COASTAL MARSH CHARACTERIZATION USING SATELLITE REMOTE SENSING AND *IN SITU* RADIOMETRY DATA: PRELIMINARY RESULTS

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ABSTRACT

Coastal marshes are an important component to the overall health of Long Island Sound. Located in the densely populated northeastern United States, Long Island Sound is subject to the extensive pressures imposed by having such a large population base living on or near its shores. Understanding the health and condition of the wetlands within the Sound plays an important part in protecting this vital resource. Researchers at the University of Connecticut's Center for Landuse Education And Research (CLEAR) and Wesleyan University are using multispectral image sources (Landsat, ASTER, and QuickBird) and various analytical methods to delineate and monitor the extent of coastal marshes throughout Long Island Sound. In addition, *in situ* spectral radiometer data are being collected at select coastal marsh locations throughout the growing season to generate a spectral library of prominent coastal marsh plant species. This information will be used to ascertain at what point during the growing season the coastal marsh plant species are most distinguishable. These data will prove beneficial when determining the window of opportunity to collect image data for coastal marsh mapping or for mapping of specific wetland plant species. This paper describes results to date and outlines future research plans.

INTRODUCTION

Coastal marshes are among the most productive environments in the northeastern United States and serve as a critical component of the Long Island Sound ecosystem. However, over the past century, a significant amount of these wetlands has been lost due to development, filling, and dredging, or damaged due to anthropogenic disturbance and modification. Global sea level rise is also likely to have a significant impact on the condition and health of coastal marshes, particularly if the marshes have no place to migrate due to dense coastal development (*e.g.,* Donnelly and Bertness, 2001). In addition to physical loss of marshes, the species composition of marsh communities is changing. Dominant species of coastal marsh grasses which include *Spartina alterniflora* (salt cordgrass), *Spartina patens* (salt marsh hay), *Juncus gerardii* (black grass) and *Distichlis spicata* (spike grass) among others, once the dominant species of New England salt marshes, are being replaced by monocultures of invasive *Phragmites australis* (common reed) in many coastal marshes (Barrett and Prisloe, 1998; Orson, 1999). Although present throughout the continental United States, non-indigenous *P. australis* invasion is most severe along the Atlantic coast (Saltonstall, 2002). For Long Island Sound, anecdotal evidence suggests approximately 50% of tidal and brackish marshes are sites of *P. australis* invasion (Chambers *et al*., 1999). *P. australis* out-competes other marsh species in areas with increased fresh water, nitrogen and sediments and is positively correlated with marsh fragmentation (Moore *et al*., 1999; Bertness *et al*., 2002). In response to the increase of *P. australis* in many marshes, The Nature Conservancy, the CT DEP and other organizations have instituted efforts (commencing in the 1980s) to restore marsh health, including the eradication of *P. australis* in some areas. Informal observation of the response of marshes to eradication has found both an increase of non-*Phragmites* marsh species and *P. australis* reinvasion (Farnsworth and Meyerson, 1999).

With the mounting pressures on coastal marsh areas, it is becoming increasingly important to identify and inventory the current extent and condition of coastal marshes located in the Long Island Sound estuary, implement a cost effective way to track changes in the condition of wetlands over time, and monitor the effects of habitat restoration and management. Currently the State of Connecticut acquires high-resolution color infrared photographs at approximately five-year intervals to monitor environmental conditions and landscape changes along the coast. New York collects similar color aerial photographs for Long Island which are interpreted by experienced analysts to produce useful information in terms of the extent of coastal land cover. More frequently collected digital, multispectral remote sensing image data, however, have several benefits that are essential to assess and monitor the location and constituent species of the dynamic coastal marsh ecosystem. Firstly, changes in marsh health due to eradication and vegetative re-growth occur on time-scales less than the approximate five-year revisit time of conventional aerial photography. With revisit periods as frequent as every four days with ASTER and 16 days with Landsat, satellite remote sensing affords the opportunity to monitor intra-seasonal change. This capability is critical to identifying times when marsh species are most distinctive during the growing season. Digital remote sensing data are radiometrically and geometrically corrected and can be immediately compared to other data sets using GIS. Digitization, radiometric calibration, geometric correction, and mosaicking of analog aerial photographs are time-consuming, complicated processes, but are necessary if this form of imagery is to be computer-processed and integrated into a GIS. Radiometry (number of photons hitting the detector) is also preserved and recorded directly in a digital remote sensing image, whereas the same information must be derived from an aerial photograph (*e.g*., using a densitometer). Finally, remote sensing systems typically have greater spectral range than black-and-white or color infrared photographs, and, in the case of Landsat and ASTER 30-meter resolution images, include several measurements of middle infrared reflected energy. These data are sensitive to variations in moisture content in vegetation and soils and thus vital to the delineation of coastal marshes. These digital data types in conjunction with the collection of *in situ* spectral radiometer data are being used to map the extent of coastal marshes and identify coastal marsh plant communities.

STUDY AREA

Long Island Sound

The study area consists of the entire Long Island Sound coastal region located in the Northeastern United States (Figure 1a) and extends up the tidally influenced portions of the three major rivers (Housatonic, Connecticut, and Thames) that supply freshwater to the Sound. Long Island Sound is bordered to the north by the states of Connecticut and New York, and to the south by Long Island, New York. The Long Island Sound is approximately 177 km long (oriented east to west) and 34 km across at the widest point and contains 965 km of coastline (Tedesco, 1995). Its maximum depth is 91 meters with an average depth of 20 meters. The entire Long Island Sound watershed area is approximately 41,440 square km extending from the Canada and United States border in the north to the Sound in the south and the extreme north shore of Long Island (Figure 1b) (LISS, 2003). Of the three major rivers that drain into the Sound, the Connecticut River watershed covers 71% of the overall area and contributes about 64% of the fresh water. Within the entire watershed area live approximately eight million people and more then 20 million people live within 80 km of the shores of Long Island Sound. The commercial and recreation value of the

(a)

(b)

Figure 1. Long Island Sound. (a) September 8, 2002 Landsat image of the full extent of Long Island Sound and the locations of the five select marshes being studied in more detail. (b) Area of the Long Island Sound watershed.

