



Object-Based Image Analysis Assists Preserve Managers with Detecting Spatial Changes in Salt Marshes

Timucuan Ecological and Historic Preserve

Natural Resource Report NPS/TIMU/NRR—2017/1452



ON THE COVER

Salt marsh and seabirds at Timucuan Ecological & Historic Preserve.
Photograph courtesy of Jeremy Cantor

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Jeremy Cantor

National Park Service
Water Resources Division
1201 Oakridge Drive, Suite 250
Fort Collins, Colorado 80525

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Executive Summary

Timucuan Ecological and Historic Preserve (Preserve) in Jacksonville, Duval County, Florida, contains over 45,000 acres of healthy and productive salt marsh (Figure 1). These salt marshes provide crucial habitat to a wide variety of organisms but are threatened by a variety of influences such as sea level rise and upland development. The National Park Service Water Resources Division aims to improve baseline information and management of landscape level changes in the Preserve. Color infrared orthoimagery (2012), LiDAR data (2007), and Trimble eCognition software were used in an object-based image analysis to classify and quantify the two dominant genera of salt marsh grasses (*Juncus* and *Spartina*) found within the Preserve. This object-based technique groups neighboring, homogeneous pixels into similar groups to classify a landscape. In addition to *Juncus* and *Spartina*, seven other classes were mapped. Approximately 35,808 acres were classified as salt marsh habitat (Table 1) and the accuracy assessment revealed an overall classification rate of 89% and a Kappa statistic of 0.86. The Preserve now has a detailed map of the salt marsh and the surrounding area and will be able to identify changes in the marsh over time.

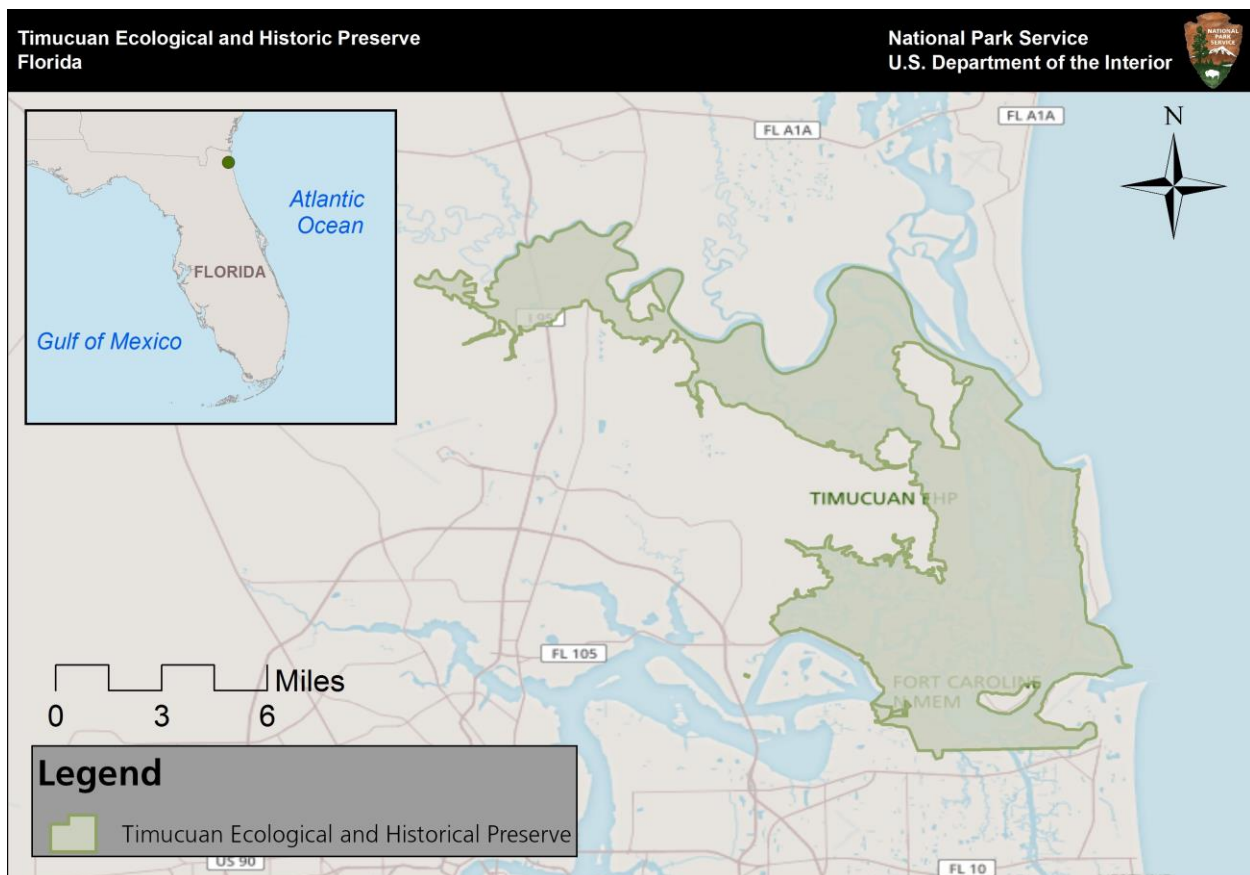


Figure 1. Map showing the location of Timucuan Ecological and Historic Preserve in northeast Florida.

