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APPLICATION OF DIGITAL MULTISPECTRAL IMAGERY TO LITTORAL ZONE SOIL AND ELEVATION MODELING *

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ABSTRACT

Four-channel digital multispectral imagery was acquired over Parramore Island, Virginia, USA, to characterize vegetation communities and model soil and elevation. An ability to remotely characterize soil conditions and elevation has important implications, especially where access to an area of interest is restricted or denied, field collection costs are prohibitively high, mapping completion times must be minimized, and safety is an over-riding concern. Flightlines extending from the open ocean to the bayside marshes were collected at approximately 1-meter ground spatial resolution. Detailed field data were acquired and used to statistically evaluate hypothesized relationships between vegetation, soil and elevation data. Upon review, statistics suggested there was association between these variables. Subsequent modeling of predicted soil type, soil compaction and elevation were tested and the results are quite promising for a barrier island environment. Image processing was used to remotely characterize the vegetation communities that served as the predictor variables for soil and elevation.

INTRODUCTION

PROJECT OBJECTIVES

The primary objectives of this study were to: 1) create an accurate vegetation cover map from high-resolution multispectral airborne imagery, and 2) create predicted soil type and elevation zone maps that were modeled from the relationships with vegetation classes. Data sources used in this effort included: multispectral airborne imagery, extensive field data characterizing vegetation and soils, and centimeter-level GPS information for precise elevation data capture. The results of the research are applicable to natural resource management of coastal zones and to military tactical concerns within the littoral zone.

SITE DESCRIPTION

The study site covered the northern portion of Parramore Island, Virginia. One of many barrier islands along the coastal side of the Eastern Shore of Virginia, the Parramore Island study site is approximately two kilometers wide and four kilometers long. The two primary landform zones found within the study area include the coastal beach zone and the dune ridge/valley complex. The coastal beach zone, located along the surf side (eastern edge) of the island is lacking in uniform vegetation cover. Frequent and seasonal storm events continually erode the boundary of the beach zone and the adjacent maritime forest/dune complex cover types. This heterogeneous transition area is characterized by dead and dying forest and shrub vegetation standing on highly mixed layers of sand and rack (i.e., debris). The dune ridge/valley complex is a successive system of longitudinally oriented upland, sandy dunes dissected by very wet marshes. This coastal geomorphology, common to many barrier islands throughout Virginia (McCaffrey and Duesser, 1990), is formed by the continuous impacts from wind and water. Parramore Island is slowly receding westward (toward the mainland) as a result of wave action, while coastal currents are rotating the island by eroding the southern tip and depositing sand at the northeastern tip (Scott, 1991). Parramore Island is part of the Virginia Coast Reserve (VCR), Long-Term Ecological Research (LTER) system.

IMAGERY ACQUISITION

High spatial-resolution multispectral images were acquired on 29 July 1998 with the Topographic Engineering Center's Computerized Airborne Multispectral Imaging System (CAMIS). This lightweight, portable airborne imaging system uses a four-camera CCD fitted with 25 nanometer bandpass interference filters centered at 450, 550, 650, and 800 nm. Each of the four progressive scan cameras acquires 8-bit frames with dimensions of 582 by 782 pixels. With an internal GPS receiver and an active antenna, the center pixel of each frame is tagged with a geographic coordinate. The CAMIS was flown in a Cessna 172. A total of 60 CAMIS frames were acquired over six east-west flightlines with 60 percent overlap and 30 percent sidelap. At an altitude of approximately 1920 meters agl, nominal spatial resolution was one meter. Post-processing of the frames included: radiometric corrections for vignetting, scene darkening, frame-to-frame histogram normalization, and creation of a mosaic. The mosaic was registered to a base map of Parramore Island using a 2^{nd} order polynomial transformation and 6 photo identifiable GPS points (RMSE ~ 10 m).