Sound contributes upwards of $5.5 billion annually to the regional economy. The Sound is classified as an estuary because it is a place where salt water and fresh water mix, but unlike most estuaries, the Long Island Sound is open on both ends – at the Race at the eastern end, and the more narrow East River and New York City Harbor at the western end. Mean tidal range varies from 0.7 meters in the east to 2.3 meters in the west (Patton and Kent, 1992). This significant difference is due to tidal resonance and the shape of the Sound.

Long Island Sound Coastal Marsh Characteristics

The coastal marshes in Long Island Sound are technically classified as estuarine emergent wetlands, because the vegetation emerges above the water level. Most of the wetlands are true salt marshes where salt marsh plant species dominate and salinity levels average about 20 to 30 ppt (parts per thousand). In the riverine systems where marshes are also abundant, the marshes become more brackish with salinity levels dropping to 15 ppt. Further up the rivers the marshes eventually become dominated by freshwater wetland plant species and the salt marsh plants largely disappear although these areas are still affected by tidal influences. Unlike the southeast and southern regions of the United States, the marsh systems in Long Island Sound are small with a mean area of approximately 39 ha (Roman *et al*., 2000). A typical coastal salt marsh is a relatively simple system comprised of a few dominant species which exhibit a distinct pattern of vegetation across a gradient of tidal flooding and salinity (Ewanchuk and Bertness, 2004). In the low marsh, which receives twice daily tidal flooding, pure stands of the tall form of *Spartina alterniflora* can be found (Figure 2). *S. alterniflora* is also common in a narrow band along mosquito ditches and creeks. The high marsh, flooded frequently, exhibits a mosaic of vegetation types. Common species here include *Spartina patens*, *Distichlis spicata*, *Juncus gerardii* and the short form of *S. alterniflora* among others. In the brackish marshes, *Typha* spp. also becomes prominent. As mentioned in the introduction, *Phragmites australis* has become a nuisance invasive species and is rapidly changing the character of coastal marshes in Long Island Sound. Dense stands of *Phragmites* can be found in many coastal marshes along Long Island Sound.

PRELIMINARY ANALYSIS

The project work plan consists of four primary goals. These are: delineation and monitoring of coastal marshes; identification of vegetative species within marshes; determining the optimal spatial, spectral, and temporal resolutions for coastal marsh system characterization; and development and delivery of outreach and education programs based on research results. This paper will focus on the preliminary results of the first two goals made to date.

Delineation and monitoring of coastal marshes

The first goal of this project is to identify the location and extent of all coastal marshes along Long Island Sound using moderate resolution (15 – 30 meter) imagery. The purpose is to determine whether moderate resolution imagery is capable of identifying coastal marshes that have an area larger than one hectare. If so, this dataset will serve as a base map for the documentation of wetland gains or losses from future and past datasets and will also be used to analyze the spatial patterns of coastal marshes in the context of surrounding land cover, most notably the proximity to developed areas. Landsat Enhanced Thematic Mapper (ETM) imagery is being used as the primary source of imagery for this dataset due to its ability to provide a synoptic view of Long Island Sound and adjacent coastline. With a scene footprint of 185 x 185 km, the Landsat ETM is capable of covering most of Long Island, Long Island Sound, and Connecticut, in a single path (WRS Path 13). Extreme eastern Long Island Sound is captured in a separate path (WRS Path 12). Additionally, the Terra Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor, with a scene width of 60 kilometers is being assessed for its ability to identify coastal marshes. To date, a temporally-consistent set of ASTER imagery has not been collected to cover the entire study area during the growing season.

