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Use of Satellite Remote Sensing in Monitoring Saltcedar Control along the Lower Pecos River, USA

By
Seiichi Nagihara
Department of Geosciences, Texas Tech University, Lubbock, TX

Charles R. Hart
Texas Cooperative Extension, Texas A&M University, Stephenville, TX

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Texas Agricultural Experiment Station
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Texas Cooperative EXTENSION
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ABSTRACT

Vegetation along the riparian corridor of the lower Pecos River in the United States has been dominated by saltcedar for the past century. In 1999 through 2004, herbicides were sprayed from helicopters along some sections of the river to reduce saltcedar infestation. Here we describe a simple methodology based on satellite remote sensing for monitoring the impact of the saltcedar control measures. Data from the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) obtained in 1999 through 2004 over a section of the Pecos near Mentone, Texas were used for the present study. Herbicides were applied in September of each year. A normalized difference vegetation index (NDVI) image was derived from the satellite data for one growing season, and then it was compared to an NDVI image from the previous year. Using the write memory insertion change detection technique, we superimposed the NDVI image pair. The superimposed image highlighted areas where vegetation was lost during the interval between the times when the two satellite data sets were acquired. The areas of vegetation loss indicated by the change detection image coincided well with the areas where herbicides were applied in the same time interval. Since the riparian vegetation previously was dominated by saltcedar, identifying the areas of vegetation loss in this case is useful in assessing the long-term impact of the herbicide treatments. The same type of change detection technique was also used to locate areas of native vegetation recovery after the herbicide application.

INTRODUCTION

The Pecos River originates in central New Mexico flows through west Texas, and joins Rio Grande on the Texas-Mexico border (Fig. 1). Riparian vegetation of the middle to lower Pecos River is dominated by saltcedar (*Tamarix* spp.). Saltcedar is an exotic plant introduced in this region in the early 1900s (Robinson, 1965).

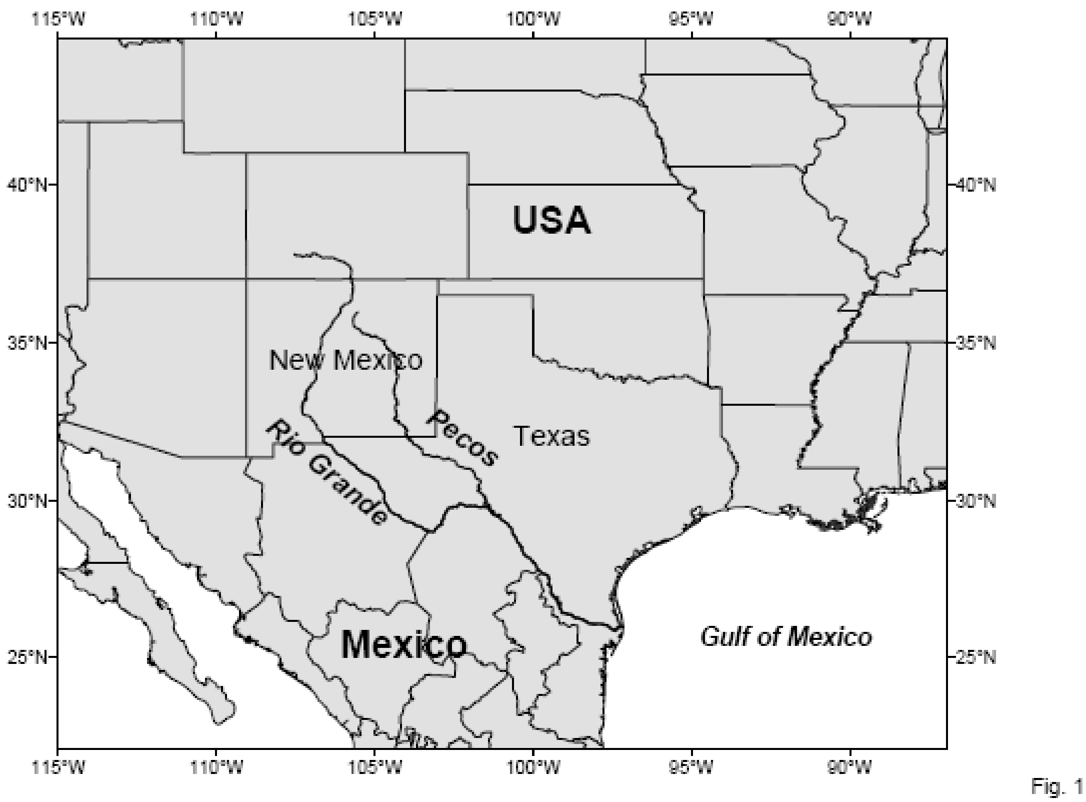

Figure 1 *Map of the south-central United States and northern Mexico showing the Pecos River and Rio Grande.*

Government agencies and land owners planted saltcedars for controlling stream bank erosion, because of their extensive root system. Such was the case for many rivers in the semi-arid southwestern United States. Within decades after introduction, saltcedars spread quickly by out-competing native riparian vegetation along those rivers. Saltcedar invasions into flood plains and river banks typically resulted in reduction of stream flow. It has been suggested by some that the rate of evapotranspiration by the saltcedar is much higher than that by other types of riparian vegetation and that is the primary cause for the drying of rivers. Others believe that the invasive nature and extreme densities of saltcedar is the primary cause of increased water use over native vegetation (see reviews by Glenn and Nagler, 2005; Wilcox et al., 2005).

The entire drainage basin of the Pecos is in semi-arid climate and water management in the basin is a critical issue. Recently, systematic efforts began to control saltcedars along the Pecos and other riparian corridors in the southwestern United States. Along the lower Pecos between the Texas-New Mexico border and Girvin, Texas (Fig. 2), herbicides have been applied from helicopters. Different sections of the river were sprayed every September in 1999 through 2004 (Hart et al., 2005). In assessing the effectiveness of such treatments and monitoring the subsequent recovery of vegetation along the 300-km stretch of the river, which runs through a sparsely populated area, we believe that satellite-based remote sensing techniques are economical and can be effective. Here, we present some simple techniques for highlighting in satellite images the areas where herbicide treatment was effective.

