Temporary Note

This is an initial reassembly of the report produced in 1999, with varied figures and tables that will be reworked during 2016. Currently, the raw text is presented alone, without Tables, Figures and Appendices.

May, 2016

FIRE MANAGEMENT PLAN FOR MAMMOTH CAVE NATIONAL PARK

PART I
PHYSICAL ENVIRONMENT, TERRESTRIAL ECOSYSTEMS AND FIRE HISTORY

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Submitted by The Nature Conservancy to Mammoth Cave National Park

Produced under Cooperative Agreement

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Field notes on vegetation by J. Campbell.

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(to make if needed) Potential natural pond sites in the Mammoth Cave area.

INTRODUCTION

This report is the first, introductory part of the Fire Management Plan produced by The Nature Conservancy for Mammoth Cave National Park. It provides background on the park's environment, biological features and fire history, to help guide the goals for fire management in the park. The second part of this document is the plan itself, ready for implementation by the park, including all necessary consideration of practical problems required before implementation.

Part I is presented below as a fairly succinct summary report, but with several lengthy technical appendices. The purpose of this report is to provide a "best estimate" of native vegetation patterns, and associated biological features, especially those that may have been related to fire during pre-park and pre-settlement times. In addition to the park area itself, consideration is given to similar lands nearby, within the Shawnee Hills and Pennyrile Regions of Kentucky. Clearly, this exercise cannot produce an accurate, site-specific model of presettlement patterns related to fire. Much further research is needed, including temporal analysis of pollen and charcoal in pond sediments, as well as more intensive spatial study of current vegetation, old tree stems, and soils. However, it is possible to suggest the general regional role of fire and its likely relationships with vegetation before settlement. These general regional concepts can be supported by a variety of prehistoric, historic and recent information. The more detailed patterns suggested below, involving variation in geology, topography and other influences on vegetation, must be considered largely hypothetical. These ideas can be tested and refined by further research on vegetation and fire history, plus real experiments with initial prescribed burns and other monitoring within the park.

The combined weight of evidence summarized in the report below indicates that extensive open, grassy woodland existed in much of the park area before settlement, and that fires generally maintained this condition for at least 3000-4000 years. It seems likely that there was an increase in the human population and their use of fire about that time. Because this pyric component of the park's natural history has now largely disappeared, together with many rare species of plant and animal, the restoraton of such endangered systems is an extremely urgent matter for consideration. Moreover, there is growing evidence from the park area (see "Terrestrial Ecosystems" below) and the region (e.g., Abrams 1992) that, without fire, oak forests in general are often being invaded by more mesophytic species. Fire, even at low frequencies, may have had subtle effects on forest composition for 1000s of years. It is time to begin managing with fire and to examine its effects.

Part II, the technical Fire Management Plan itself, uses the information from Part I in setting priorities for restoring areas with frequent fire in the park. Such areas include the most significant remnants of open woodland and grassland, and clusters of rare, relictual species. However, it is also important for park managers to consider maintaining large "control" areas, where fire can be minimized, and suitable locations for these areas are also suggested. The rationale for such controls is two-fold: (1) they can provide scientifically meaningful comparisons with frequently burned areas, in order to understand fully the long-term effects of fire; and (2) they can be managed to represent the much longer history of forest development and evolution before human burning existed. Full philosophical and scientific discussion of these issues is beyond the scope of this initial report, but it is clear that a balanced approach to fire must ultimately take account of them. Many details of fire management cannot be determined from this initial effort, but, after initial trials and further research, the optimal plan will develop.

PHYSICAL ENVIRONMENT

Ecoregional Context

Mammoth Cave National Park lies within a natural region known as the Shawnee Hills (e.g., Braun 1950, Quaterman & Powell 1978; modified by J. Campbell in Ulack et al. 1997, p. 42; Map IA). In western Kentucky, the Shawnee Hills can be broadly defined as the area dominated by Pennsylvanian bedrock, which is mostly non-calcareous, plus the surrounding belt with uplands dominated by Upper Mississippian rocks of Chester age, which includes a complex alternation of sandstone and limestone. There is also extensive Quaternary alluvium on lowlands and loess (blown in during glacial eras) on uplands. This regional definition has been followed in recent federal reports (e.g., Bailey et al. 1994, McNab & Avers 1994, Keys et al. 1994). The soils of the Shawnee Hills are mostly hapludalfs and fragiudalfs; also locally important are paleudalfs on limestone plains, dystrochrepts on more dissected sandstone; and locally on bottomlands, there are eutrochrepts, ochraqualfs, udifluvents and fluvaquents.

The park lies within the "Escarpments and Karst Section" of the Shawnee Hills, where the bedrock is mostly Lower Pennsylvanian, consisting of the Lee Formation (mostly sandstone), and Upper Mississippian, consisting of the Chester Formation (sandstones, shales and limestones) and upper Merimac Limestones. The soils on calcareous or loess-rich material are typically hapludalfs and fragiudalfs, with paleudalfs on karst plain intrusions; the less extensive soils with low base-status are mostly dystrochrepts, hapludults and fragiudults. Keys et al. (1994) did not recognize this section, but it is mostly equivalent to the "Mammoth Cave Plateau" of Quarterman and Powell (1978).

The "Escarpments and Karst Section" can be usefully subdivided into two intergrading zones--the "Dripping Springs Hills" and the "Cliff Section" (sometimes known as the Pottsville Escarpment) (Ulack et al. 1997, p. 42). Both of these are represented in the park. This subdivision has not been generally recognized in broad geographic accounts of Kentucky, but it is apparent in more detailed mappings of soils. For example, the Soil Survey of Hart County (General Soil Map in Mitchell 1993) clearly shows a corresponding division into non-calcareous associations (7 and 8) versus calcareous or mixed associations (1 and 2). Also, several biogeographic patterns are associated with this subdivision (e.g., Braun 1950). Some authors have even considered the Cliff Section to be the outer margin of the Shawnee Hills, and the Dripping Springs Hills to belong to the Mississippian Plateaus (e.g, the Physiographic Regions of Kentucky Geological Survey, recently reprinted in Ulack et al. 1997, p. 21). It is, perhaps, difficult to decide where this subdivision belongs in the hierarchy from Region to Section to Landtype Association (ECOMAP 1993, McNab & Avers 1994), and the treatment followed here must be regarded as provisional.

