REFLECTANCE CHARACTERISTICS AND REMOTE SENSING OF A RIPARIAN ZONE IN SOUTH TEXAS

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ABSTRACT—This paper presents data on utilizing remote sensing technology for characterizing a riparian zone in southern Texas. Radiometric ground reflectance measurements, color-infrared aerial photography, and computer image processing techniques were conducted for this study. Reflectance measurements were made on 8 dominant vegetation types, soil, and water. Spectral measurements were made in the visible green (0.52–0.60 μm), visible red (0.63–0.69 μm), and near-infrared (0.76–0.90 μm) wavelengths. Reflectance values differed significantly ($P = 0.05$) among the vegetation, soil, and water parameters at all 3 wavelengths. Differences in reflectance among the vegetation cover types were attributed to variable foliage coloration and vegetative density. A color-infrared photograph of the study area showed that many of the ecological surface types could be readily distinguished. An unsupervised computer classification of the photograph identified 8 ground classes. An accuracy assessment performed on the classification showed an overall accuracy of 88%.

RESUMEN—Se presenta infomación sobre cómo utilizar la tecnología de la recepción remota para caracterizar una zona riparia en el sur de Texas. Medidas radiométricas de reflectancia del suelo, fotografía aérea infrarroja a color, y técnicas de procesamiento digital de imágenes se realizaron para este estudio. Medidas de reflectancia espectral se hicieron en ocho tipos dominantes de vegetación, suelo y agua. Medidas espectrales se efectuaron en longitudes de onda correspondientes al intervalo visible verde (0.52–0.60 μm), visible rojo (0.63–0.69 μm), y del infrarrojo cercano (0.76–0.90 μm). Los valores de reflectancia variaron significativamente ($P = 0.05$) entre los parámetros de vegetación, suelo y de agua en las tres longitudes de onda. Diferencias de reflectancia entre los tipos de cobertura vegetal se atribuyeron a la coloración variada del follaje y a la densidad de la vegetatión. Fotografía aérea infrarroja del área bajo estudio mostró que muchos de los tipos surperficiales ecológicos pueden ser fácilmente identificados. Una clasificación no supervisada con computadora identificó ocho clases de capas superficiales. Una evaluación de la clasificación demostró una precisión total del 88%.

Riparian zones and other wildland areas are often too large and inaccessible to determine their characteristics by ground surveys. Remote sensing techniques offer potentially timely, cost effective means of obtaining reliable data for these areas (Tueller, 1982). Color-infrared (CIR) aerial photography has been used extensively to inventory and classify riparian and wildland areas (Bonner, 1981; Tueller, 1982; Carneggie et al., 1983; Everitt and Deloach, 1990; Lonard et al., 1998).

Field spectroradiometric light reflectance measurements have been used to distinguish among weed, wetland, and rangeland species (Best et al., 1981; Gausman et al., 1981; Everitt et al., 1986). Reflectance measurements have also been used to distinguish woody plant species (Gausman et al., 1977; Everitt et al., 1989) and related to their tonal responses on CIR aerial photographs. Aerial photographs can be digitized and subjected to computer analysis to quantify ecological cover types within these images (Everitt et al., 1990).

The objectives of this study were to: 1) describe reflectance characteristics of major vegetation types, soil, and water in a riparian zone in southern Texas; 2) evaluate large scale CIR aerial photography for distinguishing among these cover types; and 3) determine potential of computer image processing for automated classification of the area.

MATERIALS AND METHODS—This study was conducted near Tilden, in southern Texas. Tilden is located approximately 100 km south of San Antonio in the Rio Grande Plain vegetational region of Texas (Hatch et al., 1990). The study site was a riparian area located on the Frio River in Choke Canyon State Park. The adjacent area is dominated by Tamaulipan thorn shrublands on clayey calcareous soils (Correll and Johnston, 1970). Aerial photography, radiometric reflectance data, computer image analysis, and ground truth observations were conducted for this study. Reflectance measurements were collected to determine the spectral characteristics of plant, soil, and water variables within the study site and to help interpret aerial photography, and ground truth observations were collected to verify interpretations of the aerial imagery.

