Technical Report: Rhode Island Salt Marsh Habitat Mapping Project

Introduction

This project was designed to build on prior efforts within the State of Rhode Island (RI) to gauge the health and resilience of coastal salt marshes. Evidence from Narragansett Bay National Estuarine Research Reserve (NBNERR) Sentinel Site monitoring indicates a rapid change in RI salt marsh vegetation communities in response to accelerating sea level rise. In addition, broad-scale degradation of salt marsh has been captured by recent Rhode Island Salt Marsh Assessment (RISMA) monitoring efforts conducted at more than thirty salt marshes throughout the state in 2012 and 2013. The degree to which randomly placed vegetation plots and belt transects capture conditions across the complete marsh surface, the amount and condition of salt marsh occurring outside of selected study sites, and the rate of change across a latitudinal gradient remained unknown. NBNERR and the NOAA Office for Coastal Management (NOAA OCM) addressed this deficiency through the object-based classification of integrated multi-spectral imagery and LiDAR data. Funding support for the project was provided through the Coastal and Estuarine Habitat Restoration Fund and a Department of the Interior Hurricane Sandy Coastal Resiliency grant; both grants are administered through the RI Coastal Resources Management Council.

This report details the development workflow to produce the 2012 Rhode Island salt marsh habitat maps and contains information highlighting the remotely sensed data sources, field data collection, image processing and classification as well as some basic descriptions of final map products and habitat distributions.

Description of Source Data

This project applied methodologies and technologies previously tested by NOAA OCM for other applications. Specifically, a geographic object-based image analysis (GEOBIA) approach which utilizes semi-automated classification to develop a baseline map from high spatial resolution multispectral imagery and LiDAR and allows for the inclusion of information such as shape, texture and context into the mapping process.

One of the greatest benefits of object based image analysis is that it provides a framework for fusing several data types for image classification. Below is a description of the geospatial datasets used in this project.

1. Multispectral Imagery - ADS40 data acquired by the Rhode Island Eelgrass Mapping Task Force downloaded from Rhode Island Geographic Information System (RIGIS; www.rigis.org). Characteristics:

    - Spatial Resolution 0.5m
    - 4 Bands (Blue, Green, Red, Near Infrared [NIR])
    - Collected June 28 and 30, 2012

2. Spectral Derivatives

    a. Normalized Difference Vegetation Index (NDVI)
    b. Tasseled Cap Transformation (TCT)
    c. Principle Components Analysis (PCA)

3. Elevation data – Acquired as a part of the LiDAR for the Northeast Project. Data was collected during Winter/Spring 2011. Nominal post spacing of 1m or better with a vertical accuracy 0.067 RMSE. Data was downloaded as classified LAS files.

    a. Topographic Derivatives – Created using LAS Tools

        i. Bare Earth Digital Elevation Model (DEM)
        ii. Normalized Digital Surface Model (nDSM)

4. Ancillary Data – Accessed through RIGIS

    a. Impervious Surfaces
    b. RI Ecological Communities (Eco Communities)
    c. National Wetlands Inventory (NWI)
    d. Coastal Waters

<u>Salt marsh mask development</u>

The extent of salt marsh features within the state had to be determined before classification of salt marsh habitat types could occur. The process of developing a salt marsh mask utilized existing ancillary data as a starting point with additional spatial detail being added using the multispectral imagery and LiDAR source data. The three component steps of this process included GIS modeling, image segmentation, and classification.

