USE OF LIDAR DATA TO AID IN DISCRIMINATING AND MAPPING PLANT COMMUNITIES IN TIDAL MARSHES OF THE LOWER CONNECTICUT RIVER: PRELIMINARY RESULTS

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ABSTRACT

This paper summarizes the status and preliminary results of lidar research currently underway at the Center for Land Use Education and Research at University of Connecticut. Researchers are investigating uses of an October 8, 2004 lidar dataset that covers approximately a 300km^2 coastal area of Connecticut from New Haven Harbor to the mouth of the Connecticut River. Lidar data are being used to aid in the classification of tidal wetland plant communities, which is being done through classification of high-resolution Quickbird satellite and airborne imagery using eCognition image segmentation software. Plant species of primary interest include *Phragmites australis*, *Typha spp.* and *Spartina patens*. These three plant species have distinct height differences that were expressed at the time of the lidar data collection. Boundaries of relatively pure stands of each plant species manually were digitized from 0.5m resolution ADS40 airborne CIR imagery and were used to analyze specific plant community subsets of the lidar data to determine lidar height characteristics. Mean lidar-based heights for the species of interest were: *P. australis* = 3.01m; *Typha spp.* = 1.37m; *S. patens* = 0.64m. The data also are being examined to learn how lidar interacts with these tidal marsh plant communities, to characterize transition zones (edges) between plant communities and to characterize mixed vegetation communities. Results of the analysis will be used to improve image segmentation and classification of multi-temporal Quickbird imagery, especially in locations where spectral properties of Quickbird's four bands may be insufficient to adequately discriminate among plant communities.

INTRODUCTION

The lower Connecticut River estuary is unique among large river systems in the northeastern part of the United States as it does not have a large city or port at its mouth. The river's geomorphology and land use development patterns have preserved many tidal wetland systems along the river's shoreline and on islands within the river estuary. The wetlands serve important functions in the overall ecology of the area providing habitat and forage for many species of migratory waterfowl and birds. The creeks that that drain the marshes also are important habitats and breeding grounds for many species of invertebrates and fish.

Until relatively recently, the marshes in the lower Connecticut River had been fairly stable systems that supported a diverse and valuable mix of typical salt, brackish and freshwater plant communities depending on the location of the marsh along the river's salinity gradient. However, in the early to mid twentieth century, *Phragmites australis*, or common reed, rapidly began to expand its range within these tidal marshes. *P. australis* forms extremely dense monotypic stands that shade the marsh surface enabling it to out compete other more desirable plant species. Sequencing of chloroplast DNA markers (Saltonstall, 2001) suggests that this expansion is due to a non-native form of *P. australis* that may have been introduced in the past 200 years and that has replaced the native non-aggressive *P. australis*. Barrett and Prisloe (1998) quantified *Phragmites* expansion from 1968 to 1994 at 32 locations in the Connecticut River estuary and found that the number of sites with at least 5 ha of *Phragmites* increased from 10% to 55%. Warren *et al.* (2001) documented linear expansion rates of from 1% yr^{-1} in brackish marshes to almost 3% yr^{-1} in freshwater marshes in the lower Connecticut River.

In the 1980s the Connecticut Department of Environmental Protection and a coalition of other natural resource and environmental organizations began a program to eradicate *P. australis* in order to restore native tidal marsh vegetation. Eradication has been achieved as a two-step process. Patches of *P. australis* are sprayed with Rodeo® or other glyphosate-based herbicides. The dead plants subsequently are mechanically mulched. This allows sunlight to reach the marsh surface and dormant seeds from plants that previously grew on the marsh germinate and native plant populations return.

The purpose of this study is to investigate methods to integrate lidar data with high resolution multispectral satellite and airborne imagery to improve the identification, classification and mapping of *Phragmites australis*. Ultimately, these data will be used to support *P. australis* eradication and management programs.

STUDY AREA

The Ragged Rock tidal marsh is approximately 1.4 km^2 in area (Figure 1). It is located on the west bank of the Connecticut River approximately 3 km from where the river discharges into Long Island Sound. The marsh is a brackish tidal marsh subject to diurnal flooding. Much of the area of the marsh has been ditched to provide drainage of the marsh surface in an effort to reduce mosquito breeding areas.

