Special Feature: Applications of Geospatial Techniques

Evaluation of High-Resolution Satellite Imagery for Assessing Rangeland Resources in South Texas

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Abstract

QuickBird satellite imagery was evaluated for differentiating among rangeland cover types on the Welder Wildlife Refuge in south Texas. The satellite imagery had a spatial resolution of 2.8 m and contained 11-bit data. Four subsets of the satellite image were extracted and used as study sites. Field spectral measurements made among the dominant vegetation types showed significant differences in visible and near-infrared reflectance. Unsupervised classification techniques were used to classify false color composite (green, red, and near-infrared bands) images of each study site. Accuracy assessments performed on the classification maps of the 4 sites had overall accuracies ranging from 79% to 89%. These results indicate that QuickBird imagery can be a useful tool for identifying rangeland cover types at a regional level.

Resumen

Se evaluaron imágenes del satélite QuickBird para diferenciar tipos de cobertura de pastizal en el Refugio de Fauna Silvestre Welder en el sur de Texas. Las imágenes del satélite tenían una resolución espacial de 2.8 m y contenían datos de 11-bit. Cuatro subgrupos de imágenes de satélite se extrajeron y se utilizaron como sitios de estudio. Las mediciones espectrales de campo hechas entre los tipos de vegetación dominante mostraron diferencias significativas en las reflectancias visible y de infrarrojo cercano. Técnicas de clasificación no supervisadas se usaron para clasificar las imágenes compuestas de color falso (bandas verde, rojo y cercano al infrarrojo) de cada sitio de estudio. Evaluaciones de la exactitud realizadas en los mapas de clasificación de los cuatro sitios de estudio tuvieron una exactitud general que varió de 79% a 89%. Estos resultados indican que las imágenes del satélite QuickBird pueden ser una herramienta útil para identificar los tipos de cobertura a un nivel regional.

Key Words: QuickBird satellite imagery, light reflectance, image analysis, accuracy assessment

INTRODUCTION

The management of rangelands requires accurate and current information about their resources. Because rangeland areas are usually large and frequently inaccessible, determining their extent and characteristics by ground surveys is time-consuming and expensive. Remote sensing techniques can provide an alternate means to acquire rapid and low-cost evaluation procedures for inventorying, monitoring, and managing rangeland resources (Tueller 1982; Carneggie et al. 1983; Everitt et al. 1992).

Multispectral satellite imagery has been used for rangeland assessment since the 1970s (Carneggie et al. 1983). Satellite data from remote sensing platforms such as Landsat-TM, SPOT, and IRS LISS-II (spatial resolutions of 10 to 30 m) have been used successfully for a variety of rangeland applications, including classifying and mapping vegetation, assessing productivity, and detecting noxious plant species (Tueller 1989; Anderson et al. 1993; Everitt et al. 1993; Knick et al. 1997; Jakubauskas et al. 1998; Clark et al. 2001; Hunt et al. 2003).

Recently, high spatial resolution (2.4 to 4 m) multispectral satellite imagery from commercial satellite systems has become available for remote sensing applications. The Space Imaging IKONOS and DigitalGlobe QuickBird satellites enable observations in visible and near-infrared wavebands (450–900 nm). The spatial resolution of these satellites offers new opportunities for more accurate assessment of rangeland resources. The objective of this study was to evaluate QuickBird satellite imagery for differentiating among rangeland cover types on a south Texas rangeland area.

MATERIALS AND METHODS

This study was conducted on the 3 150 ha Welder Wildlife Refuge located near Sinton (lat 28°9′N, long 97°4′W), in southern Texas. Sinton is located 48 km north of Corpus Christi in a transition zone between the "Rio Grande Plain" and "Gulf Prairies and Marshes" vegetation regions of Texas (Hatch et al. 1990). Drawe et al. (1978) described the climate, soils, and vegetation of the refuge. The refuge has a diversity of major vegetation/surface types, including riparian woodland, mixed brush, grassland/forb, and wetlands. The Aransas River forms the northern border of the refuge. Satellite imagery, radiometric reflectance measurements, computer image analysis, and ground truth were conducted for this study.

