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Using QuickBird Satellite Imagery to Distinguish Two Aquatic Weeds in South Texas

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ABSTRACT

QuickBird false color satellite imagery was evaluated for distinguishing waterhyacinth [*Eichhornia crassipes* (Mart.) Solms] and waterlettuce (*Pistia stratiotes* L.) infestations in a large reservoir in south Texas. The imagery had three bands (green, red, and near-infrared) and contained 11-bit data. Three subsets of the satellite image were extracted and used as study sites. Waterhyacinth occurred in all three subset images, whereas waterlettuce was in only one subset image. Supervised and unsupervised classification techniques were used to classify the imagery. Accuracy assessments performed on supervised classification maps of images of the three sites had producer's and user's accuracies for waterhyacinth ranging from 73% to 100%, while accuracy assessments performed on unsupervised classification maps of images of the three sites had producer's and user's accuracies for waterhyacinth ranging from 74% to 100%. An accuracy assessment performed on a supervised classification map of an image from only one site showed that waterlettuce had both a producer's and user's accuracy of 100%, while an accuracy assessment performed on an unsupervised classification map of an image from the same site showed that waterlettuce had producer's and user's accuracies of 82% and 90%, respectively. These results indicate QuickBird satellite imagery coupled with image analysis techniques can be used successfully for detecting waterhyacinth and waterlettuce infestations.

Key words: QuickBird satellite imagery, false color imagery, supervised and unsupervised image analysis, accuracy assessment, *Eichhornia crassipes, Pistia stratiotes.*

INTRODUCTION

The invasion and spread of alien weeds in the United States is an extremely big problem. Nowhere are these biological invasions more evident than in rivers, lakes, and reservoirs (Barrett 1989). It is estimated that over $110 million is spent annually in the United States to control aquatic weeds (Pimentel et al. 2000).

Waterhyacinth and waterlettuce are two floating species of aquatic weeds that often invade and clog waterways. Waterhyacinth has been described as the world's worst aquatic weed. It is native to the northern neotropics of South America and is now found in many tropical and subtropical areas of the world, including over 50 countries (Cook 1990, Venugopal 1998). Waterhyacinth is believed to have been introduced into the United States at the World's Industrial and Cotton Centennial Exposition of 1884-1885 in New Orleans, Louisiana, and may have been cultivated in the United States as early as the 1860s (Tabita and Woods 1962). It is now found throughout the southeast United States and also occurs in California (Correll and Correll 1972, Anderson 1990). The growth rate of waterhyacinth is among the highest of any plant. Populations may double in size every 6 to 18 days (Mitchell 1976). Waterhyacinth infestations can reduce boating and fisheries, shade submersed plants, inhibit the growth of native aquatic plants, and reduce biological diversity in aquatic ecosystems (Anonymous 2001, DiTomaso and Healy 2003).

Waterlettuce 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) and is believed to be native to South America (Cordo et al. 1981). It is found in waterways throughout the southeast United States from Florida to Texas, and in California and Arizona (Correll and Correll 1972, DiTomaso and Healy 2003). The fast reproductive growth of waterlettuce can cause waterways to become clogged and may cause many of the same problems associated with waterhyacinth (Attionu 1976, DiTomaso and Healy 2003).

Several studies have demonstrated the value of remote sensing techniques for distinguishing waterhyacinth infestations. Everitt et al. (1999) described the light reflectance characteristics of waterhyacinth and associated vegetation. They also used airborne color-infrared videography integrated with global positioning systems (GPS) and geographic information system (GIS) technologies for detecting and mapping waterhyacinth infestations in the Rio Grande River system in south Texas. In similar study, Jakubauskas et al. (2002) used airborne conventional color videography and IKONOS multispectral satellite imagery to distinguish waterhyacinth infestations. Venugopal (1998) used SPOT satellite imagery to detect and monitor waterhyacinth infestations in India. More recently, Albright et al. (2004) demonstrated the potential of Landsat TM multispectral satellite imagery and computer image analysis to distinguish and map waterhyacinth infestations in Lake Victoria and an associated river system in south-central Africa. Remote sensing techniques have also been evaluated on waterlettuce. A study conducted in southeast Texas described the spectral light characteristics of waterlettuce and demonstrated the value of aerial color-infrared photography and videography coupled with computer image analysis to distinguish and map this aquatic weed (Everitt et al. 2003)

Recently, commercial DigitalGlobe QuickBird satellite imagery has become available for remote sensing applications.