About two thirds of the park lies within the Southern Dripping Springs Hills (including the traditional "Dripping Springs Escarpment"), also known locally as the "Mammoth Cave Plateau". This complex zone is mostly composed of moderately rugged hills and karst valleys on Upper Mississippian bedrock, consisting of the Chester Formation (sandstones, shales, limestones) and upper Merimac Limestones. About a third of the park lies within the Cliff Section. This is a moderately to highly dissected zone with uplands generally on Lower Pennsylvanian sandstones and shales, plus lower ravine slopes and bottoms on Upper Mississippian limestones, shales and sandstones. The Pennsylvanian rocks are mostly in the Caseyville Formation, and has more massive sandstone than the overlying Tradewater Formation, which underlies most of the Shawnee Hills further north.

Land Types

The following Land Type Associations (LTAs) may be broadly defined, following the general concepts of ECOMAP (1993), W.H. McNab (SE Forest Experiment Station, pers. comm.), D. Taylor (Daniel Boone National Forest, pers. comm.), and others. Different variants of these LTAs may be recognized in the Dripping Springs Hills (DSH), as compared with the Cliff Section (CS), where the soils are generally more sandy, acid or nutrient-poor, and better drained.

A. Bottomlands: DSH soils are varied but typically include fluvaquents, hapludalfs and eutrochrepts. The CS typically includes hapludults and dystrochrepts, in addition to the preceding soils.

B. Karst valleys and lower slopes between the hills: major DSH soils are hapludalfs (and perhaps locally paleudalfs); transitions to hill slopes include colluvial hapludalfs and hapludults. In the CS, karst valleys are not well-developed.

C. Colluvial slopes: major DSH soils are hapludults and hapludalfs on more or less colluvial slopes with mixed sandstone and limestone. Major CS soils are hapludults and, locally on calcareous material, hapludalfs.

D. Upper slopes and narrow ridges on sandstone: in the DSH and CS, major soils are hapludults and dystrochrepts.

E. Relatively well-drained ridges and uplands: major DSH soils are hapludalfs and fragiudalfs. PE soils are similar, probably due to the loess which covers sandy subsoils.

F. Less well-drained broad ridges and uplands: major DSH soils are fragiudults; these are especially extensive in the Chalybeate area of Edmonson County. Such conditions are not typically developed in the CS.

LTAs like these have not yet been consistently mapped in this region of Kentucky, but several federal agencies have agreed to pursue such concepts as a general, long-term mapping goal (ECOMAP 1993). They have some introductory utility in the Mammoth Cave area, and Appendix 1 presents a more detailed subdivision into land types (LTs), which are often correlated with individual soil series or small groups of series. However, there is not yet an accurate, uniform classification and mapping of soil series at Mammoth Cave National Park.

Although it is possible to develop fairly detailed concepts of land types, based on provisional relationships with soils and vegetation, the 35 land types (LTs) of Appendix 1 are not currently mapped with precision in the park. As well as the need for more intensive digital mapping of topographic features, there is a need for better soil mapping, and for more quantitative modeling of relationships between geology, topography, soils, vegetation and disturbance patterns. In contrast, the simpler system of Olson & Franz (1998) has been mapped using existing data-layers in the geographic information system of the park. The following notes develop conceptual relationships, and may clarify potential applications to analysis of vegetation patterns.

The nine Olson & Franz types are as follows, with the corresponding LTs of Appendix 1, and brief notes on forest types derived from details in Appendix 4A and 4B.

Floodplain alluvium = LT 1A above. This readily defined bottomland type typically has much sycamore (*Platanus occidentalis*) and boxelder (*Acer negundo*) in lower flooded zones; or tulip poplar (*Liriodendron)* and sugar maple (*A. saccharum)* on terraces; or locally abundant *Juniperus* in some drier old fields.

Calcareous supramesic = LTs 2B.1 + part(3B.1). These mesic N/NE-facing slopes with calcareous bedrock typically have much sugar maple (*Acer saccharum*) and beech (*Fagus grandifolia*), plus occasional northern red oak (*Quercus rubra*) and white oak (*Q. alba*) in drier transitions. Disturbed areas have local white ash (*Fraxinus americana*), tulip poplar (*Liriodendron*), etc. Composition suggests much mixture of calcareous and non-calcareous soils, probably due to spread of sandy colluvium and other material downslope (especially in the widespread Donahue soil series).

Calcareous mesic = LTs 2A + part(2B.2 + 3B.2). Typical sites are moderately mesic slopes, toeslopes and sinks on calcareous bedrock. They have much sugar/black maple (*Acer saccharum*/*nigrum*) and beech (*Fagus)*; or white oak (*Quercus alba*) in drier transitions. Disturbed areas have tulip (*Liriodendron*), walnut (*Juglans nigra*), white ash (*Fraxinus americana*), red cedar (*Juniperus*), etc. Composition suggests much mixture of calcareous and non-calcareous soils, as above.

Calcareous subxeric = LTs 2C + part(2B.2 + 3B.2) + 3C. Typical sites are subxeric to mesic or subhydric, on slopes, valley floors and broad ridges. They have much white oak (*Quercus alba*) and black oak (*Q. velutina*), plus sugar maple (*Acer saccharum*) and beech (*Fagus*) in mesic transitions; or southern red oak (*Q. falcata*) and post oak (*Q. stellata*) on broader flats, plus swamp red maple (*Acer rubrum* var. *trilobum*) in streamheads. Disturbed areas have cedar (*Juniperus*), pine (*Pinus virginiana*), tulip (*Liriodendron*), etc. Composition suggests much mixture of calcareous and non-calcareous soils, as above.

<u>Calcareous xeric</u> = LTs 2B.3 + part(3B.3). Typical sites are xeric to subxeric S/SW-facing slopes on calcareous bedrock. They have much cedar (*Juniperus*) and oaks (*Quercus* spp., especially *Q. rubra, Q. muhlenbergii, Q. alba, Q. velutina, Q. stellata*), plus local sygar maple (*Acer saccharum*) in less xeric transitions. Composition suggests some mixture of calcareous and non-calcareous soils, as above, but the most xeric sites appear to be more purely calcareous.

<u>Acid supramesic</u> = LTs part(3B.1) + 4B.1 + 5B.1. These mesic N/NE-facing slopes with non-calcareous bedrock typically have much beech (*Fagus*) with local (*Acer saccharum*, especially in calcareous transitions) or hemlock (*Tsuga candensis*, in Pennsylvanian ravines), plus occasional white oak (*Quercus alba*) and northern red oak (*Q. rubra*) in drier transitions. Disturbed areas have much tulip (*Liriodendron*).

<u>Acid mesic</u> = LTs part(3B.2 + 4B.2 + 5B.2) + 4A + 5A. Typical sites are moderately mesic slopes and toeslopes with non-calcareous bedrock. They have much beech (*Fagus*) and white oak (*Quercus alba*, predominating on Pennsylvanian). Disturbed areas have tulip (*Liriodendron*), black oak (*Q. velutina*), scarlet oak (*Q. coccinea*), and pine (*Pinus virginiana*), etc.

