PRELIMINARY INVESTIGATION OF SUBMERGED AQUATIC VEGETATION MAPPING USING HYPERSPECTRAL REMOTE SENSING

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Abstract. The use of airborne hyperspectral remote sensing imagery for automated mapping of submerged aquatic vegetation (SAV) in the tidal Potomac River was investigated for near to real-time resource assessment and monitoring. Airborne hyperspectral imagery and field spectrometer measurements were obtained in October of 2000. A spectral library database containing selected ground-based and airborne sensor spectra was developed for use in image processing. The spectral library is used to automate the processing of hyperspectral imagery for potential real-time material identification and mapping. Field based spectra were compared to the airborne imagery using the database to identify and map two species of SAV (*Myriophyllum spicatum* and *Vallisneria americana*). Overall accuracy of the vegetation maps derived from hyperspectral imagery was determined by comparison to a product that combined aerial photography and field based sampling at the end of the SAV growing season. The algorithms and databases developed in this study will be useful with the current and forthcoming space-based hyperspectral remote sensing systems.

Keywords: submerged aquatic vegetation, remote sensing, hyperspectral, species mapping, estuarine ecosystems, epiphyte, reflectance spectroscopy, computational techniques

1. Introduction

Hyperspectral remote sensing systems, or imaging spectrometers, are sensor instruments that obtain image data in many spectral bands. To date, hyperspectral remote sensing has been shown to be useful to geologists as a tool to differentiate between mineral species and lithologic units on the earth's surface (Clark, 1999). The objective of this investigation is to determine if this technology can be applied to aquatic ecology by mapping species composition of submerged aquatic vegetation (SAV) in estuarine environments. Aerial photographs have been used extensively to delineate SAV stands (Orth *et al.*, 2000; Kirkman, 1996) and to discern large changes in SAV coverage and density over time. As a result, SAV coverage information has been combined with water quality information and subsequently been used to determine habitat criteria for restoration of SAV (Batiuk *et al.*, 1992; 2000).

SAV species differ in their tolerance to environmental factors. A shift in conditions of carbon availability, water clarity or salinity, for example could selectively affect the abundance of one species more than another. Emergent and submerged aquatic species presence and absence and diversity have been used to assess stream

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water quality and to rate stream degradation (Small *et al*., 1996). An adequate species mapping technique is necessary in order to measure change in the distribution of species of SAV and ultimately to determine causal relationships between environmental factors and changes in species coverage and distribution. Although very useful for SAV abundance mapping, the lack of multispectral information in aerial photographs makes this data inadequate for species determination. The objectives of this paper are to: 1) investigate the use of high spatial resolution hyperspectral remote sensing to map SAV distributions and abundance, 2) determine if SAV can be mapped to the species level using this type of data.

2. Materials and Methods

2.1 STUDY SITE

Submerged aquatic vegetation stands were studied in the tidal Potomac River at the mouth of Nanjemoy Creek at Blossom Point, in southern Charles Co. Maryland (Figure 1). This study area is characterized as part of the transition zone between the

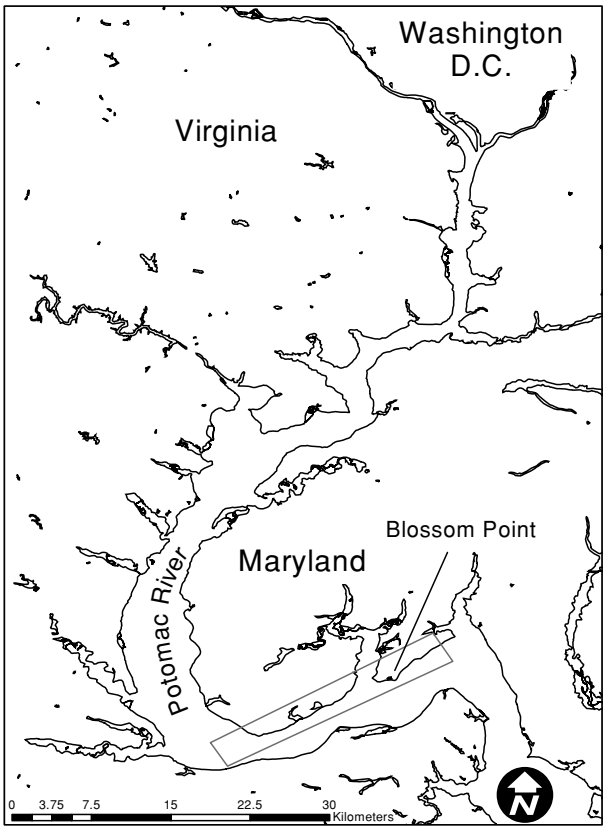

Figure 1. Location of study sites. HyMap flightline denoted as a polygon.

freshwater tidal river and the Chesapeake Bay estuary. The salinity is classified as oligohaline (0.5 to 5.0 ppt). SAV species present at this site are primarily *Vallisneria americana* (wild celery) and *Myriophyllum spicatum* (Eurasian watermilfoil).