This is Welder Wildlife Foundation contribution 609.

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Table 1. Mean spectral reflectance (%) measurements for dominant plant species and mixtures of species found on 4 rangeland study sites on the Welder Wildlife Refuge near Sinton, Texas. Measurements were made at the green, red, and near-infrared wavelengths in June 2003.

	Reflectance values[1] for 3 wavelengths		
Plant species or mixture	Green (0.52–0.62 μm)	Red (0.63–0.69 μm)	Near-infrared (0.76–0.90 μm)
American lotus	8.4 b	4.3 c	42.0 a
Hackberry	3.9 e	1.9 d	39.2 a
Honey mesquite	3.9 e	2.4 d	29.9 b
Spiny aster	3.3 e	2.1 d	16.8 d
Mixed herbaceous species—green	5.5 d	2.8 d	31.8 b
Stressed herbaceous vegetation	7.3 c	5.9 b	23.3 c
Sparsely vegetated/bare soil	11.3 a	10.7 a	20.7 c

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

Reflectance measurements were made on 10 randomly selected plant species, mixtures of species, and soil surfaces with a Barnes modular multispectral radiometer (Robinson et al. 1979). Measurements were made in the visible green (0.52 to 0.62 μm), visible red (0.63 to 0.69 μm), and near-infrared (0.76 to 0.90 μm) spectral bands using a sensor with a 15° field of view placed 1.0 to 1.5 m above each plant canopy or soil surface. The area within the sensor field of view ranged from 0.26 to 0.39 m. Reflectance measurements were made between 1130 and 1430 hours Central Standard Time under sunny conditions. Radiometric measurements were corrected to reflectance using a barium sulfate standard (Richardson 1981). Both black body and white body calibrations were made in the field for each measurement session. Overhead photographs of the plant canopies were obtained and soil surfaces were measured with the radiometer to help interpret reflectance data.

Most of the spectral measurements were made in mid-June 2003 on the dominant plant species, mixtures of species, and soil surfaces on the study sites. Reflectance measurements were made on honey mesquite (*Prosopis glandulosa* Torr.), hackberry (*Celtis laevigata* Willd.), spiny aster (*Leucosyris spinosa* [Benty.] Greene), American lotus (*Nelumbo lutea* [Willd.] Pers.), mixed herbaceous species (green), stressed herbaceous species (green and brown), and bare soil/sparsely vegetated areas. The green mixed herbaceous species and stressed herbaceous species included grasses, sedges, and broad-leaved herbs. Stressed herbaceous species were showing drought stress. The area had not received significant precipitation for nearly 2 months prior to the satellite image acquisition. The soil surface conditions were dry at the time of reflectance measurements.

Green, red, and near-infrared reflectance data were analyzed using 1-way analysis of variance. Spectral reflectance was the dependent variable and cover types were the independent variable for the analysis. The Duncan's multiple range test was used to test statistical significance at the 0.05 probability level among means (Steel and Torrie 1980).

Multispectral satellite imagery of the entire refuge was obtained on 7 June 2003 from the DigitalGlobe, Inc (Longmont, CO), QuickBird high-resolution (2.8 m) satellite. The QuickBird satellite sensors consists of the blue (450 to 520 nm), green (520 to 600 nm), red (630 to 690 nm), and near-infrared (760 to 900 nm) bands. Prior to delivery, the imagery was radiometrically and geometrically corrected, and rectified to the world geodetic survey 1984 datum and the Universal Transverse Mercator zone 14 coordinate system. The prerectified standard imagery had an average absolute positional error of 23 m and a root mean square (RMS) error of 14 m. To improve the positional accuracy, the prerectified imagery was further rectified on the basis of a set of ground points collected from the imaging area with a submeter-accuracy global positioning system (GPS) receiver. The RMS error of the re-rectified imagery was reduced to less than 5 m. The procedures for image rectification were performed using Erdas Imagine (Erdas, Inc 2002).