Table 1. Summary of acreage and percentage of land cover class for Timucuan Ecological and Historic Preserve (Preserve).

Class	Acres	% of Preserve
Bare Ground	297	0.6%
Freshwater Wetlands	300	0.7%
<i>Juncus</i>	7,781	17.0%
Other	9,109	19.9%
Salt Flats	1,262	2.8%
Sand	209	0.5%
<i>Spartina</i>	11,617	25.4%
Upland Vegetation	441	1.0%
Water	14,642	32.1%
Total	45,658	100%

Acknowledgments

Many thanks go to Shauna Allen and her staff at Timucuan Ecological and Historic Preserve for initiating this project, taking the time to show me around the park, and providing assistance in ground-truthing activities. Also, thanks to the peer reviewers who graciously volunteered their time to provide valuable comments. These individuals include: Lisa Cowart Baron and Jamie Hoover of the National Park Service, and David White of Clemson University.

Introduction

Timucuan Ecological and Historic Preserve (Preserve) in Jacksonville, Florida “protects the area where the St. Johns and Nassau rivers meet the Atlantic Ocean and form one of the largest remaining salt marsh estuaries on the Southeast Coast” (National Park Service, 2012). The Preserve is dominated by salt marsh communities, some of which are “among the least disturbed remaining on the Atlantic Coast” (National Park Service, 1996). The salt marsh provides habitat for birds, fish, dolphins, oysters, and many other organisms (National Park Service, 1996) and many ecosystem services to the surrounding area. The salt marsh also serves as a buffer from coastal storms by reducing wave action and storm surge (National Park Service, 2012). Pollutants from upstream developments are filtered by the salt marsh (National Park Service, 2012). These ecosystem services are threatened by sea level rise, dredging and channel widening, and human development (National Park Service, 1996). Therefore, it is important to have an accurate map of salt marsh habitat to identify and document changes.

Previous studies of the Preserve’s salt marsh have been conducted at low spatial resolution or have incomplete coverage. The St. Johns River Watershed Management District produced a wetlands dataset for the entirety of Duval County (SJRWMD, 2002). Mapping of the wetlands was performed at a 1:24,000 scale and is sufficient for a county-level dataset but too coarse to accurately distinguish localized vegetative community differences. Steinway-Rodkin and Montague (2004) implemented a detailed study looking at the species composition at specific sites throughout the marsh. Their study provides valuable insight into the vegetative complexity of the marsh but does not offer a Preserve-wide coverage.

In 2013, the Preserve submitted a technical assistance request to get assistance with mapping the salt marsh. The primary goal of the mapping request was to evaluate current conditions and create a baseline record of salt marsh habitat for past and future comparisons. The dataset created in this project uses object-based remote sensing techniques, assesses the entirety of the Preserve, and has a finer spatial resolution compared to previous studies.

Methods

Salt Marsh Vegetation Types

There are two dominant genera of salt marsh grasses of interest found within the Preserve, *Spartina* and *Juncus*. *Spartina alterniflora* (smooth cordgrass) is the predominant species, but other species are also found within the Preserve (National Park Service, 2005). *Spartina* is typically located along creek banks and areas of higher salinity (Steinway-Rodkin and Montague, 2004). It can grow up to three and a half feet tall (Walkup, 1991). The other main salt marsh grass is *Juncus roemerianus* (black needlerush), but other species also occur in the Preserve. *Juncus* can grow up to about five feet tall and is taller than any species of *Spartina* (Uchytel, 1992). However, *Juncus* cannot tolerate high salinity levels and is typically found further upstream from estuary inlets or in areas closer to the

ocean where sediment build up has resulted in higher ground elevations (Steinway-Rodkin and Montague, 2004).

Data Sources

There are many different remote sensing techniques that can be used to detect and classify features and vegetation on a landscape. Some conventional techniques include manual digitization, supervised classification, and unsupervised classification, and all have pros and cons dependent on the nature of each individual project. Object-based image analysis is another technique that groups pixels into homogeneous objects and then uses contextual properties to classify the imagery (Blaschke, 2009). Rather than solely relying on pixel-based spectral properties, this project uses object-based analysis to detect the salt marsh found within the Preserve.

Two main data sources were used in this project: orthoimagery and LiDAR data. The color infrared orthoimagery was collected by the U.S. Geological Survey (USGS) in May of 2012 (USGS, 2012). The imagery has a spatial resolution of 30 cm giving this project a minimum mapping unit of 9 square meters or 0.002 acres. It contains three bands: red, green, and near-infrared. The near-infrared band is particularly useful in distinguishing vegetation from water and man-made surfaces, e.g. pavement and buildings, and determining levels of vegetation health. The LiDAR data were collected by the Florida Division of Emergency Management in March of 2007 (NOAA, 2007). LiDAR uses laser pulses from an airplane to create detailed elevation data. LiDAR provides two levels of elevation information, one at the ground surface and the other at the height of vegetation above the ground surface. Since the two dominant genera of salt marsh grasses grow to different heights (Walkup, 1991; Uchytel, 1992), the LiDAR data provide important information to distinguish these grasses.

