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Prepared in cooperation with the Texas State Soil and Water Conservation Board and the Webb Soil and Water Conservation District

Mapping *Arundo donax* (Arundo Cane) With Multispectral Imagery Before, During, and After Herbicide Treatment Along the Rio Grande in Webb County, Texas, 2020–21

Pamphlet to accompany

Scientific Investigations Map 3512

U.S. Department of the Interior
U.S. Geological Survey

Cover. Photograph showing the Rio Grande. Photograph by Cassi Crow, U.S. Geological Survey, July 7, 2020.

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre

Datum

Horizontal coordinate information is referenced to the World Geodetic System of 1984 (WGS 84).

Supplemental Information

“Area of interest” refers to the bounding coordinates of the study area (see figure 1).

“Study area” refers to a 1.6-kilometer buffer that includes the herbicide-treatment area along a 19.3-kilometer reach of the Rio Grande in Webb County, Texas (see figure 1).

Abbreviations

IR	infrared
NDVI	normalized difference vegetation index
NIR1	near infrared 1
nm	nanometer
RED	red band
TSSWCB	Texas State Soil and Water Conservation Board
USGS	U.S Geological Survey

Mapping *Arundo donax* (Arundo Cane) With Multispectral Imagery Before, During, and After Herbicide Treatment Along the Rio Grande in Webb County, Texas, 2020–21

By Jennifer Villa

Abstract

Arundo donax, commonly called Arundo cane, giant reed, or Carrizo cane, is an invasive bamboo-like perennial grass common in riparian areas throughout the southwestern United States. In Texas, not only does it negatively affect riparian ecosystems, but it has also become a problem for border security because it reduces visibility along the Rio Grande. To address these problems, in 2015 the Texas State Soil and Water Conservation Board was authorized by the Texas State Legislature to develop a program to eradicate Arundo cane along the Rio Grande. In 2020, the Texas State Soil and Water Conservation Board applied imazapyr and glyphosate herbicides along a 19.3-kilometer reach of the Rio Grande, northwest of Laredo, Texas. The U.S. Geological Survey, in cooperation with the Texas State Soil and Water Conservation Board and the Webb Soil and Water Conservation District, used WorldView-3 Standard high-resolution satellite imagery to map Arundo cane extent along the reach *before*, *during*, and *after* the herbicide-treatment period on June 30, 2020, September 26, 2020, and May 7, 2021, respectively. A maximum likelihood supervised classification analysis was computed on the images to map the spatial extent and estimate the area covered by Arundo cane. The estimated area covered by Arundo cane in the *before* classification was 1,282,000 square meters, in the *during* classification was 1,064,000 square meters, and in the *after* classification was 1,108,000 square meters. The qualitative comparison of the three images shows that there was an overall decrease in vegetation classified as Arundo cane throughout the study area.

Introduction

Arundo donax commonly called Arundo cane, giant reed, or Carrizo cane, but hereinafter referred to as Arundo cane, is an invasive bamboo-like perennial grass common in riparian areas throughout the southwestern United States, including along the banks of the Rio Grande in Texas (Tracy and DeLoach, 1998). It is native to temperate and tropical parts of Asia and was introduced to the United States in the early 1800s for ornamental purposes and as a form of erosion control for ditches and canals (Perdue, 1958; Hoshovsky, 1986; McWilliams, 2004). In recent decades, Arundo cane has become a threat to the health of riparian ecosystems (Oakins, 2001). Arundo cane is a tall and fast-growing grass, capable of reaching up to 10 meters (m) in height and growth of 0.3–0.7 m per week in favorable conditions (Hopper, 2018). It provides no habitat or food for native species, yet it restricts channels, limits biodiversity, consumes water resources, and harbors cattle ticks. Arundo cane grows in thick stands, which create border security problems because they reduce visibility along the Rio Grande in Texas (Texas State Soil and Water Conservation Board [TSSWCB], 2022).

The 84th Texas State Legislature authorized the TSSWCB to “develop and implement a program to eradicate Carrizo cane along the Rio Grande River” (chap. 431, p. 1 of Texas Senate Bill 1734; Texas Legislature Online, 2015). To achieve this directive, the TSSWCB adopted an ecosystem-based approach that incorporates the use of biological, chemical, mechanical, and cultural controls to manage this perennial grass. In 2020, imazapyr and glyphosate herbicides were applied by aircraft as a chemical control. To better understand the effects of the herbicide treatment, the U.S. Geological Survey (USGS) in cooperation with TSSWCB and the Webb Soil and Water Conservation District, conducted two synoptic water-quality sampling events following the herbicide application along the Rio Grande in Webb County, northwest of Laredo, Texas (Crow, 2021). As part of the agreement, the USGS also acquired WorldView-3 Standard high-resolution satellite imagery captured *before*, *during*, and *after* the herbicide-treatment period to map Arundo cane extent along a reach of the Rio Grande in Webb County, Texas.