2.2 FIELD SPECTROSCOPY

Ground based in-situ spectra were obtained using an Applied Spectral Devices FR porTable field spectrometer. Radiance and reflectance data for sample plots in Nanjemoy Creek (BP) and the Potomac River (PR) were obtained on October 13, 2000, by deploying a fiber optic sensor head over beds of both milfoil and wild celery approximately 1 meter above the water surface. Spectra for several calibration targets, material having uniformly high reflecting spectral response such as beach sand, were used to compare to the airborne reflectance data for quality assurance. Laboratory spectra for field collected milfoil and attached epiphyte colonies were obtained on March 9, 2001. Collected milfoil and wild celery and calibration site spectra were entered into a spectral library database developed in MATLAB. This spectral library has been developed by EPA and George Mason University to enable accurate real-time mapping of target materials in a hyperspectral dataset.

2.3 HYPERSPECTRAL DATA AND IMAGE PROCESSING

Airborne remotely sensed hyperspectral imagery for the site was acquired on October 21, 2000 using the HyMap system (Cocks *et al*., 1998) (Figure 2). The flightline dimensions were 2.3 x 20 km and the ground sampling distance (pixel size) of the imagery was 4 meters. Sensor radiance data were converted to apparent reflectance using ACORN, an atmospheric correction code based on the MODTRAN 4 radiative transfer model (ImSpec, LLC). Field sample plots were located in the HyMap imagery and spectral signatures of SAV were extracted by averaging over a 50 pixel (200 m^2) area of interest for each plot. A spectral transformation of the reflectance data was accomplished using continuum removal to plot the absorption bands at each wavelength. This procedure isolates the absorption band center and allows for these features to be easily compared with other reflectance spectra (Clark, 1999; Clark and Roush, 1984; Kruse, *et al*., 1993). The depth of the absorption feature at a specific wavelength is used to identify the two species of SAV.

The first step in identifying species of SAV in the imagery was to suppress the contributions of the optically active components in the ambient water, such as chlorophyll and free floating algae. These components have spectral features that are similar to SAV in certain wavelengths. Using the spectral signatures of the SAV species and the ambient water, a band math algorithm was developed that exploited the spectral differences of SAV versus ambient water at critical wavelengths. The algorithm first processed out the influence of the ambient water by

using the continuum removed spectra data. Band differencing was used to set any pixel that did not have absorption features associated with SAV to zero. A band ratio using two SAV absorption bands was then used to map the SAV beds. Because milfoil absorbs more strongly at the 681 nm band than wild celery, the band ratio was set up to take advantage of this difference along with another ratio for the 590 nm band as follows:

(band 1 - band 2) * [(band 1 / band 2) + (band 1 / band 3)]

where band 1= 604 nm, band 2 = 590 nm, band 3 = 681 nm

This equation was used to segment the image and remove potential false positives. This pre-processing step also increased the speed of the next procedure by reducing the amount of data to be processed. Pixels that scored in a set threshold were then passed to a Spectral Feature Fitting (ENVI, 1999) procedure for SAV species identification. Spectral Feature Fitting (SFF) is an algorithm that compares image spectral data to a set of reference spectra, in this case the field-measured spectral library database, by a least-squares fit of the continuum removed spectra (Clark,