Image Analysis

Trimble eCognition Developer 8.9 software was used to perform the majority of analysis in this project. Like other remote sensing software, eCognition looks at the spectral properties of each pixel. It then groups neighboring, spectrally homogeneous pixels into image objects. Also, the eCognition software allows different weights to be applied to the data layers to proportionally emphasize or deemphasize the importance of the input data. Because the LiDAR data were captured five years prior to the orthoimagery and vegetation changes likely occurred, a lower weight was given to the LiDAR data. Another advantage of object-based remote sensing through eCognition is its ability to compare image objects using a variety of metrics including brightness, texture, tone, and color. Comparisons of image objects can be made within a class, across different classes, or omitted from the analyses. Image objects can also be filtered by area, length, or a variety of other geometrical measures.

Nine classes were used to classify the Preserve (Table 2). These classes included bare ground, freshwater wetlands, *Juncus*, *Spartina*, salt flat, sand, other, upland, and water. This classification scheme incorporated several of the classification levels produced by the Wetlands and Vegetation Inventory of Duval County from 2002 (SJRWMD, 2002).

Table 2. Table showing the classes used and source of class descriptions.

Class	Description	Description Source
Bare Ground	Barren lands devoid of vegetation.	NPS
Freshwater Wetlands	Wetland communities found far from the estuary inlet that are not influenced by the influx of salt water during tidal events.	NPS
<i>Juncus</i>	Herbaceous saline wetlands dominated by Black needlerush, often in nearly pure stands. Typically occupies a zone between the lower smooth Cordgrass zone and the high meadow community type.	SJRWMD
Other	Trees, roads, and other anthropogenic features.	NPS
<i>Spartina</i>	Herbaceous saline wetlands dominated by smooth Cordgrass, often in nearly pure stands. Typically occupies a zone between open water or tidal flat communities and a salt flat or Black needlerush zone.	SJRWMD
Salt Flat	Communities developing on sandy, hypersaline soils upland from the <i>Spartina</i> or <i>Juncus</i> zone and characterized by concentric bands of vegetation developing in response to a salinity gradient.	SJRWMD
Sand	Sandy areas that are above water.	NPS
Upland	High irregularly flooded herbaceous communities transitional between uplands and salt flats or <i>Juncus roemerianus</i> marshes and typically dominated by <i>Spartina bakeri</i> , <i>S. patens</i> , <i>Borrichia frutescens</i> , or other facultative species.	SJRWMD
Water	Unvegetated or sparsely vegetated sites subject to prolonged or semi-permanent flooding. Includes lakes, streams, ponds and other water bodies.	SJRWMD

The first step in this analysis was to segment the image into image objects using the orthoimagery and LiDAR datasets. The segmentation scale was increased or decreased depending on the average size of the classification objects. Trees, roads, and other anthropogenic features were classified as "Other" using mean elevation. To separate vegetation from water and other non-vegetated areas, a normalized difference vegetation index (NDVI) was also used. NDVI results range between -1.0 and 1.0 and can be used in remote sensing to separate vegetation and other land cover types (Gao, 1996). However, NDVI could not be used to distinguish the two genera of salt marsh grasses, as both have relatively similar spectral characteristics.

The Other class was used to group all land cover types that were not of interest to this study. The image was then re-segmented using a smaller segment size excluding the Other class. All of the remaining image objects were moved to a new image object level. In this second level, vegetation image objects were re-segmented using a larger segmentation size. This meant that smaller vegetation objects from level one now made up larger vegetation objects in level two. The image object levels provide better information about the surface texture of these vegetated areas.

Based on ground-truthing efforts and data acquired from the St. Johns River Watershed Management District, it was determined that *Spartina* appeared as a smooth, continuous surface in the orthoimagery (Figure 2). *Juncus*, on the other hand, appeared much rougher and textured. This meant that *Juncus* vegetated areas would be comprised of much smaller sub-objects in level one compared to those of *Spartina*. A threshold was determined for this mean area of sub-objects parameter to help classify vegetation as *Juncus*. In addition to surface texture, the LiDAR data were used to distinguish

Juncus from *Spartina*. *Juncus* grows taller than *Spartina*, and the first return values or top-of-vegetation heights were another piece of information used to further distinguish the two genera (Figure 3).

