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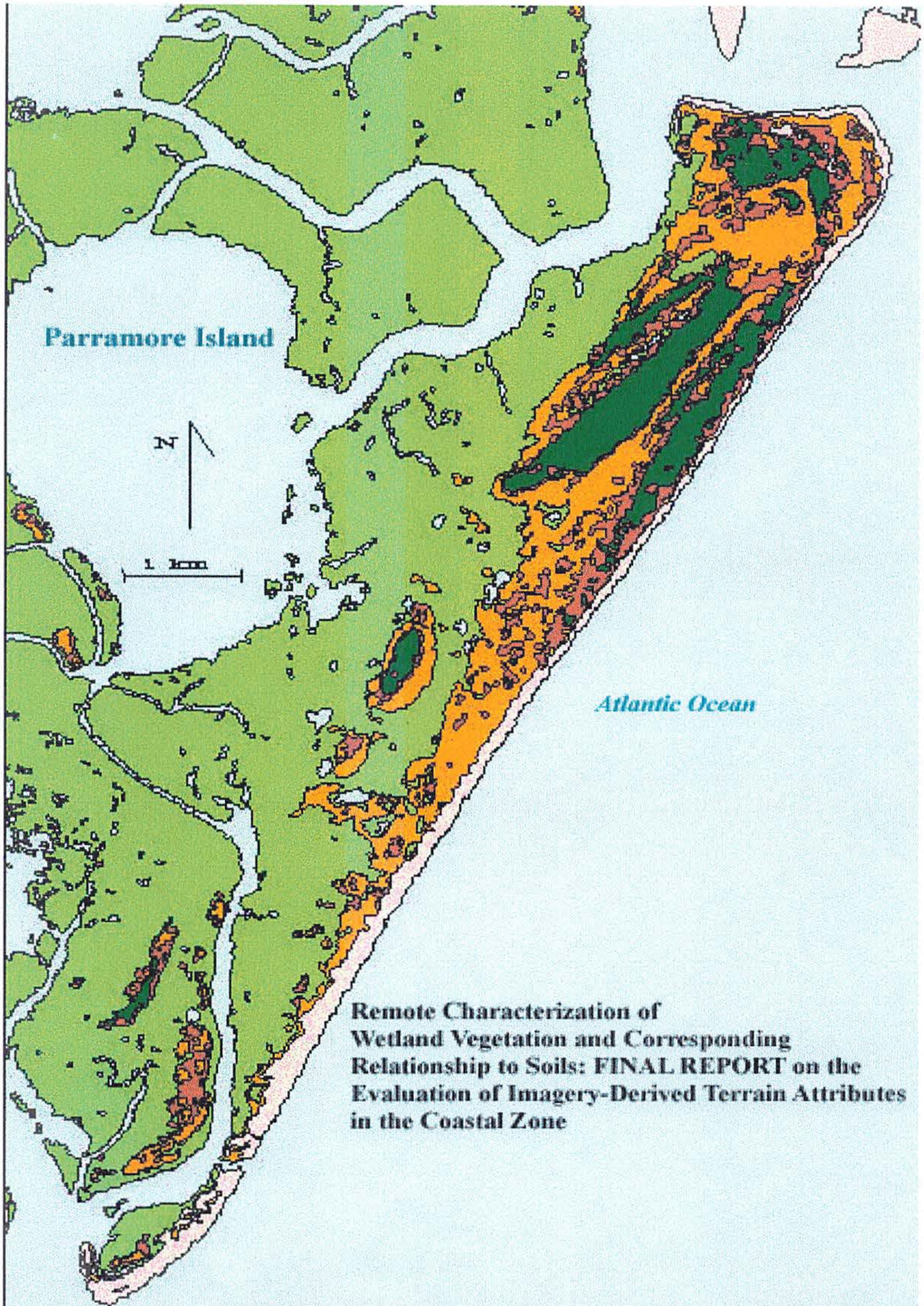
Remote characterization of wetland vegetation and corresponding relationship to soils : final report on the evaluation of imagery-derived terrain attributes in the coastal zone

John E. Anderson
Virginia Institute of Marine Science

James E. Perry
Virginia Institute of Marine Science

Jill Meyer
Virginia Institute of Marine Science



Remote Characterization of Wetland Vegetation and Corresponding Relationship to Soils: FINAL REPORT on the Evaluation of Imagery-Derived Terrain Attributes in the Coastal Zone

Remote Characterization of Wetland Vegetation and Corresponding Relationship to Soils: Final Report on the Evaluation of Imagery-Derived Terrain Attributes in the Coastal Zone

Submitted by

John E. Anderson, Principal Investigator
James E. Perry, Co-Investigator
Jill Meyer, Graduate Student VIMS

College of William and Mary
Virginia Institute of Marine Science
Coastal Ecosystems and Remote Sensing Program
Gloucester Point, Virginia 23062

for

Battelle Scientific Services Program
Research Triangle Park
200 Park Drive, Suite 211
Research Triangle Park, North Carolina 27709

and the

U.S. Army Topographic Engineering Center
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ACKNOWLEDGMENT

This work was supported by the Topographic Engineering Center (Mr. Kevin Slocum) under the auspices of the U.S. Army Research Office Scientific Services Program administered by Battelle (Delivery Order 190, Contract No. DAAHO4-96-C-0086. Additionally, the Virginia Institute of Marine Science's Coastal Ecosystem and Remote Sensing Program would like to thank the Nature Conservancy and especially Mr. Barry Truitt for allowing the use of Parramore Island as the site for this research project. We would also like to acknowledge the support of the VIMS Eastern Shore Lab at Wachapreague, Virginia for providing lodging and vessel support to the island.

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INTRODUCTION

The development of high spatial and spectral resolution sensors is allowing more detailed information to be gathered about the Earth's surface and with this information are needed basic field data that provide the relationship between segments of the terrestrial and aquatic landscape. For military operations, it is becoming increasingly important to have not only the type of terrain identified, but some understanding as to the ecological mechanisms that can serve as assets or liabilities during a conflict. In addition, military base resource managers require ecological data to make land-use decisions about sensitive training lands.

Study Objectives

Commanders as well as military resource specialists are interested in how the terrain functions as a system. Many ecological attributes of the landscape are well understood and can be used as effective terrain information for military operations. The objectives of this study were to investigate the relationship(s) between vegetation and soils and explore an initial method for predicting terrain conditions for mobility through a coastal environment for the U.S. Army Topographic Engineering Center (TEC). In the coastal zone, vegetation occurs as a major component in the field-of-view of an optical remote sensing system. By identifying broad monospecific vegetation types, and by applying basic ecological rules, a confident indication as to soil conditions should be able to be concluded. Knowledge of these attributes is extremely important in both military operations and base ecological management.

Methods

To accomplish the goals of this study, a pristine coastal barrier island environment was selected that was free from influences of urban development. This provided the optimal situation that could be expected to be encountered by military strategists and base resource managers. The site selected was Parramore Island (Figure 1). Parramore Island is the seventh island (north to south) located on the seaward margin of the southeastern Delmarva Peninsula and is one of the most dynamic and least disturbed coastal landscapes remaining in North America (McCaffrey and Dueser, 1990). The island is centered at Latitude 37° 30' and Longitude 75° 40' and is owned by the Nature Conservancy and managed as part of the Virginia Coast Reserve. The island is also included in the National Science Foundation's Long Term Ecological Research Reserve System (LTER).

Parramore Island offers the ideal ecological zonation associated with upland, wetland, and

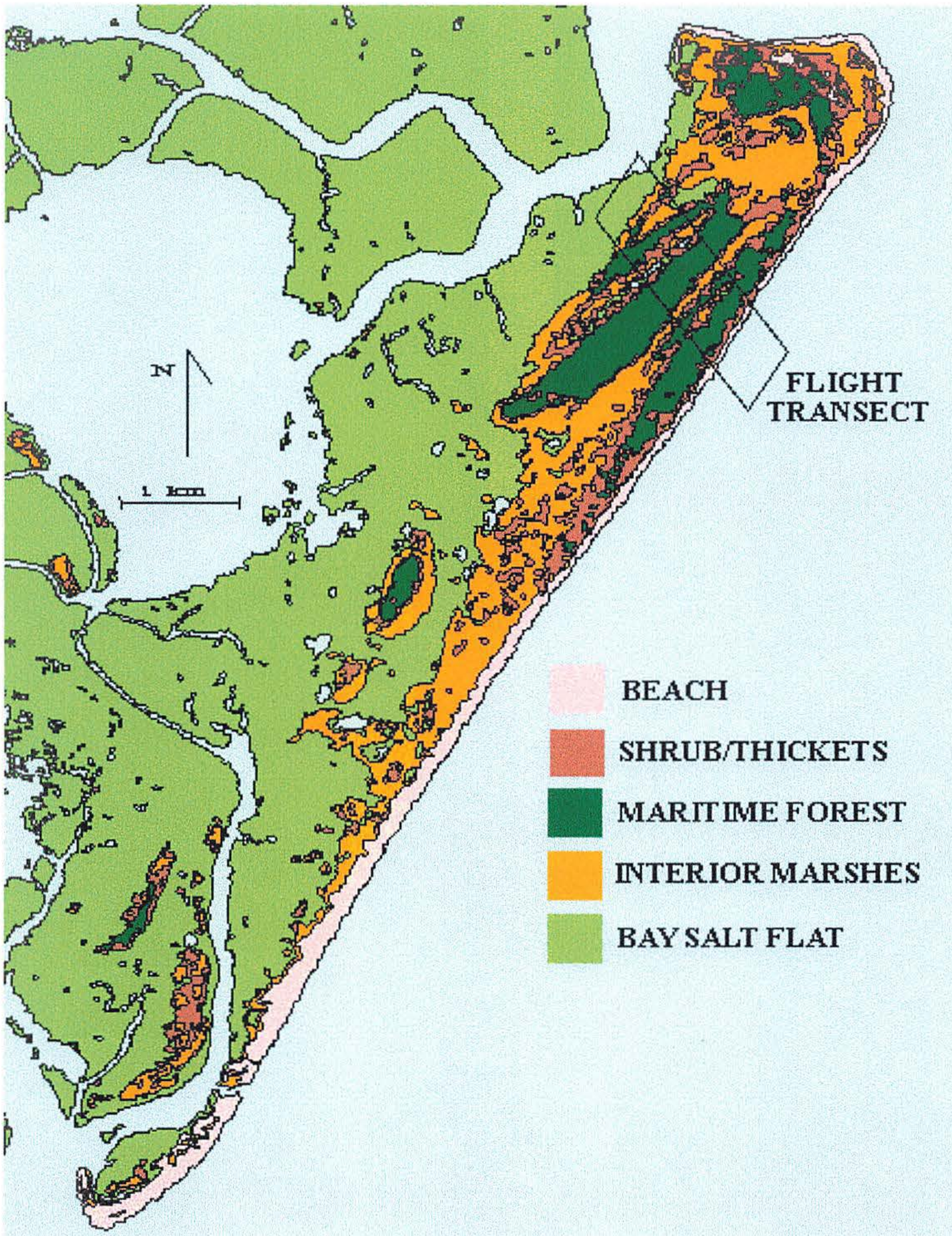


Figure 1. LTER Map of Parramore Island and Study Area (within Flight Transect box).

aquatic environments that occurs on the coastal barriers. It is this zonation that serves as the basis for models that relate vegetative cover to soil conditions in this study. Each of these zones is a specific mapping unit which contains specific vegetation and soils attributes driven by topographic and hydrologic mechanisms influenced by landscape position. On Parramore, the zonation from the ocean to the bay is as follows:

Beach - non-vegetated tidal margin with storm rack and drift material.

