Introduction to Raster Analysis

Introduction

This tutorial is designed to introduce you to raster-based analysis in ArcGIS Pro. For information about how to access ArcGIS Pro at Dartmouth, check out the following page: https://sites.dartmouth.edu/gis-geography/software/

Before beginning the exercise, familiarize yourself with foundational GIS concepts, including vector vs. raster data models and coordinate systems. We recommend the following learning pathway: https://sites.dartmouth.edu/gis-geography/basics-of-gis-training/

Important reminders for working with GIS software:

- **Use specific naming conventions for GIS**. Make sure that your computer folders, file, and ArcGIS project do **NOT** have spaces or special characters in their names, apart from an underscore (ESPECIALLY for raster data). Computers interpret spaces and special characters as a command and will run into mysterious errors during analysis.

- **Your data are not stored in a GIS project**. Geospatial data is stored on your computer's hard drive in file folders. The GIS project only points the computer to where these are located, runs analyses on them, and displays them. Once you start a project, if you change anything about your existing file configuration (move or rename any folders or files), the software will not be able to find them. To fix this, open the dataset's properties and use "Set Data Source" to link ArcGIS back to the correct location.

- **Know where your output files are going and what they are named**. You will produce many, many files while running analysis in a GIS. If you do not specify where these files are saved when you run tools, they will be sent to a default location that you will **NOT** easily find. Similarly, make sure to specify a clear name for output files that you will remember, as default names are **NOT** intuitive.

- **Each GIS dataset is made up of multiple files**. A single GIS data layer (e.g. a shapefile) is not just a single file on your computer, but a collection of 4-8 files that computers interpret together. We recommend only moving, deleting, or renaming these files through a GIS software rather than a file explorer, and zipping up all files together to share.

- **Save and back up your project frequently**. GIS software, while useful, is known for crashing unexpectedly, often at the worst possible time. Similarly, computer issues always strike when least expected. We recommend copying your entire working folder with all associated files onto a USB flashdrive or cloud drive (Google Drive, Dropbox, Onedrive, etc.).

<u>Outline:</u>

In this tutorial, you will complete a case study of a (fictional!) beetle infestation that threatens the Upper Valley's maple syrup economy.

> *In July of 2030, scientists in Vermont and New Hampshire discovered a new species of beetle that bores into sugar maple trees and feeds on sap, transmitting fungal pathogens that slowly kill the tree. Dubbed the "Maple Syrup Beetle", its discovery sent shockwaves through states, threatening their maple-dependent tourist economies. As summers become longer, wetter, and hotter, the range of this beetle is expected to spread and wreak havoc on the local maple tree population.*

In this future beetle-filled scenario, the newly formed Upper Valley Maple Syrup Farmers Union has hired you to map the spread of Maple Syrup Beetles and identify vulnerable forest stands for protection. To do this, you will utilize the following essential raster-based methods:

- **Slope calculation**: using a Digital Elevation Model (DEM) to find gently sloped areas preferred by beetles
- **Aspect calculation**: finding north-facing slopes, which stay wetter and provide better beetle habitat
- **Kernel density**: calculating density from point locations of beetles
- **NDVI**: identifying areas with stressed sugar maple trees
- **Raster calculator and reclassification**: assigning health scores to forest regions

<u>Prepare your working space</u>

a. Create a new working folder on your computer to hold the files from this tutorial. Remember to name it without spaces or special characters (e.g. *GIS_Tutorial_Raster* instead of *GIS Tutorial – Raster*).

b. Download the zip file labeled "Raster_Analysis_Tutorial_Data.zip". Unzip the file (right-click its name and select Extract All) into your working folder.

c. Open ArcGIS Pro and create a new project within your working folder. See the "Introduction to GIS Software" tutorial to remember project basics.

d. Add a new folder connection (in the Catalog pane, right-click on Folders → Add Folder Connection). Navigate to your working folder and choose OK. When you expand the arrow next to Folders, you should see the working folder appear (right-click and refresh if not).

