

## Mojave Desert Preserve Remote Sensing Project Documentation

### Project Summary

This project sought to accomplish two tasks. First, using data obtained from the MODIS sensor, to determine if there is more detectable vegetation in the Mojave Desert Preserve during a 'Super Bloom' year (2017) compared to a dry year (2015). Second, to compare Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) data from a pre-calculated source (MODIS) versus NDVI and EVI calculated within ArcGIS Pro from data in Landsat 8's multi-band image repository. Data was prepared with a variety of image processing and geoprocessing (including automation via python scripting and the arcpy package) tools. Graphing the data processed for the first task showed that there is an increase in detectable vegetation during 'Superbloom' years in the Mojave Desert Preserve. A comparison of NDVI and EVI data from different sources showed that NDVI values are comparable between the two satellite systems and differences in value ranges may be a result of the higher spatial resolution of Landsat 8 data. However, initial research showed EVI ranges were quite different between the two sources and thus are probably not comparable. Further research will be needed to determine why this occurred.

### Purpose

In 2017, the spring growing season in desert regions of California and the West coast was declared a 'Superbloom.' (Imster, 2017) 'Superbloom' is a term believed to have been developed by the media to describe events in the early 1990's where desert regions had a vastly above average abundance of wildflowers (Ober, 2019). In theory this should mean that more vegetation is remotely detectable during these 'Superbloom' years. The purpose of this project was to test this theory using remotely sensed EVI data taken by the MODIS sensor during the years 2015 (a 'dry' year) and 2017 (a 'Superbloom' year) over the region of the Mojave Desert Preserve. Since MODIS data comes pre-calculated, this project also sought to compare NDVI and EVI layers calculated from raw Landsat 8 data using ArcGIS Pro software to those layers derived from MODIS data in order to analyze the utility of the ArcGIS Pro derived data layers and to demonstrate how ArcGIS Pro can be used to calculate NDVI and EVI.

### Background Information

MODIS (Moderate Resolution Imaging Spectroradiometer) is a sensor array located on the Aqua and Terra satellites (nasa.gov). The Terra satellite takes images of the entire Earth's surface about once every 1 to 2 days. Data for this project was obtained from the Terra satellite's version 6 vegetation index package (MOD13Q1). This package contains data with a spatial resolution of 250m per cell side, aggregated from 16 days worth of images (with each file's acquisition date marked as the last collection date of data in the series), which allows for the removal or correction of cells with reflectance values contaminated by cloud cover and anisotropic reflectance from land surfaces (Sesnie, 2011). Meanwhile the Landsat 8 satellite

collects data with a spatial resolution of 30m per cell side, once every 16 days. Gains in spatial resolution are offset by the potential for 'lost' data if any observed surfaces are covered by clouds on the date data is obtained. Thus, MODIS data was chosen as the data source for the first portion of this project. It was desirable to obtain as many data points as possible to increase the validity of results. An additional consideration was the value in saving time by automating a process to aggregate data from a large number of layers where the EVI calculations had already been made, and where data has a larger chance to be accurate given it is aggregated over a larger time period than Landsat data.

NDVI and EVI are both indexes that are used to measure the health and presence of vegetation. They are both calculated from the red and NIR bands of remotely sensed data (with EVI calculations requiring an additional blue band). NDVI is calculated with the following equation:

$$NDVI = ((NIR - Red)/(NIR + Red))$$

where NIR represents data from a near infra red spectral band, and Red represents data from a red spectral band. The resulting value is a normalization of both spectral bands, with a range of -1 to 1. Higher NDVI values represent a larger NIR reflectance value compared to the Red reflectance value and are considered indicators of increased plant health because healthy vegetation correlates with a higher reflectance of NIR wavelengths, and an increase in leaf area capable of reflecting NIR wavelengths (Rouse, 1973). Values close to 0 represent bare ground, and highly negative NDVI values represent water or clouds (as these surfaces absorb NIR and reflect much more in the red wavelengths). Values in the range of .2 to .8 usually represent healthy vegetation (L3Harris, 2013). One of the problems with NDVI is its lack of sensitivity for areas of low and high vegetation (Phillips, 2008).

EVI was developed specifically to utilize data collected by MODIS (Huete, 2002). The base calculation for EVI is:

$$EVI = G * (NIR - red) / (NIR + C1 * red - C2 * blue + L)$$

Where NIR is a near infra red spectral band, red is a red spectral band, blue is a blue spectral band, G is a gain factor, C1 and C2 are coefficients for atmospheric interference used in conjunction with data from the blue band to reduce atmospheric interference of data and L is a factor used to adjust for soil and canopy background data interference (USGS, 2019). These alterations make EVI less sensitive to certain types of background noise and make it more sensitive to changes in vegetation density in heavily forested areas and jungles. Like NDVI, EVI is also represented in a range of -1 to 1 and healthy vegetation is considered to fall in the range of .2 to .8. MODIS (and ArcGIS), calculates EVI with the following equation:

$$EVI = 2.5 * (NIR - Red) / (NIR + 6 * Red - 7.5 * Blue + 1)$$

EVI was chosen as the focus of data for the first portion of this project. This was primarily because it incorporates modifications to reduce the interference from soil reflectance. Considering the study area of the first portion of this project is an arid desert region, this was of prime concern.

## Image Processing

MODIS data is delivered to clients with NDVI and EVI layers already calculated. As such, no major image processing beyond clipping was required for the 48 MODIS derived

files in hdf format. A script was written to automate extracting the EVI layers from the hdf files, mask the files to the boundary of the Mojave Desert Preserve, normalize the masked data with a .0001 conversion factor and finally export a raster that only contained cells with an EVI value of .1 or above (representing the cut off of detectable vegetation from bare soil, see the justification of this value in the Analysis section below). The script then modified tables to calculate the area of vegetated ground in square kilometers and divided this number by the area of the Mojave Desert Preserve to get the percentage of vegetated ground over the course of both study years (2015 and 2017). This data was then aggregated into one table for each year and graphed to show results.

To compare NDVI and EVI data derived from MODIS versus that derived from Landsat and calculated from within ArcGIS Pro, the region of the Sutter Buttes was used. This location was picked as an arbitrary location that had enough rainfall to show a range of NDVI and EVI values (as opposed to the original study site of the Mojave Desert Preserve). In addition, MODIS data from May 9<sup>th</sup> 2017 (this data was already on hand from previous analyses) and Landsat 8 data from May 10<sup>th</sup> 2017 was obtained from the USGS's Earth Explorer portal (<https://earthexplorer.usgs.gov/>). These satellites cover the Earth's surface in different intervals, so obtaining data for the Sutter Buttes from both remote sensors on the same date was not possible. MODIS NDVI and EVI layers were extracted from their hdf file and added to the ArcGIS Pro project via the "Multidimensional Raster Layer" option from the "Add Data" drop down in the map tab. Landsat 8 data comes in a tar.gz package containing 11 bands in separate GEOTIFF files, a metadata file and a quality assurance file. This data was extracted to a new folder, and bands 2 (blue), 3 (green), 4 (red) and 5 (near infra-red) were added to the ArcGIS project via the normal "Add Data" option. A circular polygon shapefile was manually drawn over the area of the Sutter Buttes to be used as a mask for the MODIS and Landsat 8 raster files.

