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Mapping Wild Taro with Color-infrared Aerial Photography and Image Processing

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ABSTRACT

Wild taro [*Colocasia esculenta* (L.) Schott.] is an exotic ornamental plant that has escaped cultivation and invaded many freshwater wetlands in the southeastern United States. Remote sensing techniques were evaluated for distinguishing wild taro along the Rio Grande in southwest Texas. Field reflectance measurements showed that wild taro had significantly different ($p = 0.05$) visible and near-infrared reflectance from associated plant species. Wild taro could be distinguished on color-infrared photographs where it had a bright red image response. Supervised image analysis techniques were used to classify the imagery. Accuracy assessments performed on classification maps of photographs from three sites had producer's and user's accuracies ranging from 83.3% to 100%.

Key words: Light reflectance, color-infrared photography, supervised image analysis, accuracy assessment, *Colocasia esculenta.*

INTRODUCTION

Wild taro [*Colocasia esculenta* (L.) Schott.] also known as elephant ear, is an exotic ornamental plant that has become naturalized in many fresh water wetlands throughout the southern United States (Nelson and Getsinger 2000). It also occurs in Pennsylvania and Hawaii (Glomski and Danbar 2006). Wild taro is native to India and Southeast Asia and was brought to the U.S. as a food for slaves to be used as a possible substitute for potatoes (Glomski and Danbar 2006). Today, wild taro is considered an invasive weed in the U.S. where it forms dense, monotypic stands that reduce the diversity of native vegetation (Nelson and Getsinger 2000). Wild taro is also of little value to wildlife (Stutzenbaker 1999). Herbicides such as 2, 4-D, glyphosate, and triclopyr have provided excellent control of wild taro (Nelson and Getsinger 2000, Koschnick et al. 2005), but regrowth will occur if the corms are not killed (Glomski and Danbar 2006).

Several river systems in Texas have well-established populations of wild taro (Akridge and Fonteyn 1981, Owens et al. 2001), including the Rio Grande in southwest Texas below Amistad Reservoir (Owens et al. 2005). Ground surveys are the typical means for locating and monitoring the distribution of wild taro along rivers and other waterways.

Accurate measurements of areas infested and canopy cover are essential to estimating the amount of damage or other ecological impact caused by invasive weeds on wetlands. Remote sensing techniques offer rapid acquisition of data with generally short turn-around time at costs lower than ground surveys (Tueller 1982, Everitt et al. 1994). 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). Plant canopy reflectance measurements have been used to spectrally distinguish among wetland species (Best et al. 1981, Ullah et al. 2000) and color-infrared aerial photography has been used successfully to remotely distinguish wetland plant species (Howland 1980, Martyn 1985, Marshall and Lee 1994, Everitt et al. 2002). Aerial photographs provide the highest resolution and capture the spatial and textural essence of the scene with greater fidelity than any other procedure (Tueller 1989). Digital image analysis of aerial photographs of wetlands has demonstrated that noxious plant species can be differentiated quantitatively from associated vegetation (Everitt et al. 2002).

The objectives of this study were: (1) to establish the plant canopy reflectance characteristics of wild taro and (2) to determine the potential of color-infrared aerial photography coupled with image processing techniques for distinguishing and mapping wild taro on the Rio Grande in southwest Texas.

MATERIALS AND METHODS

This study was conducted along the Rio Grande in southwest Texas, near Del Rio. This area was selected as a study area because it had several populations of wild taro. Three different study sites were selected (designated as sites 1, 2, and 3). Field radiometric reflectance measurements, color-infrared aerial photography, computer image analysis, and accuracy assessments of image analysis maps were used in this study.

Plant canopy radiometric reflectance measurements were made in the field with a hand-held radiometer sensitive from the 350 to 1050 nm portion of the spectrum with a bandwidth of 1.4 nm. Measurements were made on ten randomly selected plant canopies of wild taro, giant reed (*Arundo donax* L.), Eurasian watermilfoil (*Myriophyllum spicatum* L.), and mixed herbaceous species. Giant reed, Eurasian watermilfoil, and mixed herbaceous species were dominant species and mixtures of species that grew in association with wild taro. Mixed herbaceous species included both grasses and broad-leafed herbs. Common grasses were red grama (*Bouteloua trifida* Thurb.), three-awn (*Aristida* spp.), sand dropseed [*Sporobolus cryptandrus* (Torr.) Gray], and Bermuda grass (*Cynodon dactylon* L.), while dominant broad-leaved herbaceous species included western ragweed (*Ambrosia psilostachya* A. P. de Candolle), smartweed (*Polygonum pensylvanicm* L.), and pennywort (*Hydrocotyle verticil-*

