

COLORADO RIVER BASIN DEFOLIATION: ANALYSIS OF TAMARISK BEETLE IMPACTS

This material was developed as a remote sensing exercise for the Integrated Geospatial Education and Technology Training (iGETT) Remote Sensing 2014 Summer Institute, supported by a grant from the National Science Foundation (#DUE-1205069). Some prior experience with Esri ArcGIS 10.x software is required for this exercise and a basic understanding of satellite imagery and remote sensing analysis is recommended.

INTRODUCTION

Tamarisk (*Tamarix* spp.), is a deciduous shrub or tree, native to arid regions of Eurasia and introduced to the United States in the early 1800s. Also known as salt cedar, it tolerates very saline soils and has adapted well to the arid western U.S., where it is considered a major invasive species. The growth of dense tamarisk thickets has devastated native riparian areas in the west, where tamarisk is now often the dominant water user and has displaced native flora and fauna.



San Juan River, Utah (USGS.gov, 1997)

A variety of tamarisk control projects and riparian restoration projects have been undertaken in the U.S. but have largely been ineffective. In 2001, a biological control project was developed, focused on introduction of the tamarisk beetle (*Diorhabda* spp.), the primary pest of tamarisk plants in their native regions of Eurasia. Tamarisk beetles were released at various locations in the western U.S. and quickly evolved to cope with their new environment. Beetles were introduced in 2006 to the Virgin River area in southern Utah, near the community of St. George. By 2008 the voracious and rapidly-spreading beetles had substantially altered riparian vegetation and widespread defoliation was visible downriver from the release sites.

Although there is evidence that tamarisk trees are being heavily impacted by the beetles (repeated defoliation of tamarisk trees over several years can lead to tree death) native vegetation has not readily reestablished to replace the tamarisk. In some cases native habitats in the Colorado River watershed have been so severely impacted by changing hydrologic conditions and the tamarisk invasion that tamarisk thickets may be the only remaining suitable habitat for riparian species along some rivers. The U.S. Bureau of Reclamation reports that beetles can move downstream as much as 10 to 20 miles annually and monitoring is underway to track the changes occurring.

Remote sensing can be a very effective tool for measuring and monitoring tamarisk defoliation and changes in riparian vegetation communities along these western rivers. This exercise provides one methodology, focused on the St. George Utah region, which can be adopted for these types of studies. A Normalized Difference Vegetation Index (NDVI) is produced for two years of imagery--one before and one after the tamarisk beetle release. Additionally, a Difference or basic change detection calculation is then run to determine the difference between these two NDVI results in order to categorize vegetation change over that period and assist in identifying areas where significant defoliation has occurred.

PROJECT SETUP AND DATA

Esri ArcGIS 10.x software is used for this exercise. Satellite imagery from Landsat 7 and 8 is gathered from two summer season dates--August in this exercise--when riparian shrub and tree canopies are full. Both Landsat 7 and 8 are used: Landsat 7 captures riparian vegetation conditions before the beetle release (8/13/2002 in this exercise) and Landsat 8 captures recent or current vegetation conditions (8/3/2013 here). The August 2002 Landsat 7 scene was chosen for this analysis in order to avoid the Landsat 7 scan line failure that occurred in May 2003. Landsat imagery was downloaded at <http://earthexplorer.usgs.gov/>.

Landsat data is considered “raw” when acquired in the original format. A standard workflow for converting raw satellite imagery into scientifically meaningful formats often includes Radiometric Calibration processing steps. This can be done fairly efficiently in remote sensing / image processing software packages such as ENVI and ERDAS. In this introductory exercise, pre-analysis radiometric correction is not included, but the analyses conducted in this study are also valid for analyzing raw satellite imagery.

Prior to conducting the analysis, an examination of tamarisk beetle release locations, maps, and images for the region (see the References section for additional information) was performed in order to identify riparian habitats likely to have been impacted by tamarisk defoliation. A study area location was chosen along the Virgin River, just north of the Colorado River, near St George Utah, at approximately 37.124275° north and -113.493482° east, or Landsat imagery Path 39 and Row 34. An ArcMap project was created for the study, incorporating an Esri imagery basemap and GIS vector data for streams and rivers. If desired, data can be clipped to the area of study, which should focus on rivers with discernible riparian habitat and limited entrenchment and in areas not heavily impacted by urbanization or agriculture during the period of study.