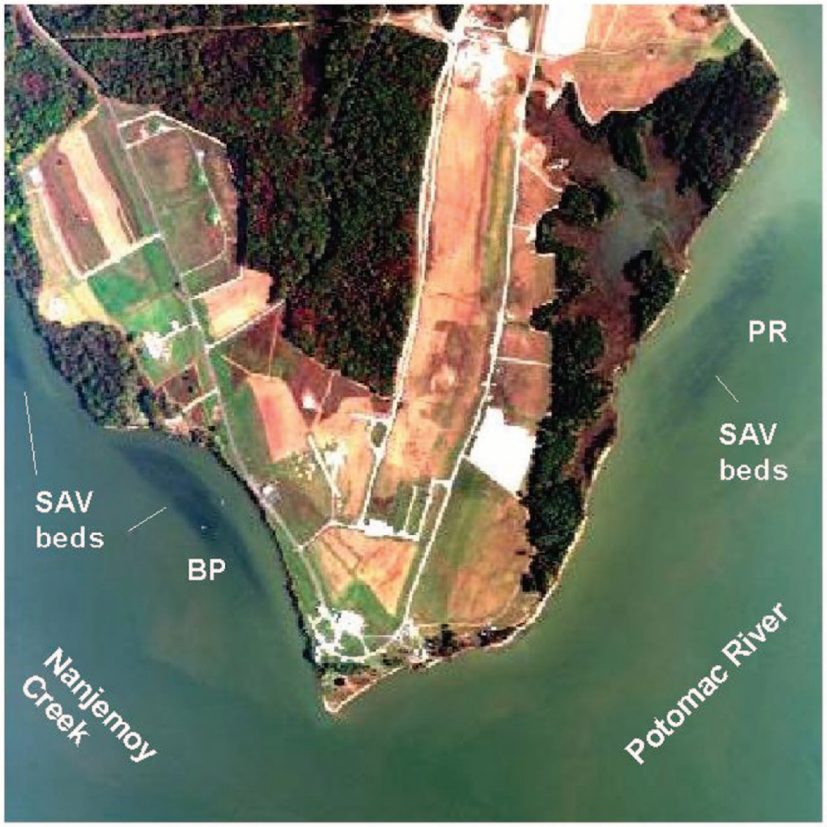

Figure 2. HyMap true color composite image of the study area.

1990). The spectral library database of field collected spectra of milfoil and wild celery was compared to each pixel in the hyperspectral image by the SFF procedure. The algorithm produced two images; a scale image measuring the depth of the absorption feature of interest, and root mean square (rms) error image that indicates the degree of match between the reference spectra from the spectral database to the image spectra. Both images were then used to identify SAV by 'best match' to the reference spectra, resulting in a determination of dominant SAV species in each target pixel.

2.4 WATER SAMPLES AND SAV SPECIES CHARACTERIZATION

Water quality parameters were obtained for two sample sites in and outside the SAV beds located at the mouth of Nanjemoy Creek (BP) and on the Potomac River (PR) (Stankelis *et al*., 2000). Total suspended solids (TSS), total volatile solids (TVS), total chlorophyll-a (CHLA-T), and active chlorophyll-a (CHLA-A) were obtained inside the SAV bed on October 13, 2000. Temperature, salinity, water depth, Secchi depth and Li-Cor underwater light field measurements at stations just below the water surface, midpoint, and at bottom, were obtained October 26, 2000. On October 26, two samples, one in and one outside of the bed, were taken for each site at 100 and 300 meters offshore for BP, and 50 and 200 meters offshore for PR (Bob Wardwell, written communication). The US Geological Survey (USGS) characterized the distribution and abundance of the SAV species for BP and PR on August 31, 2000 by shoreline survey conducted by shallow draft boat (see Ruhl *et al*., 1999 for methods). Aerial photography (1:24,000 scale) obtained on September 29, 2000, was utilized to map the distribution of SAV for the site (see Orth et al, 2000 for methods).

3. Results and Discussion

3.1 HYPERSPECTRAL IMAGERY INTERPRETATION

SAV beds were present and detecTable in the airborne hyperspectral imagery of Blossom Point (Figure 2). The two species of SAV and water were found to be spectrally separable (Figure 3). The absorption band depths at 0.681 μm, and to a lesser extant 0.574 μm, were more pronounced for milfoil than wild celery (Figure 4). This difference was likely due to the way the SAV plant canopy interacts with light (Asner, 1998) The fully submerged profile of wild celery can be characterized as being meadow forming. Plant stems are mostly vertical. If the remote sensor is oriented at a nadir position, the plant tissue surface available as a reflecting target is negligible. Milfoil is a canopy forming species. Stems are vertical near the bottom, but this species also has numerous small branches that form horizontal surfaces. This type of orientation presents a much larger reflectance target relative to the sensor. Interactions of the plants with epiphyte colonization is another source of spectral variation. These colonies, which can be made up of algae, sediment,

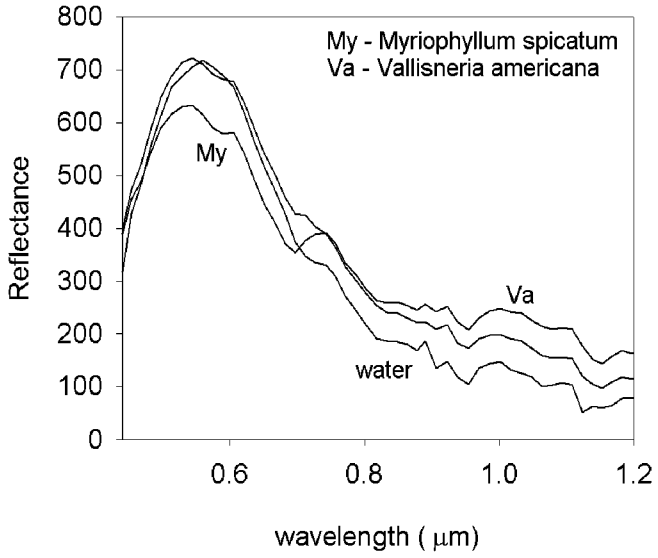

Figure 3. Relative reflectance spectra of two species of SAV and ambient water.

