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Light Reflectance Characteristics and Remote Sensing of Waterlettuce

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ABSTRACT

Waterlettuce (*Pistia stratiotes* L.) is a free-floating exotic aquatic weed that often invades and clogs waterways in the southeastern United States. A study was conducted to evaluate the potential of using remote sensing technology to distinguish infestations of waterlettuce in Texas waterways. Field reflectance measurements showed that waterlettuce had higher visible green reflectance than associated plant species. Waterlettuce could be detected in both aerial color-infrared (CIR) photography and videography where it had light pink to pinkish-white image tonal responses. Computer analysis of CIR photographic and videographic images had overall accuracy assessments of 86% and 84%, respectively.

Key words: Remote sensing, light reflectance, color-infrared photography, color-infrared videography, accuracy assessment, *Pistia stratiotes*.

INTRODUCTION

Waterlettuce is free-floating exotic aquatic weed that is one of the most cosmopolitan aquatic plants in the world. It is found on every continent except Europe and Antarctica (Gillet et al. 1968, Stoddard 1989, Anonymous 2001) and is believed to be native to South America (Cordo et al. 1981). The floating growth characteristic and fast reproductive rate of waterlettuce cause waterways to become clogged and access to fishing, swimming, and boating to be reduced or eliminated (Gillet et al. 1968, Stoddard 1989, Anonymous 2001). Waterlettuce can form dense mats that may cause oxygen depletion (Attionu 1976) and increase siltation, which ultimately can reduce the stability of the underlying substrate for mating fish (Beumer 1980) and invertebrates (Roback 1974). It is found in waterways of the southeastern United States from Florida to Texas (Correll and Johnston 1970).

Wetland resource managers need rapid techniques for management and assessment of aquatic ecosystems because of the inaccessibility and often large expanses of these areas. Consequently, remote sensing has become an important tool to wetland managers because it allows monitoring at a reasonable cost and it provides much of the needed base information (Carter 1982, Tiner 1997). Field reflectance measurements have proven useful for characterizing the spectral characteristics of wetland plant species (Best et al. 1981, Everitt et al. 2000) and aerial photography and videography have been used successfully to remotely distinguish plant species and communities in wetland environments (Seher and Tueller 1973, Martyn 1985, Mackey et al. 1987, Everitt et al. 1999).

The purpose of this study was to determine the feasibility of using remote sensing technology to distinguish waterlettuce infestations in Texas waterways. The objectives of this study were: (1) to describe the plant canopy light reflectance characteristics of waterlettuce to facilitate its detection on remotely sensed imagery; and (2) to determine the potential of using aerial color-infrared (CIR) photography and videography for distinguishing waterlettuce infestations in southeast Texas.

METHODS AND MATERIALS

This study was conducted on several waterways near Beaumont, Bridge City and Orange in southeast Texas. Aerial photography and videography, radiometric reflectance measurements, computer image analysis, and ground truth observations were conducted for this study. Reflectance measurements were made to establish the spectral characteristics of waterlettuce and dominant associated species and to help interpret the aerial photographs and video images. Aerial imagery and reflectance measurements were obtained on different dates and locations to study waterlettuce under various growing conditions.

Reflectance measurements were made in the field on July 31 and August 21, 2001 near Beaumont, on October 2, 2001 and May 21, 2002 near Orange, and on June 18, 2002 near Bridge City. At the Beaumont site, measurements were made on both dates on waterlettuce, alligator weed [*Alternathera philoxeroides* (Mart.) Griseb.], smartweed (*Polygonum pensylvanicum* L.), waterhyacinth [*Eichhornia crassipes* (Mort.) Solms], and yellow water-lily [*Nuphar luteum* subsp. *macrophyllum* (Small) E. E. Beall]. For the Orange site in October, measurements were made on waterlettuce, giant salvinia (*Salvinia molesta* Mitchell), yellow water-lily, alligator weed, smartweed, waterhyacinth, and bulrush (*Scirpus americanus* Pers.). At Orange in May, measurements were made on waterlettuce, alligator weed, yellow water-lilly, waterhyacinth, giant salvinia, and bulrush. In June at Bridge City, measurements were made on waterlettuce, waterhyacinth, and yellow water-lilly.