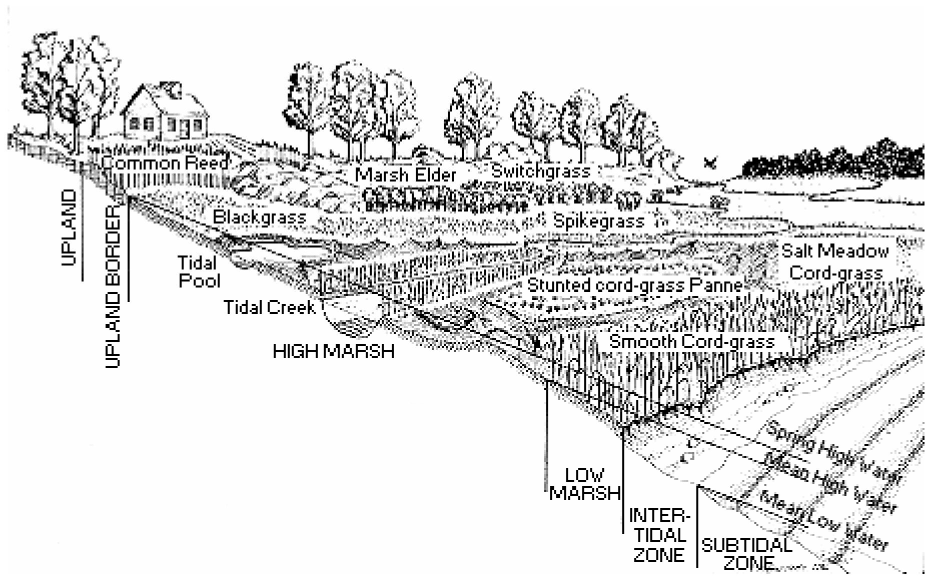


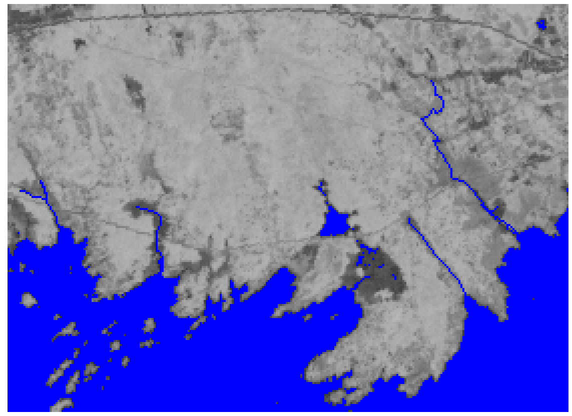
Figure 2. Cross section of an idealized coastal marsh in Long Island Sound. (Image from: Tidal Wetland Ecology of Long Island Sound. URL: http://camel2.conncoll.edu/ccrec/greennet/arbo/publications/34/FRAME.HTM)

Analysis Area. To focus analysis on just the coastal region of Long Island Sound, a Landsat ETM image acquired on September 8, 2002 was clipped to an analysis region that includes coastal marshes and adjacent uplands. This region was created based on the classification of a water layer using a normalized difference water index which identifies pixels as being "wet" based on the ratio of the difference between the near-infrared and green bands over the sum the near-infrared and green bands. The equation is as follows:

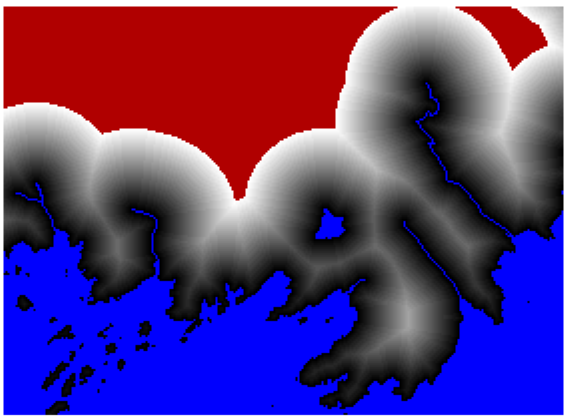
$$\frac{ETM\ \ Band\ 4 - ETM\ \ Band\ 2}{ETM\ \ Band\ 4 + ETM\ \ Band\ 2}$$

The output is a grayscale image with real values ranging from -1.0 to 1.0. These were scaled to an 8-bit image containing values from 0 to 255 with lower values representing water pixels. A threshold was identified (pixel values 65 and 66) that delineated between a water pixel and an upland pixel. Pixels that contained mixed features, such as streams that have pixels that contain both water and upland, were not sufficiently identified using the water index. Where needed, these were digitized on-screen. The water index image layer was then processed to group contiguous water pixels into individual objects of water pixels. A buffer operation was then performed to identify pixels within 1,200-meters (40 pixels) from an identified water object. The 1,200-meter distance is arbitrary and was selected only to ensure all coastal marshes were captured within the buffered region since some of these can exist some distance from water features. This buffer layer was then used to extract features from the original Landsat ETM image (Figure 3).

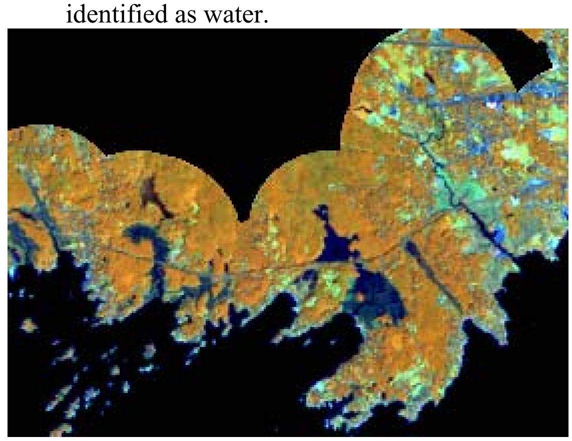
(a) September 8, 2002 Landsat ETM showing a portion of the Connecticut coast.



(b) Results following the application of the normalized difference water index and on-screen digitizing. Blue indicates pixels identified as water.



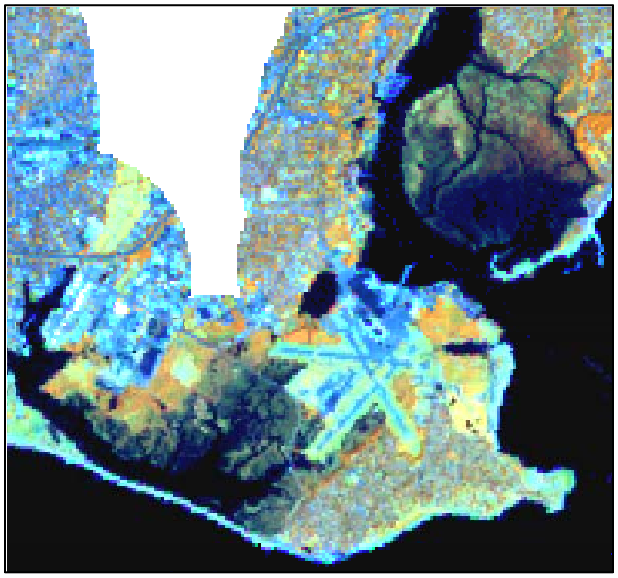
(c) Results following the application of a 40 pixel (1200-meter) buffer from water pixels. Red indicates pixels beyond 40 pixels from water whereas grey variations represent increasing distance from black to white.



