Hyperspectral Detection of SAV on Louisiana's Coast

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Abstract

Lake Ponchartrain, the Louisiana marshes and estuaries provide an ideal ecosystem for applied research for the evaluation of submerged aquatic vegetation (SAV) spatial distribution and ecodynamics in the Gulf of Mexico. Airborne hyperspectral remote sensing imagery was investigated for automated mapping of SAV in the Gulf of Mexico as a tool for near to real time resource assessment and monitoring. The Louisiana marshes are important as they provide an important fisheries habitat. Remote sensing of aquatic resources is a valuable tool in establishing trends in spatial coverage and ecological dynamics of fisheries habitat in the Gulf of Mexico. Submerged aquatic vegetation (SAV) is an important part of the food chain in the Gulf of Mexico. The dynamics for SAV covered areas in the Gulf of Mexico are of interest to scientists and resource managers. The airborne hyperspectral imagery and field spectrometer measurements were obtained in the summer of 2005. Data requirements were established. Imagery, ground truth, and other required data were collated for North Lake Ponchartrain area. A spectral library database containing selected ground-based and airborne sensor spectra was developed for use in image processing. Field based spectra were compared to the airborne imagery using the database to identify and map the dominant species of SAV (*Vallisneria americana*). Ecological applications appropriate for hyperspectral imagery (HIS) remote sensing technologies for the Gulf of Mexico coastal lakes was determined. Several applications were addressed. One site for the change detection using archived data was identified. Other sites will be identified for validation phase using new protocols. The spectral library will be used to automate the processing of hyperspectral imagery for potential real-time material identification and mapping. Procedures for research methodology will be refined after this preliminary study.

Introduction

Background

Remote sensing of aquatic resources is a valuable tool in establishing trends in spatial coverage and ecological dynamics of fisheries habitat in the Gulf of Mexico. Submerged aquatic vegetation (SAV) is an important part of the food chain in the Gulf of Mexico. Lake Ponchartrain, the Louisiana marshes and estuaries provide an ideal ecosystem for applied research for the evaluation of SAV spatial distribution and ecological dynamics for scientists and resource managers in the Gulf of Mexico area.

The Louisiana marshes are important as they provide an important fisheries habitat. In 2002, 30% commercial fisheries landings in United States were from Louisiana. This constituted over 1 billion pounds of fisheries products with a value of about $343 million (USDOC, 2002). The Louisiana marshes provide a nursery habitat for nekton. The Flooded marsh and submerged aquatic vegetation (SAV) surrounding the marsh provide both food and protection for early life stages. Blue crabs *(Callinectes sapidus)* thrives across several habitats; SAV, bare bottom and flooded marsh

SAV is found in different aquatic environments in the Gulf of Mexico. It provides shelter and nursery areas for various fisheries fauna. An increasing amount of aquatic plant life is an important indicator of an improving ecosystem in the Gulf, and is one of the major goals for to be evaluated by the CCZARS Fisheries Habitat study. The SAV are important because they serve multiple functions in improving the health of the fisheries habitat. The plants use the nutrients, filter silt and sediment, improve water clarity, and contribute oxygen to the water that is necessary for fish and other aquatic creatures. As the plants perform these functions, they help to create habitat that is suitable for further plant colonization.

Hyperspectral imaging, (HSI), a technology application originally developed by astronomers for geochemical analysis of inaccessible planetary surfaces within the solar system (Goetz, 1992) is now a primary technology for observation of the Earth with airborne and spaceborne remote sensors. Hyperspectral imagery places emphasis on the "micro-scale" monitoring of factors which cannot be spectrally discriminated by broad multispectral bands (Goetz 1992; Nassau, 1983). Mumby et al. (1997) report successful categorization of coral reef habitats including SAV. Enhanced spectral resolution provided by hyperspectral sensors can provide extra insights to ecological dynamics. Diverse terrestrial and hydrosphere materials have characteristic absorption features detected by current hyper-spectral sensors operating in the visible and infrared range of the reflected spectrum. Fyfe (2003) reports the detection of statistically significant differences in intraspecific reflectance associated with the year, season, and other characteristics of SAV's. More available spectral data allows scientists to probe ever more detail about the chemistry of natural environments. Finally Williams et al. (2002) successfully spectrally characterized *Vallisneria americana*, the dominant SAV in the field site for this study.