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This satellite enables observations in visible and near-infrared wavebands with spatial resolutions less then 3 m. The objective of this study was to evaluate the potential of QuickBird multispectral satellite imagery for distinguishing waterhyacinth and waterlettuce infestations in a large south Texas reservoir.

MATERIALS AND METHODS

This study was conducted on Lake Corpus Christi near Mathis in southern Texas. Mathis is located about 55 km northwest of Corpus Christi. Lake Corpus Christi provides water for the city of Corpus Christi and other communities in the area.

A multispectral satellite image of the north portion of Lake Corpus Christi was obtained on May 17, 2005 from the DigitalGlobe, Inc.[2] (Longmont, Colorado), QuickBird high resolution (2.8 m) satellite. The QuickBird satellite sensors consist 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 (WGS 84) datum and the Universal Transverse Mercator (UTM) zone 14 coordinate system. The pre-rectified standard imagery had an absolute positional error of 23 m and a root mean square (RMS) error of 14 m. To improve the positional accuracy, the pre-rectified imagery was further rectified based on a set of ground control points collected from the imaging area with a submeter-accuracy 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 software (Erdas 2002).

For this study, we only used the green, red, and near-infrared bands of the satellite that provided a false color image similar to color-infrared film. Three subset images were extracted from the satellite scene of the entire study area and used as individual study sites. The three locations were designated as sites 1, 2, and 3. Sizes of sites 1, 2, and 3 were 43 ha, 122 ha, and 77 ha, respectively. Waterhyacinth occurred at all three sites, however, waterlettuce was only found at site 1. Waterlettuce generally occurs in only small patches on Lake Corpus Christi. Consequently, it could not be found at any other locations within the satellite scene other than the subset image selected for site 1.

The images of the three sites were subjected to both unsupervised and supervised image analysis techniques. The unsupervised technique was an Iterative Self Organizing Data Analysis (ISODATA) that performs unsupervised classifications on the basis of specified iterations and recalculates statistics for each iteration. 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 of the three study sites created 75 classes. The 75 classes were eventually merged resulting in 4 to 7 classes. Each completed classification of site 1 created 7 classes consisting of waterhyacinth, waterlettuce, spiny aster [*Leucosyris spinosa* (Benty.) Greene], mixed herbaceous vegetation, mixed woody vegetation, water, and soil/roads. The mixed herbaceous species consisted of grasses, sedges, and broad-leaved herbs, whereas the mixed woody vegetation consisted of trees and shrubs. Each completed classification of site 2 created 4 classes, consisting of waterhyacinth, mixed vegetation (mixed herbaceous and mixed woody species), weed stubble, and water. Weed stubble consisted of terrestrial weeds that had been shredded. For site 3, each completed classification created 5 classes consisting of waterhyacinth, mixed herbaceous vegetation, mixed woody vegetation, water, and roads/houses.

For the supervised classification technique, we selected 5 subsamples from each of the 7, 4, and 5 cover types from sites 1, 2, and 3, respectively, to be used as training sites. The Maximum Likelihood classifier was then used to classify the three images of the study areas (Erdas 2002).

To assess accuracy for sites 1, 2, and 3, 125, 80, and 100 points, respectively, were assigned to the classes in a stratified random pattern using Erdas Imagine software (Erdas 2002). The number of points assigned to each site was based on the number of classes identified on the site. The geographic coordinates of the points were determined and a GPS receiver was used to navigate to the points for ground truthing. Overall accuracy, producer's accuracy, user's accuracy, and overall kappa coefficient were calculated for each site (Congalton and Green 1999). Overall accuracy is the division of the total number of correct points by the total number of points. The producer's accuracy is the total number of correct points in a category divided by the number of points of that category as derived from the reference data (ground truthing). The user's accuracy 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. The overall kappa coefficient indicates how well the classification results agree with the reference data.

RESULTS AND DISCUSSION

The false color satellite image of the site 1 study area is shown in Figure 1A. Waterhyacinth (arrow 1) has a conspicuous bright red smooth image textural response and occurs in the middle to lower portion of the image and in the upper left corner. Arrow 2 points to the whitish-pink to pink image tone of waterlettuce. Spiny aster (arrow 3) has a dark brown to black color and occurs in a narrow strip along the perimeter of the wetland in the lower portion of the image. Mixed herbaceous vegetation has variable gray, grayish-red, and brown tones and occurs in large stands throughout the image. Mixed woody vegetation has a red to brownish-red image response and is scattered throughout the image. Soil and roads have a whitish-gray color, while water has dark blue to light blue-white image tones.

