Front. Earth Sci.
DOI 10.1007/s11707-012-0330-2

RESEARCH ARTICLE

Spectral signatures of hydrilla from a tank and field setting

Alfonso BLANCO (✉), John J. QU, William E. ROPER

George Mason University, College of Science, Department of Geography and Geoinformation Sciences,
4400 University Drive, Fairfax, VA 22030, USA

Abstract The invasion of hydrilla in many waterways has caused significant problems resulting in high maintenance costs for eradicating this invasive aquatic weed. Present identification methods employed for detecting hydrilla invasions such as aerial photography and videos are difficult, costly, and time consuming. Remote sensing has been used for assessing wetlands and other aquatic vegetation, but very little information is available for detecting hydrilla invasions in coastal estuaries and other water bodies. The objective of this study is to construct a library of spectral signatures for identifying and classifying hydrilla invasions. Spectral signatures of hydrilla were collected from an experimental tank and field locations in a coastal estuary in the upper Chesapeake Bay. These measurements collected from the experimental tank, resulted in spectral signatures with an average peak surface reflectance in the NIR region of 16% at a wavelength of 818 nm. However, the spectral measurements, collected in the estuary, resulted in a very different spectral signature with two surface reflectance peaks of 6% at wavelengths of 725 nm and 818 nm. The difference in spectral signatures between sites are a result of the components in the water column in the estuary because of increased turbidity (e.g., nutrients, dissolved matter and suspended matter), and canopy being lower (submerged) in the water column. Spectral signatures of hydrilla observed in the tank and the field had similar characteristics with low reflectance in visible region of the spectrum from 400 to 700 nm, but high in the NIR region from 700 to 900 nm.

Keywords Chesapeake Bay, hydrilla, spectral library, spectral signatures, near infrared, NDVI

1 Introduction

Hydrilla is an aggressive, invasive, non-native aquatic weed that originated in South-east Asia and imported by an aquarium business dealer in 1951, but it was discovered in Snapper Creek Canal in South Florida during the early 1960's as a result of the aquarium trade (Chadwell and Engelhardt, 2008). *Hydrilla verticillata* (L.F.) Royle is either monoecious or dioecious with both male and female flowers. The monoecious strain is dominant in the Chesapeake Bay area where the study sites were located. Presently hydrilla has been found in 21 states across the US, as far north as Maine and Washington State. Hydrilla was first reported in the Chesapeake Bay1982. Once hydrilla invades an aquatic ecosystem, it competes with other native species spreading very rapidly up to 1 inch per day and forming dense mats (Langeland, 1996). Hydrilla reproduces using four mechanism, fragmentation, turions, tubers, and seeds. This noxious weed can ecologically impact the aquatic environment by blocking sunlight to other native species. It can survive to near 10 m depth, anchoring itself in soft sediments along coastal, estuarine, and freshwater habitats (Dennison et al., 1993). Invasive aquatic weeds have an annual maintenance cost of about $110 million which includes the costs of losses associated with the infestations and costs for controlling the invasion (Everitt and Elder, 2010). Waterways can be impaired by uncontrolled invasions of hydrilla. The hydrilla infestations create several transportation problems. The dense hydrilla mats blocks commercial and recreational traffic through navigable waterways, blocking ports and passenger ferry terminals. Masses of hydrilla puts a lot of pressure on bridge piers locks, and docks. The weight of large mats of hydrilla pushed by water currents can scour weakening infrastructures rendering a costly repair and replacenment. These transportation problems caused by hydrilla infestation are significant sand costly problems in the southern and coastal states, but these transportation problems are not limited to US, but to other countries like China, South America, and Africa. In the Chesapeake Bay, hydrilla has

