USING SPATIAL INFORMATION TECHNOLOGIES TO DETECT AND MAP INVASIVE WEEDS IN TEXAS RIPARIAN ZONES AND WATERWAYS

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ABSTRACT

This paper presents an overview on the application of aerial photography and airborne videography for detecting exotic invasive weeds in Texas (USA) riparian areas and waterways. Ground reflectance measurements have been used in conjunction with some of the studies to determine the spectral characteristics of the plants. Computer analyses of airborne images are used to quantify infestations and accuracy assessments are performed on classified images. Video imagery is integrated with global positioning system and geographic information system technologies to map weed infestations. Plant species addressed include waterhyacinth [Eichhornia crassipes (Mort.) Solms], hydrilla [Hydrilla verticillata (L. F.) Royle], giant salvinia (Salvinia molesta Mitchell), waterlettuce (Pistia stratiotes L.), and giant reed (Arundo donax L.).

INTRODUCTION

The National Invasive Species Act of 1996 recognized the importance and impact of invasive plants and animals in United States ecosystems. The Invasive Species Council established in 1999 by Presidential Executive Order of 13112, defines an invasive species as any plant, animal, or organism that is not native to the ecosystem under consideration and whose introduction is likely to cause harm to humans, health, environment, or the economy. It is estimated that invasive species in the United States cost its citizens over $130 billion annually (Pimentel et al. 2000; Faust, 2001).

Invasive plant species are an extremely big problem in the United States where they invade a variety of ecosystems. The invasion of riparian and aquatic zones by noxious plant species presents a serious problem to the management of these areas. The inaccessibility and often large expanses of these areas make ground inventory and assessment difficult, time consuming, expensive, and often inaccurate (Scarpace et al., 1981). More accurate measurements of area infested and canopy cover are essential to estimate the amount of damage and other ecological impact caused by invading weeds. 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., 1992).

The use of remote sensing for assessment of wetland and riparian areas is well established (Carter, 1982; Everitt and Deloach, 1990; Tiner, 1997). Field reflectance measurements have proven useful for characterizing the spectral characteristics of wetland and riparian plant species, while aerial photography and videography have been used to remotely detect plant species in these areas (Best et al., 1981; Ullah et al., 2000; Everitt et al., 2004). Within the past few years, remote sensing, geographic information system (GIS), and global positioning system (GPS) technologies have been integrated for mapping the distribution of noxious plant species in wetlands and riparian zones (Anderson et al., 1999; Everitt et al., 2004). Remote observations in georeferenced formats help to assess the extent of infestations, develop management strategies, and evaluate control measures on noxious plant populations.

During the past few years, scientists at the United States Department of Agriculture (USDA), Agricultural Research Service (ARS), Kika de la Garza Subtropical Agricultural Research Center in Weslaco, Texas, have been conducting research on the utilization of aerial photography and videography for detecting weeds in riparian zones and waterways. In this paper the author's present an overview of their own research on using airborne remote sensing techniques for detecting invasive weeds in riparian and aquatic areas in Texas.

GENERAL PROCEDURES

All the data presented in this paper have been published previously. Aerial imagery was obtained under sunny conditions with photographic and videographic systems mounted vertically in either a Cessna* 206T or Cessna 404 Titan aircraft. Additional information on photographic and videographic systems, as well as the procedures used for image digitizing, processing, and analysis, can be obtained from the literature citations.

Ground control data were collected for the research studies presented here. Field reflectance measurements were made for most of the studies. Other ground data included ground photographs, description of vegetation, and plant cover. Standard statistical techniques were used to analyze and interpret data (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Waterhyacinth and Hydrilla

Waterhyacinth [Eichhornia crassipes (Mort.) Solms] and hydrilla [Hydrilla verticillata (L. F.) Royle] are two aquatic weeds that often invade and clog waterways. Waterhyacinth is a floating species that has been called the "world's worst weed" (Cook, 1990). It is a native of South America that is now found in many tropical and subtropical areas of the world. Waterhyacinth is believed to have been introduced into the United States in the mid 1880's in Louisiana (Tabita and Woods, 1962). It is now found from Virginia to Florida and west to Texas and Missouri; it also occurs in California (Correll and Correll, 1972).

Hydrilla is a submersed species that is probably native to the warm regions of Asia. It is now a cosmopolitan species that occurs in many areas of the world, including Europe, Asia, Africa, Australia, South America, and North America (Langeland, 1996). Hydrilla was first discovered in the United States in Florida in 1960 and has since spread throughout the eastern seaboard states as well as California, Arizona, and Washington (Schmitz, 1990; Langeland, 1996). Once established in an aquatic system, hydrilla can detrimentally alter the environment by replacing native aquatic vegetation and affecting fish populations. Hydrilla also interferes with movement of water for drainage and irrigation purposes and reduces boating access, thus reducing recreational use of the water body (Langeland, 1996).

