# The Geological Foundation for Prescribed Fire in Mammoth Cave National Park

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## Karst landscape overview

The 52,830 acres of Mammoth Cave National Park are part of the South-Central Kentucky Karst, which is characterized by subterranean drainage to springs on major rivers. From the southeast to the northwest portion of the landscape (Figure 1), there is a gradient of decreasing maturity in karst development, which corresponds to the regional dip of the bedrock. The major cave-bearing limestones are barely exposed in the northwest part of the park, so cave development there is in the earliest stages. The Sinkhole Plain located south of the park is an example of highly developed karst, and the geology here had profound effects on fire propagation and vegetation until land use changes that came with settlement.

## Surface habitat types in the park

A vegetation habitat classification was developed for Mammoth Cave National Park that combines bedrock geology, slope, and aspect in the park's GIS (geographic information system; Olson and Franz 1998). For a given climate, bedrock geology largely determines soil type, and whether surface or subsurface (karst) drainage prevails. Due to the tendency for subsurface drainage to develop in calcareous bedrock such as limestone, these sites will be more

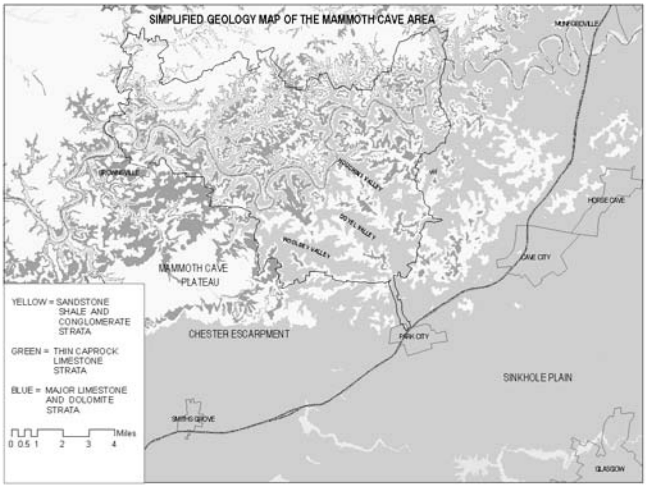

Figure 1. Simplified geology map of Mammoth Cave National Park. Note the connectivity between the Sinkhole Plain and the major karst valleys within the park. Fires set by Native Americans on the sinkhole plain could have easily spread to the karst valleys, although there is no documentation of that. Note also that the habitat type in the valleys is the same as on the Sinkhole Plain, and the lack of water due to underground drainage can facilitate fire propagation.

xeric (dry) 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.

One significant attribute of the habitat map is that natural physical influences on vegetation types are made clear in a quantitative way that is not attainable by direct study of geological quadrangle maps (see Table 1). This is especially important given the complex history of cultural disturbance over the past two centuries since settlement, and the profound impact on vegetation patterns seen today. The vast majority of coniferous forest stands in the park today are linked to pre-park agriculture. Local environmental conditions amenable or inimical to fire are controlled directly and indirectly by the factors that determine habitat type. For example, at over 9,000 acres, the calcareous mesic habitat type is important for two reasons: the change in fuel type on these shaded slopes (Tim Sexton, NPS national fire ecologist, pers. comm., 2000), and the fact that the great linear extent of these habitat patches will impede the progress of fire across the landscape.

Table 1. Areal extent of habitat classes in the park. 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. Habitat types in bold, which account for approximately one-fourth of the park, do not support fire-dependent or -tolerant plant communities.

| *Habitat Type* | *Acreage* | *Percentage of park* |
|---|---|---|
| Calcareous xeric | 150 | <1 |
| Calcareous sub-xeric | 15,400 | 30 |
| **Calcareous mesic** | **9,050** | **18** |
| **Calcareous supra-mesic** | **130** | **<1** |
| Acid xeric | 60 | <1 |
| Acid sub-xeric | 2,500 | 5 |
| Acid mesic | 20,000 | 40 |
| **Acid supra-mesic** | **1,000** | **2** |
| **Alluvium** | **2,700** | **5** |