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Reflectance measurements were made on ten randomly selected healthy plant canopies of each species with a Barnes[3] modular multispectral radiometer (Robinson et al. 1979). Measurements were made in the visible green (0.52 to 0.60 µm), visible red (0.63 to 0.69 µm), and near-infrared (NIR) (0.76 to 0.90 µm) spectral bands with a sensor that had a 15-degree field-of-view placed 1.0 to 1.5 m above each plant canopy. The area within the sensor field-of-view ranged from 0.26 to 0.39 m. Reflectance measurements were made between 1100 and 1500 hours Central Standard Time under sunny conditions. Radiometric measurements were corrected to reflectance using a barium sulfate standard (Richardson 1981). Overhead vertical photographs were obtained of the plant canopies measured with the radiometer to help interpret reflectance data. Green, red and NIR reflectance data were analyzed using analysis of variance techniques. Duncan's multiple range test was used to test statistical significance at the 0.05 probability level among means (Steel and Torrie 1980).

Color-infrared photography and videography were used for this study. Kodak Aerochrome CIR (0.50 to 0.90 µm) type 2443 film was used with a Fairchild type K-37 large format (23 cm by 23 cm) mapping camera with a film size of 23 cm by 23 cm. The camera was equipped with a 305 mm lens with an aperture setting of f11 at 1/250 sec. Aerial videography was taken with a three-camera multispectral digital video imaging system (Everitt et al. 1995). The system was comprised of three charge-coupled device (CCD) aligned cameras, a computer, a color encoder, and super-VHS recorder. The cameras were visible/NIR (0.4 to 1.1 µm) light sensitive. Two of the cameras were equipped with visible yellow-green (0.555 to 0.665 µm) and red (0.623 to 0.635 µm) filters, respectively, while the third camera had a NIR (0.845 to 0.857 µm) filter. All the cameras had fixed lenses with 12.5 mm focal lengths.

The computer is a pentium 100 MHZ system that has an image grabbing board (640 × 480 pixel resolution) and a 1000-megabyte storage capacity hard drive. The NIR, red, and yellow-green image signals from the cameras are subjected to the RGB inputs, respectively, of the grabbing board in the computer and also the RGB inputs respectively, of the color encoder. This permits the simultaneous acquisition of both digital and analog real-time CIR composite imagery. The digital imagery is stored in the computer hard drive, while the analog imagery is recorded on the super-VHS recorder. The hard drive can store 1000 CIR composite images.

Both CIR photography and CIR composite video imagery were acquired simultaneously of waterlettuce study sites near Beaumont and Orange on July 31 and October 2, 2001, respectively. Imagery was obtained at altitudes ranging from 760 to 1,225 m above ground level. The photographic scales ranged from 1:2,500 to 1:4,000, whereas the pixel resolution of the video images ranged from 0.80 to 1.30 m.

A Model 404 Cessna airplane, equipped with a camera port in the floor, was used for obtaining the aerial photography and videography. The cameras were maintained in nadir position during image acquisition. All imagery was acquired between 1100 and 1400 hours Central Standard Time under sunny conditions.

A CIR photograph and CIR video image of a waterlettuce study site were subjected to computer classification and accuracy assessment. The CIR photograph (1:2,500 scale) and CIR digital video image (0.80 m pixel size) were taken simultaneously of a bayou infested with waterlettuce and other aquatic vegetation near Beaumont on July 31, 2001. A Trimble differential global positioning system (GPS) Pathfinder Pro XRS system that provided submeter accuracy was used in the field to establish control points on the digitized photographic transparency of the waterlettuce study site. The transparency was scanned at 600 dots per inch. Erdas Imagine software (Version 8.3) was used to georeference the transparency (Erdas 1997).