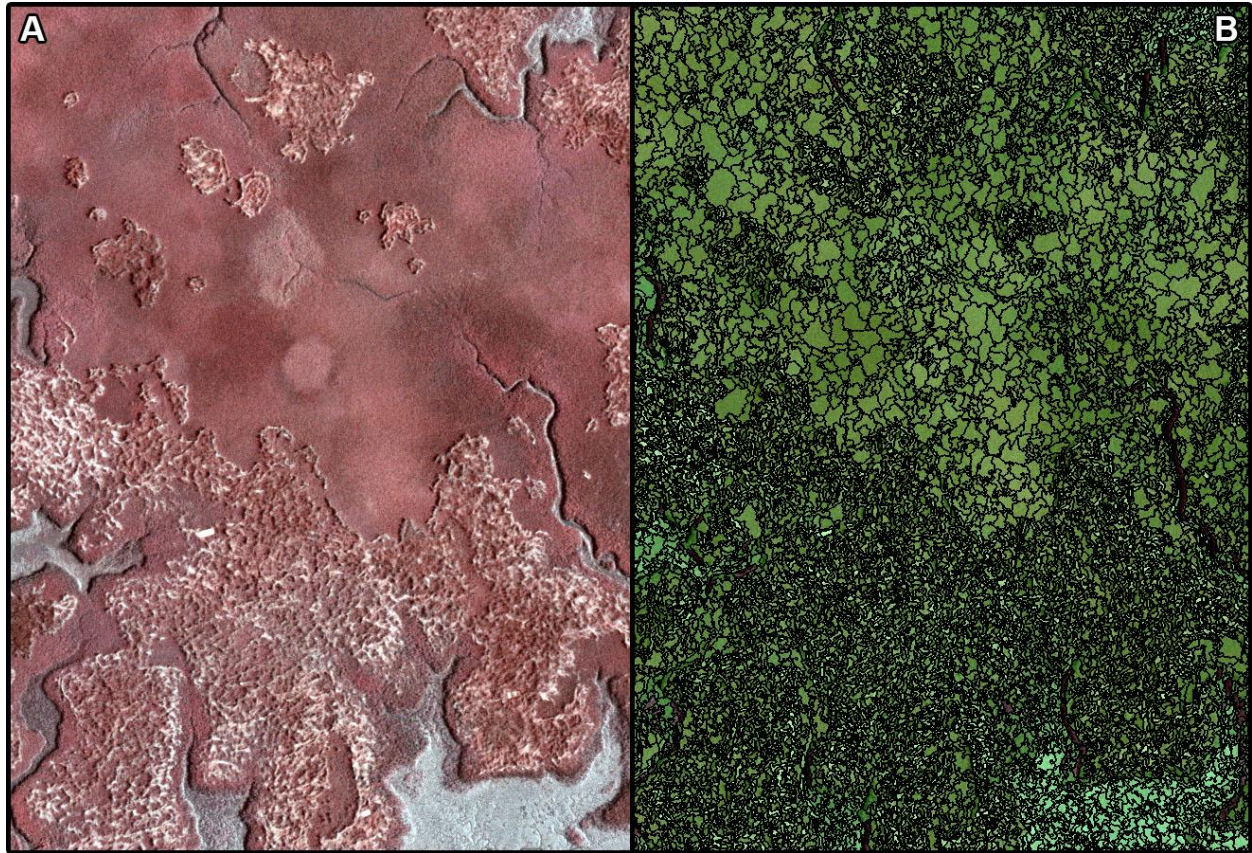


Figure 2. Image A shows the original orthoimagery. Image B shows the same area in classification view and shows the first level during image analysis within Trimble eCognition. *Spartina* dominates the upper portion of the image. *Juncus* dominates the lower portion of the image.