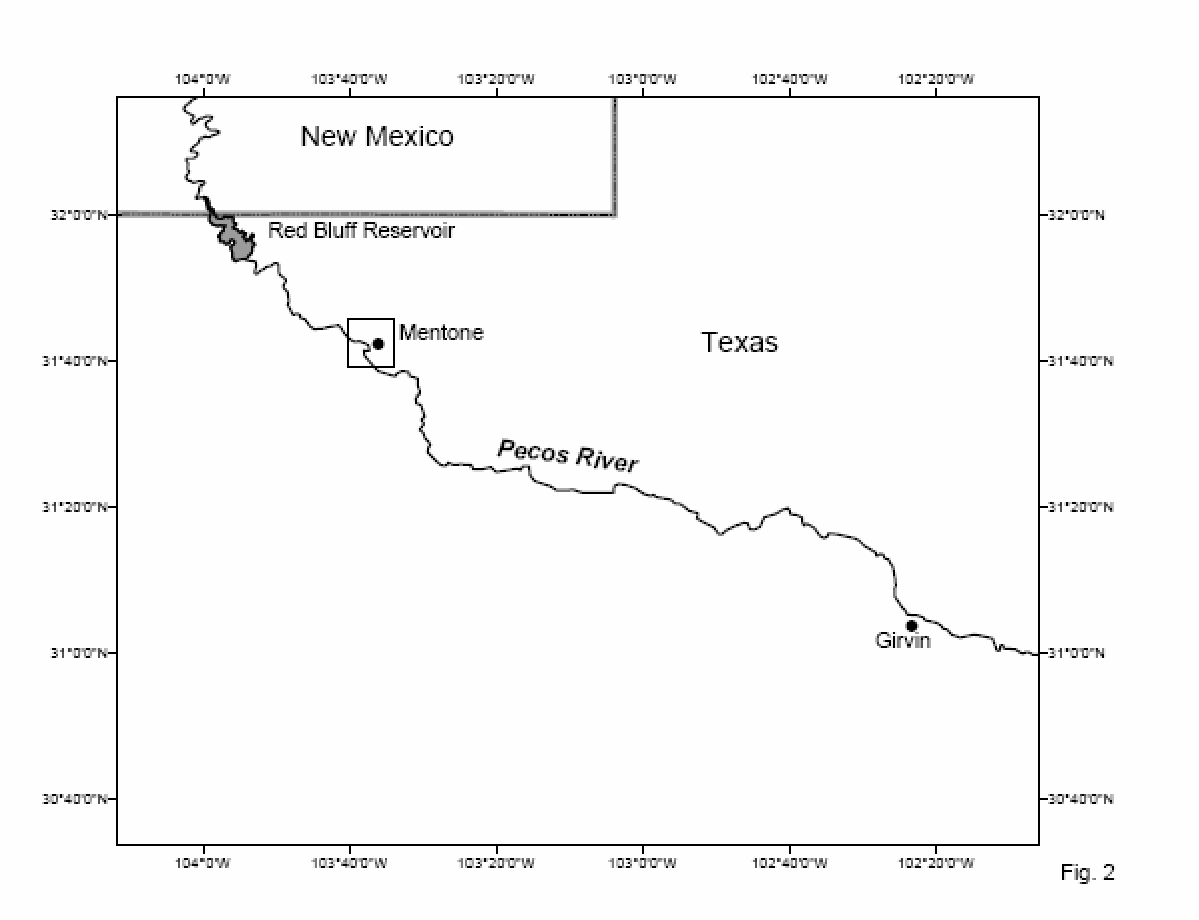

Figure 2 *Map of the lower Pecos River in west Texas Tech University. The box shows the footprint of the Landsat images used in Figs. 3, 5, 6, 7, 8, and 9.*

REMOTE SENSING SATELLITE DATA

For the present study, we used data from the Landsat 7 Enhance Thematic Mapper Plus (ETM+) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). Detailed characteristics of these remote sensing instruments have been described in recently published textbooks such as Jensen (2005) and Lillesand et al. (2004). They both are passive instruments which essentially measure the intensity (brightness) of solar radiation reflected off the earth's surface. Solar radiation consists of the sunlight visible to human eyes and ultraviolet and infrared rays. They are all electromagnetic waves and simply differ in their wavelengths. Different colors of light are different wavelengths of electromagnetic rays. The Landsat 7 ETM+ and ASTER instruments are equipped with multiple sensors (bands), each tuned to a specific color or a wavelength. The so-called “visible” to “near-visible infrared (NIR)” signals measured by these instruments are used here (Table 1).

According to the theory of optics, almost any color of visible light can be generated by mixing blue, green, and red with various intensities (Jensen, 2005). The first 3 bands of the Landsat 7 ETM+ measure the intensity (brightness) of the blue, green, and red components of the sunlight reflected off the ground. On the computer, researchers can mix these three colors back and produce a natural color image of the land. In producing images based on invisible infrared ray measurements, researchers can also develop coding systems between the infrared intensity values and the colors on computer, and produce so-called false-color images.

Landsat 7 was launched in April 1999 and has been acquiring data continuously along its orbit with a revisit cycle of 16 days. Since May 2003, however, a device failure is causing problems in data quality (Howard and Lacasse, 2004). ASTER was launched in December 1999 as one of the instruments on board the Terra spacecraft operated by the National Aeronautics and Space Administration. Unlike Landsat 7, ASTER collects data only on demand. Fewer than a dozen ASTER images have been obtained over the lower Pecos River so far. But, the ASTER visible and NIR bands offer a higher spatial resolution (geometrical details that can be observed in the image) than the Landsat 7 ETM+ (Table 1). In this study, we primarily used the Landsat 7 data, because of the data availability, but we also incorporated ASTER data for detailed analysis.

