Abstract: Saltcedar (Tamarisk), is a weedy invasive vegetation species introduced to the United States from Europe and Asia in the mid-19th century. It has become one of the most invasive vegetation species in the United States and one of the greatest invasive threats to western riparian ecosystems. Accurate mapping of the distribution and abundance of Saltcedar in a timely manner plays a central role in achieving effective control. The objective of this study is to develop sub-pixel remote sensing techniques to determine the distribution of Tamarisk spp and associated native riparian species within the past 30 years along Rio Grande River. A new sub-pixel remote sensing method, Tesellated Linear Spectral Unmixing (TLSU) was devised and applied to 19 Landsat TM scenes acquired over the past thirty years. This research shows that Saltcedar is expanding its geographical range and replacing native vegetation while forming more regular spread patches, indicating greater adaptation to local conditions.

About the speaker: Dr. Wang received his PhD degree from University of California at Berkeley. Currently, he is a Professor and Director of Undergraduate Studies in the department of Geography at the State University of New York at Buffalo. He was the chair of the Remote Sensing Specialty Group at American Association of Geographers from 2015 to 2017. Dr. Wang was the chair of the working group 3 of the commission VI, International Society for Photogrammetry and Remote Sensing from 2012 to 2016. In addition, he is currently an editor for the International Journal of Remote Sensing, a guest editor for a special issue of Remote Sensing and the Environment. He has published more than 80 peer-reviewed articles in the leading Remote Sensing and GIS science journals, which have been cited more than 3400 times. His work has been supported by National Science Foundation, United States Department of Agriculture, and the United States Agricultural Survey. He was also the recipient of 2018 Education Excellence award from CGPIS, 2008 Early Career Award from the Remote Sensing Specialty Group of the American Association of Geographers and third place of John L. Davidson President’s Award for Practical papers by the American Society of Photogrammetry and Remote Sensing (ASPRS). His website is http://www.buffalo.edu/~lewang.

Host: Good evening. Welcome to the 23rd session of English Geoscience Café. Today the presentation is about “Spatial and Temporal Remote Sensing of Invasive Species”. Our honorable guest speaker this evening is Dr. Le Wang. He is an alumnus of Wuhan University and currently a Professor and Director of Undergraduate Studies in the department of Geography at the State University of New York at Buffalo. First, the Professor will present on today’s topic and then we will have a question and answer segment. So without further ado, I would like to present Dr. Wang to enlighten us on this interesting topic.

Speaker: Thank you for inviting me, please feel free to interrupt me anytime if you have any questions during the talk. I will present my work studying invasive species using remote sensing. Questions are most welcome.
Today’s talk is about a project that has been running for more than 13 years. I started this project when I was an Assistant Professor; but before moving on, I would like to give you all the pre-requisites about the topic so that no one misses out anything.

In remote sensing, we must consider two things: spatial and temporal changes.

What is space-time? For example, I was here three years ago. I was standing here. Space and time play a great role in our daily lives. What were you doing on this day last year? What will you be doing two years from today?

What I do to remember these things is through my phone. I browse through the photos. I am very interested in photography, so I take many photos. Those images help me recall what I was doing exactly one year ago.

**Spatial change**

Let me introduce my own spatial footprint i.e. where I have been in the last 26 years. In 1992, I was in Beijing and then I moved from there to Wuhan University, to start my undergraduate studies in photogrammetry and remote sensing. I spent four years in this university. Then, I moved back to Beijing to pursue my master’s degree. I spent three years in Peking University. After that, I travelled all the way through the Pacific Ocean to San Francisco, USA to pursue my PhD degree in University of California, Berkeley. Therefore, my Bachelor’s major was in photogrammetry, my Master’s degree was in GIS and my PhD was in Environmental Remote Sensing. After that, my first job was in Texas, USA. So, I moved from San Francisco to Austin, TX. I stayed there for four years as Assistant Professor. Today, the talk is about a project I started when I was in Austin. Later on, I moved from Austin, TX to Buffalo, NY. I have been staying in Buffalo for 11 years so far. That is my spatial path.