IMAGE ANALYSIS

NDVI analysis of the before and after Landsat images is conducted based on a ratio calculation of two bands (see the final page of this document for further information regarding ArcGIS tool descriptions) but the methodology varies slightly between Landsat 7 and 8 data, given the differences in spectral bands used in each. Below is a comparison of these data (from the EarthExplorer website) with bands used for NDVI calculations shown in red--note the difference in band numbers between the two.

Landsat 7: Enhanced Thematic Mapper Plus (ETM+)

- Eight spectral bands, including a pan and thermal band:
 - Band 1 Visible (0.45 - 0.52 μm) 30 m
 - Band 2 Visible (0.52 - 0.60 μm) 30 m
 - Band 3 Visible (0.63 - 0.69 μm) 30 m
 - Band 4 Near-Infrared (0.77 - 0.90 μm) 30 m
 - Band 5 Near-Infrared (1.55 - 1.75 μm) 30 m
 - Band 6 Thermal (10.40 - 12.50 μm) 60 m Low Gain / High Gain
 - Band 7 Mid-Infrared (2.08 - 2.35 μm) 30 m
 - Band 8 Panchromatic (PAN) (0.52 - 0.90 μm) 15 m
- Ground Sampling Interval (pixel size): 30 m reflective, 60 m thermal

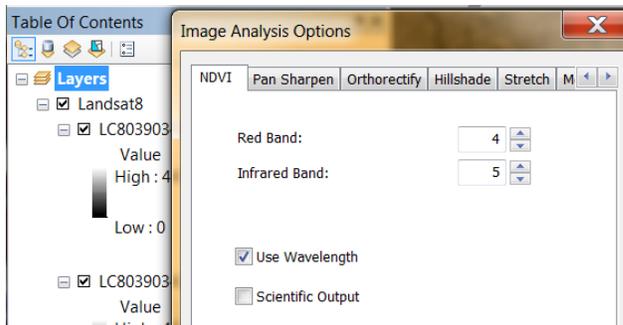
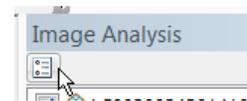
Landsat 8 Operational Land Imager (OLI)

- Nine spectral bands, including a pan band:
 - Band 1 Visible (0.43 - 0.45 μm) 30 m
 - Band 2 Visible (0.450 - 0.51 μm) 30 m
 - Band 3 Visible (0.53 - 0.59 μm) 30 m

- Band 4 Red (0.64 - 0.67 μm) 30 m
- Band 5 Near-Infrared (0.85 - 0.88 μm) 30 m
- Band 6 SWIR 1(1.57 - 1.65 μm) 30 m
- Band 7 SWIR 2 (2.11 - 2.29 μm) 30 m
- Band 8 Panchromatic (PAN) (0.50 - 0.68 μm) 15 m
- Band 9 Cirrus (1.36 - 1.38 μm) 30 m
- Thermal Infrared Sensor (TIRS); Two spectral bands:
- Band 10 TIRS 1 (10.6 - 11.19 μm) 100 m
- Band 11 TIRS 2 (11.5 - 12.51 μm) 100 m

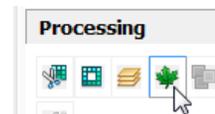
The following are steps to follow when using the NDVI tool in ArcMap:

1. In ArcMap, display the Image Analysis window: click Windows on the ArcMap main menu and select Image Analysis.
2. Determine which bands will be used for the analysis and add these to the ArcMap data display. In the Image Analysis window select/highlight only the two chosen bands from the list displayed.
3. With the two selected red and infrared inputs selected, open the **Options** window by clicking the Image Analysis tool (see graphic).
4. In the Image Analysis Options window click the NDVI tab. By default, the Red Band is 3 and the Infrared Band is 4: use bands 3 and 4 for Landsat 7 but change the inputs to the Red Band 4 and Infrared Band 5 for Landsat 8. You may need to review the metadata for your imagery to determine which bands to use (see graphic).