Radiometric measurements were collected from 10 randomly selected plant canopies of each plant species or species mixture, soil, and water surface with a Barnes modular multispectral radiometer (Robinson et al., 1979). Reflectance measurements were obtained on black willow (*Salix nigra* Marsh.), dryland willow (*Baccharis neglecta* Britt.), bermudagrass [*Cynodon dactylon* (L.) Pers.], mixed herbaceous species (MHS)-lush, MHS-moderately stressed, MHS-severely stressed, hydrilla [*Hydrilla verticilata* (L. F.) Royle], algae (*Spirogyra*), bare soil, and water. These 10 vegetation, soil, and water surface types were the dominant land cover types in the study area. The area was experiencing drought conditions during this study and consequently, the 3 classes of MHS were observed. Lush MHS were found on the floodplain zone adjacent to the river, and moderately stressed and severely stressed MHS were located on the well drained slopes. Lush MHS were comprised of grasses, sedges, and broad-leaved herbs, whereas moderately stressed and severely stressed MHS were comprised of grasses and broad-leaved herbs. Black willow and dryland willow were the dominant woody plants in the area, and bermudagrass was a dominant herbaceous species. Hydrilla and algae were dominant aquatic plant species in the area. Measurements were obtained from the visible green, visible red, and near-infrared (NIR) spectral bands with a sensor that had a 15-degree field-of-view placed 1.0 to 1.5 m above each plant, soil, and water target. The area within the sensor field-of-view ranged from 0.26 to 0.39 m. Reflectance measurements were obtained on 24 June 1998 under sunny conditions between 1100 and 1500 h CST, with some measurements made from a step ladder. Radiometric measurements were corrected to reflectance using a barium sulfate standard. Overhead vertical photographs were obtained of plant canopies, soil, and water measured with the radiometer to help interpret reflectance data.

Kodak Aerochrome CIR (0.50 to 0.90 μm) type 2443 film was used for aerial photographs. Color-infrared film is sensitive in the visible green (0.50 to 0.60 μm), visible red (0.60 to 0.70 μm), and NIR (0.70 to 0.90 μm) spectral regions. Photographs were obtained with a Fairchild type K-37 large-format (23 cm by 23 cm) mapping camera. The camera had an aperture setting of f8 at 1/250 sec and a 305-mm lens equipped with a Wratten 15 orange (minus blue) filter. Photographs were obtained on 17 June 1998 at an altitude above ground level of 600 m (scale 1:2,000). Photos (nadir) were acquired under sunny conditions with a Cessna 404 aircraft between 1130 and 1200 h CST. The camera was mounted vertically in a camera port in the floor of the aircraft.

A CIR photographic transparency of the study site was scanned and subsequently digitized to perform a computer classification of land cover and an accuracy assessment. A Trimble global positioning system (GPS) Pathfinder Pro XRS system was used in the field to establish control points on the digitized photographic transparency for georeferencing. All image processing was performed using Erdas Imagine software (Version 8.3). The image was subjected to an unsupervised classification using ISODATA (Erdas, Inc., 1997). The ISODATA technique uses minimum spectral distance to assign a cluster for each selected pixel. With a specified number of arbitrary cluster means, the technique repetitively processes them where new means shift toward the means of the clusters in the data. Initially the unsupervised classification created 16 classes at the 99% convergence threshold. Some of the initial classes were combined resulting in 8 final classes. These classes were assigned to major land cover types based on field observations. Classes consisted of black willow, dryland willow, green grass (lush MHS, moderately stressed MHS, and bermudagrass), stressed grass (severely stressed MHS), hydrilla, algae, water, and bare soil/roads. For accuracy assessment of the classification, 150 points were assigned to the 8 classes in a stratified random pattern. The geographic coordinates of these points were determined and the GPS unit was used to navigate to these points in ground truthing. Both a producer's and user's accuracy were calculated. The producer's accuracy (measure of omission error) is the total number of correct points in a class divided by the total number of points of that class as derived from the reference data (ground truthing). The user's accuracy (measure of commission error) is the total number of correct points in a class divided by the total number of points of that class as derived from the classification data (map data).

Green, red, and NIR reflectance data were ana-

TABLE 1—Field light reflectance measurements of 5 plant species, 3 mixtures of plant species, soil, and water at the green, red, and near-infrared wavelengths. Measurements were made in a riparian area along the Frio River near Tilden, Texas in June 1998.