Once all needed data layers were added to the project, each layer was masked with the Sutter Buttes shapefile. This was done via the "Extract by Mask" tool in the Spatial Analyst section of the ArcGIS toolbox. This is all of the processing that was needed to prepare the MODIS derived data for comparison. In order to calculate NDVI and EVI from Landsat derived data, an additional transformation of the raw bands needed to be performed. Each of the four bands needed to be converted to a 'Top of Atmosphere (TOA) Reflectance' value. This was done by running map algebra on each of the four band rasters with the following equation:  $\rho_{\lambda} = M_p Q_{cal} + A_p / \cos(\theta_{SZ})$  where  $\rho_{\lambda}$  is the TOA reflectance corrected for the angle of the sun,  $M_p$  is the band specific multiplicative scaling factor given in the metadata file,  $Q_{cal}$  is the raw values contained in the un-altered Landsat 8 band rasters,  $A_p$  is the band specific additive scaling factor given in the metadata and  $\theta_{SZ}$  is the angle in degrees of the sun elevation given in the metadata (USGS). To finish preparing the Landsat 8 data for image processing, the four bands were then composited into one raster layer with the "Composite Bands" tool from the Data Management section of the ArcGIS toolbox. Special care was taken that each band layer was entered into the tool in the following order: band 2, band 3, band 4 and band 5. The bands were then renamed in the newly created composite raster to the following: band 1 (blue), band 2 (green), band 3 (red) and band 4 (NIR).

The composite raster from the Landsat 8 bands was used to calculate NDVI and EVI within ArcGIS Pro. Navigating to the Imagery tab with the composite layer selected in the contents pane and selecting the 'Raster Functions' drop down allowed access to the NDVI calculator tool. Within the NDVI tool, selecting the composite raster in the raster drop down,

entering band 3 for visible and band 4 for Infra red and clicking the box for 'Scientific Output' resulted in an ArcGIS Pro calculated NDVI layer utilizing the Landsat 8 data. To calculate EVI, it was necessary to navigate to the 'Math' section of the 'Raster Functions' list and click on the 'Band Arithmetic' tool. Selecting the composite raster in the drop down, choosing 'EVI' for the method and entering the band indexes in the following space separated order: 4 3 1 (NIR, Red and Blue bands) resulted in an ArcGIS Pro calculated EVI layer.

## Analysis and Discussion Part 1

The first challenge to the outcome of this project was what value to set the EVI cutoff point at so that a vegetated surface area could be calculated for the Mojave Desert Preserve. This value would determine the amount of land that would be considered vegetated versus the land that would be considered barren. In addition it would provide data for a simple graphical analysis between the two study years of 2015 and 2017. Considering the amount of images to be processed, the correct value for this EVI cutoff point was crucial to an elegant and impactful conclusion. Initial outputs derived from the conditional statement in the raster calculator had set the EVI cutoff value at .2, in accordance with the lower value in the range associated with healthy vegetation. As one can see in Figure 1, this is a very small surface area. Differences between percent coverage between dates were very small, even insignificant.

The solution was to perform a comparison and visual analysis of actual imagery of the area and the layer representing the 'cells of interest' to verify the accuracy of setting the desired EVI value to greater than or equal to .2. After some research on the World Imagery base-map supplied by ESRI to its ArcGIS products, it was determined that the current base-map was last updated April 29<sup>th</sup> 2020 (<https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9>). MODIS data from April 22<sup>nd</sup>, 2020 (the closest date to the World Imagery base-map's recent update) was obtained and processed. Due to the large scale of the base-map it was possible to make out individual plants in the Preserve while zoomed in, and to visually compare MODIS data to actual land-cover imagery (Figure 2). As can be seen, there is a significant amount of plants outside of the .2 range. The EVI cutoff value was then lowered to be greater than or equal to .1 and the raster calculator tool was re-run. As can be seen in Figure 3, the value of .1 returns a much larger vegetated surface area result.

A comparison of the initial .2 cutoff value and the new .1 cutoff value over the entirety of the preserve was made (Figure 4). The vegetated surface area returned by setting the cutoff value to .1 was much closer to what was expected from an arid region in the middle of its rainy growth season. The decision was made to change the EVI cutoff value to .1. Additional support for this choice comes from differences in desert biome plant morphology. Desert plants include many adaptations to their unique arid biome, including having smaller leaves, only performing respiration at night and remaining dormant until the rainy season (Ward, 2016). It can be then be assumed that metrics for 'healthy vegetation' in a desert are much different than those of a forest or jungle, and that over all EVI values are expected to be much smaller for much of the year. In addition it can be assumed that the metrics for an EVI range determining healthy vegetation will contain much smaller values and a smaller range than other biomes. As a result of this determination, a final calculation and aggregation of data could be performed, and data projected in the form of a graph. A comparison of Figures

5 and 6 shows an approximate 20-30% increase in vegetated surface area in the Mojave Desert Preserve after the rainy season begins in February of 2017 (indicated by the steep line in the Figure 6 graph, representing a rapid increase in the amount of detectable vegetation per unit time). It can be concluded that there is a detectable difference in the amount of vegetated surface area of the Mojave Desert Preserve during 'Superbloom' years.

An interesting trend was observed while processing this data. The EVI ranges for each year were maximized earlier than when the maximum vegetated surface area values occurred. For example, during both 2015 and 2017 the yearly maximum for EVI values occurred in the March 9<sup>th</sup> data, while the maximum vegetation coverage values occurred sometime later, in late March or early April. It is theorized that maximum EVI values coincide with moments of highest precipitation in a desert biome, and that the delay in detectable vegetated surface area is caused by annual plants (those species needing to re-grow from seeds) versus perennial vegetation (species already grown and able to take direct advantage of spring rains and grow enough leaf area to rapidly increase the EVI values while not altering the value for vegetated surface area). However an additional comparison to precipitation data over the study years would be needed to confirm this hypothesis.

## Part 2

Figure 7 shows the MODIS derived NDVI, while Figure 8 shows Landsat derived NDVI. Figure 9 shows MODIS derived EVI while Figure 10 shows Landsat derived EVI. The most obvious and striking difference between the MODIS and Landsat data is the difference in spatial resolution. Despite this, with a comparison of Figures 7 and 8, it can be seen that MODIS and Landsat NDVI ranges are very similar, and the geographic locations of the higher and lower NDVI values are approximately the same in the two images. It can be observed from Figure 8, that the Landsat data has a slightly larger range of NDVI values. This is most likely because its higher spatial resolution picks up more precise data over the study area. Thus it seems that NDVI data obtained from MODIS and Landsat 8 are comparable.

A comparison of Figures 9 and 10 show similar trends. Examining figure 10 shows the Landsat derived EVI layer to have a larger range of values than the MODIS layer. However, this range seems to be significantly larger, more on par with values one would expect to see from NDVI data. It is unknown whether or not an increase in spatial resolution is enough of an explanation for this phenomenon. Examining MODIS derived NDVI and EVI (Figure 7 and Figure 9) it is observed that EVI maximum values are smaller than those calculated using NDVI. This is expected because EVI is designed to be less prone to being washed out by higher concentrations of vegetation. It can detect changes in vegetation in densely vegetated areas where as NDVI just becomes over saturated. A comparison of Figure 8 and Figure 10 shows this is not the case with Landsat NDVI and EVI data for some reason. This calls the validity of the Landsat EVI output slightly into question, as these layers have the same spatial resolution and the same pre-processing and source raster. Further examination of this layer will need to be done, in the mean time indications show that MODIS and Landsat derived EVI data may not be comparable.