The Fisheries Habitat (FH) research thrust is one of the four components of Southern University's Center for Coastal Zone Assessment and Remote Sensing (CCZARS). This research thrust aimed to conduct a number of change detection studies in various fisheries habitats along the Louisiana Gulf Coast using remote sensing, Geographical Information

Systems (GIS), and Global Positioning System (GPS) technology. The team comprised of ***Dr. Fulbert Namwamba, Dr. Nan Walker, Dr. Don Baltz and Dr. Jinchun Yuan.***

The vision of CCZARS is to further assist Gulf of Mexico states as they continue to address the initiatives set forth in the Coastal Wetlands Planning, Protection and Restoration Act [P.L. 101-646 (1990)] and the Coastal Impact Assistance Program, as well as issues addressed in possible future legislative actions such as the Conservation and Reinvestment Act (CARA). Hence this research thrust strives to assist NASA and other federal agencies in addressing the initiatives set forth in other legislative mandates such as the Coastal Zone Management Act, 1972, JFA, 1996, the Endangered Species Act, the Federal Sustainable Fisheries Act/Magnuson-Stevens' Fisheries Management and Conservation Act (SFA/MS-FCMA), the Coastal Barrier Resources Act (CBRA), the Coastal Barrier Improvement Act of 1990 (CBIA), the Clean Water Act (Section 404), the Water Resources and Development Act (WRDA), the Farm Bill, the Conservation and Endangered Species Act, Federal Noxious Weed Act, National Environmental Protection Act and the Marine Mammal Act.

The Louisiana State University's (LSU) Earthscan Laboratory and NASA Stennis Space Center (SSC) were part of a team that is investigating the use of airborne hyperspectral remote sensing imagery for automated mapping of submersed aquatic vegetation in the Lake Ponchartrain and generally the Gulf of Mexico. The algorithms and databases that will be developed from this study will be useful for the CCZARS Gulf of Mexico fisheries habitat study, whose main objective is to utilize remote sensing for the study of fisheries habitat ecological communities in Louisiana.

In support of this project, CCZARS will continue the development of a spectral library database containing selected ground-based and airborne sensor SAV spectra for use in image processing. The long-term goal of the spectral database is to automate the image processing of hyperspectral imagery for potential real-time material identification and mapping of SAV. For the summer of 2005, a spectral library database for field characterization and mapping SAV was developed. The summer study is a first step in the evaluation of the utility of hyperspectral technology for SAV identification and mapping.

Statement of Problem

Louisiana loses 24 square miles per year, the equivalent of losing 1 football field every 38 minutes (Barras et al., 1994), yet fisheries yields remain high. The edge effect hypothesis posits that initially with loss, there is an increase in perimeter. This perimeter increase is a suitable habitat for nursery grounds. Overall questions concerning habitat change are: 1. Does marsh perimeter increase? 2. Is there a relationship between suspended sediment, SAV, and marsh degradation? 3. Does SAV coverage change as open water increases? 4. How does salinity influence SAV? 5. Do high resolution sensors show hypothesized loss patterns related to perimeter, SAV and suspended sediment? The overall question is what role SAV has in the changing ecosystem.

Initially with loss, there is an increase in perimeter causing an edge effect. This increase provides more suitable habitat for nursery ground. Using results of work by Baltz, the FH thrust is investigating the role played by SAV in the changing ecosystem? The Null Hypothesis of the study is: *"The presence of SAV does not offset the effects of a decrease in emergent vegetation."* The FH team will be investigating whether the marsh perimeter is on increase, whether there is a relationship between suspended sediment, SAV, and marsh degradation, whether SAV coverage change as open water increases, whether salinity influence SAV? Dr. Namwamba's study in the summer of 2005 was to investigate whether high resolution sensors can effectively identify and clearly delineate SAV beds.

Goals and Objectives

The goals and objective of the CCZARS Fisheries Habitat research team are:

a) Seasonal Change Detection
b) Development of airborne data acquisition protocols
c) Development of field data acquisition protocols
d) SAV spectral signature characterization
e) Recommendation of new protocols to achieve research goals

During the summer of 2005, a major goal of CCZARS Fisheries Habitat research thrust was to evaluate the importance of SAV to blue crab habitat. The first step was an investigation of the spatial characterization of SAV beds. Remote sensing is important as it allows for satellite and airborne sensors to detect the type of substrate, amount of suspended sediment, phytoplankton, benthic algae, emergent vegetation, SAV and open water. The summer of 2005 study at SSC focused on the spatial characterization of SAV beds.

Methodology

Airborne hyperspectral imagery, using the Institute for Technology Development (ITD) sensor, together with in-situ spectral reflectance measurements using a field spectrophotoradiometer were obtained for the pilot sites during Summer 2005 (two months after flight). Bayou Lacombe image was in relative terms the clearest of the different images and field surveys in 2005 focused on Bayou Lacombe. During the summer 2005 investigation, field surveys at Bayou Lacombe evaluated SAV presence, and distribution. A spectral library database was developed for use in hyperspectral image processing of SAV. The goal of the spectral database is to provide a guideline for future image processing of spectral imagery for mapping of SAV. Field based spectra were compared to the airborne imagery using the database to identify and map SAV. *Vallisneria americana* was observed to be the most abundant of the different species of submerged aquatic vegetation commonly found at Bayou Lacombe.

