Using Multispectral Imagery to Explore the Effects of the 2020 El Dorado Fire on the Bearpaw Reserve

The 2020 El Dorado Fire was famously started by a pyrotechnic device at a gender reveal party in Yucaipa and ended up burning nearly 23,000 acres in the San Bernardino Mountains and took over a month to fully extinguish. One area at risk in the El Dorado Fire was The Wildlands Conservancy's **Bearpaw Reserve**. The reserve is about 600 acres of steep, spectacular mountains dense vegetation and home to many animals including black bears, southern spotted owls, mountain lions, and even flying squirrels. The Reserve is primarily used for environmental education programs – including several research projects by University of Redlands faculty and students.

This tutorial will use multispectral imagery analysis techniques to explore the effects of the fire as well as the recovery of the vegetation, specifically at the Bearpaw Reserve. You will learn how to download multispectral satellite imagery, use individual spectral bands for analysis, visualize imagery as image **composites** with a variety of band combinations, and explore 2 different spectral indices – the Normalized Burn Ratio (NBR) & Normalized Difference Vegetation Index (NDVI).

Project Setup

1. Create a new ArcGIS Pro project named **BearpawFire.** This will create a new folder with a ArcGIS Pro project file (.aprx), a geodatabase, and a toolbox for this project.

Find and Download Sentinel-2 Multispectral Imagery

The Sentinel-2 satellite mission from the European Space Agency's Copernicus Programme has been providing scientists with free high-quality multispectral imagery since 2015. These images are all available for public download from a number of websites. In this activity, we'll use the USGS EarthExplorer tool to browse and download the photos for our project. To download the images, you'll need to create a free account with the USGS Earth Resources Observation and Science (EROS) Center, which will allow you to download as much data as you want. For this exercise, we will be looking for imagery before, during, and after the fire.

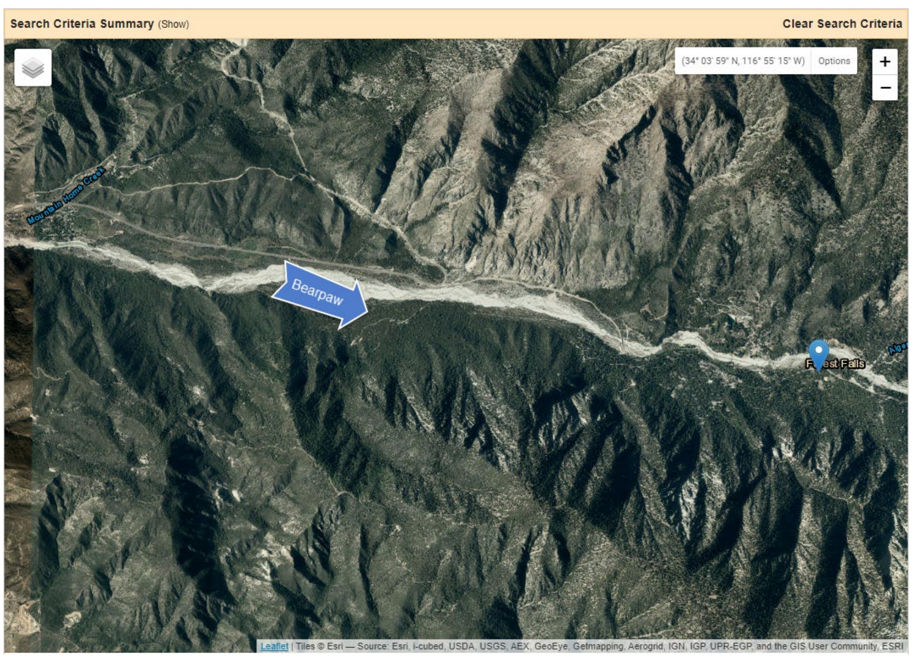
Create an EROS account or use ours

To download Landsat data, you need a USGS EROS account. The account is free but does require you to give demographic survey data and contact information.

Setting up your own EROS account

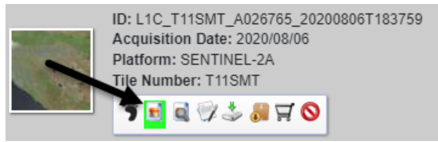
1. Go to the EROS Registration System at https://ers.cr.usgs.gov/register
2. Follow the onscreen instructions to proceed through the registration process.
3. Once you complete your registration, a message is sent to your email address to confirm your registration.
4. Click the link in the email to activate your account.

2. Go to USGS EarthExplorer at https://earthexplorer.usgs.gov/
   You'll see a search panel on the left of the screen and map to the right. The search panel helps you narrow down the data you want and preview it before downloading.
3. Use the Feature Name box to search for **Forest Falls**. The result appears below and you can click on the name to drop a pin on it.
   Forest Falls is a small city close to the Bearpaw Reserve.
4. Zoom in close so that your extent is similar to that of the screenshot below with Bearpaw roughly in the middle of the map. **This does not have to be perfect; we're just trying to narrow down our results.**



5. Click the **Use Map** button to set the search area to the current map extent.
6. The fire started on September 5th and wasn't fully extinguished until November 16th so we'll want to set a date range that covers that date range - as well as roughly a year after so we can analyze changes. Use the Date Range section to search from **August 1, 2020 – September 30, 2021**.
7. Change to the **Data Sets** tab in the search panel.
8. Browse to **Sentinel > Sentinel-2** and check the box to include this dataset in your search results. Click OK to the popup message.
9. Click **Results** to perform the data search.

10. The results are displayed in the panel to the left from the most recent to oldest. Click the **Last >>** button above the list to go to the last page of results and then scroll down to the last image (the oldest in the date range).
11. You should see a photo taken on **August 8, 2020** taken by **Sentinel-2A** for tile **T11SMT**. The tiling system is used so you can get a photo of the exact same location over time. Click the  button to show a low-res preview on the map.

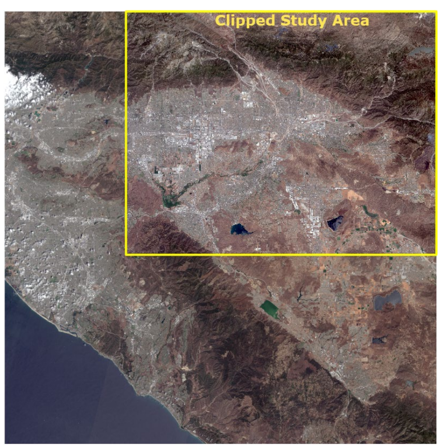


Notice that the image covers our study area nicely with no cloud cover.