The data used in this study have been obtained from the archives of the TexasView consortium and the Land Processes Distributed Active Archive Center of the United States

Geological Survey. None of these data were acquired specifically for the present study. Therefore, there are some gaps in the temporal coverage of the data. For example, there was no ASTER data acquisition in the lower Pecos valley in year the 2002. All the Landsat 7 data used here are older than 2003, before the device failure.

Table 1 Characteristics of the Landsat 7 and ASTER sensor bands used in this study

	Landsat 7 ETM+		ASTER	
Band	Wavelength (μm)	Spatial Resolution (m)	Wavelength (μm)	Spatial Resolution (m)
1	0.450 – 0.515 (blue)	30 x 30	0.52 – 0.60 (green)	15 x 15
2	0.525 – 0.605 (green)	30 x 30	0.63 – 0.69 (red)	15 x 15
3	0.630 – 0.690 (red)	30 x 30	0.76 – 0.86 (near infrared)	15 x 15
4	0.750 – 0.900 (near infrared)	30 x 30		

REMOTE DETECTION OF VEGETATION ALONG THE RIVER

Figure 3 shows a natural color image of a section of the Pecos just outside the town of Mentone, Texas (Fig. 2). The image was produced from the first three bands of the Landsat 7 ETM+ data obtained on September 30, 1999, just days after the first herbicide application. The impact of the treatment did not show till the following growing season, and thus this image represents the state of the river before any herbicide treatment-related changes took place. The vegetated banks of the lower Pecos were dominated by saltcedars, but they are not readily distinguishable in this image, because the corridors are so narrow, typically 50 m or less (Hart et al., 2005), and the stream itself is only 20- to 30-m wide, while the Landsat 7 ETM+ sensors can yield only 30-m spatial resolution (Table 1). Saltcedars along the lower Pecos are mature trees

(5 to 10 m in height) and their canopies cover much of the stream. Therefore, what shows up as a river in the image is actually a mixed zone of vegetated river banks and stream water partially covered by tree canopies.

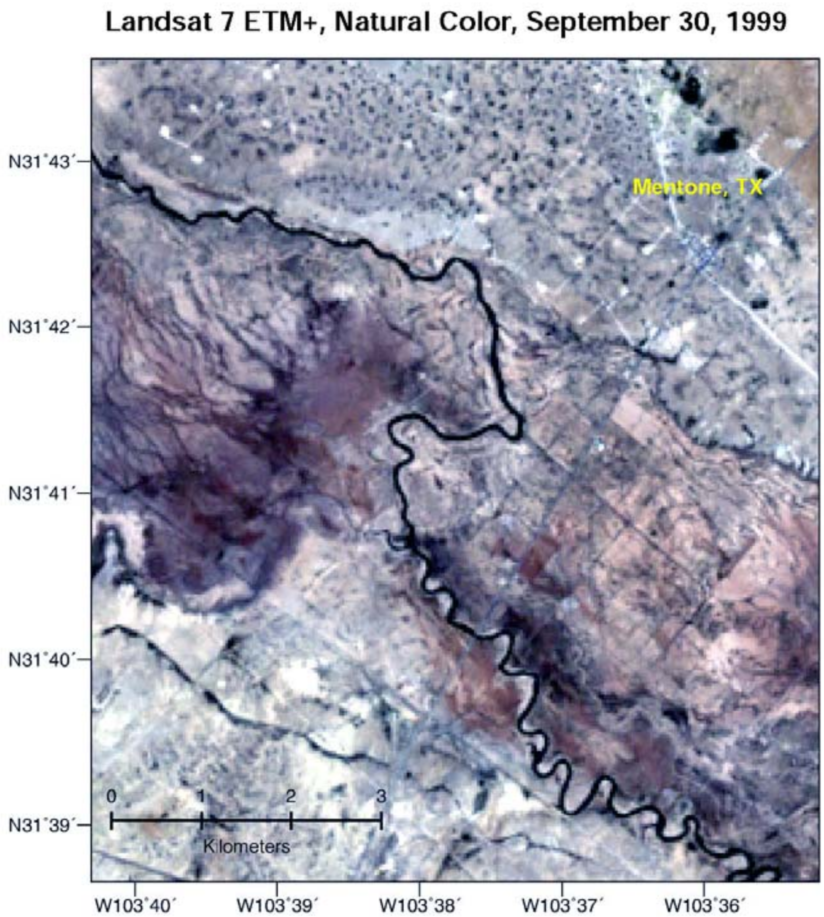

Fig. 3

Figure 3 *Natural color image of the section of the Pecos River off Mentone, TX produced from the first 3 bands of the Landsat 7 EMT+ data obtained on September 30, 1999.*