A study was recently completed demonstrating the use of airborne videography integrated with GPS and GIS technologies for detecting and mapping waterhyacinth and hydrilla infestations in the Rio Grande River of southern Texas (Everitt et al., 2003a). Figures 1A and 1B show aerial normal color videographic images of waterhyacinth and hydrilla infestations, respectively, in the Rio Grande near Brownsville, Texas. The imagery was acquired on September 19, 2002. The arrow on Figure 1A points to the green to dark green smooth textured image response of waterhyacinth, while the arrow on Figure 1B points to the deep dark green to nearly black tonal response of surfaced hydrilla. Trees, shrubs, and herbaceous vegetation adjacent to the river have various green tonal responses, while bare soil and sparsely vegetated areas have white, light tan and light gray tones. The GPS data are displayed at the top of the images. The latitude-longitude coordinates superimposed on the images are useful for georeferencing waterhyacinth and hydrilla infestations in the river.

* Mention of company name or trademark is included for the benefit of the reader and does not constitute endorsement of a particular product by the U. S. Department of Agriculture over others that may be commercially available.

Figure 1. Aerial normal color video images of infestations of waterhyacinth (A) and hydrilla (B) in the Rio Grande River near Brownsville, Texas. The arrows point to waterhyacinth and hydrilla in each respective image. The imagery was obtained on September 19, 2002 at an altitude above ground level of approximately 600 m and had an original pixel size of approximately 0.70-m.

Both waterhyacinth and hydrilla had similar color tonal responses to those shown in Figures 1A and 1B, respectively, in all normal color video imagery obtained of the Rio Grande. However, only surfaced hydrilla populations could be readily distinguished. Hydrilla submerged greater than 7.5 cm below the water surface generally could not be delineated from water. This agrees with the findings of the 1998 survey of the Lower Rio Grande (Everitt et al., 1999). The turbidity of the Rio Grande in this area contributes significantly to the inability to distinguish submerged hydrilla.

Waterhyacinth and hydrilla could be distinguished in aerial color-infrared (CIR) photography and CIR videography obtained of the Rio Grande on June 24, 2002 (imagery not shown). Waterhyacinth had a distinct red to orange-red image response, while hydrilla had a reddish-brown to dark brown image. Only surfaced hydrilla could be clearly delineated in the imagery.

The CIR photography had greater spatial resolution than the CIR or normal color videography. Consequently, it provided a more detailed image of hydrilla and waterhyacinth populations and aided in the interpretation of the coarser resolution videographic imagery. However, the videography was adequate for distinguishing most of the hydrilla and waterhyacinth. Normal color videography did a better job of penetrating the water than either the CIR photography or videography. This was attributed to its sensitivity in the visible blue (0.40 to 0.50 µm) portion of the spectrum (Avery and Berlin, 1992). This is in general agreement with the findings of Benton and Newnam (1976) who reported that normal color photography was useful for detection of submerged aquatic vegetation. One advantage of videography over photography is its cost-effectiveness. Airborne video surveys using analog imagery can be flown for about 25% the cost of aerial photography (Everitt et al., 1992).

Ground surveys of sites selected from the aerial photography and videography resulted in visual correct identification of waterhyacinth and hydrilla at all locations. However, a considerable amount of submerged hydrilla was found at some sites that could not be detected in the imagery. We also found small clumps of water stargrass [Heteranthera dubia (Jacq.) MacM.] generally less than 0.75-m in diameter intermixed with hydrilla at two sites near Brownsville and several individual plants and small patches (less than 1-m in diameter) of waterlettuce intermixed with waterhyacinth at one site west of Brownsville. Neither yellow stargrass nor waterlettuce could be distinguished in the imagery due to the small size of the plant populations.

