

# USING AERIAL PHOTOGRAPHY FOR MAPPING GIANT REED INFESTATIONS ALONG THE TEXAS-MEXICO PORTION OF THE RIO GRANDE

**Chenghai Yang**, Agricultural Engineer

**James H. Everitt**, Range Scientist

**John A. Goolsby**, Research Entomologist

USDA-ARS

Kika de la Garza Subtropical Agricultural Research Center

2413 E. Highway 83, Weslaco, Texas 78596

chenghai.yang@ars.usda.gov

## ABSTRACT

Giant reed (*Arundo donax* L.) is an invasive weed throughout the southern half of the United States with the densest stands growing along the coastal rivers of southern California and the Rio Grande in Texas. The objective of this study was to use aerial photography to map giant reed infestations and estimate infested areas along the Texas-Mexico portion of the Rio Grande. Aerial color-infrared (CIR) photographs (each covering approximately a 2.4 km by 2.4 km area with 20-30% overlaps) were taken along the Rio Grande between Brownsville and El Paso, Texas in June and July 2002. Based on the aerial photographs and ground surveys, the portion of the river from San Ygnacio to Lajitas that has a river length of 898 km was found to be infested with giant reed with the densest populations located between Laredo and Del Rio. To estimate infested areas along both the U.S. and Mexican sides of the river, 65 out of the 480 aerial photographs taken between Lajitas and San Ygnacio were randomly selected. The aerial photographs were digitized, rectified to Google Earth imagery, and then classified using maximum likelihood classification techniques. The infested areas on both sides of the river as well as water area and river length from each photographic image were determined. Based on the estimates from the 65 aerial photos, the ratio of giant reed area to water area and the ratio of giant reed area to river length were calculated. The total giant reed area along the Rio Grande between Lajitas and San Ygnacio was estimated to be 5985 ha with 3670 ha or 61% on the U.S. side and 2315 or 39% on the Mexican side. This study provides the first accurate estimates of giant reed infestations along the Texas-Mexico portion of the Rio Grande and this information will be useful for both land owners and government agencies for the management and control of giant reed.

## INTRODUCTION

Giant reed (*Arundo donax* L.) is a non-indigenous perennial grass that has become an invasive weed in many tropical, subtropical and warm-temperate regions of the world (Dudley, 2000). It was intentionally introduced to California from the Mediterranean for erosion control and for use in thatching and basket weaving, but giant reed has gradually naturalized throughout the southern half of the United States from Maryland to California (Bell, 1997). Today the densest stands are found along coastal rivers of southern California (Dudley and Collins, 1995; Bell, 1997) and along the Texas-Mexico portion of the Rio Grande (Tracy and Deloach, 1999; Everitt et al., 2004).

Giant reed is a robust bamboo-like plant that can grow up to 10 m tall. It consumes about three times as much water as native vegetation to supply its incredible rate of growth (Iverson 1994). During warm months with ample water, giant reed culms are reported to attain a growth rate of 0.7 m per week and can produce more than 20 metric tons per hectare above-ground dry mass (Perdue, 1958). Giant reed is a relentless threat to riparian areas and watersheds in impacted states of the U.S. It spreads rapidly by either rhizomes or plant fragments and can displace native vegetation, leading to the destruction of wildlife habitats (Khudamrongsawat et al., 2004; Kisner 2004). The presence of giant reed in streambeds and along stream banks affects the stream hydrology and stream morphology by retaining sediments and channeling flows (Oakins, 2001). Giant reed reduces riparian arthropod diversity and abundance in riparian ecosystems where this invasive species has become a dominant component (Herrera and Dudley, 2003). The stems and leaves contain several toxic or unpalatable chemicals that probably protect it from most native insects and other grazers (Newhouser et al., 1999).