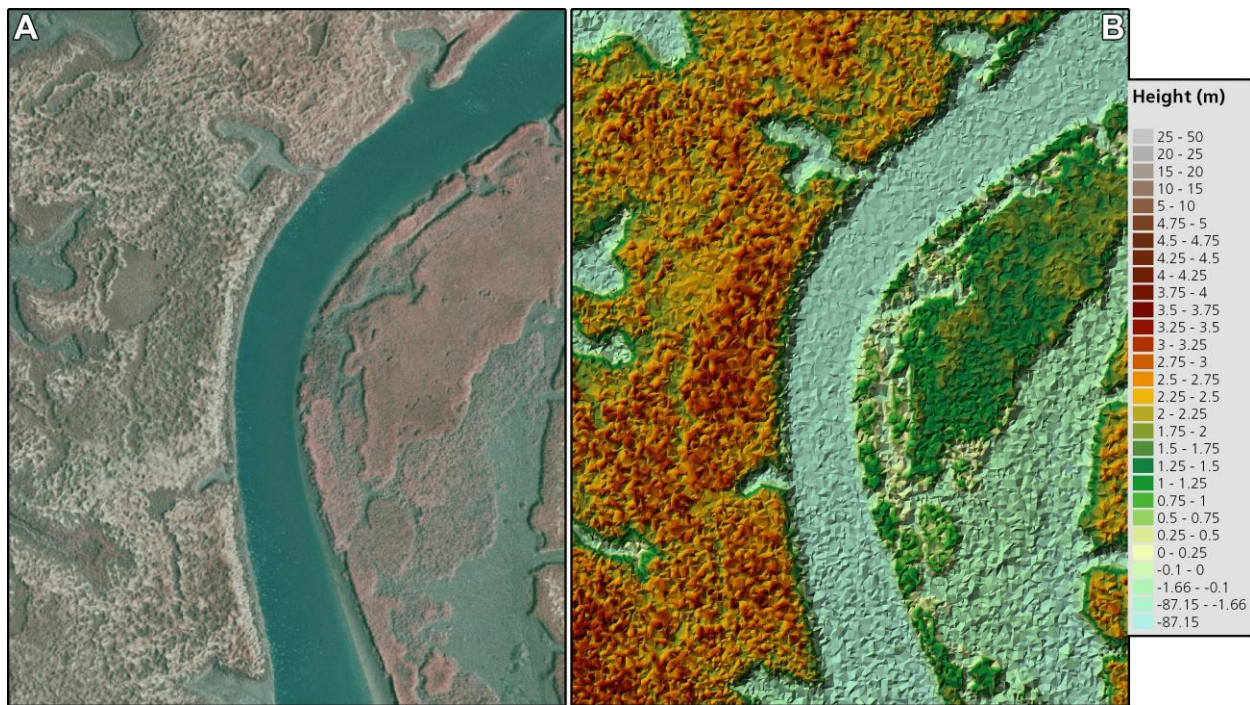


Figure 3. Image A shows the original orthoimagery. Image B shows the first returns or top-of-vegetation height from the LiDAR data. In Image B, *Juncus* on the left is taller than the *Spartina* on the right. In some areas the maximum height difference of the two is over 1 meter.

Field Visit

In August 2013, a field visit to the Preserve was conducted over a two-day period. Forty-five sites located within the southern and eastern parts of the Preserve were manually selected to represent known land cover types and areas of confusion (Figure 4). Preserve staff assisted in driving and navigating to points accessible from viewpoints along Heckscher Drive (Field Sites 28-32 and 38-45) and Cedar Point Road (Field Sites 1-2). A Garmin Oregon GPS unit was used for navigation purposes. Kayaks were also used to ground truth points found in Simpson Creek (Field Sites 36-37). A Preserve boat was used to visit points in Clapboard Creek (Field Sites 5-9), Sisters Creek (Field Sites 13-21), and Chicopit Bay (Field Sites 22-24). A plant identification was performed at each site and confirmation of the presence of *Juncus* or *Spartina* was made. Discoveries of different wetland species including *Borrchia frutescens* (sea oxeye daisy) and *Baccharis halimifolia* (salt bush) were made at some of the other points. In the two days, 30 of the 45 sites were visited. The visitation of the remaining 15 sites was prevented by downstream mud flats that are only navigable during high tide. It was not possible to align field visit times with the high tide cycle. Information collected during the field visit was used to verify species locations and improve image classification methodology.

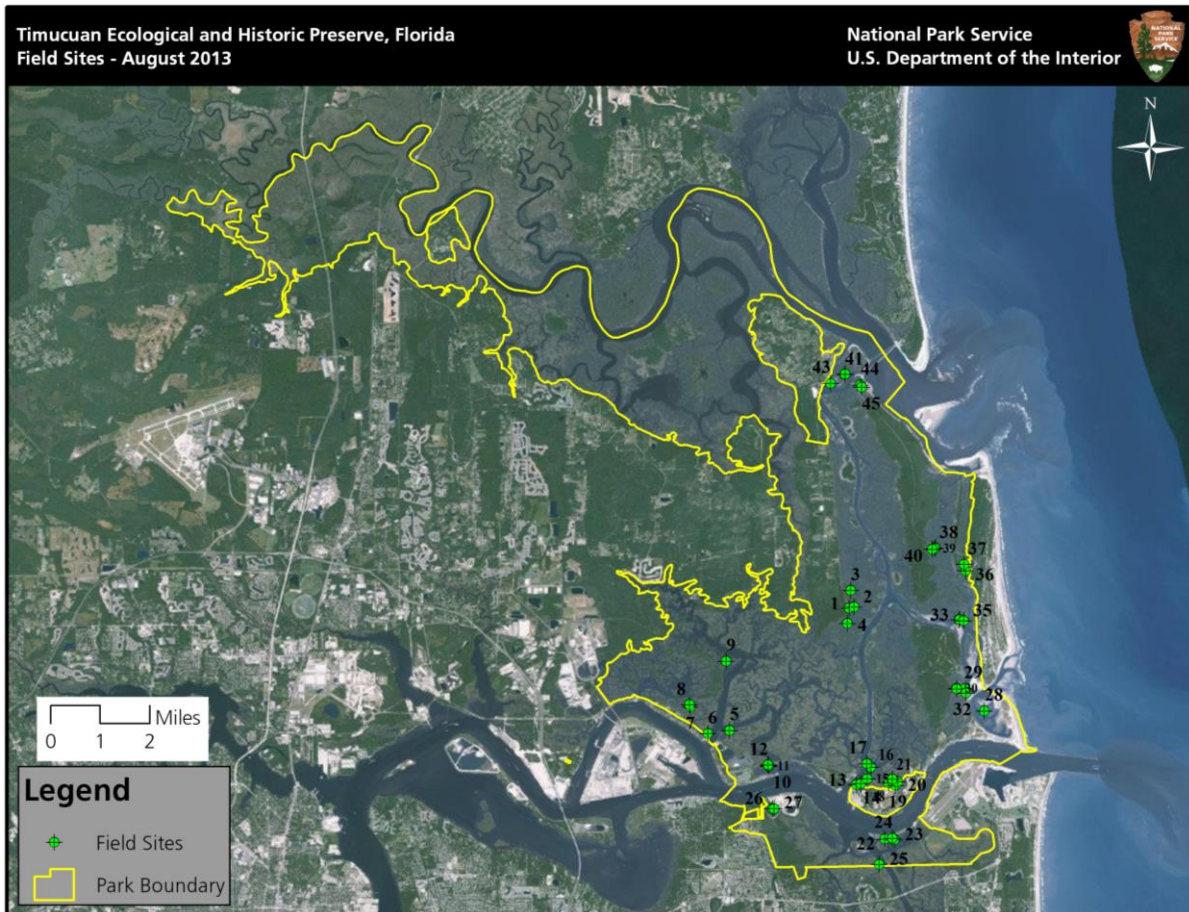


Figure 4. Map of field sites visited for ground-truthing purposes in August 2013.