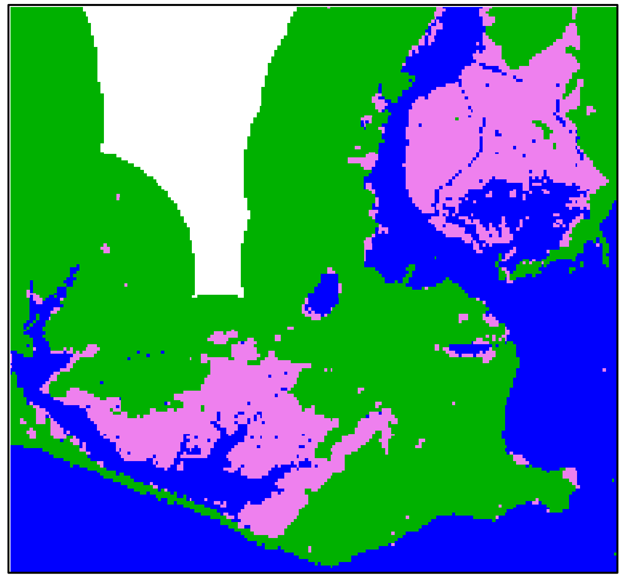
(d) Results of applying the 40 pixel distance mask to the September 8, 2002 Landsat ETM image.

Figure 3. Generation of analysis area for image processing of moderate resolution satellite imagery.

ISODATA unsupervised classification. Initial classification of the Landsat Long Island Sound analysis area was conducted using the ISODATA unsupervised classification algorithm found in Leica Geosystem's ERDAS Imagine image processing software. The goal was to produce an initial classification and to assess the ability of a Landsat image to identify coastal marshes using spectral information only. ISODATA clustering was applied to the analysis area Landsat image to produce 150 separate spectral classes. These classes were identified and labeled into one of four informational categories: water, coastal marsh, upland, and other. The "other" category contained clusters of pixels that were not readily identifiable as belonging to a single informational class. Pixels identified under the "other" category were extracted from the image and a second ISODATA clustering procedure was performed on these pixels with 100 output clusters specified. These clusters were again identified and labeled into one of the four informational categories. The process was repeated two more times with 50 clusters each. The results of the four ISODATA clustering processes were recoded and combined to create a single three category land cover image. Classification post-processing was performed in the form of a 3x3 majority filter to smooth the image and eliminate isolated pixels. Figure 4 is an example of the results of this initial classification process for a portion of the entire study area. Initial assessment shows that the iterative ISODATA clustering technique was able to identify coastal marshes, although there do exist errors of omission and substantial errors of commission.



(a) September 8, 2002 Landsat image.



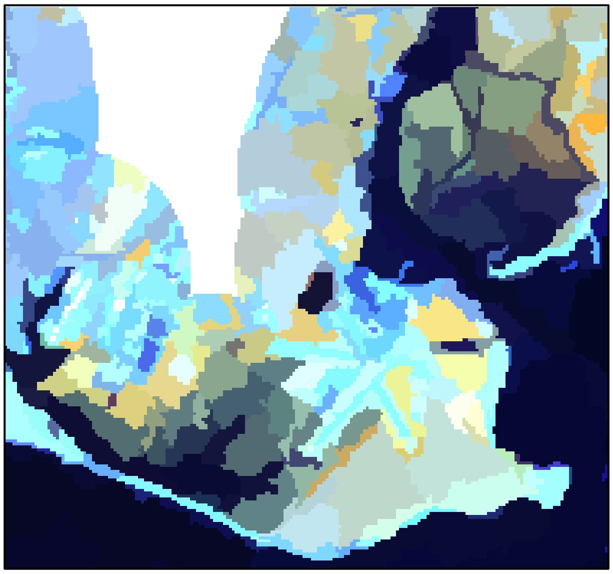
(b) ISODATA per-pixel classification (coastal marshes are colored magenta).

Figure 4. ISODATA classification results on Landsat 30-meter resolution imagery for Wheeler Marsh and Great Meadows Marsh located in Milford and Stratford respectively.

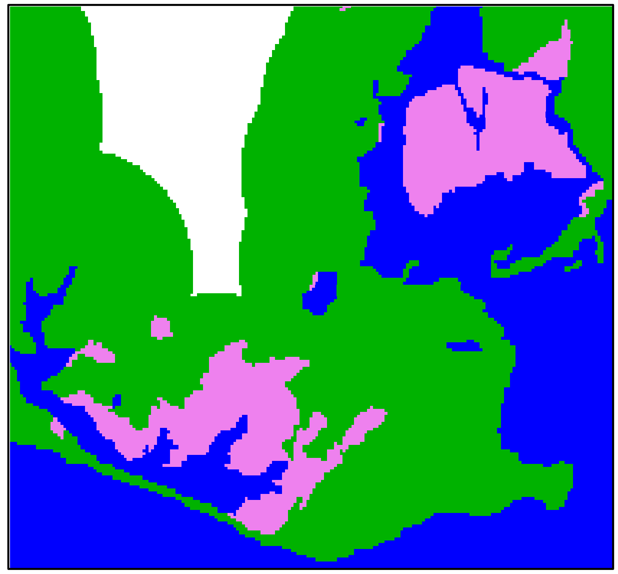
Moderate resolution image segmentation. Another classification procedure that is gaining popularity is image segmentation and object oriented classification. Image segmentation partitions an image into homogeneous image regions (objects) which provide spatial information (texture, size, shape, context) in addition to spectral information. These spectral and spatial attributes can be used to assign an object to a specific classification category, paralleling somewhat the human visual cognitive process. Such a technique requires significant knowledge of the area or feature being classified, but the benefit is a more robust classification due to the increased information, reduction in the number of units (pixels versus objects) to be classified, and the elimination of the "salt-and-pepper" effect which is common in per-pixel classifiers.