<u>Acid subxeric</u> = LTs part(3B.2 + 4B.2 + 5B.2 + 3C) + 4C + 4D + 5C. Typical sites are subxeric to mesic or subhydric, on slopes and broad ridges with non-calcareous bedrock. They have much

chestnut oak (*Quercus prinus*, predominating on sandy soils), white oak (*Q. alba*), black oak (*Q. velutina*) and scarlet oak (*Q. coccinea*), plus beech (*Fagus*) in mesic transitions; or southern red oak (*Q. falcata*) and post oak (*Q. stellata*) on broader flats, plus swamp red maple (*Acer rubrum* var. *trilobum*) in streamheads. Disturbed areas have pine (*Pinus virginiana*), cedar (*Juniperus*), tulip (*Liriodendron*), etc. There appears to be much local moderation of the influence from non-calcareous bedrock by superficial base-rich material, such as slumped limestone residuum and loess.

<u>Acid xeric</u> = LTs part(3B.3) + 4B.3 + 5B.3. Typical sites are subxeric S/SW-facing slopes with non-calcareous bedrock. They have much chestnut oak (*Quercus prinus*, especially on Pennsylvanian rock) and white oak (*Q. alba)*; or locally pine (*Pinus virginiana*) along cliffs and in disturbed areas.

TERRESTRIAL ECOSYSTEMS:
PREHISTORIC INFORMATION (BEFORE SETTLEMENT)

Palynology

It possible to make general regional inferences about vegetation history in Kentucky from the scattered palynological studies of eastern North America (e.g., Franklin 1994). However, there have only been two published palynological studies of long continuous Late Quaternary cores from within the state. One of these, by Wilkins et al. (1991; see also Delcourt et al. 1986) is from Jackson Pond in Larue County, at the southeastern corner of the Northern Karst Plain, about 30 miles NE of Mammoth Cave. This site is on the other side of the "Big Barrens" region from Mammoth Cave, but has generally similar environmental conditions. The core suggests that from about 200 to 3500 years BP (before "present" at 1950), the region had a mix of grassy open barrens and closed forest. Grass pollen was about 10-20% of the total upland pollen sum. The grassland indicator, *Dalea* (or *Petalostemon*, prairie clover), was present throughout this period. Common taxa in the tree pollen included oak (*Quercus*), ash (*Fraxinus*), hickory (*Carya*), sweetgum (*Liquidambar*) and chestnut (*Castanea*). From 3500 to 7500 years BP, during a relatively warm, dry period in eastern North America, there was much less grass pollen, but the trees were generally similar in proportions, with the addition of more *Salix*. From 7500 to 11500 years BP, in the early post-glacial era, grass pollen was also low, and the common tree taxa were oak (*Quercus*) and hornbeam (*Carpinus*), with lesser amounts of ash (*Fraxinus*, especially *F. nigra*?), hickory (*Carya*), elm (*Ulmus*) and willow (*Salix*). The sharp increase in grass pollen after about 3500 year BP is interpreted to reflect an increase in fires set by native peoples, not an increase in drought.

Some archeological data from Salts Cave is relevant here. Schoenwetter's (1974) analysis of pollen samples indicated that there is a relatively large proportion of Chenopodiaceae (pigweed) in pollen samples dated between 3000 to 3500 years BP, followed by peaks in Poaceae (grasses) and *Ambrosia* (ragweeds) in strata above this (but still probably ca. 3000 years BP). In the same period, Yarnell (1974) found an increase in the occurrence of edible annual weed seeds in human paleofeces, including much *Chenopodium* sp. (pigweed), *Helianthus annuus* (sunflower), *Iva annua* (sumpweed), *Amaranthus* (amaranth), *Panicum* sp. (panic grass) and *Phalaris caroliniana* (maygrass). These are plants that indicate openings created by native peoples for crops. Before this, their subsistence had relied more on food gathered from the wild, especially hickory nuts, acorns and meats. Such changes suggest that more stable settlement began during this period. Possibly, the regional population became larger, and there was more burning of the uplands to increase herds of deer, elk and ultimately bison.

The other thorough palynological study in Kentucky is from Cliff Palace Pond, Jackson County, on a sandstone ridge in the Cliff Section of the Appalachian Plateaus (Delcourt et al. 1998). Although from a distinct region and topography, with much less evidence of presettlement grassland, the trends in pollen and charcoal deposits provide important comparisons with the Jackson Pond site. From about 200 to 3000 years BP, non-arboreal pollen was a minor proportion, but there were distinctive amounts of *Ambrosia*, *Iva*, *Helianthus*, *Chenopodium* and other indicators of open, cultivated ground, which were generally absent in older sediments. The most common taxa of tree pollen were oak (*Quercus*, dominant), chesnut (*Castanea*), pine (*Pinus*), ash (*Fraxinus*) and hickory (*Carya*), and there was a relatively high occurrence of large-grained charcoal, indicating much local fire. From 3000 to 4800 years BP, there was a very high peak in cedar (Cupressaceae: *Juniperus/Thuja*), with lesser amounts of oak (*Quercus*), ash (*Fraxinus*) and others, and a relatively low occurrence of charcoal. Before this peak in

Cupressaceae, from 4800 to 7300 year BP, oak (*Quercus*) was predominant in the pollen, but still with much Cupressaceae, and lesser amounts of hemlock (*Tsuga*), ash (*Fraxinus*), hickory (*Carya*), maple (*Acer)* and others. The abundance of Cupressaceae (presumed largely *Juniperus*) is attributed to open successional conditions after disasterous fires. as indicated by a sharp peak in charcoal about 5000 years BP. The charcoal peak occurred while hemlock (*Tsuga*) was declining abruptly, supposedly due to insect infestation. From 7300 to 9500 years BP (at base of the core), the most common taxa were Cupressaceae (perhaps with much *Thuja*) and oak (*Quercus*), with lesser amounts of alder (*Alnus*), hophornbeam (*Ostrya*), ash (*Fraxinus*), spruce (*Picea*) and others. Charcoal occurrence was moderately high.

Another study by Delcourt & Delcourt (1998) in Daniel Boone National Forest, not yet published, dealt with a much shorter time record. This was at Curt Pond, Pulaski County, also on a sandstone ridge in the Cliff Section. Dated samples after settlement (especially after 1700) suggest local pond-filling by aquatic plants, and regional dominance by typical forest of oak (*Quercus*), sweetgum (*Liquidambar*), chestnut (*Castanea*), pine (*Pinus*), etc., but with large pulses of species that reflect disturbance history. Lower samples were undated but probably within 500-5000 years BP. These show a remarkable dominance (60-80%) of Cupressaceae pollen (presumed *Juniperus*), together with lesser amounts (ca. 5-10%) of oak (*Quercus*) and (*Liquidambar*). There was also much bracken-fern (*Pteridium*) spore (5-10%) and relatively frequent sedge (Cyperaceae), grass (Poaceae), composite (Asteraceae) and wood-fern (*Dryopteris*-type) (each ca. 1-3% and generally more than after settlement. The best interpretation of these samples may be that the sandy ridge was mostly brushland and young forest, maintained by intensive burning, and that there was much successional red cedar (*Juniperus*) forests on the more calcareous adjacent slopes.