Manual Editing

The classification results were converted to shapefiles and error checked and manually edited for quality control and accuracy purposes using ESRI ArcGIS 10.2. A reference grid covering the entire park was created in order to facilitate a thorough check of the data. This grid had dimensions of 0.1 miles by 0.1 miles. All manual editing was performed at a scale of 1:800. Areas and polygons that were inaccurately classified were reassigned the appropriate class (Table 2). A considerable amount of manual digitizing was performed in cases where one polygon included two different classes that were indistinguishable by the automated classification processes. Orthoimagery, LiDAR, and the Wetlands and Vegetation Inventory of Duval County (SJRWMD, 2002) were used to provide a general background on the spatial and spectral characteristics of the target salt marsh genera.

Accuracy Assessment

After finalizing the dataset, an accuracy assessment and Kappa statistic determined how well the classification process performed. A stratified random sampling approach was taken using the nine classes as strata. Using the National Oceanic and Atmospheric Administration's (NOAA) Sampling Design Tool for ArcGIS (NOAA, 2013), 456 random points were generated throughout the Preserve. The points were distributed based on the total area of each class or stratum. Classes with a larger total area such as water or *Spartina* were assigned more points while classes with a smaller total area such

as sand or bare were assigned fewer points. Independent imagery from Google Maps and Bing Imagery was used as the reference data.

Change detection

A comparison study was implemented to detect changes in the marsh from four different years: 1996, 2001, 2006, 2010. The NOAA Coastal Change Analysis Program (C-CAP) Regional Land Cover dataset was used in this comparison (NOAA C-CAP, 1995). The program produces a standardized database of land cover and land change information for the coastal regions of the United States at a 30-meter spatial resolution. C-CAP products provide inventories of coastal intertidal areas, wetlands, and adjacent uplands to monitor these habitats and land cover maps every five years.

To make an accurate comparison with the NOAA C-CAP data, NPS data were resampled from 0.3 meter pixels to 30 meter pixels. The classification scheme used in this study differed to the one used by NOAA. To attain consistency for comparison, the salt marsh habitats in each study were merged into a single class because the NOAA C-CAP dataset is not a genera-level dataset. Therefore, it was not possible to see whether there was an expansion or contraction of *Juncus* or *Spartina*. The Difference function in ArcGIS was then used to subtract the 2012 data from the 2010 data.

Results

Accuracy Assessment

The accuracy assessment revealed an overall accuracy of 89% (Table 3). Therefore, it can be expected that 89 times out of 100 a point in the classification will accurately represent conditions on the ground in 2012. The Kappa coefficient was 0.86, meaning the classification is better than random chance (0.50). When the four main classes of interest, *Juncus*, *Spartina*, other, and water are considered alone, the producer's and user's accuracies for these classes are generally high.

Producer's accuracy represents how well each class was initially classified. User's accuracy represents the probability that a location with a given class in the initial classification actually represents that class on the ground. However, the overall accuracy was slightly negatively influenced by the classification processes because the bare ground, freshwater wetlands, salt flats, sand, and upland vegetation classes had low classification accuracy. For these classes, a separate classification scheme was not developed and instead, these areas were assigned the appropriate class during manual editing.

Table 3. Error matrix from a stratified random sampling accuracy assessment of 456 points.

Map Data	Reference Data										User's Accuracy
	Bare Ground	Freshwater Wetlands	<i>Juncus</i>	Salt Flats	Sand	<i>Spartina</i>	Other	Upland Vegetation	Water	Total	
Bare Ground	0	0	0	0	0	2	0	0	0	2	0%
Freshwater Wetlands	0	0	3	0	0	0	0	0	0	3	0%
<i>Juncus</i>	0	0	80	0	0	5	0	0	0	85	94%
Salt Flats	0	0	3	2	0	9	0	0	0	14	14%
Sand	0	0	0	0	1	0	0	0	0	1	100%
<i>Spartina</i>	0	0	3	3	0	117	0	0	0	123	95%
Other	0	0	1	0	0	2	97	0	0	100	97%
Upland Vegetation	0	0	1	1	0	2	1	0	0	5	0%
Water	0	0	0	0	3	8	2	0	110	123	89%
Total	0	0	91	6	4	145	100	0	110	Overall Accuracy	89%
Producer's Accuracy	--	--	88%	33%	25%	81%	97%	--	100%	Kappa	0.86

Image Analysis

Of the 45,658 total acres included in Timucuan Ecological and Historic Preserve, approximately 35,808 acres are classified as salt marsh habitat (Table 4). This habitat includes the two primary genera of salt marsh grass, *Juncus* and *Spartina*, as well as tidally-influenced water bodies, salt flats, sandy areas, and areas of bare ground or mud. There are estimated to be 11,617 acres of *Spartina* and 7,781 acres of *Juncus* found within the Preserve in 2012. Water bodies including rivers, lakes, and creeks amounted to 14,642 acres. Salt flats totaled 1,262 acres. Sandy areas and bare ground were sparse at 209 and 297 acres, respectively. There were 300 acres of freshwater wetlands, 441 acres of upland vegetation, and 9,109 acres of trees, houses, roads, or other anthropogenic features.