## Park vegetation and fire regime in relation to geology

Vegetation in the park was classified into seven categories (Table 2) and mapped in the park GIS based upon individual sorting of 200 Landsat satellite spectral data channels using the habitat map as a guide (Olson et al. 2000). This vegetation classification was condensed in order to facilitate designation of fuel types for the park's fire management plan. Fuel model and fire regime group designations were completed by fire ecologist Caroline Noble of the National Park Service's (NPS's) Southeast Regional Office. Fire regimes groups were estimated based on current vegetation. The fire regime classification system utilized is that from Schmidt et al. (2002).

| Vegetation | Habitat Type | Typical Species | Fire Regime Group |
|---|---|---|---|
| 1. Subxeric deciduous forest / savanna | Acid subxeric | chestnut oak<br>post oak | I<br>Frequent, 0–35 years, surface and mixed severity |
| | Calcareous subxeric | chinkapin oak<br>blackjack oak<br>post oak | |
| 2. Mesic upland deciduous | Acid Mesic<br>Calcareous subxeric (thin beds) | white oak<br>pignut hickory<br>black oak | I<br>Frequent, 0–35 years, surface and mixed severity |
| 3. Mesic hollow / floodplain deciduous forest | Calcareous mesic<br>Acid mesic<br>Alluvium | sugar maple<br>beech<br>box elder<br>sycamore | V<br>Rare, >200 years, stand replacement severity |
| 4/5. Mixed deciduous / coniferous | Acid mesic | red maple<br>tulip poplar | III<br>Infrequent, 35–100 years, surface and mixed severity |
| Mixed coniferous / deciduous forest | Calcareous subxeric<br>Alluvium | dogwood<br>sweetgum<br>cedar/pine | |
| 6. Coniferous forest | Acid xeric to mesic<br>Calcareous xeric to subxeric | Virginia pine<br>eastern red cedar | III<br>Infrequent, 35–100 years, surface and mixed severity |
| 7. Prairie/open area | Calcareous subxeric<br>Acid mesic | native grasses and forbs<br>mown grass | II<br>Frequent, 0–35 years, stand replacement severity |

Table 2. Vegetation, habitat types, and typical species. Habitat type nomenclature follows the system of the Kentucky State Nature Preserves Commission (Evans 1991). "Acid" refers to noncarbonate bedrock, which results in acid soil, and "calcareous" refers to carbonate bedrock, which results in more alkaline soil. "Xeric" refers to dry areas, "mesic" to moist, and "alluvium" to river-lain sediments. In subxeric deciduous forest, chestnut oak and chinkapin oak sort very distinctly with sandstone and limestone substrates respectively, whereas blackjack and post oaks are less selective. With periodic fire, these forest stands may have been a more open woodland or savanna in the past.

Within mesic upland oak–hickory forests, the chemical and hydrological influence of relatively thin limestone units interbedded with sandstone on the ridges is muted in comparison with the thick limestone beneath karst valleys. This is due to weathered sandstone residuum on top of the limestone, and the limited degree of karst development possible. Karst usually leads to drier surface conditions due to subsurface drainage, but (paradoxically) upland swamps perched on sandstone may have originated as sinkholes in these thinner carbonates, such as the Haney limestone.

Mesic hollow deciduous forests are most prominent in ravines directly connected with the Green and Nolin River floodplains, but small outliers exist in karst valleys in the bottoms of large sinkholes. In addition to beech and maple, black cherry and black walnut can be locally prevalent. Floodplain forests are characterized by sycamore, silver maple, and river birch near streams, and box elder slightly further from the water. Mesic hollows were left relatively undisturbed due to the rugged terrain, which cannot be said for the once heavily farmed floodplain. Being superbly adapted to the highly disturbance-prone gravel bar habitat, sycamore trees are also found wherever significant disturbance has occurred, such as along roads. In exceptionally moist sandstone hollows, mostly found in the northwest extremity of the park, relict stands of hemlock and yellow birch are found. None of these stands are considered to be fire adapted.