Received May 5, 2012; accepted July 23, 2012

E-mail: ablanco@gmu.edu

spread very rapidly causing problems in cooling ponds for power generating utility companies. Besides causing a nuisance to the commercial and recreational industries, hydrilla offers several benefits by providing shelter, food and habitat to aquatic life, controls erosion, improves water quality, a good indicator for climate change, and provides for an early warning signal for harmful algae blooms (Everitt and Elder, 2010). The early detection of hydrilla infestation is very important to government agencies because it can reduce the costs associated with the removal of this aquatic weed. Procedures such as aerial photography, and field measurements for inventorying and assessing the presence of hydrilla are difficult, time-consuming, expensive, all of which justifies for evaluating other identification techniques, such as remote sensing (Scarpace et al., 1981). Presently remote sensing is been used for assessing wetlands and upland vegetation, but very little information is available on the identification and classification in water bodies (Adam et al., 2010). Remote sensing is the practice of deriving information about the earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the earth's surface. Conventional mapping has been based on fieldwork and projected on aerial maps, but these conventional methods are tedious, costly, and the quality of information is very limited. Remote sensing has the advantages of processing the images automatically, access the image archives, and have a large spatial coverage. Black and white or color infrared photographs have a high spatial resolution, but low spectral resolution. One advantage is that these aerial photos are inexpensive because there are large databases available for many areas and they are available at a hyperspectral resolution from 0.1.to 2 m. However, the major disadvantage is that those photos require extensive manual labor for processing. Another technique uses digital images with a much greater spectral resolution, but coarser spatial resolution

Reflectance measurements have been used to distinguish from aquatic plant species related to the responses from the images on conventional color and color infrared (CIR) photographs. It was reported by Everitt et al. (2009) that the spectral reflectance of five aquatic weeds hydrilla, eurasian watermilfoil, water hyacinth, water lettuce, and parrot feather were tested for spectral reflectance and there were distinct differences among all five species. The darker green color of water hyacinth and hydrilla reflected less of the green light and absorbed more of the blue, red, and red edge light than the other aquatic weeds with lower chlorophyll concentrations. Aquatic vegetation has unique spectral signatures that are detectable, such as low reflectance due to absorption by chlorophyll *a*, and high reflectance in the Near-Infrared (NIR) region (Everitt et al., 2009). Plant pigments that are responsible for the surface reflectance play important roles in photosynthetic light capture. Clark et al., (1993) has shown that the reflectance peak at 500 nm is the result of chlorophyll absorption (at 450 nm and 680 nm) and gives the plants the green color. The slope between 700 nm and 800 nm is named the "Red Edge" and is due to the contrast between the strong absorption of chlorophyll and the reflectance of the leaves. Chlorophyll's a and b absorbs around the blue (450 nm) and red (670 nm) regions of the light spectrum for photosynthesis. The internal spongy leaf structure (mesophyll) reflects high in the NIR region from a wavelength of 700 to 1000 nm (Lillesand et al., 2008).

Detecting the infestation of this aquatic weed early on using hyperspetral sensors, can evaluate the extent of the invasion, provide sufficient time for preparing management strategies, and aid in the design of control measures (Kemp et al., 2004). To detect invasive species with hyperspectral sensors, a spectral signature library needs to be built by collecting ground measurements of the aquatic vegetation. The purpose of the study is to build a spectral library for hydrilla through the collection of spectral signatures from two different sites. Based on the analysis of the spectral responses, the surface reflectance and the absorbance of chlorophyll *a* were examined with the regions of the electromagnetic spectrum.

2 Materials and methods

2.1 Study sites

2.1.1 Anita Leight Center site

The experimental tank site was located behind the Anita Leight Estuary Center (39° 26′ 54"N, 76° 16′ 05"W) Harford County, Edgewood, Maryland, USA (Fig. 1).

The Center grows hydrilla, wild celery, redhead grass, algae, long leaf pondweed, slender pondweed, and water stargrass, in four outdoor experimental tanks as shown on Fig. 2.

2.1.2 Otter Point Creek Estuary site

Study site 2 is located at the Otter Point Creek estuary (39° 27′ 03"N, 76° 16′ 28"W), south of the Susquehanna River, in the upper Chesapeake Bay National Estuarine Research Reserve. Otter Point Creek is one of the last remaining freshwater tidal marshes in the Chesapeake Bay, classified as oligohaline (low salinity or brackish water) with a surface area of 283 ha consisting of open water, tidal marshes, forested wetlands, and upland hardwood forests which are ideal conditions for the growth of hydrilla.