1. GIS modeling

    Preparation of ancillary data sets for input into salt marsh extent determination.

    a. Obtain/derive required data layers

        i. Impervious Surfaces
        ii. Coastal Waters
        iii. Salt Marsh

            - This layer was derived using a Union operation in ArcMap which combined estuarine emergent features from:

                a.) NWI (*where* SQL for selection: "ATTRIBUTE" LIKE 'E2EM%')
                b.) Eco Communities (*where* SQL for selection: Community = 'Salt Marsh')

iv. Woody Vegetation

- This layer was used for eliminating obvious upland features from the mapping boundary. It was derived by selecting a subset of features from the Eco Communities layer *where*

"Descriptio" = 'Forested Swamp' OR "Descriptio" = 'Mixed Deciduous/Coniferous Forests' OR "Descriptio" = 'Oak Forest' OR "Descriptio" = 'Ruderal Forest' OR "Descriptio" = 'Tree Plantation' OR "Descriptio" = 'Shrub Swamp'

v. Grassland and Shrub

- This layer was used for eliminating obvious upland features from the mapping boundary. It was derived by selecting a subset of features from the Eco Communities layer *where*

"Class" = 'Developed Land' OR "Descriptio" = 'Open Uplands (Grassland and Shrubland)'

vi. Unconsolidated Shore/Bare Land

- This layer was derived using a Union operation of Mudflat and Unconsolidated Shore features from:

a.) 2003 Narragansett Bay Estuarine Habitat layer (*where* SQL for selection: "GRP_3" = 'Pannes, Pools & Tidal Flats')
b.) 1993 Rhode Island Wetlands (*where* SQL for selection: "DESCRIPTIO" = 'Marine/Estuarine Unconsolidated Sh')
c.) NWI (*where* SQL for selection: "ATTRIBUTE" LIKE 'E2US%')

b. Clip each of the above layers to the mapping boundary from masking process

c. Process vector layers

i. Add a field called Class (Text, Length 50)
ii. Calculate Field with appropriate class name:

1. Impervious
2. Mudflat/Bare
3. Grassland
4. Forest

2. Image segmentation (*using* eCognition Developer)

Perform multiresolution segmentation algorithm of ADS40 imagery and spectral derivatives using impervious surface data as a thematic delimiter.

3. Classification into basic cover types

    a. Assign by Thematic Layer (*using* eCognition)

        i. Impervious
        ii. Uplands (Grassland and Forest)
        iii. Salt Marsh
        iv. Unconsolidated Shore
        v. Water

    b. Use rulesets based on elevation and spectral thresholds to clean up boundaries between Uplands, Salt Marsh, Unconsolidated Shore and Water.

    c. Additional manual editing was performed to address features not adequately refined through rulesets.

<u>Field Data Collection</u>

The original intent was to utilize field data collected as part of the RI Salt Marsh Assessment (RISMA) for both training and accuracy assessment (i.e. validation) points. While more than 1500 data points were collected along transects in 2012 and 2013 as a component of this state-wide assessment, they often did not include the spatial data necessary for use in map development. Other challenges included proximity of points along transects, restricted spatial distribution, and poor representation of many vegetation cover types intended to be captured in the final map product.

Field data collection to supplement RISMA data occurred over several days on two separate occasions (August 2014 and June 2015; seven days in total). This supplemental data was primarily used for training the classifier and to perform quality assurance / quality control (QA/QC) of draft maps. Data collected at hundreds of points across the state included site photos, species present, and presumed/known changes since 2012. Additionally, vegetation classes which remained poorly represented in the training data (e.g. Invasive *P.australis*, Natural pools, Dieoff depressions) were obtained by NBNERR staff based on image interpretation and site knowledge.

<u>Classification of Habitats</u>

To classify the habitats of interest located within the previously derived salt marsh mask, a hierarchical approach was employed. Classification was achieved through the step-wise utilization of known ranges/limits of certain habitat types to stratify imagery and reduce class confusion. The classification steps are as follows:

1. Dieoff Depressions and Natural Pools

Contextual Modeling was performed on the Open Water and Unconsolidated Shore classes of the Salt Marsh mask to define unvegetated classes.

a. Using the "Assign Class" algorithm in eCognition, Open Water features with "Rel. border to Salt Marsh = 1" are classified as Natural Pools while Unconsolidated Shore features with "Rel. border to Salt Marsh = 1" are classified as Dieoff Depressions. Model outputs were then manually edited based on external review.

