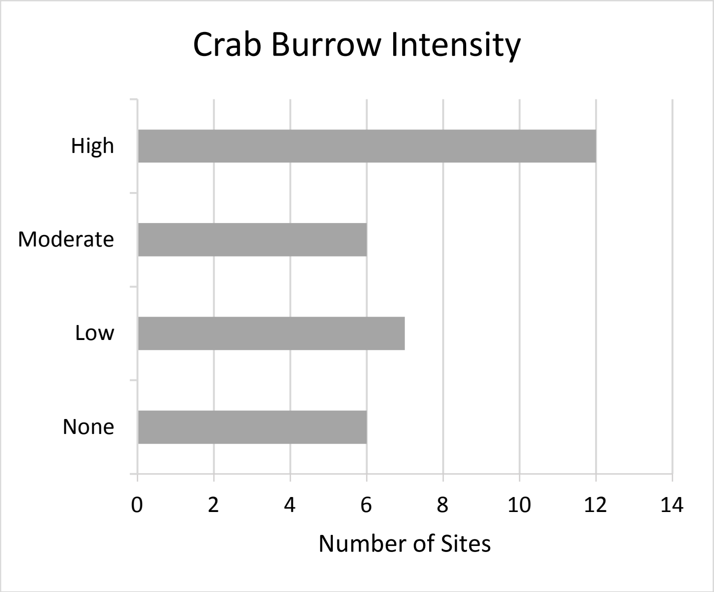


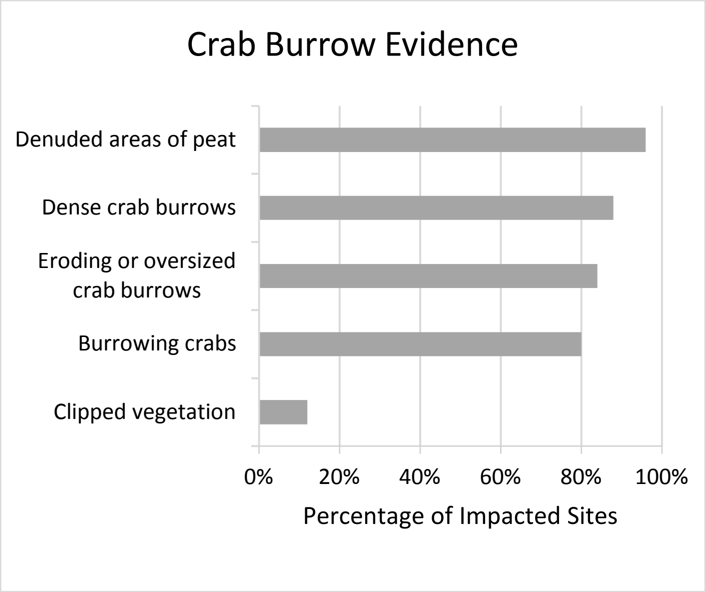
6. Edge Erosion



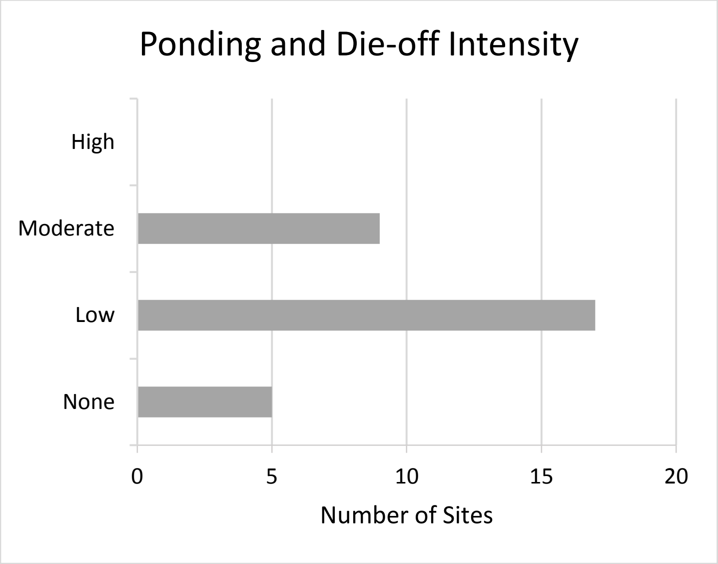