Summary of Methodology

a. Acquisition of airborne HSI data
b. Field studies of areas of interest.
c. Examination of Spectral Signatures from literature
d. Derivation of Spectral Signature Library from Field in-situ measurements
e. Geometric correction of imagery
f. Reduction of bands to required critical bands
g. Unsupervised Classification.

Airborne Hyperspectral Data Acquisition

High-resolution HSI imagery for the Gulf of Mexico was obtained from airborne remotely sensed data. On Friday, March 18, 2005 the first of a series of hyperspectral data collections from aircraft occurred. Geotek-Duncan, an SSC based flight crew (GEOTEK contact was Daniel Lee) was contracted to collect data from several key lines in coastal Louisiana (Figure 1). Data collection included three transects for the mapping of submerged aquatic vegetation (SAV), these were in the Biloxi Marsh area, the Big Branch Marsh in the vicinity of Bayou Lacombe on shores of Lake Ponchartrain, and the Chandeleur islands in the Gulf of Mexico. In addition to SAV transects, the flight covered the Davis Pond diversion into Lake Catouatchie, the middle and eastern section of Lake Salvador including floating marsh environments, the southern portion of Barataria Bay (where LSU has a monitoring station) and. A visible/near infrared hyperspectral system (VNIR 100E) was contracted from the SSC-based Institute for Technology Development (ITD) (the liaison for this study was David Lewis). This sensor provides 12-bit data in130 bands between 400 and 1000 nm. The lines were flown between 9:00 and 11:30 CDT.

Field Studies

As this sensor was not calibrated, calibration targets were chosen at the east end of Grand Isle, based on discussions with Greg Carter (Gulf Coast Geospatial Center, GCRL, Ocean Springs, MS).