The key correlation between the two major pollen studies--Jackson Pond and Cliff Palace Pond--is that after about 3000-3500 years BP at both sites, there was a shift to dominance by oak (*Quercus*), ash (*Fraxinus*), hickory (*Carya*) and chestnut (*Castanea*), plus pine (*Pinus*) at the Appalachian site, among typical upland taxa. [The sweetgum (*Liquidambar*) and blackgum (*Nyssa*) at Jackson Pond may have been concentrated close to the pond rather than regionally abundant.] Prior to this period, more fire-intolerant, mesophytic or hydrophytic trees tended to be more common at both sites. About this time there is also evidence of a shift to more cultivation by native peoples, and there seems to have been an increase in local fire frequency (as indicated by the increase in grasses at Jackson Pond, and by the larger charcoal particles at Cliff Palace Pond). Clearly, there were great differences in regional ecology, but it may be suggested that human populations became denser across Kentucky during this period, with more agricultural activity and more burning to clear ground and increase game production. This period corresponds to the shift from "Archaic" to "Woodland" cultural eras.

Although these few studies enable hypotheses to be set up regarding fire history in Kentucky, there is clearly a great need for more palynological work in order to provide real indications of local environmental history. To quote Prentice (1993, p. 152): "Unfortunately, the MCNPAIP did not have a large enough budget to fund a detailed palynological study in order to better evaluate past environmental change in the Mammoth Cave area. There are, however, two locations in the Park which hold great promise for producing the necessary pollen to make such a study possible. The natural pond at the Hawkins Farm site [1 mile NW of Chaumont intersection on S side of KY 70] and Beaver Pond [at Sloans Crossing] have been shown archeologically to be prehistoric in date and potentially could contain pollen records several thousands of years old. Should the funding ever become available, a palynological study of these two sites is to be encouraged." There are several other possible sites in the park [see project maps], though in most cases the ponds may dry out too much in the summer, and a careful pilot study of pollen preservation will be required.

An earlier effort to locate ponds with pollen in the Mammoth Cave area appeared to show only post-settlement material (Wright et al. 1966). The ponds examined in that study had apparently experienced rapid sedimentation (more than 4 m in one case) due to erosion after settlement, and it was unclear if older sediments remained at the bottom. Two ponds inside the park--Sloan's Crossing Pond and Doyel's Big Pond (now dried up)--were cored, "but the bottoms proved too hard." [Unexpectedly, the sites indicated that bald cypress (*Taxodium*) was present in recent times, but this species is virtually unknown in the region today.] Clearly, there is a need to re-evaluate the potential for ponds in the region to yield useful paleoecological data.

Archeology

Distribution of Sites

Prentice (1993; Maps IB) has summarized archeological data from the park. Although caution is needed due to lack of systematic survey in much of the park, maps of sites (see project maps) for Native American occupation, as campsites or seasonal settlements, show a fairly consistent pattern from Archaic (8000-1000 B.C.) to Woodland (1000 B.C.-A.D. 900) to Mississippian (A.D. 900-1500) periods. To quote Prentice (1993, p. 149): "There does not appear to be a significant difference in site selection processes among the major time periods. All types of sites were occupied during each of the Archaic, Woodland, and Mississippian periods." There appears to have been broad concentrations of sites in an east-central area from the Green River south to Flint Ridge (including Mammoth Cave, Great Onyx Cave, Crystal Cave, Salts Cave, etc.). Also south of the river, there are smaller concentrations in the Cedar Sink area, Silent Grove area, and Indian Hill areas. In the northwestern sector of the park, there is a large concentration of sandstone rock-shelters in the valleys of Nolin River, First Creek and Wet Prong of Buffalo Creek. There is a notable absence of sites in most of the southeast sector, where the karst valleys are most pronounced, with few surface streams or springs. The few exceptional sites in this sector are mostly near the few springs. In general, the concentrations appear to be related to the occurrence of larger caves, rock-shelters, and proximity to water, especially the Green River.

It is unclear at the outset what significance these distributions have for interpreting presettlement vegetation and fire history. As indicated on attached project maps, some of the areas of the park that probably had relatively open woodland do overlap with these site concentrations. The most striking overlap occurs in the east-central sector, and those in the Silent Grove and Indian Hill areas might also be used in building hypotheses. However, the northwestern concentration of sites in sandstone rockshelters is not associated with much evidence of open woodland, and evidence of open woodland does extend towards the southeast, where there is little or no evidence of occupation. Clearly, native peoples did not burn or otherwise open up the forest only close to their dwellings, and it is quite likely that trails into the Mammoth Cave area from the south were ignited by travelling or hunting groups.

The exact location of areas where plants were cultivated is unknown, but it is notable that; "In terms of site density, the bottomlands along the Green River contain more sites per hectare than any other topographic zone in the Park" (Prentice 1993, 1:148). Although flooding would be a hazard on most bottomland, it is likely that narrow levees and the highly fertile alluvial-colluvial transition at slope bases (see notes on land types above) were ideal zones for cultivation, just above the normal floodplain. Watson (1969, p. 76), however, considered that the Green River valley was too narrow; "so some of the gardens were probably on the uplands where the soil is likely to be less fertile. This would mean relocation of gardens fairly frequently (every two or three years or perhaps oftener)." Although Watson's concept may not need to extend far onto "uplands", small garden plots might, for example, have been possible in the moister sinkholes of some karst valleys, where *Juglans nigra* is now concentrated. Until a more detailed survey of land and soil types is conducted in the park, and a better idea of these early peoples' economy is attained, this issue must remain uncertain.