Table 4. Table showing the acreages of each class found within Timucuan Ecological and Historic Preserve (Preserve).

Class	Acres	% of Preserve
Bare Ground	297	0.6%
Freshwater Wetlands	300	0.7%
<i>Juncus</i>	7,781	17.0%
Other	9,109	19.9%
Salt Flats	1,262	2.8%
Sand	209	0.5%
<i>Spartina</i>	11,617	25.4%
Upland Vegetation	441	1.0%
Water	14,642	32.1%
Total	45,658	100%

Figure 5 shows the classification around the Sisters Creek area. *Spartina* is often found in, but not limited to, Sisters Creek, Fort George River, Simpson Creek, Gunnison Cut, Sawpit Creek, Pumpkin Hill Creek, Edwards Creek, and the Nassau River from its mouth upstream to the confluence with Edwards Creek. Outside of these areas, *Spartina* is often found in bands lining water bodies and adjacent to *Juncus* or other inland vegetative communities. *Juncus* is predominantly found in areas away from the high tide line. These areas include, but are not limited to, Browns Creek, Clapboard Creek, Cedar Point Creek, Hannah Mills Creek, the upper reaches of Pumpkin Hill Creek, and the Nassau River upstream of the confluence with Edwards Creek. In more tidally-influenced areas *Juncus* can be found, but is typically in areas where sediment has built up to increase ground elevations and lower soil salinity levels.



Figure 5. A map showing the classification of the area surrounding Sisters Creek.

Change Detection

The NOAA C-CAP dataset is not a genera-level dataset and therefore, it was not possible to see whether there was an expansion or contraction of *Juncus* and *Spartina*. However, overall, there were very few areas of land cover change between 1996 and 2010 (Figure 6). Similarly, between the 2010 NOAA C-CAP data and the 2012 data produced by this study, there were few changes in the land cover inside the boundaries of the Preserve. The only noteworthy changes occurred in the Fort George Inlet (Site D). When the two NOAA C-CAP datasets were compared, the residential areas on Black Hammock Island saw patterns of development such as changes from Evergreen Forest to Scrub/Shrub and Scrub/Shrub to Bare Land (Site A). There was also some change from Scrub/Shrub to Palustrine Emergent Wetland up Sherman Creek in the area immediately south of the Mayport Naval Station (Site B). The areas with the largest changes are found on the north bank of the mouth of the St. Johns River (Site C) and the mouth of the Fort George River (Site D). The former experienced increased erosion with Bare Land changing to Water. The latter had changes from Unconsolidated Shore to Water and Bare Land changing to Unconsolidated Shore. Since the installation of the St. Johns River jetties (Site E) in 1881, this area has experienced extraordinary

changes with increased sand deposition that threatens to close off the inlet to the Atlantic Ocean (Bauerlein, 2004).

