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Mapping Photoperiod as a Variable in Vegetation Distribution Analysis

Introduction

Photoperiod is defined as the duration of time for which an organism receives illumination. In nature, the photoperiod of a plant is the length of time it is exposed to sunlight. Generally, this would mean that the photoperiod is the day length. In areas of low relief, the effective photoperiod is or nearly is the day length, because shadowing of the landscape by higher elevation landforms is uncommon. In some areas, however, photoperiod is highly variable in its distribution throughout the landscape. In mountainous areas, for example, broad swaths of the landscape may experience a considerably shorter exposure to sunlight because of upslope shading.

In most trait-based studies of vegetation in real landscapes, photoperiod is an essential variable to keep track of in how it affects plant behavior. Sunlight is obviously very important for plant functioning as it controls photosynthesis. Via its effect on the photosynthetic cycle, sunlight can play a key role in determining how a plant transpires, flowers, respires and grows. However, photoperiod varies so little across the landscape that it is generally not important to characterize its spatial distribution. Even in mountainous terrain, photoperiod generally varies in a predictable enough way that it is a relatively simple task to separate it as its own variable in analysis. For example, when working in a region where slopes generally faced north or south, one would generally include some simple consideration of aspect in their analysis. However, in some environments with extremely complex terrain, this should be taken into consideration.

A good example of a place where mapping photoperiod may be essential to studying vegetation is the red rock country of Utah. The high-relief terrain here has been carved by rivers into a landscape of sinuous, deeply-incised canyons in which vegetation is still able to grow. Photoperiod here changes drastically inside of canyons due to variability in aspect, channel width and channel depth. Furthermore, it is primarily in these canyons that vegetation is found, because the environment is semiarid and streams provide the most persistent source of water. Using the ArcGIS Hillshade tool with real numbers for sun position allows for creation of photoperiod rasters. It is hypothesized that there will be some correlation between areas of low sun exposure and areas with low vegetation density.

Methods:

The only data that is needed to perform this study is high-resolution topographic data from an airborne LiDAR system. A bare earth DEM is necessary for input into the Hillshade tool, and a maximum return surface is needed for the vegetation density analysis. Analyzing correlation between areas of low photoperiod and low vegetation density will be done visually by comparison of the two raster layers. The resolution of LiDAR can be extremely high, frequently 1 meter and sometimes even at the scale of tens of centimeters. The advantage of having data at this resolution is that it is appropriate for a vegetation study. Data at a 10 cm or less resolution would be totally unnecessary, because that is so much smaller than a tree or a large shrub is. However, even 10 meter resolution data would be large enough that you would be analyzing a window much larger than a single tree. A resolution of 1 meter is ideal for this study.

The dataset used for the study came from www.opentopography.org and was flown by the National Center for Airborne Laser Mapping. The LiDAR was flown for a seed grant written by former UT student Lindsay Olinde called “Hite, UT: Quantifying Evolution and Stability of

Coarse Alluvial Channels". The survey date for this dataset was September 7th, 2011. This dataset is ideal, because it spans an area with several deeply-incised alluvial channels. There are several options for downloading this data, but the formats used in this study were the result of downloading a geotiff raster of Zmin at a resolution of 1 meter with null filling of 7m radius. Null Filling is performed using an IDW method and a geotiff raster of Zmax at a resolution of 1 meter with null filling of 7m radius. The spatial reference for this dataset, as provided with the available metadata, was UTM Zone 12N NAD83 (2011) in the horizontal and NAVD88 (GEOID 09) in the vertical. Figure 1 is a map of the bare earth DEM.

The Hillshade tool in ArcGIS uses a DEM to produce a shaded relief raster. This can be done by illumination angle at each cell, or it can be done with shadows from the surrounding landscape. It then assigns a value between 0 and 255 to each cell to represent how shaded that cell is. A value of zero means a cell is in full shade. The entire basis of calculating photoperiod hinges on the fact that a zero value means full shade. Inputs to the tool are the DEM, and a sun altitude and azimuth angle. The azimuth angle refers to the compass direction from which the sun is shining and the altitude angle refers to the height of the sun in the sky. By calculating the sun azimuth and altitude angle at ten minute timesteps and running the Hillshade tool for each of these angle pairs, one can calculate how many ten-minute increments a cell in a DEM is exposed to direct sunlight for. An ArcPython script was written to do just that. The concept behind the script is displayed in Figure 2. The script itself is included at the end of this report as an appendix.