The key to effective control of established giant reed is to kill its root system. Mechanical removal with heavy machinery has been ineffective because the rhizome fragments buried under the soil will resprout, and prescribed burning has not been successful because it does not affect the rhizomes (Dudley, 2000). Chemical treatment with

systemic herbicides may require continued application for several years and has the side effects of spraying surrounding vegetation and water (Newhouser et al., 1999). Typically a mechanical cut followed by herbicide application is used for better control. Nevertheless, these approaches have not been very successful and infestations of giant reed continue to expand. Biological control is often the preferred strategy for long-term management of invasive weeds (Culliney, 2005). Giant reed is an excellent candidate for biological control because there are several specialist insects from the native range in Europe and giant reed has no close relative in North or South America (Tracy and Deloach, 1988). A biological control program was initiated for giant reed at the USDA-ARS Research Center at Weslaco, Texas, a few years ago and four agents have been introduced from Europe for evaluation in quarantine (Goolsby et al., 2008). One of the agents, the eurytomid wasp (*Tetramesa romana* Walker), was evaluated and found to be specific to the genus *Arundo* and unlikely to harm native or cultivated plants in the Americas (Goolsby and Moran, 2009). This wasp was released in a section along the Rio Grande in Laredo, Texas in 2009 and other agents are still under evaluation and will be released in the near future for the biological control of giant reed throughout the Rio Grande Basin.

The first important step for successful management of giant reed is to map its spatial distribution and determine infested areas. Because of the great expanse and inaccessibility of these areas, remote sensing provides a useful tool and has the potential for mapping the spatial extent of giant reed infestations and for distinguishing it from associated plant species. Oakins (2001) evaluated color-infrared (CIR) aerial photography for mapping giant reed along the Salinas River near Gonzales, California. Their results showed that giant reed can be differentiated from other riparian vegetation classes such as willow and cottonwood. DiPietro et al. (2002) used AVIRIS hyperspectral imagery for detecting and mapping giant reed in riparian areas in southern California. Everitt et al. (2004) described the light reflectance characteristics of giant reed and demonstrated the application of aerial photography and videography for detecting and mapping giant reed infestations in riparian areas in Texas. More recently, Everitt et al. (2005, 2008) evaluated both 2.8-m QuickBird and 10-m SPOT 5 satellite imagery for distinguishing giant reed infestations along the Rio Grande in southwest Texas. Their results showed that high resolution satellite imagery could be used to accurately detect and map giant reed infestations along the river. Yang et al. (2009) used 40 QuickBird images acquired between 2002 and 2007 from the Mexican portion of the Rio Grande Basin to estimate giant reed-infested areas and they estimated a total of 4775 ha of giant reed existed along the major tributaries in the Mexican portion of the Basin.

The Rio Grande Basin lies within three U.S. states and five Mexican states. The Rio Grande is the source of life for over 13 million people and its ecosystems. The Basin as a whole is arid or semiarid with limited water resources and many threatened and endangered plants and animals. The rapid spread of invasive weeds such as giant reed and saltcedar (*Tamarix* spp.) is threatening to worsen the water shortage and degrade the ecosystem in the Basin. Therefore, it is very important to map the distribution of giant reed and quantify its infested areas in the Basin. Yang et al. (2009) mapped the distribution of the giant reed and quantified its infested areas in the Mexican portion of the Basin. Everitt et al. (2004) mapped the distribution of giant reed along the Rio Grande in Texas, but total infested areas along the river have not been determined. The research findings from the few remote sensing studies of giant reed in California and Texas have demonstrated that aerial photography, videography, hyperspectral imagery, and high resolution satellite imagery can all be used for detecting and mapping giant reed infestations. Aerial photography is a useful and relatively inexpensive remote sensing tool and provides finer spatial resolution than airborne and satellite digital imagery. The objective of this study was to estimate infested areas along both the U.S. and Mexican sides of the Rio Grande using aerial CIR photography.

## METHODS

### Study Area

The Rio Grande is one of the longest rivers of North America. It flows from its sources of southwestern Colorado to the Gulf of Mexico and serves as a natural boundary along the border between Texas and Mexico. The length of the whole Rio Grande is 3033 km and the segment of the river that forms the border has a length of 2018 km. This study was conducted along the Texas-Mexico portion of the Rio Grande between El Paso and Brownsville, Texas.