12. Scroll up on the list of images to find the next photo for this tile (**T11SMT)** and see that it's a photo from Sept 5th, the day the fire started. Click the  button to preview it on the map and notice the large cloud and smoke hovering over our study area. This means that our best "before" picture is going to be the one from August 6th.
13. Click the  next to the August 6th image to download the photo.
14. Download the **L1C Tile in JPEG2000 format** image to the C:\Sentinel folder you made at the beginning of the exercise. **This is a large download and can take several minutes to download**.
15. Find and download the following images for tile **T11SMT** to C:\Sentinel**.** *You can download the files concurrently; you do not have to wait for the files to download before starting the next one.*
    - September 10, 2020 (during the fire)
    - September 30, 2020 (fire *mostly* extinguished)
    - September 5, 2021 (1 year after the fire started)

Extract and Prepare the Images

The steps in the section below outline how to process the downloaded files so that they can be easily used as multiband TIF files in ArcGIS Pro. The process is fairly straightforward but can take an hour or more to complete - so in the interest of time, I've gone ahead and preprocessed them and clipped them to a smaller study area for you and made them available for download. The clipped area of the original photos is show in the screenshot below.



16. Download the preprocessed images from the following link and save them to your ArcGIS Pro project folder - https://urspatial.redlands.edu/files/bearpawfire/bearpawfiredata.zip
17. Extract the zip file by **right-clicking > Extract All…** and then click **Extract**.
18. Refresh the folder connection in ArcGIS Pro to see the 3 images listed.

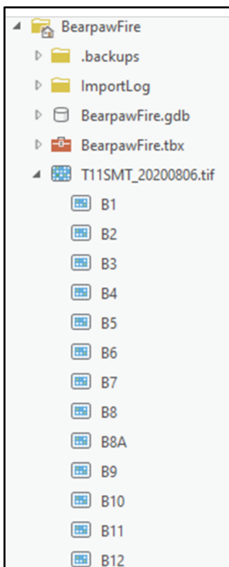
I’ve left the following steps in the tutorial for reference for your own projects – or if you’re feeling ambitious with this tutorial and have more time to spend on it – **but you do not need to complete the steps below if you download the preprocessed files above.**

1. There are some complications with extracting Sentinel data because they use very long file and folder names – so long, in fact, that they can max out a Windows limitation on the total length of file paths. The easiest way around this issue is to create a folder directly on the C drive to reduce the total path length. Open Windows File Explorer and make a new folder named **Sentinel** directly under the C drive (path will be C:\Sentinel).
2. Open C:\Sentinel and extract each zip file by **right-clicking > Extract All…** and then click **Extract**. Do this for each of the 3 zip files. These folders can now be used in ArcGIS Pro but we’ll process them into a multiband TIF file that will be easier to work with.
3. In ArcGIS Pro, make a new **folder connection** to the C:\Sentinel folder.
*Reminder: Catalog pane > Right-click Folders > **Add Folder Connection**. Browse to This PC > Local Disk (C:) > Sentinel and click OK.*
4. Expand the Sentinel folder in the Catalog pane and then expand the first Sentinel folder and its subfolder until you find the dataset named **MTD_MSIL1C.xml** and add it to the map. It can take several minutes to process the file for the first time and add it.
5. Right-click the layer in the Contents pane and select **Data > Export Raster.**
6. Set the output raster dataset parameter to export to your Pro project folder with the name **T11SMT_<YYYYMMDD>.tif** (eg T11SMT_20210806.tif).
7. Confirm that the Cell Size X and Y parameters to **10**.
8. Repeat these steps for the other photos/dates.

Exploring Individual Spectral “Bands”

A spectral band is range of wavelengths in the EM spectrum that an instrument is designed to detect. These bands are captured as rasters that we can work with in GIS where each pixel is the intensity of the wavelengths captured. We can visualize these bands either as individual raster layers or as a **composite** of 3 layers at the same time where each band is assigned a red, blue, or green color. We’ll start by looking at a few single bands.

19. In the Catalog pane, find our “before” raster from 8/6/2020 and expand it to see the available bands for this dataset. The screenshot below describes what each band is designed to detect and its spatial resolution.



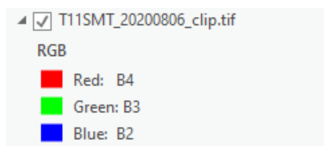
Sentinel-2 Bands

Band	Description	Resolution	Central Wavelength
B1	Ultra blue (Coastal Aerosol)	60 m	443 nm
B2	Blue	10 m	490 nm
B3	Green	10 m	560 nm
B4	Red	10 m	665 nm
B5	Vegetation Red Edge	20 m	705 nm
B6	Vegetation Red Edge	20 m	740 nm
B7	Vegetation Red Edge	20 m	783 nm
B8	Near Infrared (NIR)	10 m	842 nm
B8a	Vegetation Red Edge	20 m	865 nm
B9	Water vapour	60 m	940 nm
B10	Short Wave Infrared (SWIR) - Cirrus	60 m	1375 nm
B11	Short Wave Infrared (SWIR)	20 m	1610 nm
B12	Short Wave Infrared (SWIR)	20 m	2190 nm

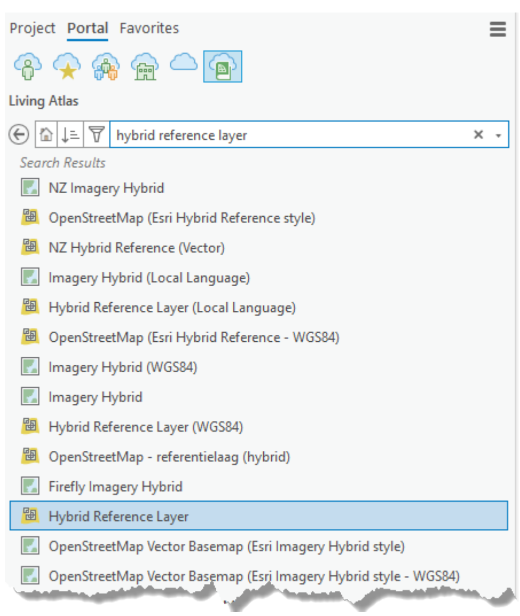
20. Using the chart above, add the **Red** band to the map. The layer displays with a default grayscale color ramp so that higher reflectance values are displayed as white and lower reflectance (and therefore higher absorption) are darker. The red band is often used to differentiate built vs natural environments.
21. Zoom around the map and notice that there is generally a stark contrast between natural and built areas.
22. Now add the **Near Infrared** (NIR) band. NIR is invisible to us but is a powerful way to detect healthy vegetation with multispectral imagery because vegetation *reflects* a massive amount of NIR radiation. It can also be used to detect water because water *absorbs* all NIR radiation.
23. Zoom around the map and notice that golf courses, farmland, and other areas of managed vegetation are clearly visible. Water also appears very dark, which offers a great contrast to identify wetlands.

