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Vegetation Habitat Mapping of Mammoth Cave National Park Using Multi-date Landsat-8 Imagery and Lidar data

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Introduction

Vegetation has considerable impacts on almost all land surface energy exchange processes, acting as an interface between land and atmosphere (Tong et al., 2016). Vegetation not only forms essential habitats for plant and animal species but is also a prerequisite for ecosystem function. Habitat type is the collective land area where one plant association occupies, or potentially will occupy in the absence of disturbance (Daubenmire, 1952). The habitat classification system was initially developed by Daubenmire and Daubenmire (1968) and later modified and adopted as a model for habitat classification in other areas, including the Mammoth Cave National Park.

Aspect and slope are alternatives for the spatial and temporal distribution of factors such as solar radiation, moisture and temperature that affect species composition and productivity (Stage and Salas, 2007). Differences in insolation period and intensity change with aspect, thereby forming a range of microclimates in multifaceted landscapes (Holland and Steyn, 1975). In general, aspect can have important influences on climate as well as the distribution of vegetation types. In the northern hemisphere, the north side of slopes often have more shaded area than the south side, which receives less solar radiation. South-facing slopes tend to be more xeric (dry) due to high levels of evapotranspiration than a north-facing slope. For example, there is a significant contrast between vegetation types on the north-facing and south-facing slopes observed in Villány Mountains (Hungary) (Khan et al., 2011; Nazarian et al., 2004; Erdős et al., 2012). The north-facing slopes bear shrubby vegetation, whereas forests occurs on the south-facing hillsides (Armesto and Martínez, 1978; Khan et al., 2011). This suggests that variations in aspect may have a great influence on the floristic and life-form composition of the vegetation (Armesto and Martínez, 1978).

The steepness of a slope can also affect the growth of plants through receiving different solar radiation. In addition, the gradient of slope influences the availability of water to the vegetation. The steeper the slope, the more likely that rain will run off rather than infiltrate. Therefore, steep slope tends to hold less water and the soil will be more xeric.

For a given climate, bedrock geology largely determines soil types, and whether surface or subsurface (karst) drainage prevail. Due to the tendency for subsurface drainage to develop in calcareous bedrock such as limestone, these sites will be more xeric than an equivalent situation underlain by sandstone or shale. The magnitude of this general difference appears to be minimized on the steepest exposures due to rapid surface drainage.

There have been several attempts to map the vegetation and habitats at the Mammoth Cave National Park in the last decades with limited success due to lack of access in parts of the park and lack of high resolution remotely sensed data. In 2010, the Park acquired high resolution Lidar data for detailed mapping. The Park is now in the process of updating their Fire Management Plan that calls for an updated habitat map to facilitate the designation of fuel types. The primary goal of this research is to classify physical attributes (bedrock geology, slope, aspect) of plant habitats to create a predictive digital habitat model for the Mammoth Cave National Park (MCNP). The resultant vegetation habitat map is valuable for fire management and wildlife habitat and biodiversity conservation analysis.

Study Area

Mammoth Cave National Park (Figure 1) is located at latitude 37.2° North and longitude 86.1° West in south central Kentucky. Mammoth Cave National Park has the world's largest network of natural caves and underground passageways, which are characteristics of limestone formations. Established in 1941, Mammoth Cave

National Park is also a World Heritage Site. The park and its underground network of more than 560 surveyed-km of passageways are home to a varied flora and fauna, including a number of endangered species. The park's 52,830 acres (21,380 ha) are located primarily in Edmonson County, Kentucky, with small areas extending eastward into Hart County and Barren County.