2. Random Forest (RF) Classification

RF is an ensemble learning method for classification which combines the results from multiple Classification and Regression Tree Analysis (CART) models. Before the RF classifier was trained and applied using the field data, the marsh platform was stratified based on vegetation height with the goal of creating two zones:

i. Tall Vegetation: *Phragmites*, *Iva frutescens* and *Typha angustifolia*

Accomplished using the Seed Approach

1. Extract Objects w/ height values of +1 meter

2. Grow segments based on spectral characteristics

ii. Short Vegetation: High Marsh (*S.patens-D.spicata)*, High Marsh (S.*alterniflora)*, Low Marsh, High Marsh (*J.gerardii*) and Wrack

a. Image segmentation

Multiresolution segmentation was performed on each "zone" prior to classification using different parameters to highlight specific habitats

b. Source data inputs

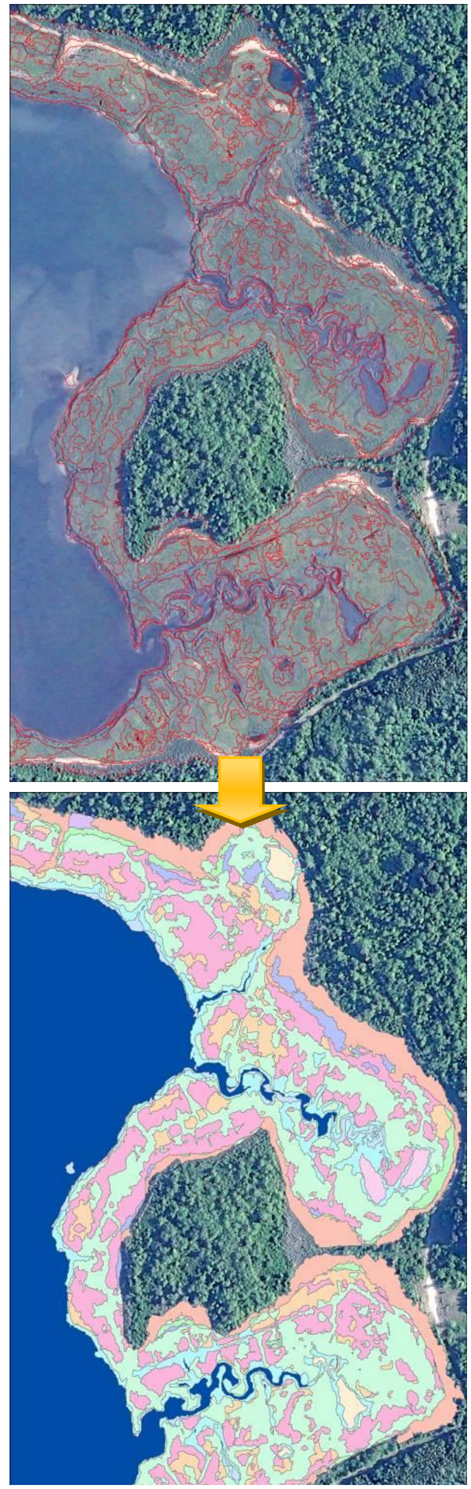

Figure 1: Segmentation of the salt marsh mask improves the classification process.

    i. Imagery and Spectral Derivatives
    ii. LiDAR
    iii. Derived context layers (e.g. Distance to Water, Relative Border to Upland, etc.)

3. Additional Modeling

   In instances where specific draft map segments were determined to be misclassified, further actions were taken in an attempt to create a greater fit with presumed 'correct' class assignment over the full extent of individual regions.

   a. Create and apply Expert Rule Sets
   b. Address specific systematic errors as part of iterative process
   c. Correct specific types of class confusion (i.e. *Juncu*s at open water edge of marsh platform)

   The process of review and correction of draft maps was iterative; each iteration of map development addressed specific misclassification issues. In addition to NBNERR staff review, a later near-final draft map was made available as a Web Map (in ArcGIS On-Line) to more than ten state wetland researchers and land managers for review and comment.