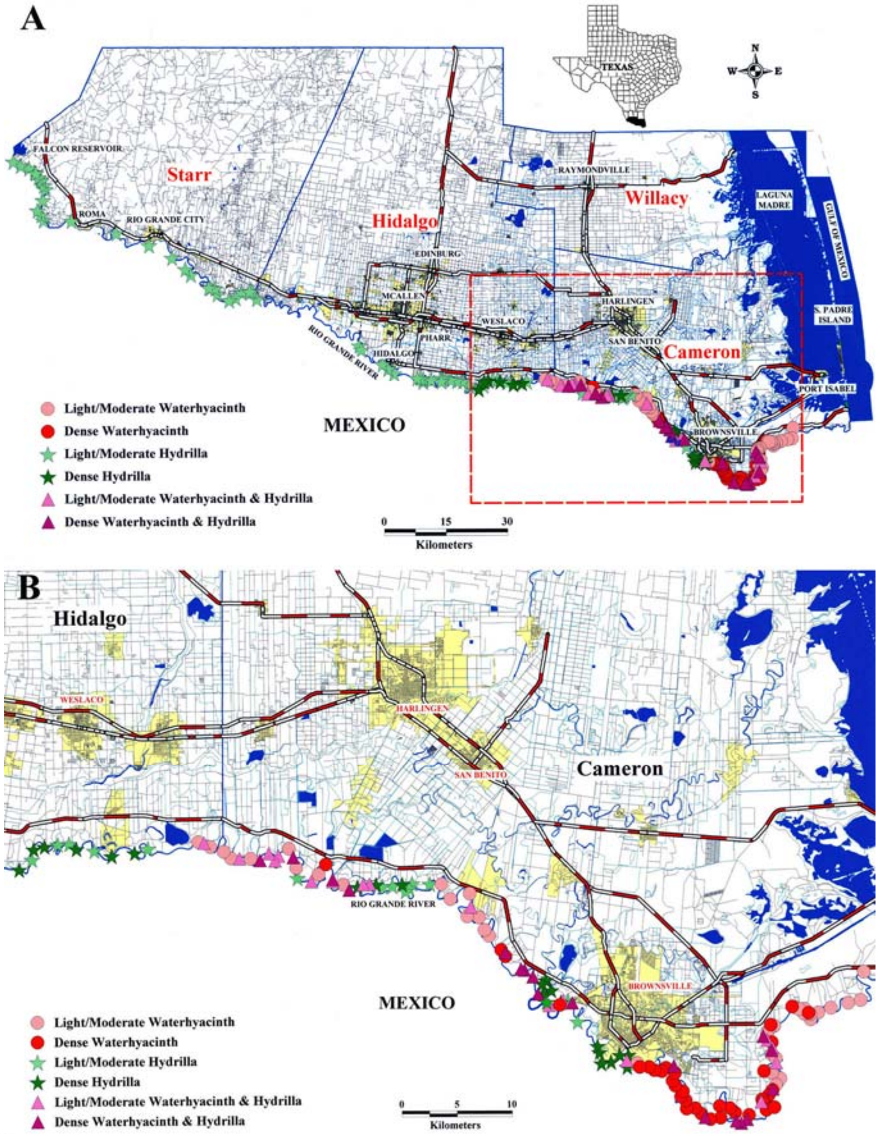

Figure 2. Regional GIS map (A) of Starr, Hidalgo, Cameron, and Willacy counties in the Lower Rio Grande Valley of south Texas. The Rio Grande River forms the lower boundary of the map with Mexico. A detailed GIS map (B) of southeastern Hidalgo and Cameron counties depicting infestations of waterhyacinth and hydrilla in the Rio Grande.

The GPS latitude-longitude data obtained from the video imagery of the Rio Grande from the June, September, and October 2002 surveys were integrated with GIS technology to georeference populations of waterhyacinth and hydrilla on a regional basis. Figure 2A shows a regional GIS map of Starr, Hidalgo, Cameron, and Willacy counties of south Texas. The Rio Grande forms the lower boundary of the map adjacent to Mexico. The map shows the Rio Grande from its mouth in southeastern Cameron County to Falcon Dam in southwestern Starr County. Light to moderate populations of waterhyacinth have pink circles, while dense populations of waterhyacinth have red circles. The light green stars represent light to moderate populations of hydrilla, while dark green stars denote dense populations of hydrilla. For mixed populations of waterhyacinth and hydrilla, light magenta triangles represent light to moderate populations, while dark magenta triangles indicate dense populations. Due to the small scale of the map many of the symbols are stacked on each other. Most symbols represent composites of two to five video scenes. The highest populations of waterhyacinth and hydrilla occurred in southeastern Hidalgo and Cameron counties where a stretch of approximately 170 river-km was infested. Waterhyacinth was found only in Cameron and extreme southeastern Hidalgo counties. East of Brownsville most waterhyacinth (60%) infestations were dense, while most sites west of Brownsville (67%) had light to moderate infestations. With the exception of a relatively short stretch of the Rio Grande in southwestern Hidalgo County, hydrilla occurred along most of the river from southeast of Brownsville to Falcon Dam.

Figure 2B shows an enlarged GIS map of southeastern Hidalgo and Cameron counties depicting the heaviest populations of waterhyacinth and hydrilla in the Lower Rio Grande. This area corresponds to the enclosed box in Figure 2A. This map shows greater detail of the area in regard to streets, roads, and hydrography associated with waterhyacinth and hydrilla populations.