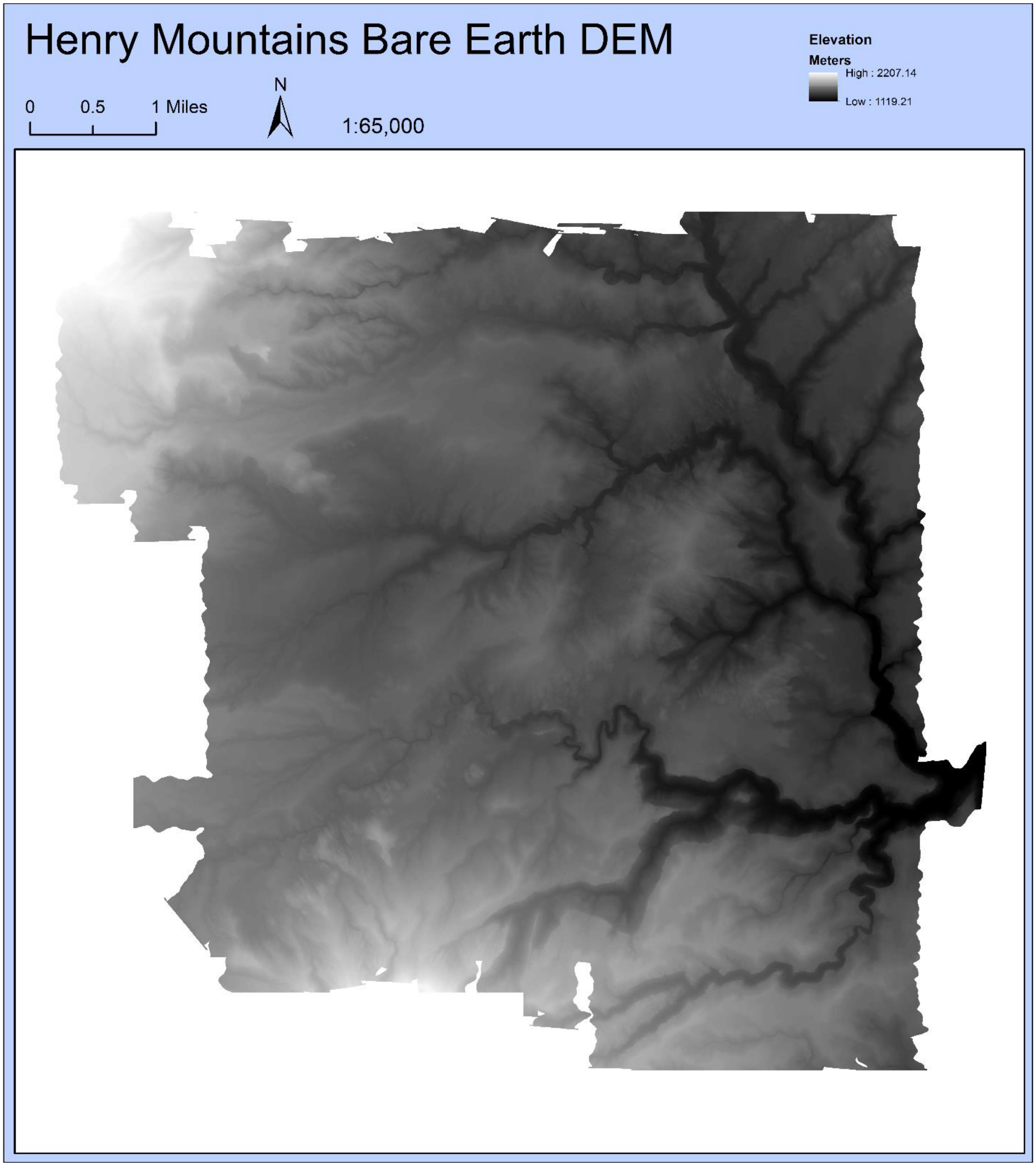

Figure 1: Map of bare earth DEM for Henry Mountains, UT.

The first part of the script uses the NumPy module in Python to calculate the altitude angle and azimuth angle of the sun and store it as a list in Python. Then, the script uses a for loop to iterate through each pair of angles through the list and perform the following workflow:

1. Hillshade with DEM, Azimuth Angle and Altitude Angle as inputs. Model Shadows ON. Z Factor = 1.
2. Reclassify hillshade raster. [0 = 0, 1:255 = 1].
3. Sum. Add values of binary, reclassified raster to the cumulative photoperiod raster.
4. Delete temporary hillshade.
5. Delete temporary reclassified raster.

Since the incremement photoperiod maps represent 10 minutes of time, the cumulative photoperiod raster is multiplied by 10 using the Times tool once the script has run. Some of the intermediate hillshades are displayed in Figures 3, 4 and 5 to illustrate how the hillshade raster changes for different sun angles.