4. Manual Editing

   For specific non-systematic instances of poor fit in the draft maps, efforts to provide more accurate classification of specific segments were made through manual editing.

   a. Clean Up
   b. Rare features

<u>Data Set Description</u>

This data set consists of salt marsh habitats for the State of RI categorized into thirteen distinct classes. Table 1 provides the definitions for each habitat class in the final map product. The state-wide distribution of salt marsh is supplied in five component regions which can be seamlessly mosaicked together to create a single map layer. The individual processing of the 2012 imagery across each of five regions limited the spectral distortions across the entire geographic area associated with image acquisition on two separate days over the course of many hours; altering available light and reflectance characteristics.

Table 1: Salt marsh habitat classes and class descriptions

Salt Marsh Habitat Class	Salt Marsh Habitat Class Description
Brackish Marsh, Native	Any area of marsh near the upland border where brackish species (e.g. *Scirpus* sp., *Typha angustifolia*) are common or dominant.
Dieoff Depression	Other unvegetated/recent die-off area (note: some die-off areas still might contain some very sparse, stunted *S. alterniflora* that is clearly dying). Shallow, wet at low tide, may have algal mat, filamentous algae or flocculent matter present.
High Marsh; *J.gerardii*	Any area where *J. gerardii* is either the lone dominant or is co-dominant with *D. spicata* or *S. patens*.
High Marsh; Mix	Any area where the dominant species include any combination of *S. alterniflora*, *S. patens* and *D. spicata*.
High Marsh; *S. alterniflora*	Areas of short form *S. alterniflora* as a monoculture, although some *Salicornia* sp. may be present.
High Marsh; *S.patens-D.spicata*	Any area where *S. patens* and *D. spicata* are either sole or co-dominants.
Invasive *Phragmites australis*	Areas where the invasive plant *Phragmites australis* is dominant.
Low Marsh	Regularly flooded, dominated by tall form (75 cm+) *S. alterniflora* usually found along creek or ditch edges. Other species may be present in this zone but *S. alterniflora* is the only dominant.
Mudflat / Bare	Natural mudflat exposed at low tide, can have some sparse *S. alterniflora.*
Natural Pool	Deeper than pannes, no vegetation, steep sides, includes natural and non-degraded areas.
Open water	Larger areas of water: bays, rivers, ponds.
Salt Shrub	Infrequently flooded; Could include areas of higher elevation on marsh platform (commonly islands or linear patches next to excavated ditches); Most common: *Iva frutescens*, *Solidago sempervirens*.
Wrack	Any area of marsh that is covered by dead wrack (generally composed of *S. alterniflora* stems).

Additional classes were attempted to be captured during map development. However, the following classes could not be distinguished as separate vegetation cover types. These classes were either too underrepresented (i.e. rare) across the full salt marsh extent, were not represented in the available training data points, or contained spectral reflectance values that were too like another class to be separated out as distinct features. Although these cover types are known to occur in RI salt marshes, they are currently included in the final classes described above. For instance, Natural Pannes would be folded into Dieoff Depressions and Grazed creek banks are likely incorporated into the Mudflat/Bare class.

- Creek (*Description*: Natural creeks and channels.)
- Ditch (*Description*: Manmade, straight ditches and associated spoils.)
- Grazed creek bank (*Description*: Any area along a tidal creek where herbivores have grazed away all vegetation and exposed bare peat.)
- Invasive *Lythrum salicaria (Description*: Areas where the invasive plant *Lythrum salicaria* is dominant.)
- Natural pannes (*Description*: Very rare, dry at low tide, species include *Plantago maritima*, *Suaeda maritima*, *Salicornia* sp., *J. gerardii*, *Aster* sp.)
- *Limonium* (*Description*: Any area where *Limonium nashii* is the sole dominant.)
- *Salicornia* spp. (*Description*: Any area where the sole dominant species is *Salicornia* spp. No attempt was made to differentiate between annual and perennial forms.)
- *S. alterniflora* / *Salicornia* spp. (*Description*: Any area where *S. alterniflora* and *Salicornia* spp. are co-dominant.)
- *S. alterniflora* / Upper salt meadow (*Description*: Any area where *S. alterniflora* and *J. gerardii* are co-dominant or where *S. alterniflora*, *J. gerardii*, and *D. spicata* are co-dominant.)
- Trail (*Description*: Any area of marsh that is clearly trampled by either human or animal foot traffic.)

