Invasive Species Detection using Spectral Angle Mapper and Mixture-Tuned Matched Filtering: Refining Present Applications and Looking Ahead

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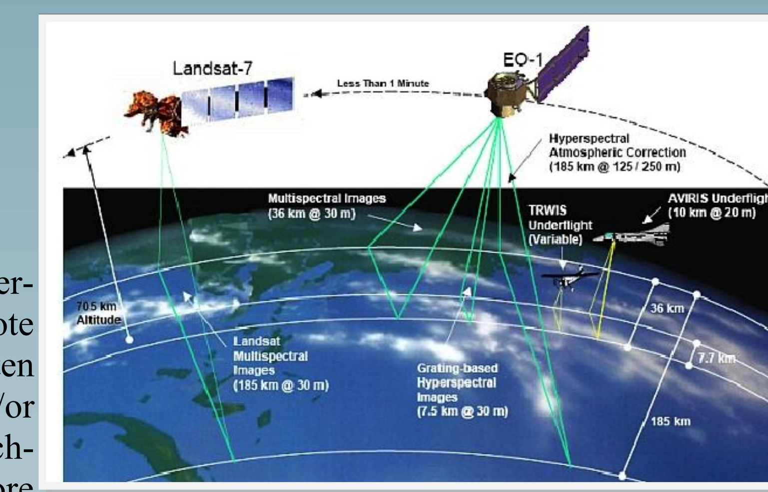
What is Leafy Spurge?

Leafy spurge (*Euphorbia esula*) is an invasive forb that displaces native vegetation on the rangelands of the greater western United States, most notably grasses that are intended for livestock. It reproduces vegetatively and spreads rapidly, thus making it resistant to attempts at removal and control. The body of the leafy spurge plant undergoes considerable phenological variation in color; most notably is its "yellow phase" where leafy spurge exhibits a yellow bract, which is a leaf-like structure adorning its flower, that distinguishes it from other moist vegetation during that period. This wide array of colors across the season lends itself to remote sensing analyses because of its unique spectral and temporal characteristics.

The phenological variation in leafy spurge across a season. From left to right: early green growth, "yellow phase", reddish-gold late summer beginning of desiccation.