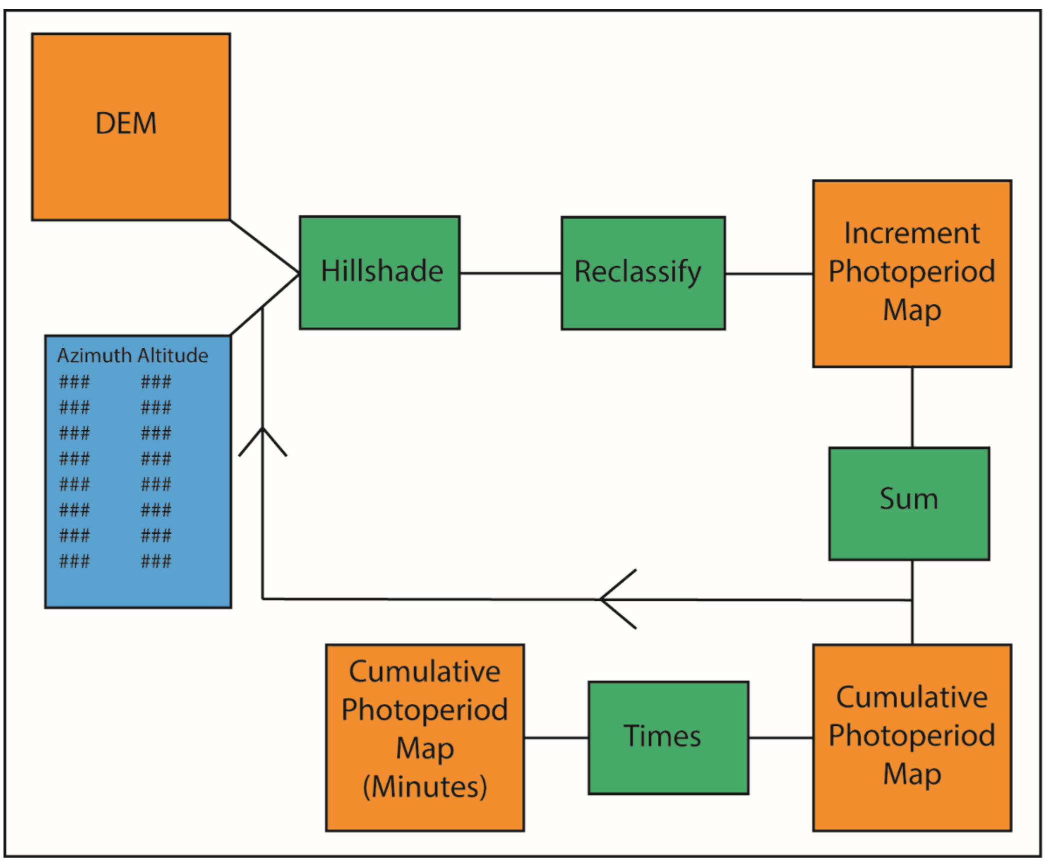

Figure 2: Diagram showing logistics of ArcPython script.

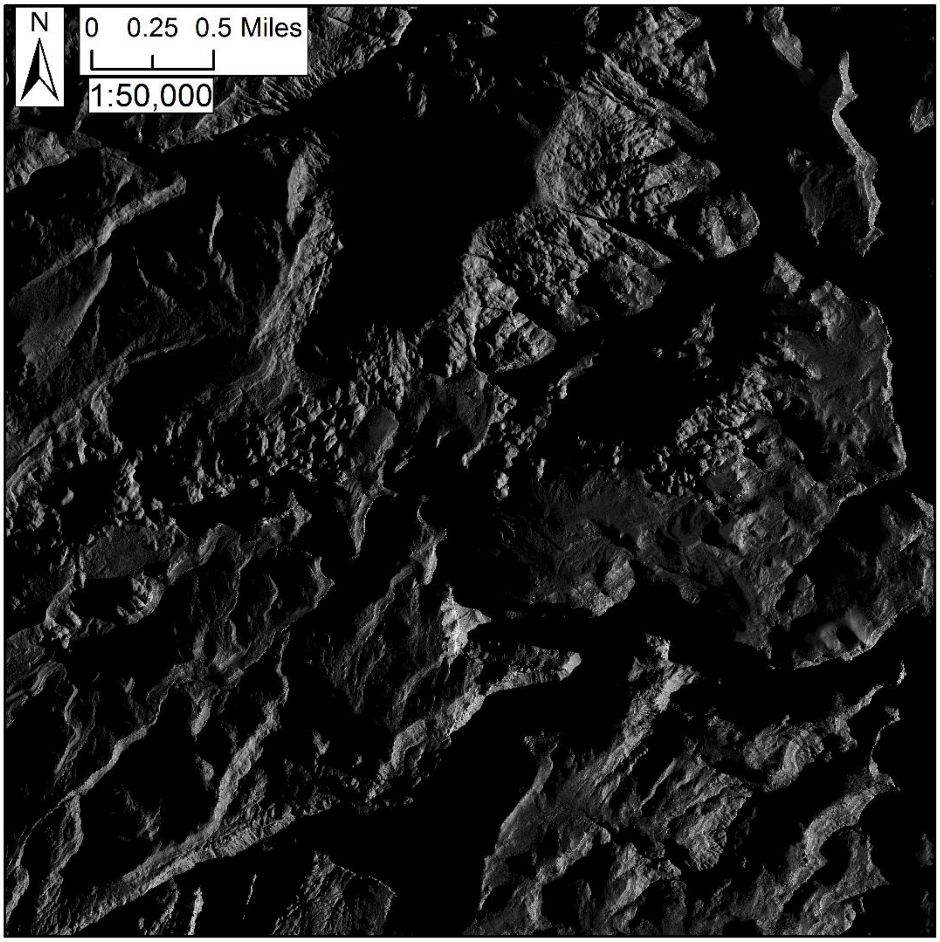

Figure 3: Hillshade at increment = 3, approximately 30 minutes after sunrise. Notice how shadows fall to west side of topographic irregularities, because sun rises in east.