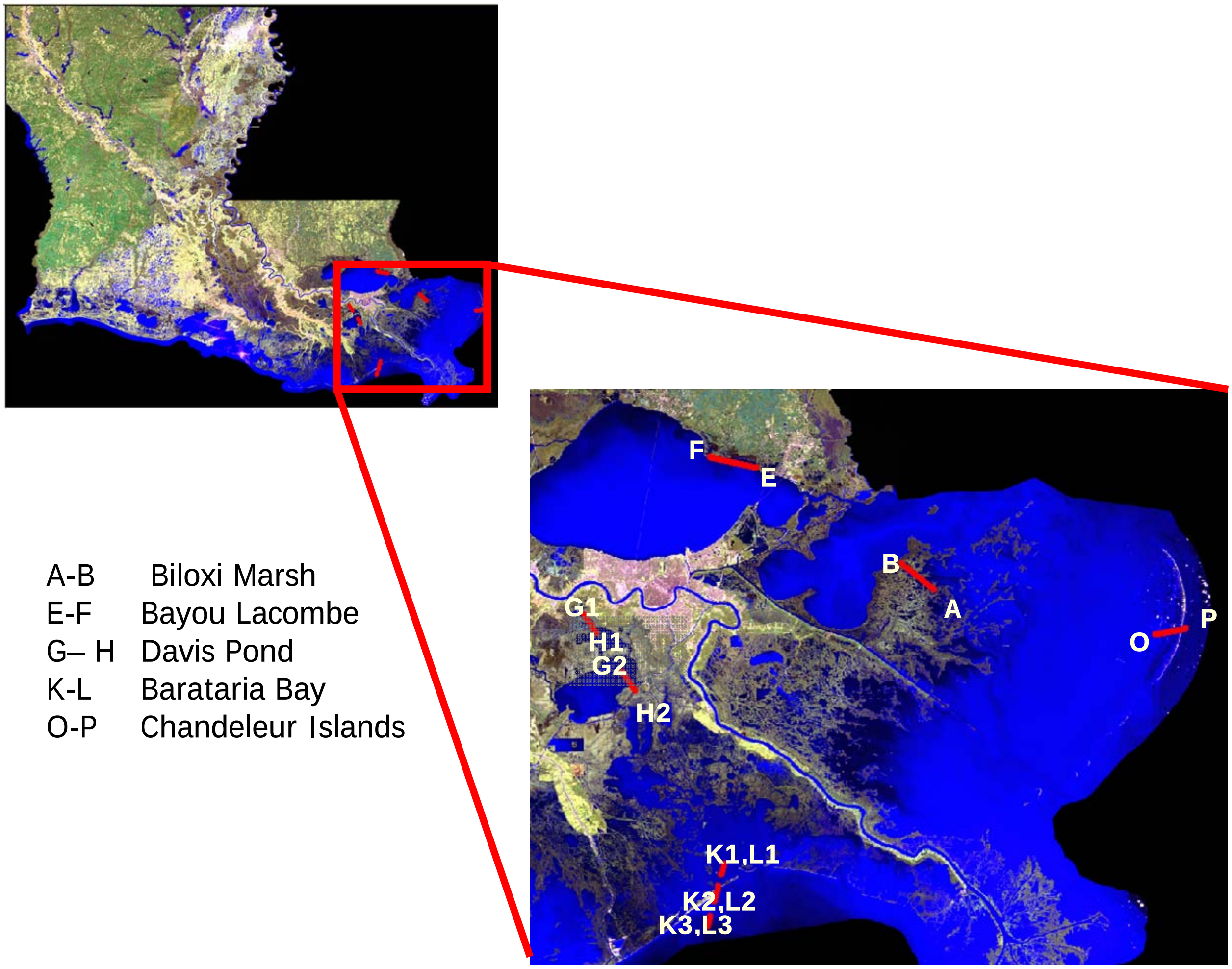

Figure 1. Study Area Transect Lines

The targets were identified two weeks prior to the flight. Dr. Nan Walker (LSU) and research assistant, Shreekanth Balasubramanian, collected the calibration data simultaneous with collection of calibration lines by the aircraft (Figure 2). The main calibration targets were a large unmarked asphalt parking lot and a concrete parking lot, within a new marina development, west of the Coast Guard station. The calibration data were collected with a GER-1500 spectrophotoradiometer. In addition to the calibration scans, measurements were obtained from the coastal ocean (from the State Park fishing pier), the adjacent Grand Isle Beach, and the beach vegetation. Target reflectances were computed from the radiance data and will be used to calibrate the 12-bit data from the hyperspectral sensor. This calibration would enable comparison of the March 18, 2005 data with future measurements.

The first phase of the fisheries habitat research focused also on field ground truth in addition to calibration of the HSI methodology for dominant SAV species. In situ measurements were made with a GER-1500 field portable spectrophotoradiometer provided by Louisiana Earthscan laboratory. This Field Spectrometer has a 350 to 1050 nanometers spectral range. The *in situ* measurements over several windows of time allowed for the calibration to identify site-specific effects on spectral properties. Possible effects of algae were investigated. Collection of plant samples during each trip was used to further investigate the SAV.

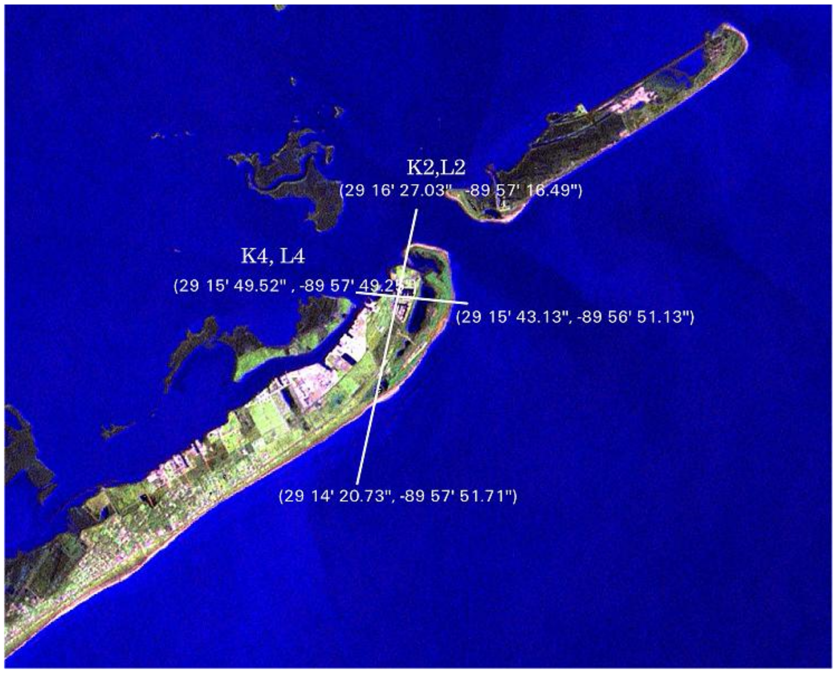

Figure 2. Calibration lines flown across the east end of Grand Isle on 18 March 2005.