The 2002 survey maps showed a marked increase in distribution of hydrilla in Hidalgo County as compared to the 1998 survey map of the area (Everitt et al., 1999). Hydrilla was found at only a few scattered locations in Hidalgo County in 1998 and had a distribution of about 5 river-km. Conversely, in 2002 hydrilla was found at numerous locations in Hidalgo County and had a distribution of approximately 50 river-km. Another notable change was the increase in the distribution of both waterhyacinth and hydrilla populations southeast of Brownsville in 2002. This represented an increase in distribution of approximately 70 river-km from the 1998 survey. This was probably due to the blockage of the mouth of the Rio Grande with silt and sand in 2001 and 2002 which decreased salinity levels in the lower stretch of the river and subsequently allowed waterhyacinth and hydrilla to move farther down stream. Blockage of the mouth of the river was primarily due to reduced stream flow due to long-term drought. The severe infestations of weeds in the river in southeastern Hidalgo and Cameron counties probably also contributed to the reduced flow. The estimated increases in river-km of hydrilla are primarily based on surfaced beds, since few of the submerged plants could be distinguished. Therefore, our estimated total river-km of hydrilla is probably an underestimation of the actual number of river-km of this invasive species in the lower Rio Grande.

Giant salvinia

Giant salvinia (Salvinia molesta Mitchell) is a floating fern native to southern Brazil that has spread to many other warm freshwaters of the world (Barrett, 1989). Giant salvinia develops dense mats that interfere with rice cultivation, clog fishing nets, and disrupt access to water for humans, livestock, and wildlife. Additionally, giant salvinia will overgrow and replace native plants that provide food and habitat for wildlife, and it blocks out sunlight and decreases oxygen concentration to the detriment of fish and other aquatic species (Cook, 1990; Mitchell and Gopal, 1991; Creigh, 1991). Giant salvinia has been found and eradicated in nurseries and ponds in the United States on several occasions (Nelson, 1984). However, in September 1998, a major occurrence of giant salvinia was found in Toledo Bend Reservoir in east Texas (Chilton, 1998). It has since spread to a number of private ponds and other waterways in east and southeast Texas.

Everitt et al. (2002) conducted a study to evaluate the potential of color-infrared (CIR) aerial photography for distinguishing giant salvinia in southeast Texas waterways. Figure 3A shows a CIR positive photographic print obtained on June 7, 2000 of a small lake infested with giant salvinia near Mont Belvieu, Texas. The print is a portion of a 23-cm photograph (1:8,500 scale). Arrow-1 points to the pink image tone of green giant salvinia, while arrow-2 points to the grayish-pink image response of senesced giant salvinia. Both classes of giant salvinia can be readily distinguished throughout the lake. The small dark red clumps are American buttonbush and live oak (Quercus virginiana Mill.) trees on small islands, whereas the small lighter red clumps are waterhyacinth. Water has dark blue to black image tones. The lake is surrounded by a dense woodland. Fallow agricultural fields are located in the lower portions of the photograph, while another lake is located on the right side of the photo.

Green giant salvinia had a similar color tonal response to that shown in Figure 3A in additional CIR photographs obtained near Liberty, Bridge City, and Milam, Texas. The CIR image response of senesced giant salvinia varied from grayish-pink (Fig. 3A) to olive-green. Some senesced giant salvinia populations near Liberty had both grayish-pink and olive-green CIR image responses. The darker image response of some senesced giant salvinia populations was attributed to a higher proportion of brown foliage in their canopies. Nonetheless, these populations could be differentiated qualitatively from other associated plant species. Both green giant salvinia and senesced giant salvinia could be distinguished in CIR photos obtained in June and July 1999, and in March and June 2000. Giant salvinia could be distinguished at photographic scales ranging from 1:1,500 to 1:8,500.

The unsupervised computer classification of the June CIR photograph (Fig. 3A) is shown in Figure 3B. Color codes and respective areas/percentages for the various land-use types are: yellow=green giant salvinia (41.4%), orange=senesced giant salvinia (27.7%), aqua=woody plants (0.7%), magenta=waterhyacinth (1.4%), and dark blue=water (28.8%). American buttonbush and live oak were included in the woody plant class. A qualitative comparison of the computer classification to the photograph shows that the computer did a good job in identifying both classes of giant salvinia.