A small rectangular section of the southwest corner of the marsh and adjacent upland areas was selected for the study. The study area covered approximately 0.4 km^2 and measures approximately 0.6 km east-west by 0.6 km north-south.

Preliminary field work conducted in the summer of 2005 found over 30 plant species in the marsh portion of the study area; however, the dominant species were *Phragmites australis, Typha angustifolia, Typha xglauca and Spartina patens.* Other common species included *Spartina cynosuroides, Solidago sempervirens, Panicum virgatum, Schoenoplectus americanus* and *Schoenoplectus pungens.*

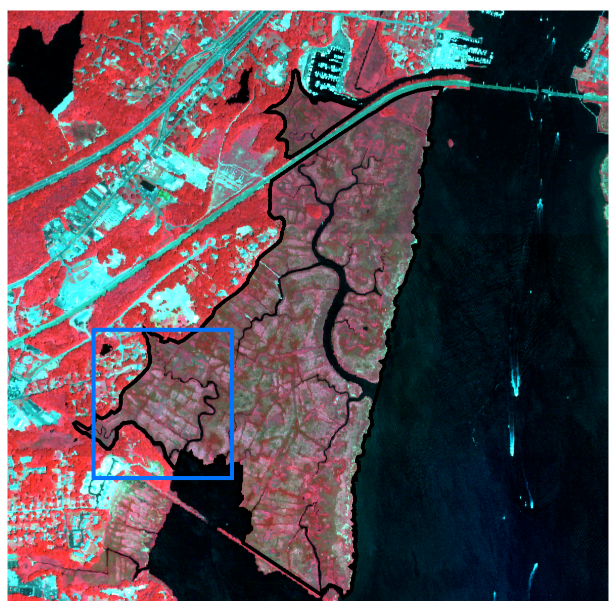


Figure 1. 7/23/05 Quickbird image of the Ragged Rock tidal marsh with the study area outlined in blue.

In general, the *Phragmites* and *Typha spp.* tend to grow as dense monocultures except at the stand edges where newer growth tends to be less dense and intermixed with other plant species. Distinct communities of *Spartina patens* also are located throughout the study site. In many cases they exist as complex mosaics with intermixed areas of *S. sempervirens, P. virgatum, S. americanus, S. pungens* and other less common species. A type view of the marsh is shown in F8/26/05 igure 2. It depicts the structural character of the marsh vegetation which can be classified into three general height categories. In this photograph, the low growing plants in the foreground are *S. patens*, those in the midground are *Typha spp.* and in the background is the tallest class which consists of *Phragmites.*

Figure 2. The structural character of the marsh vegetation is clearly visible in this 8/26/05 photograph of the three dominant plant species: *Spartina patens* (shortest), *Typha spp*. (mid height), and *Phragmites australis* (tallest).

DATA

Lidar data were provided by Woolpert LLP. Data were collected on October 8, 2004 as part of a NOAA Coastal Services Center Coastal Remote Sensing project. The project was designed to collect high-resolution multispectral imagery and high-density lidar data to support ongoing state agency coastal management programs and university research projects. Lidar data were collected at a height of 3,000 feet using a Leica ALS50 airborne laser scanner. Two returns per pulse (first and last) were recorded. A total of 41 flight lines were flown over the 300 km^2 project area, which covered the central Connecticut coast and the Quinnipiac River and Connecticut River estuaries (Figure 3). Lidar data points had a nominal ground sampling distance of 0.9m. The reported horizontal accuracy was 0.5m and the reported vertical accuracy was 0.002m based on the average error between the bare-earth DEM and 21 ground control points. The XY data are in decimal degrees, NAD83, GRS80 and Z values are in meters, NAVD88. Lidar attributes included X, Y, Z,