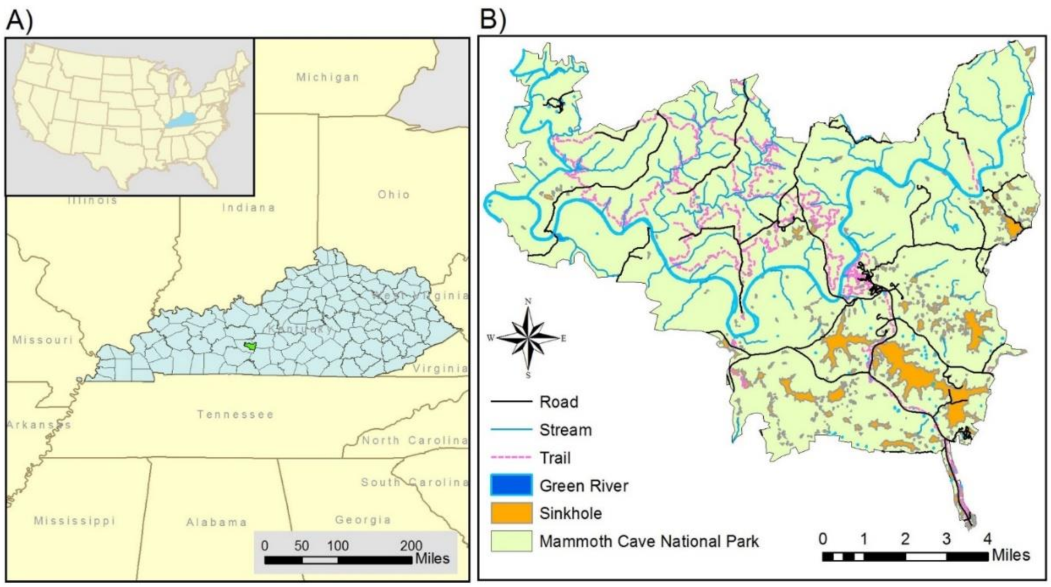

Fig.1: A) The geographic location of the Mammoth Cave National Park

B) The geographic features of Mammoth Cave National Park

Kentucky has a moderate climate, characterized by warm, yet moist conditions. Summers can average in the mid-90s (F) (32℃), while winters average in the low 40s (F) (9℃). Much of the park's average annual 52 inches (132cm) of precipitation falls in the spring. Storms occur year-round, though most occur March-September. Year-round, the cave temperature in interior passages fluctuates from around 54º (F) (12℃) to 60º (F) (15℃). Winter temperatures, however, can be below freezing at the cave entrances.

Data Sources

Airborne Light Detection and Ranging (LiDAR) dataset was provided by the Mammoth Cave National Park. The LiDAR dataset was acquired between Oct 13th and 17th, 2010, with derived digital elevation model (DEM) of 1 m pixel resolution.

We also obtained bedrock geology dataset from the Park. The geology categories were Alluvium, Calcareous, Calcareous Sub-Xeric, and Acid. “Alluvium” referred to river lain sediment. “Calcareous” referred to carbonate bedrock, which resulted in more alkaline soil. “Acid” referred to non-carbonate bedrock, which resulted in acid soil. Xeric referred to dry area.

Model Configuration

Discussions with the Park staff and field trip to the Park provided the knowledge and scheme for habitat classification. Table 1 lists the full array of habitat types based upon physical attributes of bedrock type, slope, and aspect. Figure 2 and 3 show how the combination of moderate and steep slopes with limestone or sandstone bedrock are assigned to habitat classes based on aspect. The 360 degrees of aspect are grouped into 16 wedges of 22.5 degrees each. For different levels of slopes, the corresponding aspect ranges determined how xeric or mesic the habitat type are. Supra-Mesic conditions were on the moist end of the Mesic, but not saturated or hydric. Mesic conditions were moderately moist. Sub-Mesic conditions had less moisture when compared to Mesic. Sub-Xeric conditions were intermediate between Xeric and Mesic.

1. Calcareous Xeric a. Southeast to West	Compass bearings 180-247
2. Calcareous Sub-Xeric a. Flat b. Moderate Southeast c. Moderate Southwest d. Steep Southeast e. Steep Southwest	 – 112-180 247-292 90-180 247-315
3. Calcareous Mesic a. Moderate Northwest to Southeast b. Steep Northeast	 292-112 045-90
4. Calcareous Supra-Mesic a. Steep Northwest to Northeast	 315-045
5. Acid Xeric a. Steep Southeast to Southwest	 157-247
6. Acid Sub-Xeric a. Moderate Southeast to West b. Steep Southeast c. Steep Southwest	 135-270 135-157 247-270
7. Acid Mesic a. Flat (+ Hydro-Mesic vernal Pords) b. Moderate West to Northwest c. Moderate Northeast to Southeast d. Steep West to Northwest e. Steep Northeast to Southeast	 – 270-315 045-135 270-315 045-135
8. Acid Supra-Mesic a. Moderate Northwest to Northeast	 315-045
9. Floodplain Alluvium	–