Although these cover types were not captured during map development, it may be possible to recapture some classes through additional manipulations, such as manual editing or the application of additional expert rule sets. For instance, creeks and ditches which are currently incorporated into the open water class have distinguishing characteristics that would allow them to be separated out if that level of detail were required for a specific map application.

The individual regions that comprise the final 2012 salt marsh map do not follow any specific boundary delineation based on geomorphology or adjacent landscape characteristics, but were parsed to reduce spectral variation in the images associated with date and time of image capture (Figure 2). This step reduced the confusion in outputs resulting from the RF classification. However, it is still possible to identify general differences in habitat class distribution among regions (Table 2). For example, Region 1 contains the greatest percentage of both High marsh; *S. alterniflora* and Dieoff Depression which collectively suggests salt marsh degradation in this area. By contrast, High marsh; *S.patens-D.spicata* is still the dominant cover class in Region 3 which is suggestive of generally greater marsh health. A detailed analysis of habitat class distribution across the state, while possible, is outside the intended scope of this report.

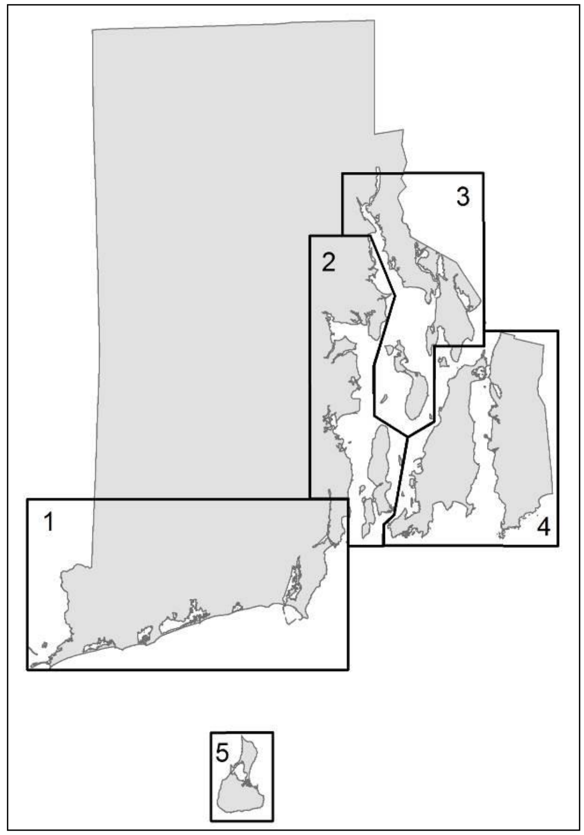

Figure 2: General location of map regions.

Table 2: Percent area by habitat within each zone. Percentages and sums exclude Mudflat/Bare and Open water classes as these classes contain areas (e.g. beach, bay) that are adjacent to and not surrounded by salt marsh.

Percent area by habitat class	*Region 1*	*Region 2*	*Region 3*	*Region 4*	*Region 5*
Brackish Marsh; Native	0.63	0.36	0.49	11.45	3.80
Dieoff Depression	3.44	0.25	0.74	1.62	0.25
High marsh; *J. gerardii*	1.84	0.73	2.01	1.98	0.22
High marsh; Mix	2.39	3.03	1.53	1.62	0.00
High marsh; *S. alterniflora*	39.62	23.45	22.53	23.89	34.03
High marsh; *S.patens-D.spicata*	14.35	20.36	30.95	13.62	16.87
Invasive *Phragmites australis*	26.88	23.98	20.91	28.23	30.48
Low Marsh	1.78	17.45	9.56	8.07	4.95
Mudflat / Bare	--	--	--	--	--
Natural Pool	3.90	2.78	1.16	2.38	3.27
Open water	--	--	--	--	--
Salt Shrub	4.91	6.81	8.80	6.56	6.13
Wrack	0.25	0.80	1.31	0.57	0.00
Total hectares / region	513.43	225.86	540.19	326.18	32.12