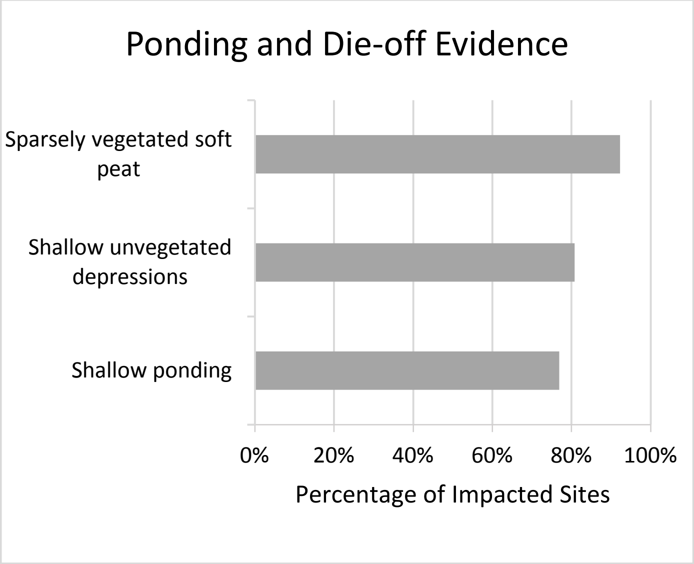
7. Crab Burrow Intensity



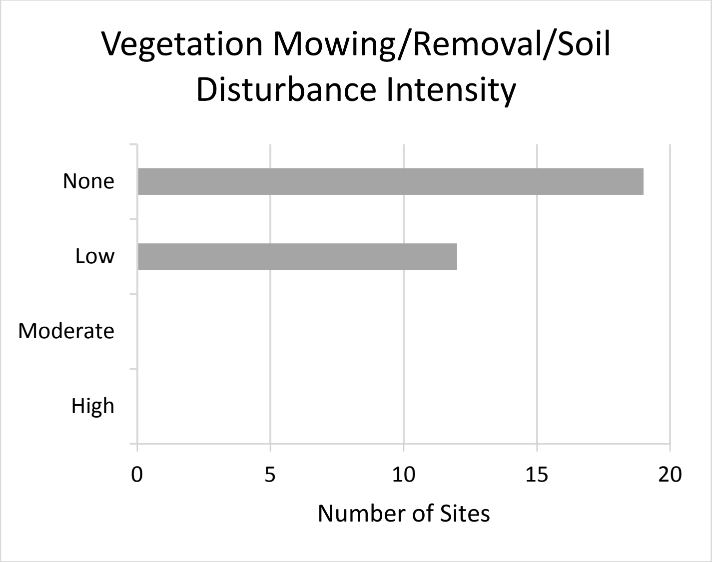