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lata Thurb.). Radiometric measurements were made on June 15, 2006. Spectral measurements were studied only from the 500 to 900 nm range because this covers the sensitivity of the color-infrared film used for this study. Data from three wavelength intervals centered in the visible green (550 nm), visible red (650 nm), and near-infrared (825 nm) were extracted for analysis. Data were averaged over approximately a 10 nm range for each of these regions. For the 550 nm, data were extracted from the 546 to 555 nm; for the 650 nm, data were extracted from the 646 to 655 nm; and for the 825 nm, data were extracted from the 821 to 830 nm. The radiometer sensor had a 15° field-of-view. Measurements were made 1 to 1.5 m above each canopy with a ground area field-of-view ranging from 0.26 to 0.39 m. A step ladder was used for measuring wild taro and giant reed. Reflectance measurements were made between 1100 and 1400 h Central Standard Time under sunny conditions. Radiometric measurements were converted to reflectance using a halon standard.

Green, red, and near-infrared reflectance data from the three species and mixtures of species were analyzed using one-way analysis of variance. Duncan's multiple range test was used to test statistical significance among the means at the 0.05 probability level (Steel and Torrie 1980).

Aerial photographs of the study sites were obtained with Kodak[2] color-infrared (0.50 to 0.90 µm) type 1443 film. Photography was obtained with a Fairchild type K-37 large format (23 by 23 cm) mapping camera. Color-infrared film is sensitive in the visible green (0.50 to 0.60 µm), visible red (0.60 to 0.75 µm), and near-infrared (0.76 to 0.90 µm) spectral bands. The camera had an aperture setting of f11 at 1/250 sec. and a 305 mm lens equipped with a Wratten 15 orange (minus blue) filter. Aerial photography was obtained of the study sites on June 15, 2006 at an altitude above ground level of 1,500 m. The photography had a scale of 1:5,000. A Model 404 Cessna airplane equipped with a camera port in the floor was used for obtaining the aerial photography. The camera was maintained in nadir position during image acquisition. Imagery was acquired between 1130 and 1230 h Central Standard Time under sunny conditions.

The color-infrared photographic images of the study sites were subjected to image analysis and accuracy assessments. A Trimble differential global positioning system (GPS) Pathfinder Pro XRS system that provided sub-meter accuracy was used in the field to establish control points on the digitized photographic transparencies of sites 1, 2, and 3. Erdas Imagine software was used to georeference the transparencies (Erdas 2002). The three images were subjected to a supervised image analysis technique. Four subsamples were selected of each major cover type on each site to be used as training sites. Sites 1 and 2 had five cover types (same for both sites) that included wild taro, giant reed, mixed woody vegetation, soil, and water. Site 3 had six cover types that included wild taro, giant reed, mixed woody vegetation, mixed herbaceous vegetation, soil, and water. Mixed woody vegetation was dominated by honey mesquite (*Prosopis glandulosa* Torr.), blackbrush (*Acacia rigidula* Benth.), desert hackberry (*Celtis pallida* Torr.), and Mexican persimmon (*Diospyros texana* Scheele). Mixed herbaceous vegetation was dominated by the same species that reflectance measurements were made on. The Maximum Likelihood classifier was used to classify the three photographs of the study sites (Erdas 2002).

To assess accuracy for sites 1 and 2, 100 points were used on each site. For site 3, 125 points were used. The points were assigned to the classes in a stratified random pattern using Erdas Imagine software (Erdas 2002). The geographic coordinates of the points were determined and a GPS receiver was used to navigate to the points in ground truthing. A small boat was used for some of the 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

Mean light reflectance values at the green, red, and near-infrared wavelengths for wild taro and three associated species and mixtures are shown in Table 1. At the visible green wavelength, giant reed had higher reflectance than the other species, whereas Eurasian watermilfoil had lower reflectance than the other species. The green reflectance of wild taro differed from that of the other species. At the red wavelength, mixed herbaceous species had higher reflectance than the other species, while wild taro had lower reflectance than the other species. Wild taro had higher near-infrared reflectance than the other species and mixtures.