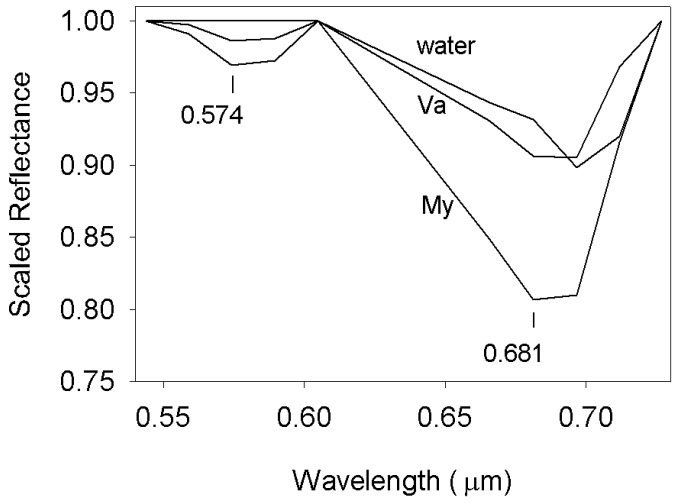

Figure 4. Continuum removed spectra of water and two species of SAV.

bryophytes, and other micro and macro organisms, coat the SAV leaf surface and therefore decrease the amount of light reaching the leaf surface (Orth *et al*., 1982; Stankelis *et al*., 2000). The species milfoil, due to its morphology, has more surface area for epiphyte attachment than the species wild celery. Comparison of spectra obtained in the lab for milfoil with and without attached epiphytes indicate that the absorption at approximately 0.574 μm is mostly a result of epiphytes and sediment coating on the SAV.

Two remnant beds of milfoil and wild celery were identified by the hyperspectral technique (Figure 5b). The locations of the beds correspond well to the locations of the bed during the peak growing season determined by the USGS (Figure 5a). The accuracy of the hyperspectral remote sensing derived SAV species map was assessed by comparison to the SAV map produced by the USGS National Research Program using field data and aerial photography. The USGS map shows SAV abundance and distribution in August 31, 2000, and does not reflect the coverage of the SAV at the time of the hyperspectral overflight. Nevertheless, the USGS map reinforces species determinations from the hyperspectral project and can be used to estimate the accuracy of the results.

3.2 WATER AND SAV FIELD DATA

The chemistry and optical properties of the ambient water at the study area are listed for the two sampling dates (Table 1). Irradiance attenuation coefficients (Kd) for the sample sites, BP-100, BP-300, PR-50, PR-200, were 1.96, 1.28, 1.15, and 1.47 (m-1) respectively. The ambient water for these sites can be characterized as moderately transparent (Kd < 2).

Table 1. Water chemistry and optical parameters for the Blossom Point (BP) and Potomac River (PR) sites for October 13 (A) and October 26 (B) of 2000.

(A) October 13

Station	*Date*	*TSS (mg/L)*	*TVS (mg/L)*	*CHLA-T (μg/L)*	*CHLA-A (μg/L)*
BP	10/13/00	8.20	2.60	2.90	2.38
PR	10/13/00	7.60	2.40	1.86	1.35

(B) October 26

Station	*Date*	*Water Temp. (deg. C)*	*Salinity (ppt)*	*Water Depth (m)*	*Secchi Depth (m)*	*LiCor 5cm*	*LiCor Mid*	*LiCor Bottom*
						(μmol s^{-1} m^{-2})		
BP-100	10/26/00	18.2	7.3	0.86	0.5	1,766.6	631	328.5
BP-300	10/26/00	17.7	6.2	1.33	0.74	1,910.5	610	350.5
PR-50	10/26/00	18.1	7.5	0.52	0.52	1,342	1,103	736.7
PR-200	10/26/00	18	7.7	2.16	0.86	1,166.5	270	48.92