### Acquisition of Aerial Photography

Aerial CIR photography was chosen as the remote sensing data for this study. A Fairchild type K-37 large format (23 cm × 23 cm) photographic camera was used for the acquisition of aerial photography. The film used was

Kodak Aerochrome CIR type 1443 film sensitive in the green (500-600 nm), red (600-700 nm), and NIR (700-900 nm) wavebands. Aerial CIR photographs were acquired of the Rio Grande from Brownsville to El Paso in June and July 2002. A Cessna 404 twin-engine aircraft with multiple camera ports in the floor was used as the platform and all photographs were taken at altitudes of 3050-3350 m above ground level between 1030 and 1400 hours Central Standard Time under sunny conditions. Each film frame covered a square area with a side of 2.3-2.5 km.

Based on CIR video imagery, which was acquired simultaneously with the aerial photography, and global positioning system (GPS) coordinates superimposed at the top of each video image, Everitt et al. (2004) developed a geographic information system (GIS) map showing the distribution and density of giant reed infestations along the Rio Grande in Texas. Giant reed existed along a stretch of the river between Lajitas and San Ygnacio, and little giant reed was found outside this portion of the river. Dense populations of giant reed were located below Del Rio with the densest populations between Del Rio and Eagle Pass in Kinney and Maverick counties, while light populations existed above Del Rio. Ground surveys confirmed the presence of giant reed at all the plotted locations on the map. Over 480 aerial photographs with overlaps of 20-30% were taken between Lajitas and San Ygnacio.



**Figure 1.** A map showing the center locations of 65 aerial photos (blue circles) selected for giant reed area estimation between Lajitas and San Ygnacio along the Texas-Mexico portion of the Rio Grande.

### Image Processing and Analysis

Considering the time and cost for image processing and classification, 65 aerial photos were randomly selected for area estimation with 35 between Lajitas and Del Rio and 30 between Del Rio and San Ygnacio. If two consecutive photos were selected, one of them was removed to avoid overlap. Figure 1 shows the center locations of the 65 aerial photos selected. These CIR photographic transparencies were scanned at 400 dots per inch (dpi) using an Epson Expression 10000XL scanner (Seiko Epson Corporation, Long Beach, California). The equivalent ground pixel size was approximately 0.65 m. The digitized CIR photographic images consisted of three spectral bands (near-infrared, red and green), and the pixels in each band had a spectral digital count value ranging from 0 to 255.

Due to the difficult accessibility for most of the imaging areas, it was not practical to collect GPS points on the ground to rectify or georeference each aerial photo. Therefore, Google Earth imagery (Google Inc., Mountain View, California) was chosen for georeferencing the digitized photos. In order to determine the positional accuracy of Google Earth imagery, three aerial photos were rectified to their corresponding Google Earth images and to the ground control points (GCPs) collected from the three sites with a submeter-accuracy GPS Pathfinder Pro XRS receiver (Trimble Navigation Limited, Sunnyvale, California). The 65 digitized aerial photos were rectified to the Universal Transverse Mercator (UTM) coordinate system (Zones 13 and 14) based on 10-15 points extracted from

Google Earth imagery. ERDAS IMAGINE (Leica Geosystems Geospatial Imaging, LLC, Norcross, Georgia) was used for image rectification.

### **Image Classification and Area Determination**

Previous studies indicate that giant reed can be accurately distinguished from the associated vegetation species and other cover types using either unsupervised or supervised classification techniques (Oakins, 2001; Everitt et al., 2004, 2008). In this study, giant reed was the main cover type to be identified and its spectral appearance and ground information were generally known on the image. Therefore, supervised classification was chosen for image classification. Several parametric classifiers, including minimum distance, Mahalanobis distance, maximum likelihood, were available in ERDAS Imagine (Richards, 1999; ERDAS, 2002; Lillesand et al., 2004). Yang et al. (2009) compared the three classifiers to classify QuickBird imagery along the Rio Grande for identifying giant reed. Their results indicate that although all three classifiers provided excellent classification results, the maximum likelihood classifier had highest overall accuracy and individual class accuracy values. The producer's accuracy and user's accuracy for giant reed were 94-100% based on the maximum classifier.