Since ISODATA is a per-pixel classifier, we wanted to compare its results with an image that was first segmented into image objects then classified to determine if coastal marshes could be better identified and delineated. The Landsat analysis area image was segmented using eCognition software. eCognition allows for the creation of objects at various resolutions (sizes) depending on user specified variables. These include a scale parameter which determines the maximum size of the objects and the composition of the homogeneity criterion which uses settings for color, smoothness and compactness that roughly determine the shape of the objects using spectral and shape information. For this analysis, the scale parameter was set at 10, color 0.7 (from 0 to 1), smoothness 0.7 and compactness 0.3. Figure 5a provides an example of the resulting objects.

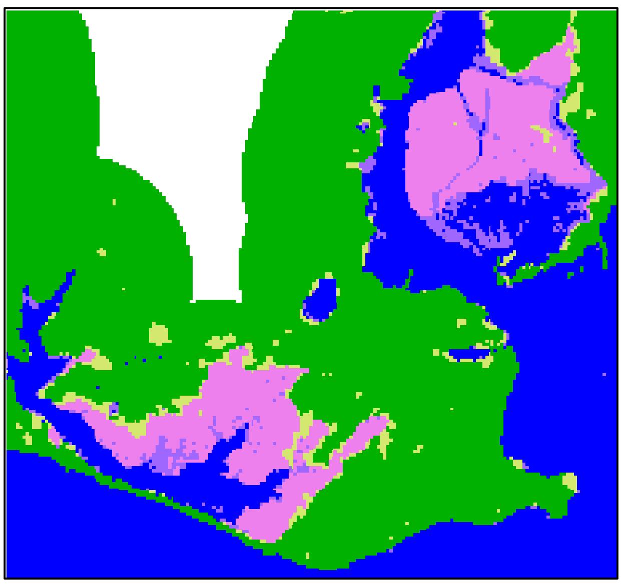
eCognition contains many tools for the classification of image objects. However, we wanted to test ISODATA on a segmented image, so the spectral information was exported from eCognition to ERDAS Imagine and classified using a single ISODATA iteration. For this process, 200 clusters were specified. These were labeled into one of three categories; upland, water, or coastal marsh. An example of the object oriented classification is provided in Figure 5b. When compared to the per-pixel based ISODATA classification (see Figure 4b) it is readily apparent that the object based classification is much smoother, however, based on the size of the objects smaller coastal marshes may not be identified. Altering the scale parameter during the segmentation process may correct for this. Figure 5c provides an example of the difference between the two classification results and Figure 5d compares these results with an aerial photograph-derived coastal marshes delineation.



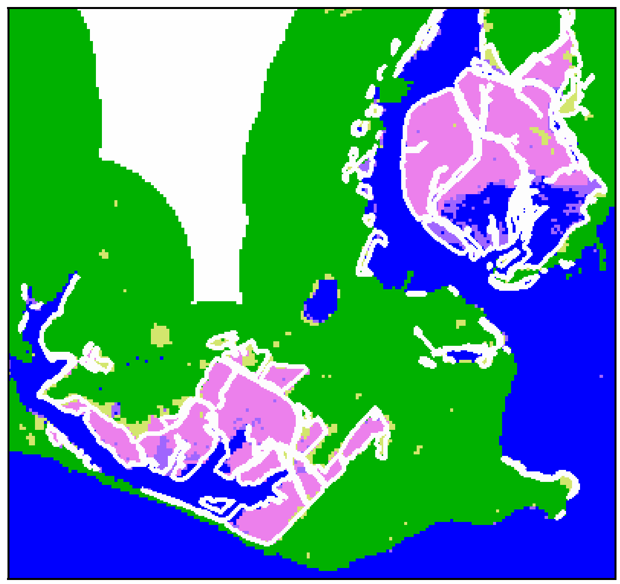
(a) Image segmentation and resulting image objects.



(b) ISODATA classification of image objects (coastal marshes are colored magenta).



(c) Combined results of per-pixel and image object ISODATA classifications. Identified coastal marshes in both techniques are colored magenta, light green is confusion with upland, and purple is confusion with water between both techniques.



(d) Combined results of per-pixel and image object ISODATA classifications with Connecticut DEP derived coastal marsh layer (white lines) draped on top.

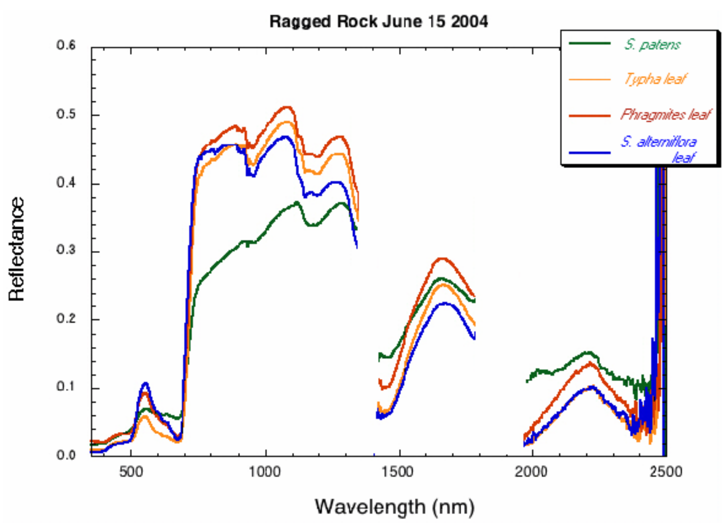
Figure 5. Image segmentation and object oriented classification results on Landsat 30-meter resolution imagery for Wheeler Marsh and Great Meadows Marsh located in Milford and Stratford respectively.