The bright red image color of waterhyacinth was attributed to its low visible and high near-infrared reflectance (Everitt et al. 1999), while the whitish-pink to pink image response of waterlettuce was primarily due to high visible green reflectance (Everitt et al. 2003). The dark brown-black image of

[2]Trade names are included for information purposes only and do not imply endorsement of or a preference for the product listed by the United States Department of Agriculture.

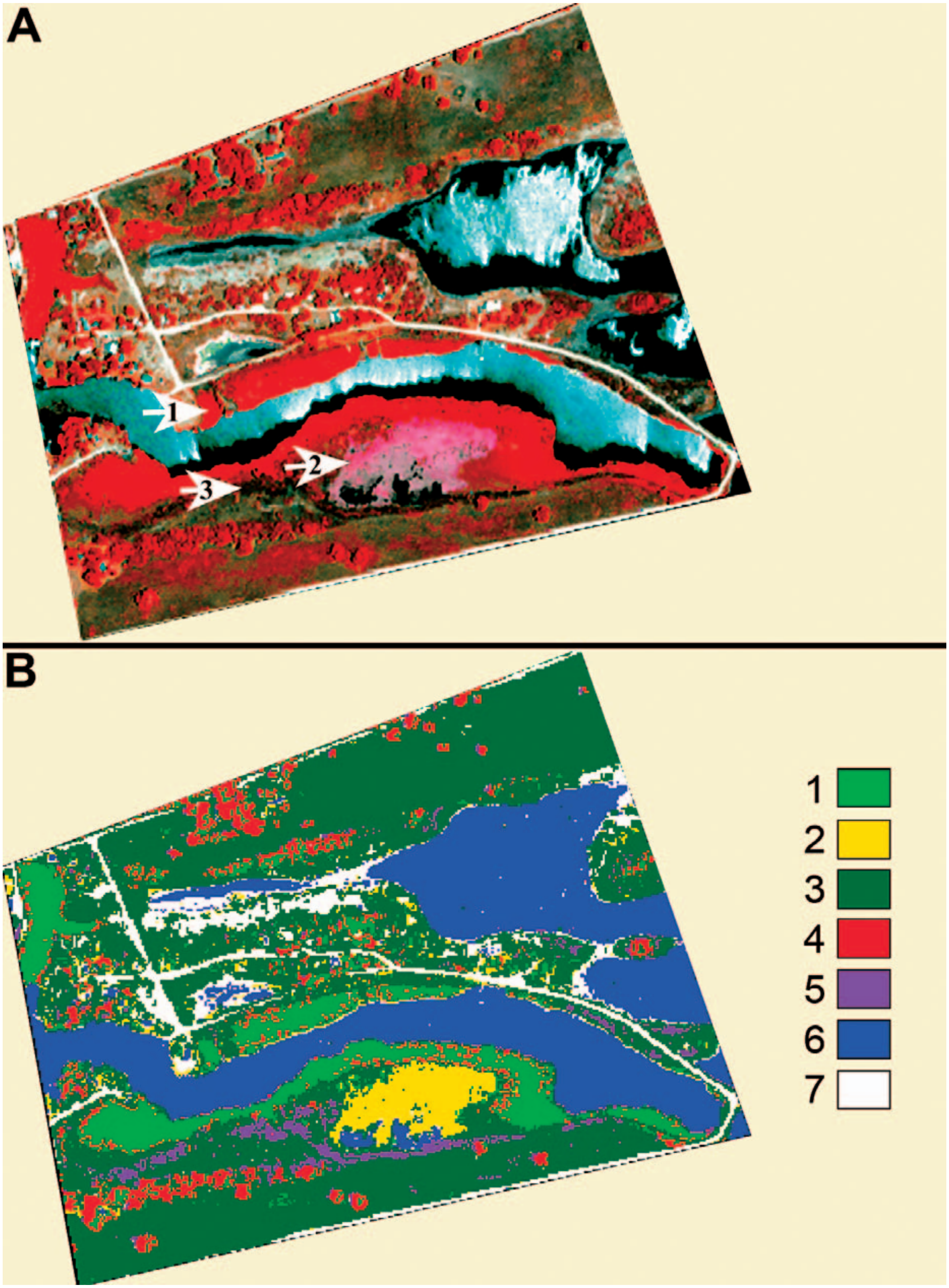

Figure 1. QuickBird false color satellite image (A) obtained May 17, 2005 from site 1 on Lake Corpus Christi near Mathis, Texas. The arrows on print A point to the following plant species: 1 = waterhyacinth, 2 = waterlettuce, and 3 = spiny aster. Supervised classification (B) of the satellite image. Map classes are: 1 = waterhyacinth, 2 = waterlettuce, 3 = mixed herbaceous vegetation, 4 = mixed woody vegetation, 5 = spiny aster, 6 = water, 7 = soil/roads.