View Rasters as a True Color Composite

24. Turn off the individual band rasters and this time add the entire "before" dataset **T11SMT_20200806_clip.tif** to the map. ArcGIS recognizes that this is a Sentinel-2 image and displays the bands as a **True Color Composite**. This means that Band 4 is displayed as shades of red, Band 3 as shades of green, and Band 2 as shades of blue. This reassembles the individual bands into something similar to how our eyes perceive color so should more or less just look like a regular photo taken from the satellite. Take a look at the layer in the Contents pane to confirm this. Compare to the list of bands above.



25. It may be helpful to add a "reference layer" from ArcGIS Online to help get your bearings. In the Catalog Pane, switch to the **Portal** tab and then the **Living Atlas** tab. Search for "**hybrid reference layer"** and find the layer with that exact name in the list (there are several others that come up first so make sure you get the right one). See screenshot below.



26. Now switch to the **ArcGIS Online** tab in the Catalog pane and search for "**twc bearpaw reserve boundary**". Add the resulting layer to the map.

27. Explore the image a bit to understand the spatial resolution of the image. The visible bands all have a 10-meter spatial resolution. El Dorado Park, where the gender reveal that started the fire happened, is marked on the map below.

28. Notice that there is already smoke in the area near the eastern edge of the photo. This is another smaller fire burning near Oak Glen a month before the El Dorado fire began during a very active fire season in 2020.

29. Rename the layer **Aug 6, 2020 (True Color)** in the Contents pane
30. Add the other photos and name them using the table below

T11SMT_20200910_clip.tif (during)	Sept 10, 2020 (True Color)
T11SMT_20200930_clip.tif (after)	Sept 30, 2020 (True Color)
T11SMT_20210905_clip.tif (1 yr later)	Sept 5, 2021 (True Color)

31. Flip through the layers so you get an idea of what each one contains. Notice that the Sept 30th photo has a pretty noticeable burn scar around Oak Glen and all the way up past Angelus Oaks. The scar actually continues some off of this satellite photo.
32. Use the measure tool to see that it is roughly 9 miles from El Dorado Park to the edge of the visible scar.

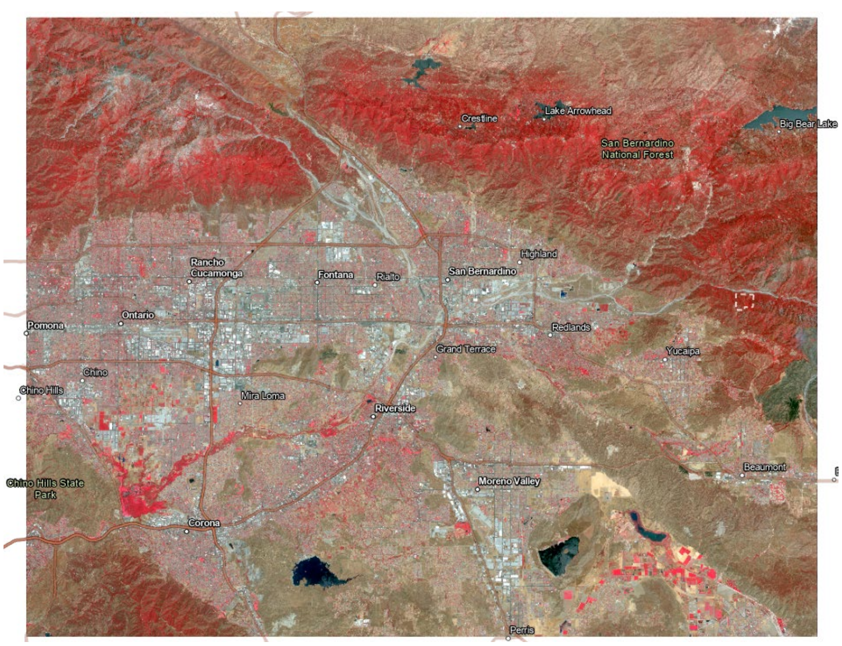
Explore Other Band Combinations

Explore the “Before” Image - August 6, 2020

33. Turn on the Aug 6th image and turn off all the other raster layers.
34. Make a copy of the **Aug 6, 2020** layer and rename it **Aug 6, 2020 (NIR Composite)**.
35. Turn off all the other raster layers except the new NIR composite layer.
36. Using the list of Sentinel-2 bands below, change the Symbology of the layer so that Red uses the **NIR band**, Green uses the **Red** band, and Blue uses the **Green** band. The image on the map changes automatically.

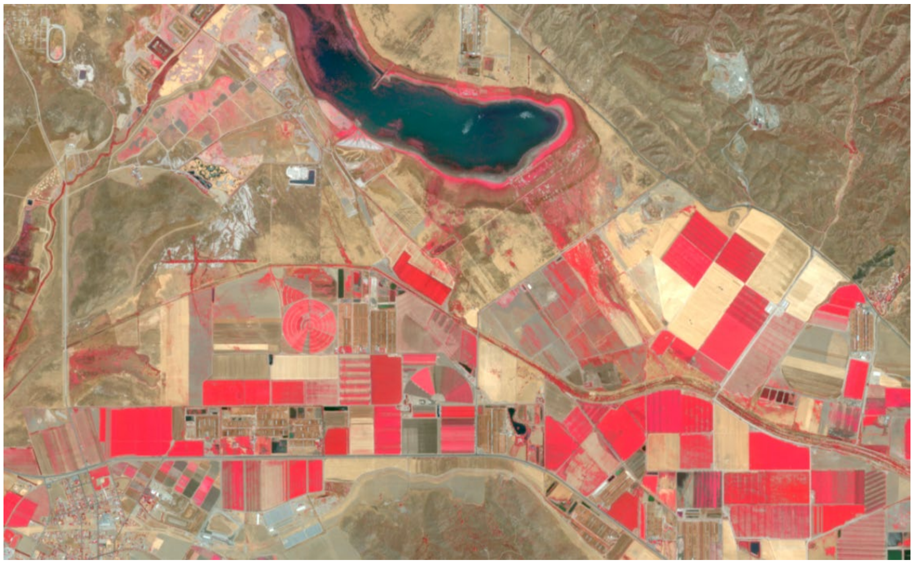
Band	Description	Resolution	Central Wavelength
B1	Ultra blue (Coastal and Aerosol)	60 m	443 nm
B2	Blue	10 m	490 nm
B3	Green	10 m	560 nm
B4	Red	10 m	665 nm
B5	Vegetation Red Edge	20 m	705 nm
B6	Vegetation Red Edge	20 m	740 nm
B7	Vegetation Red Edge	20 m	783 nm
B8	Near Infrared (NIR)	10 m	842 nm
B8a	Vegetation Red Edge	20 m	865 nm
B9	Water Vapor	60 m	940 nm
B10	Short Wave Infrared (SWIR) - Cirrus	60 m	1375 nm
B11	Short Wave Infrared (SWIR)	20 m	1610 nm
B12	Short Wave Infrared (SWIR)	20 m	2190 nm

This band combination is also called the **Near-Infrared (NIR) Composite** or a **Color Infrared Composite**. It uses near-infrared (8), red (4), and green (3). Because chlorophyll reflects near-infrared light, this band composition is useful for analyzing vegetation. In general, areas in red have better vegetation health. Dark areas are water and urban areas are white.