Interior Dune Ridge - vegetation dominated by *Pinus taeda* with dense areas of *Myrica cerifera* and *Iva frutescens* mixed on the transition margins.

Interior Freshwater Marshes (< 1 °/₀₀) - characterized by *Spartina patens* (salt marsh cordgrass) and *Typha angustifolia.*

Interior Brackish Marshes (1-18 °/₀₀) - characterized by *D. spicatum* and *S. patens* with *I. frutescens.*

Maritime Forest - characterized by mixed species small hardwood trees and tall shrubs forming a dense topographically low woodland of *M. cerifera, P. paustris, Smilax spp., R. radicans, Juniperus virginiana.* Minor species on Parramore include *Acer rubrum, Ilex spp., Liquidamber styraciflua.*

(Bay) Salt Flat (>40 °/₀₀)- characterized by tall and short form *S. alterniflora* and *Salicornia virginica.* These areas are exposed by tidal fluxes and present uniformly dark-toned areas dominated by hard sand and peat as well as crusts associated with sulfur bacteria.

This study concentrated data collection in each of these zones. Ecological variables sampled included vegetation, soil, soil compaction at depth, elevation (by TEC), spectral reflectance, salinity, digital imagery acquisitions, and well hydrology by tide gage (in three zones). Hydrologic monitoring was continuous, but the other variables (excluding imagery) were sampled during two specific data collection periods. These periods were April 1998 and August 1998. A sampling and verification exercise was performed in early December 1998 by TEC.

Image acquisitions were performed by VIMS and TEC in February 1998, August 1998, and September 1998. Imagery data collection was plagued by poor weather and uncooperative instrumentation. The September mission was with TEC's CAMIS system which was deployed to acquire data for the entire island. Due to weather conditions the August mission did not produce good quality data. In addition, the TEC digital multispectral video system operated by VIMS only acquired data along the sample transect through the middle of the island. Both systems were configured with the same spectral bandpasses (450nm, 550nm, 650nm, and 800nm @ 25nm wide) and all imagery was acquired to achieve .5 and 1 meter pixel ground sample distance (GSD). The goal of acquiring two resolutions was to facilitate comparisons of vegetation classes and image DNs across resolutions; however, only the September 1998 scene produced imagery values that were close to the collection time (August 1998) for the field data. This allowed only one analysis to be performed using field and imagery data.

Due to the small size of the data set and limited number of variables, the data analysis procedure selected to determine the relationships between the variables was indirect, multivariate ordination using principal components analysis (PCA). Following Sokal and Rohlf (1981) and Manly (1994), PCA was applied using the field and imagery data to establish patterns of relationships that could be used effectively to predict terrain conditions. The objective behind standard PCA ordination for ecological analysis is to analyze a series of (usually highly correlated) variables and find combinations of these to produce indices that are uncorrelated. The lack of correlation permits the measure of different dimensions in a given data set where variance is ordered so that the largest amount of variation in a set of variables is represented by the first and second principal components. When plotted, the resulting PCAs should reveal patterns and distributions of the data that explain the relationships between certain variables. This study produced PCAs for the April 1998 and August 1998 data collection periods.

TECHNICAL DISCUSSION BY ORDER OF TASK

Task A. Spectral Data Collection for Major Plant Communities

Field spectral reflectance measurements were acquired during April 1998 and August 1998 on major plant communities, soils, and open water features. Procedures followed Satterwhite and Henley (1990) for the collection of spectroradiometric data. Spectral data was recorded using an ASD PS II field spectroradiometer at a distance of 1 meter above the target of interest between 1000 and 1400 local solar time. A Spectrolon standard was used to calibrate the radiometer and a bubble level was used to maintain a nadir viewing angle. The instrument recorded a continuous spectrum from 350nm to 1100nm. The instrument has steep data fall-offs due to noise from 350nm to 400nm and from 950nm to 1100nm. Spectral data collected from both periods are included in Appendix A of this report. In addition, during both data collection periods, weather posed a problem and limited the number of spectra generated; however, spectra for all major plant communities relevant to the study were obtained. Of the two sampling periods, April produced the best spectra. The August data suffers from scattered high clouds and haze that developed in the area after 1100 local solar time. Unfortunately, use of the spectral data to calibrate the image data to reflectance units could not be performed since imagery missions and field missions did not successfully coincide. In addition, the ground spectra was not used in the PCA analysis as originally planned due to the limited data set.

Figure 2 provides a reflectance comparison for some of the major vegetation and soils features on Parramore Island acquired during the April 1998 collection. Each of these signatures represent vegetation communities that occupy the following zones:

Vegetation Type	Zone
S. alterniflora (Tall Form)	Bayside Tidal Flats
S. patens	Interior Brackish Marsh
P. taeda	Italian Ridge Dune (Highest Elevation)
T. angustifolia	Interior Freshwater Marsh

As presented in Figure 2, the separability of these vegetation types is most pronounced in the near infrared region (760nm - 800nm). As applied to imagery data, the unique canopy morphological configurations identified among these vegetation types, and the contribution of the understory (e.g., water or soil components), makes the near infrared the most effective spectral region to differentiate the communities.

Task B. Imagery Data Collection

Imagery data was successfully acquired during February 1998 (winter) and September 1998 (summer) missions. The February mission was flown by VIMS using the TEC DMSV configured with 25nm wide bandpass interference filters centered at 450nm, 550nm, 650nm and 800nm. Two flight lines were acquired along the sample transect through the mid section of the island. Imagery was collected at two altitudes to produce data sets at .5 meters/pixel ground resolution and 1 meter/pixel ground resolution. Figure 3 presents an example of the DMSV February mission at .5 and 1 meter ground sample distance showing areas of *S. alterniflora*. Imagery in the same spectral wavebands was acquired by the TEC CAMIS system in September, providing a summer data set. Figure 4 presents the CAMIS data showing the main sampling area through the island as well as indicating (white box) areas of bayside *S. alterniflora*.

The acquisition of the image data at two resolutions provided imagery statistical information on the vegetation communities. A 5X5 window was used to extract mean digital numbers (DNs) for samples of vegetation in each zone. These numbers were used as input to the PCA analysis to test the strength of a prediction model whereby imagery (spectral) signatures could be used to identify specific vegetation types and therefore be used to infer soil condition.

Spectral Reflectance Data
Parramore Island
April 1998

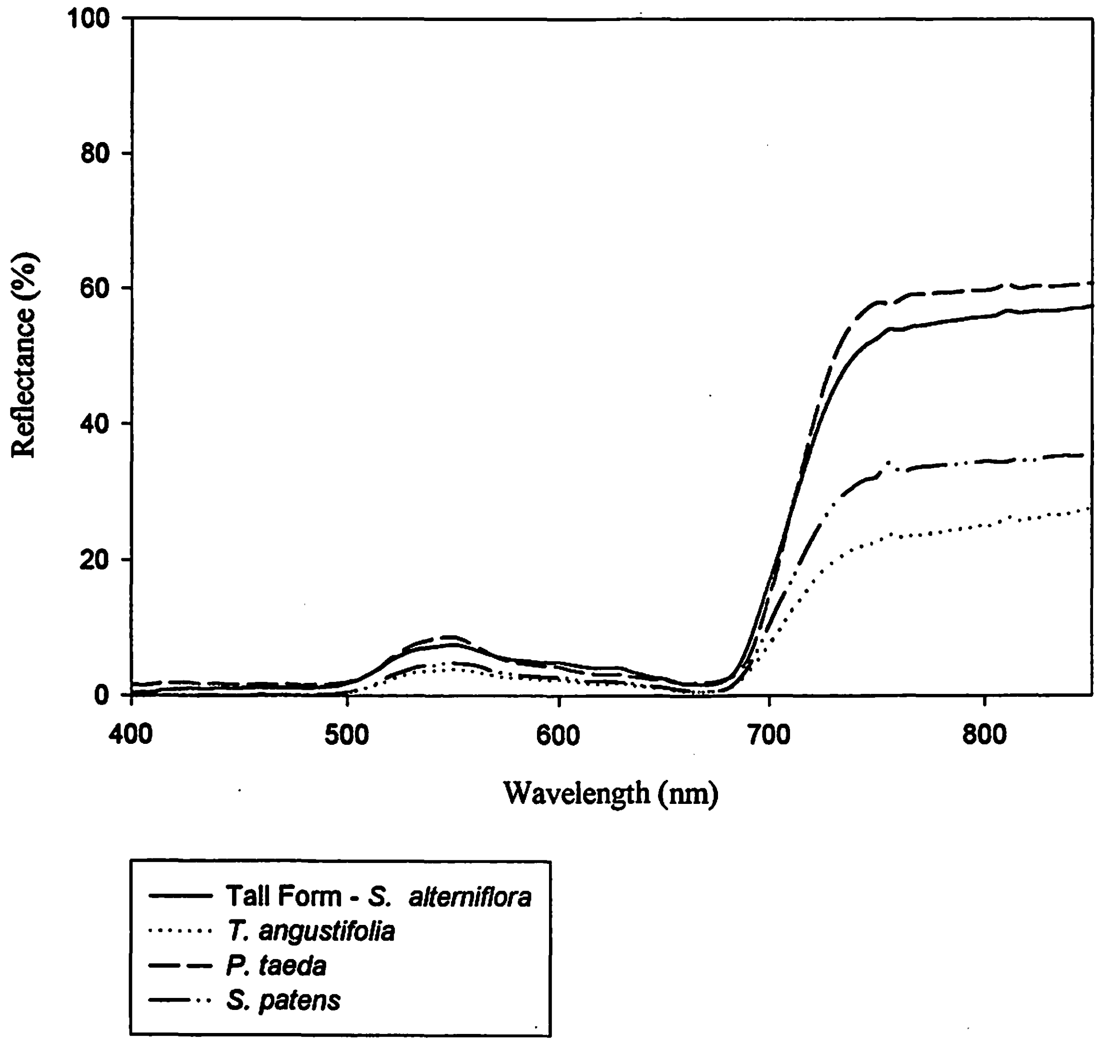


Figure 2. Spectral reflectance data for major vegetation types at Paramore Island.