spiny aster was attributed to its very low near-infrared reflectance (Everitt et al. 1987); whereas the gray, grayish-red, and brown tones of mixed herbaceous vegetation were attributed to its generally low to moderate near-infrared reflectance (Everitt et al. 1987). The red to reddish-brown image tones of mixed woody vegetation was due to the moderate near-infrared reflectance of honey mesquite (*Prosopis glandulosa* Torr.) which was one of the dominant woody plants in this vegetation type (Everitt et al. 1987).

The supervised classification of the false color satellite image (Fig. 1A) of the site 1 study area is shown in Figure 1B. Table 1 shows an error matrix comparing the classified data with the ground truthed data for the 125 observations from the supervised classification of site 1. The overall classification accuracy was 94.4%, indicating that 94.4% of the category pixels in the image were correctly identified in the classification map. The producer's accuracy of individual classes ranged from 76.5% for mixed woody vegetation to 100% for waterlettuce, spiny aster, water, and soil/roads. The user's accuracy ranged from 85.7% for soil/roads to 100% for waterlettuce, spiny aster, mixed woody vegetation, and water. Waterhyacinth had both a producer's and user's accuracy of 94.7%. Thomlinson et al. (1999) set a target of an overall accuracy of 85% with no class less than 70%. Based on these guidelines, the overall accuracy was excellent, as well as both the producer's and user's accuracies of waterhyacinth and waterlettuce. The lower producer's accuracy of mixed woody vegetation was primarily due to its confusion with mixed herbaceous vegetation. The kappa estimate was 0.933, indicating the classification achieved an accuracy that is 93.3% better than would be expected from the random assignment of pixels to classes.

The error matrix comparing the classified data with the ground data for the 125 observations from the unsupervised classification of the image (Fig. 1A) of site 1 is shown in Table 2 (computer classification not shown). The overall accuracy was 80%. The producer's accuracy for the individual categories ranged from 35.3% for mixed woody vegetation to 100% for water, whereas the user's accuracy ranged from 66% for mixed herbaceous vegetation to 100% for spiny aster and water. Waterhyacinth had a producer's accuracy of 89.5% and a user's accuracy of 73.9%, while waterlettuce had a producer's and user's accuracy of 81.8% and 90%, respectively. The lower user's accuracy of waterhyacinth was due to its confusion with mixed woody vegetation. Although both waterhyacinth and waterlettuce had lower producer's and user's accuracies with the unsupervised compared to the supervised classification, their accuracies were considered good. The poor producer's accuracy of spiny aster was due to its confusion with mixed herbaceous vegetation. The even poorer producer's accuracy of mixed woody vegetation was due to its confusion with mixed herbaceous vegetation. Similar spectral characteristics among classes, as well as grading from one class to another may have contributed to some of the errors among classes. Differences in error matrices may also be due to mapping error (Congalton and Green 1999). The kappa estimate for the unsupervised classification was 0.754.

Tables 3 and 4 show the error matrices by comparison of the classified data with the ground data for the 80 observations from the supervised and unsupervised classifications, respectively, of the satellite image of site 2 (satellite image and computer classification not shown). The supervised classification had an overall accuracy of 86.3% (Table 3). Waterhyacinth had a producer's accuracy of 100% and a user's accuracy of 72.7%. The overall accuracy of the unsupervised classification was 90%; waterhyacinth had a producer's accuracy of 100% and a user's accuracy of 80% (Table 4). The lower user's accuracy of waterhyacinth in both classifications was due to its confusion with mixed vegetation. The kappa estimates for the supervised and unsupervised classifications were 0.812 and 0.862, respectively.