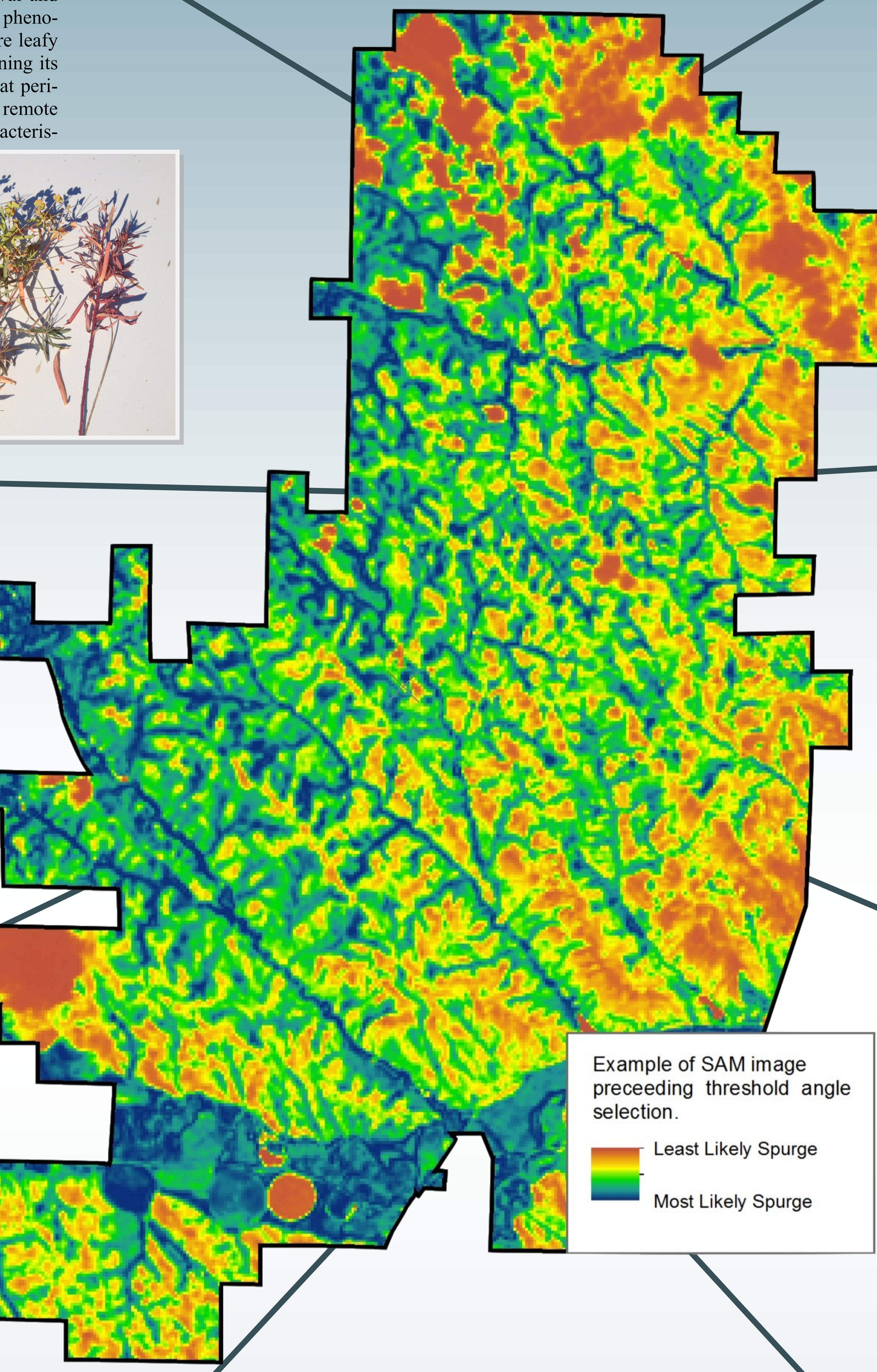
Remote Sensing



Examples of common sources of remotely sensed data.

Though fundamentally different in methodology, remote sensing and GIS analysis often complement, mirror, and/or inform each other. Researchers are finding more and more applications for intertwining both the data and the products from GIS and remote sensing.

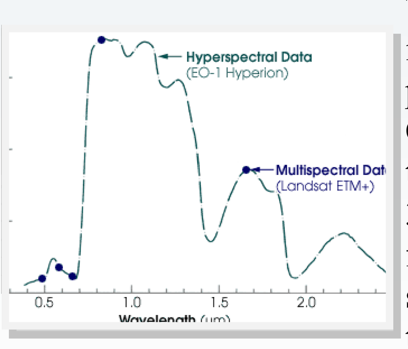
Unlike GIS, remote sensing relies on one very specific source for data input: satellite images. Analyzing the reflectance of objects on the earth allows for identification and classification of land cover types and other geographic phenomena. Satellite sensors enable researchers to use a wider array of wavelengths than the human eye is capable of seeing while also allowing them to process information over large land areas. This technology saves time and resources as well as offers a visually stimulating way to share results and information, much like GIS. Remote sensing and GIS operate synergistically, and advancements in one technology often support the other technology.



Example of SAM image preceeding threshold angle selection.

Data

In the past few decades, considerable strides have been made in the quality and extent of remotely sensed data. Specifically, the spatial (pixel size) and spectral (wavelength breadth and detail) resolution of satellite imagery have improved.

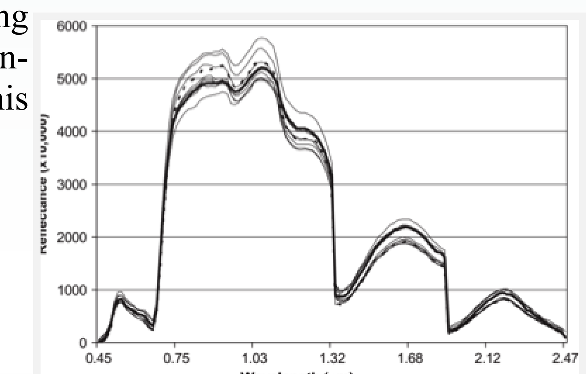


This study uses "hyperspectral imagery" captured from the Hyperion sensor of NASA's Earth Observing 1 (EO-1) satellite; this sensor returns images with 30-meter pixels that contain reflectance data for wavelengths spanning 0.4 µm to 2.5 µm of the electromagnetic spectrum (divided into 220 bands). To put this detail into perspective, Landsat TM (a commonly used free data source of the same spatial resolution) covers from 0.45 µm to 2.35 µm spread over only 8 bands. This increase in distinction between bands provides greater opportunity to identify subtle differences between reflectance qualities of various land cover types.

Classification and Endmembers

Regardless of the spectral resolution of the dataset, each pixel has a unique spectral profile, which is the reflectance values of that pixel across each band contained within the data. Using the distinct spectral signature of each pixel, remote sensing classification groups pixels with similar spectral profiles into land cover types.