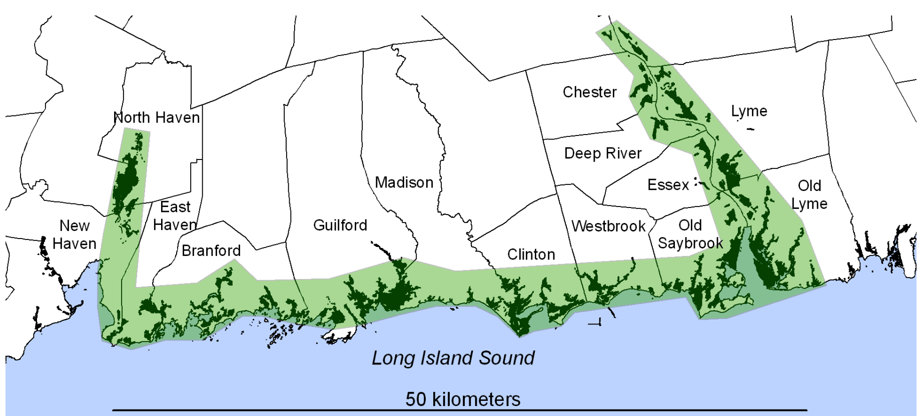


Figure 3. Lidar data collection area shown in light green. The solid black areas are state regulated tidal wetlands.

intensity, return number, number of returns, and a class code which identified points as being ground, first return non-ground, second return non-ground, water, outliers, and low point outliers. Data were delivered to the NOAA Coastal Services Center in an ASPRS LAS binary format. NOAA converted the LAS data to an ASCII format for delivery to the research team. The entire dataset consisted of 264 tiles.

16-bit ADS40 RGB and CIR orthoimagery with 0.5m resolution were acquired for Connecticut's 36 municipalities located within the state's Coastal Area Management zone. Imagery was collected on September 20 and 22, 2004 by EarthData, Inc. The data were delivered as two sets of 122 tiles each (one RGB and one CIR) referenced to UTM Zone 18N, NAD83, GRS80.

PRELIMINARY ANALYSIS

ASCII files of lidar data, formatted as comma separated values, were processed to add a header record that contained field names for each data element. Each file was then added to ArcGIS 9.1 as an XY event layer and was exported to a shapefile format in UTM Zone18N, NAD83, coordinates. A total of nine tiles, which covered the entire Ragged Rock tidal marsh, were merged into a single point shapefile and those points that fell within the area of the Ragged Rock tidal marsh were selected and exported as a shapefile. This file contained just over 3.75×10^6 point features. A subset of lidar point features also was extracted to cover the smaller study area (see Figure 1). The file, which contained just over 1.0×10^6 point features, was used for analysis.

Several studies (Rosso et al., 2005; Morris et al., 2005) have used of lidar to map marsh vegetation and Rosso notes the difficulty of extracting accurate ground returns from the data. A question the research team wanted to investigate was the degree to which plant height and structure in the study area could be characterized using lidar non-ground returns. Field observations demonstrated that at this site there is distinct height stratification (see Figure 2) among marsh plant communities and it was hypothesized that comparable height classes could be derived from the lidar data.

In ArcGIS, several transects were digitized across the study area using an ADS40 CIR image for reference. All lidar point features within 0.5m of each transect were selected and UTM XY coordinates were added as attributes to these data subsets. The UTM XY coordinates, Z values and class values were exported to Excel. The classes were determined by the lidar vendor and included codes to indicate ground or non-ground returns. Figure 4 depicts a plot of the ground and non-ground returns for one transect. Changes in non-ground return heights correspond to changes in vegetation communities. For example, from 10m to 50m the vegetation is *S. patens*, from 50m to 85m the