Plant species/mixtures, soil, and water	Light reflectance (%) for 3 wavelengths		
	Green	Red	Near-infrared
Black willow	5.6 d[1]	2.7 f	38.4 b
Dryland willow	4.6 e	3.6 e	21.6 de
Bermudagrass	6.2 d	3.5 e	43.0 a
Hydrilla	3.2 f	2.0 g	14.5 f
Algae	13.7 b	8.8 b	24.2 d
Mixed herbaceous species (lush)	7.3 c	3.6 e	39.9 b
Mixed herbaceous species (moderately stressed)	6.3 d	5.4 d	19.5 e
Mixed herbaceous species (severely stressed)	7.8 c	8.0 c	15.4 f
Bare soil	18.1 a	17.3 a	27.0 c
Water	3.2 f	1.9 g	0.8 g

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

lyzed using analysis of variance techniques. Duncan's multiple range test was used to test statistical significance among means at the 0.05 probability level (Steel and Torrie, 1980).

RESULTS AND DISCUSSION—Mean light reflectance measurements for the 8 plant species and mixtures, bare soil, and water are given in Table 1. At the visible green and red wavelengths, bare soil had higher reflectance than the plant species, mixtures of species, and water. Conversely, hydrilla and water had lower green and red reflectance values than the associated plant species, mixtures of species, and soil. Algae had lower visible green and red reflectance than bare soil and higher reflectance than the associated plant species, mixtures of species, and water. Green reflectance values of lush MHS and severely stressed MHS were similar, and those for bermudagrass and moderately stressed MHS did not differ. Green reflectance of dryland willow differed from that of the other plant species, mixtures of species, soil, and water. Red reflectance values of severely stressed MHS, moderately stressed MHS, and black willow differed from each other and from those of the other species and mixtures, soil, and water. Dryland willow, bermudagrass, and lush MHS had similar red reflectance values.

The high visible reflectance of bare soil was because of its bright whitish-gray color (Bowers and Hanks, 1965; Gerbermann et al., 1987). Differences in visible reflectance among the plant species and mixtures of species were attributed to foliage color and exposed soil background (Myers et al., 1983; Gausman, 1985). Plants varied in color from the very light yellow-green of algae to deep, dark green of hydrilla. Severely stressed MHS were a mixture of light green and brown foliage and had a large amount of exposed soil background within their canopies. Foliage of the other species and mixtures were various intermediate green colors. Plants with darker green foliage (higher chlorophyll concentrations) reflected less green light and absorbed more red light than plants with lighter green foliage (lower chlorophyll concentrations; Gausman, 1985). The dark color of the water contributed to its lower visible reflectance values.

Bermudagrass had higher NIR reflectance than the other species and mixtures, soil, and water (Table 1). Conversely, water had lower NIR reflectance than the plant species, mixtures of species, and soil. Near-infrared reflectance in vegetation is highly correlated with plant density (Myers et al., 1983; Everitt et al., 1986). An overhead view of the plant species and mixtures of species showed that bermudagrass, lush MHS, and black willow had greater vegetative density and less gaps in their canopies than the other species and mixtures, but hydrilla and severely stressed MHS had more gaps and breaks in their canopies.

A large percentage of hydrilla plant biomass is below the water surface and cannot be adequately measured with the radiometer sensor. The extremely low NIR reflectance of water was attributed to its strong absorption of NIR light (Wiesnet et al., 1997). Although the low NIR reflectance of hydrilla can be partially attributed to its open canopy, the integration of water with the canopy also absorbed a large percentage of the NIR light (Myers et al., 1983; Wiesnet et al., 1997). Like hydrilla, algae had some water integrated with its canopy, which probably contributed to its moderate NIR reflectance value. The moderate NIR reflectance