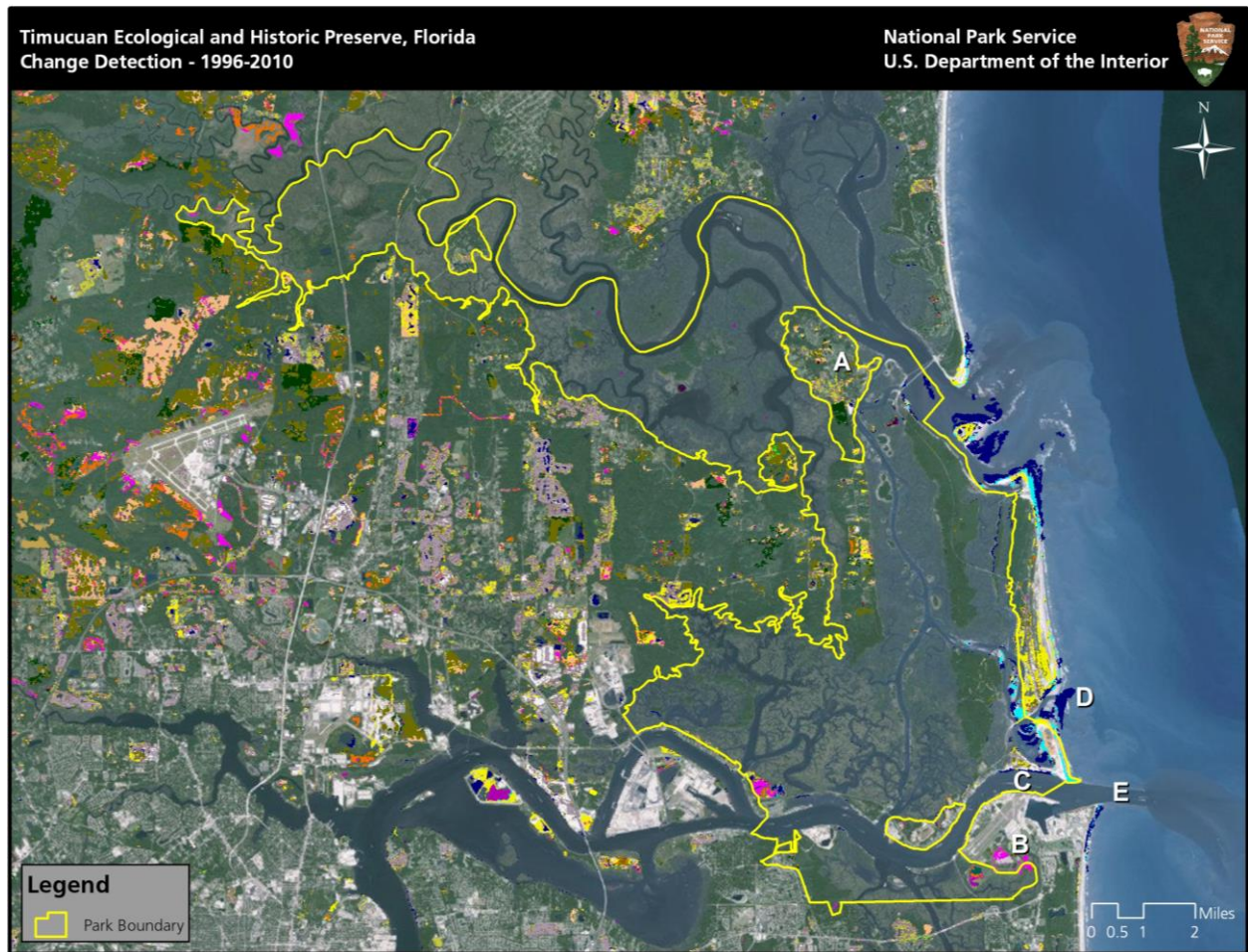


Figure 6. Highlighted areas represent changes in land cover from 1996 to 2010 using NOAA C-CAP data and natural colored areas have remained unchanged.

Discussion

The goal of this project was to produce an accurate vegetation map of the salt marsh in the Timucuan Ecological and Historic Preserve. Over 45,000 acres were mapped to provide detail for this dynamic and critical environment. The data provide an important baseline snapshot of conditions in the salt marsh in 2012. This baseline dataset is essential to measure the changes in land and vegetated cover from different sources, such as sea level rise and dredging projects on the St. Johns River.

The ability to incorporate multiple datasets into analyses is a desirable feature of object-based image analysis. The combination of LiDAR and orthoimagery data in this study were valuable and provided crucial details that would have been limited if the datasets were used separately. For example, *Juncus* and *Spartina*, grow to different heights and the LiDAR data added top of the vegetation elevation information that improved upon the spectral-based orthoimagery.

There are multiple caveats to note that may impact aspects of this analysis. First, a normalized digital surface model (nDSM) could not be created, which would have improved the analysis. LiDAR has the ability to penetrate the vegetation canopy, it not only provides the top-of-vegetation elevation (first return), but also the elevation of the land surface. Subtracting the land surface elevation from the first return results in the actual height of vegetation relative to the ground. The nDSM is useful because it removes the variation in vegetation heights caused by differences in local topography. In this study there were not enough points detailing ground elevation in the LiDAR dataset to create an accurate nDSM ground surface. Instead, elevation parameters in eCognition had to be adjusted according to each image's average elevation. Second, the LiDAR data were collected over five years prior to the collection of the orthoimagery and thus were less dependable in the analyses when segmenting the images. For future studies, it is recommended that LiDAR data be collected at the same time as the orthoimagery if funding is available. Doing so has the potential to make a much more accurate classification. Third, there were very few areas of land cover change between the 2010 NOAA C-CAP data and the 2012 data produced by this study. Similar to previous years in the NOAA C-CAP study, the only noteworthy changes occurred in the Fort George Inlet (Figure 6, Site D). For the remaining areas, we posit that merging classification schemes and resampling the finer resolution data could also have adversely influenced land cover change detection. Finally, although remote sensing data provide many advantages in assessing a wide geographic extent compared to field transects, there was a substantial amount of time that was spent on developing and refining the ruleset in eCognition. We suggest that further enhancements to the ruleset are necessary to reduce the amount of errors in the output and help minimize the amount of time spent on manual edits. Such efforts would lessen the amount of time and labor required to reproduce this map on a more frequent timescale.

Conclusions

This study produced a detailed map of Timucuan Ecological and Historic Preserve using color infrared orthoimagery, LiDAR data, and an object-oriented remote sensing technique. NDVI, surface texture, and vegetation height provided the most information used to perform the classification.

Juncus and *Spartina* land cover within the Preserve totaled 17% and 25%, respectively. Open water was also a major land cover type occupying 32% of the Preserve. The dataset produced by this study will serve as a baseline information for monitoring future vegetation and changes produced by events such as sea level rise and dredging. The techniques used in this study could be applied to subsequent studies or in other regions where *Juncus* and *Spartina* are found.

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Natural Resource Stewardship and Science
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