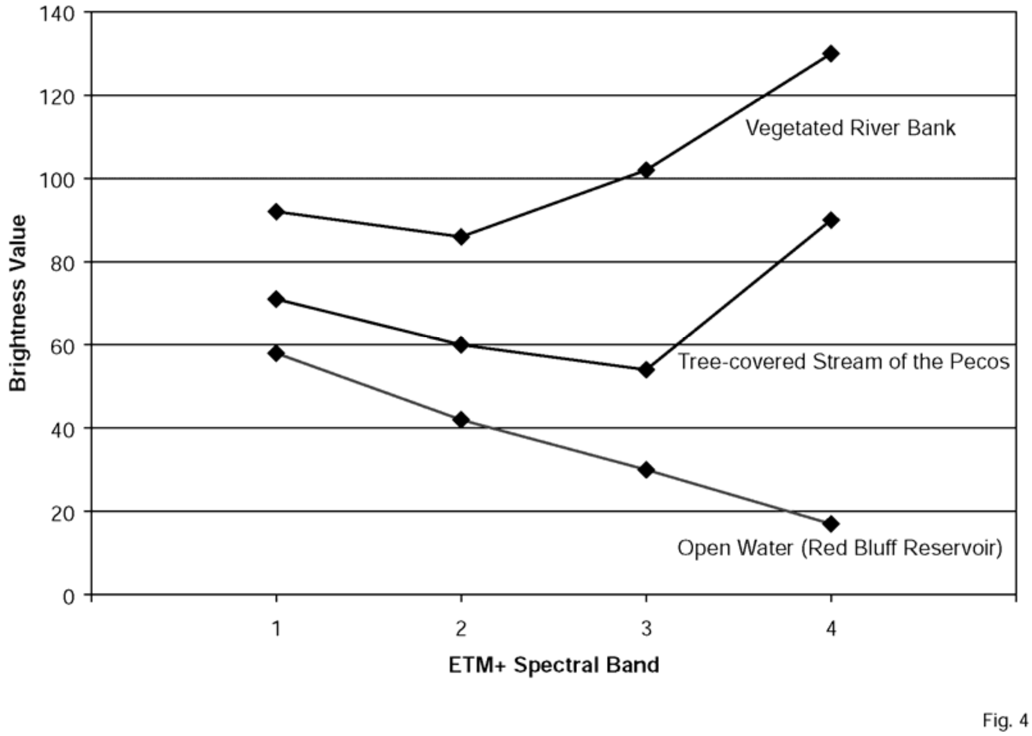

Figure 4 *Graph comparing brightness values of the first 4 bands of the Landsat 7 ETM+ data from 1999 measured in the Red Bluff Reservoir, the river bank, and the stream water off Mentone.*

Detailed examination of the spectral signature of the satellite data can reveal the difference between vegetated corridors on the banks, tree canopies over the stream, and an open water body. Figure 4 compares brightness values observed in the Red Bluff Reservoir upstream (Fig. 2), a stream segment covered with saltcedar canopies near Mentone, and a vegetated river bank for the same Landsat 7 ETM+ data used in Fig. 3. Brightness values for open water are generally low and show greater absorption (i.e., less reflection) of the solar radiation in longer wavelengths. Values for the vegetated bank are much higher especially for Band 4, the near-infrared signal. The tree-covered stream segment is a mixture of the two land cover types previously mentioned. It shows low values for the visible bands, which are the effect of the water in the background, and a high near-infrared value, which is attributed to saltcedar canopies.

One of the most common remote sensing data processing techniques in highlighting vegetated land is to produce an image based on the normalized difference vegetation index, or NDVI (Jensen, 2005). For each pixel location in the image, NDVI is obtained as the following:

$$NDVI = \frac{BV_{NIR} - BV_{red}}{BV_{NIR} + BV_{red}}, \qquad (1)$$

where BV_{NIR} is the brightness value for the near-infrared band and BV_{red} is the brightness value for the red band. In case of the Landsat 7 ETM+, Band 4 corresponds to BV_{NIR} and Band 3 corresponds to BV_{red}. Well vegetated lands tend show high BV_{NIR} values and low BV_{red} values (Fig. 4), and thus high NDVI values. Figure 5 shows a grayscale image based on NDVI values obtained from the ETM+ data used in Fig. 3. Bright (white) colors denote high NDVI values and vice versa. The Pecos River and its banks together show up as a line of well vegetated land in the NDVI image.

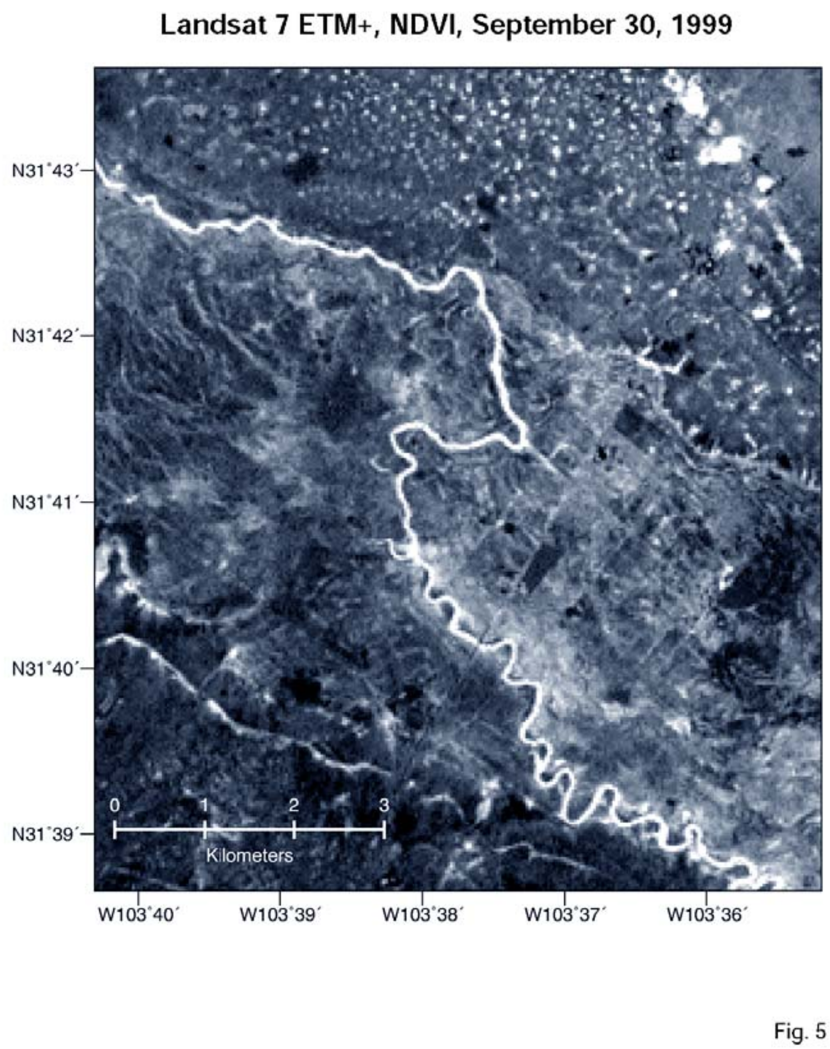

Figure 5 Grayscale NDVI image generated from the same 1999 Landsat 7 ETM+ data used in Fig. 3.