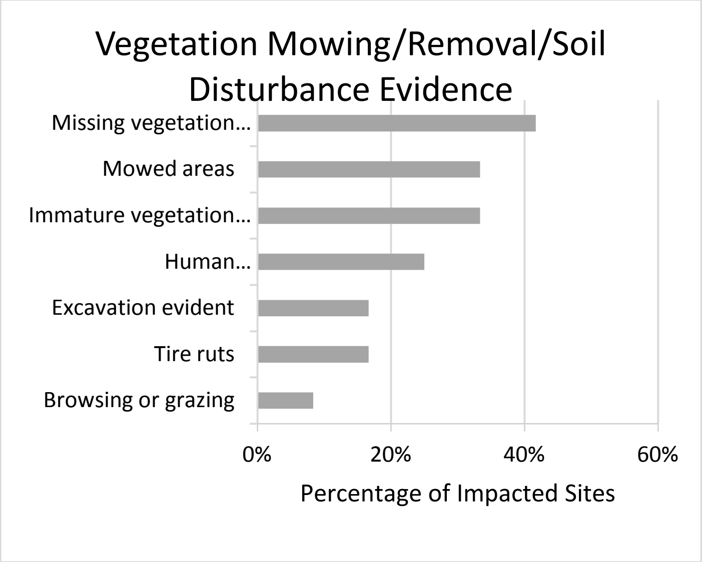
8. Ponding and Die-off

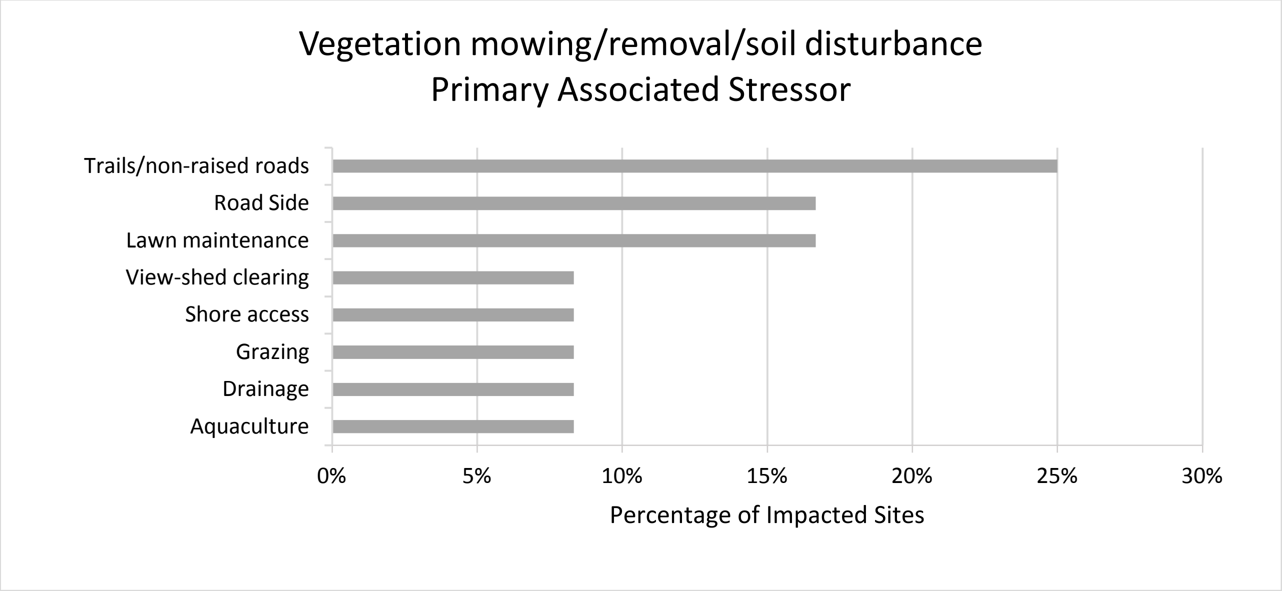


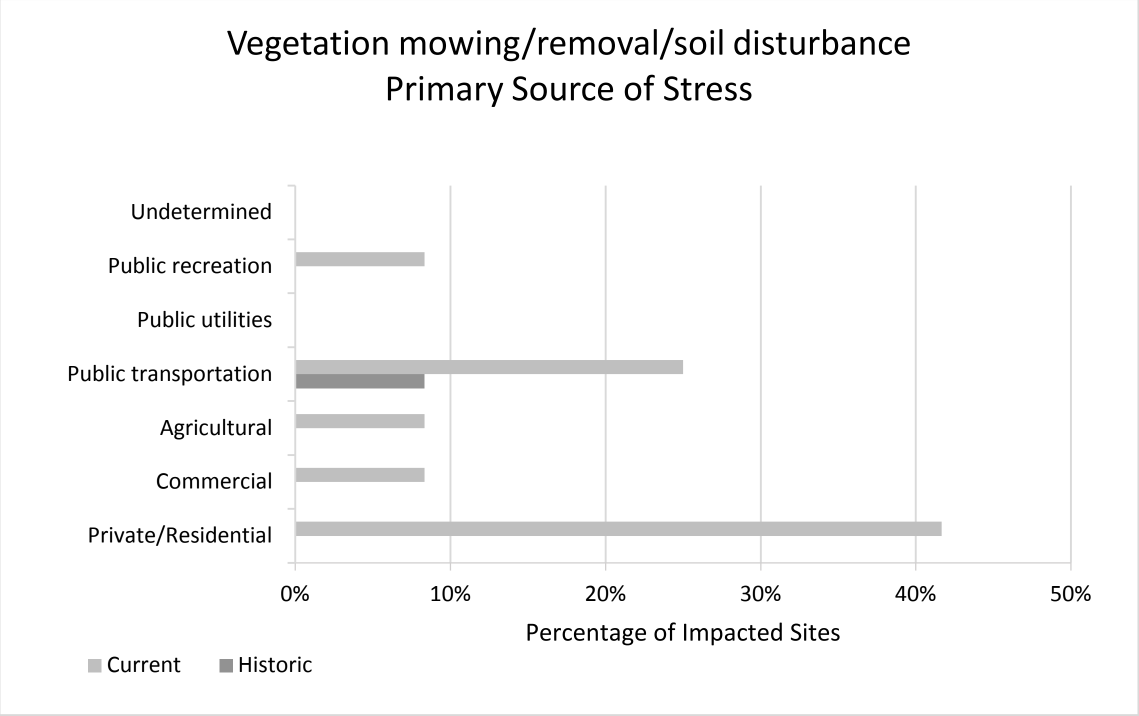