Mixed deciduous/coniferous (and vice versa) forests in the park are overwhelmingly successional after pre-park pasture and row crop use. These old fields are generally found in three habitat types: (1) on relatively level uplands with interbedded sandstone and limestone, (2) in subxeric limestone habitats found in karst valleys, and (3) on floodplain alluvium. The nonsuccessional mixed stands are found in sunny, xeric habitat types with the plant community specific to the geologic substrate. Virginia pine associated with chestnut oak is found at the tops of tall sandstone cliffs, and eastern red cedar with chinkapin oak is found on relatively steep limestone slopes. Many of these stands appear to be virgin in contrast to the profoundly disturbed old fields. On xeric limestone sites, solutional features called *rillenkarren* indicate that the thin soil and exposed bedrock is not due to post-settlement erosion.

Coniferous forests in the park, like the mixed stands previously discussed, are overwhelmingly successional after pre-park agriculture. Stands in karst valleys are dominated by eastern red cedar, and those on sandstone uplands are mostly Virginia pine, but considerable mixing occurs.

Prairie in the park is limited to small areas, each no greater than 40 acres, and none can be considered actual remnants from presettlement times. Even so, these areas are rich in prairie grasses and forbs, such as big bluestem, Indian grass, goldenrod, and tall coreopsis. They serve as refuges for species marginalized by conversion of former prairie on the sinkhole plain to agriculture, and by fire suppression within and beyond park boundaries (Seymour 1997). Other open areas in the park are largely mown roadsides, cemeteries, and lawns around developments maintained in fescue.

## Selection of prescribed fire areas

The process for selection of prescribed fire areas with ecological criteria was GIS-based and is shown graphically in Figure 2. Only habitat types that would naturally support fire-dependent or -tolerant vegetation communities were included. Next, vegetation was considered, and the overwhelming majority of prescribed fire areas consisted of vegetation mature enough to benefit from fire. Limited areas of successional vegetation were included as part of an adaptive management strategy, and fire should be

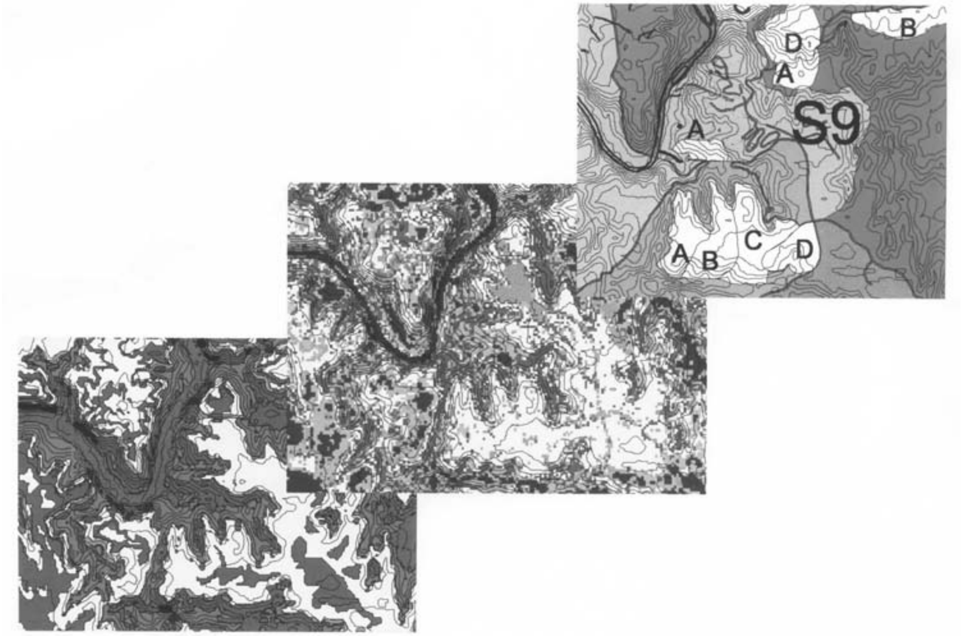

Figure 2. Prescribed fire areas (lettered areas at upper right) were selected on the basis of habitat types (lower left) and vegetation types (center) that are ecologically appropriate for application of fire. GIS-based screening for cultural resources was also conducted.

applied in these areas with caution and careful study of what the restoration goals should be for each habitat and vegetation type.