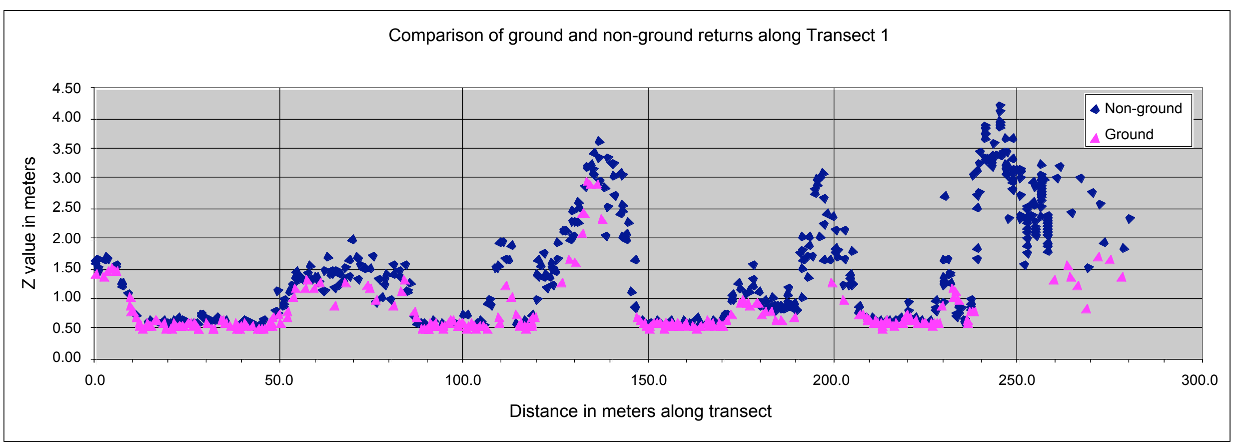


Figure 4. A scatter plot of Z values (elevation) along a 300m transect for ground returns (triangle markers) and non-ground (diamond markers) returns. The height of the non-ground returns corresponds to changes in vegetation along the transect; however, note that many points classified as ground returns in fact are returns from within the plant canopy.

vegetation is *Typha spp*., and from 105m to 145m the vegetation is *P. australis*. In general, *S. patens* is the dominant plant along the lowest four portions of the plot and *Typha* and *Phragmites* are the two higher classes. The vertical scatter of points within the *Typha* and *Phragmites* likely is the result of the increasing density from top to bottom of these plant communities. While some returns came from near the top of the plant canopy, others were able to penetrate into the canopy and were returned from the dense under story. As Figure 4 shows, it appears that no returns from the *Phragmites* or *Typha* actually were from the ground. This is consistent with the extremely dense nature of these communities seen in the field. We had hoped to be able to use the lidar ground returns to produce a bare-earth DEM and the non-ground returns to produce a "top" of canopy surface. However, it became obvious that many points that were classified as ground returns were in fact returns from within the plant biomass and therefore unsuitable to use to generate a ground surface. At approximately 135m along the transect, there were several lidar returns classified as ground returns that had Z values of close to 3m. While we did not have vertical benchmarks at any location within the study area, the marsh is essentially flat. It was estimated that the marsh surface varied by 0.5m or less across the entire area.

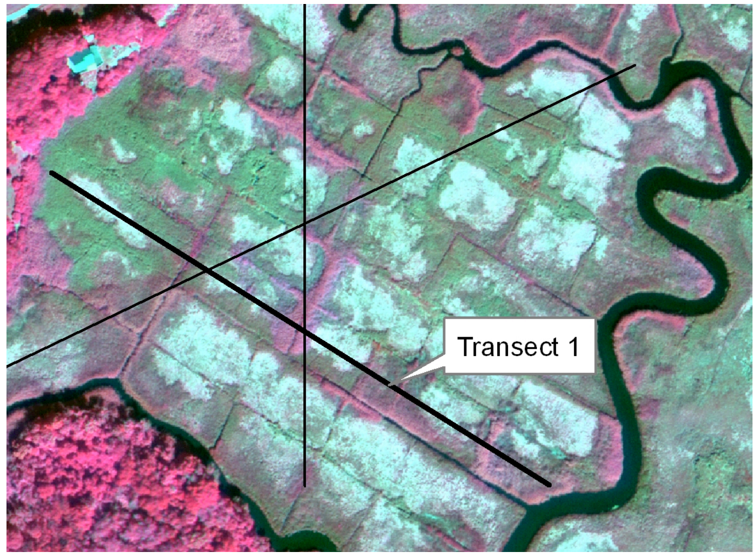


Figure 5 Transect 1 intersects each of the dominant plant communities. It is displayed on a 0.5m resolution ADS40 CIR image taken in September 2004. *Typha spp*. appear as the dark green areas, *S. patens* are the cyan colored patches and *P. australis* is found in the bright pink areas.