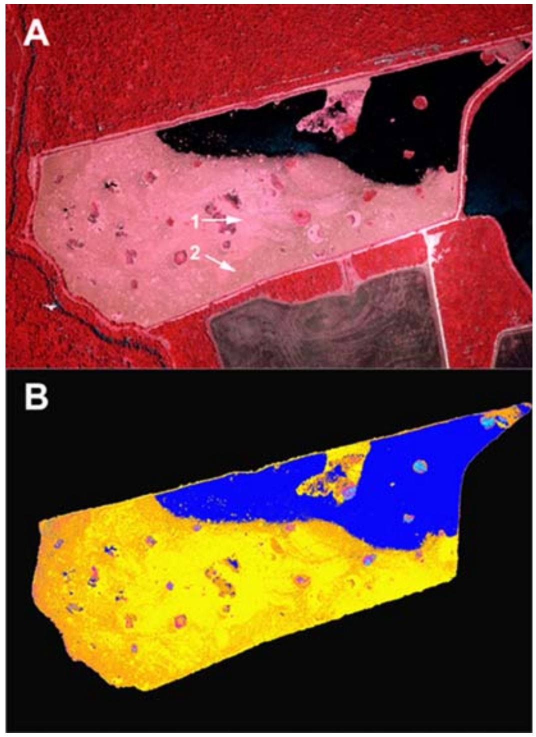

Figure 3. Aerial color-infrared photographic print (A) obtained on June 7, 2000 of a small lake near Mont Belvieu, Texas, infested with giant salvinia. Arrow 1 points to the pink image tone of green giant salvinia, whereas arrow 2 points to the grayish-pink response of senesced giant salvinia. The photograph had an original scale of 1:8,500. Unsupervised computer classification (B) of print A. Color codes for the various land-use types are yellow = green giant salvinia; orange = senesced giant salvinia; aqua = woody plants; magenta = waterhyacinth; and dark blue = water.

Table 1. An error matrix generated from the classification data and ground data for the June 7, 2000 color-infrared photograph of the Mont Belvieu, Texas study site.

	Actual Category						
Classified Category	Water	Woody plants	Senesced GS	Water-hyacinth	Green GS	Total	Users=s Accuracy
Water	23	0	0	0	0	23	100%
Woody plants	0	6	0	2	0	8	75.0%
Senesced GS	0	0	18	2	3	23	78.3%
Waterhyacinth	0	1	0	6	1	8	75.0%
Green GS	0	0	1	3	34	38	89.5%
Total	23	7	19	13	38	100	
Producer=s Accuracy	100%	85.7%	94.7%	46.2%	89.5%		

Overall accuracy = 87.0%. Kappa = 0.825. GS - giant salvinia.

Table 1 shows an error matrix by comparison of the classified data with the ground data for 100 observations within the study area. The overall classification accuracy was 87.0%, indicating that 87% of the category pixels in the image were correctly identified in the classification map. The producer's accuracy of individual categories ranged from 46.2% for waterhyacinth to 100% for water, whereas the user's accuracy ranged from 75% for both woody plants and waterhyacinth to 100% for water. Water was the easiest category to identify, while waterhyacinth was the most difficult to differentiate. Both the producer's accuracy and user's accuracy for giant salvinia were quite good. Green giant salvinia had 89.5% accuracy for both the producer's and user's accuracy, while senesced giant salvinia had a producer's accuracy of 94.7% and a user's accuracy of 78.3%. The errors in both giant salvinia classes were insignificant because they were primarily due to confusion between the two. This was attributed to grading between healthy plants with green foliage and senesced plants with mixtures of green and brown foliage. The low producer's accuracy of waterhyacinth was caused by confusion with woody plants and the two classes of giant salvinia. Some of the error was due to small clumps of waterhyacinth less than 1 m in diameter that were intermixed with the two classes of giant salvinia. The confusion of waterhyacinth with the woody plant category was attributed to the similar reflectance values of the plants (Everitt et al., 1987; Everitt et al., 2002). Another accuracy measure, the kappa estimate for this study, was 0.825, indicating the classification has achieved an accuracy that is 82.5% better than would be expected from random assignment of pixels to categories.

Waterlettuce

Waterlettuce is free-floating exotic aquatic weed that is one of the most cosmopolitan aquatic plants in the world. It is found on every continent except Europe and Antarctica (Gillet et al., 1968; Stoddard, 1989) and is believed to be native to South America (Cordo et al., 1981). The floating growth characteristic and fast reproductive rate of waterlettuce cause waterways to become clogged and access to fishing, swimming, and boating to be reduced or eliminated (Gillet et al., 1968). It is found in waterways of the southeastern United States from Florida to Texas and in California (DiTomaso and Healy, 2003).

Everitt et al. (2003b) conducted a study to determine the light reflectance characteristics of waterlettuce and evaluate color-infrared (CIR) aerial photography and videography for distinguishing infestations of this noxious weed in southeast Texas waterways. They showed that waterlettuce had higher visible green reflectance than other associated species on several dates over the growing season that facilitated its detection on CIR photography and videography.