I found it best to check the **Use Wavelength** checkbox shown, which works well to guarantee the correct bands are indeed used. When the settings are correct, close the Options window. You are now ready to run the NDVI process.

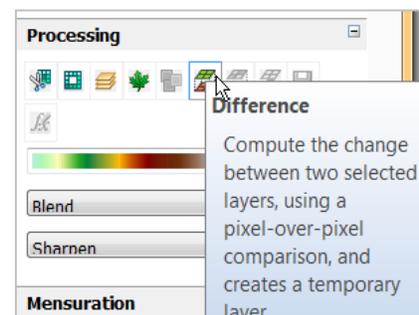
5. Click the NDVI button in the Processing section (shown in the graphic) to create the new NDVI output. This is added as a temporary layer to the table of contents. By default, a color map renderer is applied where green represents vegetation, unless the Scientific Output option is checked.



This processing is applied to the layers "on the fly" and the original data remain unaltered. The Image Analysis processing tools output a new temporary raster layer rather than creating another data file (which can take time to generate). If you wish to save the temporary layer as a permanent file, export it: right-click the layer and choose Data - Export Data.

Examine the NDVI processing results for the two images. Displayed in grayscale, brighter or white pixels (higher ratio values) indicate more green vegetation, while dark pixels (lower ratio values) indicate a lack of green vegetation.

After constructing the two years of NDVI image (in my case, for August in 2002 and August 2013), calculate the difference between the two NDVI ratios. Again, be sure the two NDVI images



are the only ones selected in the Image Analysis list, and then click the Difference button in the Processing section (see graphic; refer to the final page of this document for more information about this process).

The new image is added as a temporary layer to ArcMap and is displayed in grey scale. Make it easier to view by double-clicking the layer and, in the Symbology tab, change the color ramp to distinguish more colors. For example, I chose a red to green color ramp:



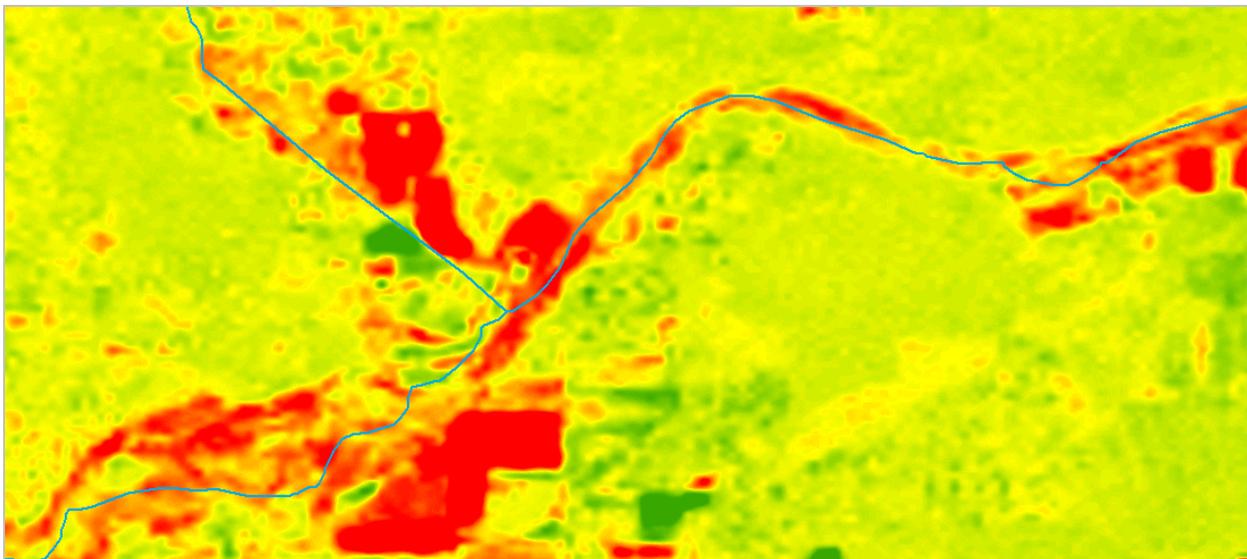
With this color ramp, pixels in yellow represent areas that had similar NDVI values for the two years. Pixels in the red or green ranges represent areas where NDVI values differ significantly.