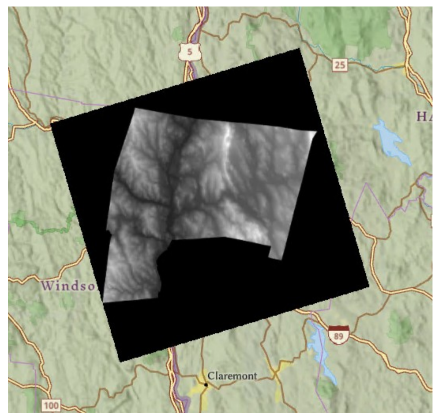
e. Within the Raster_Analysis_Tutorial_Data folder, you should see the following datasets:

- **UV_DEM_proj.tif**: a Digital Elevation Model (DEM) downloaded from the USGS 3D Elevation Program, masked to the Upper Valley, and projected into UTM Zone 19N
- **Beetle_Sightings.shp**: a point shapefile of Maple Syrup Beetle sightings collected by citizen scientists, projected into UTM Zone 19N
- **c8_21_25_Sentinel_B2, B3, B4, and B8**: imagery of the Upper Valley on August 21, 2025 downloaded from the Sentinel-2 program as raster bands 2, 3, 4, and 8, projected into UTM Zone 19N
- **Study_Area_Polygon.shp**: a polygon shapefile of the Upper Valley Boundary, projected into UTM Zone 19N

PART A:

1. Understanding Digital Elevation Models (DEMs)

One of the most common types of raster data in GIS is a Digital Elevation Model (DEM). These are representations of a continuous elevation surface, where each pixel (also known as a cell) is given the elevation value at that particular location.



a. Add the dataset UV_DEM_proj.tif to your project (right-click → Add to Map, or drag and drop onto the Map Canvas). You should see an image like the screenshot at right.

b. Right-click on the DEM's name in the Contents pane and select Properties. Expand the arrows next to the different headers to see specific properties of this dataset, including cell size, statistics, and spatial reference. Using this window, find answers to the following questions about the DEM:

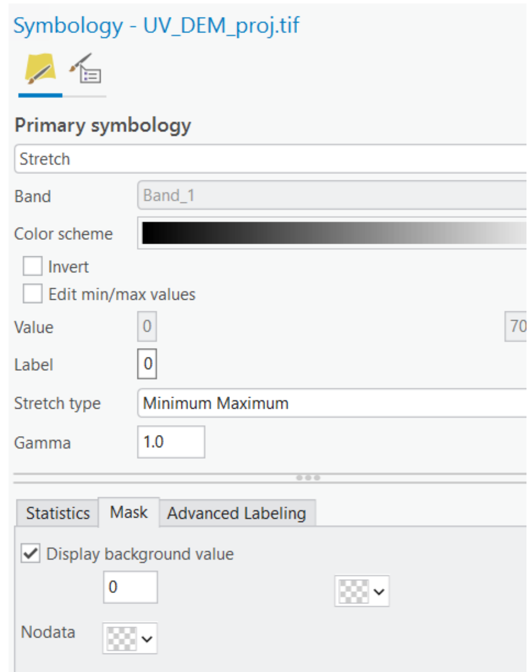
- ***What is its coordinate system?***
- ***What unit of measurement is used for elevation?***
- ***What is the spatial resolution (e.g. cellsize)?***
- ***How much area on the ground does one cell cover?***[1]

c. This DEM was downloaded from a national dataset and masked to a polygon of the Upper Valley. In the Contents pane, note that the elevations are symbolized with a gradient of black to white, where white represents higher elevations. ***Why does the DEM have a border of black values?***

Recall that raster data are composed of regular grids of cells. To represent a non-rectangular area (e.g. the Upper Valley), GIS software will mask the raster to hide pixels outside the area of interest. However, these pixels still exist in the underlying data, given a value of 'no data'.

d. Right-click on the DEM's name in the Contents pane and select Symbology. By default, the

[1] To check your answers, view the answer key on the last page



layer uses Stretch symbology, which creates a continuous gradient of color between the highest and lowest values. Try changing the symbology from Stretch to the other options. ***What seems like the best way to symbolize this elevation data?***

e. To mask the surrounding area out, set the symbology back to Stretch and select the Mask tab at the bottom. Check the box next to 'Display background value'. This makes the 'no data' values transparent, effectively masking the data to just the Upper Valley.