An aerial photo (29°16'57" N, 100°51'58" W) taken along the Rio Grande near Del Rio, Texas on 25 June 2002 was used to compare the differences in classification results among the three classifiers. This photo was classified using unsupervised classification in a previous study (Everitt et al., 2004). The classes in the study sites consisted of giant reed, mixed brush, mixed herbaceous vegetation, bare soil and water. Because of the spatial variation within each class, each class was further divided into 2 to 3 subclasses. For supervised training, different numbers of areas were visually selected from each subclass. Because of the distinct spectral response of giant reed, it could be easily identified in the image based on our knowledge on the weed. As for the other two vegetation classes, we didn't try to identify the specific species on the ground, but we selected the training pixels for each subclass based on the color tones of these species in the CIR image. Before the classification, all the signatures calculated from the training samples were evaluated. The image was then classified into the five classes using the three classifiers.

For accuracy assessment of these three classification maps, the same 100 ground-verified points used for accuracy assessment of the unsupervised classification map in our previous study were used. Error matrices for each classification map were generated by comparing the classified classes with the actual classes at these points. Overall accuracy, producer's accuracy, user's accuracy, and kappa coefficients were calculated based on the error matrices and kappa analysis was also performed to test if each classification was significantly better than a random classification and if any two classifications were significantly different (Congalton and Green, 1999).

Accuracy assessment of the three classification maps showed that maximum likelihood performed better than the other two classifiers (see the results below). Therefore, all the 65 aerial photographic images were classified using maximum likelihood. Because each photographic image covered extra areas where no giant reed existed, an area of interest (AOI) was defined for each image to eliminate these areas outside the AOI during image classification. Based on our previous studies on the use of aerial photography and high resolution satellite imagery for mapping giant reed (Everitt et al. 2004, 2005; Yang et al., 2009), giant reed can be accurately identified from associated species and cover types in the Rio Grande Basin with about 90% accuracy. Therefore, it was not necessary to perform the same accuracy assessment procedures for each of the 65 images classified in this study. Nevertheless, care was taken to ensure giant reed was correctly identified by visually comparing each classification map with its original CIR photographic image. In addition, ground verifications were made for areas that could be confused with other vegetation. Giant reed area and water area were estimated from each classification map, and the ratio of giant reed area to water area was calculated. The river length was also determined from the map, and the ratio of giant reed area to river length was calculated. To determine the giant reed areas on the U.S. side and the Mexican side of the river, a new AOL was defined to only include the U.S. side of each classification map. The giant reed area on the U.S. side was first determined and the giant reed area on the Mexican side was calculated for the map. The total giant reed area was calculated by the river length times the ratio of giant reed area to river length.

## **RESULTS AND DISCUSSION**

Table 1 summarizes positional differences for the selected GCPs between the Google Earth images and the GPS points for the three sites. The root mean square (RMS) errors for rectifying the three photos based on the two different reference data sources are also shown in the table. The points extracted from the Google Earth images were 11.2 m to the west and 6.5 m to the south for site 1, 12.7 m to the west and the same in the y-direction for site 2, and 14.3 m to the east and 3.1 m to the south, relative to the GPS points. The total shift was about 13-15 m for the three

sites. The RMS errors for sites 1 and 3 were very low for both reference data sources, indicating that the Google Earth images on the two sites had very little distortion even though there were some offsets relative to their true positions. The RMS errors for site 2 were 6.0 m based on the Google Earth image and 2.3 m based on the GPS points. The relative higher error for the image rectified with GPS points was partially due to the distortion of the aerial photo since the photo may have not been taken at perfect nadir position. However, the much higher RMS error for the image rectified with Google Earth points was due to the fact that the GCPs were extracted from two Google Earth images that were mosaicked. Generally, geographic coordinates extracted from the transitional areas where multiple images were pieced together have higher positional errors. Nevertheless, these errors were acceptable for area estimation considering the extent of the area involved in this study.