## Conclusions

An increase in vegetation in arid areas is detectable by remote sensing. Landsat data offers options for finer spatial resolution than MODIS, but additional processing requirements means it may be more efficient to use MODIS data, especially if one is covering a larger geographic region and require a smaller resolution. A comparison of the NDVI and EVI outputs for layers obtained from MODIS and Landsat show that the NDVI values are close enough in range to be comparable, while EVI values leave some doubts.

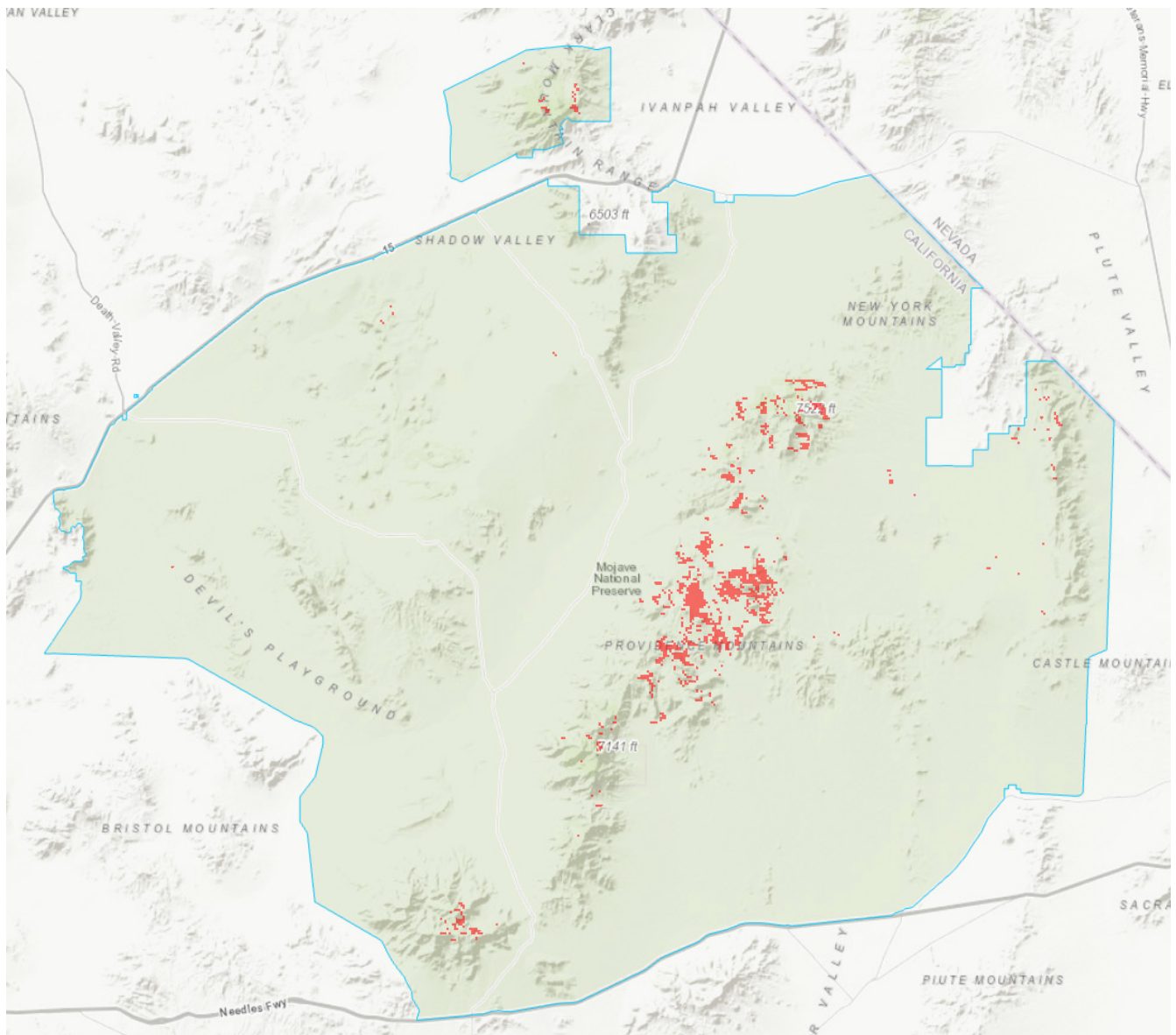


Figure 1. This is processed MODIS data from April 22<sup>nd</sup>, 2020. The red cells represent the output from the initial conditional statement setting cells of interest at EVI values larger than or equal to .2. Notice how low the area covered by vegetation is with this setting. Consider also, that April is normally a wetter month in the Mojave Desert thus more vegetation coverage is expected. The base layer is the Topographic map provided by ESRI to ArcGIS Pro.