The raster of vegetation height was generated using the Minus tool in ArcGIS to subtract the bare-earth DEM from the ZMax DEM. The new raster effectively reports the height of the first return over the last return at every cell, which can be assumed to be the height of vegetation. The color ramp to display these layers was set to a minimum of zero and a maximum of 10, to cap the range to reasonable values only. This method is useful because it highlights swaths of vegetation in some places, and in others it highlights individual trees as circles on the map. Photoperiod and Vegetation Height rasters were then overlain for visual comparison.

Results:

An initial goal of the analysis was to write a script that calculates the path of the sun, using the NumPy Python module, for any Julian Day at any latitude. I was unable to do this in the timeframe of this project, but I was able to generate a list of sun positions in Python that approximated very nearly the sun's path during a day in the growing season. The cumulative photoperiod map (Figure 6) produced using this method stands up to visual inspection and does seem to highlight areas on the inside of canyon walls as areas that do not receive sunlight.

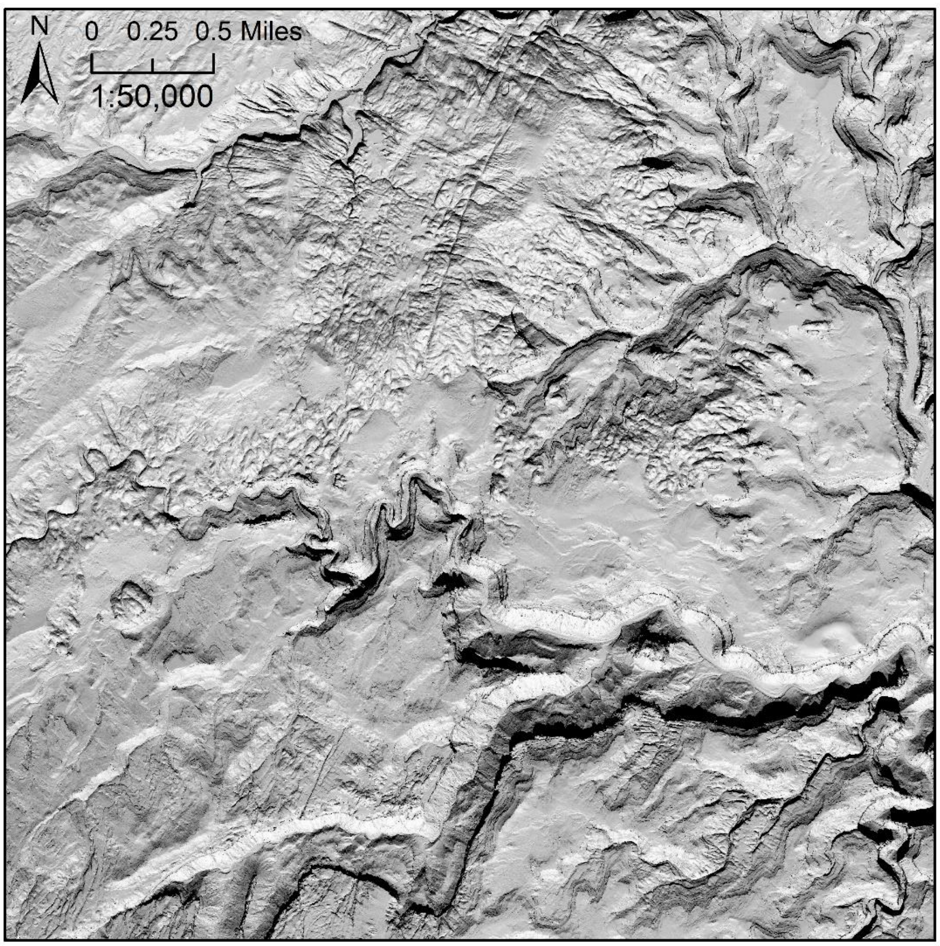

Figure 3: Hillshade at increment = 45, near solar noon. Notice how illumination values are much higher throughout landscape than at increment 3.