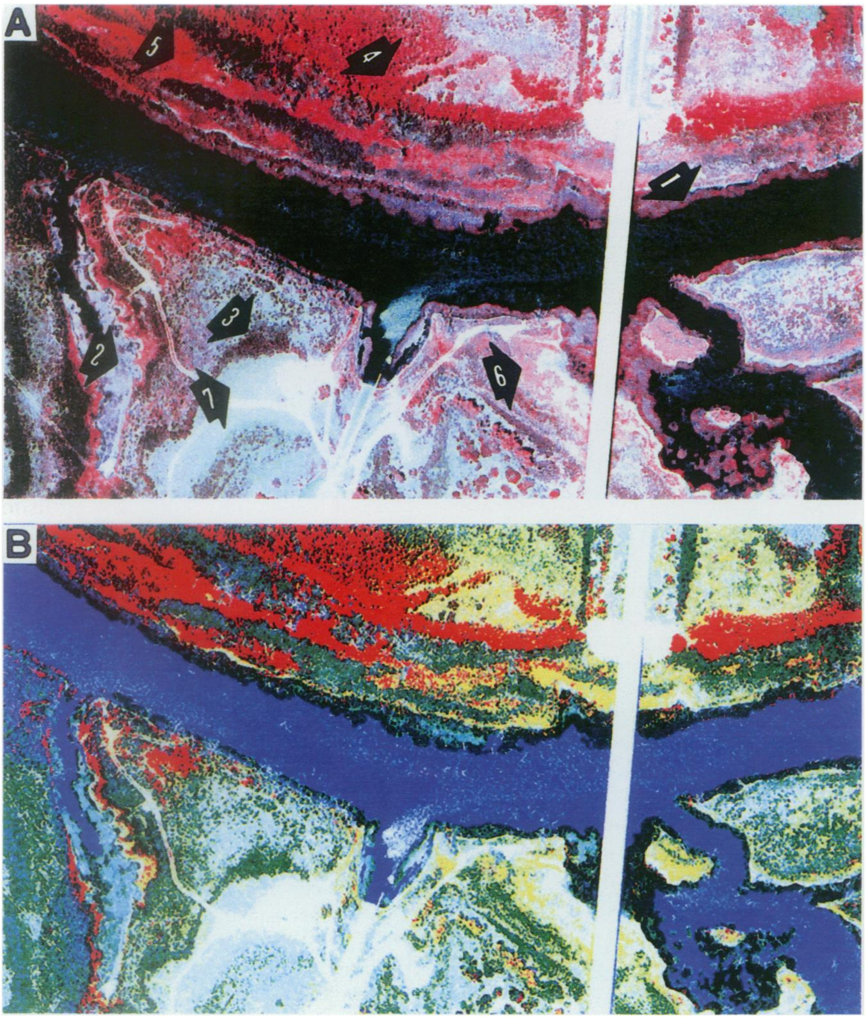

FIG. 1—Aerial color-infrared photographic print (A) of a riparian site on the Frio River near Tilden, Texas. The arrows on print A point to the following vegetation types: 1 = hydrilla, 2 = algae, 3 = dryland willow, 4 = black willow, 5 = lush mixed herbaceous species/bermudagrass, 6 = moderately stressed mixed herbaceous species, and 7 = severely stressed mixed herbaceous species. Unsupervised computer classification (B) of the photographic print. Color codes for the various land cover types are: black = hydrilla, aqua = algae, green = dryland willow, red = black willow, yellow = green grass, gray = stressed grass, white = bare soil/roads, and blue = water.

of bare soil agrees with the findings of other researchers (Bowers and Hanks, 1965; Gerbermann et al., 1987).

Figure 1A shows a large-scale (1:2,000) aerial CIR photographic print of the study site on the Frio River near Tilden. The print is a portion of an original 23-cm photograph. Water has a dark blue image tone, whereas bare soil, roads, and sunglint on the water have a whitish image response. Hydrilla (arrow 1) can be readily distinguished by its reddish-brown image response along the perimeter of the river and in the cove in the lower right portion of the photo. Algae (arrow 2) can be differentiated in the cove on the lower left side of the photo by its conspicuous whitish-pink image response. Other algae can be delineated within the hydrilla beds in the center of the photo. Dryland willow (arrow 3) has a brown to dark brown tone and is scattered throughout the photograph.

The reddish-brown image of hydrilla is related to its low visible and NIR reflectance values. The brownish image of dryland willow can be attributed to its moderately low NIR reflectance, but its generally low visible green and red reflectance values also contributed to its film tonal response (Table 1). The distinct whitish-pink tone of algae was attributed to its high visible green and red reflectance.

Dense stands of black willow (arrow 4) occur in the upper portion of the photograph where they have a bright red, coarse textural image response (Fig. 1A). A small stand of black willow is located in the left side of the photograph on the right side of the cove. Several mixed brush species (*Acacia*) with magenta-red image tones are located in the lower center of the photograph on the left side of the bridge. Lush MHS and bermudagrass (arrow 5) have a bright red color similar to that of black willow, but can be separated from the latter by their smooth textural image responses. The largest stands of lush MHS and bermudagrass are located in the upper portion of the photograph, but some small patches occur around the coves and in the lower center of the photograph adjacent to the bridge. The similarity in film image responses of lush MHS, bermudagrass, and black willow are attributed to their comparable visible and NIR reflectance values (Table 1). Despite statistical differences among some of their reflectance values, the spread between their reflectance values was not great.