**Table 1.** Comparison on positional accuracy between Google Earth imagery and GPS points for rectifying three aerial photos taken along the Rio Grande in Southwest Texas.

Site	Image center Coordinates	No. of points	Positional shift relative to GPS points (m)			RMS <sup>[a]</sup> errors for Google Earth-rectified images (m)			RMS error for GPS-rectified images (m)		
			x	y	Total	x	y	Total	x	y	Total
1	27°42'11"N, 99°44'32"W	12	-11.2	-6.5	12.9	1.0	0.8	1.3	0.8	1.0	1.3
2	28°22'51"N, 100°44'32"W	14	-12.7	0.0	12.7	5.5	2.3	6.0	1.3	2.0	2.4
3	29°10'13"N, 100°45'57"W	12	14.3	-3.1	14.7	0.8	0.8	1.1	0.9	0.7	1.2

<sup>[a]</sup> RMS=root mean square.

Table 2 summarizes the accuracy assessment results for the three classification maps based on the three classification methods for the aerial photographic image near Del Rio, Texas. Overall accuracy was 82% for minimum distance, 85% for Mahalanobis distance, and 86% for maximum likelihood. Kappa pairwise analysis showed that there were no significant differences among the three classifiers for the overall classifications. However, maximum likelihood provided more reasonable producer's and user's accuracy values for giant reed. For example, the maximum likelihood classifier resulted in a producer's accuracy of 92% and a user's accuracy of 96% for giant reed, compared with a producer's accuracy of 83% and a user's accuracy of 100% for giant reed from the minimum distance classifier. These results indicate that 92% of the giant reed areas on the ground were correctly identified as giant reed on the maximum likelihood classification map, while 96% of the areas called giant reed on the classification map were actually giant reed. In contrast, although 100% of the areas called giant reed on the minimum distance classification map were actually giant reed, only 83% of the giant reed areas on the ground were correctly identified as giant reed on the map. All three classifiers provided excellent classification results for the mixed brush and water classes. However, the producer's and user's accuracy values were generally lower for the mixed herbaceous and bare soil classes due to the confusion between the two classes.

**Table 2.** Accuracy assessment results for classification maps generated from an aerial photographic image using three classifiers for a giant reed-infested area along the Rio Grande in southwest Texas.

Classifier†	Overall accuracy (%)	Overall kappa	Producer's accuracy (PA, %) and user's accuracy (UA, %)									
			Giant reed		Mixed brush		Mixed herbaceous		Bare soil		Water	
			PA	UA	PA	UA	PA	UA	PA	UA	PA	UA
MD	82.0	0.766	83.3	100.0	90.9	100.0	76.9	62.5	75.0	77.8	100.0	100.0
MAHD	85.0	0.805	87.50	100.0	90.9	90.9	84.6	68.8	78.6	84.6	90.9	100.0
ML	86.0	0.818	91.7	95.7	90.9	90.9	84.6	73.3	78.6	84.6	90.9	100.0