2.2 Data collection

2.2.1 Experimental tank measurements

The data was collected on August 5, 2008 behind the Anita

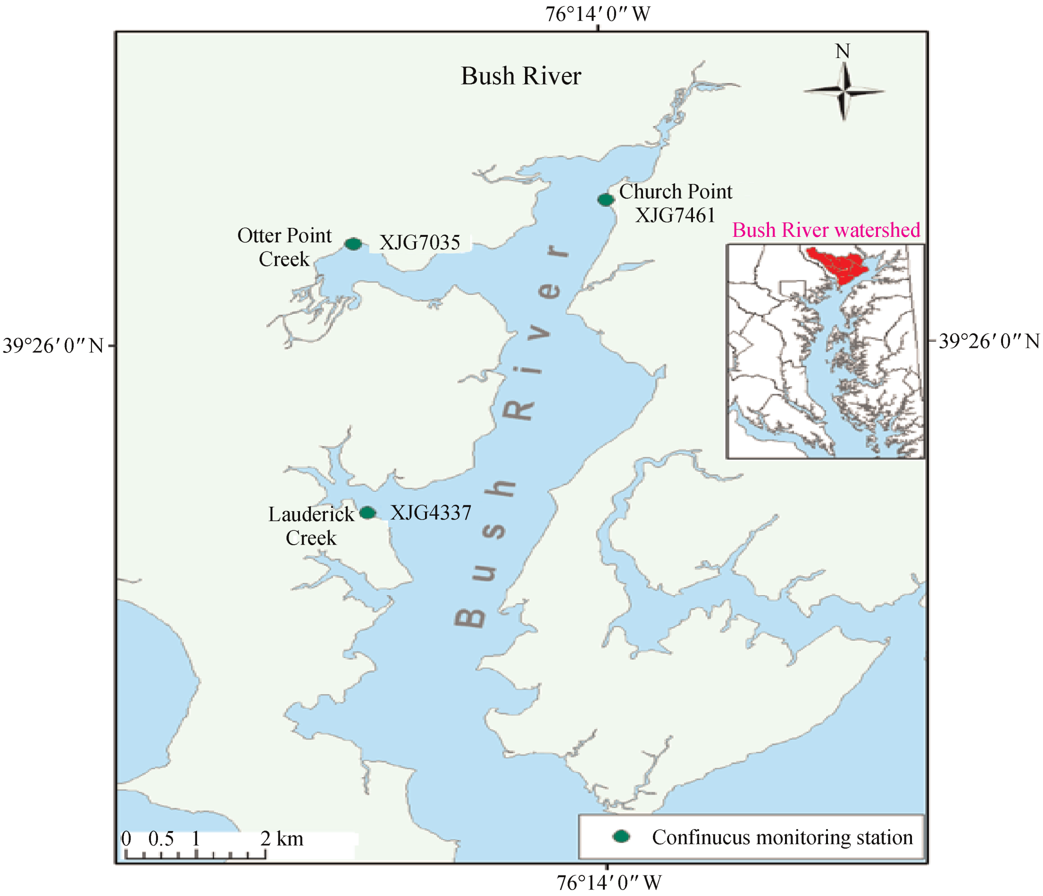

Fig. 1 Location of Anita Leight Center and Otter Point Creek study sites (Pasternack and Hinnov, 2003)

Fig. 2 Anita Leight Center experimental tanks (Photo provided by Anita Leight Center)

Leight Center from an experimental tank containing hydrilla. A total of 35 reflectance measurements were collected and processed with an Analytical Spectral Devise (ASD) spectroradiometer FieldSpec Pro Full Range (FR)[1]. The spectroradiometer has three spectrometers recording wavelengths from 350 nm to 2500 nm with an spectral resolution of 1 nm. The instrument averaged the readings to compensate for noise and ten readings were analyzed. The hydrilla in the experimental tank was observed to be emergent without suspended matter or turbidity that could attenuate the light. The measurements were collected from 10:00 am to 10:30 am. The weather conditions at the time of collecting the data were partly cloudy, but there was no precipitation. In order to account for changes in light conditions and instrument drift, he ASD instrument was calibrated every 10 min according to the instrument manufacturer by taking measurements above-water down-welling irradiance with a Spectralon (Labsphere, North Sutton, NH, USA)[2] white reference panel. The Spectralon panel has a high diffuse reflectance over a wide spectral range and converts it to percent reflectance. The Field Spec FR has a 1.5 m fore optic (25º field of view) which was positioned at nadir approximately 46 cm above the vegetation as shown on Fig. 3.