The error matrices showing comparison of the classified data with the ground data for the 100 observations from the supervised and unsupervised classifications of the satellite image of site 3 are shown in Tables 5 and 6, respectively. The overall accuracy of the supervised classification was 87% (Table 5). Waterhyacinth had a producer's accuracy of 89.5% and a user's accuracy of 85%. The unsupervised classification had an overall accuracy of 90% (Table 6). Waterhyacinth had producer's and user's accuracies of 94.7% and 81.8%, re-

TABLE 1. AN ERROR MATRIX FOR THE SUPERVISED CLASSIFICATION GENERATED FROM THE CLASSIFICATION DATA AND GROUND TRUTHED DATA FOR THE MAY 17, 2005 QUICKBIRD SATELLITE IMAGE OF SITE 1 ON LAKE CORPUS CHRISTI NEAR MATHIS, TEXAS.

	Actual category								
Classified category	Waterhyacinth	Mixed herb.[1]	Spiny aster	Water	Mixed woody	Waterlettuce	Soil/roads	Total	User's accuracy
Waterhyacinth	18	0	0	0	1	0	0	19	94.7%
Mixed herb.[1]	1	32	0	0	3	0	0	36	88.9%
Spiny aster	0	0	11	0	0	0	0	11	100.0%
Water	0	0	0	21	0	0	0	21	100.0%
Mixed woody	0	0	0	0	13	0	0	13	100.0%
Waterlettuce	0	0	0	0	0	11	0	11	100.0%
Soil/roads	0	2	0	0	0	0	12	14	85.7%
Total	19	34	11	21	17	11	12	125	
Producer's accuracy	94.7%	94.1%	100%	100%	76.5%	100%	100%		

Overall classification accuracy = 94.4%. Overall kappa = 0.933.
[1]herb. = herbaceous.

TABLE 2. AN ERROR MATRIX FOR THE UNSUPERVISED CLASSIFICATION GENERATED FROM THE CLASSIFICATION DATA AND GROUND TRUTHED DATA FOR THE MAY 17, 2005 QUICKBIRD SATELLITE IMAGE OF SITE 1 ON LAKE CORPUS CHRISTI NEAR MATHIS, TEXAS.

	Actual category								
Classified category	Waterhyacinth	Mixed herb.[1]	Spiny aster	Water	Mixed woody	Waterlettuce	Soil/roads	Total	User's accuracy
Waterhyacinth	17	0	0	0	6	0	0	23	73.9%
Mixed herb.[1]	2	31	6	0	5	2	1	47	66.0%
Spiny aster	0	0	5	0	0	0	0	5	100.0%
Water	0	0	0	21	0	0	0	21	100.0%
Mixed woody	0	1	0	0	6	0	0	7	85.7%
Waterlettuce	0	1	0	0	0	9	0	10	90.0%
Soil/roads	0	1	0	0	0	0	11	12	91.7%
Total	19	34	11	21	17	11	12	125	
Producer's accuracy	89.5%	91.2%	45.5%	100%	35.3%	81.8%	91.7%		

Overall classification accuracy = 80.0%. Overall kappa = 0.754.
[1]herb. = herbaceous.

spectively. The kappa estimates for the supervised and unsupervised classifications were 0.831 and 0.869, respectively.

Our results indicate that QuickBird false color satellite imagery combined with computer image analysis can be used for distinguishing waterhyacinth and waterlettuce in a south Texas waterway. Accuracy assessments performed on supervised classified maps from three study sites had mean producer's and user's accuracies for waterhyacinth of 95% and 84%, respectively. Accuracy assessments performed on unsupervised classified maps from the same three study sites had mean producer's and user's accuracies for waterhyacinth of 95% and 79%, respectively. An accuracy assessment performed on a supervised classification map from a single study site showed that waterlettuce had both a producer's

TABLE 3. AN ERROR MATRIX FOR THE SUPERVISED CLASSIFICATION GENERATED FROM THE CLASSIFICATION DATA AND GROUND TRUTHED DATA FOR THE MAY 17, 2005 QUICKBIRD SATELLITE IMAGE OF SITE 2 ON LAKE CORPUS CHRISTI NEAR MATHIS, TEXAS.

	Actual category					
Classified category	Waterhyacinth	Mixed vegetation	Weed stubble	Water	Total	User's accuracy
Waterhyacinth	16	6	0	0	22	72.7%
Mixed vegetation	0	19	2	0	21	90.5%
Weed stubble	0	3	8	0	11	72.7%
Water	0	0	0	26	26	100.0%
Total	16	28	10	26	80	
Producer's accuracy	100.0%	67.9%	80.0%	100.0%		

Overall classification accuracy = 86.3%. Overall kappa = 0.812.