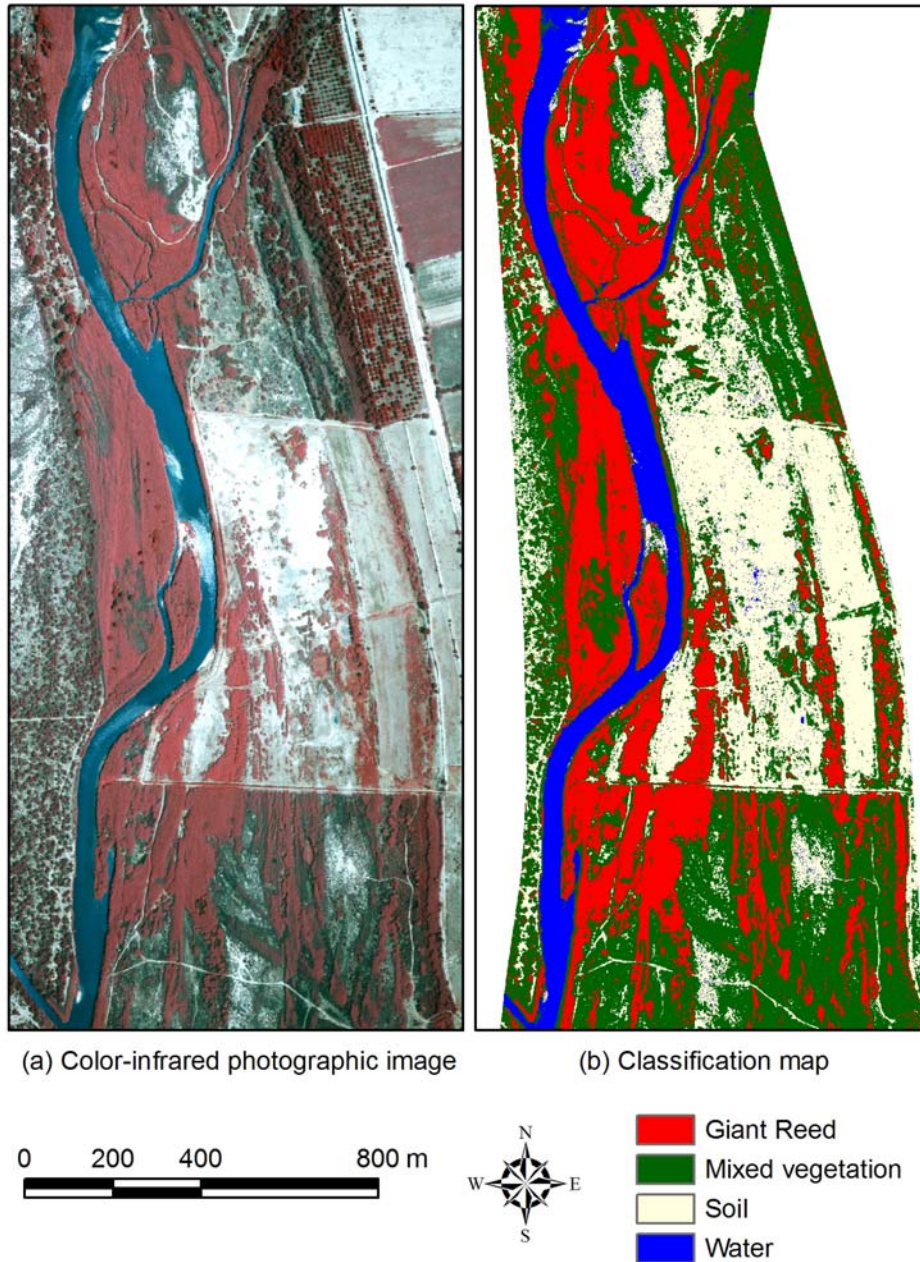
† MD = minimum distance, MAHD = Mahalanobis distance, and ML = maximum likelihood.

Since the focus of this study was to estimate the giant reed area along with the water area in each image, the other three classes (mixed brush, mixed herbaceous vegetation and soil) were merged as one single class so that each classification map had three classes (giant reed, water and mixed cover). As expected, the overall accuracy increased to 96% for maximum likelihood, though the producer's and user's accuracy remained the same for both giant reed and water. It should be noted that these results are based on one photographic image and results may vary for different photographic images. Nevertheless, our previous studies have showed that maximum likelihood is a



reliable and accurate classifier for mapping giant reed in the Rio Grande Basin (Everitt et al., 2005, Yang et al., 2009). Therefore, all the 65 aerial photographic images were classified using maximum likelihood into the five major classes which were then optionally merged into four classes (giant reed, water, mixed vegetation, and soil) or three classes (giant reed, water, and mixed cover).