The digital video image of the waterlettuce site was subjected to pixel line correction and image to image registration using Adobe Photoshop and Image Pro software, respectively.

For the image registration process, the red band was used as the image base to rectify the other two bands. The registered CIR composite video image was georeferenced to the CIR photographic image of the waterlettuce site using an image to image procedure in Erdas Imagine (Erdas 1997).

Both the photographic and video images were subjected to an Iterative Self Organizing Data Analysis (ISODATA) which performs unsupervised classifications on the basis of specified iterations and recalculates statistics for each iteration (Erdas 1997). The ISODATA technique uses minimum spectral distance to assign a cluster for each selected pixel. It begins with arbitrary cluster means, and each time the clustering repeats, the means of the clusters are shifted. The new cluster means are used for the iteration.

For both the photographic and video images of the waterlettuce site, each completed unsupervised classification created four data iterations at the 0.99% convergence threshold. The classes consisted of: waterlettuce; water; mixed aquatic vegetation composed of alligator weed, smartweed, and waterhyacinth; and riparian vegetation. For accuracy assessment, 80 points were assigned to the four classes in a stratified random pattern. For each image, the geographic coordinates of the points were determined and the GPS was used to navigate to the points in ground truthing. Both a producer's and user's accuracy were calculated. The producer's accuracy is the measure of omission error and is the total number of correct points in a category divided by the total number of points of that category as derived from the reference data (ground truthing). The user's accuracy is the measure of commission error and is the total number of correct points in a category divided by the total number of points of that category as derived from the classification data or map data.

RESULTS AND DISCUSSION

Mean light reflectance measurements for waterlettuce and associated plant species at three wavelengths for five sampling dates at three locations in southeast Texas are shown in Table 1. In July 2001 at Beaumont, waterlettuce had higher visible green and red reflectance than the other species, whereas waterhyacinth had lower reflectance than the other species at these two wavelengths. Visible reflectance in vegetation is primarily affected by plant pigments (Myers et al. 1983). The species varied in color from the light

TABLE 1. MEAN LIGHT REFLECTANCE MEASUREMENTS OF WATERLETTUCE AND ASSOCIATED PLANT SPECIES ON THREE SITES IN SOUTHEAST TEXAS ON FIVE DATES. REFLECTANCE MEASUREMENTS WERE MADE IN THE VISIBLE GREEN, VISIBLE RED, AND NEAR-INFRARED WAVELENGTHS.

		Reflectance values[1] for three wavelengths		
Location and date	Plant species	green	red	near-infrared
July 2001	Waterlettuce	10.3 a	4.9 a	38.2 b
Beaumont, TX	Yellow water-lily	5.8 b	3.2 b	48.2 a
	Alligator weed	5.3 bc	2.4 c	33.9 c
	Smartweed	5.0 c	2.3 c	36.5 bc
	Waterhyacinth	3.2 d	1.5 d	37.6 bc
August 2001	Waterlettuce	10.5 a	5.5 a	33.9 ab
Beaumont, TX	Yellow water-lily	5.6 b	3.0 b	36.7 a
	Alligator weed	5.7 b	2.6 c	32.9 b
	Smartweed	4.8 c	2.1 d	35.0 ab
	Waterhyacinth	3.0 d	1.4 e	29.9 c
October 2001	Waterlettuce	9.2 a	5.1 a	36.1 b
Orange, TX	Giant salvinia	7.4 b	4.6 b	37.7 b
	Yellow water-lily	5.4 c	2.9 c	44.0 a
	Alligator weed	4.7 d	2.6 d	31.1 c
	Smartweed	5.0 d	3.0 c	37.6 b
	Bulrush	3.5 e	2.5 d	24.8 d
	Waterhyacinth	3.1 e	1.8 e	29.1 c
May 2002	Waterlettuce	8.9 a	5.0 a	35.2 b
Orange, TX	Giant salvinia	7.2 b	5.1 a	34.8 b
	Yellow water-lily	5.6 c	3.9 b	36.6 b
	Alligator weed	5.1 d	3.1 c	29.8 c
	Bulrush	5.0 d	2.9 c	18.3 d
	Waterhyacinth	3.5 e	2.3 d	47.6 a
June 2002	Waterlettuce	10.3 a	5.8 a	38.7 b
Bridge City, TX	Yellow water-lily	5.7 b	3.2 b	41.5 a
	Waterhyacinth	3.6 c	1.8 c	35.2 c