Figure 3. Bayou Lacombe (Line EF) Field Studies

Results

Data files were stored in LAN format with headers files (HDR) formatted for direct reading in RSI ENVI remote sensing software. Quick look images for each transect were generated in JPG format using to approximate three typical Near-Infra-red bands. Even though the initial "quick-looks" were good, when the LAN files were examined in ENVI several technical problems were encountered. There were technical challenges arising from the performance of the ITD hyper-spectral camera. From a visual examination of the imagery there was a lack of uniformity of scale on both x and y axes on the airborne acquired imagery. Discussion with the field crew and ITD personnel indicated that the difficulties may have arisen from lack of uniform airplane velocity, lag time after flying over required area and switching off computer, and rolling of camera in the plane. These problems were tackled during image analysis. There were also major problems with the calibration results from Grand Isle. Even though the field measurements were good, the ITD camera had been set to be sensitive to low reflectance to accommodate the low radiance for data from below the water surface. The camera therefore reached the maximum radiance of 4050 DN for the recording of concrete at the sites of the calibration. It was not hence possible to use the field results for calibration.

Figure 4a Geotek "first-look" Hyperspectral Imagery

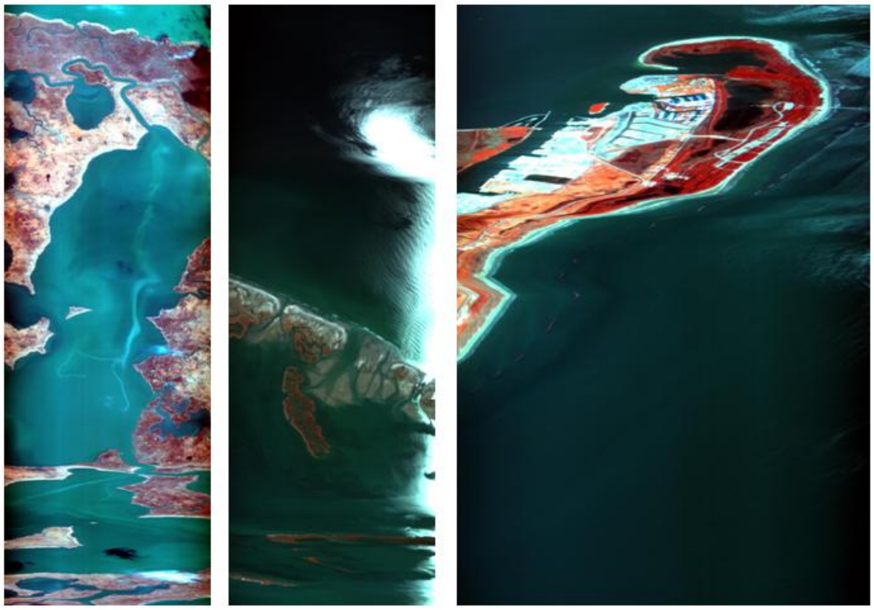

Figure 4b Geotek's "first-look" Hyperspectral Imagery

Image Analysis

To overcome these problems several procedure were adopted:

a. Correct alignment of image(s)

b. Geometric correction of image(s)

c. Reduction (by Subset) of bands to manageable numbers (from 130 to 70)

d. Comparison of Spectral Signatures from Literature with those from Field in-situ measurements

e. Unsupervised Classification.

When the original images in LAN format displayed in ENVI were compared to the digital orthoquadrangle quarter (DOQQ) images of the flight areas (obtained from the Louisiana State University Atlas website), they were found to be oppositely congruent (mirror images) of the “quick-looks” and DOQQ images. Also the top of the image was not necessarily North but the flight direction given to the pilot.

Flipping the images was necessary to correct the congruence of the images. However again after congruence was corrected it was necessary to align the image to approximate the DOQQ. These necessitated the use of the ***flip*** and ***rotate*** procedures in ERDAS imagine, the “***flip***” corrected the congruence, while the ***“rotate”*** procedure approximately aligned the image with the coincident DOQQ images. The procedure used for transformation and geometric transformation is described in ERDAS (2005)

Geometric correction was achieved using the ***"rubber-sheet"*** procedure in ERDAS imagine. The specifications of the "rubber-sheet" required forty points for the Bayou Lacombe image, which was used for SAV identification and classification. The image was warped by use of a "cubic convolution".

After the Bayou Lacombe image was corrected it was still necessary to reduce the number of bands to a manageable number. This was initially done by removing the first fourteen bands (in the ultraviolet range wavelengths), and also the most in the infra-red (in the range absorbed by water)