The probe was positioned at several locations inside the

---

1) Analytical Spectral Devices Boulder, CO, http://www.asdi.com/
2) Spectralon http://www.labsphere.com

Fig. 3 Collection of spectral signatures in the experimental tank (Photo taken by A. Blanco 8-5-2008)

tank to collect the highest reflectance values. The spectral signatures collected were pre-analyzed on the ASD instrument computer to ensure accuracy of the data before processing it. The radiance measurements were converted to reflectance by dividing them with the Spectralon and recorded by the instrument. The reflectance ranged from 0.0 to 1.0 or 0 to 100%.

2.2.2 Field measurements

A sample of hydrilla from the hydrilla tank is shown on Fig. 4. Hydrilla thrives along the shore of Otter Point Creek on silty to muddy substrata, as shown in Fig. 5. The hydrilla lacks chlorophyll *a* because of its dark brown color compared to the sample from the tank on Fig. 4. Figure 6 shows the hydrilla mats submerged on the left side of the pier at high tide.

Fig. 4 Sample of Hydrilla collected from the tank (Photo taken by A. Blanco 8-5-2008)

Fig. 5 Hydrilla mats near the shore of Otter Point Creek at low tide (Photo taken by A. Blanco 8-9-2009)

Fig. 6 Submergent hydrilla beds on the left side of the pier (Photo taken by A. Blanco 8-9-2009)

The Otter Point Creek site is optimum because hydrilla is the dominant species (i.e., monoecious). The density of hydrilla at the pier site was 100 %, similar as to the hydrilla tank. No other aquatic plant species were identified within the hydrilla canopy. The spectral signatures were collected on August 9, 2009 at high tide from 10:00 a.m. to 11:00 a.m. The conditions of the water in the pier area were turbid and the depth was about 0.8 feet at 10:47 a.m.. The weather conditions were excellent, sunny, no cloud cover, and no precipitation. The ASD instrument was calibrated every 10 min with the Spectralon white reference panel for accounting for changes in light conditions and instrument drift. Twenty nine readings were collected and processed by the ASD instrument at the site, but only twelve spectra were plotted for clarity. The spectral signatures were processed and converted from ASD format to text format, then graphed using Excel 2007 software program.

3 Results and discussion

Due to water absorption recorded by the ASD instrument above 900 nm, only wavelengths from 400 to 900 nm were used for comparing the hydrilla between the tank and the field measurements because this range covers the sensitivity of conventional color. A total of 35 spectral measurements were collected from the tank. The spectral measurements, as per instrument specifications, were averaged to ten spectra (Fig. 7) for compensating for noise.

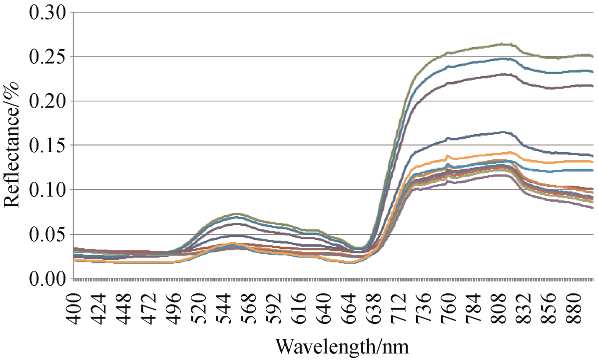

Fig. 7 Results of spectral signatures in the experimental tank

Each colored spectra was extracted from the moist hydrilla leaves from a different location in the tank. A separation was noted between the third and fourth spectra due to the movement of the probe from one location to another. The surface reflectance of hydrilla was plotted against wavelengths between 400 nm and 900 nm and compared to the field measurements collected at the pier. The maximum reflectance in the experimental tank was observed in the NIR region at 26.5% and a wavelength 818 nm. Chlorophyll absorbance was noted at a wavelength of 488 nm, 2.6% and 670 nm, 3.26%. An irregular reflection was noted at 760 nm for all the spectral signatures, due to water absorption by the ASD instrument.