[1]Values within a column at each sampling date followed by the same letter do not differ significantly at the 0.05 probability level, according to Duncan's multiple range test.

gray-green of waterlettuce, to intermediate green of yellow water-lily, alligator weed, and smartweed, to dark green for waterhyacinth. The darker green foliage of waterhyacinth reflected less green light and absorbed more red light than the light gray-green foliage of waterlettuce and various intermediate green foliage colors of yellow water-lily, alligator weed, and smartweed, respectively (Gausman 1985).

At the NIR wavelength, yellow water-lily had higher reflectance than the other species. The NIR reflectance of waterlettuce did not differ from that of smartweed and waterhyacinth. Near-infrared relectance in vegetation is positively correlated with vegetative density (Myers et al. 1983, Everitt et al. 1986). An overhead view of the plant species showed that yellow water-lily had greater leaf density and less gaps in its canopy than the other species. The canopy of waterlettuce had similar density to that of alligator weed and smartweed.

Visible reflectance data for August 2001 at Beaumont followed a similar pattern to that shown in July 2001 (Table 1). Waterlettuce had higher green and red reflectance than the other species, while waterhyacinth had lower reflectance than the other species. Waterhyacinth had lower NIR reflectance than the other species in August. The NIR reflectance of waterlettuce could not be separated from that of yellow water-lily, alligator weed, and smartweed.

At Orange in October 2001, waterlettuce had higher green and red reflectance than the other associated species (Table 1). Bulrush and waterhyacinth had lower green reflectance values than the other species. At the red wavelength, waterhyacinth had lower reflectance than the other species. Giant salvinia had lower green and red reflectance than waterlettuce, but higher reflectance than the other species at these two wavelengths. The NIR reflectance of waterlettuce was similar to that of giant salvinia and smartweed.

In May 2002 at Orange, waterlettuce had higher green reflectance than the other associated species. Conversely, waterhyacinth had lower green reflectance than the other species. At the red wavelength, waterlettuce and giant salvinia had higher reflectance than the other species, but their reflectance values were similar. Waterhyacinth had lower red reflectance and higher NIR reflectance than the other species in May. The NIR reflectance value of waterlettuce could not be separated from that of giant salvinia and yellow waterlilly.

Spectral measurements made at Bridge City in June 2002 showed that waterlettuce had higher green and red reflectance than the other two associated species (Table 1). The NIR reflectance of waterlettuce also differed from that of the other species.

These findings indicate that the visible green wavelength was the optimum spectral region for distinguishing waterlettuce from associated plant species. However, with the exception of one date, waterlettuce could also be distinguished at the visible red wavelength. These results indicate that waterlettuce can be spectrally separated from other associated species throughout the growing season from May through October.

Figures 1A and 1B show a positive CIR photographic print and a CIR video image, respectively, obtained July 31, 2001 of a small bayou infested with waterlettuce and other aquatic plants near Beaumont. The print is a portion of a 23-cm photograph with a scale of 1:2,500. The video image has a 0.80 m pixel size and was extracted from a larger video scene. The arrows on the two images point to waterlettuce. Waterlettuce has a light pink to whitish-pink image tone on the photograph, while on the video image it has a similar tonal response. Other mixed aquatic vegetation has a more reddish response, water is black, surrounding riparian vegetation has various shades of red, pink, magenta, gray, and brown, and bare soil to sparsely vegetated areas have a white to light blue color. The slightly different tonal responses of the video image, as compared to the photograph, are due to electronic coding of the video versus chemical emulsion layers of the film. Waterlettuce had a similar color tonal response to those shown in Figures 1A and 1B in additional CIR photographs and video images, respectively, acquired near Orange in October 2001.