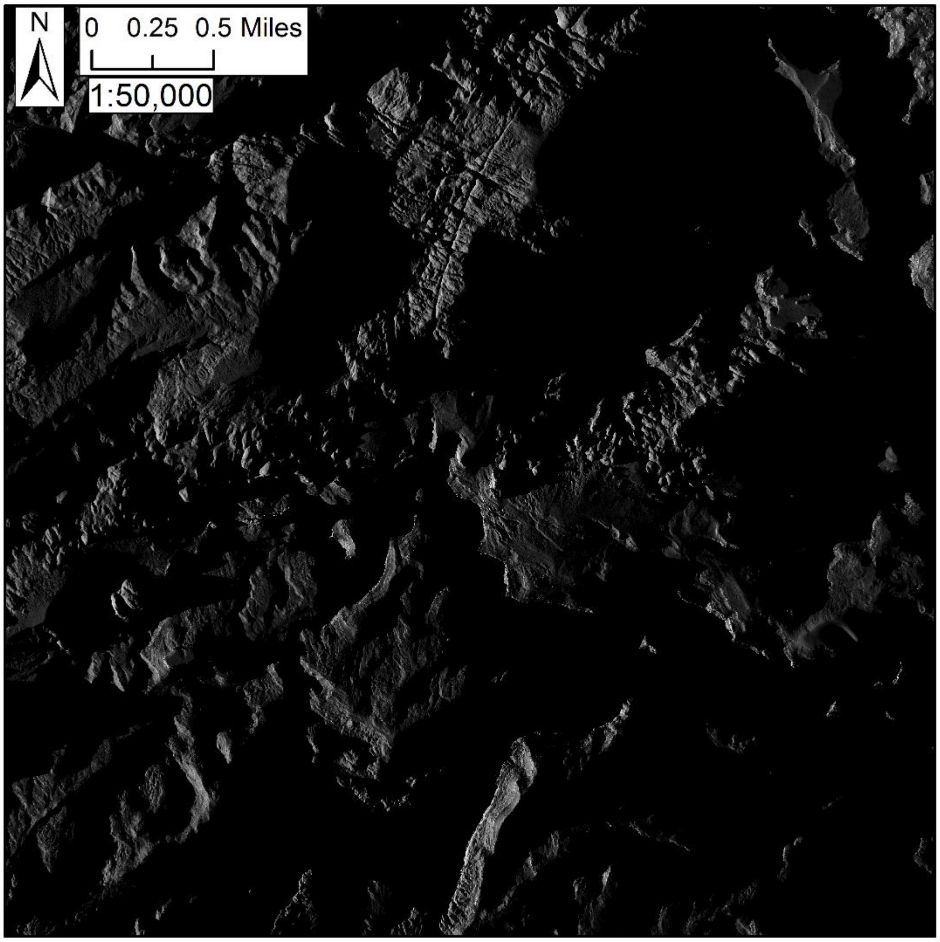

Figure 5: Hillshade at increment = 87, approximately 30 minutes before sunset. Notice how shadows fall to east side of topographic irregularities, because sun rises in west.

Furthermore, many of these areas of darkness are on the southeast to southwest sides of canyon walls, which makes sense given that this area is in the Northern Hemisphere.

It is not clear, based on the vegetation height map, if short photoperiod can be clearly correlated with low vegetation height on a cell-by-cell basis. Figure 7 shows the map of the area for which vegetation height was produced. Note that this is a subset of the dataset, because only some areas of the larger study area actually had significant in-channel vegetation. Figure 8 shows, in more detail, two of the areas where a lot of vegetation could be seen in channels.