For this study, we used only the green, red, and near-infrared bands of the satellite, which provided a false color image similar to color-infrared film. Four subsets were extracted from the satellite scene of the study area. The subsets were extracted along the northern border of the refuge and included the Aransas River. These locations were chosen due to a greater diversity of cover types near the river. The 4 locations were designated sites 1, 2, 3, and 4.

The 4 study sites were subjected to an Iterative Self Organizing Data Analysis (ISODATA) that performs unsupervised classifications on the basis of specified iterations and recalculates statistics for each iteration (Erdas, Inc 2002). 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 classes are shifted. The new cluster means were used for the following iteration.

Initially, the unsupervised classification for each of the 4 study sites created 75 classes. The 75 classes were eventually merged resulting in 6 to 8 classes. Each completed classification for site 1 created 6 classes consisting of riparian woodland, spiny aster, green herbaceous vegetation, stressed herbaceous vegetation, sparsely vegetated/bare soil, and water. For sites 2 and 3, each completed classification created 8 classes. The classes consisted of riparian woodland, mixed brush, spiny aster, American lotus, green herbaceous vegetation, stressed herbaceous vegetation, sparsely vegetated/bare soil, and water. For site 4, each completed classification created 7 classes consisting of riparian woodland, mixed brush, spiny aster, green herbaceous vegetation, stressed herbaceous vegetation, sparsely vegetated/bare soil, and water.

To assess accuracy, 100 points were assigned to the classes for each site in a stratified random pattern using Erdas Imagine software (Erdas, Inc 2002). For each site, the geographic coordinates of the points were determined, and a GPS receiver was used to navigate to the points for ground truthing. Both producer's accuracy and user's accuracy were calculated for each site. 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