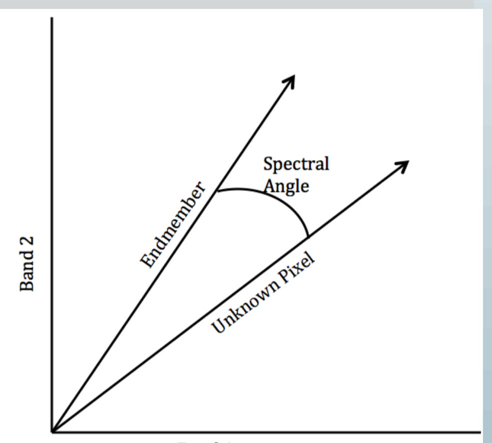
Some classification methods, like those used in this study, match a pixel's spectral profile to the spectral signature of a specified landcover type instead of grouping pixels within an image. The spectral signature to which the pixels are matched is called an endmember. Using endmember classification is preferred when the user is both familiar with the scene and interested in identifying specific land cover types. The goal of this classification is to produce an image in which each pixel is categorized according to the presence/absence or relative abundance of the land cover of interest (in this case, leafy spurge).



An example of an endmember spectral signature of Leafy Spurge using hyperspectral data.

Spectral Angle Mapper

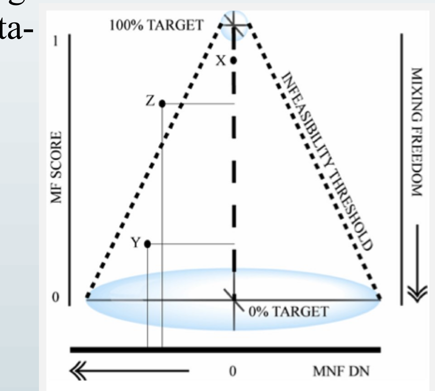
Spectral Angle Mapper (SAM) is a technique that provides an "endmember presence/absence" classification for each pixel within an image. Mathematically, the angle between the endmember spectral signature vector and the pixel spectral signature vector (starting from the coordinate origin) is computed in multidimensional-space; for clarification, the number of bands contained in the dataset equals the number of dimensions in which these signatures are compared. The smaller the spectral angle between the endmember and the pixel, the more likely the endmember is present in the corresponding land area. The researcher chooses a threshold for a proven angle of difference and classifies each pixel with an angle that is lower than the threshold value as "present" and all other pixels as "absent".



An example of SAM visually represented in two dimensions.

Mixture-Tuned Matched Filtering

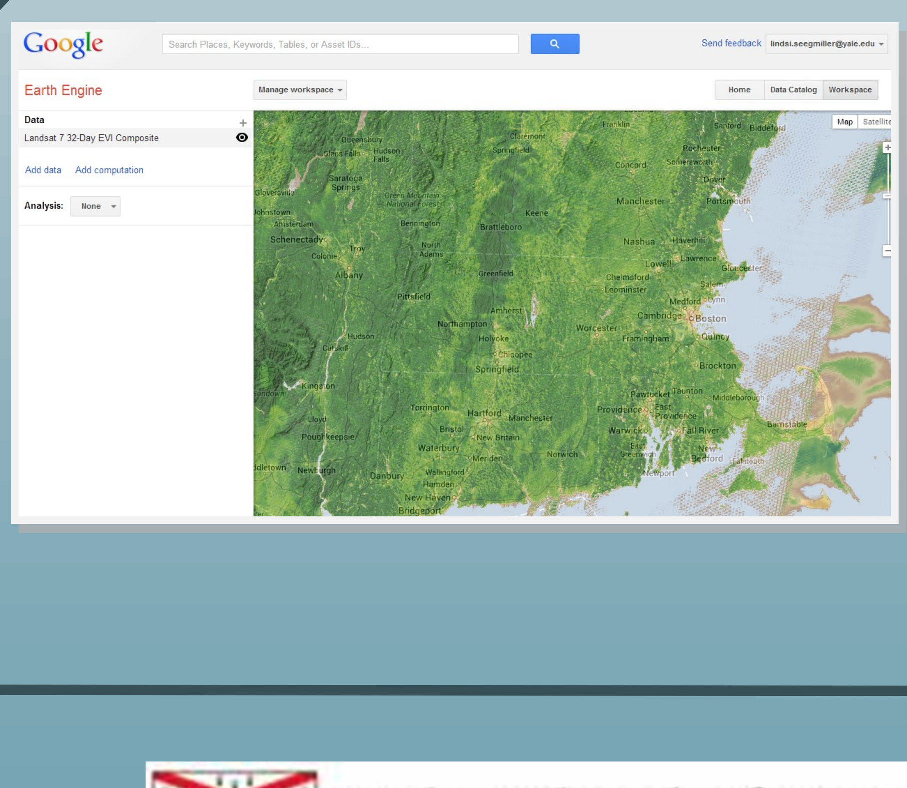
Mixture-Tuned Matched Filtering (MTMF) is a statistical algorithm that allows a researcher to determine relative abundance of an endmember within a pixel (the "matched filtering") as well as the likelihood of the classification itself being a "false positive" prediction (the "mixture tuning"); thus, MTMF provides two outputs for each pixel (an "MF Score" and an "infeasibility" score). A unique aspect of MTMF is the fact that, before the analysis takes place, the data is transformed such that the noise within the image is reduced to the greatest extent possible, and the extraneous data from the imagery is ignored. MTMF, therefore, capitalizes on highly detailed datasets (e.g. hyperspectral data) without sacrificing computational efficiency.