![Spatial Footprint](image)

**Temporarl Change**

Moving on to temporal change, Figure 2 shows temporal change I experienced throughout this duration. This was me 26 years ago and here this is me now (illustrating comparison of a past photo and a current one). That is my temporal change.
These were the examples of spatial and temporal changes in our personal lives. Now, we will discuss about how we can use temporal and spatial information in remote sensing to understand invasive species.

What do we mean by “invasive species”? I assume all of you can understand the keyword “invasive”. To give you an example, this is the best season in Wuhan to eat crayfish. They were introduced to Japan from USA in 1929. In 1939, crayfish were introduced to China by Japan. That is where the crayfish in China come from. They are actually an invasive species, not native to China.

Now as you know this study involves invasive species. What you are looking at, is a shrub, an invasive shrub. This particular invasive species is called Tamarisk, also known as Saltcedar. It was introduced to USA from China. China is the native habitat for Saltcedar. Currently, it is a posing significant problem in USA. Figure 3 shows a map of the USA indicating where Saltcedar is likely to grow. It is the south-west region of the United States. Water shortage is a big issue here. Unfortunately, Saltcedar consumes a significant amount of water. If Saltcedar replaces native species, it poses a greater threat than native species to the already existing water-shortage problem.
What is Phenology?

In vegetative remote sensing, you need to consider **Phenology**, the study of cyclic and seasonal natural phenomena. For example, this particular species has a pink flower in March. It is the growing season. In July, it turns green. Later on, in the months of November and December, it turns pale yellow or orange. Therefore, if you look at the variation of these colors, they form a complete cycle. Here the question arises, can we make use of Phenology to study the invasive species?

**Time series remote sensing**

We have to consider two aspects of Phenology in our study.

1. Intra annual: Monthly change in a year.
2. Inter annual: Yearly changes in the same month.

Fig. 5 is a collage of 12 different Landsat images focused on our study area. This reddish color shows the presence of Saltcedar. So you notice, here monthly change from January to December is illustrated. Landsat provides monthly/semi-monthly images related to intra-annual phenology.
The inter-annual cycle reflects yearly change. Figure 6 illustrates the inter-annual change in a river basin located in Peru.

So now, when we are aware of key terms, let me introduce you the concept of spectral unmixing in remote sensing. I assume everyone is aware of the term spectral mixing.

**Spectral Mixing**

What is spectral mixing? Figure 7 depicts a remote sensing image made up of numerous pixels. Each box represents a pixel. The problem is that when the spatial resolution is not up to the mark, some pixels, for instance this pixel, will have more than one land cover type. This is what we call as a “mixed” pixel. In other words, it is not a pure pixel. If you talk of a Landsat image’s resolution, it is 30x30 meters which is equal to 900 m^2. So this 900 m^2 includes this lab (the whole building) and the playground right in front of the building. All of them are contained in one pixel. Thus, we can call it a mixed pixel.
Spectral Unmixing

Spectral Unmixing is a way to understand the proportion of each land cover type within a mixed pixel. In other words, what fraction each “pure” land cover type occupies within a mixed pixel. We denote these pure land cover types/classes as n-number. Therefore, in this case, the “invasive species” is one n-number. “Native species” is another n-number. Besides these two, there is another class called “Other”. That makes three n-numbers. Our goal is spectral unmixing of this pixel i.e. trying to resolve the fractions of different pure land cover types or classes. In this example, 50% of the selected pixel is invasive species. We sometimes call the fraction of each land cover type as abundance. This is somewhat different from the traditional remote sensing classification because in usual classification schemes, we would classify this mixed pixel either as an invasive species or as native species. We make use of assumptions in classifying pixels as one land cover type. In spectral unmixing however, we have more than one land cover types / n-numbers in one pixel.