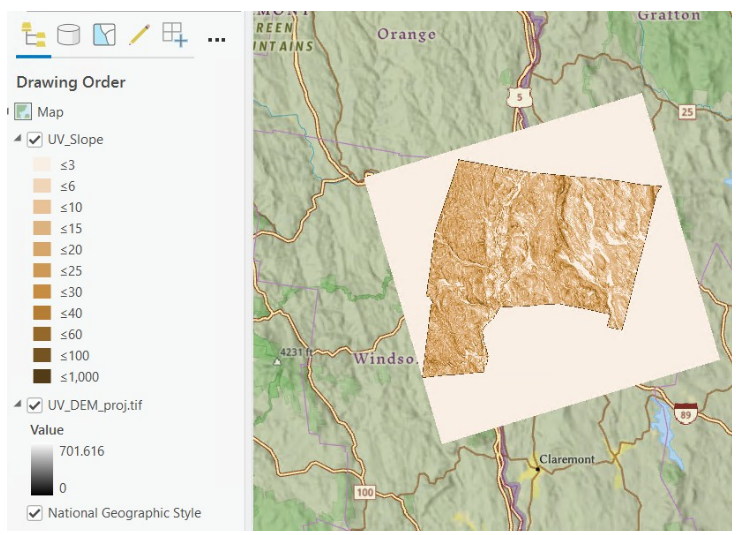
2. Calculate Slope from a DEM

You will use the DEM to calculate slope, or the steepness of terrain.

a. Go to the Analysis tab in the upper ribbon and open the red 'Tools' toolbox. In the Geoprocessing pane at right, search for the tool 'Slope' (Spatial Analyst).

b. Run the tool with the following parameters:

- **Input raster**: DEM
- **Output raster**: choose a reasonable location and give it a name like *UV_Slope*
- **Output measurement**: percent rise
- **Method**: planar



c. When finished, you should have a layer that looks like the screenshot at right, where each cell has been given a slope value as a percentage.

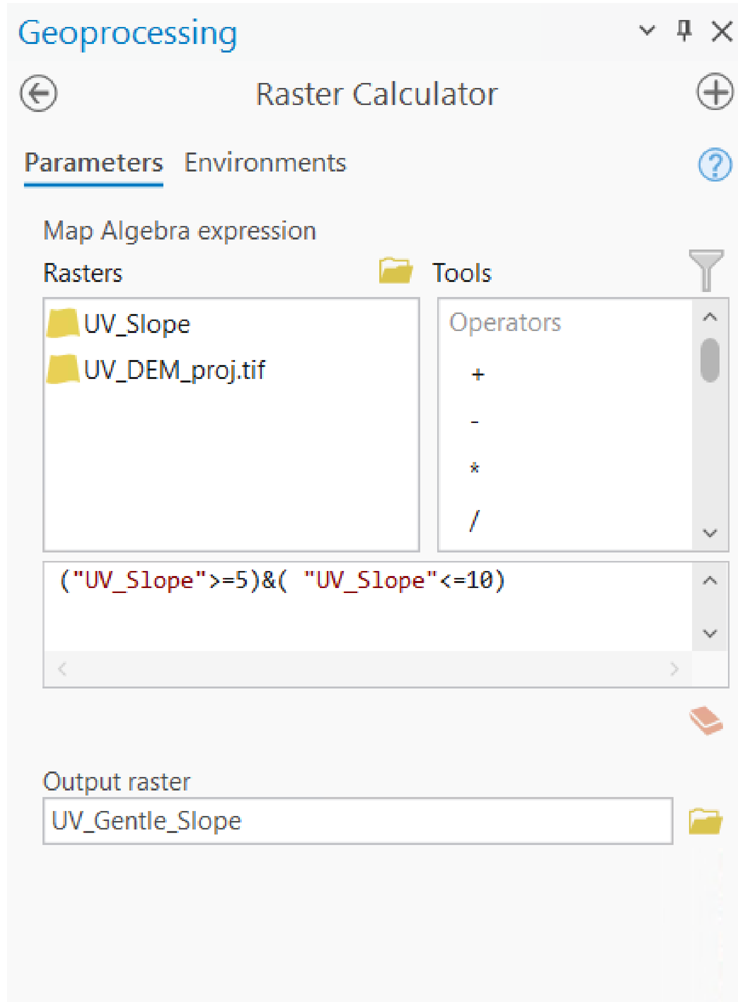
3. Find Areas with Gentle Slope (Raster Calculator)

According to scientists, the Maple Syrup Beetle prefers habitats with gently sloped terrain, as this prevents rain from filling their ground burrows while still remaining easy to walk. You will identify areas within the preferred range of 5-10% slope.