Since the early 2000s, high spatial resolution imagery, coupled with geographic information systems and a Global Positioning System, have been used to map the extent of invasive species in wetlands and riparian zones (Everitt and others, 2006). In the southwestern United States, supervised classification, unsupervised classification, and spectral discrimination techniques have been used to identify and map Arundo cane on a variety of airborne remote sensing data sources such as aerial photographs (Oakins, 2001; Yang and others, 2010;

Tidwell, 2012), video (Everitt and others, 2004), multispectral (Everitt and others, 2005; Everitt and others, 2008; Yang and others, 2009; Yang and others, 2011; Fernandes and others, 2013; Fernandes and others, 2014; Avery and others, 2017), and hyperspectral (DiPietro, 2002) imagery from open sources and commercial satellites. Because of Arundo cane's unique spectral characteristics (Everitt and others, 2005, 2008; Yang and others, 2009; Fernandes and others, 2013), remote sensing techniques can be used to distinguish between Arundo cane and other surrounding vegetation types, therefore making it favorable for mapping extents in the areas of interest.

Purpose and Scope

The purpose of this study was to (1) map the spatial extent of Arundo cane *before*, *during* and *after* herbicide treatment and (2) estimate the area covered by Arundo cane along a 19.3-kilometer reach of the Rio Grande in Webb County, Texas. The reach (hereinafter referred to as the study area) is located approximately 48.3 kilometers northwest of Laredo and extends 1.6 kilometers on the U.S. side of the Rio Grande centerline. The area of interest is the entire area within the bounding coordinates of the study area; the study area begins just upstream from and ends just downstream from the herbicide-treatment area (fig. 1). Herbicides (imazapyr and glyphosate) were applied to the study area between July 31 and August 3, 2020, and between December 13 and December 15, 2020.

Methods

Previously published methods for interpreting high-resolution multispectral imagery (Yang and others, 2009; Lillesand and others, 2015; Congalton and Green, 2019) were used to evaluate changes in the extent of Arundo Cane *before* and *after* the application of herbicides along a section of the Rio Grande in south Texas. Multispectral imagery scenes were acquired from the Maxar Technologies (2020) WorldView-3 Standard high-resolution satellite for June 30, 2020 (*before* herbicide application), September 26, 2020 (*during* herbicide application), and May 7, 2021 (*after* herbicide application). Ensembles of multispectral imagery are hereinafter referred to as "scenes" (ENO Institute, 2023). Two scenes were acquired for June 30, 2020, and for September 26, 2020, and four scenes were acquired for May 7, 2021, to cover the area of interest (fig. 1). WorldView-3 imagery contains a 31-centimeter-resolution panchromatic band (450–800 nanometers [nm]) and eight 1.24-m-resolution multispectral bands: coastal (397–454 nm), blue (445–517 nm), green (507–586 nm), yellow (580–629 nm), red (626–696 nm), red edge (698–749 nm), near infrared 1 (765–899 nm), and near infrared 2 (857–1039 nm) (Maxar Technologies, 2020). Standard imagery products were projected to the Universal Transverse Mercator Zone 14 North coordinate system, World Geodetic System of 1984 datum.

Earth Resources Data Analysis (ERDAS) software (ERDAS IMAGINE) (Office of Surface Mining and Enforcement, 2023) and ArcGIS Pro (Esri, 2023) were used to extract and analyze information obtained from the collected images. By using the ERDAS IMAGINE software, all scenes were radiometrically corrected, pan-sharpened, mosaicked, and clipped (Hexagon, 2022) to the rectangular area of interest (fig. 1). In ArcGIS Pro (Esri, 2023), the *before* image was co-registered to National Agriculture Imagery Program 2020 imagery (U.S. Department of Agriculture, Aerial Photography Field Office, 2022) acquired from the Texas Natural Resources Information System DataHub (Texas Water Development Board, 2023). To improve the fit among the images being analyzed, tie points (Lillesand and others, 2015) were added to the four corners of the image; tie points were added to semi-permanent natural features (rock outcrops) along the river and to anthropogenic structures near the riparian area. The *during* image was co-registered to the *before* image by using these same methods. Co-registration of the *after* image to the *before* image was not possible. Two of the four scenes mosaicked for the *after* image were collected on the same day but at different times. This caused the images to match in some areas and mismatch in others, resulting in root-mean-square error values (Helsel and others, 2020) greater than 1.0 m. Several attempts based on polynomial and spline transformation methods were made to co-register the *after* image to the *before* image and maintain the root-mean-square error value less than 0.5 m. These transformation methods caused the image to distort the entire area of interest. To avoid introducing additional errors caused by distortion, the decision was made to complete the classification of the *after* image without co-registration and rely on qualitative image interpretation (Congalton and Green, 2019).