Many studies have already been conducted on spectral unmixing. In our example, we only had three n-numbers i.e. “Invasive”, “Native” and “Others”. In reality, a pixel usually has many land cover types. However, the number of n-numbers is constrained by the number of bands. This is a constraint. Therefore, we developed a method to solve for any number of n-numbers. For instance, in a pixel, we have 50 n-numbers. We can choose any combination of n-numbers among those 50. The method is called Tessellated Linear Spectral Unmixing (TLSU). The point ‘P’ in Figure 8 is a mixed pixel. In order to do Spectral unmixing for this pixel, I selected the nearest n-number A, D, and B; for every pixel, before we carry out spectral unmixing, we try to decide the optimal combination of n-numbers among a large pool of n-numbers. If you are interested to get into the details of this technique please go through my paper;
Incorporating Temporal Information in Spectral Unmixing

The next step is to incorporate temporal information in spectral unmixing; Figure 9 shows our beautiful data set in which you can see Saltcedar. The time is the end of November or early December. The wisdom behind choosing this period was the fact that Saltcedar changes its color to orange brown at this time of the year whereas the surrounding native species remain unchanged. Thus, we can easily differentiate Saltcedar from the native species at this time. Figure 11 shows the relationship NDVI of Saltcedar throughout the year. We can call this a phenological curve. It is evident that after the month of September, the color starts to change significantly. In the month of November, it turns orange brown whereas at the end of the year, leaves fall off. Therefore, we try to make use of this period, from late October to mid-November for our analysis.
Different coloration at different locations

However, this is not easy. Saltcedar has a different coloration at different locations. Why does the same species have different coloration at different locations? Reason being, phenology is spatially dependent. In other words, phenology has spatial differences. Even the same type of tree or flower might have different phenology at different locations. Thus, if we do not consider this information, our study will be erroneous.

For this problem, we developed a very simple method. It is as simple as this equation,

\[ T_c = \alpha \times T_{EoST} + \beta \]

\( T_c \) is the timing of the Saltcedar coloration or when the specific pixel changes to orange brown. End of the season time \( T_{EoST} \) is the information we get from a product by MODIS, so we do not have to calculate \( T_{EoST} \) on our own. The \( \alpha \) and \( \beta \) values are two other parameters. As long as we know these parameters, we can easily know when Saltcedar in the area changes its color. Once
we have this information, we know the time when we can use Landsat images for our analysis. It will solve the problem related to the spatial differences in phenology. This paper was published in Remote Sensing of Environment just because of the equation that we developed.

Fig. 12 shows an example. On the left hand side, these are MODIS image pixels. The $T_{EoST}$ is the $345^{th}$ day of the year. It was made in the month of December. On the right hand side are Landsat image pixels. The values of $\alpha$ and $\beta$ are pre-calculated. Using the equation, the $T_{c}$ is calculated for different pixels and then shown in different colors for different months of coloration. That is how we incorporated temporal information in spectral unmixing.

Incorporating Spatial Information in Spectral unmixing.

Moving further, we will discuss about how to incorporate spatial information in Spectral Unmixing.

We also developed a model called a “spatially lagged linear mixture model”. This model simply takes account of the fractions of land cover types in the neighboring pixels for spectral unmixing of a particular pixel. For instance, if the neighboring pixel has 50% of Saltcedar, that particular pixel should also be comprised of 40% to 55% Saltcedar; just like how we are influenced by our neighbors or our surroundings. It was the first model ever developed that incorporates spatial information. If you want to learn more, please go through my paper; C. Shi and L. Wang, "Linear Spatial Spectral Mixture Model," in IEEE Transactions on Geoscience and Remote Sensing, vol. 54, no. 6, pp. 3599-3611, June 2016.

By incorporating this information, we monitored the monthly change in growth of Saltcedar and this was the total change in the growth of Saltcedar from Dec 2004 to Dec 2005. The red color represents the growth of Saltcedar. Next step is to identify the patterns in its growth.
Spatial Patterns

We need to understand where Saltcedar has grown more than the other parts; in other words, to understand its spatial patterns. By understanding the spatial patterns, we learn why some areas have dense Saltcedar distributions. Right now in this room, you are sitting in different clusters, which make patterns. These clusters are not random. You would prefer to sit with someone you know. This is what we are interested in knowing about Saltcedar because patterns give us a lot of information about the species. In order to accomplish this, we made use of landscape metrics developed and used specifically for this purpose. Previously, landscape metrics were calculated using classification results but we used spectral unmixing in our study. This enabled us to discover hidden spatial patterns of Saltcedar. This was the first time the fractions of the land cover types were taking into account in identifying spatial patterns.