Polygon boundaries of relatively pure patches of *P. australis*, *Typha spp*. and *S. patens* and edge patches between *P. australis* and *Typha spp*. and between *Typha spp*. and *S. patens* were digitized in ArcGIS using ADS40 CIR imagery for reference. Interestingly, within the study area there were no clearly visible large edge patches where *P. australis* transitioned directly into *S. patens*. The polygons were manually classified based on visual interpretation and with the aid of a set of GPS field points, collected in the summer of 2005, which recorded dominant plant species information. Polygons were overlaid on the lidar points and all non-ground lidar point features were extracted into a dataset. Descriptive statistics for lidar Z values for each class of vegetation were generated using JMP statistical software. Values for relatively pure stands of *P. australis*, *Typha spp*. and *S. patens* and for the two edge patch classes are reported in Table 1. Frequency distributions and box plots of the same data are shown in Figures 6 and 7.

Table 1. Descriptive lidar Z statistics for vegetation patches in the study area.

	Count	Mean meters	Median meters	Standard deviation	Minimum Z	Maximum Z
P. australis	20780	3.0133	3.06	0.5210	-0.16	4.92
Typha spp.	9453	1.3670	1.37	0.2391	0.42	3.46
S. patens	13693	0.6390	0.63	0.0763	0.49	1.65
Phrag-Typha edge	2699	1.8124	1.81	0.7305	0.53	4.02
Typha-patens edge	1554	1.0337	0.98	0.3745	0.51	2.99

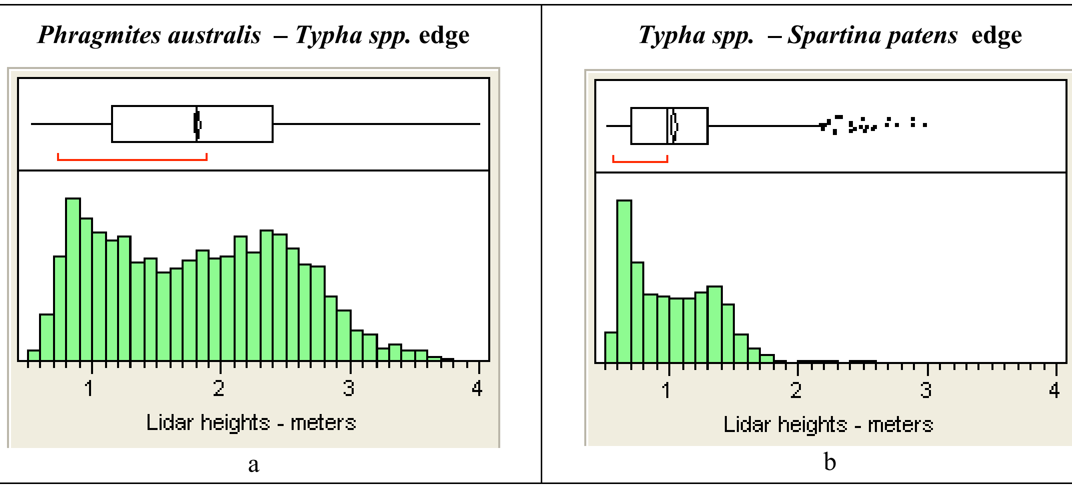
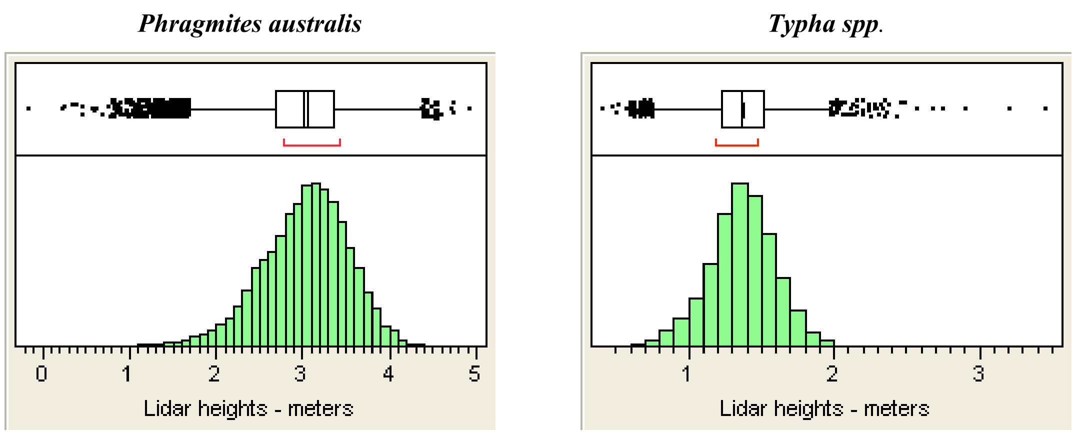