A total of 29 measurements were collected from the pier, but only twelve were plotted for simplicity. Figure 8 shows three reflectance peaks, one peak is in the visible region at 567 nm with a surface reflectance of 4.36%, and two in the NIR region, one at 716 nm and the other at 817 nm with a peak reflectance of 6.43% and 7.71%, respectively. The two absorption troughs shown on the graph are attributed to the absorption of chlorophyll a at a wavelength of 679 nm, with a 2.8% surface reflectance and at 740 nm, and 3.0% surface reflectance.

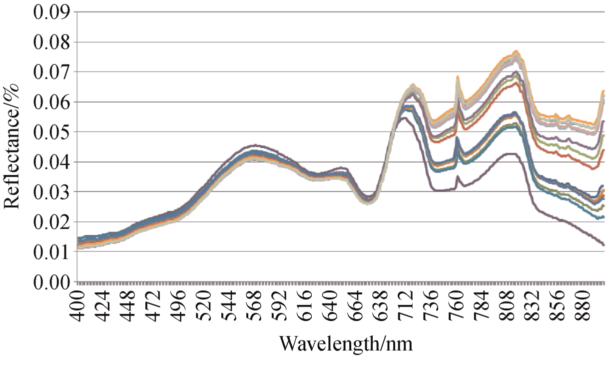

Fig. 8 Results of spectral signatures in the field from the pier

The spectral signatures for the tank and field measurements were averaged as shown on Fig. 9. The data shows that there were some differences in the spectral signatures collected from the experimental tank and from the field. As seen in Figs. 7 and 8, the field data generated two reflectance peaks which are assumed that the hydrilla leaves in the experimental tank were emergent and not exposed to turbidity, sediments, nutrients, or other elements contained in the water column, while the hydrilla mats in the field were submerged and exposed to the effects of light attenuation. The difference between the reflectance of hydrilla in the tank and in the field is 16% and 6%, respectively. The double peaks at 723 nm and 800 nm are the result of water absorption in the canopy. The spectral signatures of hydrilla observed in the tank and the field had similar characteristics, of low reflectance in the visible region of the spectrum from 400 to 700 nm, but high reflectance in the NIR region 700 to 900 nm. Everitt et al. (2009) reported similar results for measurements of aquatic vegetation where the maximum reflectance in the green region has been reported at 550 nm with a maximum reflectance in the NIR region of 700 nm. The wavelengths at the red edge 680–730 nm are important for reflectance measurements. Spectral signatures for hydrilla under turbid water conditions behave different than in non-turbid conditions. There were several external factors during the collection of spectra which influenced the hydrilla reflectance characteristics, such as cloud cover, instrument drift, atmospheric changes, and turbidity. It has been reported that the performance of hyperspectral response by aquatic vegetation depends on the submergence, dissolved organic matter and on turbidity (Tian et al., 2010). Also

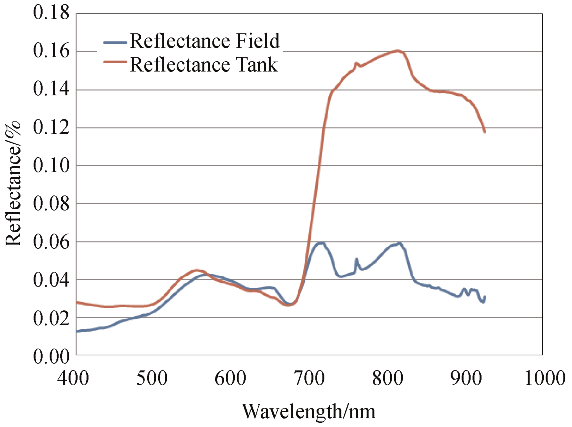

Fig. 9 Results of the average measurements collected in the tank and the field

reported that hydrilla was submergent and had lower NDVI values than other emergent aquatic species (Cho et al., 2008). The findings in this study showed that the reflectance measurements in the tank were higher than in the field because hydrilla in the tank was emergent. Both spectra collection were spectrally distinct over the NIR regions as shown on Figs. 7–9. Similarly as in the experimental tank measurements, an irregular reflection was observed at 760 nm caused by water absorption registered in the ASD instrument. It is more noticeable on the spectra collected on the field than in the experimental tank.