FIELD DATA COLLECTION

Detailed vegetation and soils characterization information were collected during May, August, and December 1998. Detailed descriptions of the species composition within the herbaceous, understory, and overstory layers were acquired using fixed-area plots. Soil compaction measurements, quantified in pounds per square inch (psi), were determined at successive 7.5 cm intervals from the surface to approximately 45 cm using a soil penetrometer. A qualitative soil description within each plot provided information concerning depth and character of the organic layer, the A horizon, and the underlying sand. Three representative soil compaction and soil description samples were acquired at each plot location. Centimeter-level differentially corrected GPS positions were also recorded at each plot.

RESULTS

FIELD DATA DESCRIPTIONS

Vegetation Data

The bay-side salt marsh community was characterized by both the tall and short forms of smooth cord grass (*Spartina alterniflora*). These areas along the western shore of Parramore Island are tidal and are therefore regularly inundated. The valleys within the dune complex support a different species of cord grass (*Spartina patens*). These areas are less influenced by daily tides. Homogenous stands of cattails (*Typha angustifolia*) were also recorded within the inland marshes. The ridges within the dune system support maritime forest dominated by loblolly pine (*Pinus taeda*), with a less frequent codominant component of black cherry (*Prunus serotina*), southern red cedar (*Juniperus silicola*), and holly (*Ilex opaca*). The transition zone between the low, inundated cord grass marshes and the sandy forest ridges include two distinct shrub/scrub vegetation communities. The low density shrub type is characterized by the presence of low (< one meter) to moderately (~ two meters) high, widely spaced marsh elder (*Iva frutescens*) and groundsel-tree (*Baccharis halimifolia*). The herbaceous component of the low density shrub community includes cord grass and cattails. The high density shrub community is characterized by the transition of the elder and groundsel-tree to taller (> two meters) and more closely spaced wax myrtle (*Myrica cerifera*). As the shrub canopy becomes more dense the herbaceous layer of cord grass and cattails disappears. Widely scattered patches of reed (*Phragmites australis*) exist at the transition zone between the marshes and the shrub/scrub communities. With dense stands to three meters in height, the homogenous reed vegetation type has no associated codominant species and a sparse to absent herbaceous layer of cord grass. Greenbrier (*Smilax spp.*) is common within both the shrub/scrub and maritime forest communities and in some areas within the shrub types has covered the woody vegetation to become the dominant species. Dune grasses (*Ammophila spp.*) exist within the coastal dunes of the sandy beach zone. The above description of the species compositions suggests eight distinct vegetation communities, compiled from a field data set with 78 records compiled from three (May, August and December) 1998 sample periods. Vegetation classes include:

1. *Spartina alterniflora* – smooth cord grass,
2. *Spartina patens* – cord grass,
3. *Typha angustifolia* – cattail,
4. *Phragmites australis* – reed,
5. *Ammophila spp.*- dune grasses,
6. *Iva frutescens* and *Baccharis halimifolia* – low density shrub/scrub,
7. *Myrica cerifera* – high density shrub/scrub, and
8. *Pinus taeda* – maritime forest.

The vegetation data were rank ordered from the short marsh cordgrasses through to the drier dune grasses, into the transitionary shrub/scrub communities, and ending with the maritime forest community. Rationale for ranking vegetation classes came from an estimate of percent cover differences within the classes and observed patterns of vegetation spatial behavior between the classes.

Soil Data

The soil observations from each plot, including the qualitative descriptions and the quantitative soil compaction measures were analyzed. Four unique soil categories were defined, including:

1. Saturated, fibrist and saprist epipedon surface over a saturated grayish sand, with no

A horizon; low to very low soil compaction,

2. Moist to very moist to saturated histic epipedons and highly decayed organic surface, over variable A horizon (2 to 8cm), over a moist to very moist grayish sand; moderate soil compaction,
3. Dry to moist surface duff over a well defined A horizon (5 to 15cm) over a dry brownish sand; moderate to high soil compaction, and
4. Heterogeneous beach sand composed of random layers of unconsolidated sand and various types of vegetation litter.

Soil class data were rank ordered from the wet Class 1 to the dry Class 3 soil. The unconsolidated dry beach sands were placed in Class 4. Qualitative assessments of soil moisture to contributed to the assignment of soil class.

Soil compaction measurements at each sample site were averaged for each 7.5 cm depth interval. The mean compaction measures were then placed into 21 discrete classes, with each class representing a range of 20 psi. The compaction classes were ranked from Class 1 (0 to 20 psi) to Class 21 (400 to 420 psi).