Differences in visible reflectance among the plant species and mixtures of species were primarily attributed to differences in foliage color and subsequent plant pigments (Myers et al. 1983, Gausman 1985). Foliage colors varied from blue-green for giant reed, to various shades of green and brown for mixed herbaceous species, to darker green for Eurasian watermilfoil and wild taro. Plants with darker green foliage

TABLE 1. MEAN LIGHT REFLECTANCE MEASUREMENTS FOR WILD TARO AND THREE ASSOCIATED SPECIES AND MIXTURES AT THE GREEN, RED, AND NEAR-INFRARED WAVELENGTH INTERVALS. MEASUREMENTS WERE MADE NEAR DEL RIO, TEXAS, ON JUNE 15, 2006.

	Reflectance values[1] for three wavelengths		
Species	Green	Red	Near-infrared
Giant reed	14.5 a	7.5 b	59.2 b
Mixed herbaceous species	10.3 b	9.2 a	30.2 c
Eurasian watermilfoil	4.5 d	4.1 c	11.8 d
Wild taro	5.6 c	2.0 d	61.6 a

[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.

[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.

(higher chlorophyll concentration) reflected less of the green light and absorbed more of the red light than plants with mixtures of green and brown, and blue-green foliage (lower chlorophyll concentration) (Gausman 1985). Differences in near-infrared reflectance among the plant species and mixtures were primarily due to differences in their vegetative density (Myers et al. 1983). An overhead view of the plant species and mixtures showed that wild taro and giant reed had greater vegetative density and less gaps in their canopies than the mixed herbaceous species and Eurasian watermilfoil. The integration of water with the canopy of Eurasian watermilfoil absorbed a large percentage of the near-infrared light that also contributed to its lower reflectance at this wavelength (Myers et al. 1983, Everitt et al. 1989). Internal leaf structure measurements were not made, but this could also contribute to the near-infrared reflectance differences among the plant species (Gausman 1974).

Figure 1A shows a color-infrared positive photographic print of the site 1 wild taro study area. The print is a portion of a 23 cm photograph (original scale 1:5,000). The arrow on the print points to the bright red image tonal response of wild taro. Giant reed, the dominant plant species on the study site, has dark pink or gray-pink tonal responses. Mixed woody vegetation has dull red to reddish-brown tones, soil has a white color, and water is dark blue. The distinct image response of wild taro was primarily attributed to its low visible red reflectance, although its high near-infrared reflectance also contributed to tonal response. The pink image tone of giant reed was attributed to its high visible green reflectance. Mixed brush species such as honey mesquite and