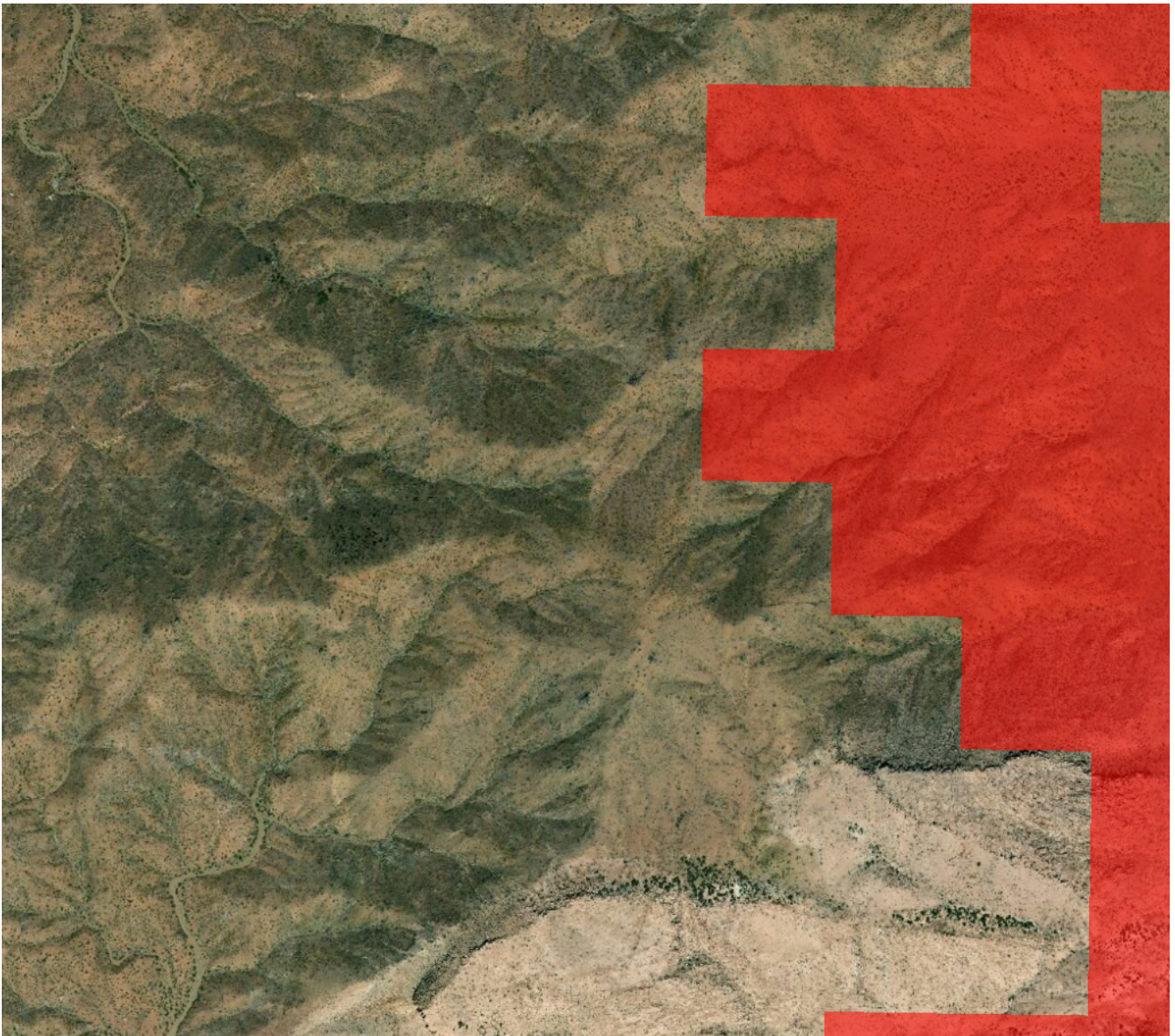


Figure 2. This image shows the edge of an area containing cells with an EVI value of .2 or greater from April 22, 2020 data (the slightly transparent red shaded areas). One can see the vegetation present in areas covered by the cells of interest. The large scale World Imagery base-map shows that there is plenty of vegetation present outside of the .2 EVI value. Thus indicating that the EVI cut off value should be adjusted.



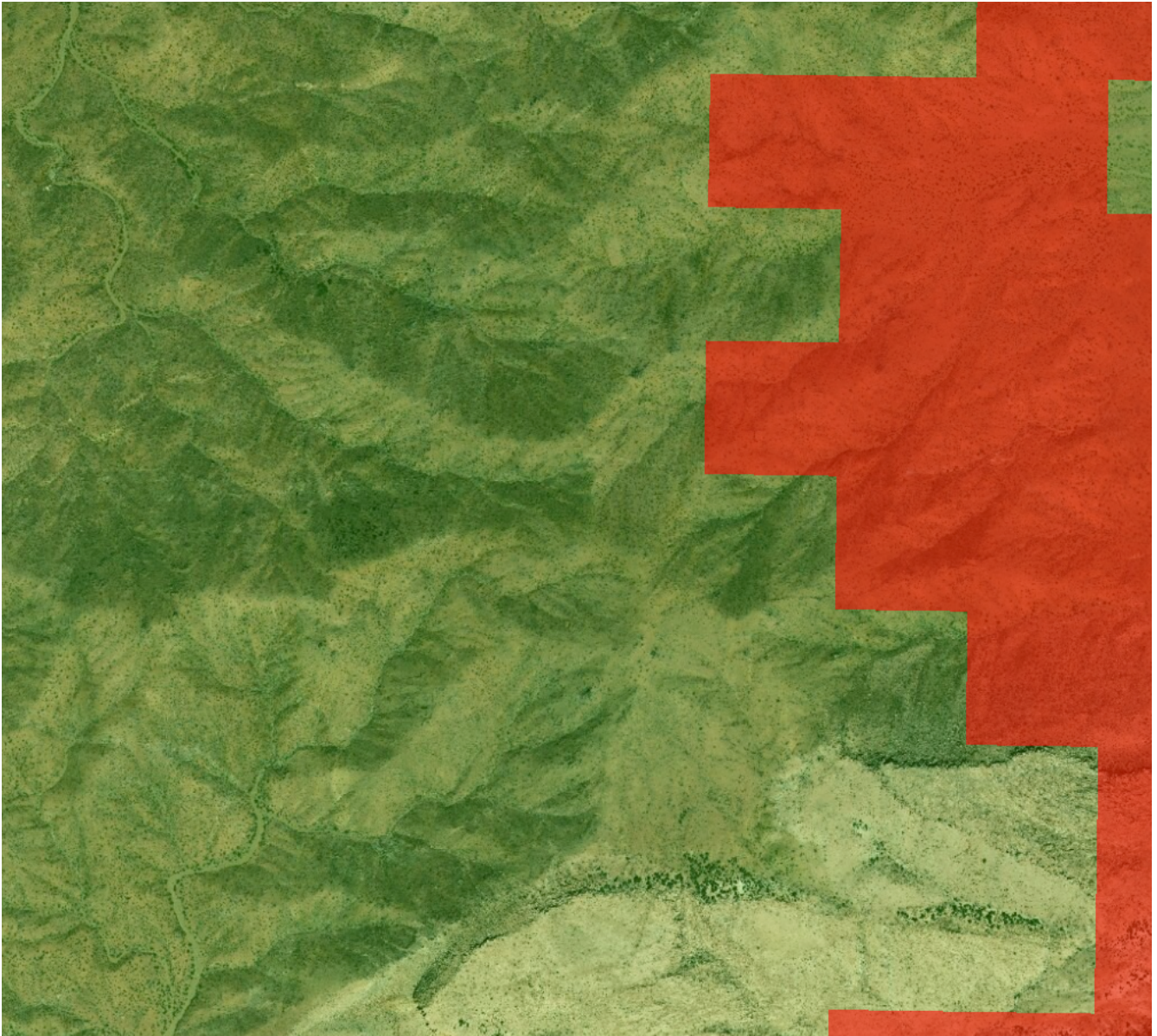


Figure 3. This is the same area captured by Figure 2. However the conditional statement has been re-run to return all cells (green in the image) with an EVI value greater than or equal to .1. It can be clearly seen that all vegetated areas missed by the .2 layer (red cells) are now included in the .1 value layer.