Elevation Data

GPS data were subdivided into three elevation classes, with elevation class breaks defined by vegetation zones delineated through the analyses of the field data. The maximum elevation value from the low density shrub/scrub class (1.68 m) was chosen as the high elevation range for elevation Class 1. Elevation class 1 represents the elevation range for vegetation classes 1-4 and 6. The minimum elevation from vegetation class 8, maritime forest, was chosen as the low value for elevation Class 3. Field data supports inclusion of dune grass, vegetation class 5, within elevation Class 3. Lastly, elevation Class 2 includes only vegetation class 7, the high density shrub/scrub, and is defined by the high elevation value of Class 1 and low elevation value of Class 3. Selection of three elevation classes was intended to coincide with the three field observed primary vegetation ecosytems (marsh grasses, shrub/scrub community, and maritime forest). Elevation classes assigned:

1. less than 1.68 m,
2. between 1.68 - 1.98 m, and
3. greater than 1.98 m.

STATISTICAL ANALYSIS

Statistical Techniques

Discrete classes assigned to vegetation zones, soil types, soil compaction ranges, and elevation zones were analyzed using lower order statistical tests. Continuous elevation data were analyzed with higher order statistics. The critical test for this research was assessing the association of the vegetation classes with the soil characteristics and elevation zones. Gamma rank correlation tests were used with the understanding that vegetation, soil, and elevation class data variables were rank ordered (i.e., ordinal). Gamma is a probability value computed as the differences between the probability that the rank ordering of two variables agree minus the probability that they disagree, divided by 1 minus the probability of ties (Statistica, 1995). A second test was Cramer's V, designed specifically for unequal contingency tables of nominal categorical terrain data. A more thorough discussion of Gamma and Cramer's V algorithms can be found in Sokal (1995) and Barber (1988).

Vegetation Association With Soil Type

Gamma coefficient of the measure of association between ordinal vegetation classes and soil classes was 0.9034. Cramer's V coefficient was 0.8436. For each test, 84 test data points were evaluated. These measures of association regard vegetation as a strong predictor of expected soil type.

Vegetation Association With Soil Compaction

Cramer's V tests reported moderate to moderately high associations for 7.5 through 45.0 cm depths (Table 1). The total number of sample points tested varied from 69 to 42 for the deepest depths. Statistical test results suggest there is moderate confidence in predicting soil compaction at depths between 7.5 and 45.0 cm within the barrier island complex.

Vegetation Association With Elevation

Gamma coefficient between vegetation classes and continuous elevation data was 0.60. This indicates a moderate measure of association between elevation and the vegetation class. Vegetation Classes 1, 2, 3, 4, and 6 exist at similar elevations in the barrier island environment. The total range in elevation within these five vegetation classes is 1.40 to 1.68 meters. As expected, low density shrubs are found at the high end of this elevation range while grasses and marsh species grow at the lowest elevations. The gamma statistic for elevation classes compared to vegetation classes was 1.00. Thirty-five out of 36 field data sample plots were perfectly correlated between vegetation and elevation class. Only a high density shrub sample plot grew within elevation class 1. This outlier plot is at the transition between elevation classes 1 and 2. Given that the delineation of the vegetation classes determined the defined elevation zones, a perfect correlation is expected.

Table 1. Vegetation Statistical Association with Soil Compaction Rate

Soil Depth	*N*	*Cramer's V*
Surface	69	0.322
7.5cm	69	0.405
15.0 cm	69	0.388
22.5 cm	69	0.492
30.0 cm	69	0.574
37.5 cm	42	0.618
45.0 cm	42	0.734

IMAGE PROCESSING AND ACCURACY ASSESSMENT

The CAMIS mosaic was processed using commercially available image processing software. A supervised classification approach was applied to produce a vegetation map. The vegetation thematic classes were then recoded to compile predicted soil and elevation maps (Table 2). All three products were tested for accuracy. Accurate delineation of vegetation communities was considered critical for predicting soil conditions and elevation classes.