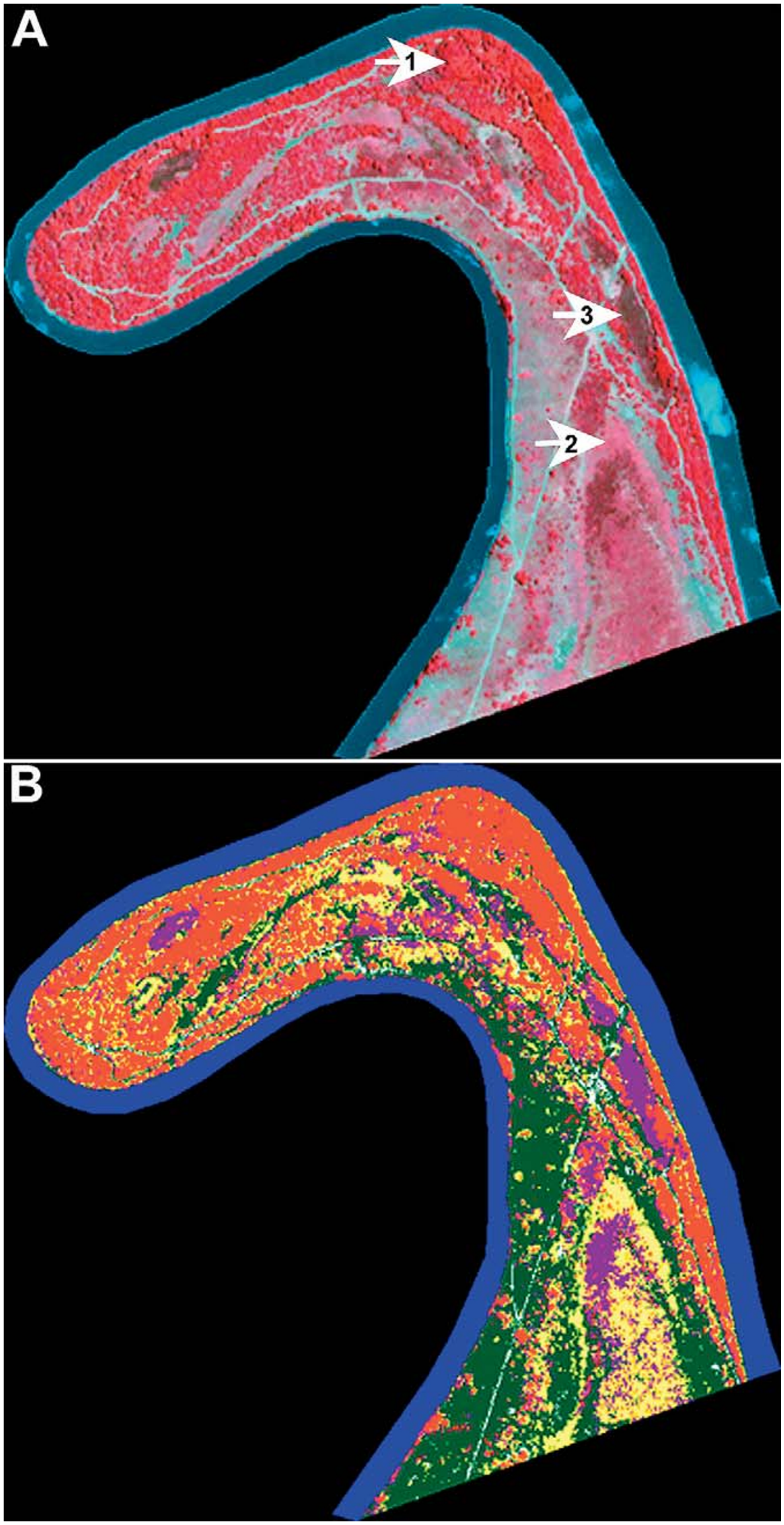

Figure 1. QuickBird false color satellite image (**A**) of site 1 on the Welder Wildlife Refuge. The arrows on print **A** point to the following cover types: 1, riparian woodland; 2, green herbaceous vegetation; and 3, spiny aster. Unsupervised classification (**B**) of the satellite image. Color codes for the various cover types are as follows: red, riparian woodland; yellow, green herbaceous vegetation; purple, spiny aster; green, stressed herbaceous vegetation; white, sparsely vegetated/bare soil; and blue, water.

Table 2. An error matrix generated from the classification data and ground data for the 7 June 2003 QuickBird satellite image of site 1 on the Welder Wildlife Refuge near Sinton, Texas.[1]

	Actual category							
Classified category	Water	Riparian woodland	Green herbaceous vegetation	Stressed herbaceous vegetation	Sparsely vegetated	Spiny aster	Total	User's accuracy
Water	21	0	0	0	0	0	21	100.0%
Riparian woodland	0	22	0	0	0	0	22	100.0%
Green herbaceous vegetation	0	2	12	2	0	0	16	75.0%
Stressed herbaceous vegetation	0	0	2	20	0	1	23	87.0%
Sparsely vegetated	0	0	0	3	5	0	8	62.5%
Spiny aster	0	0	1	0	0	9	10	90.0%
Total	21	24	15	25	5	10	100	
Producer's accuracy	100.0%	91.7%	80.0%	80.0%	100.0%	90.0%		

[1]Overall accuracy, 89.0%; overall kappa, 0.864.

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

Reflectance Measurements

Mean spectral reflectance measurements for the dominant plant species, mixtures of species, and sparsely vegetated/bare soil areas at 3 wavelengths from the study sites are shown in Table 1. Sparsely vegetated/bare soil areas had higher visible green and red reflectance values than the other plant species and mixtures. American lotus had higher green reflectance than the other plant species and mixtures. Both stressed herbaceous species and green herbaceous species had distinct green reflectance. The green reflectance values of hackberry, honey mesquite, and spiny aster could not be separated. The red reflectance values of stressed herbaceous species and American lotus could be separated from the other plant species and mixtures. The other 3 plant species and green herbaceous species had similar red reflectance values. Visible reflectance in vegetation is primarily affected by foliage color and subsequent plant pigments (Myers et al. 1983; Gausman 1985). The species and mixtures varied in color from blue-green for American lotus; to mixtures of light brown and green for stressed herbaceous species; to various shades of green for green herbaceous species; to dark green for hackberry, honey mesquite, and spiny aster. Generally, plants with darker green foliage (i.e., higher chlorophyll concentration) reflected less of the green light and absorbed more of the red light than plants with lighter green and brown foliage (lower chlorophyll concentration) (Gausman 1985). Visible reflectance in soil is primarily affected by color (brightness) (Bowers and Hanks 1965). The soil had a variable gray-brown to brown color that gave it relatively high visible reflectance.