Figures 1C and 1D show the unsupervised computer classifications for the bayou and the adjacent riparian vegetation around its perimeter for the photograph and video images, respectively. Color codes and percentages of respective areas for the various land-use types in both photographic and video images are: yellow = waterlettuce (15% for photograph and 19% for video); red = mixed aquatic vegetation (19% for photograph and 21% for video); green = riparian vegetation (41% for photograph and 37% for video); and blue = water (25% for photograph and 23% for video). A qualitative assessment of the two classifications showed that the computer did an adequate job in identifying most of the waterlettuce in both images, but the photographic classification was more accurate. For example, a stand of waterlettuce in the center of the bayou was identified as riparian vegetation in the classification of the video image.

Tables 2 and 3 show the error matrices for the photographic and video images, respectively, by comparison to the classified data with the ground data for the 80 observations within the study area. The overall classification accuracies for the photographic and video images were 86% and 84%, respectively, indicating that 86% and 84% of the category pixels in each respective image were correctly identified in the classification map.

For the photographic image (Table 2), the producer's accuracy of individual categories ranged from 71% for mixed aquatic vegetation to 100% for water, whereas the user's accuracy ranged from 80% for waterlettuce to 95% for water. Water was the easiest category to identify. Waterlettuce had a producer's accuracy of 86% and user's accuracy of 80% which were considered good. The errors in waterlettuce were mainly caused by its confusion with mixed aquatic vegetation and riparian vegetation. The lower producer's accuracy of mixed aquatic vegetation was primarily due to its confusion with riparian vegetation.

The producer's accuracy of individual categories for the video image (Table 3) ranged from 67% for mixed aquatic vegetation to 93% for waterlettuce, while the user's accuracy