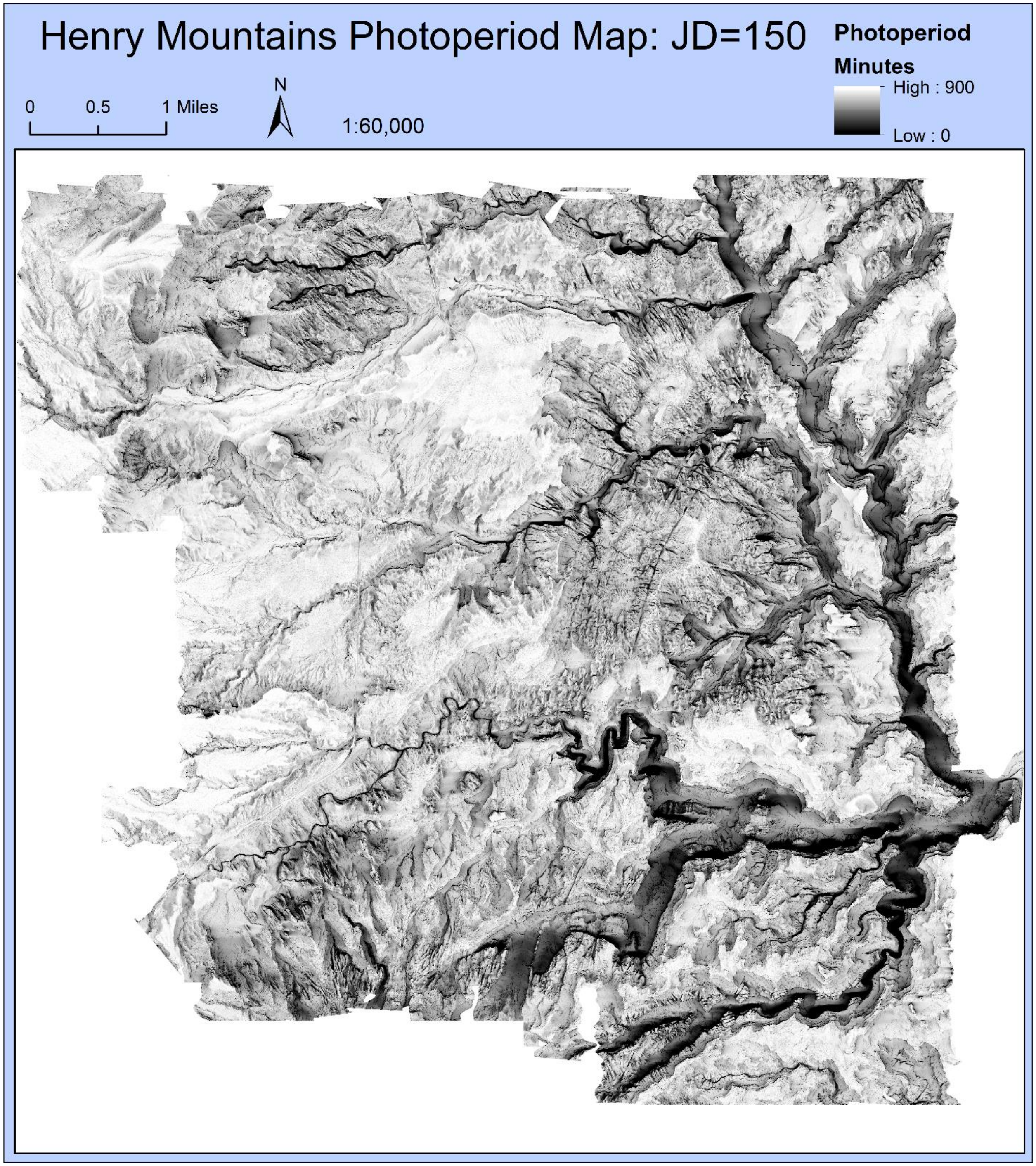

Figure 6: Cumulative photoperiod map for Henry Mountains, UT.

Some areas of low photoperiod do show very little vegetation, especially in the bottom portion of Figure 8. In some areas, however, a step on a cliff face may be appearing as a low photoperiod