Spectral measurements at the near-infrared wavelength showed that American lotus and hackberry had higher reflectance than the other plant species, mixtures of species, and sparsely vegetated/bare soil (Table 1). Spiny aster had lower near-infrared reflectance than the other associated species, mixtures of species, and sparsely vegetated/bare soil. Near-infrared reflectance in vegetation is positively correlated with vegetation density (Myers et al. 1983; Everitt et al. 1986). An overhead view of the plant species and mixtures of species showed that American lotus and hackberry had greater leaf density and fewer gaps in their canopies than the other species, whereas spiny aster had the most gaps in its canopy. The near-infrared reflectance of sparsely vegetated/bare soil agrees with the findings of Gerbermann at al. (1987).

Satellite Imagery

Figure 1A shows a false color satellite image of site 1. The arrows on the image denote some of the different plant species and vegetation types. Riparian woodland (arrow 1) has a conspicuous dark red tone and occurs along the right portion of the study site and throughout the upper part. Green herbaceous vegetation (arrow 2) has a pink-magenta image response and is scattered throughout the area. Spiny aster (arrow 3) can be readily distinguished by its dark gray to nearly black tone, which occurs at several locations within the area. Stressed herbaceous vegetation has a dull magenta-gray color, whereas sparsely vegetated/bare soil areas have a light blue-white color. Water has a dark blue or light blue tone.

The bright red color of the riparian woodland was attributed to the high near-infrared reflectance of hackberry, which was the dominant plant species on this site (Table 1). The pink-magenta image tone of green herbaceous vegetation was due primarily to its moderate green and near-infrared reflectance, whereas the dark gray to nearly black color of spiny aster was attributed to its low near-infrared reflectance. The dull magenta-gray color of the stressed herbaceous vegetation was due primarily to a combination of its relatively high visible (green and red) and low near-infrared reflectance, whereas the light blue-white color of sparsely vegetated/bare soil areas was attributed to their high green and red reflectance.

Figure 1B shows the unsupervised computer classification of the satellite image (Fig. 1A) of site 1. Table 2 shows an error matrix comparing the classified data with the ground data for the 100 observations within site 1. The overall classification accuracy was 89%, indicating that 89% of the category pixels in the image were correctly identified in the classification map. The producer's accuracy of individual