Figure 6. Histograms and box plots of lidar Z values for edge patches. The ends of the box plots are the 25th and 75th quartiles of the distribution; the straight line across the box is the median value; the diamond is the mean value; the tails indicate the upper and lower range of the distribution; the dots in 5(b) indicate possible outliers; and the red line shows the most compact 50% of the values. Note the difference in the shapes of the distributions from those of the of homogeneous plant patches as shown in Figure 7.



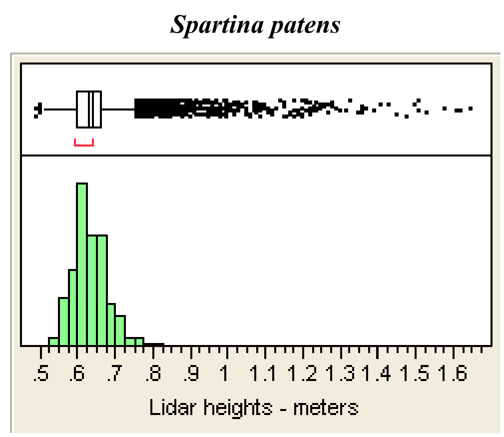


Figure 7. Distribution of lidar Z values for the three dominant plant communities. The box plots display "outliers" which represent returns that penetrate into the canopy in the case of the *P. australis* or that likely are from taller vegetation mixed in with the *Typha spp*. and *S. patens*.

Lidar point data for non-ground returns were converted to a grid layer using the ArcGIS 3D Analyst's natural neighbors interpolator. These data, shown as a shaded relief map in Figure 8(a), clearly show the 3D structure of the marsh vegetation in the study area. The *S. patens* patches appear as the smooth rectangular areas. The elevated areas surrounding the *patens* typically are *Typha spp.* and the areas that appear the tallest are patches of *P. australis.* The overall rectangular pattern of the marsh is a result of mosquito ditches that were dug to drain the marsh surface to reduce mosquito breeding habitat. This past management practice contributed to changes in marsh vegetation and provided a mechanism for *P. australis* to become established along ditch edges (Bart et al., 2006). The highly textured areas in the northwest and southwest corners of the map are upland areas outside of the marsh study site.

Figure 8(b) shows the grid data reclassified into 4 height groups; three which represent the dominant vegetation classes and the fourth group being upland areas outside the marsh. Vegetation class breaks were set at 2 standard deviations above the mean lidar heights for the 3 dominant plant communities (see Table 1).