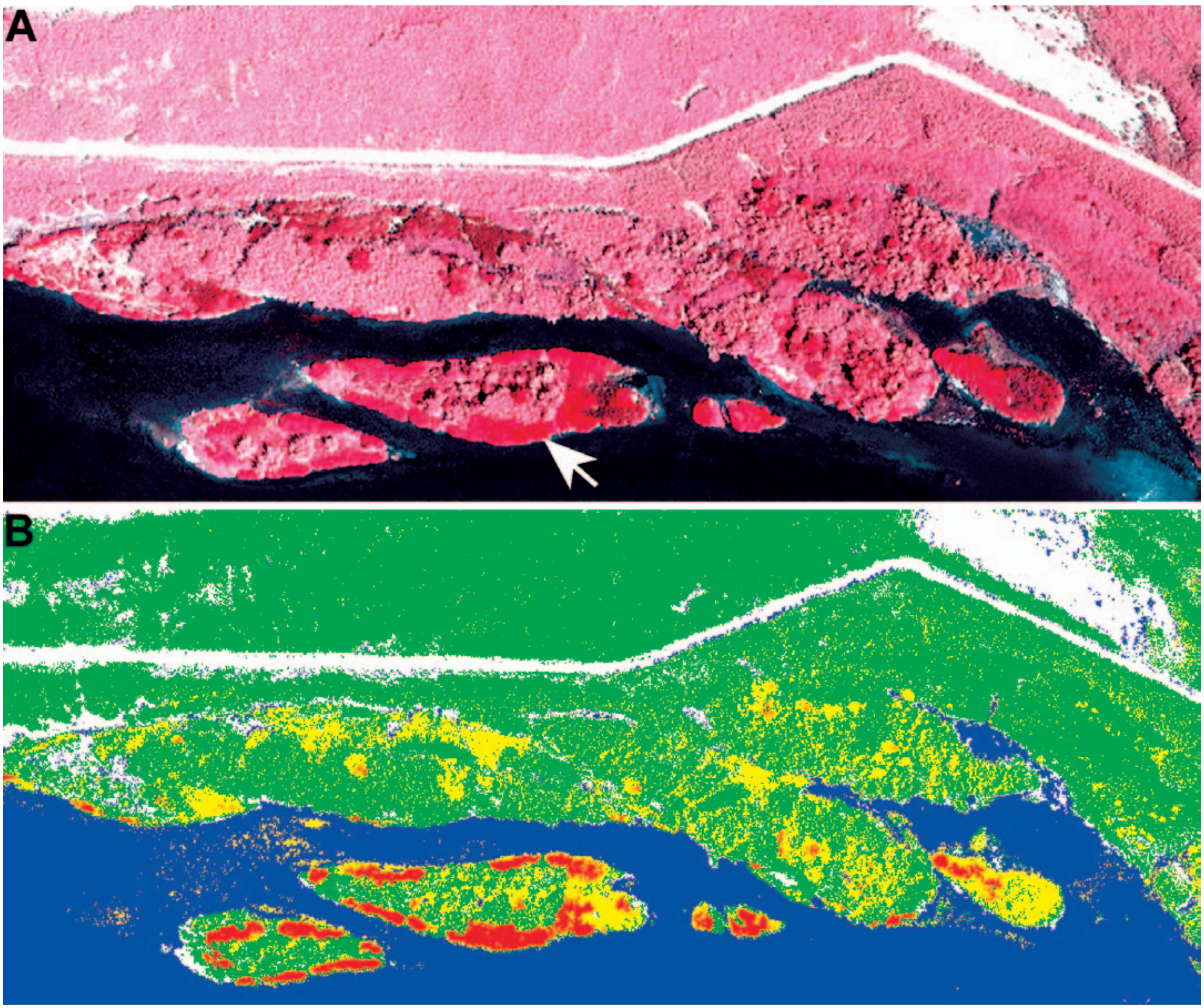

Figure 1. Color-infrared aerial photographic image (A) obtained June 15, 2006 from site 1 on the Rio Grande near Del Rio, Texas. The arrow on print A points to the bright red color of wild taro. Supervised classification (B) of the photograph. Color codes for the map classes are: red, wild taro; green, giant reed; yellow, mixed woody vegetation; white, soil; and blue, water.

TABLE 2. AN ERROR MATRIX FOR THE SUPERVISED CLASSIFICATION GENERATED FROM THE CLASSIFICATION DATA AND GROUND DATA FOR THE COLOR-INFRARED PHOTOGRAPH OF THE SITE 1 WILD TARO STUDY AREA ON THE RIO GRANDE NEAR DEL RIO, TEXAS.

Classified category	Actual category					Total	User's accuracy
	Soil	Giant reed	Wild taro	Woody	Water		
Soil	12	3	0	0	0	15	80.0%
Giant reed	0	35	0	0	1	36	97.2%
Wild taro	0	0	10	0	0	10	100%
Woody[1]	0	0	0	14	0	14	100%
Water	0	1	0	1	23	25	92.0%
Total	12	39	10	15	24		
Producer's Accuracy	100%	89.7%	100%	93.3%	95.8%	100	

Overall classification accuracy = 94.0%. Overall kappa = 0.920.
[1]Woody = mixed woody vegetation.

blackbrush have low to moderate visible and near-infrared reflectance that gives these plants duller red to reddish-brown image responses (Everitt 1985, Everitt et al. 2004).

The supervised classification map of the color-infrared photograph of the site 1 study area is shown in Figure 1B. Table 2 shows an error matrix comparing the classified data with the ground data for the 100 observations from the supervised classification of site 1. The overall accuracy was 94%, indicating that 94% of the category pixels in the image were correctly identified in the classification map. The producer's accuracy of individual categories ranged from 89.7% for giant reed to 100% for wild taro and soil. The user's accuracy ranged from 80% for soil to 100% for wild taro and mixed woody vegetation. Thomlinson et al. (1999) set a target of an overall accuracy of 85% with no class lower than 70%. Based on these guidelines, the overall accuracy was excellent, as well as both the producer's and user's accuracies for wild taro and most of the other classes. The kappa estimate was 0.920, indicating the classification achieved an accuracy that is 92% better than would be expected from the random assignment of pixels to classes.