Figure 2 shows an aerial CIR photographic image and a four-class classification map based on maximum likelihood for a site near Quemado, Texas. The CIR image reveals diverse cover types within the scene. On the CIR image, giant reed shows a bright reddish tone, while mixed woody species have a dark reddish color. Mixed herbaceous species have a greenish tone because of the dry ground conditions, water has a dark blue color, and bare soil has a bright white to grayish color. A visual comparison of the four-class classification map with the CIR image indicates that giant reed and the other cover types within the image were well separated on the classification map.



**Figure 2.** (a) Color-infrared photographic image and (b) a four-class classification map for a giant reed-infested site (28°59'21"N, 100°38'53"W) along the Rio Grande near Quemado, Texas. The U.S. is on the east side of the river.

Giant reed has unique spectral characteristics which distinguish it from associated plant species. Field spectral measurements taken in July indicate that giant reed has higher green and NIR reflectance than associated woody and herbaceous species (Everitt et al., 2004). Therefore, giant reed can be accurately separated from other vegetation species. However, some agricultural crops, grass species, and woody species can cause confusion with giant reed at certain time of the year. Generally, most of these vegetation areas can be eliminated from the image with the definition of areas of interest before image classification. However, if species with similar spectral response to giant reed were included in the portion of the image to be classified, more training pixels were selected from the species to distinguish them from giant reed and minimize the confusion.

Table 3 shows the simple statistics for total giant reed area on both sides of the river, area on the U.S. side, area on the Mexican side, water area, and river length determined from the 35 aerial photographic images between Lajitas and Del Rio, Texas, and from the 30 aerial photographic images between Del Rio and San Ygnacio, Texas, along the Rio Grande. Table 4 gives the giant reed to water ratio, the giant reed to river length ratio, and the giant reed percentage on either side of the river calculated from the statistics listed in Table 3. The total giant reed areas for both sides of the river and for either side of the river estimated from the river length and the giant reed to river length ratio are also shown in Table 4. The total giant reed-infested area was 543 ha from the 35 images between Lajitas and Del Rio and 880 ha from the 30 images between Del Rio and San Ygnacio. The mean giant reed area to water area ratio was 0.93 ha/ha between Lajitas and Del Rio and 1.28 between Del Rio and San Ygnacio, indicating there were 0.93 ha and 1.28 ha of giant reed for every hectare of water area for the respective river segment. The mean giant reed area to river length ratio was 4.21 ha/km between Lajitas and Del Rio and 9.56 between Del Rio and San Ygnacio, indicating there were 4.21 ha and 9.56 ha of giant reed for each river kilometer for the respective river segment. Clearly, there was more giant reed on the portion of the river east of Del Rio than on the portion of the river west of Del Rio. The significantly lower giant reed area on the western portion of the river from Del Rio is mainly due to the fact that this portion of the river is surrounded by mountains and there is limited floodplain for giant reed to grow.

**Table 3.** Summary of giant reed area, water area and river length determined from 35 aerial photos between Lajitas and Del Rio, Texas and 30 aerial photos between Del Rio and San Ygnacio, Texas, along the Rio Grande.

Statistics	Giant reed area (ha)			Water area (ha)	River length (km)
	Both sides	U.S. side	Mexican side		
From Lajitas to Del Rio, Texas					
Minimum	0.0	0.0	0.0	4.6	2.3
Maximum	35.3	20.1	22.6	55.0	6.0
Mean	15.5	7.7	7.8	16.6	3.7
STD	9.4	5.5	5.5	9.6	0.8
Sum	542.5	270.1	272.4	581.4	128.7
From Del Rio to San Ygnacio, Texas					
Minimum	6.8	2.1	2.3	14.2	2.4
Maximum	74.5	53.9	28.0	43.0	5.8
Mean	29.3	19.7	9.6	22.9	3.1
STD	19.5	14.7	6.8	6.6	0.7
Sum	879.7	591.9	287.8	687.4	92.0