Local Changes in Soils

Much more work will be required to uncover what local effects the native peoples had on soils, due to their transport of materials, burning or digging. But there is one extraordinary site that demonstrates how much change is possible. This is Indian Hill, where the current vegetation includes much ash (*Fraxinus* spp.), chinquapin oak (*Quercus muhlenbergii*), red cedar (*Juniperus*), etc., but no pine (*Pinus virginiana*). This is a highly unusual vegetational component for a narrow Pennsylvanian ridge in this region, and suggests base-rich conditions. The rich soil here was exploited during much of the pre-park settlement as a corn field, and its fertility may have been augmented then, but there are probably more ancient causes. Carroll (date?) noted: "Indian Hill is one of the many strange elevations common in Kentucky. It is about a mile in circumference [with adjacent uplands], and rises gradually to a height of about 100 feet above the level of the surrounding land. On the Summit of the hill were indications of a fortification, and in the immediate vicinity were a number of mounds and burial places." Jones (1933) noted: "There is a ten acre plot on the top of Indian Hill which I am sure will produce some excellent skeletons, artifacts, pot shards, spear and arrow heads if properly worked, even though the surface area of this hill has been scoured and searched for years. It is my belief that the earth on this hill has been carried there over a period of years and even generations and with proper supervision in exacavating will undoubtedly produce a wealth of material for a Park Museum in this area." Hibbard (1934b-35) noted on Aug 12, 1934: "On the hill is a place where a large number of fresh water shells were found--some places to a depth of a nearly solid layer of 12"."

Another site worthy of investigation for soil effects is in the Great Onyx Cave area. Hibbard (1934b-35) noted on Dec 21, 1934: "On the ridge west of Onyx Cave is evidence of a large Indian village. One of the "natives" states that in an old field now restocking when he plowed it years ago there was found mounds of shells, ashes and that flints are abundant. Many pieces of chipped flint are present upon the ground. He also reports that just across the river is a large mound of shell. A young stand of walnuts and butternuts is developing along the ridges."

Cave Torch Materials

Material found in the caves of this area indicates that the following species were primarily used for torch fuels by Archaic and Woodland cultures: *Arundinaria gigantea* (cane), *Aureolaria* sp. (false foxglove), probably *A. flava* [reported under the synonym *Gerardia f.*], and *Solidago* sp. (goldenrod) (Watson 1969, 1974). Olson (1998) noted that *Arundinaria* appears to have been used relatively little in some areas (including Salts Cave and Bluff Cave), compared to the other two plants. His experiments with "false foxglove" ("*Gerardia*") and "tall Goldenrod" ("*Solidago*") indicated that these plants, and also giant ragweed (*Ambrosia trifida*) are superior in several burning characteristics. He noted that cane, false foxglove and goldenrods are generally more common in open woodland, such as influenced by repeated burning, and that this provides circumstantial evidence of presettlement burning. *Aureolaria* spp. are generally considered semi-parasitic on roots of oaks and other tree species (less often on herbaceous species), and they may be most abundant in open oak woodlands (Musselman & Mann 1978). However, F. Michaux (1805, p. 218; see Appendix 2B, p. 2) noted that "gerardia flava" was typical of the more open grasslands in the Barrens on the Pennyrile Karst Plain, which suggests that it may persist on resprouting tree roots (or even some herbaceous species) where the forest has been burned off for 100s or 1000s of years.

Olson's argument is persuasive, but more details are required before this can be considered hard evidence of open woodland in large areas. It would be desirable to have at least a rough estimate of how much material was consumed in the caves, and how much capacity the environment has to supply this material. It is possible that much of the torch material could have been gathered from lowland areas, especially around garden plots on subxeric to mesic, fertile soils. Some of these species might also have been locally abundant along trails used by large animals and the native peoples.

Cane is primarily a lowland species in the park area, being largely confined to the Green River corridor and major tributaries, though it might have been promoted by native peoples elsewhere. Watson (1969, p. 33) noted that torch cane remnants are up to one inch in diameter, which is exceptionally large for Kentucky, and probably had to come from the most fertile, bottomland sites.

Aureolaria spp. are known to be concentrated in open oak woodland and edges, especially on subxeric sites, and they often benefit from fire (J. Campbell and T. Simmons, pers. obs.), but they can also persist at lower density in generally forested country. *A. patula* occurs on rocky calcareous slopes along the Green River; *A. flava* is scattered widely on base-rich soils; *A. virginica* is scattered widely on base-poor soils. In the park currently, it appears that deer have a strong preference for eating inflorescences of *Aureolaria* (R. Seymour, pers. comm.), and it may well be that a lower deer density would have allowed these plants to be more numerous in shady areas. There are several *Solidago* species in the park area, occupying various habitats. The *Aureolaria* and *Solidago* species used in the caves needs to be determined with more precision before this hypothesis can be fully developed.

Slipper Material

Archeological remains of slippers from the Mammoth Cave area (Watson 1969; King 1974) are often made from the fibres of *Eryngium yuccifolium* (rattlesnake-master). This source of fibre seems to have been preferred in the Salts Cave material, though various other species were also used. This species is restricted to open grassy woods and grasslands, and is currently very rare within the park. With more information about the abundance of slippers with this material in the park or nearby, and the likelihood, or not, of transport from other more distant areas, it might be possible to use this as further evidence of presettlement conditions.

TERRESTRIAL ECOSYSTEMS:
HISTORIC INFORMATION (BEFORE PARK FORMATION IN 1930s)

Appendix 2 presents, in chronological order, historical information relevant to the park's presettlement vegetation and its ecological interpretation. Many sources do not refer to the park area specifically, but they do provide a general regional view of presettlement vegetation on the Pottsville Escarpment, Dripping Springs Hills, and Pennyrile Karst Plain. The following general features of the vegetation may be gleaned from these early accounts.

1. Annual fires on the Pennyrile Karst Plain. The predominance of grassland ("barrens") on this karst plain before settlement in 1780-1810 was attributed by several early writers to frequent fires set for many centuries by native peoples (F. Michaux 1805, Short ex Davidson 1840, Short ex Drake 1850, Ross 1882, Sargent 1884, Shaler 1884). These accounts indicate that fires generally occurred each year during the pioneer era, with seasons ranging from "autumn" and "winter" to "March and April". In some areas, the frequent burning was continued for a few years by pioneers for hunting and to maintain pasture, but eventually it declined greatly as the land was enclosed by farms. By about 1820-30, it appears that settlement had removed most of the previous fire-regime, and the "barrens" that were not yet farmed became filled with young forest stands.

2. Openings in the Dripping Springs Hills. There are also a few notes in early descriptions of the region suggesting that the uplands of the Dripping Springs Hills were partly open and grassy when first settled in about 1790-1800, though this condition may generally have been open woodland rather than true grassland (Bullitt 1844 in Meloy 1985, Hussey 1876, DeFriese 1880). A few notes in the early Edmonson County deeds indicate "barrens" and a "Gum Thicket" in the

Chalybeate flatlands. There may even have been a "barrens" area north of the river, perhaps near the place named "Grassland". Hussey suggested that much of Edmonson County had started to grow back to open woodland or forest some years before the more extensive "barrens" of Barren Co. were released from fire.