A supervised classification of each image was used to estimate the area covered by Arundo cane *before*, *during*, and *after* herbicide treatment. In this type of classification, spectral reflectance (the amount of incident energy that is reflected from a surface feature, measured as a function of wavelength [Lillesand and others, 2015]) is used to collect signature training samples of the different land cover types. If the quality of the training samples is acceptable after evaluation, the training samples are used to "supervise" the pixel-based classification process (Lillesand and others, 2015). To aid in the selection of training samples, a normalized difference vegetation index (NDVI) and a false color infrared (IR) WorldView-3 multispectral composite were generated for reference. NDVI was calculated by using the red band (RED) and near infrared 1 (NIR1) with the following equation:

$$NDVI=(NIR1-RED)/(NIR1+RED) \quad (1)$$

where

NIR1 is WorldView-3 multispectral near infrared 1 band 7, in nanometers; and

RED is WorldView-3 multispectral red band 5, in nanometers.

The false color infrared composite was generated by displaying bands 7 (near infrared 1), 5 (red), and 3 (green) in the standard red, green, and blue bands, respectively. For each of the 3 images, 12 signature training samples were collected for each of the 9 land cover classes identified: Arundo cane, mixed woody, mixed herbaceous, barren, built environment, Rio Grande, standing water, cloud cover, and shadows. In spectral reflectance imagery analysis, the term “signature” refers to a set of data values that define a training sample, and the term “training sample” refers to the set of pixels selected to represent a potential class (Hexagon, 2022).

The quality of the training samples was evaluated by inspecting the signature mean plots for each of the grouped cover classes. The term “signature mean plot” refers to a line graph showing the “mean values of one or more selected signatures” (Hexagon, 2022). If the signature of a training sample did not match the pattern in the signature mean plot of the grouped cover class evaluated, the training sample was considered questionable, and the histograms were examined. If the histograms associated with the training sample were unimodal and close to a normal distribution, the training sample was considered acceptable because it represents one cover class. If there were more than four multimodal histograms or highly skewed distributions, the training sample was assumed to be unrepresentative of the cover class because training samples with these characteristics may include more than one cover class. Unrepresentative training samples were deleted and thus not used in the supervised classification (Lillesand and others, 2015; Nesbit, 2016).

Representative grouped training samples were merged into one of the nine cover classes and used for the supervised classification (fig. 2). The supervised classification of the area of interest was conducted by using the maximum likelihood parametric rule (Yang and others, 2009) on high-resolution WorldView-3 Standard imagery to identify the spatial extent of Arundo cane *before*, *during*, and *after* the application of imazapyr or glyphosate herbicides. Because the focus of this study was to estimate the area of Arundo cane cover, six classes (mixed woody, mixed herbaceous, barren, built environment, cloud cover, and shadows) were merged into a combined mixed-cover class, and two classes (Rio Grande and standing water) were merged into a combined water class so that each classification consisted of only three classes: Arundo cane, water, and mixed cover (Yang and others, 2009). Once the supervised classification was completed, the area of Arundo cane cover in the study area was calculated for each of the *before, during, and after* images.