To do this, you will use the Raster Calculator tool to perform **map algebra**, which creates new raster outputs by treating each raster layer like a variable in an algebraic expression.

a. In the toolbox/Geoprocessing pane, find the tool *Raster Calculator* (Spatial Analyst). Using the screenshot for reference, type the following expression into the calculator, double-clicking on the UV_Slope name under Rasters.

This expression strings two queries together (>=5 and <=10) using a Boolean operator (&, or *and*). It will create a new layer with only the pixels that fall within this elevation range. Name the output something like UV_Gentle_Slope and run the tool.



b. The output should be a binary raster layer with only two values in the legend. Cells with values of 0 do not fit the criteria and have slope outside of the desired range. Cells with values of 1 have elevations between 5-10%.

Test your understanding*: right-click on the gentle slope layer and open the attribute table. The field named 'Count' tells you the number of cells with each value of 0 and 1. What is the total area of terrain that falls within the gentle slope range?*[2]

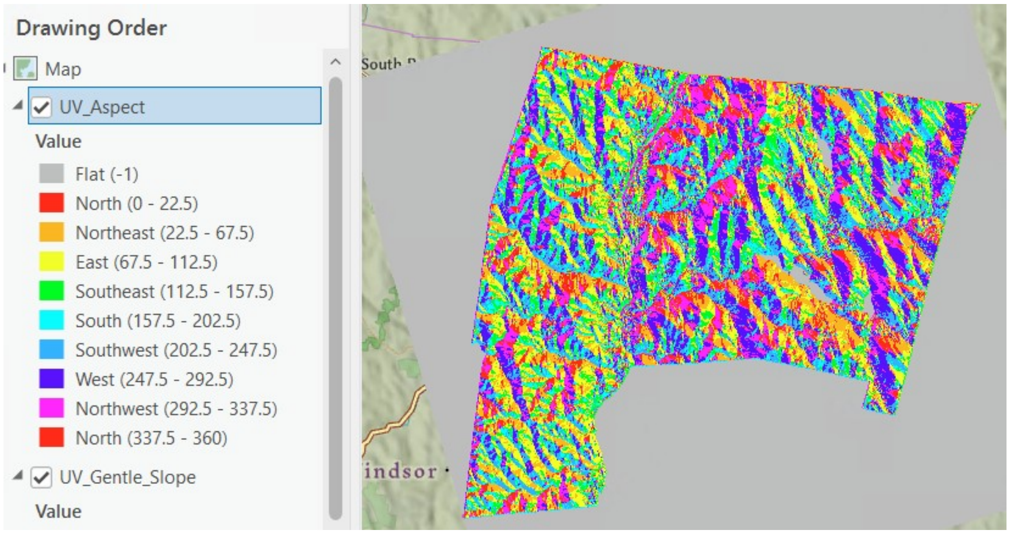
4. Calculate Aspect from a DEM

The Maple Syrup Beetles also prefer north-facing slopes with less direct exposure to the sun, resulting in wetter, cooler climates. You will calculate the slope direction (also known as **aspect**) of the terrain using the appropriately named Aspect tool.

a. Open the tool *Aspect* (Spatial Analyst). Run the tool with the following parameters:
   - **Input raster**: DEM
   - **Output raster**: UV_Aspect
   - **Method**: planar

b. The resulting output should look something like below:

[2] To check your answers, view the answer key on the last page

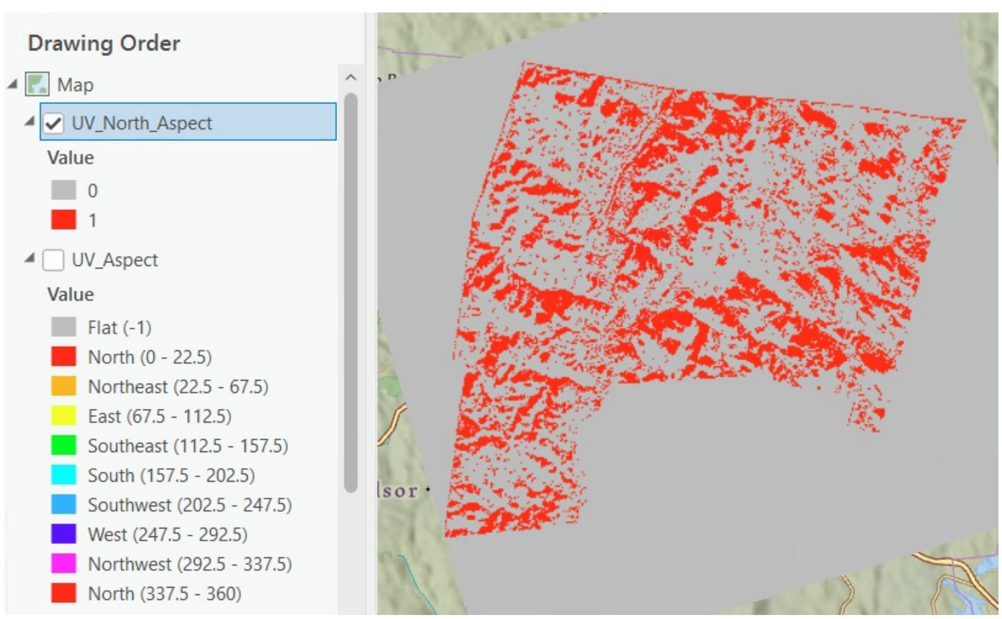


c. Similar to the previous step with slope, use the raster calculator to construct an expression that will return only cells with a north-facing slope. For this purpose, consider North, Northeast, and Northwest values to all be north-facing. Use the numeric values in parentheses in the expression rather than the slope description.

   This will be a trickier expression than for slope; you will want to find values that fit into one range (0-67.5) OR values that fit into another range (292.5-337.5). In the raster calculator, ‘Or’ can be written with the Boolean operator **|** (either typed on your keyboard or double-clicked from the list of operators). Make sure you use parentheses wisely.

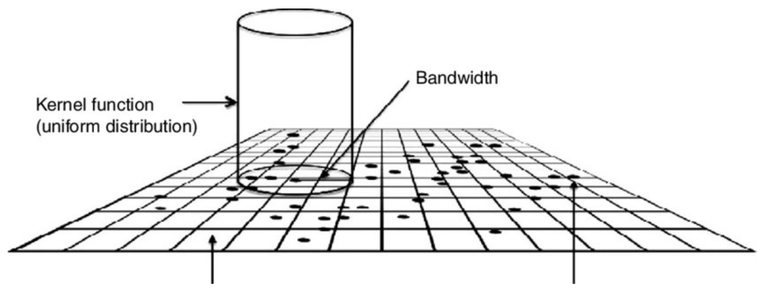
   What expression should you use?[2]

d. Apply the expression. Your output should look something like below:



5. Calculate beetle density (Kernel Density Estimation and Reclassification)

To determine the current spatial distribution of Maple Syrup Beetles, citizen scientists provided a point shapefile of beetle sightings. You will use a method called **Kernel Density Estimation** to generate a continuous surface of beetle density from the vector point locations. ArcGIS calculates this by drawing a "kernel" (or neighborhood) around each point and calculating the density of points within (weighting closer points more heavily than further away points). A raster surface is produced, where the value of each cell is the estimated density of points in that given area.



Hart 2014

a. Add the dataset *Beetle_Sightings.shp* to your project from the original data folder. You should see locations of beetle sightings within the Upper Valley on your map.

b. In the toolbox/Geoprocessing pane, open the tool Kernel Density. Use the following parameters to run the tool:
   - **Input points**: Beetle_Sightings
   - **Population field**: none (this calculates density by number of points rather than a field value)
   - **Output raster**: something like Beetle_Density
   - **Output cell size**: 30
   - **Search radius**: leave empty, which will use a default algorithm to calculate
   - **Area units**: square kilometers
   - **Output cell values**: densities

c. Examine the resulting density layer. Does it seem to make sense based on the beetle locations? What happens if you run the tool with different search radius values specified? Make sure you leave the original Beetle_Density layer as the blank search radius.