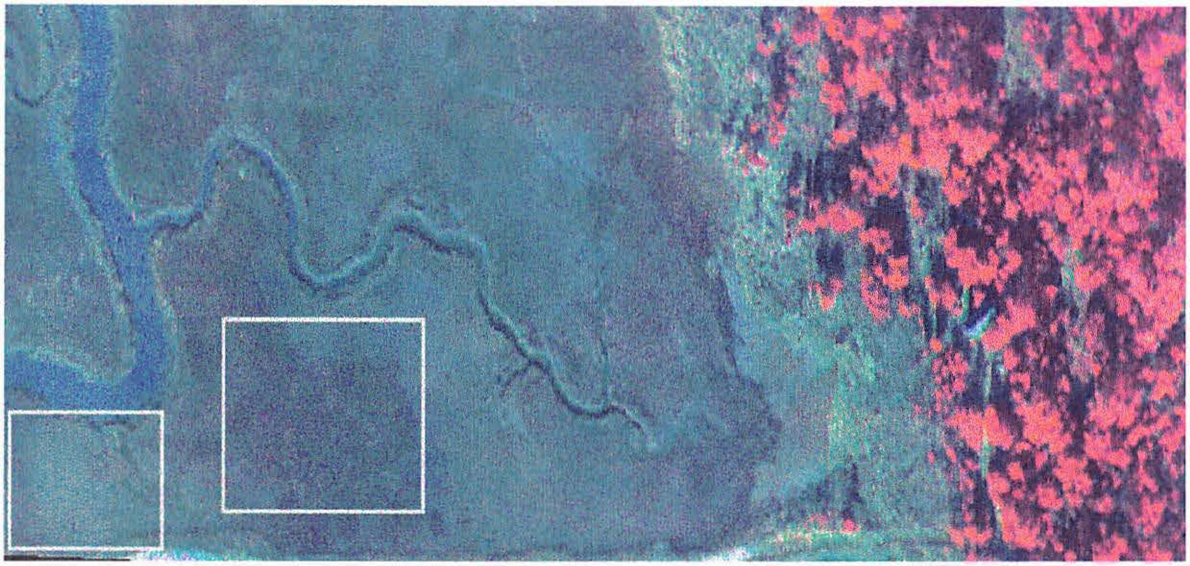


Figure 3. .5 meter GSD digital multispectral video image at two resolutions showing bayside *S. alterniflora* tall (left box) and short (right box) forms.

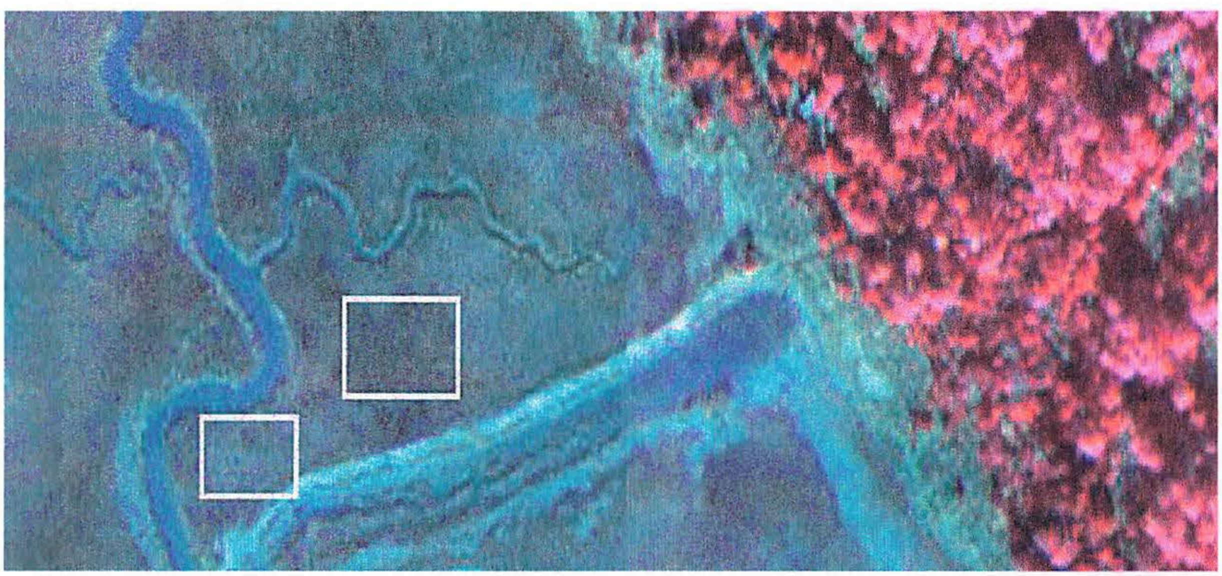


Figure 3. 1 meter GSD digital multispectral video image at two resolutions showing bayside *S. alterniflora* tall (left box) and short (right box) forms.

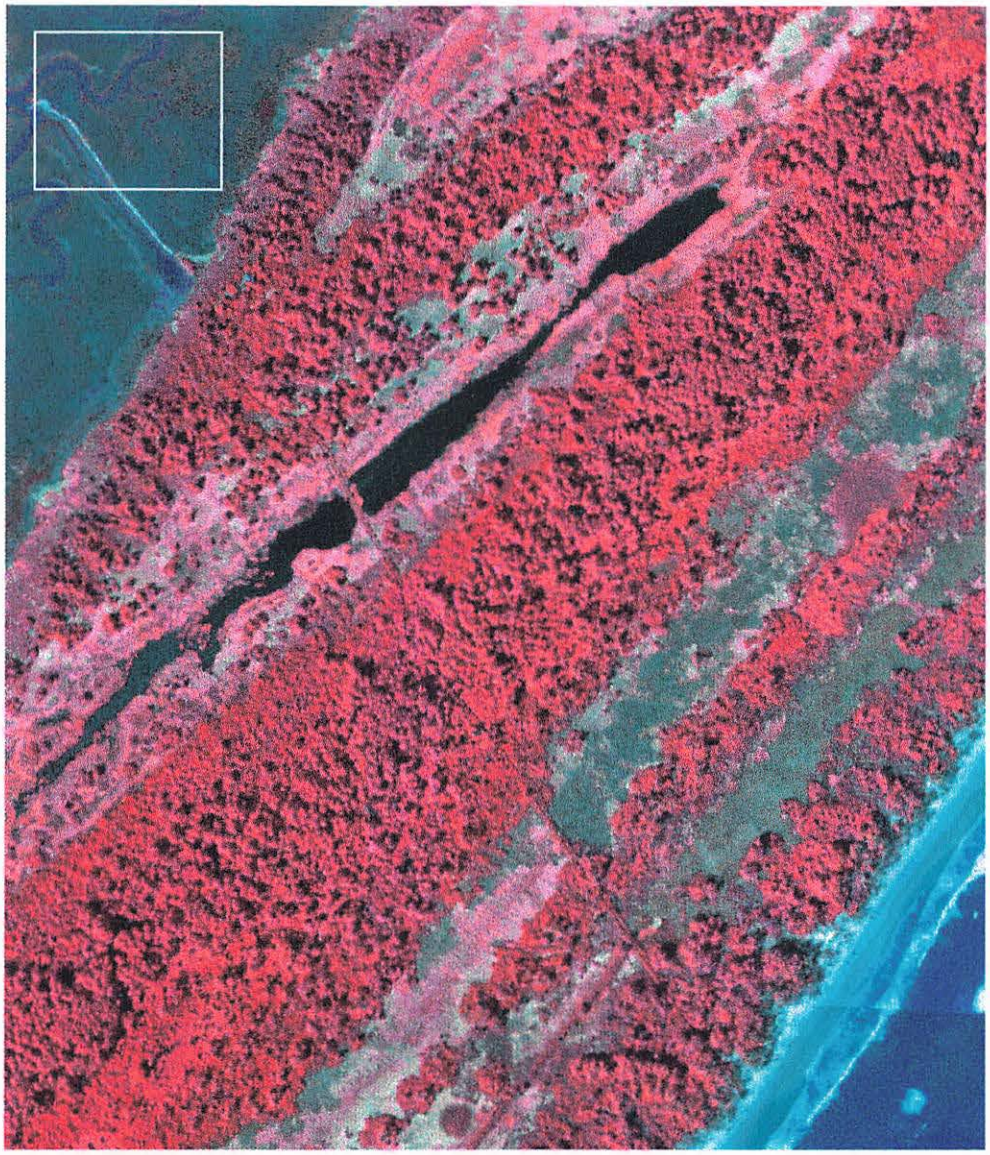


Figure 4. CAMIS multispectral video image showing bayside *S. alterniflora* and sample area. Image date is September 1998.

Task C. Comparison of Spectral Signatures of Known Local "Ecotypes"

Of the vegetation communities analyzed at Parramore Island, *S. alterniflora* offered an example of a single species having different, but separable, (near infrared) signatures. The bayside salt flat is dominated by short form (17-25cm in height) *S. alterniflora* (cord grass) interspersed with *Salicornia virginica*. The occurrence of this short form cord grass is indicative of a low energy wave environment subject to intermittent flooding events that increases soil salinity. Stands of short-form *S. alterniflora* were dense on Parramore Island and occupied firm organic substrates. At lower elevations, where innundation periods from tidal fluxes are longer, the less dense, tall form *S. alterniflora* occurs. The tall form is typically 90cm-160cm in height and occupies fine-grained, mucky sediments.

Figure 5 provides a comparison of the spectral reflectance difference between tall and short form *S. alterniflora* collected in April 1998. Figure 6 illustrates the spectral difference between both vegetation forms using multispectral imagery in the near infrared at 800nm acquired during the February and September 1998 missions. Seasonal variability is indicated between both scenes where vegetation senescence in the February scene produces darker signatures for both community types. This is due mainly to exposed wet organic soils contributing to the reflectance signature from reduced canopy biomass. Higher vegetation reflectance is observed in the September imagery at the peak of the growing season when canopies are most dense. However, in each case, both the tall and short form *S. alterniflora* is separable. From a mobility standpoint, the difference between each vegetation type is important. Traffic through short form *S. alterniflora* will typically encounter "drier" soils that will support more weight than areas occupied by tall form *S. alterniflora*. Soils compaction tests in areas of both tall and short form recorded values of 5 lb/in^2 and 15 lb/in^2, respectively (Slocum et al., 1998).

Task D / E. PCA Ordination on Sampled Ecological Variables

Indirect gradient analysis using PCA ordination allowed the analysis of relationships between the input variables vegetation, surface soil materials, elevation, and imagery reflectance. PCAs were developed for the two data collection periods in April 1998 and August 1998 using the ecological data only. Three additional PCAs were developed that considered imagery reflectance (DN) samples at the two resolutions acquired (.5 meters and 1 meter GSD). Tables 1 and 2 provide information regarding the plot identification number and corresponding vegetation type code. Each table represents data codes recorded by TEC for April 1998 and August 1998, respectively. These tables are meant to serve as legends when examining the PCA data plots, which only record the site identifications numbers (plot ID) and not the associated vegetation