Arundo Cane Multispectral Imagery Classification Accuracy and Limitations

Supervised classification accuracy was assessed within the entire area of interest (fig. 1), which included dense Arundo cane patches on both the Mexico and U.S. sides of the Rio Grande. By using ArcGIS Pro (Esri, 2023), two feature classes containing accuracy assessment points were created for each of the three classified images. The equalized stratified random sampling strategy (Congalton and Green, 2019) was used to select 150 points in the study area and 30 additional points elsewhere in the area of interest. In the attribute table for the point feature class, the classification name was hidden to avoid introducing bias, and the reference name was updated with the cover class that the pixel represented. Producer’s and user’s accuracies represented classification accuracies for individual cover classes. Producer’s accuracy pertains to false negatives or errors of omission, where the pixels are excluded from the correct cover class. User’s accuracy pertains to false positives or errors of commission, where the pixels are included in the incorrect cover class. Overall accuracy is the number of correctly classified sample points divided by the total number of sample points (Congalton and Green, 2019). Because of border security regulations and limited access to private land, collecting ground-truthing data was not possible. In place of the ground-truthing data, a confusion matrix analysis with producer’s, user’s, and overall accuracy calculations was done by using the equalized stratified random sampling strategy (Congalton and Green, 2019). A subject-matter expert from the USGS acquainted with the herbicide application in the study area completed a confusion matrix analysis to assess image accuracy (C.L. Crow, U.S. Geological Survey, written commun., 2022).

Mapping Arundo Cane Multispectral Imagery Focus Area Results Before, During, and After Herbicide Treatment

Focus areas A, B, and C (fig. 3) are small parts of the study area that had abundant Arundo cane and images with minimal cloud cover *before*, *during*, and *after* the herbicide treatment; the fine-scale-resolution images of focus areas A, B, and C show in detail the effects of the herbicide treatment on Arundo cane. In the false color infrared *before* and *during* composites (fig. 3: FA–IR–1, FA–IR–2; FB–IR–1, FB–IR–2; FC–IR–1, FC–IR–2), healthy Arundo cane appears in a bright reddish-magenta tone, which makes it easier to distinguish from other types of surface cover. However, in the *after* images (fig. 3: FA–IR–3, FB–IR–3, FC–IR–3), Arundo cane in the herbicide-treatment area appears in a brown tone, indicating a possible decline in vegetative health. Similarly, in the *before* images (fig. 3: FA–IR–1, FB–IR–1, FC–IR–1), the mixed herbaceous vegetation appears in a bright pink tone, but in the *during* and *after* images (fig. 3: FA–IR–2, FA–IR–3; FB–IR–2, FB–IR–3; FC–IR–2, FC–IR–3), mixed herbaceous vegetation appears in a brown tone. Unchanged in all false color infrared composites, mixed woody vegetation appears in bright red tones, barren surfaces appear in brownish-gray (taupe) tones, and water appears in dark blue tones.

The accuracies of the *before*, *during*, and *after* cover classifications are summarized in figure 4. For the cover classifications *before* herbicide treatment, the overall accuracy assessment for images of the study area was 93 percent. For individual cover classifications in the study area, the producer’s accuracy was 84 percent for mixed cover and 100 percent for water cover. Arundo cane cover had a producer’s accuracy of 95 percent. The user's accuracies were 84 percent for Arundo cane, 96 percent for mixed cover, and 98 percent for water. In the area of interest, the overall accuracy assessment was also 93 percent. For individual cover classifications in the area of interest, the producer’s accuracy was 83 percent for mixed cover and 100 percent for Arundo cane and water. The user’s accuracy for this same area was 80 percent for Arundo cane and 100 percent for mixed cover and water.

For the cover classification *during* herbicide treatment, the overall accuracy assessment in the study area was 92 percent. For individual categories in the study area, the producer’s accuracy was 81 percent for mixed cover and 100 percent for Arundo cane and water. The user’s accuracy was 76 percent for Arundo cane and 100 percent for mixed cover and water. In the area of interest, the overall accuracy assessment was 87 percent. For individual categories in the area of interest, the producer’s accuracy was 71 percent for mixed cover and 100 percent for Arundo cane and water. The user’s accuracy for this same area was 80 percent for Arundo cane and water, and 100 percent for mixed cover.

For the cover classification *after* herbicide treatment, the overall accuracy assessment in the study area was 76 percent. For individual categories in the study area, the producer’s accuracies were 58 percent for mixed cover, 94 percent for Arundo cane, and 100 percent for water. The user’s accuracies were 30 percent for Arundo cane, 98 percent for mixed cover, and 100 percent for water. In the area of interest, the overall accuracy assessment was 70 percent. For individual categories in the area of interest, the producer’s accuracy was 53 percent for mixed cover, and 100 percent for Arundo cane and water. The user’s accuracy for this same area was 10 percent for Arundo cane, and 100 percent for mixed cover and water.