TABLE 4. AN ERROR MATRIX FOR THE UNSUPERVISED CLASSIFICATION GENERATED FROM THE CLASSIFICATION DATA AND GROUND TRUTHED DATA FOR THE MAY 17, 2005 QUICKBIRD SATELLITE IMAGE OF SITE 2 ON LAKE CORPUS CHRISTI NEAR MATHIS, TEXAS.

	Actual category					
Classified category	Waterhyacinth	Mixed vegetation	Weed stubble	Water	Total	User's accuracy
Waterhyacinth	16	4	0	0	20	80.0%
Mixed vegetation	0	22	2	0	24	91.7%
Weed stubble	0	2	8	0	10	80.0%
Water	0	0	0	26	26	100.0%
Total	16	28	10	26	80	
Producer's accuracy	100.0%	78.6%	80.0%	100.0%		

Overall classification accuracy = 90.0%. Overall kappa = 0.862.

TABLE 5. AN ERROR MATRIX FOR THE SUPERVISED CLASSIFICATION GENERATED FROM THE CLASSIFICATION DATA AND GROUND TRUTHED DATA FOR THE MAY 17, 2005 QUICKBIRD SATELLITE IMAGE OF SITE 3 ON LAKE CORPUS CHRISTI NEAR MATHIS, TEXAS.

	Actual category						
Classified category	Waterhyacinth	Mixed herbaceous	Mixed woody	Roads/houses	Water	Total	User's accuracy
Waterhyacinth	17	0	3	0	0	20	85.0%
Mixed herbaceous	0	17	1	0	1	19	89.5%
Mixed woody	1	1	10	0	0	12	83.3%
Roads/houses	0	3	2	9	0	14	64.3%
Water	1	0	0	0	34	35	97.1%
Total	19	21	16	9	35	100	
Producer's accuracy	89.5%	81.0%	62.5%	100.0%	97.1%		

Overall classification accuracy = 87.0%. Overall kappa = 0.831.

TABLE 6. AN ERROR MATRIX FOR THE UNSUPERVISED CLASSIFICATION GENERATED FROM THE CLASSIFICATION DATA AND GROUND TRUTHED DATA FOR THE MAY 17, 2005 QUICKBIRD SATELLITE IMAGE OF SITE 3 ON LAKE CORPUS CHRISTI NEAR MATHIS, TEXAS.

	Actual category						
Classified category	Waterhyacinth	Mixed herbaceous	Mixed woody	Roads/houses	Water	Total	User's accuracy
Waterhyacinth	18	1	2	0	1	22	81.8%
Mixed herbaceous	1	17	2	0	0	20	85.0%
Mixed woody	0	2	12	0	0	14	85.7%
Roads/houses	0	1	0	9	0	10	90.0%
Water	0	0	0	0	34	34	100.0%
Total	19	21	16	9	35	100	
Producer's accuracy	94.7%	81.0%	75.0%	100.0%	97.1%		

Overall classification accuracy = 90.0%. Overall kappa = 0.869.

and user's accuracy of 100%; whereas an accuracy assessment performed on an unsupervised classified map from the same site showed that waterlettuce had producer's and user's accuracies of 81.8% and 90%, respectively. Although both supervised and unsupervised techniques both did a good job in identifying waterhyacinth and waterlettuce, the supervised had slightly higher accuracy.

Waterhyacinth accuracy assessment data from this study are comparable or slightly better than that of Everitt et al. (1999) who reported a producer's and user's accuracy of 85% for waterhyacinth using an unsupervised classification of airborne videographic imagery. Our accuracy assessment data for waterlettuce are in agreement with or better than those of Everitt et al. (2003) who reported producer's and user's accuracies for waterlettuce ranging from 77% to 93% using unsupervised classifications on aerial photographic and videographic imagery. Like the current study, the study by Everitt et al. (2003) reported accuracy from only a single study site. Additional research needs to be conducted to further determine the accuracy of remotely sensed imagery for mapping waterlettuce. The capability to remotely distinguish waterhyacinth and waterlettuce infestations on waterways with high resolution satellite imagery should be useful to wetland resource managers who are interested in infestation monitoring and control of noxious aquatic vegetation. The satellite imagery can provide a record that can be stored and examined for comparative purposes.

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