To improve the display of the Difference layer, highlight the layer in the upper Image Analysis window and, in the Display section of the window, **check DRA** to use a dynamic range adjustment for the display. I also experimented with the resampling method settings (see graphic). For example, in my image, the Cubic Convolution resampling method produced a sharper image than did the default Nearest Neighbor method.



ANALYSIS RESULTS

My study area near the intersection of the Virgin River and Mill Creek shows considerable similarity in areas away from the rivers, but areas near watercourses show significant difference (darker greens and reds). There is a strong likelihood that these NDVI differences are a result of the defoliation that began here, not long after the tamarisk beetle's introduction to the region, beginning in 2006:



The following page contains Google Earth views of the project area for 2007, before this region was impacted by the tamarisk beetle and heavily defoliated, and for 2014, after beetle populations exploded and defoliation became widespread here. These show the die off of riparian vegetation in the intervening years. In the two views, compare especially the before and after vegetation appearance for the three sites indicated with red arrows. Although some green vegetation can be seen in the 2014

scene at the base of the slope on the western side of the stream, very little green vegetation is visible east of the stream.



DIGGING DEEPER

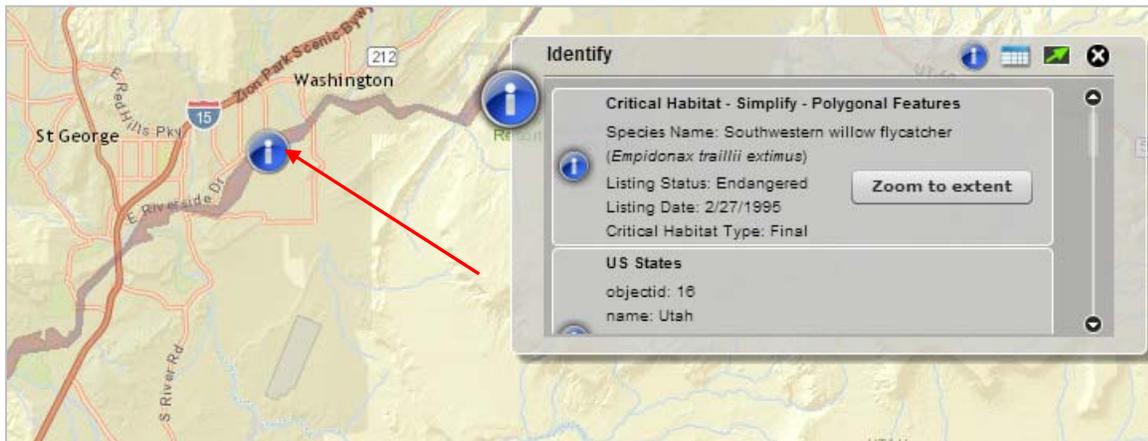
Loss of riverine habitat for is especially problematic with respect to threatened and endangered species such as the Yellow-billed Cuckoo and Southwest Willow Flycatcher. Habitats for these birds have already

been significantly impacted in the southwestern U.S. and populations have declined dramatically, thus the listing of the species.

At the US Fish and Wildlife Critical Habitat website (<http://ecos.fws.gov/crithab/>) GIS data can be downloaded for use in ArcMap (see graphic for flycatcher data). For example, this could be added to ArcMap in order to focus analysis in designated critical habitat. The data can also be viewed in the USFWS Mapper tool.

Flycatcher, Southwestern Willow (<i>Empidonax traillii extimus</i>)	Federal Register (Jan 3, 2013)
Population description: Entire	1. Spatial Metadata Spatial Data View in Mapper
	Critical Habitat Type: Final designated

The St. George riparian area examined in this study contains critical habitat for the Southwestern willow flycatcher, shown below in the Mapper tool (see the red arrow for the approximate locations of the study site and use of the Identify tool in the Mapper; the reddish polygon along the stream is critical habitat data). Where native habitat has already been eliminated or severely compromised, tamarisk has, in some cases, become nearly the only remaining suitable habitat for flycatchers. How might the loss of tamarisk vegetation impact these birds and how will critical habitat be affected?