DETECTION OF VEGETATION CHANGES ASSOCIATED WITH HERBICIDE APPLICATIONS

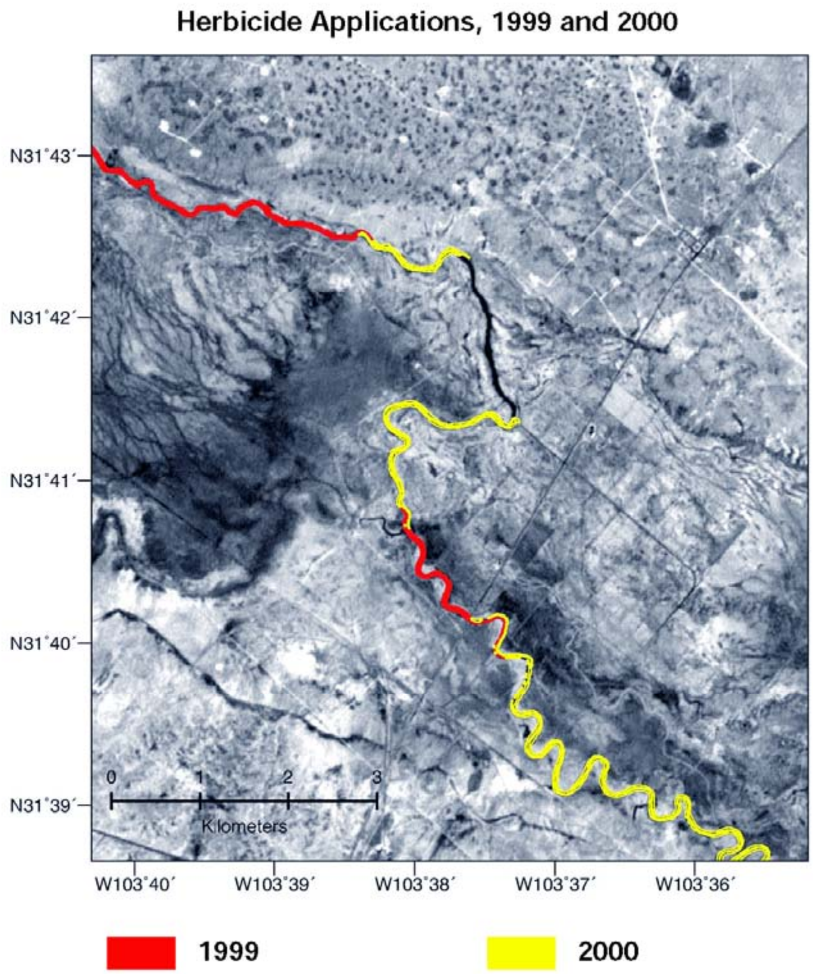

Fig. 6

Figure 6 *Grayscale image of the Mentone section of the Pecos generated from the panchromatic band of the Landsat 7 ETM+ data obtained on September 30, 1999. The area of herbicide applications in 1999 and 2000 are highlighted in red and yellow, respectively.*

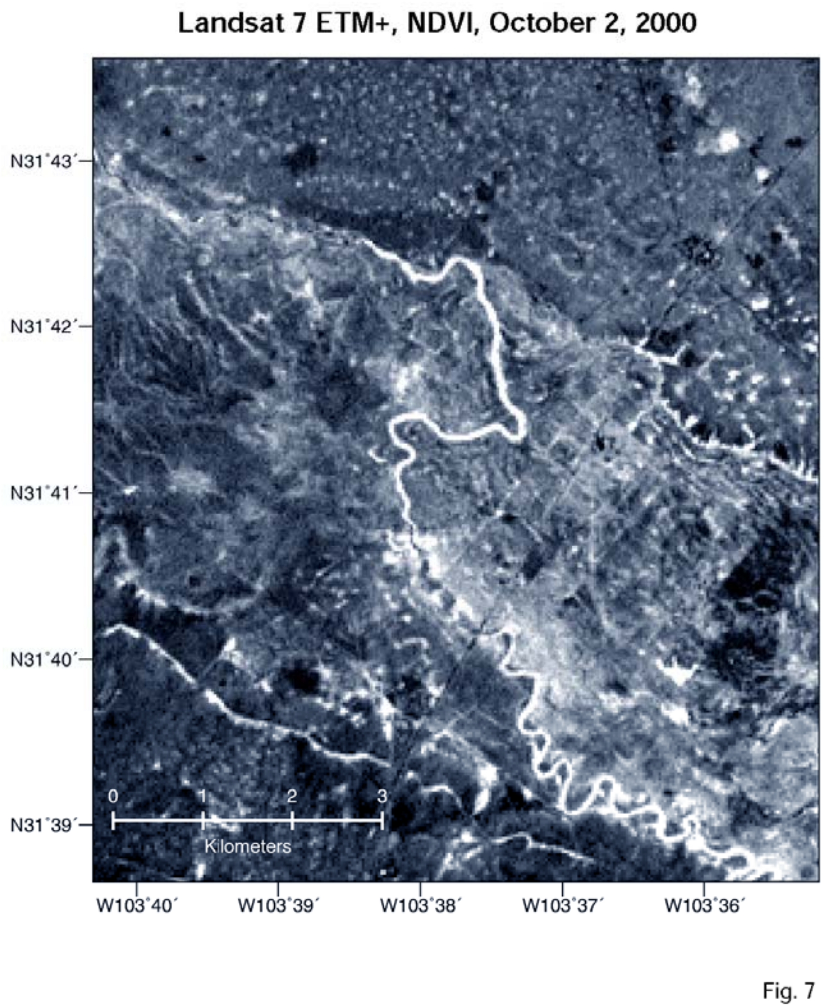

Figure 7 *Grayscale NDVI image generated from the Landsat 7 ETM+ data obtained on October 2, 2000.*

In September 1999, herbicides were applied for the first time along some sections of the river (Fig. 6). The impact of the treatment did not show till the following growing season, which corresponds to ground observations. Figure 7 shows an NDVI image produced from Landsat 7 ETM+ data obtained in early October 2 of 2000. Note in Fig. 7 that the areas of 1999 herbicide applications are considerably darker than in the NDVI image from the previous year (Fig. 5).