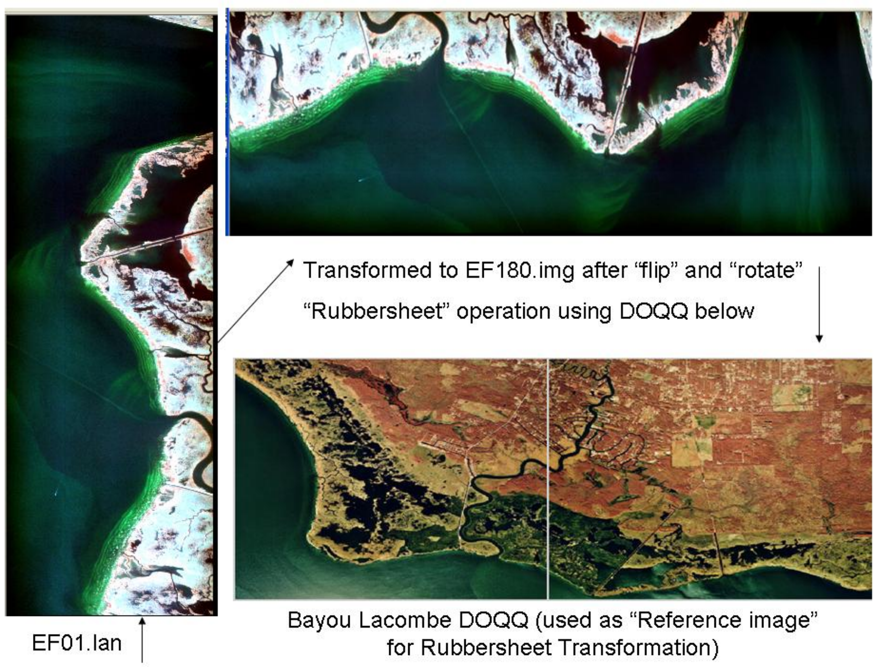

Figure 5. Bayou Lacombe Transformation Process to Geometrically Correct Image

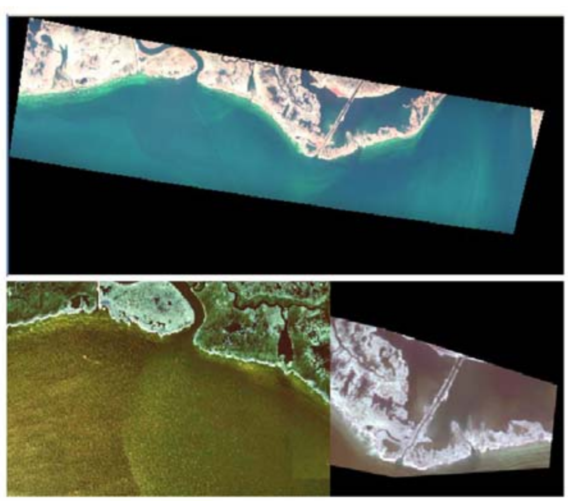

Figure 6. Bayou Lacombe Corrected Image Compared to DOQQ

Comparison of Field Spectra and Spectra from Literature

Examination of characteristic spectra of SAV and near-shore sand bottoms provided a helpful guide for the expected spectral characteristic of SAV in the Bayou Lacombe area (Williams, et al., 2002; Fyfe, 2003, Mumby, 1997). Characteristic spectra obtained from Williams at. Al. (2002) displayed in Figure 7, demonstrated similar characteristics to in-situ measurements from field studies for *Vallisneria americana.* Underwater sand bottom and sediment from Bayou Lacombe (Figures 8 and 9) had a brighter reflectance that SAV for the green to red spectra. Algae had similar characteristics to SAV but was generally brighter.

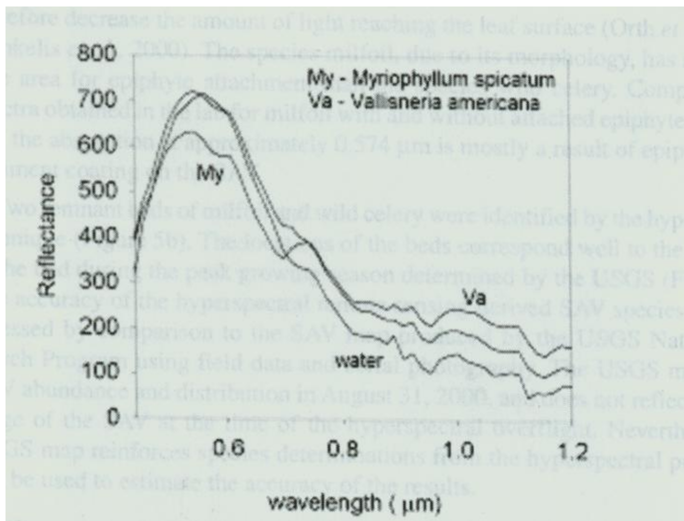

Figure 7. Relative Reflectance spectra of 2 species of SAV and ambient water (From Williams et al. 2000)