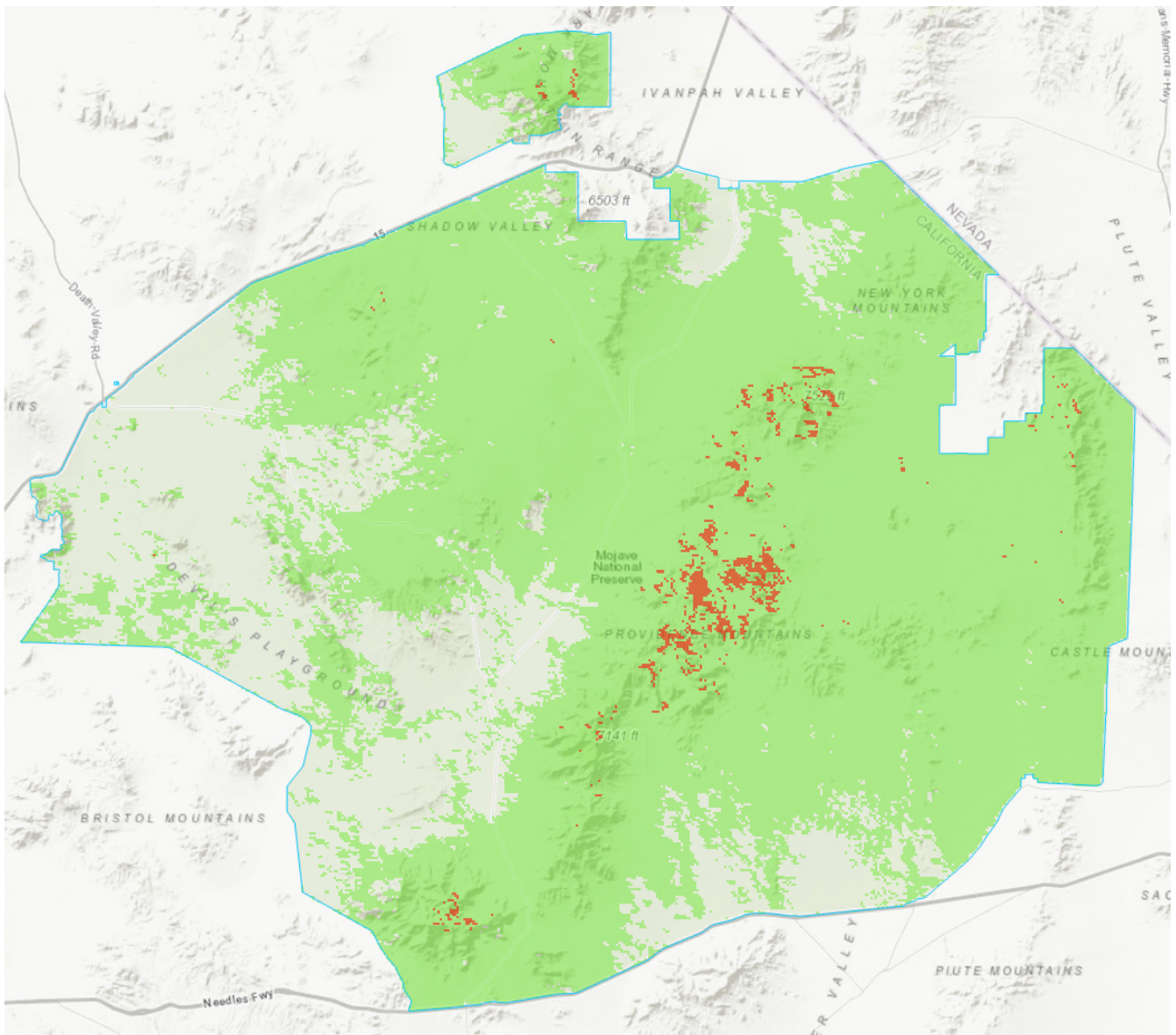


Figure 4. This image compares the much larger vegetated surface area returned by setting the EVI cutoff value to greater than or equal to .1 (green areas of map) with the original surface area shown in Figure 1 (red areas of map). The base layer is the Topographic map provided by ESRI to ArcGIS Pro.

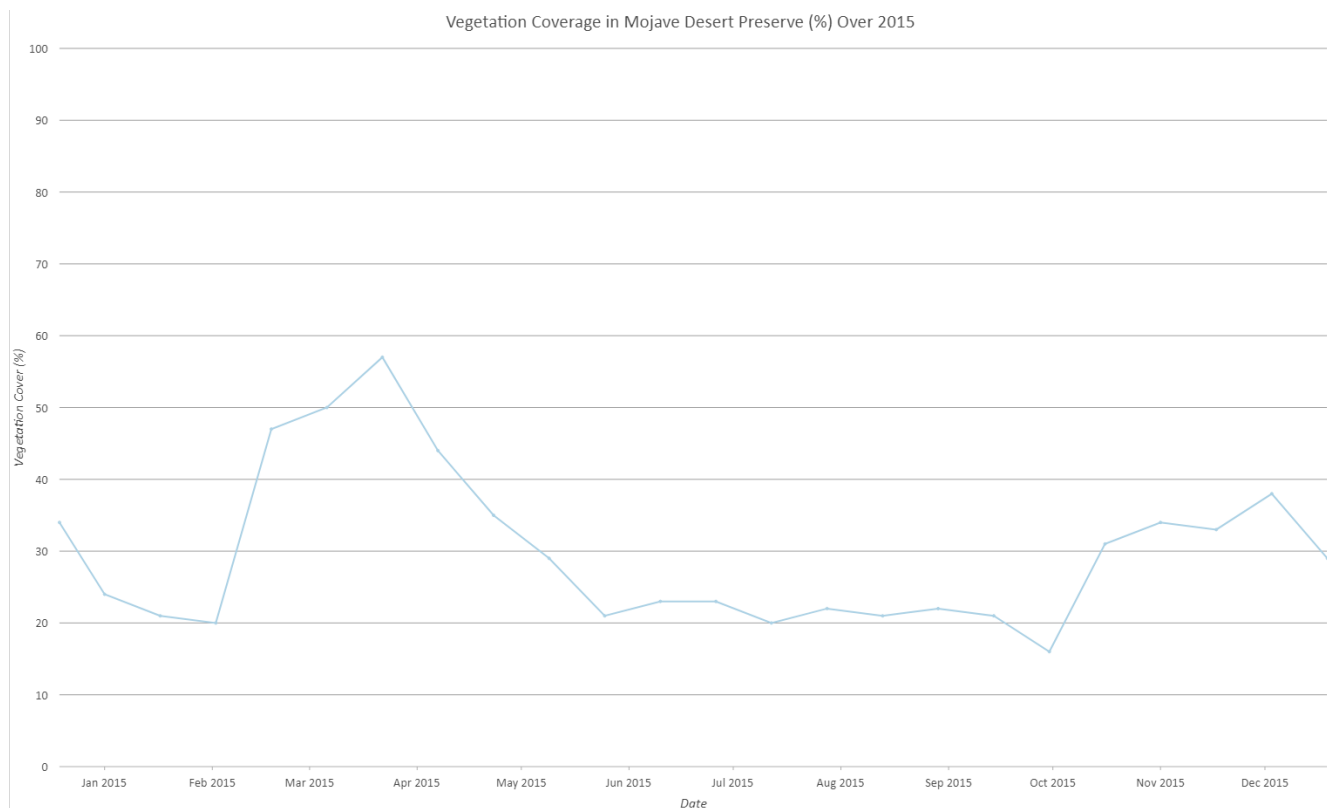


Figure 5. This image represents a graphical summary of the change in vegetated surface area of the Mojave Desert Preserve over 2015.