That means that these areas are less vegetated than in the previous year, indicating that the herbicide application had a significant impact.

In more clearly highlighting the difference between years 1999 and 2000, we superimpose the two Landsat NDVI data sets (one from September 30, 1999 and the other from October 2, 2000) in the composite of red, green, and blue (Fig. 8). This is a type of the write memory insertion "change detection" technique often used in satellite remote sensing (Jensen, 2005). Red color intensity in this image indicates the 1999 NDVI value. Green and blue together indicate the 2000 NDVI value. In this coloring scheme, areas where NDVI values are comparatively higher in 1999 show red color. Areas where NDVI values are higher in 2000 show cyan (i.e., equal mix of blue and green). Areas that were equally well vegetated in 1999 and 2000 show white or light grey color (i.e., equal mix of red, green, and blue). Areas that were not vegetated in both years show black.

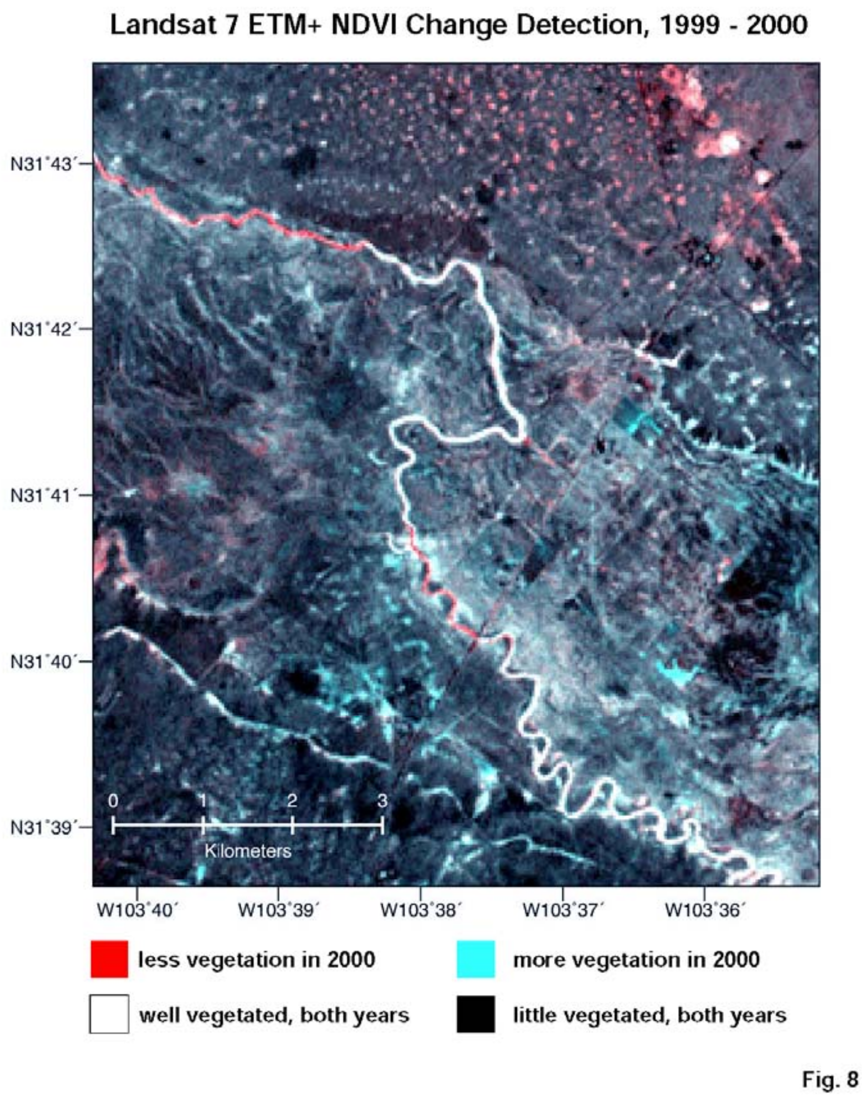

Figure 8 *NDVI change detection image comparing the Landsat 7 ETM+ data from 1999 and 2000.*

Red zones in Fig. 8, which indicate less vegetation in 2000, coincide well with the zones of herbicide applications in 1999 (Fig. 6). That suggests that the treatment was very effective. Ground observations indicated a canopy reduction of 85 to 90% from herbicide applications (Hart et. al., 2005). Herbicides were applied again in September 2000 along other sections of the river (Fig. 6).