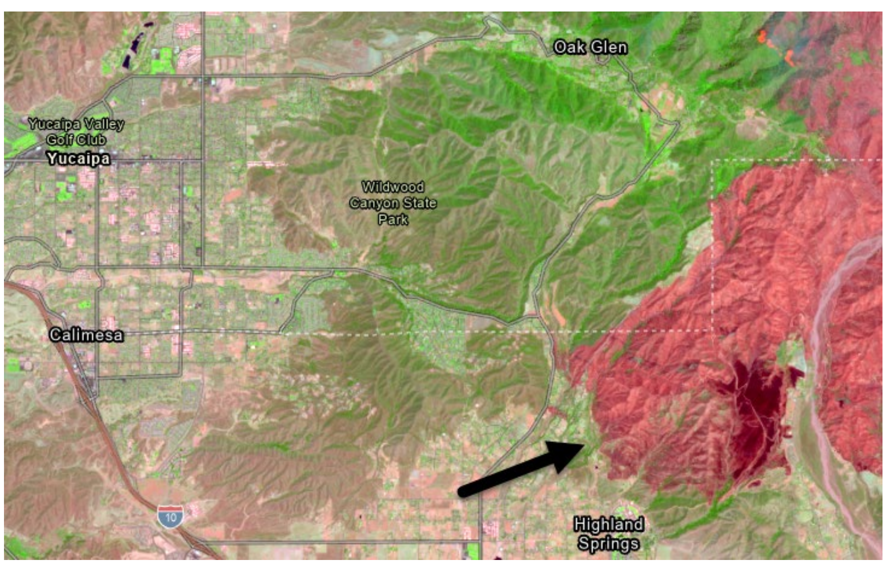


37. Zoom in to the Bearpaw study area and notice the deep reds of the vegetation in the area.
38. Zoom to the southeast corner of the image to find the agricultural fields near Lake Perris. Toggle on/off the true color vs NIR composite to understand the difference. The NIR composite clearly shows the

healthier fields (and even parts of fields) as darker reds which isn't obvious using the visible spectrum that our eyes see. You can imagine the value of this "hidden" information for farmers!

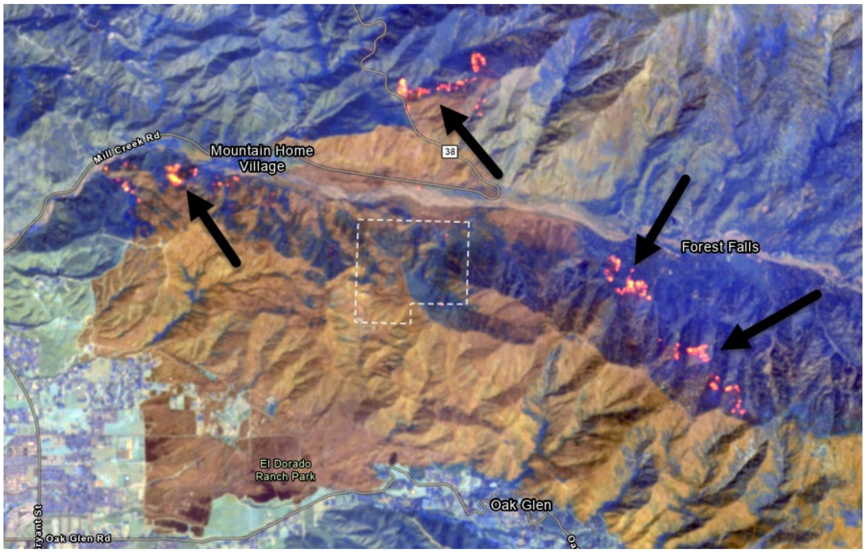


39. Make another copy of the August 6th layer and name it **Aug 6 2020 (SWIR Composite).**
40. Change the symbology to **12 8 4**. This is shorthand for Red: B12, Green: B8, & Blue: B4.
    This band combination is known as **Short-Wave Infrared.** This composite displays vegetation in shades of green. While darker shades of green indicate denser vegetation, sparse vegetation has lighter shades. Urban areas are blue and soils have various shades of brown.
41. Explore the image to see how well vegetation pops out. Golf courses and other managed vegetation are all very obvious with this composite.
42. Burned areas reflect a lot of short-wave infrared radiation so this composite is very helpful in identifying burn scars. Look at the area east of Oak Glen that we identified earlier as still burning. You can clearly see the large burned area south of that point. This photo was taken roughly a month before the El Dorado fire; this area was obviously hit hard by wildfires that year.



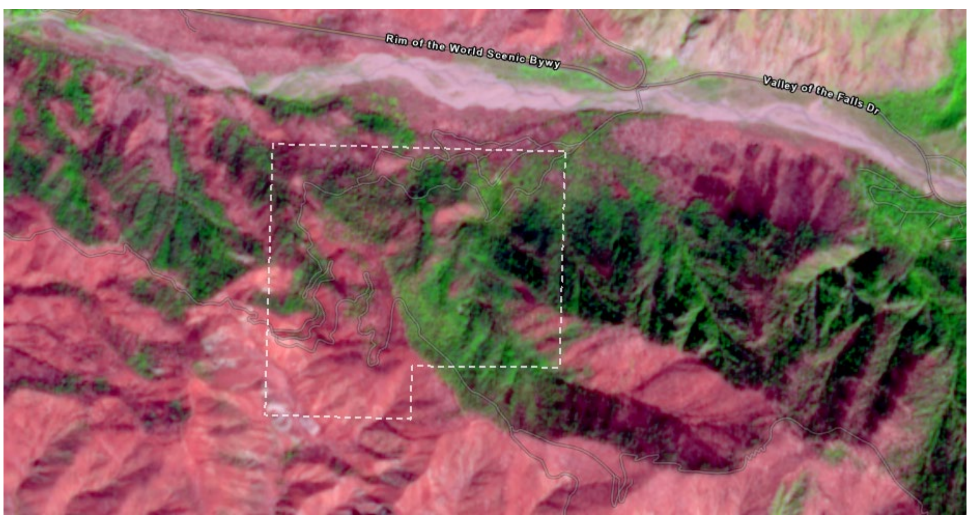
Explore the "During" Image - September 10, 2020

43. Now let's look at the "during" photo from Sept 10. Turn on the layer and take a look at the area around Bearpaw, Oak Glen, & Forest Falls. The photo is difficult to interpret due to all the smoke but these ares are clearly threatened by fire.
44. Make a copy of the Sept 10th layer and rename it **Sept 10, 2020 (Smoke Penetrating)**.
45. Change the band combination to 12 11 8A. Now you can "see" through the smoke and even see hotspots where the fire is currently burning.