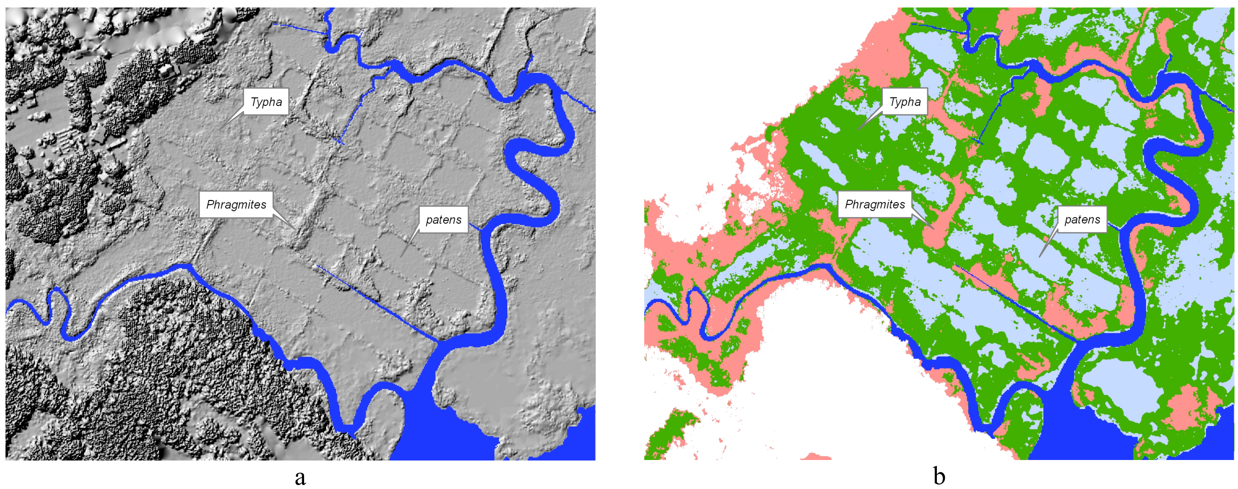


Figure 8. Shaded relief map of lidar generated vegetation canopy surface (a) and a grid reclassification of the vegetation canopy into 3 classes (b) that represent the general distribution of *P. australis, Typha spp*. and *S. patens*.

DISCUSSION

Preliminary work with the lidar data has demonstrated that it effectively can be used to help characterize plant heights for the three species of interest. Based solely on lidar non-ground returns, it is possible to discriminate among areas dominated by *P. australis*, *Typa spp.* and *S. patens*. Since we were unable to extract a bare-earth DEM from the lidar data, we were unable to use the data to measure actual plant heights and to map subtle changes in the marsh surface. It would be desirable to be able to extract this information; especially marsh surface elevations that can be used to help explain spatial changes in plant community composition and diversity. Nonetheless, the lidar data can be used to create an accurate representation of the plant canopy surface and the underlying community structure. The histograms of lidar non-ground returns for *P. australis*, *Typa spp.* and *S. patens* show very good separability with almost no overlap.

A visual comparison of Figures 5 and 8(b) show a strong correlation between the vegetation groups that can be seen in the ADS40 CIR image and the vegetation height classes created from the lidar data. Future image classification and field work will provide additional data with which we will assess the lidar data and its potential uses to improve classification.

FUTURE WORK

The next phase of the research will involve two activities; 1) extending the lidar analysis to the entire area of the Ragged Rock tidal marsh, and 2) segmenting lidar data and Quickbird imagery in eCognition and developing a rules-based classification hierarchy to produce more detailed and accurate vegetation maps of the marsh. Of particular interest will be assessing the degree to which mixed vegetation communities, typical of portions of the *S.*

patens dominated pans, can be identified through a combination of lidar and Quickbird data. We suspect that the lidar data may provide information on surface texture that could help identify mixed height vegetation communities that we have observed in *S. patens* meadows but that may not have unique spectral characteristics. Field work planned for the summer of 2006 will collect detailed vegetation data across the entire marsh. The goal of this work, which is being funded through a grant for the Connecticut Department of Environmental Protection, is to develop a complete floristic inventory (not just dominant species), to develop a vegetation community-based classification system and to prepare detailed maps of the marsh that will serve as validation data for lidar-image classification work. For this research we hope to be able to determine the extent that we can accurately identify and map dominant brackish tidal marsh plant communities and the level to which we can identify and classify subtle differences within and among more heterogeneous plant communities. Also to be collected during the 2006 field season, are vegetation data at 500 randomly generated point locations. These data will be used to conduct an accuracy assessment of the lidar-imagery classification work.

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