Identification of vegetative species within marshes

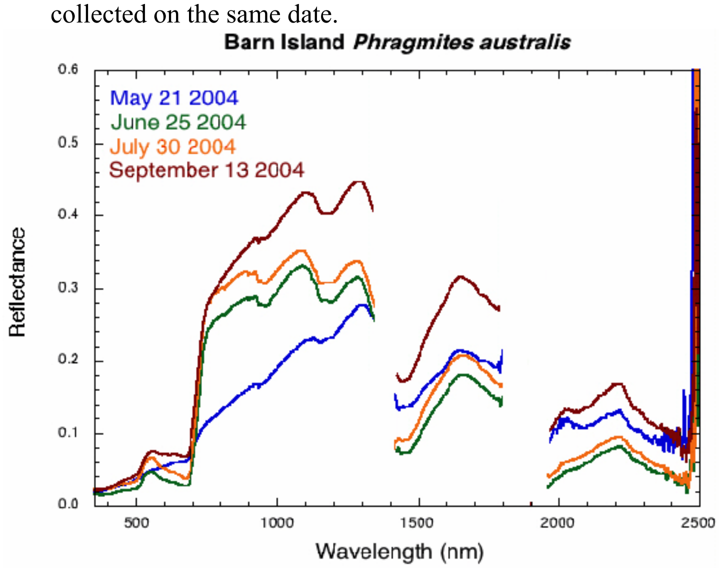
The second goal of this project is to identify various plant communities that comprise the low and high marsh ecosystems. Most notably we hope to delineate the extent of *P. australis* invasion into the coastal marsh environment and provide an assessment the effectiveness of *P. australis* eradication efforts. As specified in the

Introduction, the composition of marsh vegetation is changing in many coastal marshes where *P. australis* is out-competing many of the native wetland species. We expect high resolution imagery from satellite sensors will be capable of identifying individual vegetative species within the marshes. DigitalGlobe's QuickBird imagery is being used as the primary source of imagery for this analysis due to its high spatial resolution and availability. In addition, to assist in the accurate identification of marsh species from these images, and to determine at what point in the growing season provides the best discrimination among coastal marsh plant species, a library of seasonally calibrated spectral signatures for the species of concern is being developed. This work is being conducted in five select marshes distributed throughout Long Island Sound (see Figure 1a).

Collection of spectral radiometer data. Detailed field spectra of select marsh plants are being collected using a FieldSpecFR (Analytical Spectral Devices, INC., ASD) fiber optic spectrometer at each of the five study marshes. The FieldSpecFR is a high performance single-beam field spectro-radiometer that uses three detectors operating over three wavelength domains, the 350-1000 nm region (VIS), the 1000-1800 nm region (SWIR1) and the 1800-2500 nm region (SWIR2). Because the instrument is typically operated without reaching full equilibrium, there are offset differences due to the response of the various detectors, potentially producing distinct relative reflectance differences for different wavelength regions. These offsets are corrected during post-processing. A typical data collection sequence consists of measuring the reflectance of a bright, spectrally neutral reference target followed by measurements of the sample of interest. The spectrometer is operated in an automated mode such that the dark current is subtracted from both measurements and the ratio of the sample to reference is calculated for immediate display. The reflectance measurements are made with a 1.5 meter fiber optic cable with a 25-degree field of view, at a height about 1-meter above the target to ensure a homogeneous sample. Each measurement consists of an average of ten spectra and five to ten measurements are taken of each target. To date, each of the five study sites have been visited at least once during the growing season with GPS and spectrometer data collected for several of the most common coastal marsh plants species: *S. alterniflora*, *S. patens, J. gerardii, D. spicata,. P. australis* , and *Typha* spp. Figure 6 provides two spectral plots based on preliminary results of the spectral radiometer field collection. During the month of June, subtle differences in spectral reflectance are evident among several dominant plant species, where *S. patens* has the highest red and 2000-2500 nm reflectance and lowest ~800 nm (NIR)



(a) Preliminary spectral plot of four coastal marsh plant species collected on the same date.



(b) Preliminary spectral plot of an integrated stand of *P. australis* collected on four different dates during the 2004 growing season.

Figure 6. Preliminary spectral plots comparing (a) four different coastal marsh plant species and (b) *P. australis* on four different dates. Atmospheric water bands at 1400 and 1900 nm are omitted for clarity.

reflectance at Ragged Rock creek marsh (Figure 6a). Thus we predict that in early summer, *S. patens* may be distinguishable from other species in satellite data by utilizing Landsat bands 3,4 and 7 (or their equivalent in other data). It is important that we also understand spectral changes resulting from the phenology of each marsh species around Long Island Sound. For example at Barn Island marsh, *P. australis*, shows an increase in green and NIR reflectance throughout the growing season as the plant increases in health and biomass, with a peak in the NIR during late summer (Figure 6b). The breakdown of chlorophyll is marked by an increase in red:green in late summer as the plants begin to senesce. This information will prove useful for maximizing the detailed mapping of coastal marsh plant species from high-resolution imagery.

High resolution image segmentation. Classification of QuickBird 2.4-meter spatial resolution and pan-sharpened 60-centimeter high-resolution multispectral imagery is being conducted using eCognition to segment the image into usable image objects. This work is being conducted on a select number of coastal marshes (see Figure 1a) to evaluate the capability of QuickBird imagery to identify and map coastal marsh plant communities and species in Long Island Sound. Due to the spatial complexity of high-resolution imagery, per-pixel classifiers tend to be inefficient for deriving classifications. By segmenting the image and creating homogenous image objects, the image is able to be much more efficiently classified.