9. Vegetation / Soil Disturbances

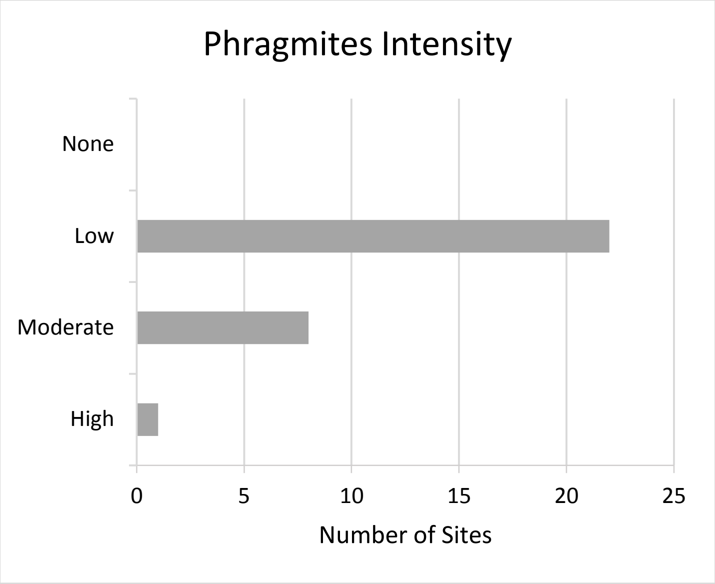


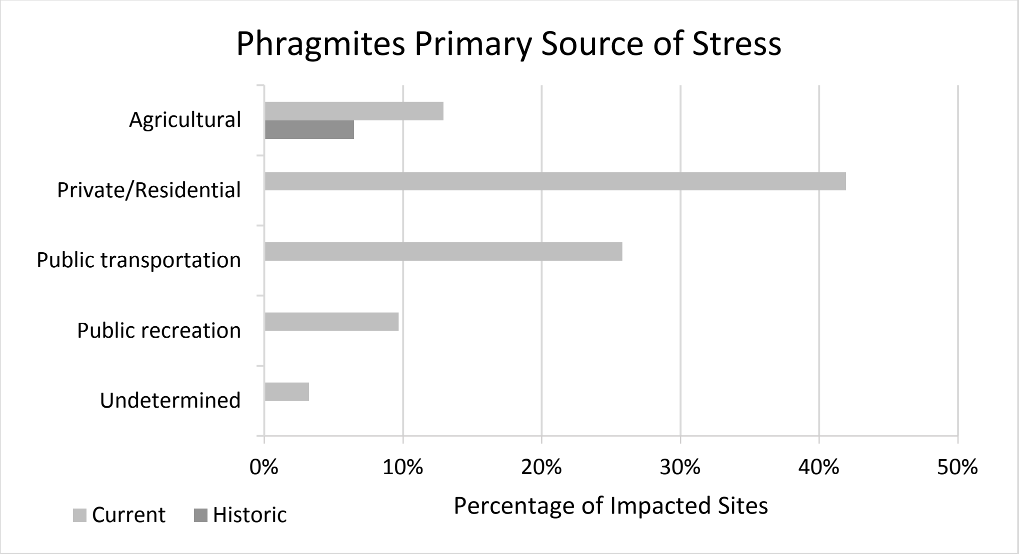