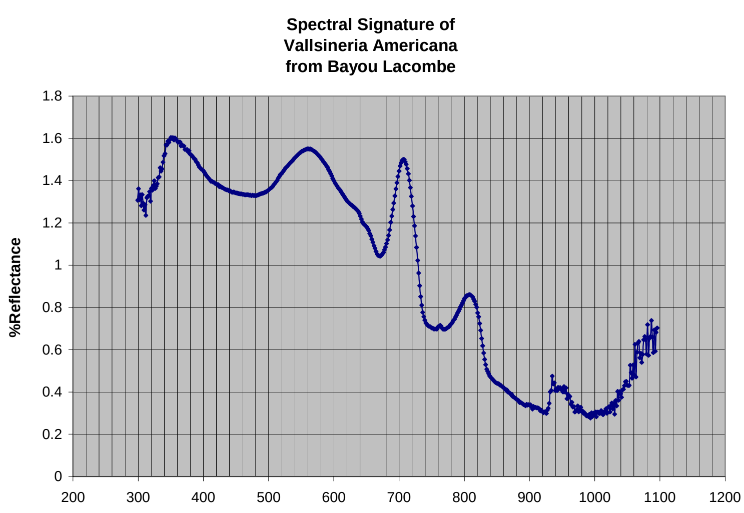

Figure 8. Relative Reflectance spectrum of *Vallisneria americana* from Bayou Lacombe (Collected from in-situ measurements using the GER 1500 Spectrophotoradiometer)

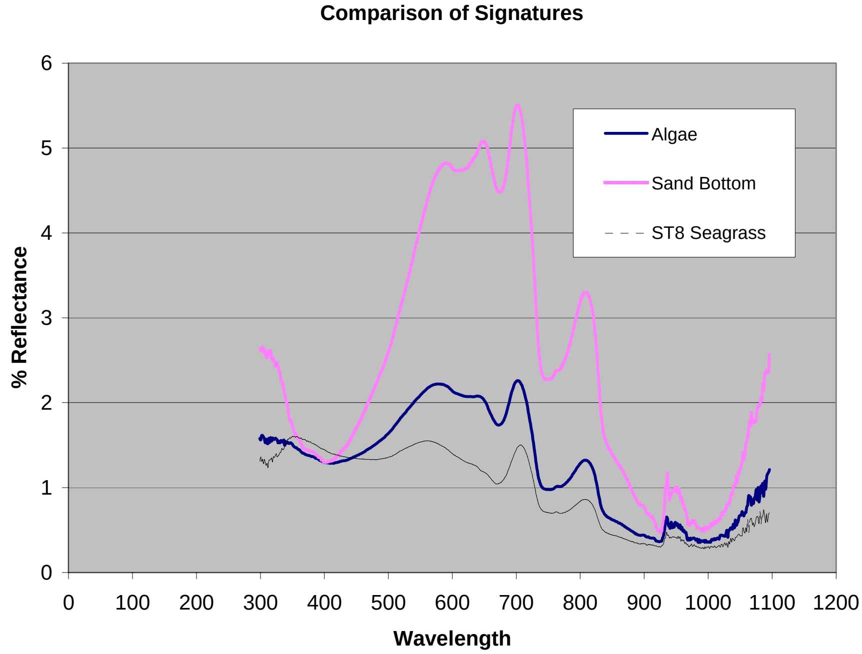

Figure 9. Relative Reflectance spectra of *Vallisneria* SAV, submerged sand bottom and algae
(Collected from in-situ measurements using the GER 1500 Spectrophotoradiometer)

It was not possible to do atmospheric correction as the FLAASH software has only been available after the summer period, however because of the distinct difference in brightness between sand bottom and SAV, an unsupervised classification was still able to identify the SAV. This classification will be completed once an atmospheric correction is done. The ISODATA procedure used for unsupervised classification is described in ERDAS (2005)

Results from Unsupervised Classification

- The bands were reduced from 70 to 15. Initially the files were large (approximately 4.7 gigabytes). They had to be reduced to a manageable number representing the observed trends. The reduction was implemented using the "subset" procedure in ERDAS-Imagine software. The bands were selected in the Visible to Near-Infrared range.
- The choice was driven by identification of "critical bands" within the 500 to 700 nm range. Examination of the field SAV, subsurface sand bottom, and algae spectra (in Figure 7) as well the *Vallisneria* spectrum displayed in Figure 8, indicated specific inflection points critical to identification. The bands selected for unsupervised classification were those close to identified critical inflection points.

- Originally there were a maximum of 25 iterations, but after three of four attempts at classification it became evident that the number of iterations rarely exceeded ten. Eventually, a maximum of 15 iterations was found to be adequate to achieve the desired convergence criterion.
- Three standard deviations were considered as an adequate representation of a statistical spread of 97% of the clusters of ISODATA classes required.
- The 97% convergence criterion was achieved after about 11 iterations.