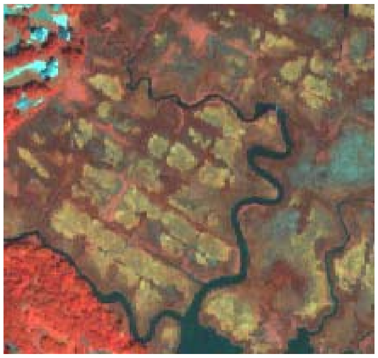
As mentioned in a previous section, image objects are derived in eCognition by setting user defined parameters. In the case of eCognition, image objects of different resolutions can be defined and stored in different levels and used to derive a final classification. An important concept concerning this is that all image objects defined in a lower level will be nested within image objects of a higher level. For this preliminary study, two image object levels were derived. The first (level 2) is a more general segmentation with larger image objects used to identify the basic land cover categories of water, forest, developed/barren, grass, and marsh. The second level (level 1) is the more detailed segmentation with smaller image objects which represent building structures, roads, individual plant communities and/or pure stands of individual species. The image object size for each level was determined based on the scale parameter (250 for level 2 and 35 for level 1). Figures 7a through 7e provide examples of a QuickBird image collected on July 20, 2004 for a portion of a brackish coastal marsh and the resulting Level 1 and Level 2 image segmentations.

Classification is performed in eCognition by selecting sample objects that represent each class of interest. In the case of the Level 2 classification only a couple sample objects were necessary due to the limited number of total image objects within the image. Classification was performed using a nearest neighbor classifier. The procedure is the same for the Level 1 classification, however, due to the greater number and complexity of the image objects, more sample objects were needed for each class. Again, a nearest neighbor classifier was utilized. In addition, for the Level 1 classification, rules were developed that assisted the classification by using the results of the Level 2 classification. For instance, there existed a significant number of omission and commission errors, most notably with objects clearly located in the marsh being classified as forest. To eliminate this problem, a rule was developed that forced any Level 1 object located in the Level 2 marsh category from being classified as anything other then one of the four marsh categories of *S. patens, P. australis*, *Typha* spp., and *S. robustus*. Similar rules were developed to address other Level 1classification problems. Figures 7f and 7g provide preliminary results of these classifications. As can be seen throughout the examples in Figure 7, it is apparent that the spatial and spectral resolution of the QuickBird image will be suitable for identifying coastal marsh species. More work is needed, however, to refine and improve these classifications.

DISCUSSION

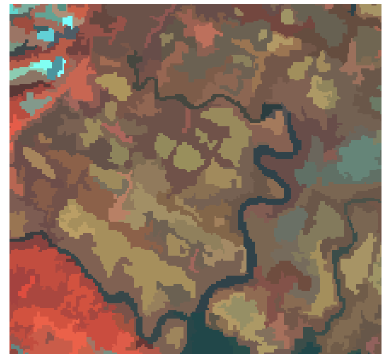
This project is only a few months into its inception and most effort to date has concentrated on the collection of GPS ground truth data and spectral radiometer data. As discussed in a previous section, the spectral radiometer data has shown there is a spectral distinction among many of the coastal marsh plant species. Additionally, these plant species change throughout the growing season offering more opportunities for identifying distinct reflectance characteristics. Further processing and analysis of the spectral radiometer data will provide conclusive results as to what period, or possibly multiple periods, during the growing season the coastal marsh plant species are most identifiable and indicate at what time of year image data should be collected.

Results based on preliminary analysis of the Landsat and QuickBird datasets indicate that the image processing techniques being employed on these data types are producing anticipated results. Mapping the extent of coastal



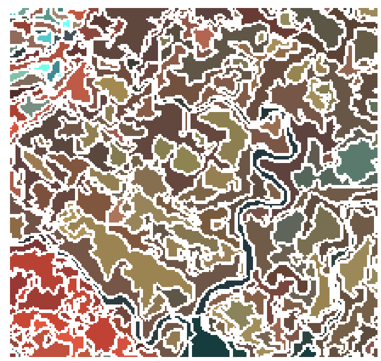
(a) Pixel level image
(in the marsh, yellow areas are *S. patens*, bright red *P. australis*, deep red *Typha* spp., and cyan *Scirpus robustus*. Forest is in the lower left, developed in upper left)

(b) Level 2 segmentation

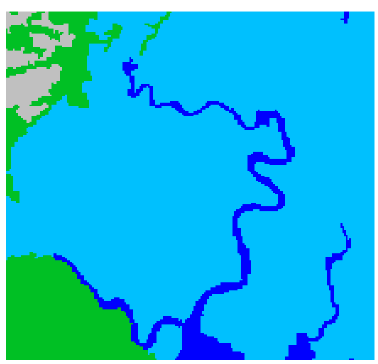


(c) Level 1 segmentation

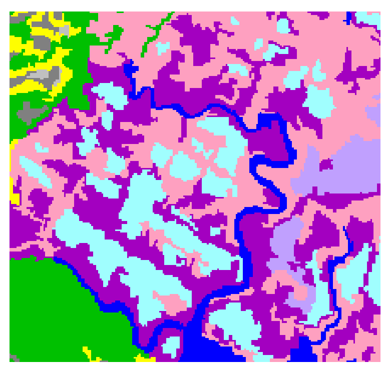
(d) Level 2 segmentation (with image objects outlined)



(e) Level 1 segmentation (with image objects outlined)



(f) Level 2 segmentation basic classification.



(g) Level 1 segmentation detailed classification.

Figure 7. Examples of image segmentation and object oriented classification of a QuickBird 2.4-meter resolution multispectral image collected July 20, 2004 for a portion of a Long Island Sound coastal marsh located in Old Saybrook, Connecticut.

marshes throughout Long Island Sound has posed the most challenging aspect of the project. This is due to the 30-meter spatial resolution of the Landsat imagery and the resulting mixed pixel effect which is common along the water/upland boundary where pixels produce spectral reflectance characteristics similar to the marshes. Confusion with some upland land cover types, most notably along transportation routes, also pose a problem. Further refinement of techniques will be necessary to address these problems. The QuickBird 2.4-meter data has been providing positive results. Refinement of the image segmentation and object oriented classification techniques should further improve the results.