Table 3 shows the error matrix comparing the classified data with the ground data for the 100 observations from the supervised classification of the color-infrared photograph of the site 2 study area (aerial photograph and computer classification map not shown). The overall accuracy was 88%. Wild taro had a producer's accuracy of 83.3% and a user's accuracy of 100%. The errors in the producer's accuracy for wild taro were due to its confusion with mixed woody vegetation. The poor user's accuracy of mixed woody vegetation was primarily due to its confusion with wild taro and giant reed. The kappa estimate was 0.838.

Table 4 shows an error matrix by comparison of the classified data with the ground data for the 125 observations from the supervised classification of the color-infrared photograph of the site 3 study area (aerial photograph and computer classification map not shown). The overall accuracy was 92.8%. Wild taro had a producer's accuracy of 83.3% and a user's accuracy of 100%. The two errors in the producer's accuracy of wild taro were due to its confusion with mixed woody vegetation and giant reed. The kappa estimate was 0.912.

Results from this study indicate that the spectral visible and near-infrared reflectance of wild taro facilitates its detection on color-infrared aerial photographs. Supervised image analysis of aerial photographs showed that wild taro populations could be quantified. Accuracy assessments performed on supervised classification maps of color-infrared photographs from three sites had mean producer's and user's accuracies of 88.9% and 100%, respectively. Qualitative assessment of archive color-infrared photography of the study area obtained in June 2002 and September 2004 showed that wild taro could be readily distinguished from

TABLE 3. AN ERROR MATRIX FOR THE SUPERVISED CLASSIFICATION GENERATED FROM THE CLASSIFICATION DATA AND GROUND DATA FOR THE COLOR-INFRARED PHOTOGRAPH OF THE SITE 2 WILD TARO STUDY AREA ON THE RIO GRANDE NEAR DEL RIO, TEXAS.

Classified category	Actual category					Total	User's accuracy
	Soil	Giant reed	Wild taro	Woody	Water		
Soil	12	3	0	0	1	16	75.0%
Giant reed	2	36	0	1	0	39	92.3%
Wild taro	0	0	10	0	0	10	100%
Woody[1]	0	2	2	7	1	12	58.3%
Water	0	0	0	0	23	23	100%
Total	14	41	12	8	25		
Producer's Accuracy	85.7%	87.8%	83.3%	87.5%	92.0%	100	

Overall classification accuracy = 88.0%. Overall kappa = 0.838.
[1]Woody = mixed woody vegetation.

TABLE 4. AN ERROR MATRIX FOR THE SUPERVISED CLASSIFICATION GENERATED FROM THE CLASSIFICATION DATA AND GROUND DATA FOR THE COLOR-INFRARED PHOTOGRAPH OF THE SITE 3 WILD TARO STUDY AREA ON THE RIO GRANDE NEAR DEL RIO, TEXAS.

	Actual category							
Classified category	Soil	Giant reed	Wild taro	Woody	Water	Mixed herb.	Total	User's accuracy
Soil	27	0	0	0	0	1	28	96.4%
Giant reed	0	23	1	0	0	0	24	95.8%
Wild taro	0	0	10	0	0	0	10	100%
Woody[1]	0	0	1	19	0	0	20	95.0%
Water	0	0	0	0	25	0	25	100%
Mixed herb.[2]	2	0	0	4	0	12	18	66.7%
Total	29	23	12	23	25	13		
Producer's Accuracy	93.1%	100%	83.3%	82.6%	100%	92.3%	125	

Overall classification accuracy = 92.8%. Overall kappa = 0.912.
[1]Woody = mixed woody vegetation.
[2]Mixed herb. = mixed herbaceous vegetation.

associated vegetation where it had a similar image response to that shown in this study. Previous research has shown that waterhyacinth [*Eichhornia crassipes* (Mart.) Solms] has a similar image response to wild taro on color-infrared aerial photography (Everitt et al. 2000). Consequently, it may be difficult to separate these two species on color-infrared aerial photos of areas where they occur together.

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