3. Regional transitions in vegetation and fire. The transition from grassland on the karst plain to open woodland and closed forest in adjacent hills was generally gradual in terms of increasing tree density (F. Michaux 1805, DeFriese 1880). This was presumably due to a gradient of decreasing fire frequency or intensity. Several interacting factors may have been involved in this gradient: (a) possible concentration of ignitions along human trails through the karst plain; (b) drier conditions in the central karst plain; (c) more grass fuel in the central karst plain; (d) more fire-slowing barriers in hilly transitions (rocky knobs, saddles, sinks, valleys and streams). In the transition from the barrens nearest the park, DeFriese's (1880) notes suggest that there may have been a shift to open woodland (with post oak on uplands and white oak limited to the sinks) north of Glasgow Junction [Park City], and then a more continuous forest in Doyel Valley. From Mammoth Cave to Cave City, he noted a shift from "poor" [fire-influenced?] wooded ridges and forested sinkholes, "into the present eastern barrens, about twelve [mistaken two?] miles from Cave City, and within about eighteen miles of Greensburg"; this was probably just east of Toohey Ridge [or did he take a more northern route?].

4. Fire-break effect of large river valleys. Defriese (1880, p. 11, 21-22) suggested, from the general condition of the forest and historical distribution of "barrens" vegetation, that the valleys of the Clarks River, Tennessee River, Cumberland River, Big Barrens River and Little Barren River acted, to various degrees, as fire-breaks, restricting the influence of fires on the adjacent forest, and the reducing the spread of more open grassy vegetation. [But even within Land-

Between-the-Lakes, there is evidence of some presettlement grassland (Franklin 1994).] Defriese's detailed account of the Mammoth Cave area suggests a similar, though more diffuse, effect in the transition from the barrens towards the Green River. In addition to rivers and streams themselves acting as firebreaks, it is likely that associated topography with higher relief also reduced the spread of fires, both on mesic N/NE-facing slopes with damp fuels, and on some xeric rocky slopes, cliffs and narrow ridges with less continuous fuels.

5. Local topographic patterns. Within the karst plain, the few "groves" of forest were along mesic stream valleys and around the low isolated "knobs" with more siliceous or sandy material, especially on their north faces (Hussey 1876, Gorn 1929, Dicken & Brown 1938, Gardiner 1940). The south sides of these knobs and transitional hills, especially on the Girkin Formation (with siliceous limestones and shales) often supported rocky, open red cedar woods and xeric grassland (see also Owen 1856). At least the summits of some knobs in the transition to the Dripping Springs Hills may have had relatively open or brushy woodland, based on some early statements: "lofty eminence, slightly adorned with trees" near Dripping Spring (F. Michaux 1805); "lofty range of barren highlands" towards Munfordville (Bullitt 1844 in Meloy 1985). This pattern is also suggested by some place names on USGS Quadrangles between Park City and Cave City: Bald Knob, Brushy Knob and Huckleberry Knob. More open grassland also appears to have enveloped some of the forested knobs in transitions to hilly regions, for example the knobs between the L.& N. railroad and the NW corner of Barren County (Gardiner 1940).

Within the Dripping Springs Hills, it is likely that the isolated karst valley intrusions in the Mammoth Cave area, separated from the main karst plain by partially forested knobs and saddles, experienced less frequent fire due to these potentially fire-slowing topographic barriers. Such patterns were specifically suggested in the case of Doyel Valley and probably Houchins Valley by

DeFriese (1880), noting the "growth of chestnut" on valley slopes, though it is likely that this species was still somewhat favored by a moderate fire regime (Delcourt et al. 1998). The notes of Hussey (1876) and DeFriese suggest that the broad upland ridges of Edmonson County had been relatively open and grassy, perhaps even like the "barrens" in places, while forest was concentrated on slopes, sinks and bottomlands.

6. Predominance of post oak in deeds. Post oak (*Quercus stellata*) appears to have been the most abundant tree species in Edmonson County during the pioneer era, based on deed surveys recorded in 1826 (Appendix 2A). Indeed, percentages of post oak in deeds of Edmonson County (15.9%) and Barren County (15.7%) during the 1820s are remarkably similar, even though most of Edmonson County is in the Dripping Springs Hills and Pottsville Escarpment, whereas Barren County is mostly on the Pennyrile Karst Plain. It is generally considered that abundant post oak before settlement in the central Mississippi drainage was associated with fires frequent enough to retard succession towards white oak (*Q. alba*) (e.g., Sargent 1884, Fralish et al. 1993, Franklin et al. 1993, Cutter & Guyette 1994). Post oak is also abundant on xerohydric soils (Alliance IB2Na385 in Nature Conservancy 1998), such as prevail on flatlands with fragipan soils near Chalybeate in southern Edmonson County, but such sites are probably not extensive enough to explain the overall predominance of post oak in deeds.

7. Black/red oak group more in Edmonson County than Barren County deeds. The two other trees most frequently associated with fire-maintained post oak woodlands (Nature Conservancy 1998; Appendix 4B, p. 39) are probably blackjack (*Q. marilandica*) and Spanish oak (*Q. falcata*), and these were recorded more often in deeds of Edmonson County (7.2% and 2.1%) than Barren County (4.4% and 1.4%). Other records of trees in the red/black oak group were also more frequent in Edmonson (15.8%) than Barren (9.8%), whereas white oak itself (*Q. alba*) had similar

frequencies (10.3% and 9.7%, respectively). From general autecological knowledge (e.g., Fowells 1965), species in the red/black oak group are generally less long-lived than those in the white/post oak group, and they several would be potentially successional in areas of open post oak woodland released from fire. A higher incidence of successional forest would accord with Hussey's (1876, p. 8-12; Appendix 2B, p. 8) suggestion that, perhaps during the early 1800s, Edmonson in general had been released for longer from more intensive fire effects, becoming "forest-covered a generation before Barren Co."

8. Early records of rare plants. The few early records suggest that some plant species largely dependent on open woodland or grassland conditions were common (individually or as species clusters) in parts of the Dripping Springs Hills. Among the most indicative species is *Trifolium reflexum* (buffalo clover). This species was noted as abundant on the Mammoth Cave Ridge by Hussey (1876), and even in the 1930s it may have been locally common (Hibbard 1934b-35), but it is now virtually extinct in the region. Several other species noted by Hussey are now very rare or unknown in the Dripping Springs Hills and adjacent Karst Plains, including *Castilleja coccinea, Corydalis sempervirens, Leavenworthia uniflora, Phlox amoena, P. pilosa* and *Scutellaria galericulata*. Price (1893 addenda) collected *Drosera intermedia, Platanthera ciliaris, Polygala cruciata* and *Rhynchosia tomentosa* from the Chalybeate [Kalibeet] area; this grouping suggests that grassy openings occurred on the seasonally wet acid soils here. [From data on file at TNC, similar conditions appear to have occurred in "glades" on Mississippian sandstone lenses in the Eastern Karst Plain, e.g., in the Hazel Dell area of N Pulaski Co.]. For most of these species, general knowledge of their ecology suggests that frequent fires were a major factor maintaining populations before settlement; more detailed autecological notes are presented below (Appendix 5).