d. Rather than creating a binary 0/1 layer of high and low beetle density, you will create a "stepped" raster that assigns scores based on particular ranges. Open the tool **Reclassify** (Spatial Analyst). Use the density raster as the input, and Reclass field as Value.

e. In the Reclassification table, you will see the current ranges of density values for the raster. This tool will calculate new values (in the right column) for these values. In the first five rows, double-click into boxes and update them to match the screenshot at right, which assigns scores of 0-4 to certain density ranges.

f. Once the first five rows look correct, click on the sixth row so that it is highlighted blue. Use the delete key on your keyboard (not backspace,

Reverse New Values

Start	End	New
0	0	0
0.01	0.5	1
0.5	1	2
1	1.5	3
1.5	2	4
0.939896	1.127876	6
1.127876	1.315855	7
1.315855	1.503834	8

Reverse New Values

Start	End	New
0	0	0
0.01	0.5	1
0.5	1	2
1	1.5	3
1.5	2	4
NODATA	NODATA	NODATA

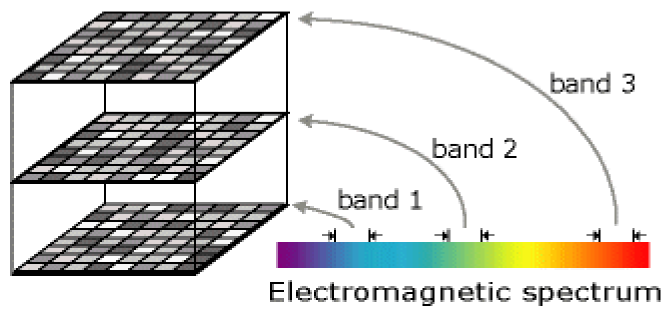
Classify Unique

but delete) to remove it. In the same way, delete the other rows of values until you are left with just the first five and the 'NODATA' row. Your final table should look like the bottom screenshot at right.

g. Give the output raster a name like Density_Score and run the tool. Examine the outputs to make sure it worked.

6. Understanding Multi-Band Rasters

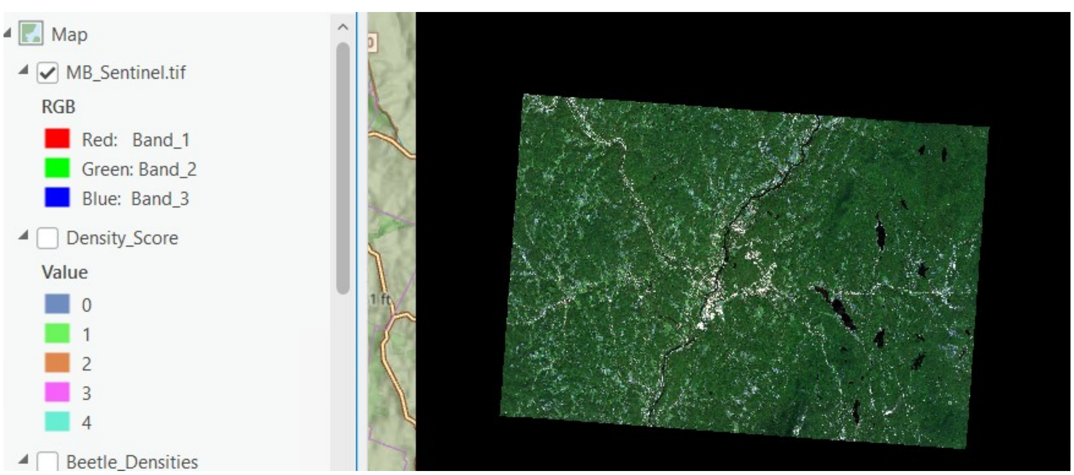
So far, you have been working with single-band raster data, where each pixel location measures a single characteristic (e.g. elevation). Another common form of data is a **multi-band raster,** where each pixel location has multiple values. These different measures are organized into separate "bands" (layers), which represent measures of reflectance at different portions of the electromagnetic spectrum.