Table 1. Habitat physical attribute classification

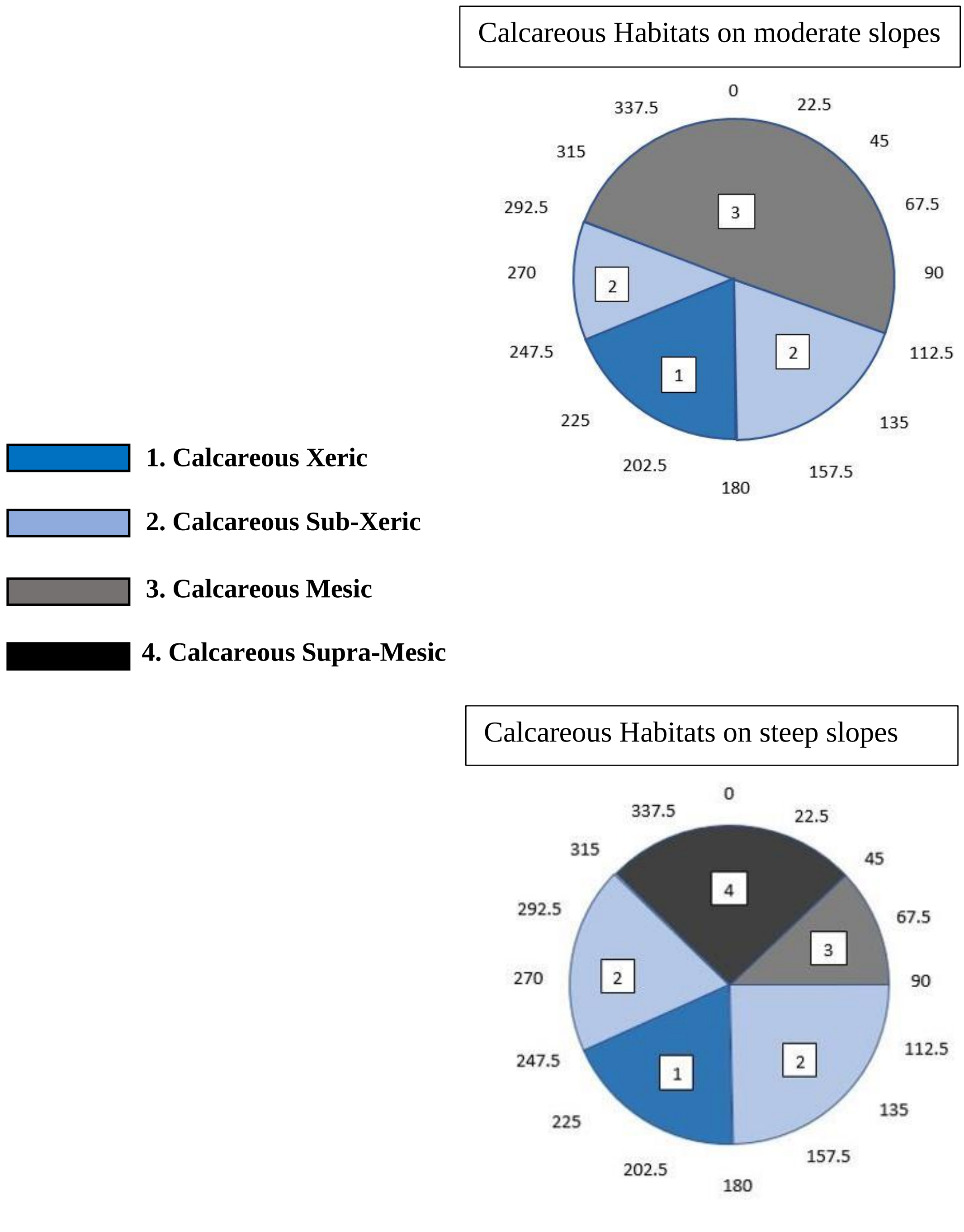

Fig. 2: Limestone assigned to Calcareous habitat based on slope and aspect

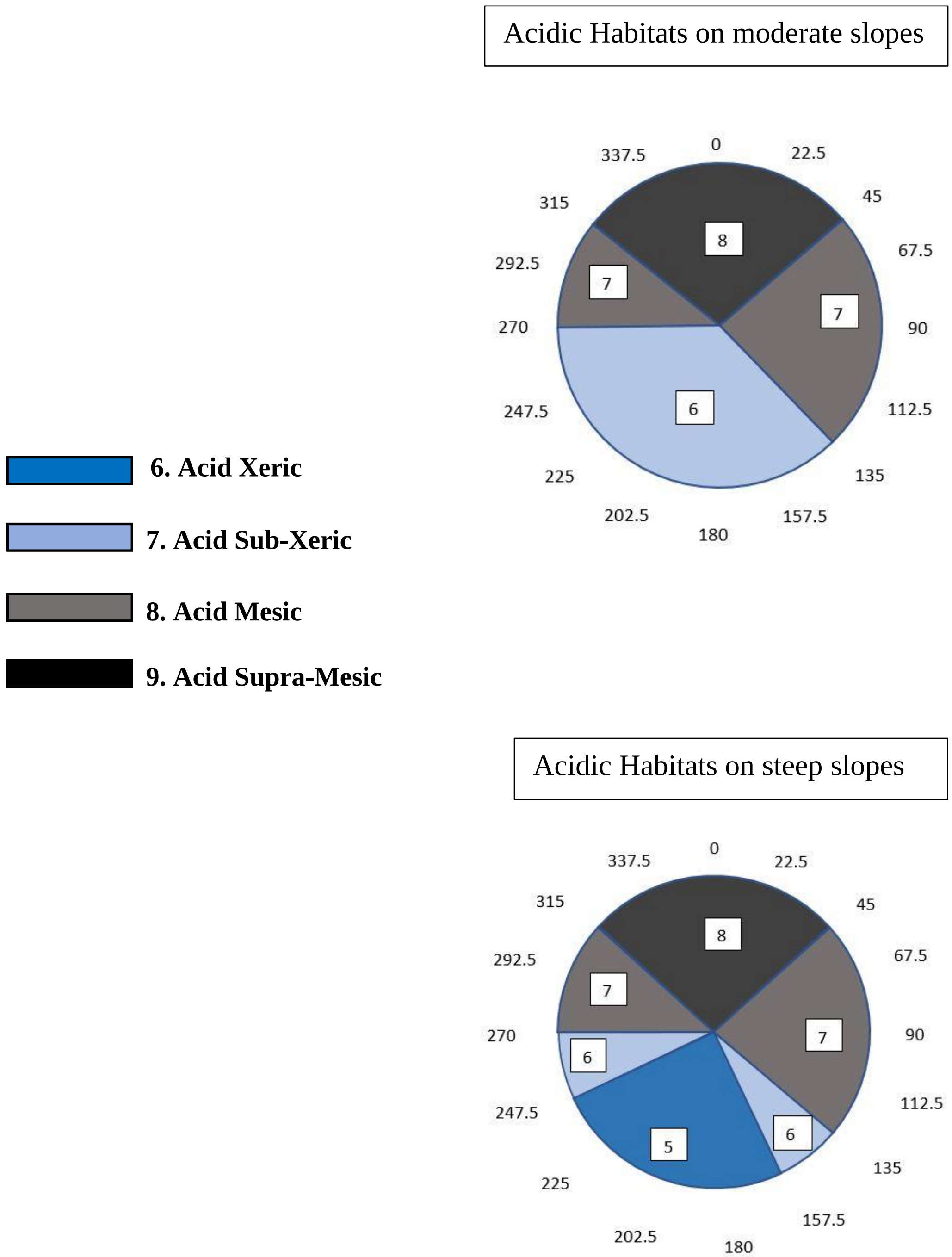

Fig. 3: Sandstone assigned to Acid Habitat based on slope and aspect

Data Preparation

We calculated aspect and slope from LiDAR-derived DEM data and reclassified them. The categories of slope were divided into flat (0-4.9 degrees), Moderate (5-22.9 degrees), Steep (23-90 degrees), as suggested by Park management based on their field observation and experience. The 360 degrees of aspect were grouped into 16 wedges of 22.5 degrees each.

The geology dataset was simplified into broader categories: Alluvium, Calcareous, Acid, and Calcareous Sub-Mesic. Calcareous sediments mostly contain a large portion of calcium carbonate while Acid are mainly formed by sandstone caprock. Calcareous Sub-Mesic rocks are caprock limestone where limestone units are found on top of insoluble sandstone that create moist conditions on the surface of upland areas.

GIS Overlay and classification

GIS overlay function was applied to determine habitat types by integrating aspect, slope and bedrock geology. Given the bedrock geology types, certain slope combined with certain aspect can determine the habitat types (Table 1). For example, moderate Calcareous with an aspect of 135° will be Calcareous Sub-Xeric habitat type.

Results

The LiDAR-Derived DEM shows that the highest elevation is 287 m and the lowest 107 m (Figure 4). Lower elevation values are near streams and the Green River while higher elevation areas are in northwest and southeast portions of the Park.