Spectral Reflectance Data
Parramore Island
April 1998

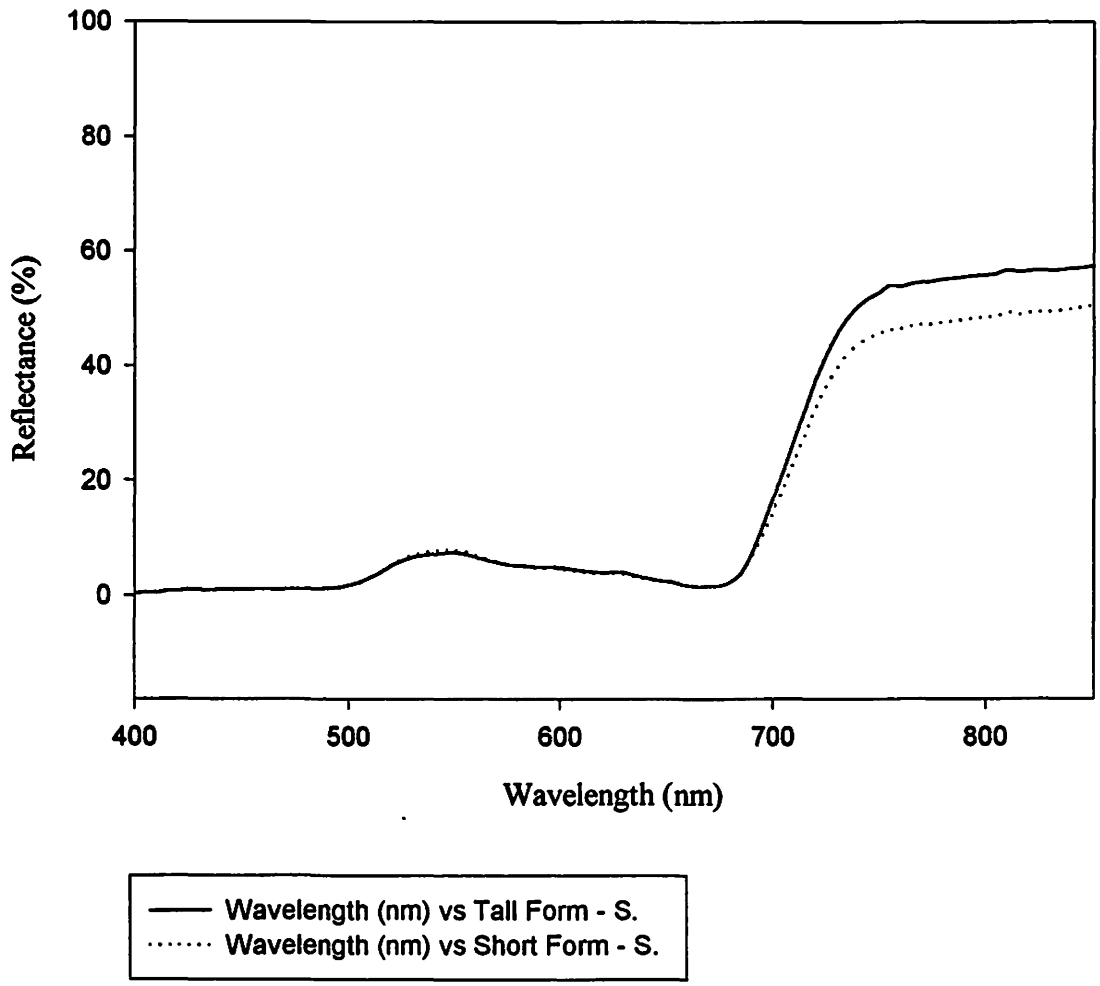


Figure 5. Comparative spectral reflectance of tall and short form *S. alterniflora* acquired during the April 1998 data collection.

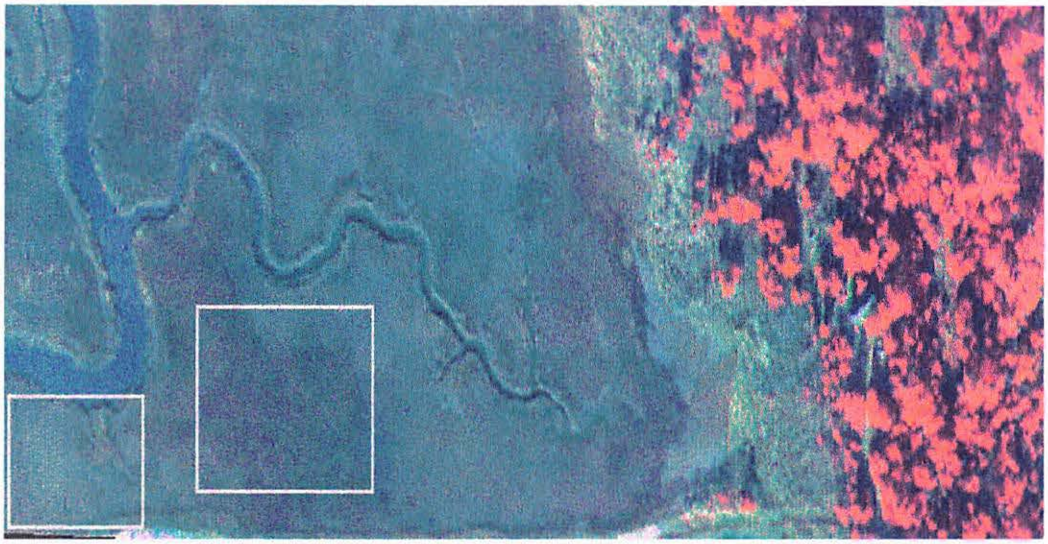


Figure 6. February 1998 multispectral image showing *S. alterniflora* tall form (left box) and short form (right box).

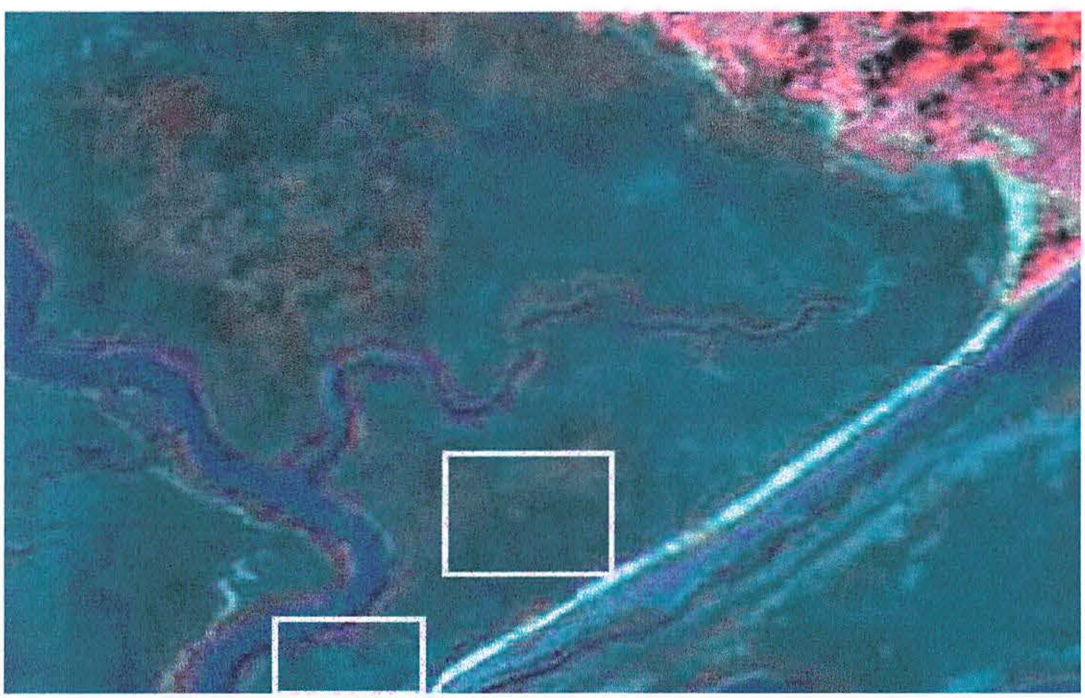


Figure 6. September 1998 multispectral image showing *S. alterniflora* tall form (left box) and short form (right box).

class.

Table 1. Plot Identification and Associated Vegetation Class for April 1998 Data.

PLOT IDs	Vegetation Category
18A, 18B, 11, 8, 2A, 2B, 101, 102	S. patens & T. angustifolia
7, 17.5, 17, 15, 13, 12, 11B, 9, 8, 103, 3	Shrub / Scrub
16, 14, 6, 5, 104, 105	Dune Ridge & Maritime Forest
1, 10	S. alterniflora

Table 2.Plot Identification and Associated Vegetation Class for August 1998 Data.

PLOT IDs	Vegetation Category
17, 86, 39, 34, 60, 27	S. patens & T. angustifolia
48, 3, 35, 95	Shrub / Scrub
64, 10, 76, 53, 6, 5, 120	Dune Ridge & Maritime Forest
20, 14, 66	S. alterniflora

Figure 7 and 8 present PCA ordinations on the ecological data performed during the April 1998 and August 1998 data collection periods. As indicated by the eigenvalues for the PCAs, each ordination analysis indicates that the majority of the variance is contained within the first two principal components. Figure 9, 10, and 11 present the PCA ordinations for the ecological and imagery data. As with the previous analysis (Figures 7 and 8), these data show that the majority of the variance is contained within the first two principal components.

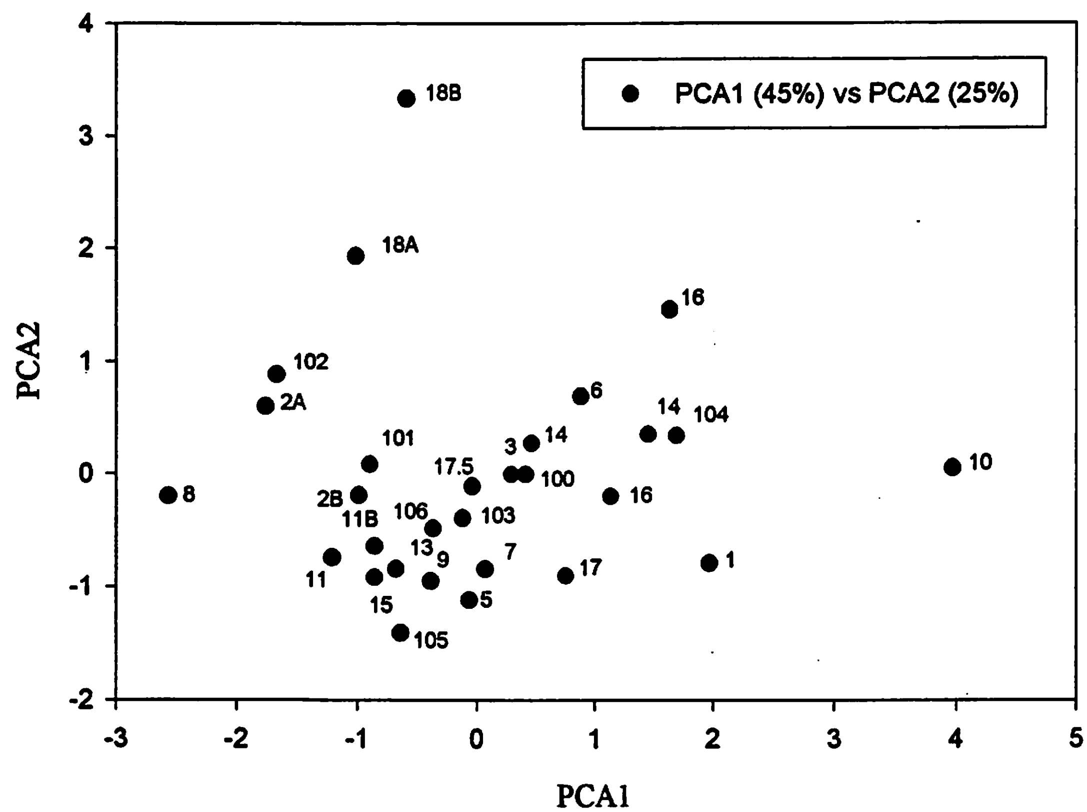
Task F. Statement on TEC/VIMS Data Exchange for Presentations

Data exchange between TEC and VIMS occurred on a regular basis during the duration of the study. Information and analytical products were used to present a joint paper/poster at the 21st Army Science Conference in Norfolk, Virginia.