### Setting fire restoration targets for park vegetation communities

Geology and archaeology provide clues to past vegetation and the role of fire. Miles of cave passages within the park contain abundant artifacts left by Native Americans, mostly between 2,000 and 3,000 years ago. Much of this ancient material consists of plant remains from various uses, and these artifacts provide insight into some presettlement vegetation characteristics under similar climatic conditions (Watson 1969; Watson et al. 1974; Olson 1998). These plant remains preserved in park caves indicate that vegetation conditions other than closed-canopy forest existed since light intensity on the ground beneath a closed canopy would have been inadequate. Given this evidence from park caves, it would not be unreasonable to set a restoration target for some portion of the mesic upland deciduous forest to be open woodland or savanna.

### The question of presettlement vegetation in karst valleys

Historically and prehistorically, barrens bordered by savanna covered large portions of the Sinkhole Plain. Barrens are similar to prairie, and botanist Francois Michaux made some geological observations while studying vegetation in the summer of 1802: "It appears there are a great number of subterraneous caverns in the Barrens, some of which are very near the surface.... We remarked in these meadows several holes, widened at the top in the shape of funnels, the breadth of which varies according to depth" (Michaux 1805). In doing so, he noted both caves and sinkholes, which are the geological foundation for fire-dependent barrens vegetation on the Sinkhole Plain. The lack of surface streams and relatively level terrain facilitates propagation of fire. Karst valleys within the dissected upland of the Mammoth Cave Plateau offer an identical habitat type to the Sinkhole Plain in smaller parcels (see Figure 1), but no historical descriptions of presettlement vegetation have been found.

The ecology of shingle oak *(Quercus imbricaria)* offers some insights into presettlement vegetation. Locally, shingle oak is common and almost exclusively found in karst valleys and the Sinkhole Plain in and near the park, especially at the edge of forest openings (Olson 2003). The fidelity of this species with karst valleys is remarkable. It is rare at any location up on Mammoth Cave Plateau lands that surround all of these valleys. If the occurrence of shingle oak were simply linked to forest openings, then we would expect to find this species up on the plateau since forest openings are common. Shingle oak was historically reported on the Sinkhole Plain near the edges of sinks where fire would be less intense (Baskin and Baskin 1981). In a study of savanna restoration, shingle oak was found to be more fire-resistant than black cherry, and less resistant than bur oak (Hruska and Ebinger 1995). Significantly, this medium-sized tree is an edge species found at transitions between grassland and forest vegetation. The high frequency of shingle oak in karst valleys within the park, the virtual absence of this species on the surrounding Mammoth Cave Plateau even at forest edges, and the presence of shingle oak out on the Sinkhole Plain where prairie maintained by fire was documented, all lead to the hypothesis that presettlement vegetation in the park's karst valleys was at least a mosaic of grassland and forest. Therefore, consideration should be given to pursuing this as a working hypothesis with restoration goals set limited in scale.

## Fire effects monitoring and adaptive management

The park has been implementing a fire effects monitoring program utilizing the NPS standard fire monitoring protocol methodologies since 2002. While limited sample size precludes statistically conclusive evidence, the general trend appears to be toward achieving stated objectives in target prescribed-fire communities. A limitation of the fire effects monitoring program is that monitoring is not currently occurring in nontarget communities, primarily due to staffing and funding constraints.

These nontarget communities have been a source of struggle for park staff as they try to balance the application of prescribed fire in previously agreed-upon areas while limiting the application of fire in adjacent nontarget mesic sites. The park fire management plan states that "portions of these very moist habitat types will be included within a prescribed fire unit to make the fire line safer and easier to manage, but this fire-intolerant vegetation will not be forced to burn." Balancing these operational and ecological goals is best achieved through collaborative planning and communication prior to burn implementation. The fire effects data and ecologists play a key role in facilitating this adaptive management process.

## Acknowledgment

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