Figures 4A and 4B show a positive CIR photographic print and a CIR video image, respectively, obtained July 31, 2001 of a small bayou infested with waterlettuce and other aquatic plants near Beaumont, Texas. The print is a portion of a 23-cm photograph with a scale of 1:2,500. The video image has a 0.80-m pixel size and was extracted from a larger video scene. The arrows on the two images point to waterlettuce. Waterlettuce has a light pink to whitish-pink image tone on the photograph, while on the video image it has a whitish-pink to light blue response. Differences in image tonal responses between the photograph and video image were attributed to chemical emulsion layers of the film versus electronic coding of the video imagery. Other mixed aquatic vegetation has a more reddish response, water is black, surrounding riparian vegetation has various shades of red, pink, magenta, green, gray, and brown, and bare soil to sparsely vegetated areas have a white to light blue color. The slightly different tonal responses of the video image, as compared to the photograph, are due to electronic coding of the video versus chemical emulsion layers of the film. Waterlettuce had a similar color tonal response to those shown in Figures 4A and 4B in additional CIR photographs and video images, respectively, acquired near Orange, Texas, in October 2001.

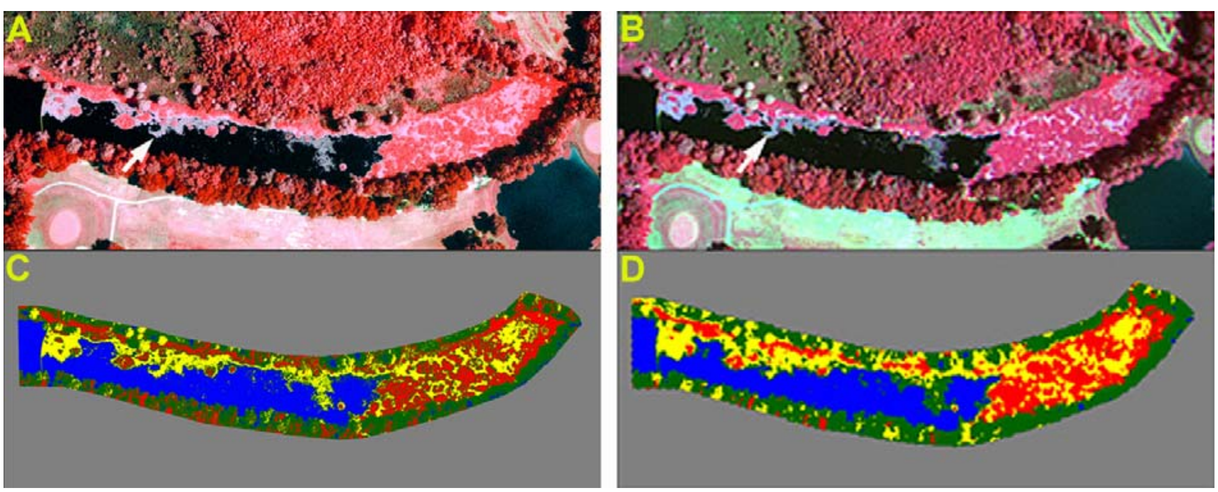

Figure 4. Aerial color-infrared photographic (A) and videographic (B) images obtained on July 31, 2001 of a bayou near Beaumont, Texas, infested with waterlettuce and other aquatic vegetation. The arrows point to the light pink, whitish-pink, or light blue tonal responses of waterlettuce. The photograph had an original scale of 1:2,500, whereas the video image had an original pixel size of 0.80-m. Unsupervised computer classifications of the photographic (C) and videographic (D) images. Color codes for the various land-use types are: yellow = waterlettuce, red = mixed aquatic vegetation, green = riparian vegetation, and blue = water.

Figures 4C and 4D show the unsupervised computer classifications for the bayou and the adjacent riparian vegetation around its perimeter for the photograph and video images, respectively. Color codes and percentages of respective areas for the various land-use types in both photographic and video images are: yellow = waterlettuce (15% for photograph and 19% for video); red = mixed aquatic vegetation (19% for photograph and 21% for video); green = riparian vegetation (41% for photograph and 37% for video); and blue = water (25% for photograph and 23% for video). A qualitative assessment of the two classifications showed that the computer did an adequate job in identifying most of the waterlettuce in both images, but the photographic classification was more accurate. For example, a stand of waterlettuce in the center of the bayou was identified as riparian vegetation in the classification of the video image.

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

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

Table 2. An error matrix generated from the classification data and ground data for the July 31, 2001 color-infrared photograph of the Beaumont study site.

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

Overall accuracy = 86.3%. Kappa = 0.814.

Table 3. An error matrix generated from the classification data and ground data for the July 31, 2001 color-infrared video image of the Beaumont study site.

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

Overall accuracy = 83.8%. Kappa = 0.763.

The producer's accuracy of individual categories for the video image (Table 3) ranged from 67% for mixed aquatic vegetation to 93% for waterlettuce, while the user's accuracy ranged from 77% for waterlettuce to 93% for mixed aquatic vegetation. The high producer's accuracy for waterlettuce was considered quite good, while the moderate user's accuracy was acceptable. Like the photographic image classification, errors in the user's accuracy for waterlettuce were primarily due to its confusion with mixed aquatic vegetation and riparian vegetation, while the lower producer's accuracy of mixed aquatic vegetation was mainly due to it confusion with riparian vegetation.