Esri

a. Add the four c*8_21_25_Sentinel* geotiff datasets to your project. These are single-band raster layers downloaded from Sentinel-2, a constellation of satellites that collect electromagnetic radiation over the entire Earth and separate wavelengths into 13 individual bands. On your map, you will see bands 2 (blue wavelengths), 3 (green wavelengths), 4 (red wavelengths) and 6 (near infra-red wavelengths). In order to organize these into a single dataset for analysis, you will need to combine them first.

b. Open the tool Composite Bands. Set the input rasters to be all four Sentinel bands, organized in sequential order (2, 3, 4, 8). Note: it is important to keep them in this order, as they will be relabeled in the new raster! Call the output raster something like *MB_Sentinel.tif.* When finished, the output should look something like below. Remove the single band layers from your project.



c. You will notice that different bands have been assigned to red, green, and blue labels in the legend. Computer screens display images by emitting three different channels of light: red, green, and blue. By varying the intensity of these channels, the screen can create any color. When a multiband image is added to ArcGIS, it must assign one band to each of these three channels. If the image has more bands, only three can be displayed at a time.

d. Open the properties of the multiband image (right-click in Contents → Properties) and expand the Band Metadata heading. ArcGIS relabeled each band with the numbers 1-4, rather than keeping 2, 3, 4, and 8. Band 1 is now blue, 2 is green, 3 is red, and 4 is infrared. These new band numbers correspond to the order you added them in the Compose Band tool.

e. Close the properties and open the multiband image's symbology. The layer is currently displayed as RGB, with the first three bands assigned to red, green, and blue channels respectively. If you wanted to display a **true color composite**, where red, green, and blue bands are assigned to their corresponding channels, ***how should you change the band assignments?***[3]

f. Zoom in to see the image details. ***What is the spatial resolution of this image? Where might you find this information?***

7. Calculate NDVI

The Normalized Difference Vegetation Index (NDVI) is common way to measure vegetation in a given area. During photosynthesis, plants absorb high levels of red wavelengths and reflect high levels of near infrared wavelengths. NDVI calculates the difference between these wavelengths as a ratio.

$$\frac{Near\ Infrared\ - Red}{Near\ Infrared + Red}$$

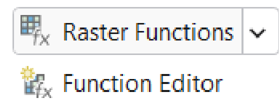
Class	NDVI Range
Water	−0.28–0.015
Built-up	0.015–0.14
Barren Land	0.14–0.18
Shrub and Grassland	0.18–0.27
Sparse Vegetation	0.27–0.36
Dense Vegetation	0.36–0.74

Akbar et al. 2019

NDVI values range from -1 to +1. Scientists determine thresholds of NDVI values for particular land cover or vegetation types through scientific studies. Individual species often have their own established thresholds that vary with season and plant health. Based on a study by Mulozi et al. 2023[4], healthy sugar maples typically have an NDVI of around 0.55, while stressed maples fall between 0.4-0.5. You will use this NDVI range to guide your analysis.

[3] To check your answer, view the answer key on the last page.

[4] Mulozi L., Vennapusa Amaranatha R., Elavarthi S., Jacobs Oluwatomi E., Kulkarni Krishnanand P., Natarajan Purushothaman, Reddy Umesh K., & Melmaiee K. (2024) "Transcriptome profiling, physiological, and biochemical



a. In the analysis tab, click on the Raster Functions button to open up a pane at right. Select the NDVI option (not colorized).

b. Set the following tool parameters:
- **Raster**: multiband Sentinel image
- **Visible band ID**: red band number
- **Infrared band ID**: infrared band number
- Check the box next to scientific output

c. Run the tool to produce a temporary raster layer. The legend values should range from roughly -1 to +1.

d. Export this into a permanent dataset by right-clicking its name → Data → Export Raster. Save the output raster dataset with a name like NDVI_Sentinel.tif, leave everything else as default, and select Export.

8. Isolate Areas with Stressed Vegetation

a. Based on what you have learned in this tutorial so far, create a new binary raster that assigns cells with a NDVI value of 0.4-0.5 as 1 and everything else as 0. ***What tool will you use to do this?***[5] Save the new layer with a name like *Stressed_Vegetation.tif*.

b. Consider the extent of this layer, which stretches beyond the Upper Valley. From your original data folder, add *Study_Area_Polygon.shp* to the project. Run the tool Extract by Mask with your new vegetation layer as the input and the study area polygon as the input feature mask. Save the output into your folder with a name like *UV_Stressed_Vegetation.tif*.