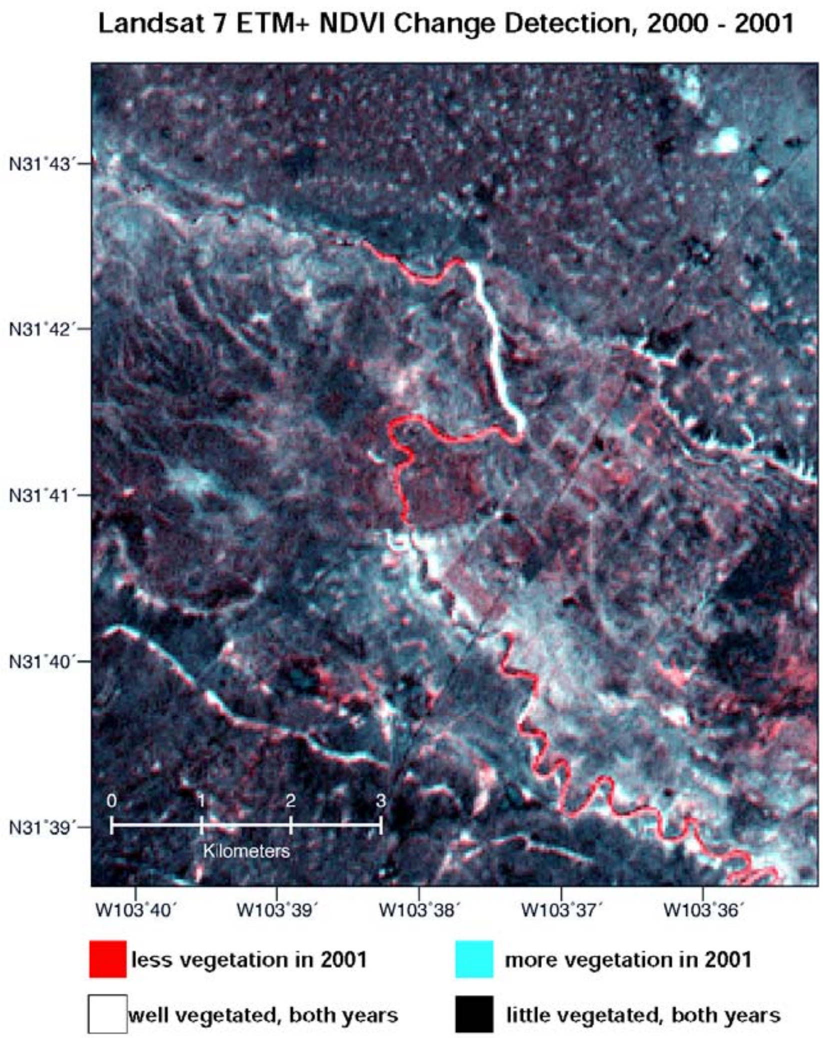

Fig. 9

Figure 9 *NDVI change detection image comparing the Landsat 7 ETM+ data from 1999 and 2000.*

Figure 9 is an image comparing the ETM+ NDVI values from October 2, 2000 and the values from May 30, 2001, using the write memory insertion technique. Again, red zones in Fig. 9 coincide well with the zones of herbicide applications in 2000.

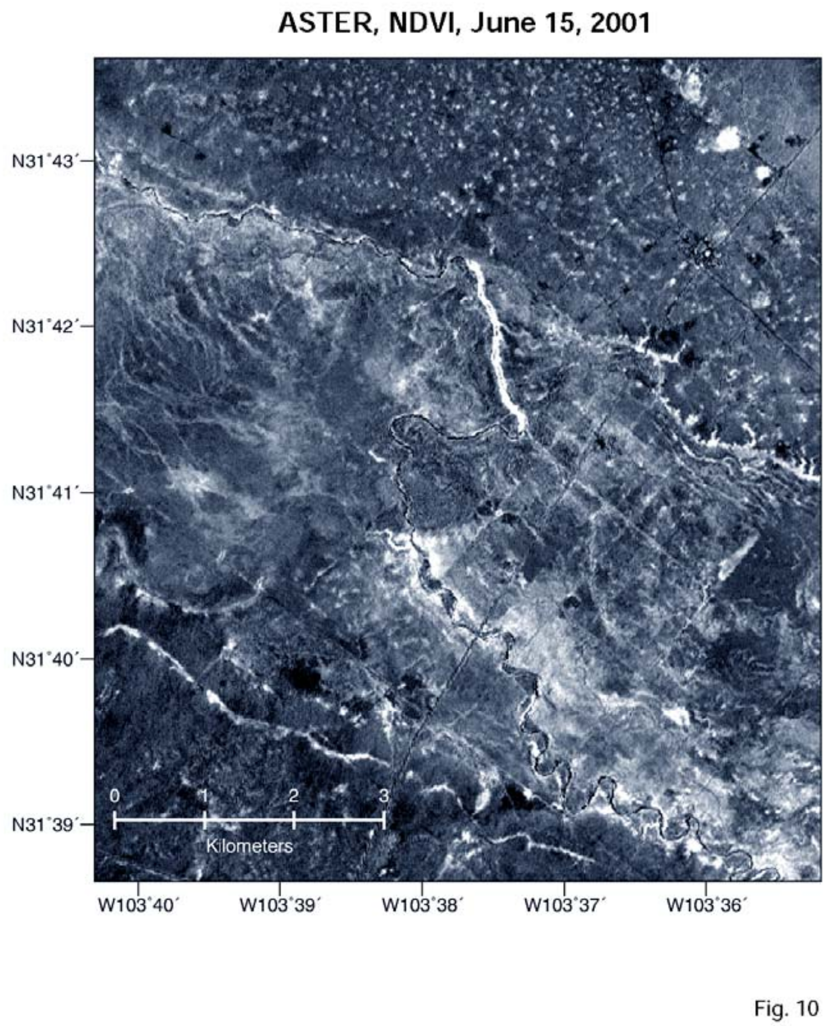

Figure 10 *Grayscale NDVI image generated from the ASTER data obtained on June 15, 2001.*

Figure 10 shows an NDVI image produced from ASTER data obtained on June 15, 2001. Compared with the two Landsat NDVI images shown earlier (Figs. 5 and 7), the ASTER image yields more geometrical detail, because the spatial resolution of the instrument is twice as better (Table 1). The stream water body is more easily distinguishable from the vegetated banks in the ASTER image. Comparison of the three NDVI images (Figs. 5, 7, and 10) also shows that the herbicide treatments in 1999 and 2000 almost wiped out the riparian vegetation except for the 2-

km long, north-south untreated stretch just outside Mentone. Upstream from this point, patches of vegetated areas (shown in white) are present especially along the northern bank. They basically survived the previous herbicide applications. In the following analysis, we focus on this section of the river.

Figure 11 shows an NDVI change detection image produced from superposition of two ASTER images obtained on June 15, 2001 and September 11, 2004. The image is compared with a map showing the areas of herbicide applications in 2001 and 2002.