The Kappa estimates were 0.814 and 0.763 for the photographic and video image classifications, respectively. This indicated that the classifications achieved accuracies that were 81% and 78% better than would be expected from random assignment of pixels to categories.

Giant reed

Giant reed is a robust, perennial grass 2 to 8 m tall growing in many stemmed cane-like clumps. It is native to India, but has been introduced as an ornamental and for erosion control. Subsequently, it has become naturalized and invasive in many tropical, subtropical, and warm-temperate regions of the world (Dudley, 2000). It is found throughout the southern half of the United States from Maryland to California (Dudley and Collins, 1995; Bell, 1997). Giant reed is a severe threat to riparian areas where it displaces native plants by forming massive stands. It also alters channel morphology by retaining sediments and constricting flows, and uses excessive amounts of water (Bell, 1997; Dudley, 2000).

A study was conducted in Texas to determine the feasibility of using aerial photography and airborne videography integrated with GPS and GIS technologies for detecting and mapping giant reed infestations (Everitt et al., 2004).

Figure 5A shows a positive color-infrared photographic image obtained 25 June 2002 of an area along the Rio Grande near Del Rio, Texas, infested with giant reed. The photo is a portion of a 23 cm photograph (1:10,000 scale). The arrow points to the distinct pink image tonal response of giant reed. Mixed brush has a reddish-brown image, mixed herbaceous vegetation has reddish-gray, gray or dark gray tones, soil has a light gray to white color, and water has a black response. The gray diagonal area below the Rio Grande at the bottom of the photograph is Mexico.

The unsupervised computer classification of the color-infrared photograph (Fig. 5A) of the Rio Grande study site is shown in Figure 5B. Color codes for the various land-use types are: yellow = giant reed; red = mixed brush; green = mixed herbaceous vegetation; white = soil; and blue = water. The computer appears to have done a very good job in identifying giant reed.

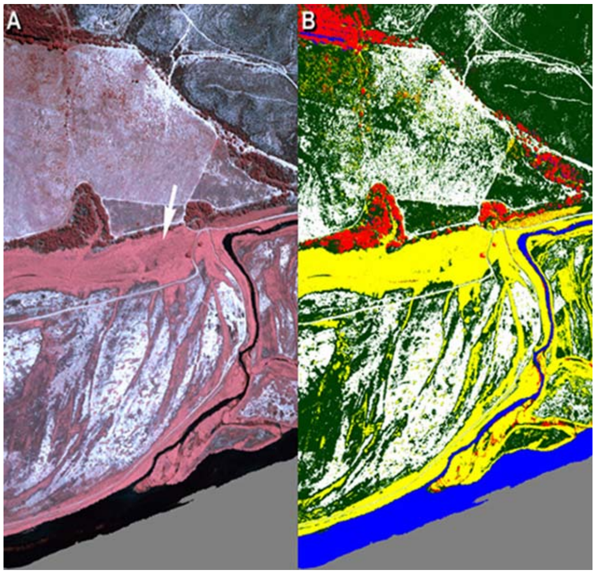

Figure 5. Color-infrared photographic image (A) obtained on June 25, 2002 of an area along the Rio Grande near Del Rio, Texas, with an infestation of giant reed. The arrow points to the pinkish response of giant reed. Unsupervised classification (B) of the photographic image. Color codes for the various land-use types are: yellow = giant reed; red = mixed brush; green = mixed herbaceous vegetation; white = soil; and blue = water. The gray diagonal area at the bottom on both illustrations is Mexico.

Table 4 shows an error matrix for the color-infrared photographic image by comparison of the classified data with the ground data for the 100 observations within the Rio Grande study site near Del Rio. The overall classification accuracy was 83.0%, indicating that 83% of the category pixels in the image were correctly identified in the classification map. The producer's accuracy of individual categories ranged from 72.4% for soil to 100% for water, whereas the user's accuracy ranged from 60% for mixed herbaceous vegetation to 100% for giant reed, water, and mixed brush. Water was the easiest category to identify. Both the user's and producer's accuracy for giant reed were very good. The errors in the producer's accuracy for giant reed were due to its confusion with mixed herbaceous vegetation. The relative low user's accuracy for mixed herbaceous vegetation was primarily due to its confusion with soil and giant reed. The kappa estimate for this study was 0.780.

Table 4. An error matrix generated from the classification data and ground data for the 25, June 2002 color-infrared photograph of the Rio Grande study site near Del Rio, Texas.