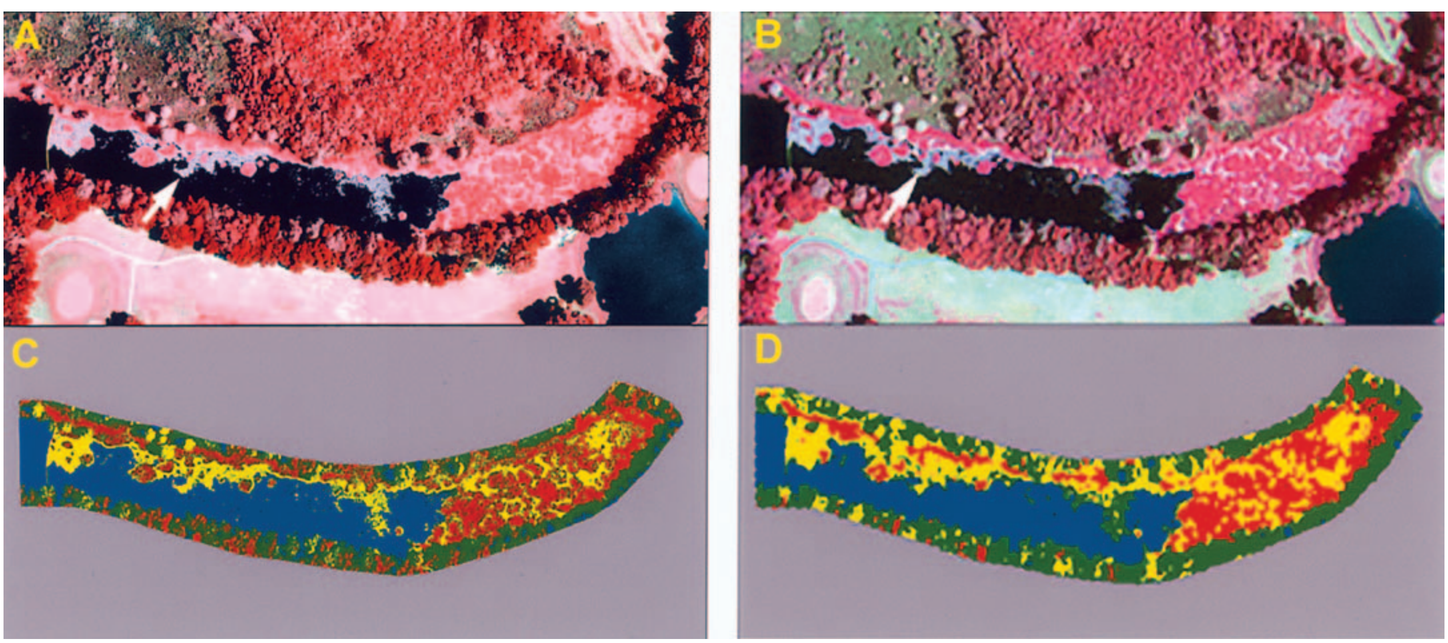

Figure 1. Aerial color-infrared photographic (A) and videographic (B) images obtained on July 31, 2001 of a bayou near Beaumont, Texas infested with waterlettuce and other aquatic vegetation. The arrows point to the whitish-pink tonal responses of waterlettuce. Unsupervised computer classifications of the photographic (C) and videographic (D) images. Color codes for the various land-use types are: yellow = waterlettuce, red = mixed aquatic vegetation, green = riparian vegetation, and blue = water.

TABLE 2. AN ERROR MATRIX GENERATED FROM THE CLASSIFICATION DATA AND GROUND DATA FOR THE JULY 31, 2001 COLOR-INFRARED PHOTOGRAPH OF THE BEAUMONT, TEXAS STUDY SITE.

	Actual Category					
Classified Category	Water	Riparian	Waterlettuce	Mixed aquatic	Total	Users's Accuracy
Water	19	0	1	0	20	95.0%
Riparian	0	23	1	4	28	82.1%
Waterlettuce	0	1	12	2	15	80.0%
Mixed aquatic	0	2	0	15	17	88.2%
Total	19	26	14	21	80	
Producer's Accuracy	100%	88.5%	85.7%	71.4%		

Overall accuracy = 86.3%. Kappa = 0.814.

TABLE 3. AN ERROR MATRIX GENERATED FROM THE CLASSIFICATION DATA AND GROUND DATA FOR THE JULY 31, 2001 COLOR-INFRARED VIDEO IMAGE OF THE BEAUMONT, TEXAS STUDY SITE.

	Actual Category					
Classified Category	Water	Riparian	Waterlettuce	Mixed aquatic	Total	Users's Accuracy
Water	17	1	1	0	19	89.5%
Riparian	1	23	0	5	29	79.3%
Waterlettuce	1	1	13	2	17	76.5%
Mixed aquatic	0	1	0	14	15	93.3%
Total	19	26	14	21	80	
Producer's Accuracy	89.5%	88.5%	92.9%	66.7%		

Overall accuracy = 83.8%. Kappa = 0.763.

ranged from 77% for waterlettuce to 93% for mixed aquatic vegetation. The high producer's accuracy for waterlettuce was considered quite good, while the moderate user's accuracy was acceptable. Like the photographic image classification, errors in the user's accuracy for waterlettuce were primarily due to its confusion with mixed aquatic vegetation and riparian vegetation, while the lower producer's accuracy of mixed aquatic vegetation was mainly due to it confusion with riparian vegetation.

The Kappa estimates, another accuracy measure, were 0.814 and 0.780 for the photographic and video image classifications, respectively. This indicated that the classifications achieved accuracies that were 81% and 78% better than would be expected from random assignment of pixels to categories.

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