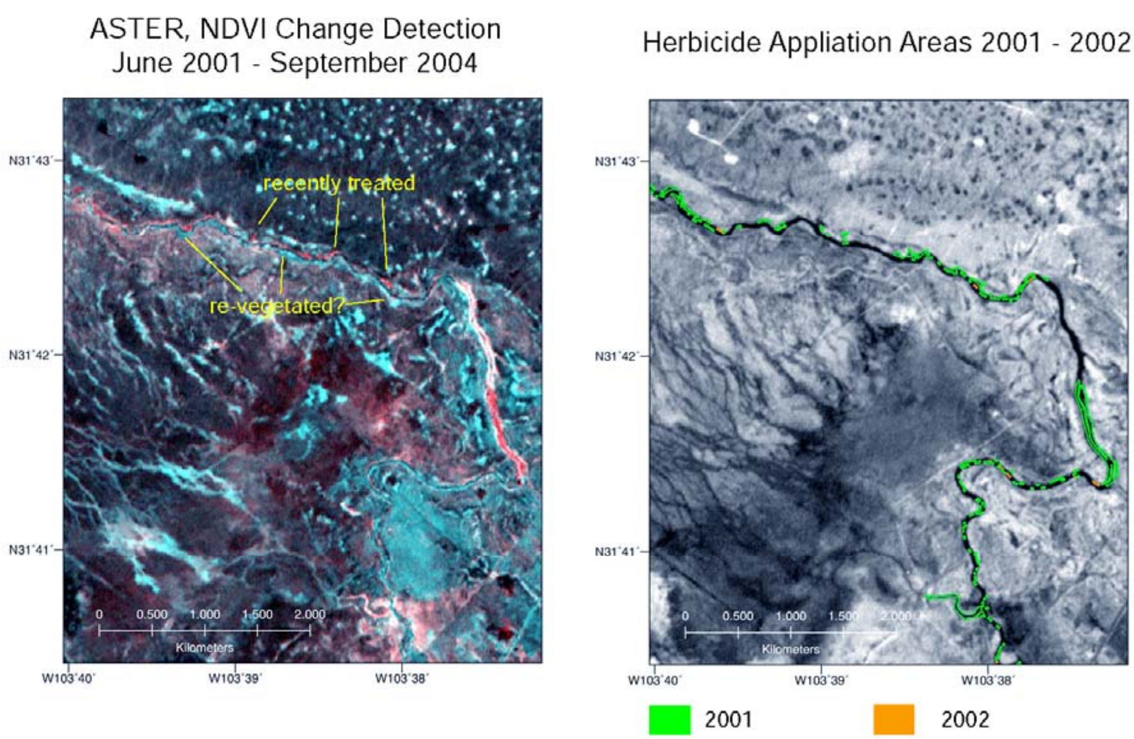

Fig. 11

Figure 11 *Left: NDVI change detection image comparing the ASTER data from June 2001 and September 2004. Right: map highlighting the herbicide application areas in 2001 (green) and 2002 (orange).*

In 2003, no herbicide was applied along this section of the river. The 2001 and 2002 treatments focused on the relatively small, isolated stands left on the northern bank. The change detection image analysis shows that the treatments had significant impact, showing red colors. In contrast, the southern bank of the river is colored in cyan, indicating that there was more vegetation in 2004 than in 2001. This implies that the area has been re-vegetated somewhat since the 1999 and 2000 treatment.

DISCUSSION AND CONCLUSIONS

The change detection by superimposing Landsat and ASTER NDVI images obtained at different times was very effective in assessing the impact of saltcedar control measures taken along the lower Pecos River. That was well demonstrated by the comparison between the map of treated areas and the image highlighting the areas of vegetation loss in the same time period. In this case, our knowledge of the exact locations of each herbicide application was helpful in assessing the effectiveness of the remote sensing technique. Because of the high saltcedar mortality from the herbicide used (Hart et al., 2005), the NDVI contrast between the pre- and post-application was very clear. That made the interpretation of the images relative easy.

Herbicides are effective, but also very expensive. Researchers in other areas are using other types of saltcedar control measures. Recently, a special kind of beetle has been imported to feed exclusive on saltcedar leaves and are being tested at various localities in the southwestern United States (Lewis et al., 2003). The satellite remote sensing-based tracking technique may also be very useful in monitoring the spread and resulting canopy reduction of saltcedar from these beetle populations.

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RERERENCES CITED

Glenn, E.P. and Nagler, P.L., 2005. Comparative echophysiology of Tamarix Ramosissima and native trees in western U.S. riparian zones. J. Arid Env., 61(5): 419-446.

Hart, C.R., White, L.D., McDonald, A. and Sheng, Z., 2005. Saltcedar control and water salvage on the Pecos river, Texas, 1999-2003. J. Environ. Management, 75: 399-409.

Howard, S.M. and Lacasse, J.M., 2004. An evaluation of gap-filled Landsat SLC-off imagery for wildland fire burn severity mapping. Photogrammetric Eng. & Remote Sens., 70(8): 877-880.

Jensen, J.R., 2005. Introductory Digital Image Processing: A Remote Sensing Perspective. Prentice-Hall Series in Geographic Information Science. Prentice Hall, Upper Saddle River, NJ, 526 pp.

Lewis, P.A., DeLoach, C.J., Knutson, A.E., Tracy, J.L. and Robbins, T.O., 2003. Biology of Diorhabda elongata deserticola (Coleoptera: Chrysomeliade), and asian leaf beetle for biological control of saltcedars (Tamarix, spp.) in the United States. Biol. Control, 27(6): 101-116.

Lillesand, T.M., Kiefer, R.W. and Chapman, J.W., 2004. Remote Sensing and Image Interpretation. John Wiley & Sons, New York, NY, 763 pp.

Robinson, T.W., 1965. Introduction, spread, and area extent of saltcedar (Tamarix) in the western United States. 491-A, United States Geological Survey, Washington.

Wilcox, B.P., Dugas, W.A., Owens, M.K., Uekert, D.N. and Hart, C.R., 2005. Shrub control and water yield on Texas rangelands: current state of knowledge. 05-1, Texas Agricultural Experimentation Station, College Station.