Classified Category	Actual Category					Total	User's Accuracy
	Giant Reed	Water	Mixed Brush	Soil	Mixed Herbaceous		
Giant Reed	20	0	0	0	0	20	100.0%
Water	0	11	0	0	0	11	100.0%
Mixed Brush	0	0	10	0	0	10	100.0%
Soil	0	0	0	21	3	24	87.5%
Mixed Herbaceous	5	0	1	8	21	35	60.0%
Total	25	11	11	29	24	100	
Producer's Accuracy	80.0%	100.0%	90.9%	72.4%	87.5%		

Overall accuracy = 83.0%. Kappa = 0.780.

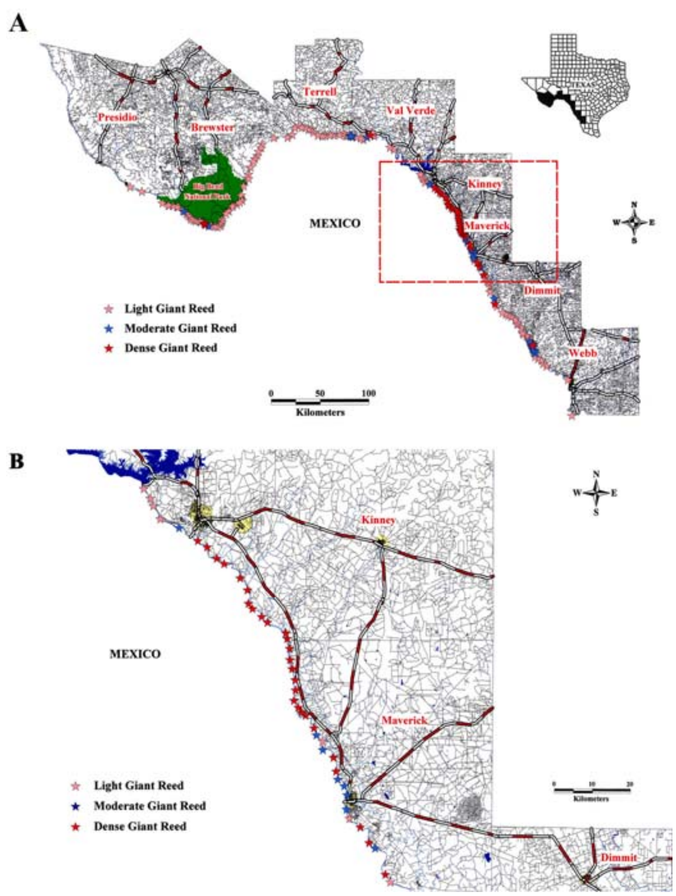

Figure 6. Regional GIS map (A) of an 8-county area along the Rio Grande in southwest and west Texas. The Rio Grande forms the western boundary of the map with Mexico. The symbols along the Rio Grande represent GPS latitude-longitude coordinates of giant reed infestations obtained from airborne video imagery. A detailed GIS map (B) of a portion of the Rio Grande with several dense infestations of giant reed.

Figure 6A shows a regional GIS map of an 8-county area of southwest and west Texas. The Rio Grande forms the boundary of the map adjacent to Mexico. The GPS latitude-longitude data provided on the aerial videographic imagery of the Rio Grande from the June 2002 over flight have been integrated with the GIS to georeference infestations of giant reed along the river. Areas with red stars represent the densest populations of giant reed, those with blue stars have moderate populations, and those represented by pink stars have light populations. Approximately 600 river-km of the Rio Grande area surveyed was infested with giant reed. The densest populations of giant reed are located in Kinney and Maverick counties in southwest Texas. Due to the small scale of the map, many of the symbols are stacked on each other. Consequently, some symbols represent a composite of 3 or 4 video scenes. Ground surveys confirmed the presence of giant reed at all the plotted locations on the map. Small stands or individual plants of common reed were found growing in association with giant reed at several scattered locations. However, very little common reed could be distinguished in the imagery. Where it could be differentiated, common reed generally had a reddish-pink image response as compared to the pink image tone of giant reed.

Figure 6B shows a more detailed GIS map of the portion of the Rio Grande with the densest infestations of giant reed in Kinney and Maverick counties and corresponds to the enclosed box in Figure 6A. This map more clearly depicts the infested areas and allows one to associate the general land-use characteristics (i.e., highways, roads) with the GPS locations where giant reed occurred.

CONCLUSIONS

Data presented in this paper has shown the potential of remote sensing for distinguishing invasive weeds in waterways and riparian areas.. Both aerial photography and videography are useful tools for detecting noxious plant species. Computer analyses of remote sensing imagery can be used to quantify weed infestations. This technique can provide area estimates of noxious weed infestations that can be useful for monitoring their spread or contraction. The electronic format of videography makes it highly compatible with computer image processing techniques, GPS, and GIS technologies. These technologies can enable resource managers to develop regional maps depicting where weed infestations occur over large and inaccessible areas.

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