Figure. 5 shows the resultant map of slope reclassification. Most areas at lower elevation (except water areas) had moderate to steep slopes, indicating that gullies or depressions existed in those regions. Therefore, these shaded regions tended to be more mesic (moisture-laden) than sun-exposed areas. In contrast, areas at higher elevation with steep slopes tend to divert water away fast, which caused more xeric (dry) conditions.

The amount of solar radiation on the landscape changes during a day and seasonally, according to the aspect that the slope is facing. Aspect values fell between 90° and 270° would be regarded as south-facing slopes and values fell between 270° and 90° would be counted as north-facing slopes (Figure 6). Typically, south-facing slopes are exposed to much more sunlight compared to north-facing slopes in the northern hemisphere. Thus, south-facing areas were more xeric while north-facing slopes regions were more mesic.

The geology reclassification map (Figure 7) shows the distribution of Calcareous, Acid and Calcareous Sub-Mesic bedrock types. Lower elevation areas are mostly Calcareous bedrock, which is the dominant bedrock south of the Green River in the Park. Acid bedrock, on top of Calcareous bedrock, spreads throughout the park. Higher elevation areas are mainly Calcareous Sub-Mesic bedrock, which is the very top caprock limestone over insoluble sandstone.

Figure 8 is the habitat resultant map considering bedrock geology, aspect, and slope. The two major habitat types were largely determined by bedrock geology (Table 2). The various habitat types formed are due to the variation of slope and aspect. Most of Calcareous-Xeric and Calcareous habitat areas are in southeastern part while Calcareous Sub-Mesic habitat spread across the Park. The Acid Xeric and Acid Sub-Xeric habitat mostly were in northwestern part while moderate elevation regions in southeast formed Acid mesic habitat.