The total giant reed area on both sides of the river was estimated to be 2046 ha along the Rio Grande between Lajitas and Del Rio and 3939 ha between Del Rio and San Ygnacio. Combined, the total giant reed area along the Rio Grande between Lajitas and San Ygnacio was estimated to be 5985 ha with 3670 ha or 61% on the U.S. side and 2315 or 39% on the Mexican side. With regard to the distribution of giant reed on both sides of the river, the U.S. and Mexico each had about 50% of the giant reed on the portion of the river west of Del Rio. However, the U.S. had 67% or 2/3 of the giant reed, while Mexico had only 33% or 1/3 of the giant reed on the portion of the river between Del Rio and San Ygnacio. Although the exact cause of more invasiveness on the U.S. side is unknown for the eastern portion of the river, grazing animals are known to impact riparian vegetation and may also have an impact on giant reed populations (Belsky et al., 1999; Jansen and Robertson 2001). Cattle, goats and sheep are common grazing animals in the riparian habitats. During drought conditions, grazing animals are known to feed on the new

shoots of giant reed. Some ranchers along the Rio Grande burn back giant reed each year and this practice stimulates new growth for grazing. The USDA-APHIS ‘Tick Fence’ along portions of the Rio Grande from Brownsville to El Paso was constructed to prevent animal movement in the U.S. to restrict the spread of Texas cattle fever tick. There are no data regarding the impact of grazing on giant reed, but ranchers and landholders in the Basin frequently state that grazing limits giant reed growth. Giant reed infestations appear to be denser in the absence of grazing. Differences in grazing practices between the U.S. and Mexico may partially contribute to the difference in giant reed invasiveness on both sides of the river.

**Table 4.** Giant reed area estimates based on the giant reed to river length ratio and the river length between Lajitas and Del Rio, Texas and between Del Rio and San Ygnacio, Texas, along the Rio Grande.

River segment	River length (km)	Giant reed to water ratio (ha/ha)	Giant reed to river length ratio (ha/km)	Giant reed percentage (%)		Estimated giant reed area (ha)		
				U.S. side	Mexican side	Total	U.S. side	Mexican side
Lajitas-Del Rio	486	0.93	4.21	49.8	50.2	2046	1019	1027
Del Rio-San Ygnacio	412	1.28	9.56	67.3	32.7	3939	2651	1288
Total	898					5985	3670	2315

## CONCLUSIONS

This study provides the first accurate estimates of giant reed infestations along the Texas-Mexico portion of the Rio Grande based on 2002 aerial photography. The total giant reed area along the Rio Grande between Lajitas and San Ygnacio, Texas, was estimated to be 5985 ha with 3670 ha or 61% on the U.S. side and 2315 or 39% on the Mexican side. Furthermore, the U.S. and Mexico each had about 50% of the giant reed along the portion of the river between Lajitas and Del Rio, while the U.S. had 2/3 of the giant reed on the portion of the river between Del Rio and San Ygnacio. In our previous study, an estimated 4775 ha of giant reed existed along the major tributaries in the Mexican portion of the Rio Grande Basin. Clearly, more giant reed existed along the Rio Grande than in the Mexican portion of the Basin.

The results from this study will be very useful for both land owners and government agencies for the management and control of this invasive weed along the Rio Grande in both the U.S. and Mexico. These results and the aerial photographs are currently being used for the planning and release of the *Arundo* wasp for the biological agent control of giant reed along the river. Moreover, this study is an important first step toward the complete documentation of giant reed infestations along the river and for the long-term control and management of giant reed in the whole Rio Grande Basin. Although it is important to know the total areas of giant reed on both sides of the river, our eventual goal is to develop a GIS database to document the giant reed distribution and monitor its area for every kilometer of river between Lajitas and San Ygnacio. New aerial photography has been obtained since 2008 and the work is underway to process the new aerial CIR photographs and develop the database.

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