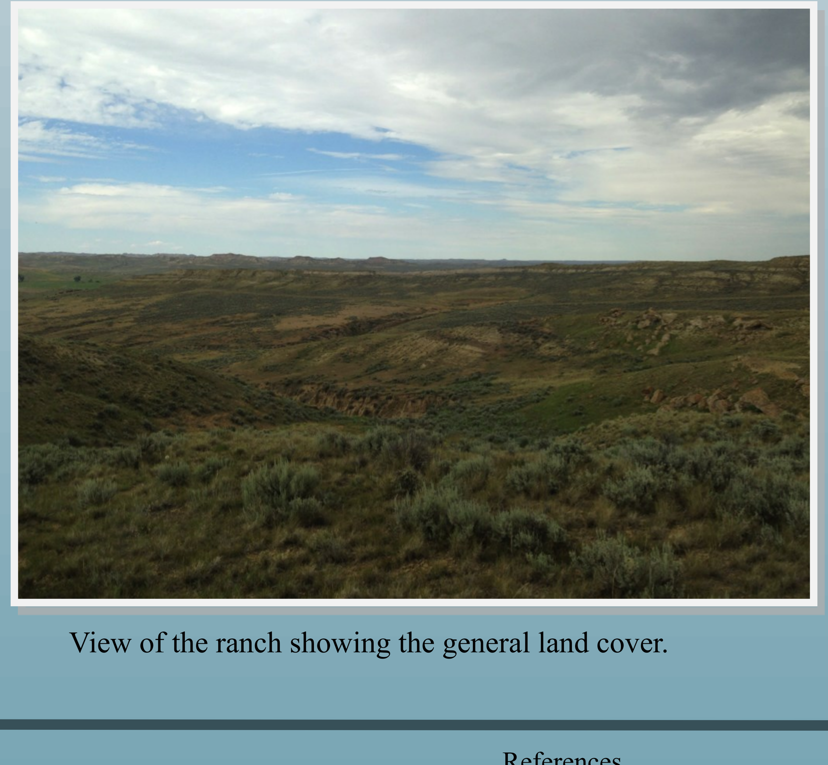
The y-axis of this plot is the "MF score" (the value from 0 to 1 corresponds to percent coverage of the pixel by the endmember); the x-axis of this plot is the "infeasibility score". Pixels with a higher MF score that fall inside of the infeasibility threshold (e.g. point X) denote a high likelihood of the endmember being present (and in a high abundance). As the MF score decreases, the infeasibility threshold expands (e.g. point Y). Pixels that fall outside of the infeasibility threshold, at any MF value (e.g. point Z), are likely false positives.

Benefits and Google

Successfully identifying leafy spurge using SAM and MTMF will allow ranchers in the western United States to rapidly and consistently monitor the health of their rangelands. Applying these techniques over multiple seasons will further allow managers to assess the success of their grazing strategies temporally then adjust them accordingly to improve reduction and control of spurge patches. Both of these techniques, as well, are not unique to the analysis of leafy spurge; once developed, ranchers (and land managers working in other ecosystems) can use these tools to assess any land cover—including other species of plants—as endmembers within the analysis.



This study attempts (1) to refine the MTMF process for classifying spurge on free, publically available data using existing proprietary software and (2) to integrate both SAM and MTMF into Google Earth Engine (an online geospatial platform that has ingested the complete history of Landsat data, among others, will soon include EO1 data, and runs analysis in the cloud as opposed to on local machines), which will allow anyone in the world to use them.



View of the ranch showing the general land cover.

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