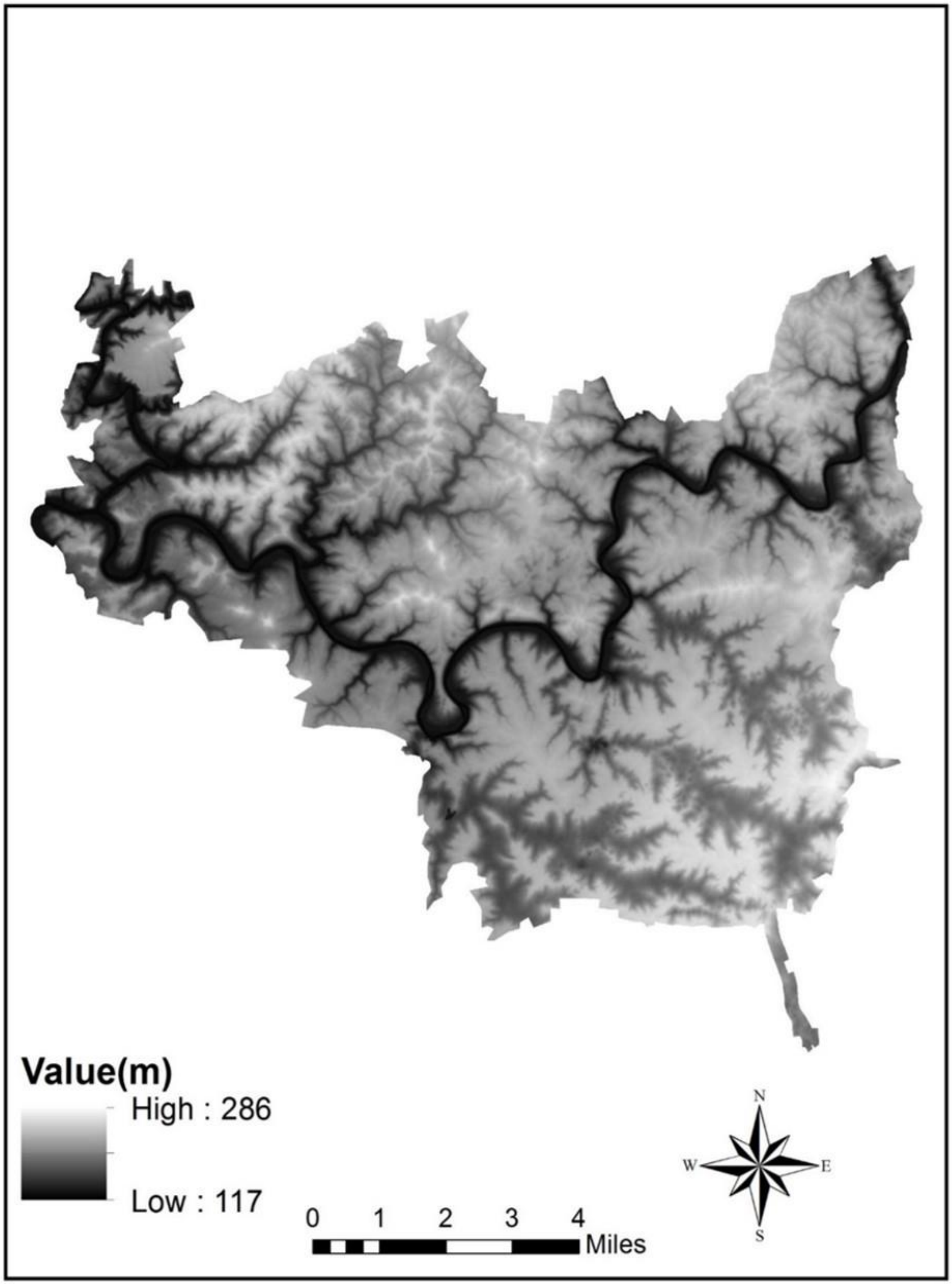

Fig. 4: Derived Digital Elevation Model of LiDAR Dataset

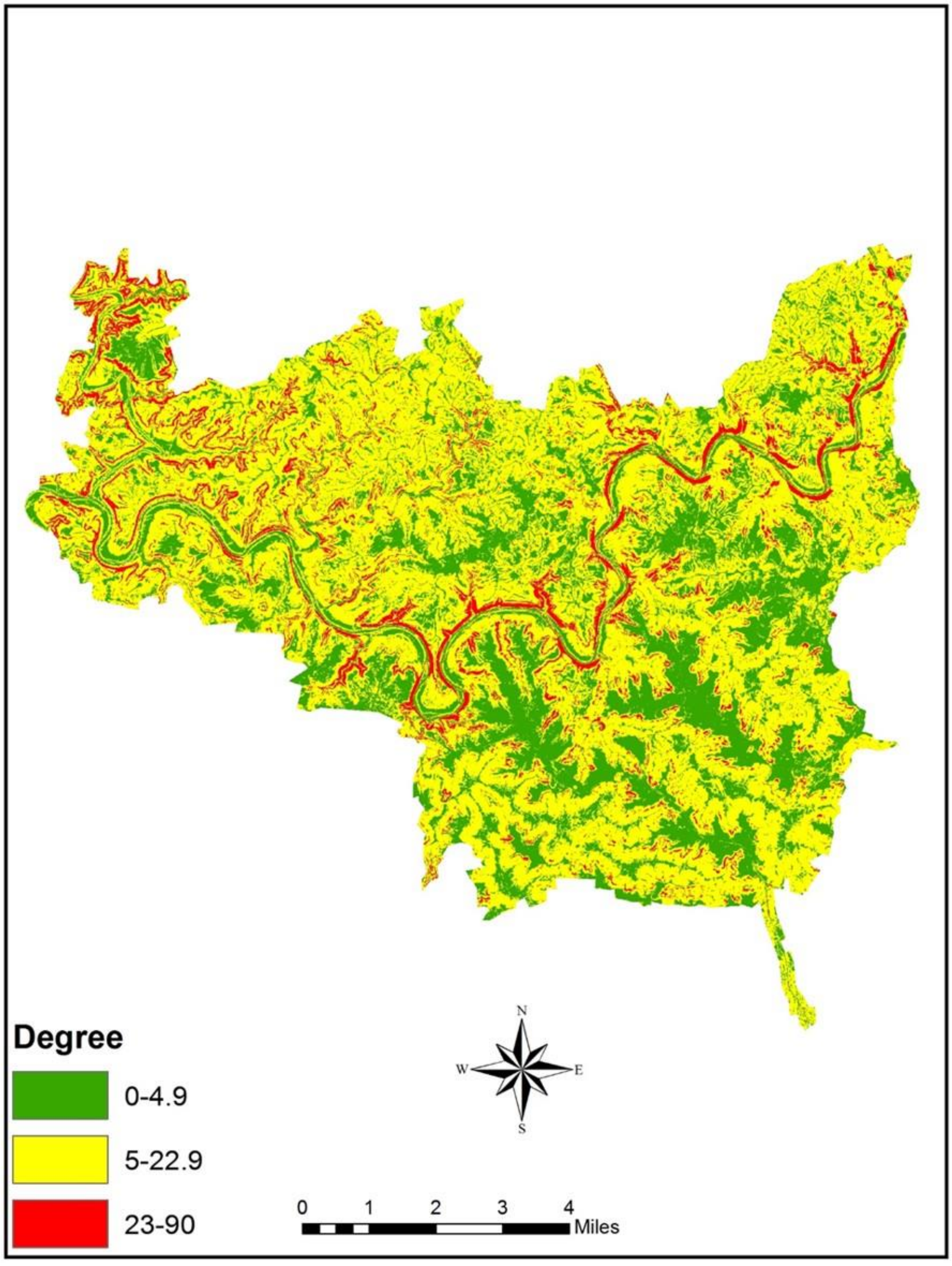

Fig. 5: Slope Reclassification of Mammoth Cave National Park

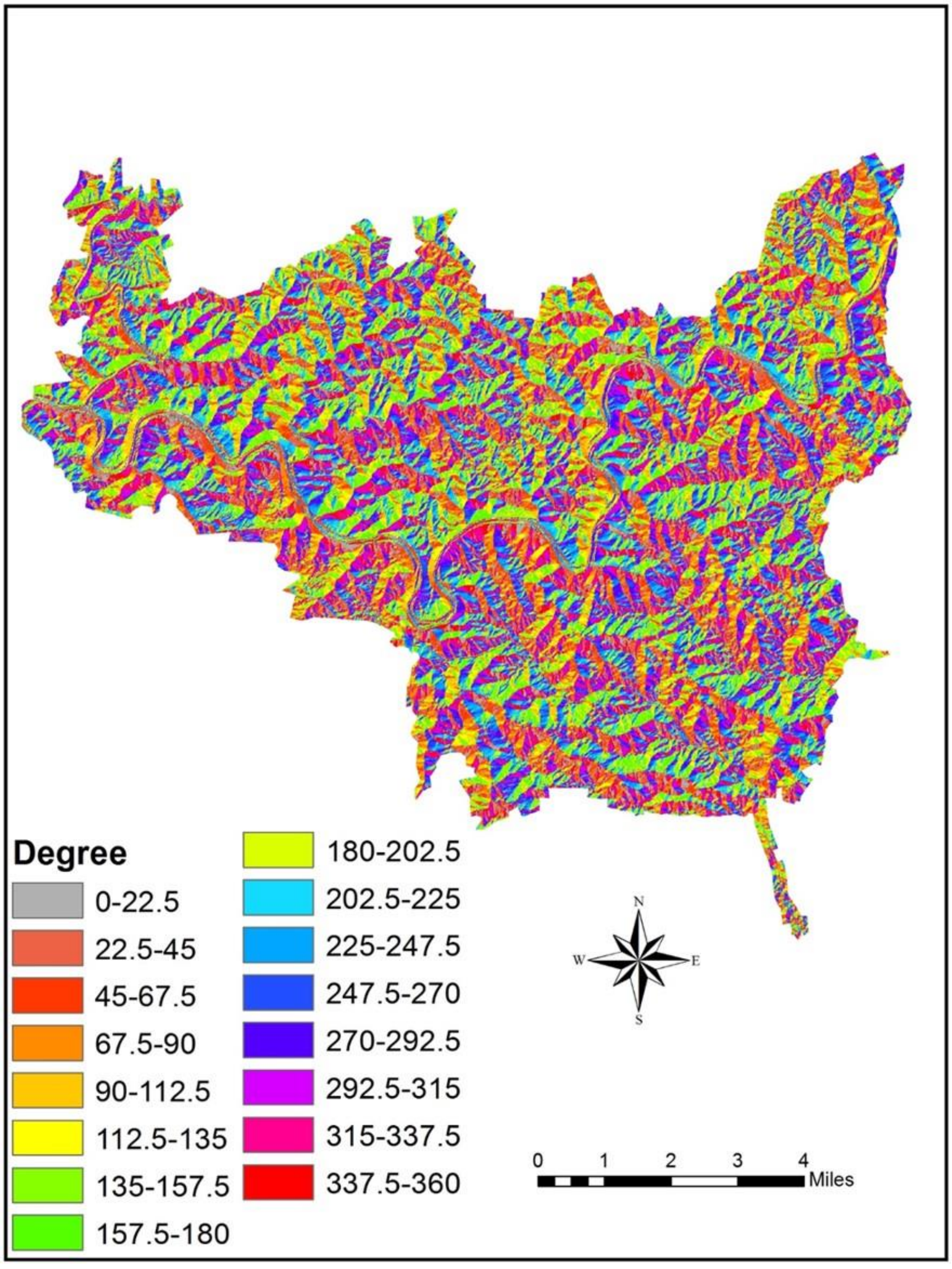

Fig. 6: Aspect Reclassification based on Digital Elevation Model

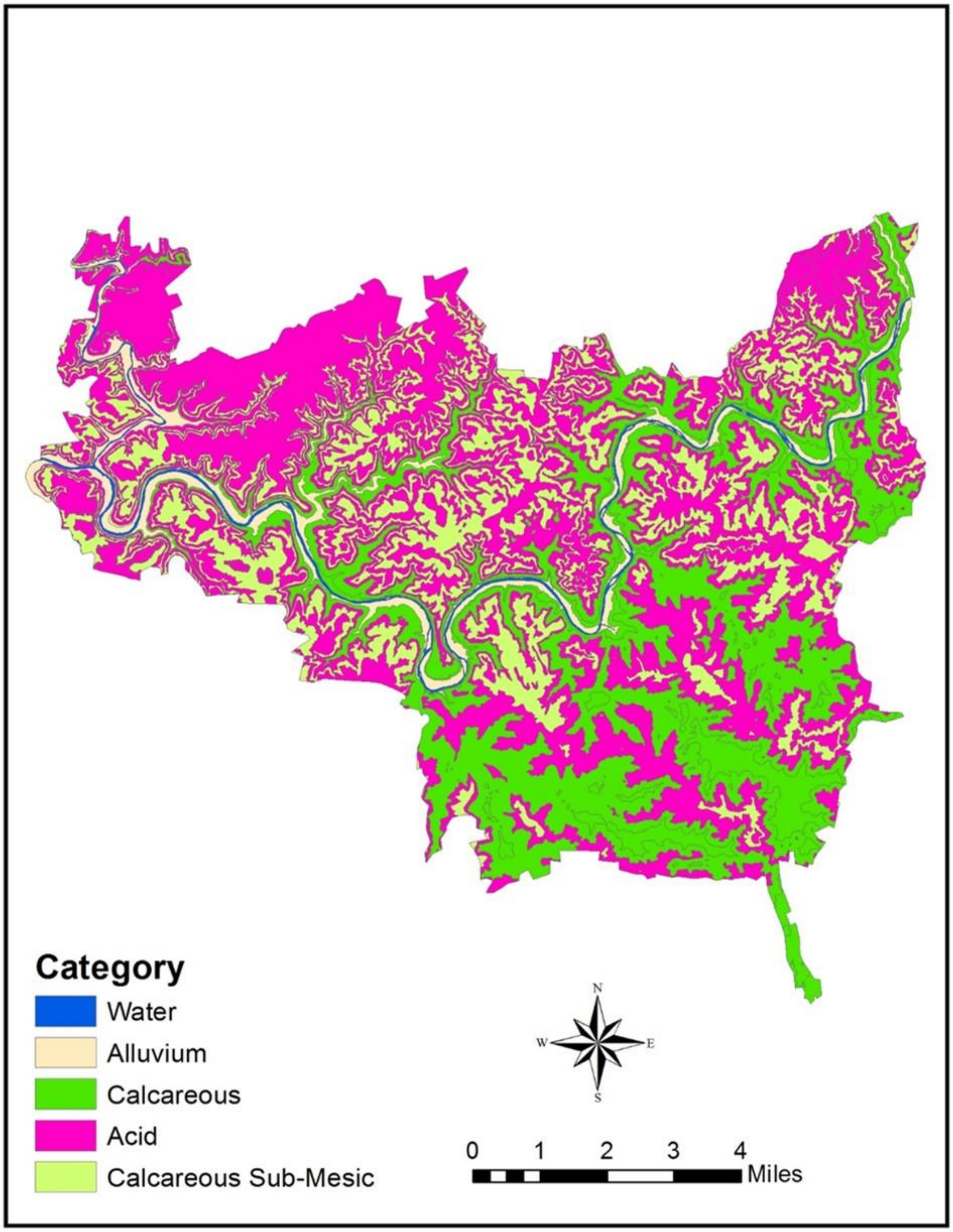

Fig. 7: Bedrock Geology Raster Reclassification Dataset

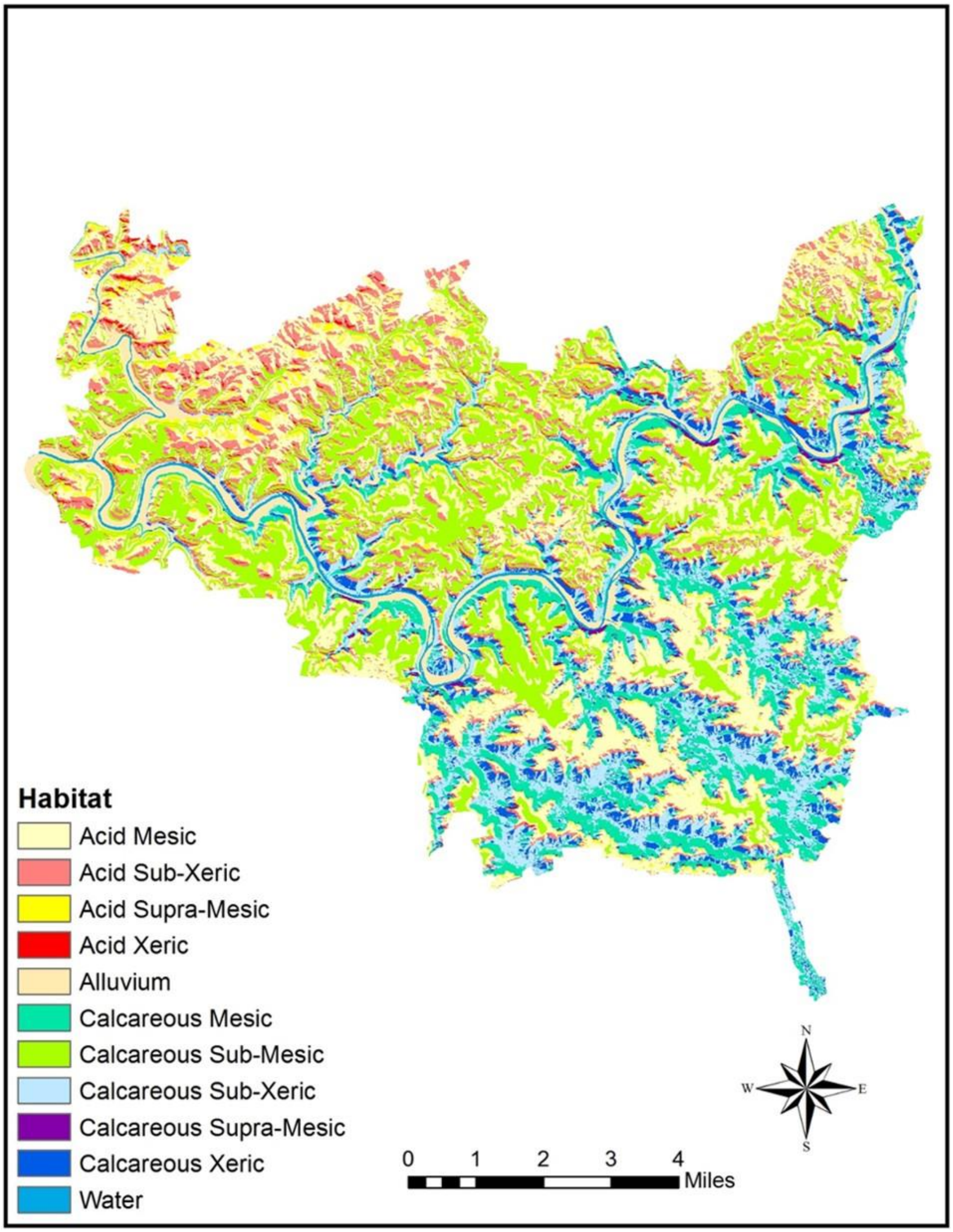

Fig. 8: Habitat physical attributes map based on geology, slope, and aspect

Habitat Type	Acreage	Percentage of the Park (%)
Calcareous Supra-Mesic	**440.41**	**0.87**
Calcareous Mesic	**5,667.45**	**11.18**
Calcareous Sub-Mesic	10,662.63	21.03
Calcareous Sub-Xeric	5,995.60	11.83
Calcareous Xeric	2,448.75	4.83
Alluvium	**2,036.59**	**4.02**
Acid Supra-Mesic	**2,180.86**	**4.30**
Acid Mesic	14,832.60	29.26
Acid Sub-Xeric	5,962.35	11.76