Task G. Final Report Generation and Recommendation for Follow Up Work

Conclusions on the Parramore Island study are included in this report. Recommendation

Plot of PCA1 and PCA2
For 29 Sites at Parramore Island
April 1998 Data Collection Period



Component	Eigenvalue	Proportion
PC1	1.7988	0.4697
PC2	0.9876	0.2469
PC3	0.6568	0.1642

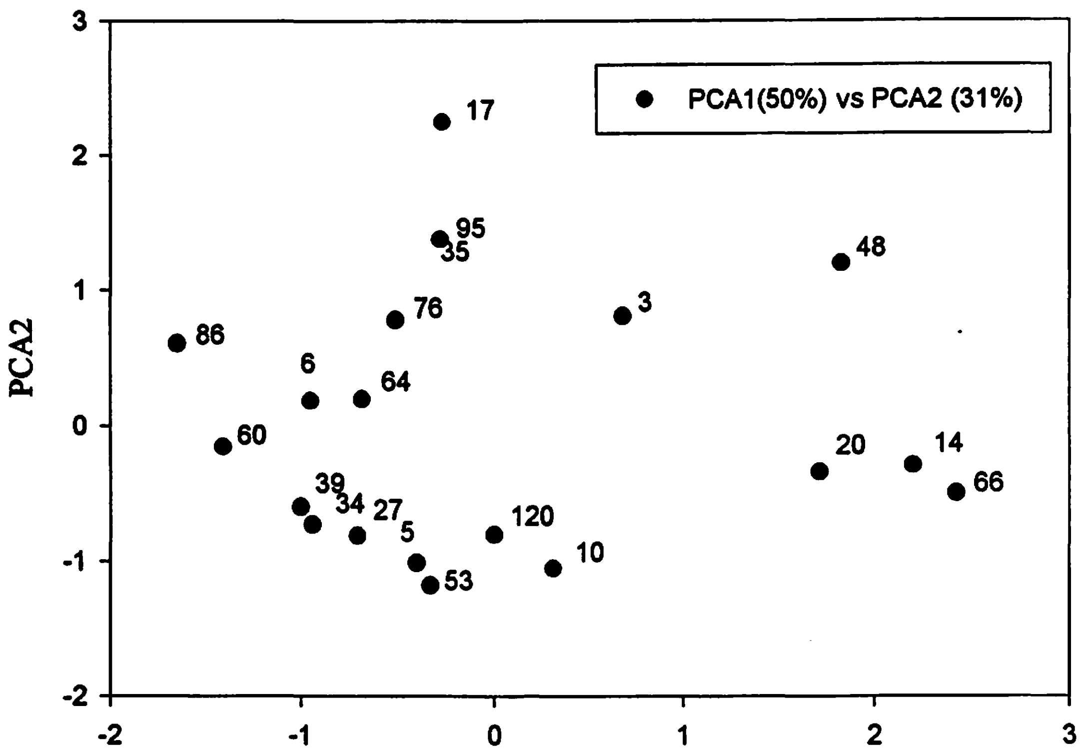
Eigenvectors

Variable	PC1 (45%)	PC2 (25%)	PC3
Elevation	0.5496	-0.0025	0.8246
Vegetation	-0.5561	0.3493	0.2566
Soil	0.5805	-0.0297	-0.4922

ref: (Manly, 1986) (Sokal and Rolf, 1981)

Figure 7. PCA ordination for April 1998 data collection period.

Plot of PCA1 and PCA2
for 21 Sites at Parramore Island
August 1998 Data Collectuion Period



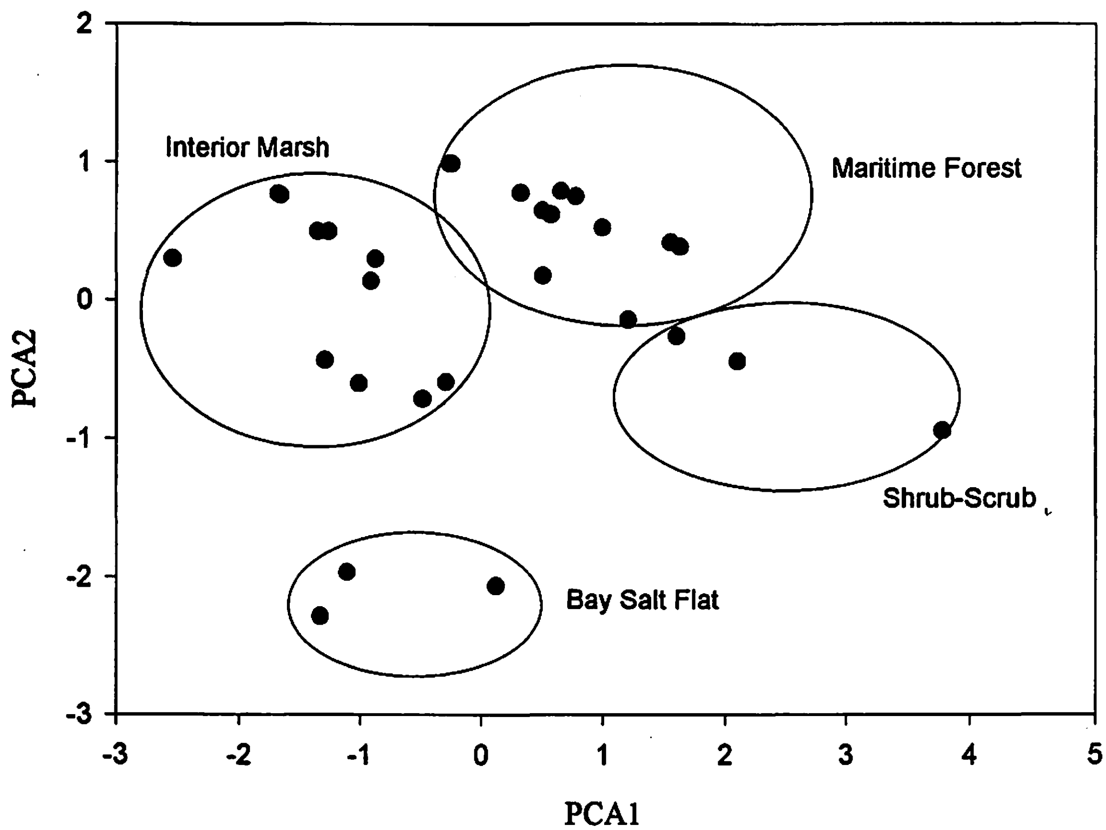
Component	Eigenvalue	Proportion
PC1	1.4950	0.4983
PC2	0.9176	0.3059
PC3	0.5874	0.1958

Eigenvectors			
Variable	**PC1(50%)**	**PC2(31%)**	**PC3**
Elevation	0.6685	0.1458	0.7293
Vegetation	- 0.4048	0.8940	0.1923
Soil	0.6239	0.4237	- 0.6566

ref: (Manly, 1986) (Sokal and Rohlf, 1981)

Figure 8. PCA ordination for August 1998 data collection period.

PCA for April 1998
Using 1m Image DNs

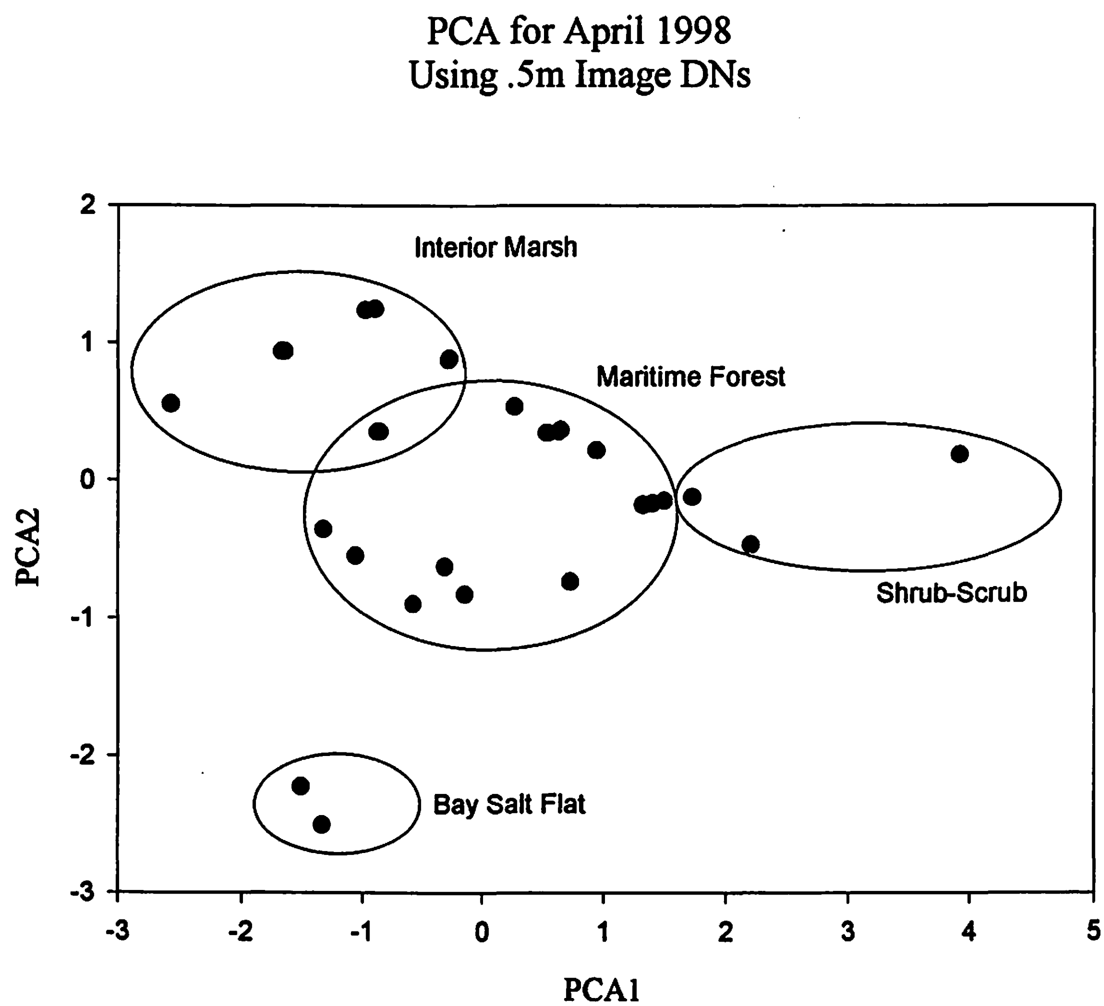


Component	Eigenvalue	Proportion
PC1	1.9340	0.4835
PC2	0.8251	0.2063
PC3	0.6614	0.1654

Eigenvectors			
Variable	**PC1(48%)**	**PC2(20%)**	**PC3**
Elevation	0.5128	-0.1592	0.8422
Vegetation	- 0.5323	0.3309	0.3309
Soil	0.5417	-0.1961	- 0.4082
DN1m	0.4003	0.9092	-0.0665

ref: (Manly, 1986) (Sokal and Rohlf, 1981)

Figure 9. PCA ordination for April 1998 data collection period including mean DNs for 1 meter GSD DMSV imagery.