Hydrilla in the experimental tank were emergent, while the hydrilla in field were submerged. The low reflectance at the visible region was attributed to the presence of absorption of chlorophyll a, which indicates healthy conditions of the species (Tian et al., 2010). Hydrilla showed the typical vegetation reflectance pattern in the tank both sites; green region peaking at a wavelength of 550 nm, red absorption near 670 nm, and NIR greater than 700 nm. Figure 8 shows a reflectance difference between the tank and the field measurements from a wavelength of 685 to 839 nm. Spectral studies performed near nadir decreased the effects of solar angle on the submerged aquatic plant leaves (Malthus and George, 1997).

In the tank, hydrilla registered a peak reflectance at a wavelength of 818 nm and 16% and 6% for the field. Lee et al. (2007) reported that the wavelength of 710 nm is important for turbid coastal waters and waters with phytoplankton blooms (red tide), and wavelength of 700 nm and other near-infrared bands are important because they are required for atmospheric correction or for highly turbid inland waters.

The Normalized Difference Vegetation Index (NDVI) was developed by Rouse et al. (1974). NDVI is based on the contrast between the maximum absorption in the red region due to chlorophyll pigments and the maximum reflection in the infrared caused by leaf cellular structures using hyperpsectral narrow wavebands. This index is shown by the following equation (Wu et al., 2008).

$$\mathrm{NDVI}[670,\ 800] = \mathrm{R800} - \mathrm{R670}/\mathrm{R800} + \mathrm{R670} \qquad (1)$$

Vegetation indices incorporating bands in the green- and red- edge parts of the spectrum were developed to measure the absorption by chlorophyll in the red region (670 nm). Results for the NDVI values for ten spectral measurements of hydrilla were calculated for the hydrilla in the experimental tank and are reported in the website indicated in the footnote. The average NDVI for hydrilla was 0.695 for the experimental tank and 0.345 for the field. Kim et al. (1994) developed the Chlorophyll Absorption Ratio Index (CARI) which measures the depth of chlorophyll absorption at 670 nm relative to the green reflectance peak at 550 nm and the reflectance at 700 nm. This ratio index was developed to reduce the changes of the active radiation due to the presence of different materials. The index uses bands which correspond to minimum absorption of the pigments which are centered at wavelength 550 nm and 700 nm, in conjunction with the maximum chlorophyll a absorption band which is at 670 nm. Wu et al. (2008) modified this chlorophyll ratio index (MCARI) as follow.

$$\begin{aligned}&\mathrm{MCARI}[670{,}700]\\&\quad = [(\mathrm{R700} - \mathrm{R670}) - 0.2(\mathrm{R700} - \mathrm{R550})]\\&\qquad \times (\mathrm{R700}/\mathrm{R670}) \qquad (2)\end{aligned}$$

The MCARI average values for ten spectral measurements of hydrilla were 0.026 for the experimental tank and 0.01665 for the field. The results for the hydrilla spectral library, a Normalized Difference Vegetation Index (NDVI) and the Modified Chlorophyll Absorption Ratio Index (MCARI) are shown at the following website:

http://estc.gmu.edu/database/Hydrilla/

4 Conclusions

This study shows that identification and use of the spectral signatures of aquatic vegetation are typical of riverine and creek habitats which are very useful for image classification. A better understanding has been gained from this study about those regions of the electromagnetic spectrum because it shows the behavior hydrilla under different settings. Thus collecting the spectral signatures is an important step for the image classification of hydrilla with remote sensing techniques. The peaks of reflectance and the troughs in the NIR are an important spectral region for delineating hydrilla. A deduction can be made that hydrilla is characterized by differences in the structure of the canopy, as well as the difference in the pigment content observed in the absorptive strength in the visible region of the spectrum.