Acid Xeric	466.28	0.92

Table 2. Habitat type area in hectares and the corresponding percentages by the Park in 2017

Habitat types in regular typeface are capable of carrying fire during the spring and fall fire seasons. These habitat types account for approximately three-fourths of the park (Olson and Noble, 2005). Habitat in bold in Table 2, which account for approximately one-fourth of the park, do not support fire independent or –tolerant plant communities (Olson and Noble, 2005). Based on the table, it can be inferred that Acid and Calcareous are the two dominant habitats within the park, which accounted for 46.24% and 49.74% of the total park area respectively (Table 2). Acid Mesic had the largest areas of a single category followed by Calcareous Sub-Mesic, which accounted for 29.26% and 21.03% respectively. Calcareous Supra-Mesic and Acid Xeric accounted for less than 1%. Calcareous Mesic, Calcareous Sub-Xeric and Acid Sub-Xeric habitat types occupy about the same area in the Park (11-12%). The remaining three habitat types are less than 5% each.

Conclusion

Habitat types are controlled by a combination of bedrock geology, aspect, and slope. The underlying rationale is that bedrock geology largely determines soil types and drainage, while aspect and slope determine the amount of light and moisture. Based on recently acquired Lidar dataset and bedrock geology, we modeled the habitats inside the Mammoth Cave National Park. Our results show that Acid and Calcareous are the two dominant habitats. Calcareous habitats are found throughout the park over limestone bedrock. Acid Xeric and Acid Sub-Xeric habitats mostly are in the northwest part while the moderate elevation region in southeast formed mostly Acid mesic habitat. Calcareous Sub-Mesic habitats formed where limestone overlays on top of sandstone and does not drain very well.

Vegetation habitat types provide baseline data set for the development of successional plant community classification for Mammoth Cave National Park (Cooper et al., 1991). Habitat also provides a natural plant stratification within the Park area (Cooper et al., 1991). Furthermore, it acts as a means of predicting both site quality and response following disturbance (Cooper et al., 1991). The fire-vulnerable habitat types account for one-fourth of the total Park area and the rest are fire-resistant habitat types. The location of the fire-vulnerable habitat types can provide critical information for the Park's fire management, for classification of fuel types and for delineation of fire management units.

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