Explore the "After" Image – Sept 30, 2020

46. Make a copy of the Sept 30th raster layer and rename it **Sept 30, 2020 (SWIR Composite)**
47. Change the display to a SWIR composite with a band combination of **12 8 4**.
48. Recall that, among other things, this composite helps to visualize burn areas. Use this layer to visually assess the extent and severity of the fire.
49. Zoom in to the Bearpaw boundary. You can see that while the majority of the area was burned, there are still pockets of vegetation that were saved.



50. Make another copy of the layer and name it **Sept 30, 2020 (NIR Composite)**.
51. Change to the NIR composite band combination of **8 4 3**

52. Look at the Bearpaw area with this composite. The colors are pretty dull with the exception of the saved areas in red because this combination is meant to show healthy vegetation.

Explore the "1-Year After" Image – Sept 5, 2021

Now let's start to look at the recovery by looking at an image taken a year after the fire was started (to the day).

53. Make a copy of the Sept 5, 2021 layer and rename it **Sept 5, 2021 (NIR Composite).**
54. Change to the NIR composite band combination of **8 4 3.**
55. Zoom in to Bearpaw area and toggle between the Sept 30, 2020 and Sept 5, 2021 NIR composite layers to visually compare them. You can see that the vegetation is recovering!
56. Now toggle between the Aug 6, 2020 and Sept 5, 2021. The area obviously has a long way to go to recover to its pre-fire state.

Assess Burn Scars Using the Normalized Burn Ratio (NBR)

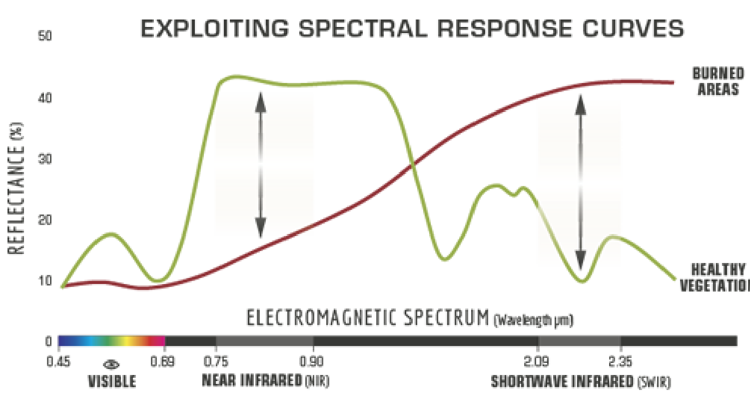
While band combinations alone are often useful for visual exploration and analysis, it is often necessary to perform mathematical functions between the bands to derive new data. In this step, you'll use an equation to quantitatively identify burned areas. This equation is known as the Normalized Burn Ratio (NBR). It mathematically compares the Near Infrared and Shortwave Infrared 2 bands (bands 8/8A and 12, respectively) to determine burn severity. Then, you'll compare the NBR of the before and after fire imagery to calculate **NBR Change**, showing only areas that have been burned between the dates both images were taken.

$$NBR = (NIR - SWIR2)/(NIR + SWIR2)$$

We can use either 8 or 8A as the NIR band for this but we'll use 8A in this case because both 8A and 12 have the same spatial resolution.

$$\text{Sentinel-2 NBR} = (\text{Band 8A} - \text{Band 12})/(\text{Band 8A} + \text{Band 12})$$

Pre-fire, healthy vegetation has very high near-infrared reflectance and low reflectance in the shortwave infrared portion of the spectrum. Recently burned areas on the other hand have relatively low reflectance in the near-infrared and high reflectance in the shortwave infrared band. A high NBR value generally indicates healthy vegetation while a low value indicates bare ground and recently burned areas.



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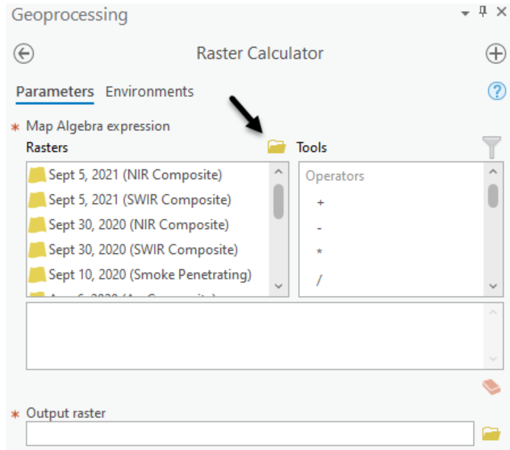
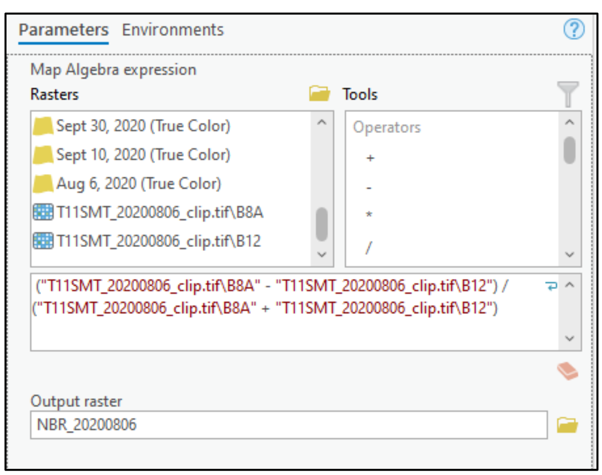
Calculate the Normalized Burn Ratio for the Pre-Fire and Post-Fire Images

57. Open the Raster Calculator geoprocessing tool.
    We have several layers available to us to select from in the **Rasters** list but these are all the composites that we've created in the previous steps - we need to perform calculations on the individual bands so we'll need to add those to the list.