9. Burning by settlers. Most of the Pennyrile Karst Plain "barrens" became agricultural in the 19th Century. The original grassy vegetation, together with its fire regime, largely disappeared after 1820-30. However, it is likely that inhabitants of the more forested Dripping Springs Hills did continue to use fire frequently for clearing ground and improving rough pasture in the open, cutover woodlands. This practice was widespread up to the time of park formation (Hibbard 1934a, 1934b-35). Even today, local farmers often burn fields in the fall at some sites (e.g., near Smiths Grove in the 1990s, according to R. Olson, pers. comm.), but these sites generally lack diverse native grassland.

10. Post-settlement increase of white oak in transitional hills. Despite some continued burning, the timber survey reported by Barton (1919) suggests that by the early 20th Century white oak had become much more abundant than post oak in the "Escarpments and Karst Section". Percentages from Edmonson and Grayson Counties, which lie largely within this section, are 15% and 9.3% for white oak, versus 2.0% and 4.4% for post oak. Also, in the eastern transition of the karst plain, an anecdotal point of interest here is to compare Michaux's 1802 observations on the Little Barren River crossing (in Thwaites 1904, p. 215: "ground in the environs is dry and barren, and produces nothing but a few..." [*Juniperus*, *Pinus virginiana* and *Quercus marilandica*]) with DeFriese's 1878 observations at the same site (1880, p. 27: "good sample of the timbers"... [*Prunus serotina, Robinia pseudoacacia, Q. muhlenbergii*?, *Juglans nigra*, etc. ... "plenty of" [*Castanea dentata* and *Q. alba*]...").

In contrast, Barton's (1919) data (see also DeFriese 1880, Sargent 1884) suggests that post oak remained much more abundant than white oak in remaining woodlands on the Pennyrile Karst Plain or nearby, as largely exemplified in Barren and Hart Counties. Percentages in these counties were 21% and 26% for post oak, versus 9.3% and 3.4% for white oak. In the more heavily forested Escarpments and Karst Section (especially the relatively rugged Edmonson Co.), it is possible that the frequency and intensity of fires became much less after settlement, allowing most post oak woodland to succeed to black oak and white oak forest. The more limited Karst Plain woodlands probably remained more open due to fire, grazing, cutting and other human disturbances in that largely agricultural landscape.

TERRESTRIAL ECOSYSTEMS:
RECENT INFORMATION (AFTER PARK FORMATION)

The native vegetation of the Shawnee Hills in general includes various oak-hickory forest types on uplands, with much post oak, southern red oak, white oak, black oak and cherrybark oak. On mesic sites, beech, tulip tree, sugar maple and northern red oak are locally abundant on mesic sites. On bottomlands towards the interior, there are extensive swampy areas with southern and northern bottomland oaks, sweetgum, red maple, etc., and locally bald cypress. The Escarpments and Karst Section, where the park is located, generally lacks swampy ground, except for some seasonally wet areas on broad non-calcareous ridges and flats. This section is also distinct in having many drier slopes and some broad ridges with remnants of more grassy and open woodland in places.

The Cliff Section (Pottsville Escarpment) includes much former oak-chestnut in addition to the usual oak-hickory types on most uplands. In some sandstone ravines, there are patches of hemlock (*Tsuga canadensis*), yellow birch (*Betula allegheniensis*) and bigleaf magnolia (*M. macrophylla*), disjunct from their main Appalachian or northern ranges. The Dripping Springs Hills have a complex transition in natural vegetation between types of the generally calcareous Pennyroyal Karst Plain and non-calcareous Shawnee Hills, with a wide range of mesic, subxeric and xeric types, including remnants of grassy open woodlands.

<u>Forest changes from 1930s to 1990s</u>

Appendix 3 analyzes changes that appear to have occurred in forests of Mammoth Cave National Park since park formation. The 1930s vegetation mapping by Ellsworth et al. (Map IC) provides a important reference point, and various vegetation surveys have occurred more recently, especially in the 1990s. The existing data cannot be used to make definitive statistical statements, but there are strong indications of some major trends within some of the 1930s types, especially in more open or xeric vegetation.

There appears to have been little change in dominant species within mesic or subxeric mid- to late successional forest types. However, in early to mid-successional subxeric types, there have been large increases in white oak (*Quercus alba*, now dominant) and perhaps minor increases in beech (*Fagus*), tulip poplar (*Liriodendron*) and chestnut oak (*Q. prinus*). In subxeric to xeric forest types that are thought to have been associated with fire, it appears that post oak (*Q. stellata*) and especially blackjack oak (*Q. marilandica*) have declined greatly, while there have been some increases in black oak (*Q. velutina*), southern red oak (*Q. falcata*), white oak (*Q. alba*), and perhaps red cedar (*Juniperus virginiana*), which probably filled in more open woods.

Red cedar (*Juniperus virginiana*) and scrub pine (*Pinus virginiana*) types in the 1930s now appear to have much oak (*Quercus* spp.) and maple (*Acer* spp.), and these types may be partly successional. However, much of the red cedar type remains dominated by that species on xeric calcareous slopes. Old fields and young thickets of the 1930s have now become dominated by red cedar on calcareous uplands and by pine on non-calcareous uplands, but there is much intermixing of these two species. Variation in these young forest types and more mature forest types is related to land type.

These apparent changes at Mammoth Cave are generally similar to the regional trends indicated in the central Mississippi Valley (e.g., Sargent 1884, Campbell 1987, Campbell et al. 1991, Abrams 1992, Fralish et al. 1993, Franklin et al. 1993, Franklin 1994, Cutter & Guyette

1994, Baskin et al. 1997, Delcourt et al. 1998). The developing consensus is that without fire, there is a gradual shift on typical upland sites from grassland and open woodland, typically with much post oak (*Quercus stellata*), or locally shortleaf pine (*Pinus echinata*), etc., towards subxeric forest, typically with much white oak (*Q. alba*), or locally chestnut oak (*Q. prinus*), etc.), and from subxeric forest towards mesic forest, typically with much sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*), etc. While complete shifts along this gradient are unexpected, it is likely that shifts in dominant species will occur at least in transitional stands, as seems to be the case at Mammoth Cave. The overall extent to which this successional trend will continue without fire remains to be seen, but it is clear that the more open grassy extremes have already been largely lost, even when not farmed or otherwise developed, due to forest succession.