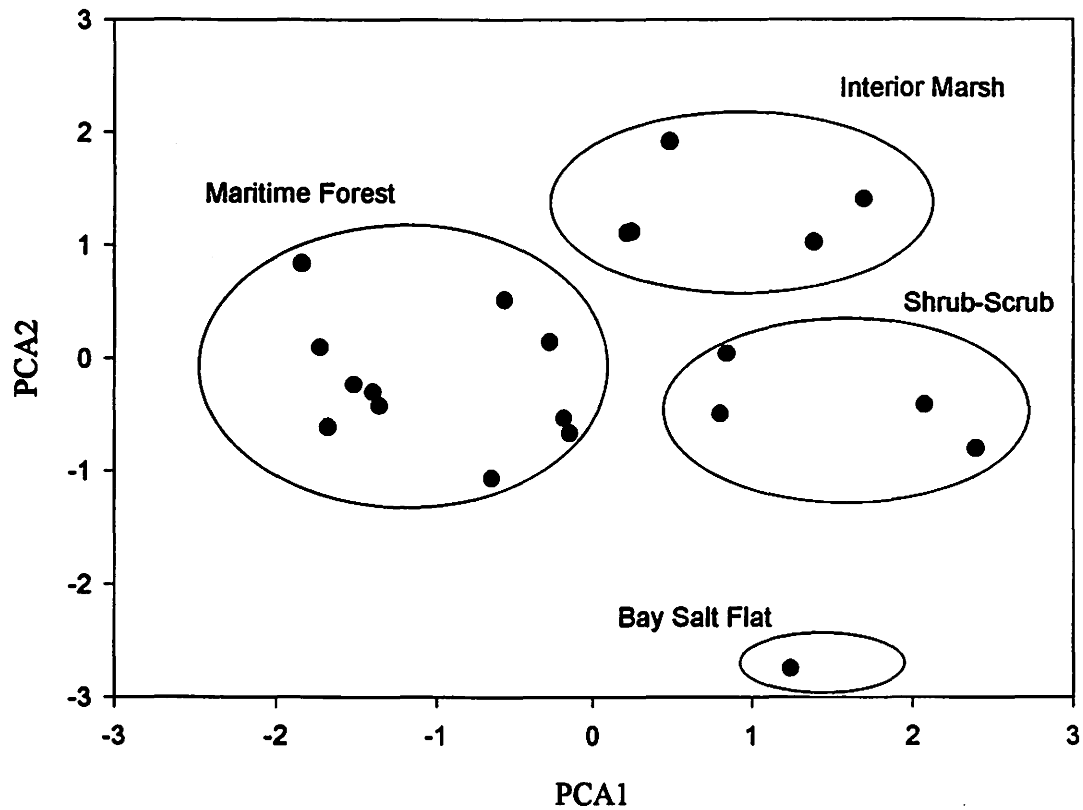
Component	Eigenvalue	Proportion
PC1	1.9750	0.4938
PC2	0.8027	0.2007
PC3	0.6405	0.1601

Eigenvectors			
Variable	PC1(49%)	PC2(20%)	PC3
Elevation	0.5184	0.0757	0.8506
Vegetation	- 0.5229	0.3906	0.2473
Soil	0.5234	-0.3719	-0.3215
DN1m	0.4288	0.8387	-0.3345

ref: (Manly, 1986) (Sokal and Rohlf, 1981)

Figure 10. PCA ordination for April 1998 data collection period including mean DNs for .5 meter GSD DMSV imagery.

PCA for August 1998
Using 1m Image DNs



Component	Eigenvalue	Proportion
PC1	1.7202	0.4300
PC2	1.0758	0.2689
PC3	0.7577	0.1894

Eigenvectors			
Variable	**PC1(43%)**	**PC2(27%)**	**PC3**
Elevation	0.4231	-0.4818	0.7594
Vegetation	- 0.2641	0.7423	0.6155
Soil	0.6263	0.2899	-0.0600
DN1m	-0.5992	-0.3644	-0.2022

ref: (Manly, 1986) (Sokal and Rohlf, 1981)

Figure 11. PCA ordination for August 1998 data collection period including mean DNs for 1 meter GSD CAMIS imagery.

for follow on work is included in the section "PCA Analysis on Variables Vegetation, Soil, DN Reflectance, and Elevation."

RESULTS AND DISCUSSION

PCA Analysis on Variables Vegetation, Soil, DN Reflectance, and Elevation

All ordinations were performed using SAS software and plts were generated in Sigma Plot. Initial ordinations were computed using all variables collected at Parramore Island; however, these analyses did not yield favorable results. In particular, the incorporation of the well data and soil compaction measurements perturbed logical patterns in each PCA. By process of eliminating these variables, stronger, more logical ordination patterns were developed. The remaining variables that did account significantly to the trends observed in the ordination patterns were vegetation, elevation, and soil type. In each ordination three distinct zones can be observed. In Figure 7 the distribution of points moves from left to right and can be grouped according the ecological zones: interior marsh, shrub-scrub zone, maritime forest, and salt flat (see Table 1 for plot identifications). This pattern groups the variables along logical ecological zones that is consistent with wetland zonation. A similar (but more loosely defined) pattern can be observed for Figure 8. Again, moving from left to right between axes four zones can be observed that associate the variables vegetation, soils, and elevation. PCAs developed for April 1998 had variables that were associated with 29 observations. PCAs developed for August 1998 had variables that were associated with 21 observations. These are relatively small sample numbers and it is anticipated that with a larger data set better ordinations can be developed.

The PCAs developed for the April and August data demonstrated the relationship between the ecological variables measured at a variety of sites on Parramore Island. The next logical step in this analysis was to sample the existing imagery DNs in areas of known vegetation types to test the relationship between the ecological variables and signatures extracted from the imagery. The April 1998 data used signatures queried from the DMSV mission flown in the previous February. While not an optimal representation of the season, many of the plant communities associated with this sample period were still in senescence. The results indicate weak patterns whereby vegetation, soils, elevation, and imagery signatures cluster in four zones (see Figure 9). PCAs were developed using both the .5 meter and 1 meter GSD data. The .5 meter data exhibits the same trend as the 1 meter PCA result (see Figure 10). Many of the classes overlap and are clearly associated with one another. The use of imagery DNs incorporated into the PCA for August 1998 yielded more favorable results with four distinct and separate classes emerging (see Figure

11). The image and field data were only a few weeks apart and the vegetation was still actively growing. Also, the CAMIS data were collected during ensuing low tide and vegetation exposure was at its maximum for tidal and interior marsh plants.

The results from VIMS' ordination analyses and independent correlation analyses executed by TEC, reveal meaningful trends in the association between the detection of vegetation communities and their relationship to soil conditions in the coastal zone. This report finds enough evidence to recommend follow on work at another coastal zone location and compare results with those generated at Parramore Island. Using just variables representing vegetation, soils, elevation, and imagery signatures this report would like to suggest the following:

1. Coordinate concurrent field and aerial acquisitions of data.
2. Maintain consistency in data reporting and formats between respective investigators.
3. Reserve a number of standard sample sites as controls while adding more sites to ensure statistical validity.

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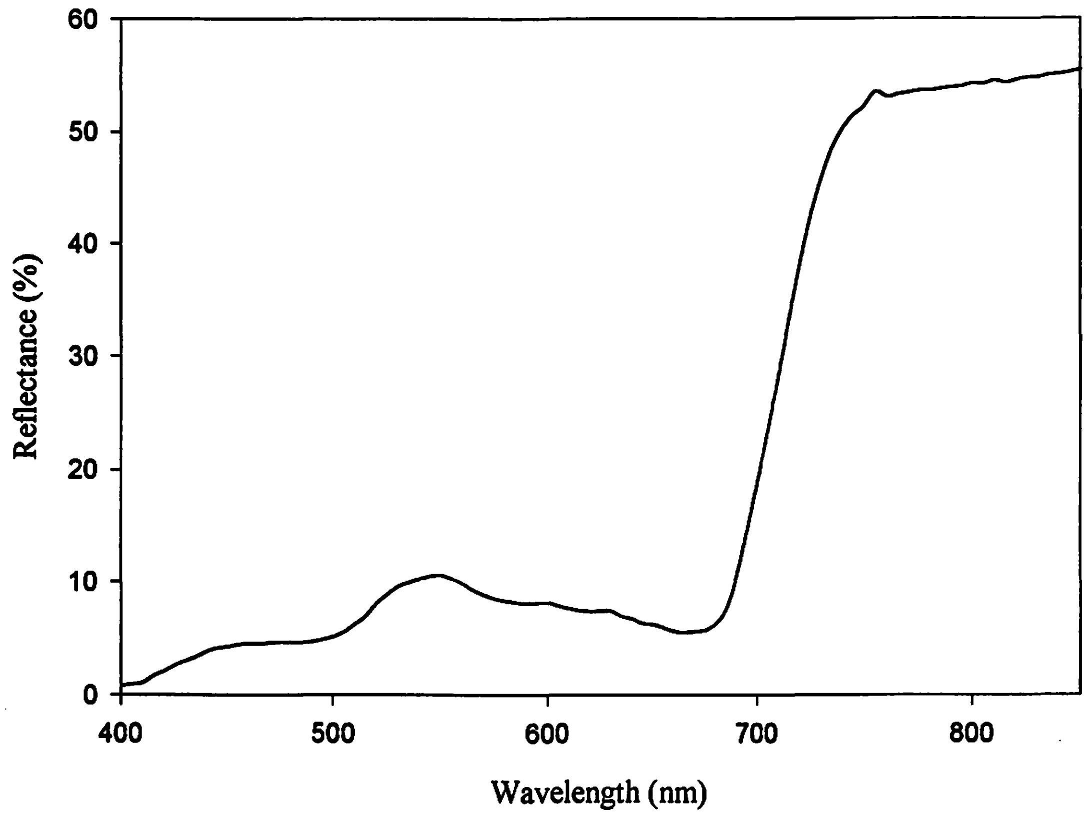
APPENDIX A
Spectral Data Plots