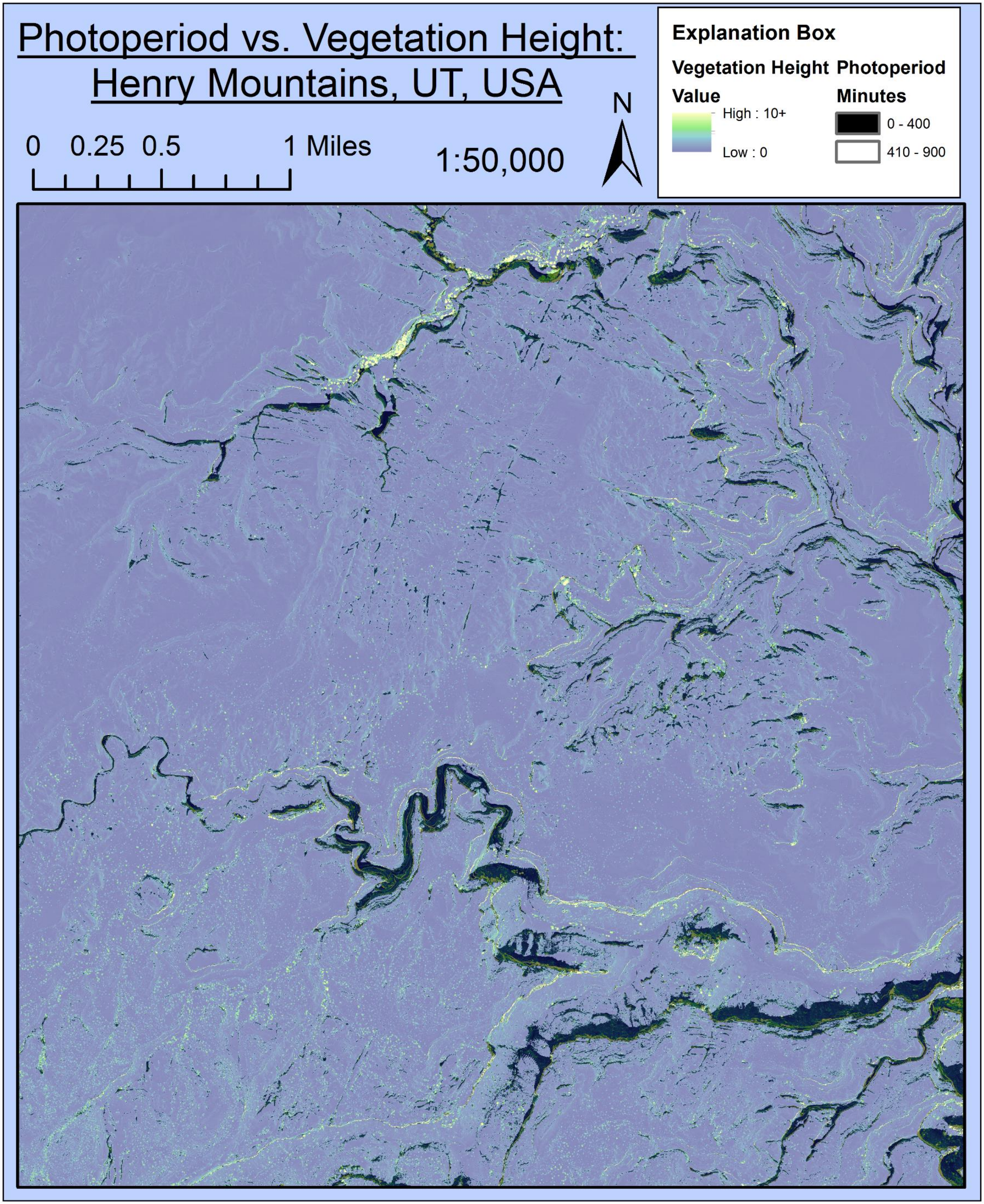

Figure 7: Map of Vegetation Height overlaid on map of cumulative photoperiod. Note that this extent is subset of larger study area, to highlight areas where vegetation is actually prevalent in canyon bottoms.