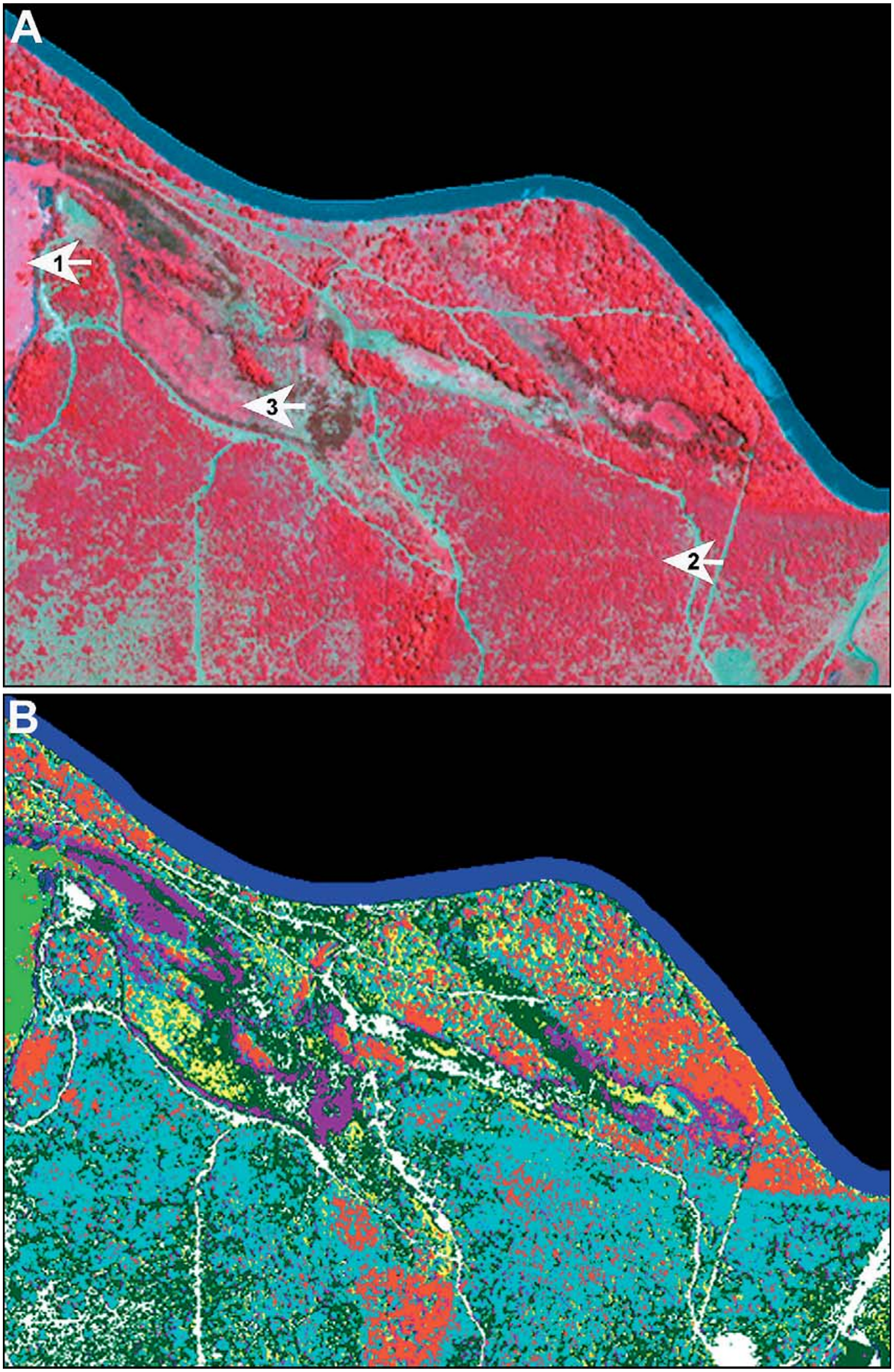

Figure 2. QuickBird false color satellite image (**A**) of site 2 on the Welder Wildlife Refuge. The arrows on print **A** point to the following cover types: 1, American lotus; 2, mixed brush; and 3, green herbaceous vegetation. Unsupervised classification (**B**) of the satellite image. Color codes for the various cover types are as follows: red, riparian woodland; yellow, green herbaceous vegetation; dark green, stressed herbaceous vegetation; light green, American lotus; purple, spiny aster; aqua, mixed brush; white, sparsely vegetated/bare soil; and blue, water.

Table 3. An error matrix generated from the classification data and ground data for the 7 June 2003 QuickBird satellite image of site 2 on the Welder Wildlife Refuge near Sinton, Texas.[1]

	Actual category									
Classified category	Water	Riparian woodland	Green herbaceous vegetation	Stressed herbaceous vegetation	Sparsely vegetated	Spiny aster	Mixed brush	Lotus	Total	User's accuracy
Water	10	0	0	0	0	0	0	0	10	100.0%
Riparian woodland	0	12	0	0	0	0	0	0	12	100.0%
Green herbaceous vegetation	0	1	9	0	0	0	0	0	10	90.0%
Stressed herbaceous vegetation	0	0	2	12	1	2	2	0	19	63.2%
Sparsely vegetated	0	0	0	5	6	0	0	0	11	54.6%
Spiny aster	0	0	0	0	0	10	0	0	10	100.0%
Mixed brush	0	2	0	0	0	0	18	0	20	90.0%
Lotus	0	0	1	0	0	0	0	7	8	87.5%
Total	10	15	12	17	7	12	20	7	100	
Producer's accuracy	100.0%	80.0%	75.0%	70.6%	85.7%	83.3%	90.0%	100.0%		