Arrow 6 points to the light red-pink image of moderately stressed MHS. Most of the moderately stressed MHS are located in the upper right and lower right portions of the photograph. The image tonal response of moderately stressed MHS can be attributed to their moderate visible green and red reflectance and moderately low NIR reflectance values (Table 1). Severely stressed MHS (arrow 7) have a light tan to gray image response and are predominantly located in the lower half of the photograph. Their distinct CIR film response can be attributed to their high visible green and red reflectance and low NIR reflectance. Dead trees (scattered throughout photo) also have a gray image tone.

Figure 1B shows an unsupervised classification of the CIR photograph (Fig. 1A) of the study site. Color codes and relative percentages for the various land cover types are: black = hydrilla (13.7%), aqua = algae (2.7%), red = black willow (8.0%), yellow = green grass (10.5%), green = dryland willow (17.4%), gray = stressed grass (16.7%), white = bare soil/roads (12.4%), and blue = water (18.7%). A qualitative comparison of the computer classification to the photograph shows that the computer performed an adequate job in identifying most of the classes; however, the computer misclassified portions of the green grass as black willow. The major errors are in the upper left portion of the photograph. Although green grass had a smooth textural image response versus the coarse texture of black willow, the bright red CIR image tonal responses of these types were often spectrally similar, and thus could not be readily distinguished by the computer. The brighter red image of the green grass in the upper left portion of the photo can be attributed to lush bermudagrass and lush MHS in this area.

Table 2 shows an error matrix from comparing the classified data to the ground data for 150 observation points within the study site. The overall classification accuracy was 88%, indicating that 88% of the category pixels in the image were correctly identified in the classification map. The producer's accuracy of individual classes ranged from 68% for green grass to 100% for algae, hydrilla, and bare soil and roads, whereas the user's accuracy ranged from 73% for black willow to 100% for water and algae. The lower producer's accuracy for green grass is because of spectral confusion among green grass, black willow, and stressed grass, but the lower user's accuracy for black willow was due to the confusion between black willow and green grass. The kappa estimate was 0.862, indicating the classification achieved an accuracy that is 86% better than would be expected from random assignment of pixels to classes.

CONCLUSIONS—Field radiometric light reflectance measurements at 2 visible and 1 NIR wavelength varied greatly among 8 vegetation cover types, bare soil, and water in a riparian zone in southern Texas. Differences in reflectance among the vegetation types were related to variable foliage colors and vegetative density. A CIR aerial photograph of the study site showed that many of the vegetation types could be distinguished qualitatively. Field reflectance measurements could be related to

TABLE 2—An error matrix generated from classification data and ground data for the study area.

Actual category	Classified category: Water	Algae	Hydrilla	Dryland willow	Black willow	Green grass	Stressed grass	Bare soil/ roads	Total	Producer's accuracy[1]
Water	24	0	0	0	0	0	0	1	25	96.0
Algae	0	10	0	0	0	0	0	0	10	100.0
Hydrilla	0	0	18	0	0	0	0	0	18	100.0
Dryland willow	0	0	1	20	0	0	2	0	23	87.0
Black willow	0	0	1	2	11	1	0	0	15	73.3
Green grass	0	0	0	0	4	15	3	0	22	68.2
Stressed grass	0	0	0	1	0	1	17	1	20	85.0
Bare soil/roads	0	0	0	0	0	0	0	17	17	100.0
Total	24	10	20	23	15	17	22	19	150	
User's accuracy	100.0	100.0	90.0	87.0	73.3	88.2	77.3	89.5		

[1] Overall accuracy = 88.0%. Kappa = 0.862.

the CIR film tonal responses of many of the vegetation cover types; however, textural image response was also useful in separating some vegetation types. Computer image analysis of the CIR photograph identified 8 ground classes within the study area, including 6 vegetation classes. An accuracy assessment performed on the classified image showed an overall accuracy of 88%. These findings should be of interest to plant ecologists and wildland resource managers who are interested in riparian land cover mapping. Aerial photographs also provided a record that can be stored and examined for comparative purposes at any point in time. These photographs provide the highest resolution and capture the spatial essence of the scene with greater fidelity than any other procedure (Tueller, 1989).

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