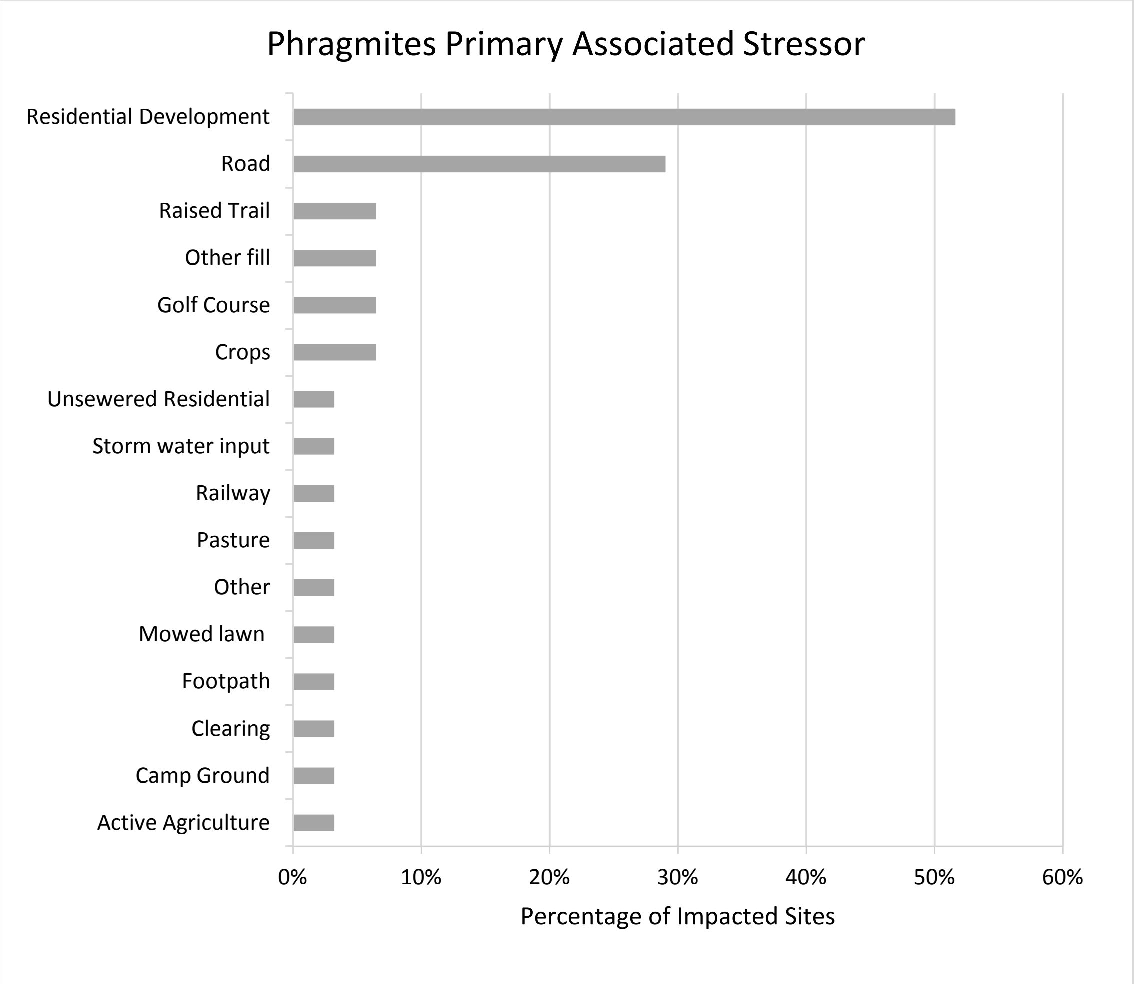


10. Phragmites





Phragmites Primary Source of Stress



Phragmites Primary Associated Stressor