Table 2. Vegetation Recoding Scheme

Vegetation Class	*Soil Class*	*Elevation Class*
S. alterniflora	1	1
S. patens	1	1
Typha	1	1
Phragmites	2	1
Dune Grasses	4	3
Low Density Shrub/Scrub	2	1
High Density Shrub/Scrub	2	2
Maritime Forest	3	3

Of the 57 field points tested, 38 were identified correctly (Table 3). Delineation of *Typha spp*. and *Phragmites spp*. with high resolution imagery holds promise for the monitoring of invasive species. There was difficulty in separating high density shrub/scrub communities from the adjacent low density shrub/scrub and maritime forest. The overall vegetation classification accuracy measure was 67 percent, with a Kappa coefficient of 0.60.

Classification inaccuracies resulted from several sources. First, the CAMIS image mosaic was not accurately geographically registered. Therefore, field plot locations were not accurately located across the image. Second, field data were purposely collected at the transition points between the identified ecotones. Therefore, a slight misregistration of the sample site could result in an incorrect class assignment. Lastly, most classification errors arose in the highly heterogeneous geographic area closest to the beach zone. This dynamic environment is subject to extensive sand and saltwater intrusion, dying trees and snags, and exhibits high spectral variability.

Table 3. Vegetation Classification Accuracy Matrix

Vegetation Class	1	2	3	4	5	6	7	8	TOTAL	Commission Error
1. *S. alterniflora*	2	0	0	0	0	0	0	1	3	0.67
2. *S. patens*	0	13	0	0	0	3	1	0	17	0.76
3. *Typha spp.*	0	1	3	1	0	0	1	0	6	0.50
4. *Phragmites spp.*	0	0	0	2	0	0	0	0	2	1.00
5. Dune Grasses	0	0	0	0	3	0	0	0	3	1.00

6. Low Density Shrub/Scrub	0	0	2	0	0	6	2	0	10	0.60
7. High Density Shrub/Scrub	0	1	0	1	0	3	5	2	12	0.42
8. Maritime Forest	0	0	0	0	0	0	0	4	4	1.00
TOTAL	2	15	5	4	3	12	9	7	57	
Omission Error	1.00	0.87	0.60	0.50	1.00	0.50	0.55	0.57		*0.67

*Overall Accuracy

Classification accuracy for the predicted soil and elevation maps are shown in Table 5. Figure 1 displays the predicted soil types and elevation zones.

Table 5. Soil and Elevation Accuracy

Variable	*Sample Size*	*Kappa Coefficient*	*Overall Accuracy*
Soil Classes	21	0.6200	0.76
Elevation Classes	38	-0.0084	0.50

Classification accuracy of soil type outside the dynamic beach zone was always correct. Overall accuracy is expected to improve with additional mosaic geometric control and an increased sample size. Classification accuracy of the elevation zones were low. Given that Gamma and Cramer's V statistics suggested that vegetation class is an adequate predictor of elevation zone, the poor classification accuracy is likely the result of inaccurate field plot registration within the rectified imagery.

CONCLUSION

This research effort successfully acquired and post-processed high resolution multispectral imagery over a dynamic coastal study area. The overall accuracy of the vegetation class map was encouraging. The moderate thematic accuracies of predicted soil and elevation class maps suggest that terrain information can be modeled using vegetation classes as predictors. Additional field data collection is required to strengthen the relationship between vegetation composition and soil characteristics, including both soil type and soil compaction. Improved field sampling will also verify the relationship between vegetation type and subtle changes in the micro-relief throughout the Parramore Island study site. Accuracy assessments of the map products require a significant increase in the number of field plots to satisfy statistical constraints. Finally, geometric registration of the image mosaic must be improved.

Additional research will address development of a model to estimate a maximum elevation value for Class 3 that supports dune grasses and maritime forest. Studies will evaluate existing sand dune development models (Cooke et al, 1993). The hypothesis is that dune crest height is proportional to total dune length, with length measured as the width of maritime forests having greater than 50 percent canopy cover. Incorporation of image classification rules adopted from field and laboratory knowledge will also be pursued.

Figure 1. Predicted Soil and Elevation Data

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