9. Combine Data to Assess Forest Health

Now that you have successfully created datasets to meet each of the criteria, you will combine them to generate a forest health score that identifies areas of high risk for Maple Syrup Beetle infestation. The score will be created by adding the different binary raster layers together.

a. Open the Raster Calculator. One of the simplest methods for scoring locations based on particular factors is a simple weighted summation:

$$(Criteria\,1 * Weight\ of\ importance) + (Criteria\,2 * Weight\ of\ importance) \ldots .\ etc.$$

This is a relatively subjective process, though the importance of particular factors can be determined by referencing relevant literature. For this project, we will weight vegetation health more heavily than slope or aspect. The beetle density scores are already relatively

analyses provide new insights towards drought stress response in sugar maple (Acer saccharum Marshall) saplings". Frontiers in Plant Science, 14 DOI=10.3389/fpls.2023.1150204

[5] To check your answer, view the answer key on the last page.

weighted by value.

b. Type in the following equation to the raster calculator:

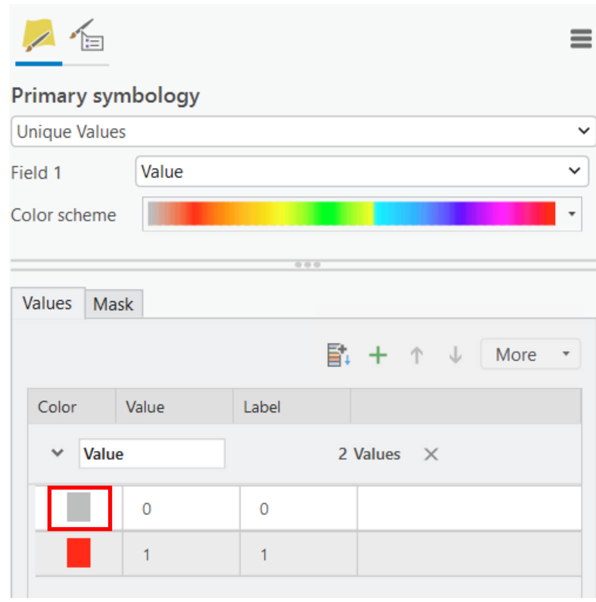
*("UV_Stressed_Vegetation"*3) + "UV_Gentle_Slope" + "UV_North_Aspect" + "Density_Scores"*

Save the output with a name like *Forest_Health_Score.tif* and run the tool.

c. Examine the output. ***What is the range in health scores?***

d. To recommend only those at highest risk, use the Raster Calculator or Reclassify tool to create a new layer that only shows scores of 4 and above. Name the output something like High_Risk_Sites.

e. Open the symbology for your final output and click on the gray box next to the 0 value to change the color to transparent. Examine the final site locations, changing your basemap as needed. ***What areas are most at risk of beetle infestation?***



Conclusion

You have now successfully completed the tutorial for introductory raster analysis! There are many other types of raster data and methods of analysis within GIS, and we encourage you to explore other online tutorials and literature. For a tutorial on vector-based analysis, check out the GIS Learning Hub. Feel free to reach out to aletha.e.spang@dartmouth.edu with any questions.

Answer Key

3b. What is the total area of terrain that falls within the gentle slope range?

Approximately 179,762,400 *(cell area (30 x 30) * count of cells with value of 1 (199736))*

4c. What expression did you use to create a new layer of only north-facing terrain?

Should be something similar to:

(("UV_Aspect">=0)&("UV_Aspect"<=67.5))|(("UV_Aspect">=292.5)&("UV_Aspect"<=360))

6e. If you wanted to display a true color composite, where red, green, and blue bands are

assigned to their corresponding channels, how should you change the band assignments?

Red channel = band 3, green channel = band 2, blue channel = band 1

8. Based on what you have learned in this tutorial so far, create a new binary raster that assigns cells with a NDVI value of 0.4-0.5 as 1 and everything else as 0. What tool will you use to do this?

Either the Raster Calculator with an expression like *("NDVI_Sentinel.tif">=0.4)&("NDVI_Sentinel.tif"<=0.5)* OR Reclassify.