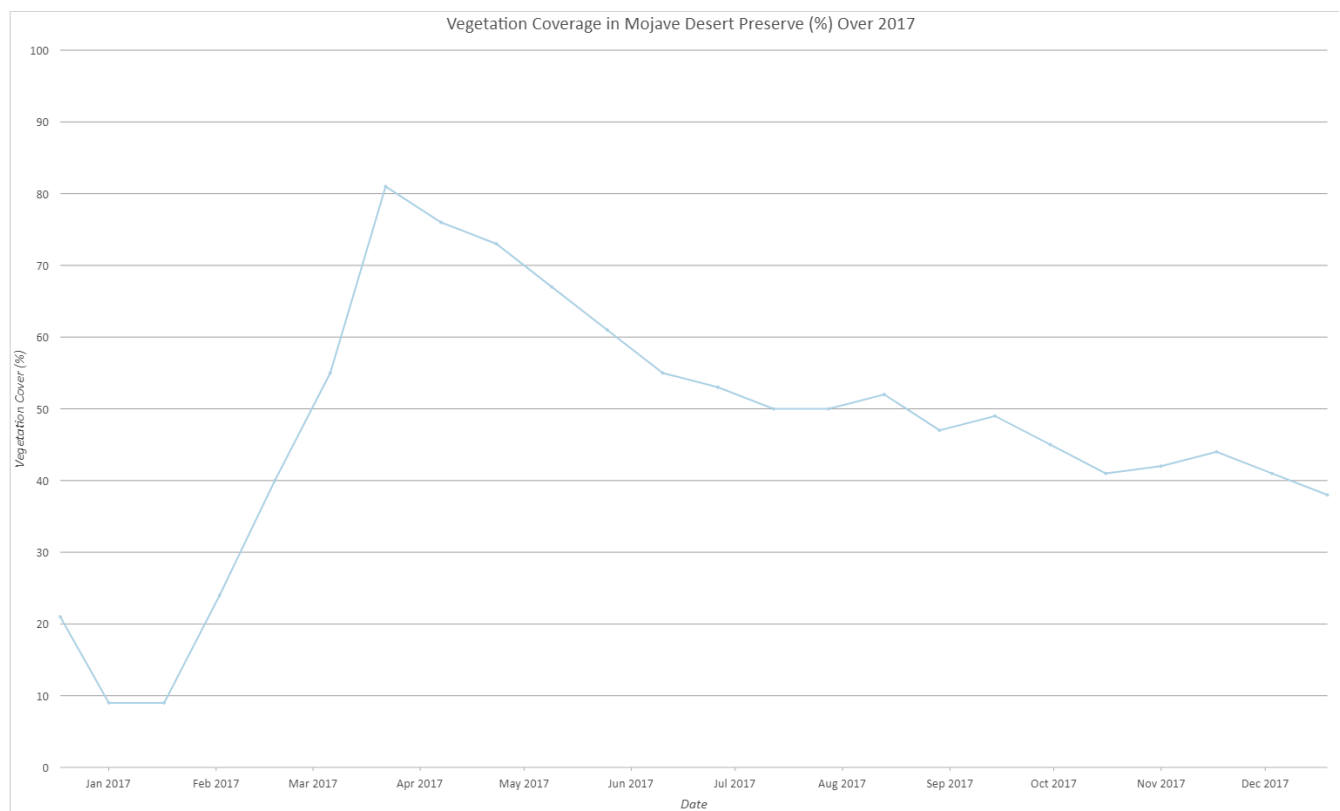


Figure 6. This image represents a graphical summary of the change in vegetated surface area of the Mojave Desert Preserve over 2017. When compared to Figure 5, it can be observed that there is an approximate increase in vegetated surface area of 20-30% over the entire year.



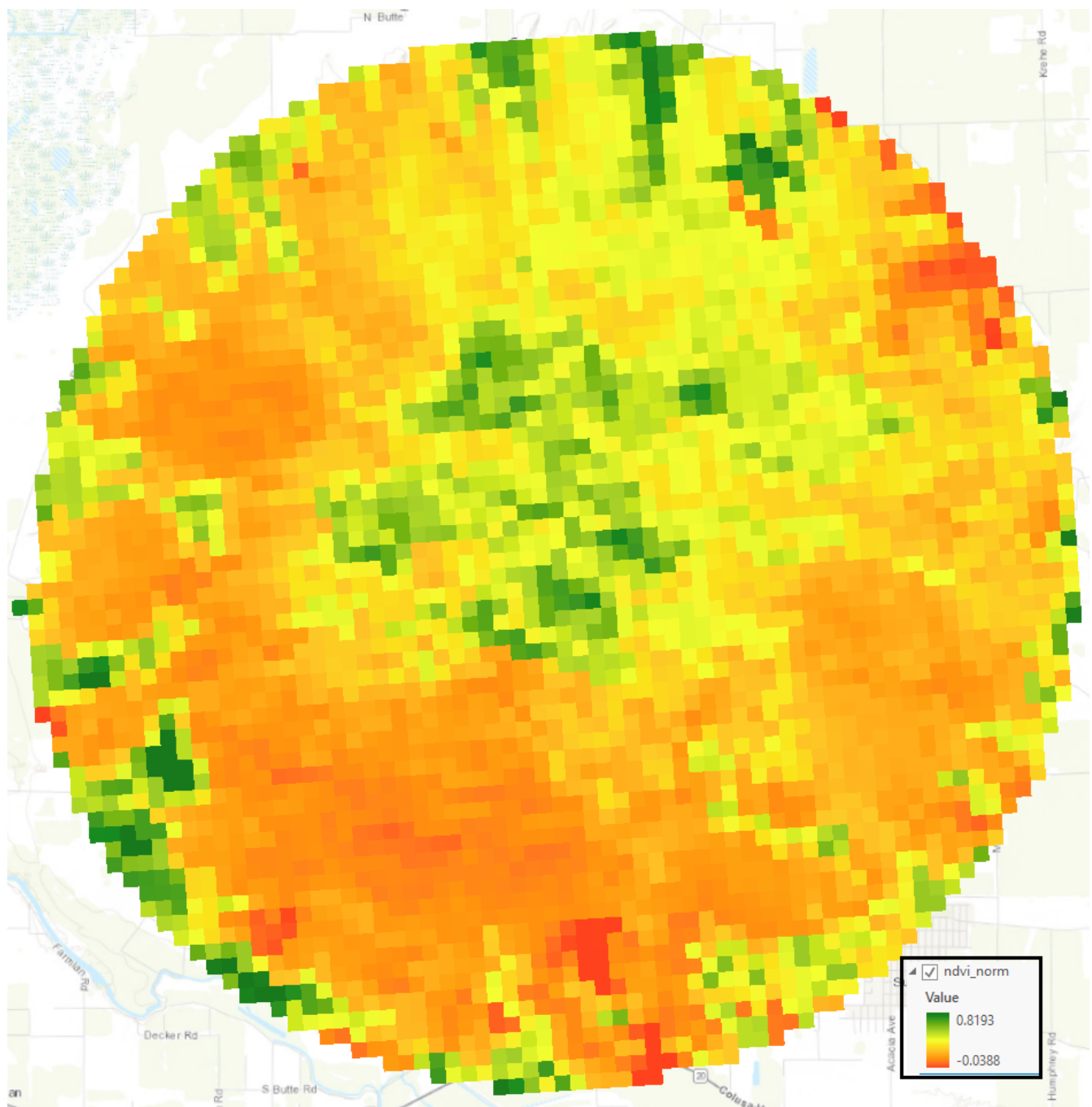


Figure 7. This image represents the MODIS derived NDVI for the Sutter Buttes area. Notice the NDVI values range from -.0388 to .8193. The 250m resolution makes it difficult to make out any geographic features in this image, and only a very general idea of the location of healthy vegetation is observable at this resolution. Data is displayed in the “Percent Clip” stretch type. The base layer is the Topographic map provided by ESRI to ArcGIS Pro.