[1]Overall accuracy, 84.0%; overall kappa, 0.815.

classes ranged from 80% for green herbaceous vegetation and stressed herbaceous vegetation to 100% for water and sparsely vegetated/bare soil. The user's accuracy ranged from 62.5% for sparsely vegetated/bare soil to 100% for water and riparian woodland. The low user's accuracy for sparsely vegetated/bare soil was the result of its confusion with stressed herbaceous vegetation. The kappa estimate was 0.864, indicating the classification achieved an accuracy that is 86% better than would be expected from the random assignment of pixels to classes.

Figure 2A shows the false color image of site 2. The arrows on the image point to some of the plant species and other vegetation types in the scene. Arrow 1 points to the dark pink image response of American lotus in a wetland area. Mixed brush (arrow 2) has a dull red-magenta tonal response and dominated the lower half of the study site. Arrow 3 points to the light red-magenta image tone of green herbaceous vegetation. Riparian woodland has a bright red color and primarily occurs near the river in the upper part of study site. Spiny aster can be readily distinguished by its dark tonal response, whereas stressed herbaceous vegetation has a dull magenta-gray color. Sparsely vegetated/bare soil has a light blue-white color.

The bright pink image of American lotus was attributed to its high visible green and near-infrared reflectance (Table 1). The dull red-magenta color of mixed brush was probably significantly contributed by the moderate near-infrared reflectance of honey mesquite, which is one of the common woody plants in this vegetation type. This color was also contributed by other common mixed brush species found on this site such as blackbrush (*Acacia rigidula* Benth.), Texas persimmon (*Diospyros texana* Scheele), and lotebush (*Ziziphus obtusifolia* [T. & G.] Gray), which also have relatively low to moderate near-infrared reflectance (Everitt 1985).

The unsupervised computer classification of the satellite image of site 2 is shown in Figure 2B. A comparison of the computer classification to the satellite image shows that the computer did an adequate job in identifying most of the cover types. However, there appears to be some misclassification

Table 4. An error matrix generated from the classification data and ground data for the 7 June 2003 QuickBird satellite image of site 3 on the Welder Wildlife Refuge near Sinton, Texas.[1]

	Actual category									
Classified category	Water	Riparian woodland	Green herbaceous vegetation	Stressed herbaceous vegetation	Sparsely vegetated	Spiny aster	Mixed brush	Lotus	Total	User's accuracy
Water	10	0	0	0	0	0	0	0	10	100.0%
Riparian woodland	0	15	0	0	0	1	0	0	16	93.8%
Green herbaceous vegetation	0	2	12	0	0	0	0	0	14	85.7%
Stressed herbaceous vegetation	0	0	4	17	0	0	2	0	23	73.9%
Sparsely vegetated	0	0	0	2	7	0	0	0	9	77.8%
Spiny aster	2	0	0	0	0	9	0	0	11	81.8%
Mixed brush	0	0	7	0	0	0	2	0	9	22.2%
Lotus	0	0	1	0	0	0	0	7	8	87.5%
Total	12	17	24	19	7	10	4	7	100	
Producer's accuracy	83.3%	88.2%	50.0%	89.5%	100.0%	90.0%	50.0%	100.0%		

[1]Overall accuracy, 79.0%; overall kappa, 0.755.