For the study area, the estimated total area covered by Arundo cane is about 1,282,000 square meters (m^2) in the *before* classification; about 1,064,000 m^2 in the *during* classification, and about 1,108,000 m^2 in the *after* classification (table 1) (Villa, 2023), but accuracy limitations must be considered. Though previous studies (Everitt and others, 2005, 2008; Yang and others, 2009, 2011; Fernandes and others, 2013, 2014; Avery and others, 2017) have shown that the use of remote sensing techniques have been successful in mapping Arundo cane extent, the accuracy assessment conducted for this study indicates that producer’s and user’s accuracies for Arundo cane decreased from 95 percent and 84 percent, respectively, in the *before* classification to 94 percent and 30 percent, respectively, in the *after* classification. A possible explanation for this reduction in accuracy could be the lack of access for field visitations for ground-truthing purposes. In the absence of field checks to verify land cover classification and the estimated extent and condition of Arundo cane, the accuracy assessment analyst relies only on image interpretation, which can result in errors (Congalton and Green, 2019). Another possible explanation for the observed reduction in accuracy could be related to positional accuracy issues introduced in the co-registering step, in which the *after* image could not be co-registered to the *before* image. In this case, Congalton and Green (2019) recommend performing a qualitative comparison to identify differences among the classifications on the images. Also, the estimated values of the area classified as Arundo cane decreased between the *before* and the *after* classifications, but the values in the *after* classification were higher than the *during* classification. A plausible explanation for this observation is the presence of cloud cover over the study area in the *during* image, whereas in the *after* image, there is no cloud cover over the study area. The qualitative comparison of the three classified images shows that the extent of Arundo cane in the study area has seemingly decreased over time (Villa, 2023). Again, this observation is more evident in the *after* classification where there is no cloud cover and Arundo cane is identified in other types of wet areas outside of the Rio Grande’s riparian area, such as in surrounding creeks, irrigation canals, and ponds.

Finally, Arundo cane has apparently decreased within the study area, but other factors such as Arundo cane phenology, water quality and availability, soil moisture, weather variability, and other variables that could affect the increase or decrease of area of Arundo cane (Perdue, 1958; Fernandes and others, 2013) were not analyzed in this report. A more robust study design that includes the evaluation of control plots, the incorporation of data from repetitive field visits, and field access for ground-truthing purposes would likely improve the estimates of the area of Arundo cane cover before, during, and after herbicide treatment.

Summary

Arundo donax, commonly called Arundo cane, giant reed, or Carrizo cane, is an invasive bamboo-like perennial grass common in riparian areas throughout the southwestern United States. In Texas, not only does it negatively affect riparian ecosystems, but it has also become a problem for border security because it reduces visibility along the Rio Grande. To address these problems, in 2015 the Texas State Soil and Water Conservation Board was authorized by the

Texas State Legislature to develop a program to eradicate Arundo cane along the Rio Grande. In 2020, the Texas State Soil and Water Conservation Board implemented the use of imazapyr and glyphosate herbicides along a 19.3-kilometer reach of the Rio Grande, northwest of Laredo, Texas. The U.S Geological Survey, in cooperation with the Texas State Soil and Water Conservation Board and the Webb Soil and Water Conservation District, used WorldView-3 Standard high-resolution satellite imagery to map Arundo cane extent along the reach *before*, *during*, and *after* the herbicide-treatment period on June 30, 2020, September 26, 2020, and May 7, 2021, respectively.

Previously published methods for interpreting high-resolution multispectral imagery were used to evaluate changes in the extent of Arundo Cane before, during, and after the application of herbicides along a section of the Rio Grande in south Texas. The qualitative comparison of the *before*, *during*, and *after* image classifications indicate a reduction of land cover classified as Arundo cane throughout the riparian area. A maximum likelihood supervised classification analysis was computed on the images to map the spatial extent and estimate the area covered by Arundo cane. The estimated area covered by Arundo cane in the *before* classification was 1,282,000 square meters, in the *during* classification was 1,064,000 square meters, and in the *after* classification was 1,108,000 square meters. The qualitative comparison of the three images indicates an overall decrease in vegetation classified as Arundo cane throughout the study area.

In focus areas A, B, and C, the differences between the *before* and the *after* classified images are especially noticeable. These differences are also visible in the natural color and false color infrared composites. Furthermore, the estimated area covered by Arundo cane also indicates a decrease of vegetation classified as Arundo cane between the *before* and the *after* analyses, supporting the qualitative comparison done between the classified images. While causality cannot be directly determined by using the methods from this study, the application of imazapyr and glyphosate herbicides on the Arundo cane in the study area seems to be associated with a reduction in the area of Arundo cane cover. To gain a better understanding of how Arundo cane responds to herbicide treatment, relations to other contributing factors should be studied.

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