The resulting image is displayed in Figure 10.

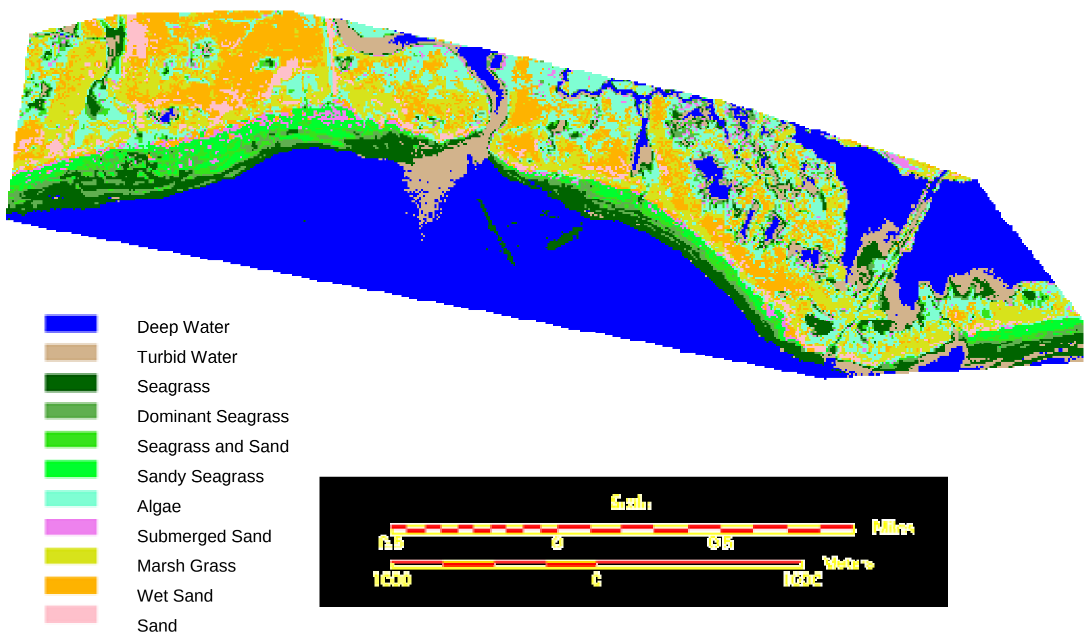

Figure 10. Classified image of Bayou Lacombe Area (Line E-F) after ISODATA (unsupervised) Classification.

Discussion and Conclusions

The main goal for this project was to evaluate the utility of HSI data to effectively map submerged aquatic vegetation (SAV) off the Louisiana marshes and coastal areas.   We encountered major technical challenges in the quality of the hyperspectral imagery. A spectral library populated with spectral signatures for all SAV species found at the Bayou Lacombe pilot site will be developed for blue crab habitat studies. During this past year, flight data gathered at Grand Isle for purposes of calibration had major problems. The DN values for concrete were higher than the allowed sensitivity for the ITD camera. This work will not be complete until atmospheric correction is completed. This will be achieved using the FLAASH atmospheric correction algorithm in ENVI.

The data will come from various sources including the laboratory and field measurements done under this project. CCZARS fisheries-habitat studies are being conducted in stages, and most of the fieldwork will be conducted along the Gulf of Mexico. Later studies will address variables associated with the water column (like turbidity, depth). Experiences gained in this study will be useful for decision making in future remote sensing data acquisition. Several conclusions are drawn from this study:

1. The hyperspectral imagery was very useful in identification of SAV beds.
2. Though SAV beds were clearly identified, there is need to establish an atmospheric correction protocol to convert radiances (Digital Numbers) into reflectance for accurate delineation of SAV characteristics.
3. It was possible to spectrally discriminate pre submerged sand beds, pure SAV beds and identify SAV submerged sand mixtures.
4. The data quality of the imagery from the ITD hyperspectral camera for this study was poor. Several measures will be taken during flight planning to ensure a steady acquisition of good quality data.

The Future

The complete classification for Bayou Lacombe SAV beds is not complete. It will be completed after an atmospheric correction is done using the FLAASH atmospheric algorithm in ENVI software. After DN numbers are converted to reflectance values the image will be reclassified. In the future there is a need to examine the possibility of doing this work in multispectral imagery. The multispectral imagery cameras acquire the imagery in frames, a factor that guarantees uniform x and y scales across most of the image. With atmospheric corrections accurately done it is possible to detect the SAV beds, and run algorithms to delineate different densities of SAVs solely based on multspectral data SAV beds (SAV) were clearly identified. Future flights should be over the same area so as to establish a time series criterion for change detection. In the future it will be necessary to collect ground spectral data from Bayou Lacombe during the overflight.

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