Table 5. An error matrix generated from the classification data and ground data for the 7 June 2003 QuickBird satellite image of site 4 on the Welder Wildlife Refuge near Sinton, Texas.[1]

	Actual category								
Classified category	Water	Riparian woodland	Green herbaceous vegetation	Stressed herbaceous vegetation	Sparsely vegetated	Spiny aster	Mixed brush	Total	User's accuracy
Water	12	0	0	0	0	0	0	12	100.0%
Riparian woodland	0	13	1	0	0	0	2	16	81.3%
Green herbaceous vegetation	0	0	11	0	0	0	1	12	91.7%
Stressed herbaceous vegetation	0	0	4	20	1	1	2	28	71.4%
Sparsely vegetated	0	0	0	2	8	0	0	10	80.0%
Spiny aster	0	1	0	0	0	10	1	12	83.3%
Mixed brush	0	2	0	0	0	0	8	10	80.0%
Total	12	16	16	22	9	11	14	100	
Producer's accuracy	100.0%	81.3%	68.8%	90.9%	88.9%	90.0%	57.1%		

[1]Overall accuracy, 82.0%; overall kappa, 0.787.

among stressed herbaceous vegetation, green herbaceous vegetation, and sparsely vegetated/bare soil areas. The error matrix showing comparison of the classified data with the ground data for the 100 observations from site 2 had an overall accuracy of 84% (Table 3). The producer's accuracy for individual categories ranged from 70.6% for stressed herbaceous vegetation to 100% for American lotus and water. The user's accuracy for the different classes ranged from 54.6% for sparsely vegetated/bare soil areas to 100% for riparian woodland, spiny aster, and water. The lower producer's accuracy of stressed herbaceous vegetation was due to its confusion with sparsely vegetated/bare soil areas. The low user's accuracy of sparsely vegetated/bare soil was due to its confusion with stressed herbaceous vegetation, whereas the lower user's accuracy of stressed herbaceous vegetation was due to its confusion with several classes. The kappa estimate for site 2 was 0.815.

Table 4 shows the error matrix by comparison of the classified data with the ground data for the 100 observations within the site 3 study area (satellite image and computer classification not shown). The overall classification accuracy was 79%. The producer's accuracy of individual categories ranged from 50% for green herbaceous vegetation and mixed brush to 100% for sparsely vegetated/bare soil and American lotus. The user's accuracy ranged from 22.2% for mixed brush to 100% for water. The low producer's accuracy for green herbaceous vegetation was primarily due to its confusion with mixed brush and stressed herbaceous vegetation, whereas the low producer's accuracy of mixed brush was due to its confusion with stressed herbaceous vegetation. The poor user's accuracy of mixed brush was due to its confusion with green herbaceous vegetation. Green herbaceous vegetation and honey mesquite (a common species in the mixed brush class) had similar red and near-infrared reflectance values, which may have contributed to the confusion between these classes (Table 1). The kappa estimate for site 3 was 0.755.

The error matrix showing comparison of the classified data with the ground data for the 100 observations from site 4 is presented in Table 5 (satellite image and computer classification not shown). The classification had an overall accuracy of 82%. The producer's accuracy for individual categories ranged from 57.1% for mixed brush to 100% for water, whereas the user's accuracy ranged from 71.4% for stressed herbaceous vegetation to 100% for water. The lower producer's accuracy of mixed brush was primarily due to its confusion with riparian woodland and stressed herbaceous vegetation, whereas the lower producer's accuracy of green herbaceous vegetation was primarily due to its confusion with stressed herbaceous vegetation. Site 4 had a kappa estimate of 0.787.

CONCLUSIONS

Our results indicate that QuickBird satellite imagery combined with image processing can be a useful tool for differentiating among a diversity of cover types on a south Texas rangeland area. Unsupervised classification is an effective technique for identifying cover types. Field reflectance measurements made on the dominant vegetation types on the study sites generally supported the classification results. Accuracy assessments performed on 4 separate study sites had overall accuracies ranging from 79% to 89%. The satellite imagery can measure the entire spatial extent of an area and provide a permanent record that can be stored and examined for comparative purposes at any time. The spatially registered satellite imagery can be readily entered into a geographic information system and enable resource managers to perform various applications such as integrating the imagery with soil maps and areas of wildlife habitat. It is anticipated that the joint use of these technologies can be used far a variety of other natural resource management applications. This study was one of the initial evaluations of high spatial resolution satellite imagery for identifying rangeland resources.

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