Parramore Island Spectral Data
April 1998

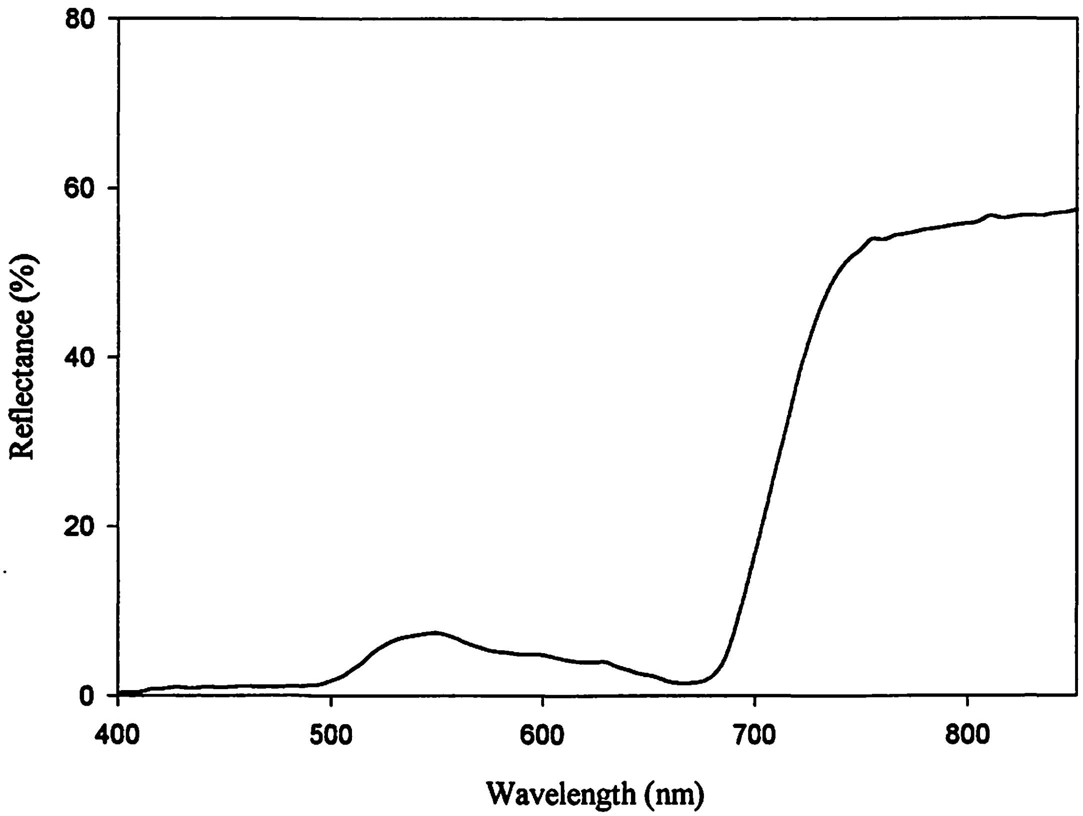


Target: Mixed shrub community (*M. cerifera, I. frutescens*)
Date: April 1998
Time: 1100 lst
Spectrum No. PRMR498
Site Location: Parramore Island, Virginia

Instrument: ASD PSII Spectrometer (350nm-1100nm)

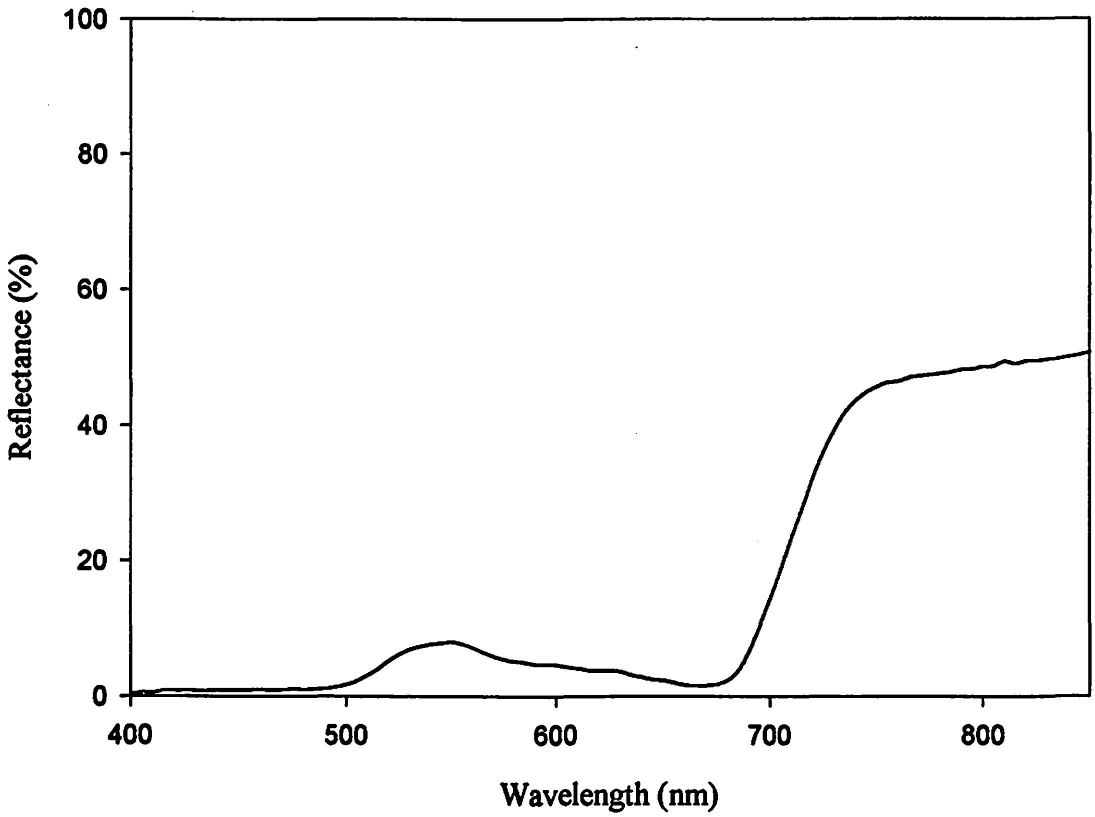
Sample: Spectral reflectance of the mixed canopy was measured at a height of 1 meter using a 10 degree field of view. Instrument calibration was performed using a Spectrolon standard. Canopy cover was estimated at 70%.

Parramore Island Spectral Data
April 1998



——	Target: *Spartina alterniflora* (Tall Form) Date: April 1998 Time: 1130 lst Spectrum No. PRMR498A Site Location: Parramore Island, Virginia Instrument: ASD PSII Spectrometer (350nm-1100nm) Sample: Spectral reflectance of the vegetation canopy was measured at a height of 1 meter using a 10 degree field of view. Instrument calibration was performed using a Spectrolon standard. Canopy coverage was estimated at 50%.

Parramore Island Spectral Data
April 1998

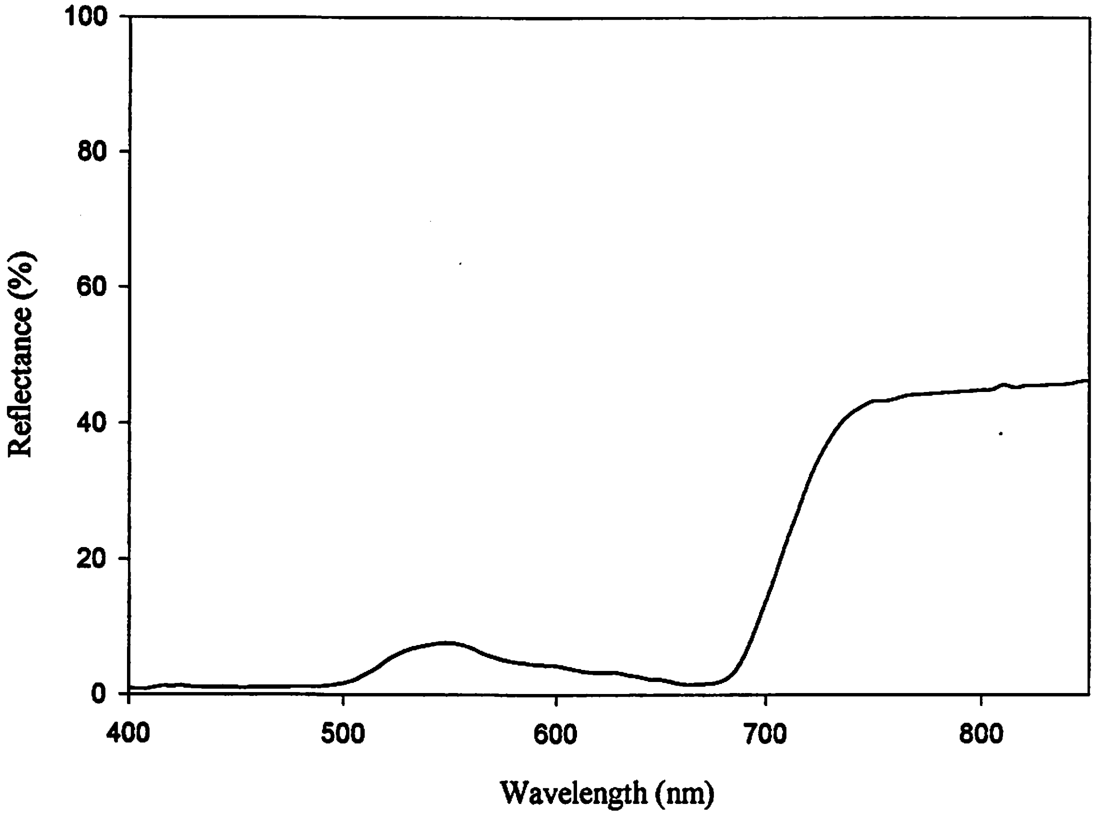


—— Target: *Spartina alterniflora* (Short Form)
Date: April 1998
Time: 1150 lst
Spectrum No. PRMR498B
Site Location: Parramore Island, Virginia

Instrument: ASD PSII Spectrometer (350nm-1100nm)

Sample: Spectral reflectance of the vegetation canopy was measured at a height of 1 meter using a 10 degree field of view. Instrument calibration was performed using a Spectrolon standard. Canopy coverage was estimated at 90%

Parramore Island Spectral Data
April 1998

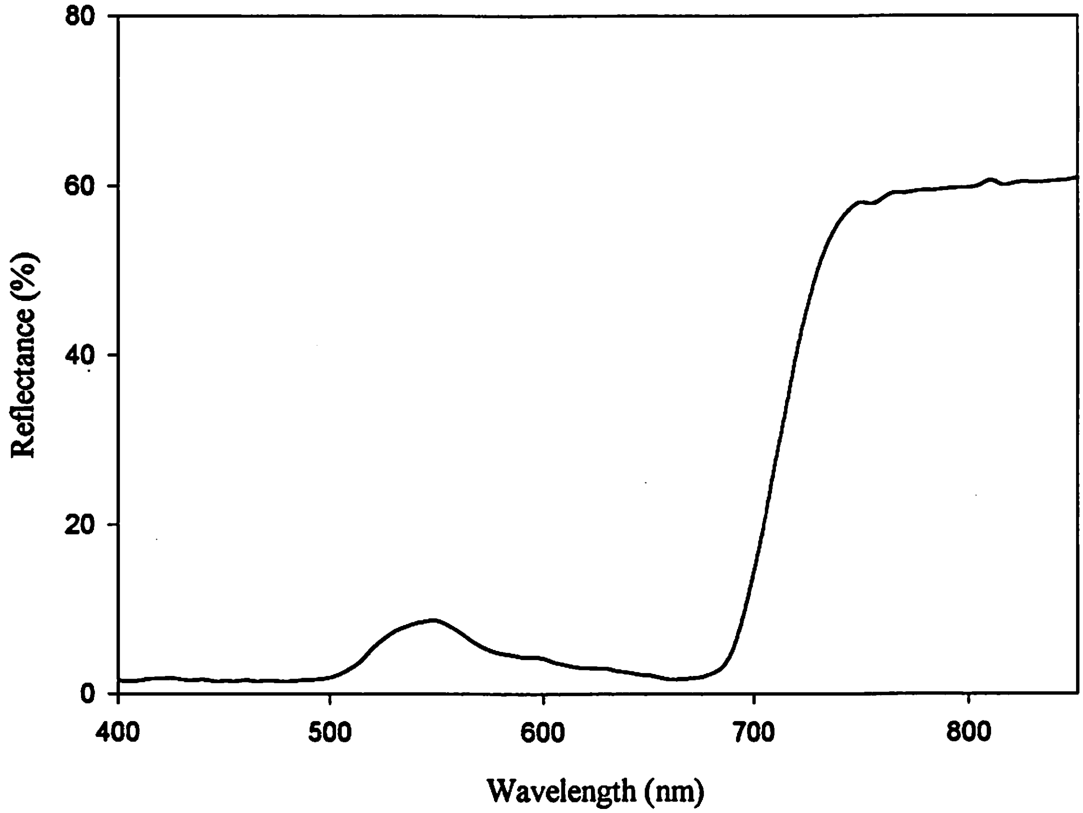


Target: *Typha angustifolia*
Date:April 1998
Time: 1210 lst
Spectrum No. PRMR498C
Site Location: Parramore Island, Virginia

Instrument: ASD PSII Spectrometer (350nm-1100nm)

Sample: Spectral reflectance of the vegetation canopy was measured at a height of 1 meter using a 10 degree field of view. Instrument calibration was performed using a Spectrolon standard. Canopy coverage was estimated at 30%.