Accuracy Assessment

Given that development of this dataset was initiated several years after the collection of the imagery, some compromises were made in the assessment of its accuracy. To evaluate the map using field data collected as close to the acquisition date of the imagery as possible, a subset of transects from RISMA were utilized. This restricted the ability to follow certain best practices associated with the accuracy assessment of maps derived from remotely sensed imagery. As such, we were unable to employ a stratified random sampling strategy or use an adequate number of samples for all the categories included in the map. In the final accuracy assessment (Table 3), 237 accuracy assessment points were used but none of the classes have a minimum of 50 accuracy assessment points. While the accuracy assessment conducted does help inform us about the map's errors, there are shortcomings as an overall representation. It is hoped that a more complete field effort can be performed as part of any future update to this data.

As previously mentioned, specific challenges associated with utilizing the approximately 1500 RISMA field data points for map development (i.e. training data) and for the assessment of map accuracy (i.e.

Table 3: Final Accuracy Assessment Matrix Table

Reference Data (Producer)

Mapped Classification (User)	Brackish Marsh, Native	Dieoff Depression	High Marsh; *J. gerardii*	High Marsh; Mix	High Marsh; *S. alterniflora*	High Marsh; *S.patens-D.spicata*	Invasive *P. australis*	Low Marsh	Mud flat / bare	Natural Pool	Open water / creek	Salt Shrub	Unclassified	Wrack	Total Mapped	User's Accuracy (%)
Brackish Marsh, Native	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Dieoff Depression	0	14	0	0	0	0	0	0	0	1	0	0	0	0	15	93.3
High Marsh; *J. gerardii*	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	100.0
High Marsh; Mix	1	1	0	5	1	1	0	0	0	0	0	0	0	0	9	55.6
High Marsh; *S. alterniflora*	0	1	0	10	33	8	0	1	0	0	0	0	0	0	53	62.3
High Marsh; *S.patens-D.spicata*	0	0	1	1	4	36	0	2	0	0	0	0	0	0	44	81.8
Invasive *P. australis*	1	0	0	0	0	0	26	0	0	0	0	0	0	0	27	96.3
Low Marsh	0	0	0	0	0	0	0	6	0	0	0	0	0	0	6	100.0
Mud flat / bare	0	0	0	0	1	0	0	0	14	0	0	0	0	0	15	93.3
Natural Pool	0	2	0	0	0	0	0	0	0	20	1	0	0	0	23	87.0
Open water / creek	0	0	0	0	0	0	0	0	0	1	19	0	0	0	20	95.0
Salt Shrub	0	0	0	0	0	0	0	0	0	0	0	8	0	0	8	100.0
Unclassified	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0.0
Wrack	0	0	0	0	0	0	0	0	0	0	0	0	0	12	12	100.0
Total Field Pts	2	18	4	16	39	45	26	9	14	22	20	10	0	12	237	
Producer's Accuracy (%)	0.0	77.8	75.0	31.3	84.6	80.0	100.0	66.7	100.0	90.9	95.0	80.0	0.0	100.0		

Overall Accuracy (= Observed agreement) 82.7% **Chance Agreement 11.7%** **Kappa (K) 0.804**

validation points) were the result of missing or inaccurate spatial data associated with transect start and end points, proximity of points and capture of cover types reflecting polygon features less than the minimum mapping unit, restricted spatial distribution across the marsh platform, and poor representation of many vegetation cover types intended to be captured in the final map product. This led to a rejection of most of the data points originally believed to be available through a process of manually reviewing this data and rejecting individual points that were redundant (e.g. contained within a single vegetation cover feature or transect 'belt') or representative of narrow features (< 5 m) to avoid possible inaccuracies associated with imprecisely placed transect lines. Another challenge was associated with a potential mistranslation of original RISMA data to NBNERR-defined habitat classes as these vary based on relative amounts of different species present. For example. depending on the amount of *S. alterniflora* that is present, a habitat could be interpreted as High marsh; *S.patens-D.spicata* or High marsh; Mix or High marsh; *S.alterniflora* or Dieoff Depression. The solution to many of the challenges associated with applying this collection of field data to supplement training and validation data is to ensure that, in future, spatial data for transect start and end points and percent cover estimation for each species present at individual data points are consistently captured on field data sheets.