Generally, the low reflectance noted for the visible region could be attributed to the presence of high concentrations of chlorophyll *a*. High absorption of chlorophyll visible and NIR regions indicate healthy conditions of the aquatic vegetation. The chlorophyll content can determine the difference in the spectral signal in hydrilla species by the strength of the red light absorption in the broad trough of the wavelength between 700 to 900 *nm*. However, the spectral regions where hydrilla is most distinct are those associated with the leaves reflectance in the green and near infrared red light, rather that the absorption troughs. The identification of hydrilla depends on the tides and the season. Hydrilla observed in the experimental tank were emergent and the water was not turbid, sediments, nutrients, or other elements, but the hydrilla mats observed alongside the pier were submerged and exposed to the effects of light attenuation. Hydrilla submergent in the estuary had lower NDVI values than the emergent hydrilla in the tank. The study concludes that conventional NDVI can be used to depict hydrilla canopies at the water surface, but is not a good indicator for submergent hydrilla. The NDVI values could be improved if spectral reflectance with light attenuation is collected simultaneously with ground truth measurements. It can be concluded that emergent and submergent aquatic vegetation can be identified and mapped from a hyperspectral image by matching the spectral signature collected on the field. This spectral library is very useful to water resource managers and scientists for identifying and classifying hydrilla invasions when used with special image visualization software. Future work will entail integrating the spectral library[1] in the database into an image visualizing software for identification and classification.

Acknowledgements The author would like to thank Terry Slonecker of USGS for assistance in collecting the spectral signatures and the Anita Leight Center personnel for allowing us to gain access to the sampling sites.

References

Adam E, Mutanga O, Rugege D (2010). Multispectral and hyperspectral remote sensing for identification and mapping of wetland vegetation: a review. Journal of Wetlands Ecology and Management, 18(3): 281–296

Chadwell T B, Engelhardt K (2008). Effects of pre-existing submerged vegetation and propagules pressure on the invasion success of *Hydrilla verticillata*. J Appl Ecol, 45(2): 515–523

Cho H J, Kirui P, Natarajan H (2008). Test of multi-spectral vegetation index for floating and canopy-forming submerged vegetation. Int J Environ Res Public Health, 5(5): 477–483

Clark R N, Swayze G A, Gallagher A J, King T V, Calvin W M (1993). The U.S. Geological Survey, Digital Spectral Library: Version 1: 0.2 to 3 Microns. In: U.S. Geological Survey Open File Report 93–592, U.S. Geological Survey, Reston, USA. http://speclab.cr.usgs.gov

Daughtry C S T, Wallhall C L, Kim M S, Brown de Colstrum E, McMurtrey J E III (2000). Estimating corn leaf chlorophyll concentration from leaf and canopy reflectance. Remote Sens Environ, 74(2): 229–239

Dennison W C, Orth R J, Moore K A, Stevenson J C, Carter V, Kollar S, Bergstrom P W, Batiuk R A (1993). Assessing water quality with submerged aquatic vegetation requirements as barometric of Chesapeake Bay health. Bioscience, 43(2): 87–94

Everitt J H, Elder S H (2010). Evaluating airborne multispectral digital video to differentiate Giant Salvinia from other features in Northeast Texas. Remote Sensing, 2(10): 2413–2423

Everitt J H, Summy K R, Glomski L M, Owens C S, Yang C (2009). Spectral reflectance and digital image relations among five aquatic weeds. Subtropical Plant Sciences, 61: 15–23

Kemp M W, Batleson R, Bergstrom P, Carter V, Gallegos C L, Hunley W, Karrh L, Koch E W, Landwehr J M, Moore K A, Murray L, Naylor M, Rybicki N B, Court Stevenson J, Wilcox D J (2004). Habitat requirements for submerged aquatic vegetation in Chesapeake Bay: water quality, light regime, and physical-chemical factors. Estuaries, 27(3): 363–377

Kim M S, Daughtry C S T, Chapelle E W The use of high spectral resolution bands for estimating absorbed photosynthetically active radiation (Apar.). In: Proceedings of the Sixth Symposium on Physical Measurements and Signatures in Remote Sensing. January 17–21, 1994, Val D' Isure, France, 299

Langeland K A (1996). *Hydrilla verticillata* (L.f.) Royle (Hydrocharitaceae), The Perfect Aquatic Weed. Castanea, 61: 293–304http://aquat1.ifas.ufl.edu/hydcirc.html

Lee Z P, Carder K, Arnone R, He M X (2007). Determination of Primary Spectral Bands for Remote Sensing of Aquatic Environments. Sensors (Basel Switzerland), 7(12): 3428–3441