Studies have shown that continued defoliation of tamarisk (perhaps over seven years or more) leads to death of the trees. Some studies have also shown that tamarisk beetles can expand their range quickly, travelling 10-20 miles downstream in just a year's time. How could remote sensing analysis be used to determine the degree of riparian vegetation loss over time? How could it be used to measure the spread of tamarisk beetles downstream from release sites in the western U.S.?

REFERENCES

- Tamarisk Coalition. 2014. Tamarisk Leaf Beetle Monitoring Program. Available: <http://www.tamariskcoalition.org/programs/tamarisk-leaf-beetle-monitoring-program>
- Tamarisk Coalition. 2014. Yearly Distribution (2007-2013) of Tamarisk Leaf Beetle. Available: http://www.tamariskcoalition.org/sites/default/files/images/Tamarisk_Coalition_2013_TLB_Distribution_Map_Final.pdf
- US Bureau of Reclamation. 2014. Lower Colorado River Multi-Species Conservation Program. Available: <http://www.lcrmscp.gov/>
- Nathanael Massey and ClimateWire. 2012. Introduced Beetle Bids to Curb Water-Sucking Tamarisk, Reprinted from ClimateWire. Available: <http://www.scientificamerican.com/article/introduced-beetle-bids-curb-water-sucking-tamarisk/>
- Mary Anne McLeod. 2013. Beetle Mania: The Unintended Consequences of Introduced Species. SWCA Environmental Newsletter *The Wire*. Available: <http://www.swca.com/index.php/media/newsdetail/beetle-mania-the-unintended-consequences-of-introduced-species>
- Wikipedia. 2014. *Diorhabda carinulata*. Available: http://en.wikipedia.org/wiki/Diorhabda_carinulata
- Wikipedia. 2014. *Tamarix*. Available: <http://en.wikipedia.org/wiki/Tamarix>
- US Fish and Wildlife Service. 2014. Critical Habitat Portal. Available: <http://ecos.fws.gov/crithab/>

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Esri ArcGIS Tool and Desktop Help Descriptions

NDVI function:

The Normalized Difference Vegetation Index (NDVI) is a standardized index allowing you to generate an image displaying greenness (relative biomass). This index takes advantage of the contrast of the characteristics of two bands from a multispectral raster dataset—the chlorophyll pigment absorptions in the red band and the high reflectivity of plant materials in the near-infrared (NIR) band.

An NDVI is often used worldwide to monitor drought, monitor and predict agricultural production, assist in predicting hazardous fire zones, and map desert encroachment. The NDVI is preferred for global vegetation monitoring because it helps compensate for changing illumination conditions, surface slope, aspect, and other extraneous factors (Lillesand 2004).

The differential reflection in the red and infrared (IR) bands enables you to monitor density and intensity of green vegetation growth using the spectral reflectivity of solar radiation. Green leaves commonly show better reflection in the near-infrared wavelength range than in visible wavelength ranges. When leaves are water stressed, diseased, or dead, they become more yellow and reflect significantly less in the near-infrared range. Clouds, water, and snow show better reflection in the visible range than in the near-infrared range, while the difference is almost zero for rock and bare soil. The NDVI process creates a single-band dataset that mainly represents greenery. The negative values represent clouds, water, and snow, and values near zero represent rock and bare soil.

The documented and default NDVI equation is as follows:

$$NDVI = ((IR - R)/(IR + R))$$

- *IR = pixel values from the infrared band*
- *R = pixel values from the red band*

Esri ArcGIS Difference tool:

Clicking the Difference button performs a basic change detection algorithm by computing the difference between two raster or image service layers. This can be used to compare classified images, elevation models, and more.

This tool does not account for radiometric differences between images, such as atmospheric noise or haze. It also will not account for geographic shifts between two data layers. It only makes a pixel-over-pixel comparison. If the images are not perfectly aligned, this will show up as a difference between the images. Therefore, it is recommended that you preprocess the images to geographic and radiometrically shift them if required.