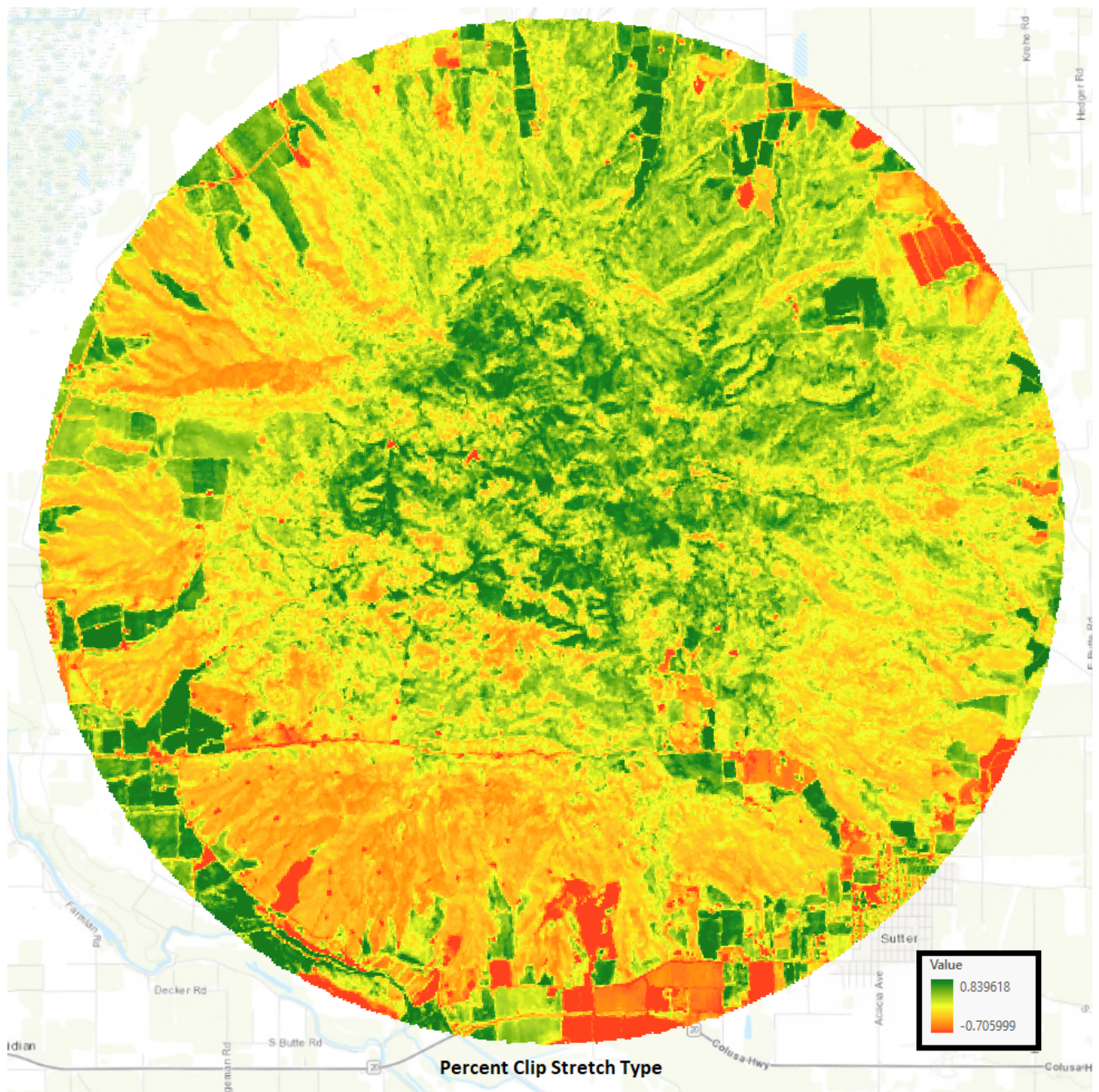


Figure 8. This image represents the NDVI calculated from Landsat data after converting it to TOA reflectance values. You can make out areas of higher vegetation health probably representing farm fields, around the boarder of the image due to the finer resolution of the Landsat data. Note the NDVI values range from  $-0.705999$  to  $0.839618$ , very similar to the range of values given by the MODIS NDVI near this date (May 10<sup>th</sup> 2017). The base layer is the Topographic map provided by ESRI to ArcGIS Pro.

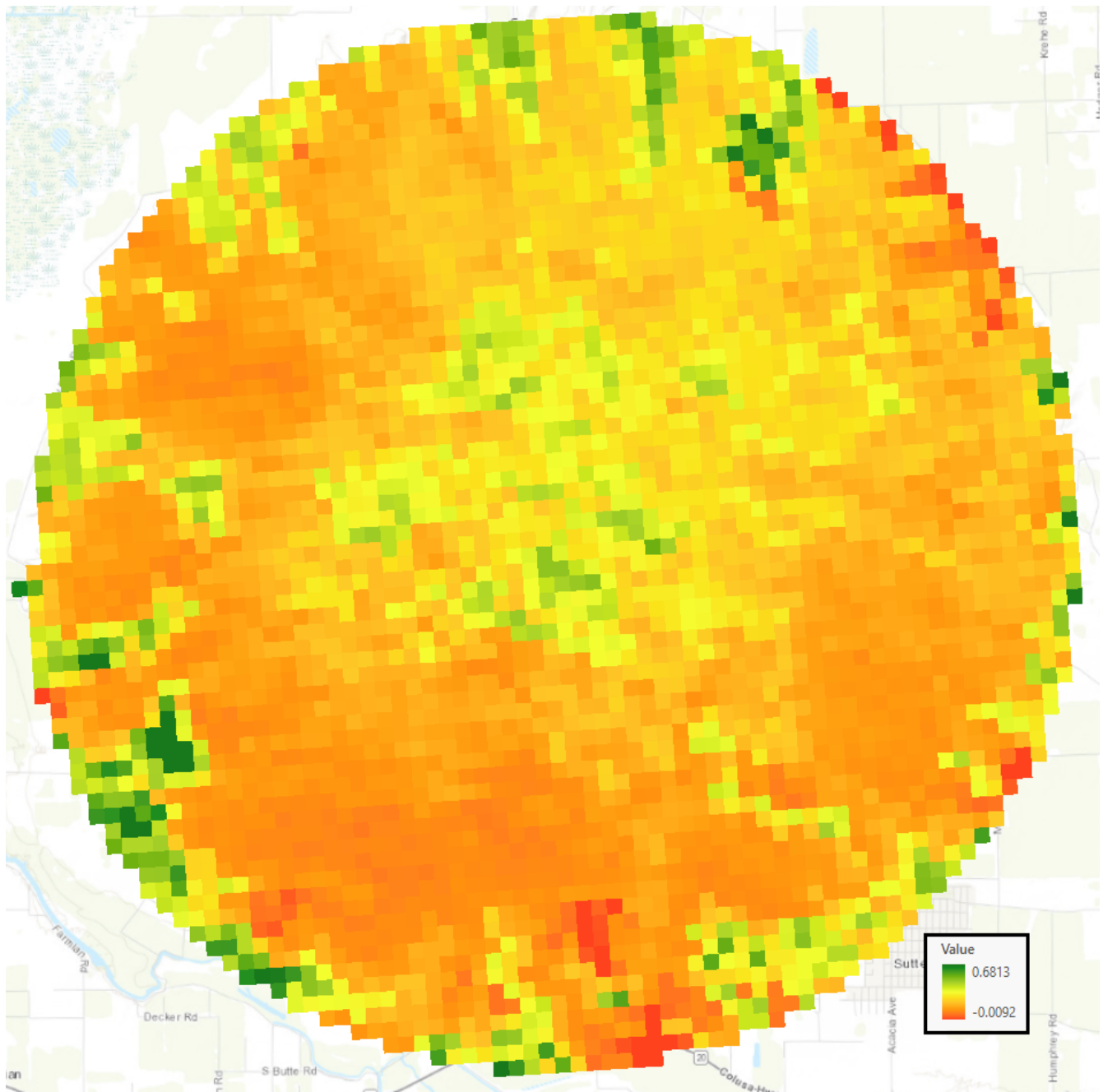


Figure 9. This image represents MODIS derived EVI data for the Sutter Buttes area. Notice the EVI values range from  $-0.0092$  to  $0.6813$ , with a smaller maximum value than the MODIS NDVI data. This image is displayed in the Percent Clip stretch type. The base layer is the Topographic map provided by ESRI to ArcGIS Pro.