Parramore Island Spectral Data
April 1998

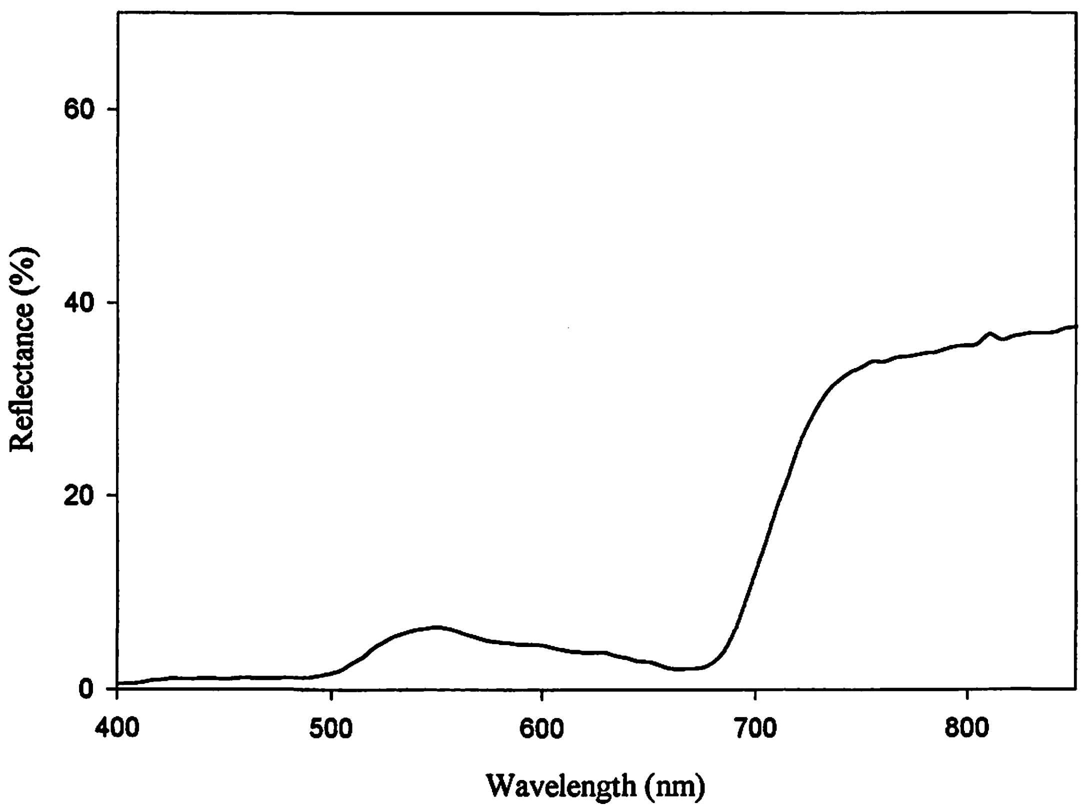


Target: *Pinus taeda*
Date: April 1998
Time: 1225
Spectrum No. PRMR498D
Site Location: Parramore Island, Virginia

Instrument: ASD PSII Spectrometer (350nm-1100nm)

Sample: Spectral reflectance of the canopy mosaic was measured at a height of 1 meter using a dark background and a 10 degree field of view in full sunlight. Instrument calibration was performed using a Spectrolon standard. Canpoy coverage for the mosaic was estimated at 85%.

Parramore Island Spectral Data
April 1998

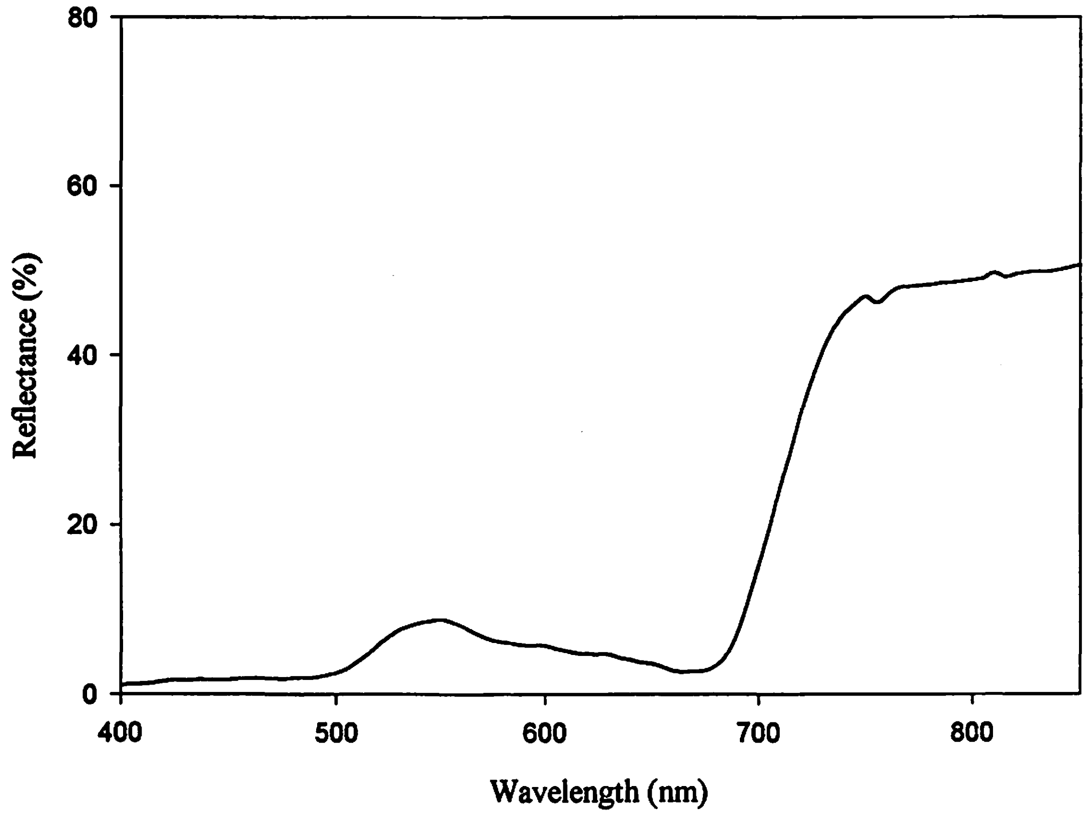


Target: *Juniperus virginiana*
Date: April 1998
Time: 1230 lst
Spectrum No. PRMR498E
Site Location: Parramore Island, Virginia

Instrument: ASD PSII Spectrometer (350nm-1100nm)

Sample: Spectral reflectance of the vegetation leaf mosaic was measured at a height of 1 meter using a 10 degree field of view. Instrument calibration was performed using a Spectrolon standard. Canopy coverage was estimated at 95%.

Parramore Island Spectral Data
April 1998

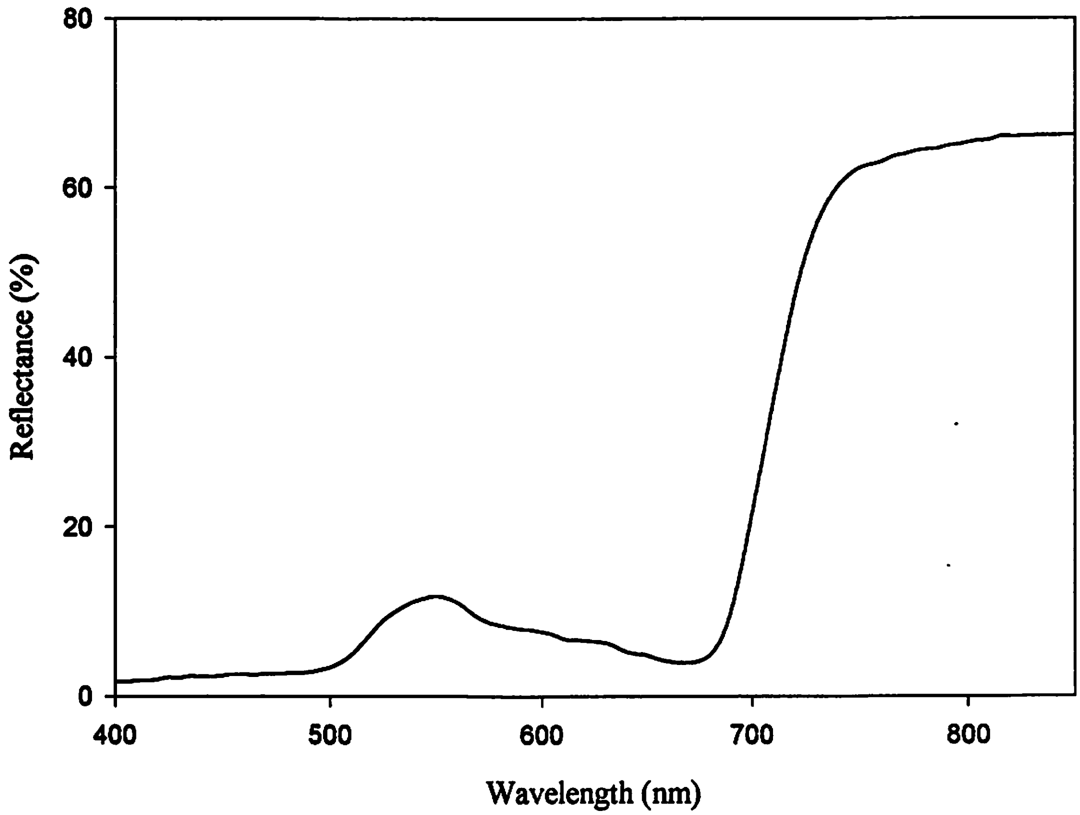


Target: *Iva frutescens*
Date: April 1998
Time: 1240
Spectrum No. PRMR498F
Site Location: Parramore Island, Virginia

Instrument: ASD PSII Spectrometer (350nm-1100nm)

Sample: Spectral reflectance of the canopy was measured at a height of 1 meter using a 10 degree field of view in full sunlight. Instrument calibration was performed using a Spectrolon standard. Canpoy coverage for the mosaic was estimated at 60%.

Parramore Island Spectral Data
April 1998



Target: *Myrica cerifera*
Date: April 1998
Time: 1255
Spectrum No. PRMR498G
Site Location: Parramore Island, Virginia

Instrument: ASD PSII Spectrometer (350nm-1100nm)

Sample: Spectral reflectance of the canopy was measured at a height of 1 meter using a 10 degree field of view in full sunlight. Instrument calibration was performed using a Spectrolon standard. Canpoy coverage for the mosaic was estimated at 75%.