58. Click the browse/folder button above raster.
59. Browse to the August 6th raster (T11SMT_20200806_clip.tif) in your project folder and double-click it to see the available bands. Select both bands B8A and B12 by holding Ctrl on the keyboard. These are the NIR and SWIR2 bands.
60. Press OK to add them to the list of rasters in the tool.
61. Now we'll enter the formula for NBR: **NBR = (NIR – SWIR2) / (NIR + SWIR2)**
62. Start the equation by typing a **(** in the box below the list of rasters.
63. Find the two new bands that you added at the bottom of the list. Double-click the band 8A raster to add it to the equation
64. Double-click the minus sign (or type the sign) to add it to the equation
65. Double-click the band 12 raster from the list to add it and then close your parenthesis with **)**.
66. Continue this to make the equation below and name the output raster **NBR_20200806**. *Line breaks and spacing between operators don't matter in the equation.*

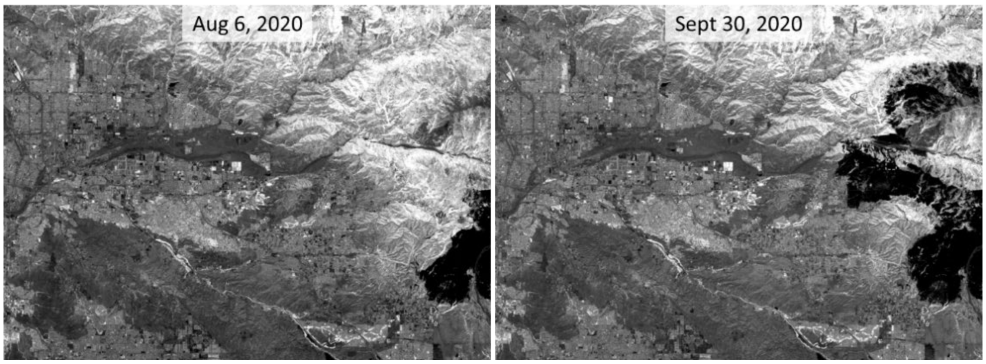


67. Run the tool.

The resulting layer is black and white and gives little information about burn scars because this is the pre-burn image (although the large burn area southeast of Oak Glen is clearly visible). Only when you determine how much the NBR changed between the two dates will the burn scars become apparent. To make this comparison, you'll repeat the calculation for Sept 30th.

68. Calculate the NBR for September 30, 2020 and name the resulting image **NBR_20200930**
The equation should look like the one below. *Line breaks and spacing between operators don't matter in the equation.*

```
("T11SMT_20200930_clip.tif\B8A" - "T11SMT_20200930_clip.tif\B12") /
("T11SMT_20200930_clip.tif\B8A" + "T11SMT_20200930_clip.tif\B12")
```

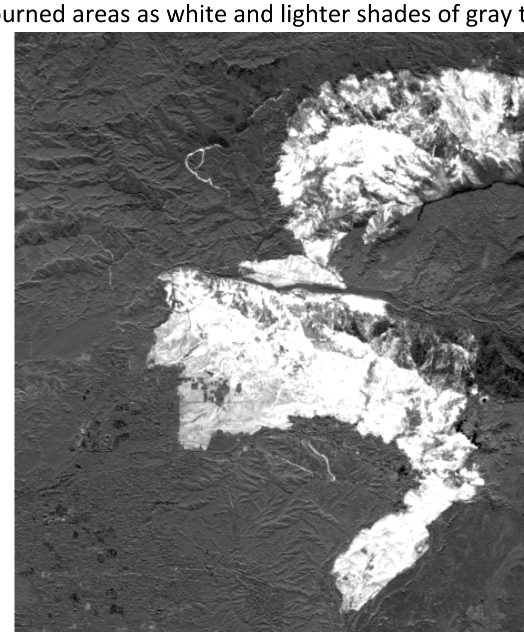


Calculate the Difference NBR

We want to find the change, or difference, between the two NBRs. To do so, you'll simply subtract the post-fire NBR from the pre-fire NBR. The formula for this is

$$dNBR \text{ or } \Delta NBR = PrefireNBR - PostfireNBR$$

69. Open the Raster Calculator tool and calculate the expression: `"NBR_20200806" - "NBR_20200930".`
Name the output raster **NBR_Diff**
The resulting raster shows burned areas as white and lighter shades of gray to represent burn severity.



You'll notice that the burn area southeast of Oak Glen doesn't appear in this result because it was already burned in the prefire image so no additional pixels were classified as burned in this area in September.

It should also be noted that new (or newly exposed) water flows will lead to <u>false positives</u> in the Difference NBR. You'll notice several linear patterns where this is the case in your result. Normal agricultural crop rotations can also lead to false positives.

70. Let's change the symbology to show different classes of burn severity. Change the symbology for the **NBR_Diff** layer from Stretch to **Classify**.
71. Change the number of classes to **5** and the method to **Manual Interval**
72. Change the color ramp to **Condition Number (**green to red). *Tip: Click the <u>Show Names</u> checkbox at the bottom of the color ramp list.*
73. Set the breaks and labels using the screenshot below. *Tip: 1) Change the numbers from highest to lowest (reverse order) and 2) change the numbers first and then go back and change the labels.*

Classes | Mask | Histogram

More ▾   + 0.0   - 0.0

Color	Upper value	Label
(dark green)	≤ -0.1	Regrowth
(yellow-green)	≤ 0.1	Not Burned
(yellow)	≤ 0.25	Low Severity
(orange-yellow)	≤ 0.5	Medium Severity
(red)	≤ 1.0	High Severity

Calculate some burn statistics for the Bearpaw Reserve

74. Zoom into Bearpaw and take a look at the areas that burned (and where didn't). This is interesting but we'll want some numbers to report – what is the area burned and the percent of the area that burned at the 3 levels of intensity.
75. The various classes of severity are currently displayed using symbology but we'll need to actually **reclassify** the values to a new raster to do any real analysis of those classes. Open the **Reclassify** tool and set the input raster as **NBR_Diff.** The value ranges will be set automatically for you based on the current symbology. Set the new values based on the screenshot below:

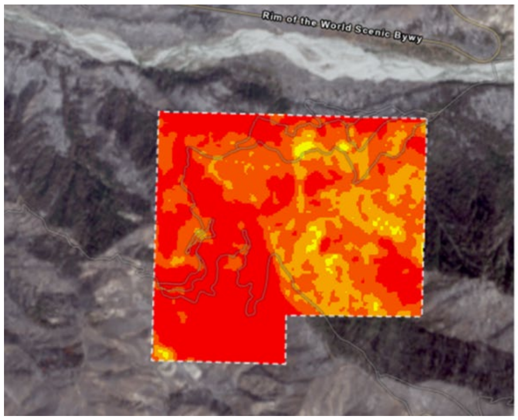
Start	End	New
-1.157308	-0.1	-1
-0.1	0.1	0
0.1	0.25	1
0.25	0.5	2
0.5	1	3
NODATA	NODATA	NODATA

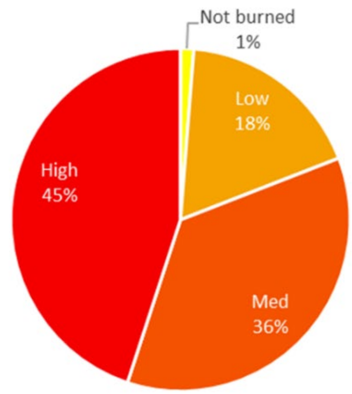
76. Name the output **NBR_Diff_Severity** and run the tool. You now have a new raster with severity coded with values -1 – 3.
77. For this analysis, we only need to know the values in the Bearpaw Reserve so first we'll extract this area using the **Extract by Mask** tool. Open the **Extract by Mask** geoprocessing tool and set the new severity raster as the input and use the Bearpaw polygon as the mask. Name the output **BearpawBurnSeverity**.
78. Open the attribute table for the BearpawBurnSeverity raster. This tells you **<u>how many cells/pixels</u> of each burn severity class** there are in the raster.