Lillesand T M, Kiefer R W, Chipman J W (2008). Remote Sensing and Image Interpretation, 6th edition. John Wiley and Sons, New York, NY, USA

Malthus T J, George D G (1997). Airborne remote sensing of macrophytes in Cefni Reservoir, Anglesey, UK. Aquat Bot, 58(3–4): 317–332

Pasternack G B, Hinnov L A (2003). Hydrometeorological controls on water level in a vegetated Chesapeake Bay tidal freshwater delta. Estuar Coast Shelf Sci, 58(2): 367–387

Rouse J W, Haas R H, Schell J A, Deering D W, Harlan J C (1974). Monitoring the Vernal Advancements and Retrogradation of Natural Vegetation. In: NASA/GSFC, Final Report, Greenbelt, USA, 1–137

Scarpace F L, Quirk B K, Kiefer R W, Wynn S L (1981). Wetland mapping from digitized aerial photography. Photogrammetry Engineering Remote Sensing, (47): 829–838

Tian Y Q, Yu Q, Zimmerman M J, Flint S, Waldron M C (2010). Differentiating aquatic plant communities in a eutrophic river using hyperspectral and multispectral remote sensing. Freshwater Biology, 55: 1658–1673

Wu C Y, Niu Z, Tang W (2008). Estimating chlorophyll content from hyperspectral vegetation indices: Modeling and validation. Agric For Meteorol, 148: 1230–1241

AUTHOR BIOGRAPHY

Mr. Alfonso Blanco, P.E., DWRE, obtained his B.S. in Civil Engineering from Merrimack College North Andover, Massachusetts (1972), and his M.S. in Environmental Engineering from Tufts University Medford, Massachusetts (1981). He is a Ph.D. Candidate at George Mason University, College of Science, Fairfax, Virginia majoring in Earth Sciences and Geoinformatics Systems. He has over 37 years of professional experience in the environmental field and presently employed as an Environmental

---

[1] http: //estc.gmu.edu/database/Hydrilla/

Engineer with the US Environmental Protection Agency in Washington, DC. His current research focuses on hyperspectral imaging techniques of submerged aquatic vegetation (hydrilla) in coastal estuaries in the Chesapeake Bay. He is a Licensed Professional Engineer and a Diplomate from the American Academy of Water Resources Engineers. He is a member of the American Society for Photogrammetry and Remote Sensing (ASPRS), Water Environment Federation (WEF), and the American Academy of Water Resources Engineers (AAWRE). E-mail: ablanco@gmu.edu.

Prof. John J. Qu obtained a B.S. in Meteorology from Nanjing Institute of Meteorology (now, Nanjing University of Information Science & Technology (NUIST)), China in 1983, M.S. in Forest Meteorology in 1993, and Ph.D.in Remote Sensing from Colorado State University in 1997. Currently he is a professor, Department of Geography and Geoinformation Science, College of Science, George Mason University (GMU). He is the Founder and Director of the Environmental Science and Technology Center (ESTC) and EastFIRE Lab at GMU. His research areas include: satellite remote sensing algorithms, Earth sciences, global and regional climatic and environmental changes, satellite remote sensing data analysis and application software design, and satellite sensor testing, calibration and validation, and geographic Information Systems (GIS) applications. He also service as WMO/CAgM Representative to Group on Earth Observations (GEO) and Global Climate Observing System (GCOS) and WMO/CAgM Management Group member. He has published over 100 peer reviewed papers, book chapters, and has edited four books.

Dr. William Roper obtained a B.S. in Mechanical Engineering from University of Wisconsin in 1965, M.S. from Agricultural Engineering University of Wisconsin in 1966, Ph.D. in Environmental Engineering from Michigan State University in 1969. Currently he serves on the faculty of George Mason University and as a visiting Professor at Johns Hopkins University. Prior to joining George Mason he was Professor and Chair of the Civil and Environmental Engineering Department at George Washington University. He is a former Federal Senior Executive Service Career Executive having served as the Director and CEO of the Army's Topographic Engineering Center and as the Director of the Army Corps of Engineers World-Wide Civil Works Research and Development Program. Dr. Roper is a member of the American Society of Civil Engineers has been appointed to a number of National Academy of Science Boards and Committees, has authored over 180 technical papers, four books and presented at numerous national and international forums.