Potential Applications

The level of detail provided by the break-out of salt marsh into thirteen distinct habitat classes allows for relative condition assessments across all marshes in the state and complements ongoing efforts by NBNERR, Save The Bay, and other agencies to gauge the health and resilience of this critical habitat. These detailed maps also serve as an important resource for individuals and agencies engaged in coastal wetland restoration and coastal resiliency planning. Serving as a baseline, any additional salt marsh maps to be developed for future time periods will allow for high resolution change detection analysis and will provide a more broad-scale understanding of the vegetation transitions that are currently being detected with monitoring efforts throughout Rhode Island's salt marsh communities.

Recommendations\Lessons Learned

Spectral variation of imagery

Stratification of the full study area into five discrete regions was effective in limiting impacts on the classification. Image processing steps requiring the separation of cover classes based on spectral reflectance characteristics is best performed when the spectral variation of the images is minimized. The size of the study area required that image collection take place over many hours on each of two days, impacting light angle/direction and reflectance levels. Limiting the geographic extent of the images being processed was effective at reducing spectral distortions in each region which resulted in a greater capacity to separate out individual vegetation cover classes based on distinct spectral signatures and improve classification results.

Training data

The quality of the classification is determined by the geographic coverage and habitat class representation available from training data. Many of the challenges identified above in applying available RISMA field data for the accuracy assessment (i.e. as validation points) applies equally to their use as training data. RISMA data points are located along transects, often in close proximity, and may not be representative of all habitat classes present in the marsh or, collectively, across the entire project area. Although additional field work was conducted to gather more geographically diverse and representative training data, these activities occurred two to three years past the date of image acquisition which is not ideal, particularly for habitat classes that are presumed to be in transition. Although it may be possible to rely on datasets derived for another purpose (e.g. RISMA) to supplement training data, it is recommended that field data collection generally follow accepted protocols (e.g. minimum distribution and representation of habitat classes, overlap with image acquisition dates) to achieve higher classification quality.

Supervised Classification

While the Random Forest classifier provided reasonable results, it could not be relied on as a means to classify the entire study area at once. Many of the defined habitat classes contained similar spectral characteristics; making separation through supervised classification difficult. Stratifying the marsh platform based on vegetation height and performing two separate classifications yielded better results. Additionally, the inclusion of contextual information in expert rule sets, such as known range/limits was most successful for separating certain habitat classes for which general assumptions can be made. For instance, Natural Pools are spectrally similar to Open Water features but they are relatively smaller and typically surrounded by marsh vegetation. Marsh vegetation is commonly known to be distributed across the marsh platform in zones defined by flooding duration; associated with elevation relative to mean high tide. The incorporation of contextual information using rule sets proved to be a necessary supplement to the supervised classification of salt marsh habitats.

LiDAR

The integration of LiDAR data was critical for both the establishment of salt marsh extent as well as for determining a distinction between habitat classes based on vegetation height. Salt marsh vegetation varies based on the duration of tidal flooding, so there is little variation in elevation on the marsh platform beyond the normal tidal range above mean high water at the study location. As a result, it is possible to distinguish the ‘edge’ at which increased elevation would not support marsh vegetation to determine marsh extent. Some habitat classes such as salt shrub and Invasive; *P.australis* are distinctive because their canopy is situated well above that of the surrounding vegetation. The inclusion of LiDAR data in the image analysis and semi-automated processing steps enhanced the contextual information that could be applied to the final classification resulting in a higher quality map product.