	OBJECTID *	Value	Count
1	2	0	304
2	3	1	4300
3	4	2	8636
4	5	3	10803

This output tells us that there were 304 pixels with a value of 0 (not burned), 4,300 cells with a low severity, 8,636 cells with medium severity, and 10,803 cells with high severity.

If we add up all the counts, it tells us that there are a total of 24,043 cells/pixels in this raster. Of those cells only 304 weren't burned (about 1%), which means that 99% of the area burned at some level of severity. If we continue that math, we'd find the following percentages:



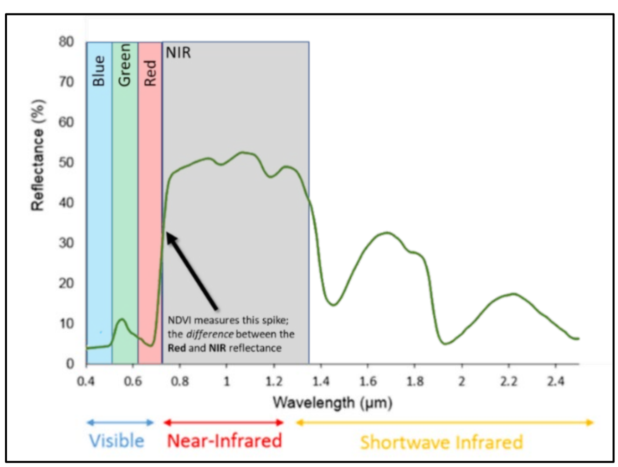


These numbers can also be easily translated to area. We know these are 10-meter resolution cells - which means each cell has an area of 100 square meters (10x10) - so we can simply multiply the counts by 100 to find area in square meters (and/or convert to other units). In this case about 1km^2 was burned with a **high severity**.

Assess Vegetation Regrowth Using the Normalized Difference Vegetation Index (NDVI)

Earlier in this tutorial, we used the NIR and SWIR composites to visualize vegetation loss and regrowth. Now we'll use the Normalized Difference Vegetation Index (NDVI) to quantitatively analyze the images and compare changes over time.

In general, healthy vegetation 1) **absorbs** a lot of red light (because it is used by chlorophyll in photosynthesis) and 2) **reflects** large amounts of near infrared light. Knowing this, if we measure the difference between red light and NIR light, we can find healthy vegetation.



We then normalize the difference over the total amount of light in those wavelengths to give us a number between -1 and +1.

The formula for NDVI is therefore:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

With Sentinel-2 imagery, that means:

$$NDVI_{Sentinel\text{-}2} = \frac{(B8-B4)}{(B8+B4)}$$

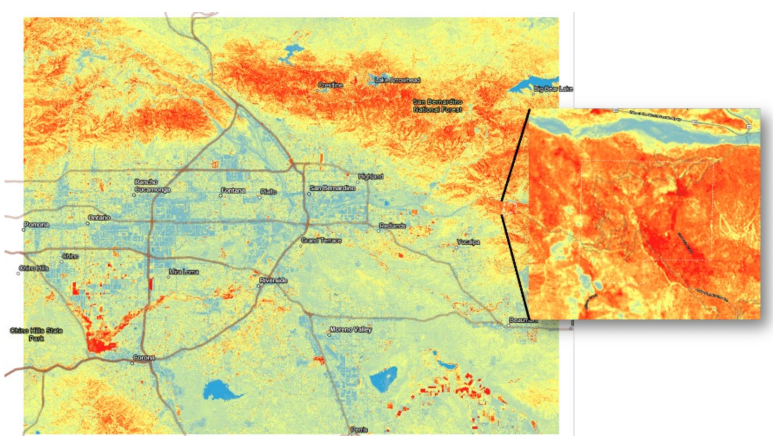
79. Open the **Raster Calculator** geoprocessing tool.
80. Use the browse button above the list of rasters to add **B4** & **B8** from the August 6th raster (T11SMT_20200806_clip.tif).
81. Build the expression as shown in the screenshot below

```
( "T11SMT_20200806_clip.tif\B8" - "T11SMT_20200806_clip.tif\B4") /
( "T11SMT_20200806_clip.tif\B8" + "T11SMT_20200806_clip.tif\B4")
```

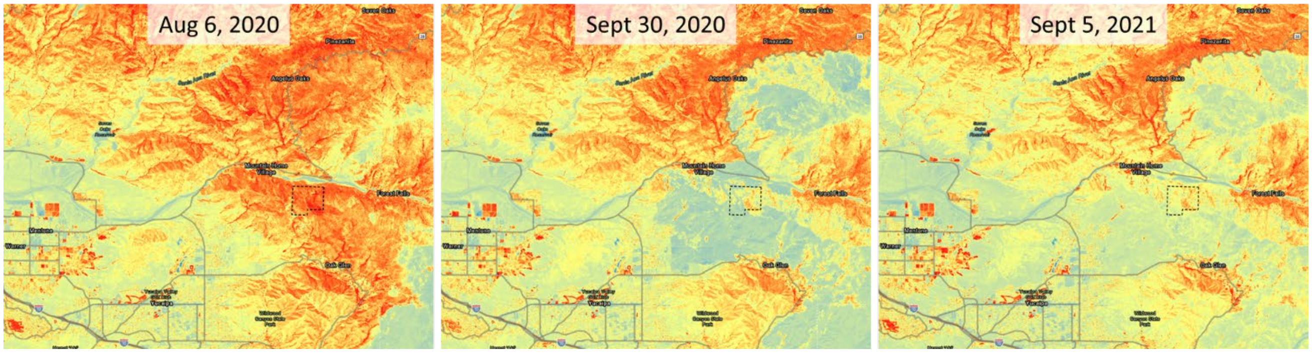
82. Name the output **NDVI_20200806** and run the tool.
    The resulting layer is grayscale with possible values from -1.0 – 1.0 (our analysis runs from -0.79 – 0.91). Typical values may be interpreted as:

0.5 - 1.0	Thick vegetation
0.14 – 0.5	Medium vegetation
.09 – 0.14	Scarce vegetation
0.025 - .09	Bare ground
0.002 - .025	Clouds
-.046 - 0.002	Ice and Snow
-1 - -0.046	Deep Water

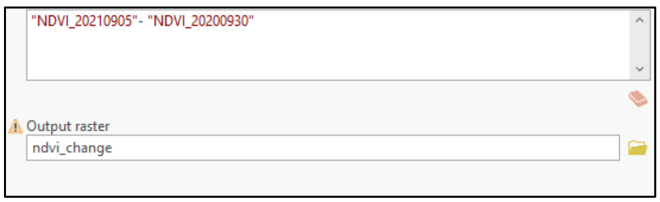
83. Change the symbology of the NDVI to the **Prediction** color scheme. *Remember to turn on the **Show all** and **Show Names** options to find the right one.*
84. This map gives us a good idea of the landcover and vegetation health before the fire. Explore the map to see the results in different areas. Take careful note of the Bearpaw area.