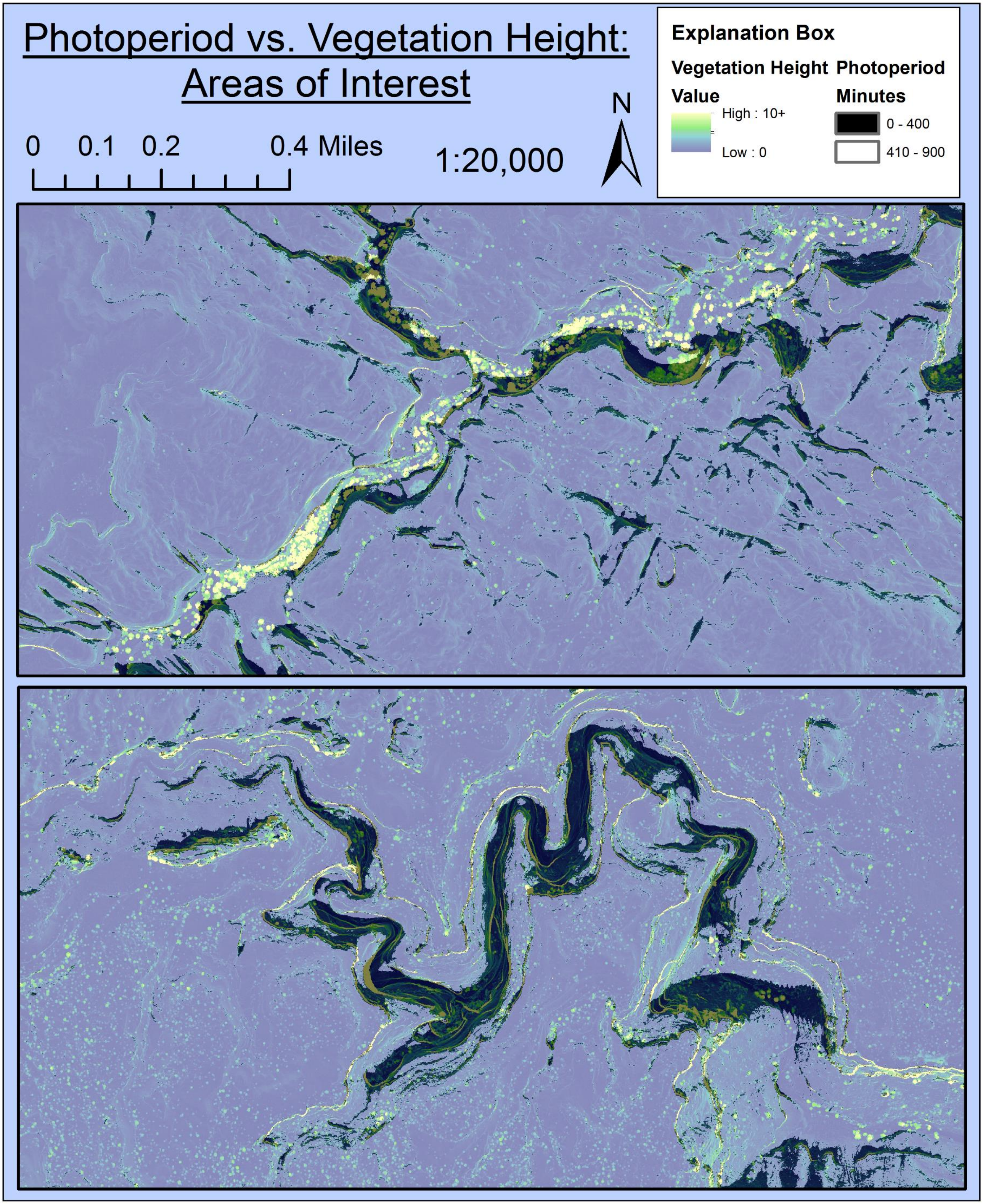

Figure 8: Map of Vegetation Height overlaid on map of cumulative photoperiod. Two areas of dataset shown at higher zoom to show detail.

area with little vegetation (i.e. positive correlation) when it is in fact an area of bare rock that cannot support vegetation. Another issue with this analysis that likely is hindering the correlation of our two variables is the fact that water is probably more of a limiting factor on plant growth than sunlight is in this environment. The fact that water tends to accumulate in topographic lows, which are the exact areas highlighted as having low photoperiod, means that it is harder to see the correlation expected. Plant species distribution, rather than plant distribution in general, might be a more convincing dataset if we were trying to examine the effects of terrain-controlled photoperiod differences on a landscape.

Appendix:

```
# Make a raster with photoperiod length values stored in each cell based on sun's position throughout the day in a high-relief environment


# Import necessary modules
import numpy as np
import arcpy
from arcpy import env
env.workspace = "C:\Users\ps29626\Documents\Photoperiod_Runs"


# Ask user for Latitude, Longitude, Julian Day
Lat = float(input("Latitude?: "))
JD = float(input("Julian Day?: "))
DEMin = input("DEM File name?: ")


# Calculate sun altitude angle vector
# Find Latitude and declination in radians
# Convert lat to radians
LatRad = np.radians(Lat);
# Calculate declination angle
Dec = 23.45*np.sin((360/365)*(JD+284));
```

```
# Convert declination to radians

DecRad = np.radians(Dec);



# Create Vector of all possible Hour Angle vectors

# Find Hour Angle at sunrise/sunset

HrAMaxRad=np.arccos(-np.tan(LatRad)*np.tan(DecRad));

# Calculate 10 minutes in radians

CF=np.radians(15/6);

# Find how many 10-minute increments in half of day

DayLength=np.floor(HrAMaxRad/CF);

# Create vector of all 10 minute increments

PossHrA=np.linspace(CF*-DayLength,CF*DayLength,2*DayLength+1);

# Convert Hour Angle vector to Altitude Angle vector

PossAltARad=np.arcsin((np.sin(DecRad)*np.sin(LatRad))+(np.cos(DecRad)*np.cos(LatRad)*np.cos(PossHrA)));

# Convert Altitude Angle vector to Radians

PossAltA=np.degrees(PossAltARad);




# Calculate Solar Azimuth Angle
```

```
PossAziARad=np.arccos((np.sin(DecRad)-
(np.sin(LatRad)*np.sin(PossAltARad)))/(np.cos(LatRad)*np.cos(PossAltARad)))

# Convert to degrees

PossAziA=PossAziARad*(180/np.pi);

# Change negative angles to compass directions

Length=len(PossAziARad)

for i in range(len(PossAziARad)):

        if i>=(int(Length/2)+1):

                Corr=180-PossAziA[i]

                PossAziA[i]=180+Corr

        elif PossAziA[i]<180:

                PossAziA[i]=PossAziA[i]

        else:

                if Lat>Dec:

                    PossAziA[i]=180

                else:

                    PossAziA[i]=0



# Perform Hillshade for each timestep

for i in range(len(PossAltA)):

        print("Running instance ",i," of ",len(PossAltA))
```

```
        newhs="HSOut_{}".format(i)
        arcpy.HillShade_3d(DEMin,newhs,PossAziA[i],PossAltA[i],"SHADOWS",1)
        if i==0:
                arcpy.Reclassify_3d(newhs,'VALUE',"0 0 0;1 255 1",'PP_Map_{}.tif'.format(i+1),"0")
        else:
         oldhs="HSOut_{}".format(i-1)
                oldfile="PP_Map_{}.tif".format(i)
                newfile="PP_Map_{}.tif".format(i+1)
                arcpy.Reclassify_3d(newhs,'VALUE',"0 0 0;1 255 1",'ReOut.tif',"0")
                arcpy.Plus_3d(oldfile,'ReOut.tif',newfile)
                arcpy.Delete_management(oldfile)
                arcpy.Delete_management(oldhs)
                arcpy.Delete_management('ReOut.tif')
arcpy.Times_3d(newfile,10,'PP_Map.tif')
```