ASTER data has been a problem in terms of the lack of temporally consistent data being available for the entire Long Islands Sound study area. Images that are available contain significant cloud cover or were collected during the winter season when coastal marshes are less discernable from surrounding land cover. Recently, a high quality scene was acquired, collected on September 9, 2004, for the western third of the Sound. This scene will be classified and compared with the Landsat image for that part of the Sound to assess the capability of ASTER, with its improved spatial and spectral properties, to identify coastal marsh extent.

FUTURE EFFORTS

At the time of this paper's preparation, work is just beginning on the analysis of image data. Preliminary results are promising, but it is evident that improvements are necessary. The next few months will focus on determining the extent of coastal marshes throughout Long Island Sound using both Landsat and available ASTER imagery. Classification techniques will be refined and the use of Knowledge Based classification will be employed and assessed. Following the completion and accuracy assessment of this task, the identified coastal marshes will be analyzed in the context of surrounding land cover. Researchers at CLEAR have recently completed a suite of Landsat derived land cover for Connecticut and the Long Island Sound region for four years (1985, 1990, 1995, and 2002). Coastal marshes will be assessed as to their proximity to development, proximity to changes in land cover, and limits in their ability to migrate due to natural (*i.e.* elevation) or anthropogenic (*i.e.* adjacent development) causes. Additionally, change in marsh area will be assessed (accounting for tidal fluctuations) by examining the resulting coastal marsh extent with historic Landsat image data.

Mapping of coastal marsh species will continue using QuickBird 2.4-meter resolution imagery and image segmentation and object oriented classification. The image segementation and classification techniques will be further refined and applied to image data at each of the five study marsh locations. For study sites at the confluence of the Connecticut River with Long Island Sound, four dates of imagery have been collected throughout the 2004 growing season. Each of these will be classified using the same technique and assessed as to which period during the growing season provides the best discrimination among wetland plant species. Additionally, for the Barn Island Marsh site in the far eastern end of Long Island Sound, pan-sharpened (70 centimeter) multispectral QuickBird imagery was acquired. This image will be classified and assessed to determine if the finer spatial resolution provides improved results over the 2.4-meter resolution data product.

Further analysis will be performed on the raw radiance spectral radiometer data. Data collected in the field will be converted to reflectance data automatically using RS3 software provided by Analytical Spectral Devices. These reflectance data will then be converted to text files using ASDs ViewSpec program and imported into Microsoft Excel for analysis. The data will be averaged according to plant type, location and time of year. Furthermore, the spectral data will be reduced to mimic the bands of the QuickBird, ASTER and Landsat data which will allow for direct comparison with the satellite sensor response. The spectral data will be analyzed using a ratio of near-infrared to red and compared with similar results from the image data. Regions of the electromagnetic spectrum that provide the best discrimination among coastal marsh plant species will be identified and used to identify the optimal spectral range of image sensors to map coastal marshes.

Lastly, all the results from this project; images, wetland maps, derived analysis, and wetland spectral library, will be made publicly available from a dedicated website and through formal outreach education programs. This will provide additional support to ongoing coastal marsh vegetation classification and monitoring efforts being conducted by other agencies and organizations in Long Island Sound.

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REFERENCES

Barret, N., and S. Prisloe.1998. Spatial patterns of expansion of by *Phragmites australis* (Cav.) Trin. Ex Steud. within the tidelands of the Connecticut River from 1968 to 1994. CD-ROM and report to The Nature Conservancy, Middletown, CT, 1 June 1998.

Bertness, M. D., P. J. Ewanchuk and B. R. Silliman. 2002. Anthropogenic modification of New England salt marsh landscapes, *PNAS, 99,* 1394-1398.

Chambers, R. M., L. A. Myerson and K. Saltonstall. 1999. Expansion of *Phragmites australis* into tidal wetlands of North America, *Aquatic Botany, 64,* 261-273.

Donnelly, J. P. and M. D. Bertness 2001. Rapid shoreward encroachment of salt marsh cordgrass in response to accelerated sea-level rise, *PNAS, 98,* 14218-14223.

Ewanchuk, P.J. and M.D. Bertness. 2004. Structure and organization of a northern New England salt marsh plant community. *Journal of Ecology*. 92, 72-85.

Farnsworth, E. J. and L. A. Meyerson. 1999. Species composition and inter-annual dynamics of a freshwater tidal plant community following removal of the invasive grass, *Phragmites australis*, *Biol. Invasions, 1,* 115-127.

Long Island Sound Study. 2003. Sound Health 2003: a report on status and trends in the health of the Long Island Sound. EPA Long Island Sound Office. Stamford, CT. 17p.

Moore, H. H., W. A. Niering, L. J. Marsicano and M. Dowdell. 1999. Vegetation change in created emergent wetlands (1988-1996) in Connecticut (USA), *Wetlands Ecol. Manag., 7,* 177-191.

Orson, R. A. 1999. A paleoecological assessment of *Phragmites australis* in New England tidal marshes: Changes in plant community structure during the last few millennia, *Biol. Invasions, 1,* 149-158.

Patton, P.C. and J.M. Kent. 1992. A Moveable Shore: The Fate of the Connecticut Coast. Duke University Press. Durham, NC. 143 p.

Roman, C.T., N. Jaworski, F.T. Short, S. Findlay and R.S. Warren. 2000. Estuaries of the Northeastern United States: habitat and land use signatures. *Estuaries* 23(6) 743-764.

Saltonstall, K. 2002. Cryptic invasion by a non-native genotype of *Phragmites australis* into North America. *Proceedings of the National Academy of Sciences, USA* 99(4): 2445-2449.

Tedesco, M. 1995. Long Island Sound Management Plan. Long Island Sound Study. Stamford, CT., URL: http://www.epa.gov/region01/eco/lis/ 22 Nov. 2004.