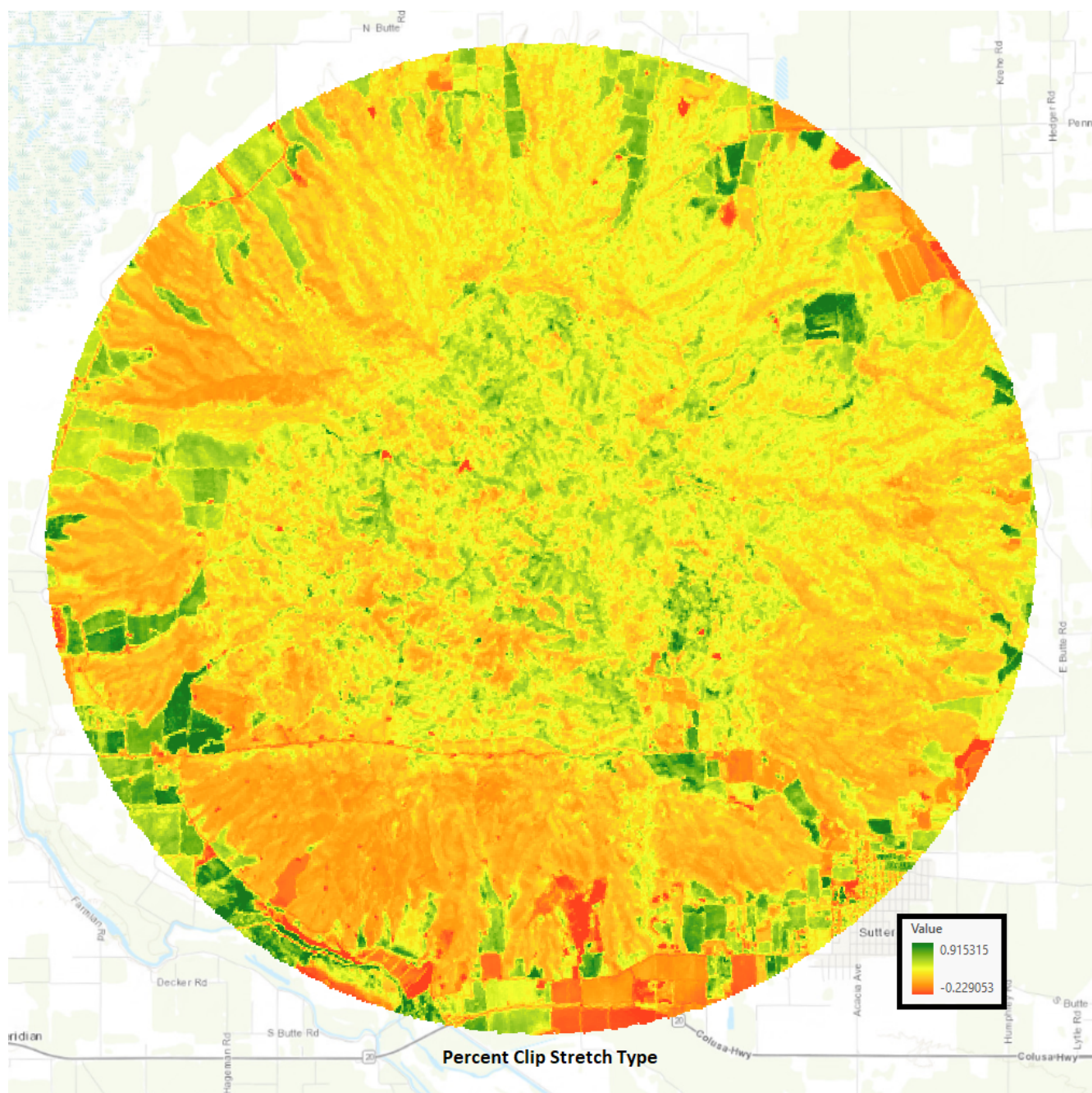


Figure 10. This image represents the Landsat derived EVI data. Notice the EVI value ranges from -.229053 to .915315. This is surprising, normally NDVI data contains larger maximum values for the same geographic area. The base layer is the Topographic map provided by ESRI to ArcGIS Pro.

## Works Cited

- Didan, Kamel; Armando Barreto Munoz, Ramon Solano, Alfredo Huete, *MODIS Vegetation Index User's Guide (MOD13 Series)* The University of Arizona, 2015  
[https://vip.arizona.edu/documents/MODIS/MODIS\\_VI\\_UsersGuide\\_June\\_2015\\_C6.pdf](https://vip.arizona.edu/documents/MODIS/MODIS_VI_UsersGuide_June_2015_C6.pdf)
- Huete, A., K. Didan, T. Miura, E.P. Rodriguez, X. Gao, and L.G. Ferreira. 2002. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sens. Environ.* 83:195–213
- Imster, Eleanor "2017 California desert superbloom" EarthSky, April 5, 2017  
<https://earthsky.org/earth/california-desert-superbloom-2017>
- L3Harris Geospatial "Vegetation Analysis: Using Vegetation Indices in ENVI", December 18, 2013  
<https://www.harrisgeospatial.com/Learn/Whitepapers/Whitepaper-Detail/ArtMID/17811/ArticleID/16162/Vegetation-Analysis-Using-Vegetation-Indices-in-ENVI>
- NASA, About  
<https://modis.gsfc.nasa.gov/about/>
- Ober, Holly "Superbloom? If you say so." March 19, 2019 UC Riverside  
<https://news.ucr.edu/articles/2019/03/15/superbloom-if-you-say-so>
- Phillips, Linda B.; Hansen, Andrew J.; Flather, Curtis H. 2008. Evaluating the species energy relationship with the newest measures of ecosystem energy: NDVI versus MODIS primary production. *Remote Sensing of Environment.* 112: 4381-4392.
- Rouse, J.W., R.H. Haas, J.A. Schell, and D.W. Deering, 1973, "Monitoring vegetation systems in the Great Plains with ERTS,"Third ERTS Symposium, NASA SP-351 I:309–317.
- Steven Edward Sesnie, Brett Gary Dickson, Steven Sheldon Rosenstock & Jill Marie Rundall (2011): A comparison of Landsat TM and MODIS vegetation indices for estimating forage phenology in desert bighorn sheep (*Ovis canadensis nelsoni*) habitat in the Sonoran Desert, USA, *International Journal of Remote Sensing*, DOI:10.1080/01431161.2011.592865
- USGS, Using the USGS Landsat Level-1 Data Product  
<https://www.usgs.gov/land-resources/nli/landsat/using-usgs-landsat-level-1-data-product>

USGS, Landsat Surface Reflectance-Derived Spectral Indices, Landsat Enhanced Vegetation Index, 2019

[https://www.usgs.gov/land-resources/nli/landsat/landsat-enhanced-vegetation-index?qt-science\\_support\\_page\\_related\\_con=0#qt-science\\_support\\_page\\_related\\_con](https://www.usgs.gov/land-resources/nli/landsat/landsat-enhanced-vegetation-index?qt-science_support_page_related_con=0#qt-science_support_page_related_con)

Ward, D. Morphological and Physiological Adaptations of Desert Plants to the Abiotic Environment. 2016 In The Biology of Deserts. Oxford University Press.