This study helped me to calculate four different types of patterns,

i. Number of Patches (Larger NP → fragmented)
ii. Patch size Coefficient of Variation (PSCOV)
iii. Cohesion
iv. Normalized Landscape Shape Index (nLSI)
Findings in the study (Native vs. Invasive species)

What we found out is,

i. Native species lose total area over time but the number of patches increases. Native species are dispersed in small patches, in a fragmented landscape.

ii. Native species are less compact at high proportions while Saltcedar occupies sites directly adjacent to rivers.

If you are more interested about this technique, please go through our paper:


Assessing Biological Control Impacts

Let me share with you an interesting application of these studies. In order to control Saltcedar biologically, a beetle was raised in lab. It was purposely developed by the United States Department of Agriculture. The unique property of this beetle was that it only eats Saltcedar leaves. So, after releasing this type of beetle in the field, they spread towards the Saltcedar and eat it. This is a biological control.

Have a look at this before and after beetle-induced Tamarisk/Saltcedar defoliation.

The biologists/researchers were interested in tracking the movements of these beetles, in determining how far these beetles were travelling from the initial point and in knowing how effective the beetles were in eating out the Tamarisk/Saltcedar. That was where our role came in.

We tried to answer the Where? When? and What?

- Where: Where do the beetle move or travel to?
- When: When do they reach at different locations?
- What: What environmental factors affect the route of these beetles? Let us try to think like a beetle. If we were a beetle, what would be in our mind? We would move towards where the food is, in this case, Saltcedar. Also we would move towards water, appropriate precipitation and areas with an ideal temperature for us.

The main objectives in this study were,
i. To detect and describe the spatiotemporal patterns of beetle-induced tamarisk defoliation.

ii. To explore the relationship between defoliation pattern and riparian environmental conditions.

**NDVI based defoliation detection**

Let us look at the NDVI of Saltcedar. Fig. 15 shows a healthy Saltcedar, which means, there is low reflectance in red band and significantly high reflectance in the Near Infrared band. The NDVI will be high. Whereas Fig. 16 depicts the reflectance curve when a Saltcedar shrub/tree is hit by beetles (Defoliated Saltcedar). The NDVI will be relatively lower in this case. Thus, we can easily know if the trees are hit by beetles by just comparing its NDVI with the NDVI of a healthy Saltcedar.

\[
NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}}
\]

**Fig. 15 NDVI of a healthy Saltcedar**

![Healthy Saltcedar](image1)

**Figure 16 NDVI of defoliated Saltcedar**

![Defoliated Saltcedar](image2)
Fig. 17 shows the comparison between monthly changes in NDVI of a healthy Saltcedar with that of a defoliated clump. Thus, NDVI helped us to monitor the movements of beetles and find out if the Saltcedar was hit by beetles, or not.

So, as we previously talked about, in our study we found out four environment factors for the movements of beetles, i.e.

i. Tamarisk percent cover (availability of Tamarisk)
ii. Distance to beetle release site.
iii. Distance to river.
iv. Elevation.

Lastly, I would like to share with you really an interesting finding in the study. Through this study, we got knowledge about something, which was not previously known. We found out that the beetle we used for our analysis (subtropical beetle) has the capability to travel up to 102-130 km per year. Previous research suggested that the farthest a beetle (Northern beetle) could travel was 25 km per year (Nagler et al., 2014). That is how remote sensing helped reveal an unknown fact about beetles.

Having said that, in my opinion, remote sensing is not a type of technical support but a technical support. I think the main goal of working in this field is to answer tough scientific questions and to previously unknown uses for remote sensing.

Q & A Session

Question 1: Thank you Professor for such an enlightening lecture. My question is, did you try using this method for others species as well?
Answer: That is a very good question. Yes, we did try to use this method for other species as well and it worked quite well. We tested it and the results were promising.

Question 2: How about using the same method with Hyperspectral Remote sensing?

Answer: It would be great but it is quite expensive and costly whereas in this study we used Landsat images, which are free and generated great results.