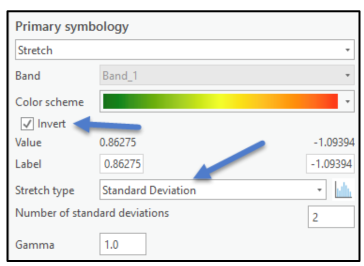
85. Repeat the steps to make NDVI layers for the September 30, 2020 and September 5, 2021 images.
86. Toggle between the 3 layers to compare loss and regrowth. Again, you can see that the vegetation is slowly growing back.

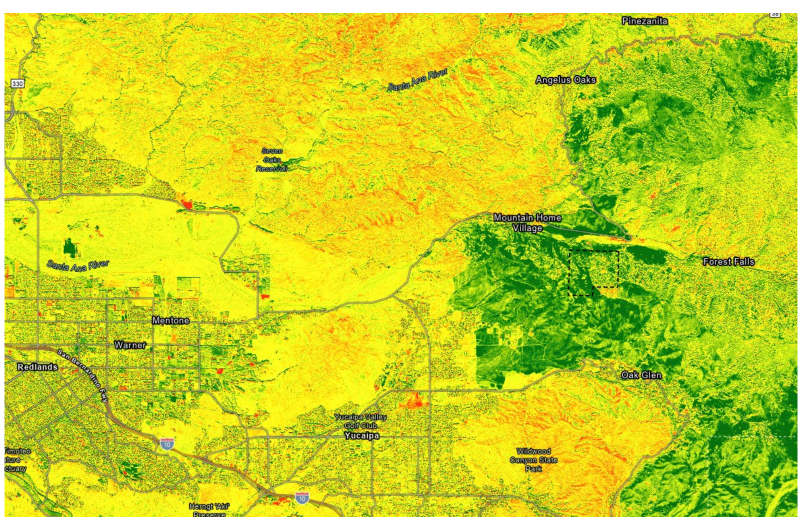


87. Now let's compare the **after** and **1-year later** NDVI results mathematically to understand where it is rebounding well vs where the vegetation is struggling to return. Use the raster calculator to subtract the Sept 30, 2020 NDVI from the Sept 5, 2021 NDVI and name the output **NDVI_Change.** See the screenshot below.



88. The results show the change between the two rasters. A cell value <u>equal to 0</u> means nothing changed (no growth or loss), anything <u>above 0</u> means that the vegetation is regrowing, and anything <u>below 0</u> means the cell actually had less vegetation one year later.
89. Change the symbology of the layer to use the **Condition Number** color scheme and then **Invert** the color scheme with the checkbox. Also change the Stretch type to **Standard Deviation**.

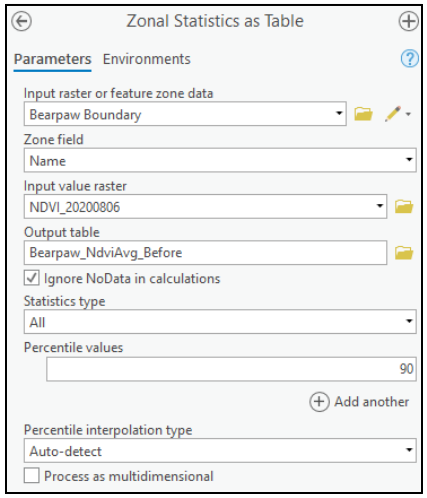




Calculate some NDVI statistics for the Bearpaw Reserve using Zonal Statistics

Lastly, we'll find the average NDVI cell values in the Bearpaw Reserve over time. This will give us a single number for each date to compare over time.

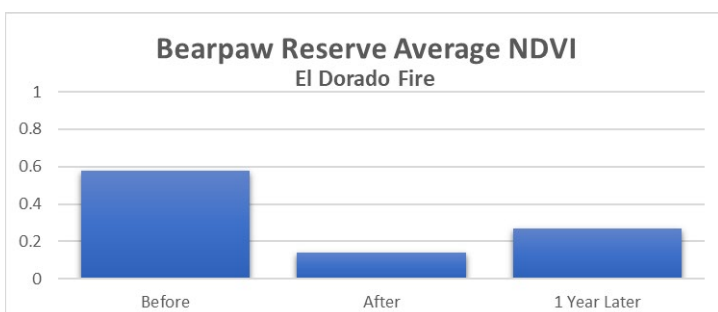
90. Run the **Zonal Statistics As Table** tool using the parameters as shown below:



91. Run the tool and open the resulting table (it's just a table so it will be at the bottom of the Contents pane). The table just has one row (because there was just one zone polygon) and contains a number of statistics based on the NDVI cell values in the zone. The one we're interested in is the MEAN value. This is the average NDVI score of all the cells in Bearpaw.

	OBJECTID *	Name	ZONE_CODE	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM	MEDIAN	PCT90
1	1	Bearpaw	1	24043	2404300	0.051454	0.799008	0.747554	0.58232	0.100366	14000.724741	0.600737	0.691739
	Click to add new row.												

92. Run the **Zonal Statistics As Table** tool 2 more times using the Sept 30, 2020 and Sept 5, 2021 images as input. Name then **Bearpaw_NdviAvg_After** and **Bearpaw_NdviAvg_1Yr** respectively.
93. Review and compare the 3 resulting tables. Before the fire, Bearpaw had an average NDVI of **0.58** – a decently high value that classifies it in the **thick vegetation** range. Immediately after the fire, that average NDVI dropped to a **0.139** – putting it in the **scarce vegetation** category. A year later, the average NDVI in Bearpaw has risen to **0.27** – putting it into the **medium vegetation** category. The hope is that this average continues to rise back to its pre-fire state or better!



Submit your work

94. Take a full screenshot of ArcGIS Pro showing the entire application with the NDVI_Change layer displayed as described earlier in the tutorial. Bearpaw should be visible on the map but the extent is not important for the submission.