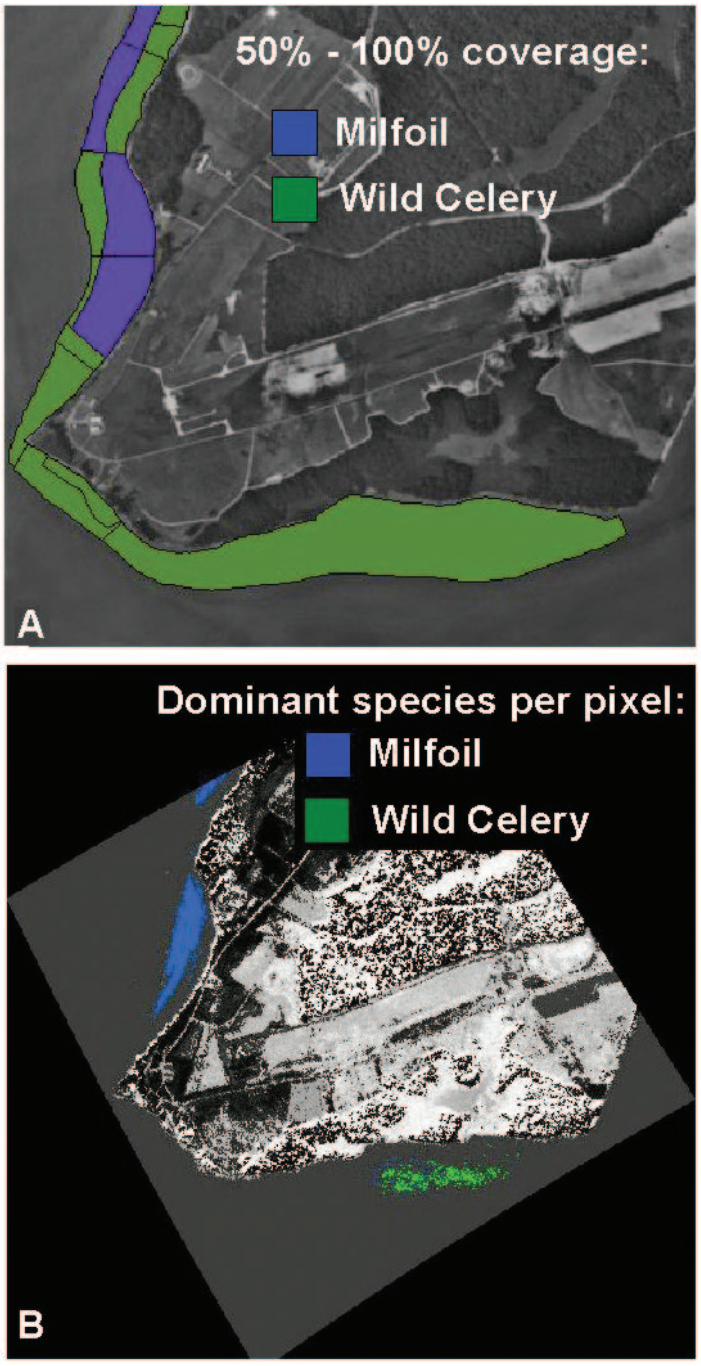

Figure 5. a) USGS field-derived SAV species and abundance map for August 31, 2000; and b) HyMap imagery-derived map for October 21, 2000. By October, large portions of the SAV population has senesed, only a remnant of the August bed is present in October.

Field data showed dominance of milfoil at BP and wild celery at PR (Figure 5a) in August, the peak of the growing season. In October, 2000, each bed was field checked and the dominance of milfoil and wild celery was established, although each bed had mixed composition and the demarcation between species in Figure 5a are often a gradient rather than a sharp separation. The species composition for the BP site were 90 % mifoil and 10% wild celery, while the PR site was 97% wild celery, 3% milfoil, and 1% *Ceratophyllum demersum*.

4. Conclusion

Hyperspectral imagery was used to identify and classify SAV beds in an aquatic environment that can be characterized as optically complex given the significant concentrations of suspended solids and chlorophyll. The primary absorption band for photosynthesis (680 nm) was detecTable in the submerged plant canopies. The differentiation of SAV species was done by exploiting the way light is scattered or absorbed by physically different plant canopies, rather than by some unique bio-chemical signature. Our data suggests that the presence of epiphytes and sediment coating on the SAV obscure species' biochemical reflectance signatures. This bio-physical methodology might be limited in beds of SAV plants with similar canopy profiles, or during low tide when the leaves of meadow forming species become horizontal at the surface. Further research into the spectral signatures of various SAV species with a focus on bio-chemical differences is warranted. Proper timing of the overflight to collect SAV spectra before dense epiphyte colonization might allow for more accurate species identification.

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