Vegetation Types

Appendix 4 presents fairly detailed notes on the natural vegetation types found in Mammoth Cave National Park or nearby. Although these notes are mostly based on recent observations, an effort has been made to incorporate historical data, and to indicate apparent changes and dynamic relationships of vegetation types. The first part (4A) presents raw data in relation to the landtype classification of Appendix 1, as part of the refinement of that classification. Decisions on categories in the land type classification are based partly on the degree to which vegetation differences exist when comparing land types. The second part (4B) is a thorough listing of all vegetation types, with keys to types, brief descriptions, and cross-references to the TNC National Classification (Weakley et al. 1998).

At this point, it is important to introduce the basic concepts of vegetational variation in relation to land- or habitat-type and fire-regime, as referred to in this report. Throughout the report, major compositional differences at species, genus or family level are emphasized in the broader divisions, while minor compositional differences or mere physiognomic differences related to disturbance are emphasized in the narrower divisions. The broad "formations" (generally moisture-related) and "superalliances" (generally soil pH-related) that are outlined in Appendix 4B are provisional groupings that have much predictable relationship with abiotic factors on the landscape. To some extent, these broad classes are also involved in long-term successional changes, especially where there are probably substantial changes in soil during succession. More short-term disturbance patterns are mostly related to differences between the finer divisions of this classification ("alliances", "associations", "phases", etc.), though it is often difficult to separate out this variation from fine-scale variation in abiotic relationships.

In Part II (e.g., Table 1, p. 17), the effect of fire on typical upland forests is expressed as the following generalized sequence.

Rare fire (25-50 year intervals): before settlement, this condition was perhaps typical only in mesic forest, but is now typical of most subxeric and xeric forest.

Occasional fire (5-25 year intervals): before settlement, this was perhaps typical of most subxeric forest, especially in more hilly terrain with less development of grassy ground cover.

Frequent fire (3-5 year intervals): before settlement, this was perhaps typical of most subxeric to xeric or hydric sites on broader ridges and some high terraces with soils that can develop dense grassy ground cover, resulting in partially open pyric woodland.

Very frequent fire (1-3 year intervals): before settlement, this was perhaps typical of subxeric to xeric or hydric sites on plains with little relief and surface water, especially the karst plain, resulting in very open woodland ("savanna") or true grassland.

Within each generalized landtype on uplands, one can expect some degree of variation between the above phases, but the details of what to expect, in terms of fire behavior, physiognomy and composition are largely unknown. As fire is returned to the landscape, such details will emerge.

Coarse Patterns

The word "coarse" is used here in relation to broad compositional variation of the vegetation, rather than large-scale spatial variation. The best examples of some coarsely defined compositional types, including a wide range of conservative species, such as rocky openings in general, are restricted to very small sites in the park. In summarizing these patterns, it is useful to begin with broad vegetation classes such as the "formations" referred to Appendix 4B. To a certain extent, each formation includes potential undisturbed forest phases and disturbance-dependent open phases. However, the following whole formations can be identified as partly or largely fire-associated. These represent systems within which native, presettlement biodiversity is apparently enhanced at community and species levels by repeated intense disturbances such as fire, grazing, mowing or cutting at appropriate intervals.

1. Xeric-subxeric pine-oak or cedar-oak forest and rocky openings (Appendix 4B, p. 57).
2. Non-hydric oak forest and grassland on gentle slopes, plains and flats (Appendix 4B, 37).
3. Hydric oak forest and grassland on high terraces and flats (Appendix 4B, p. 32).

Of these formations, the second is clearly most prone to intense pyric influences, since it lacks rocky ground with thin vegetation that leaves light fuel loads, as in the first, and it lacks seasonally wet zones, as in the third. This "non-hydric oak plains" class is the most extensive of the three within the park. It is also the formation most typical of the "Big Barrens" of the Pennyrile Karst Plain, where trees were largely absent before settlement.

More open, grassy, fire-maintained phases can be defined within each of the above three broad formations. The park has very few current remnants of these phases.

1. Within the "xeric-subxeric conifer-oak" formation, there are several small openings on S/SW facing rocky slopes, clifftops, and occasional flatrocks (including artificially scraped or eroded sites). However, these are all very small (mostly < 1 acre), and in most cases they appear to be gradually contracting further, as the forest slowly builds up shade and soil depth.

2. Within the "non-hydric oak plains" formation, there are no truly natural openings remaining, but in a few old fields that have been maintained by mowing or grazing, disturbed phases of native grassland have survived. The only really significant examples are the Wondering Woods Meadow, in a karst valley; and Crystal Cave Meadow and Great Onyx Cave Meadow, both on sandy ridges. Numerous other rights-of-way, eroded spots, and small openings in old field forests, also have depauperate remnants of native grassland or open woodland, but these are widely scattered and very small (mostly < 0.1 acre).

3. The "hydric oak flats" formation is much more limited within the park, but it may have had distinct grassland or open woodland composition before settlement (see also section on Floristic Patterns below). There are no truly natural openings (excepting the seasonally flooded pond

centers that belong in the "Shrubby/Graminoid Swamp/Marsh" formation). However, a few of the damper old fields still have fairly thin forest, with scattered species typical of open seasonal wetlands in the ground vegetation.

Two other formations are likely to have had considerable influences from fire, but probably not generally intense enough to create open woodland or grassland before settlement.

4. Subxeric oak forest on moderate-to-steep slopes (Appendix 4B, p. 48).
5. Submesic-subhydric forest on damp uplands and terraces (Appendix 4B, 24).

In recent years, much literature from eastern North America has suggested that oaks often benefit from fire on typical subxeric slopes, and even in seasonally damper sites (e.g, Abrams 1992, Cutter & Guyette 1994, Jenkins & Rebertus 1994). There are frequent indications that more mesic or shade tolerant species, such as maples (*Acer* spp.), beech (*Fagus grandifolia*), ashes (*Fraxinus* spp.), white pine (*Pinus strobus*), hemlock (*Tsuga canadensis*), etc., are invading large areas of formerly stable subxeric oak forest, now that fires have been generally suppressed. While there are few good data on these trends in Kentucky, it does seem likely that occasional fires before settlement did have some long-term effects on these kinds of forest. There is little evidence that distinctive grassland vegetation, with conservative species (see next section), can be readily regenerated by fires or other disturbances in these forests. However, the proportion of fire-sensitive species, which are mostly more mesophytic or shade tolerant, was probably reduced by fires.

In remaining formations, which are typical of more mesic or hydric sites, there is no clear evidence that fires have played a significant role in maintaining biodiversity before settlement.

Fine Patterns

The word "fine" is used here in relation to narrow compositional variation of the vegetation, rather than small-scale spatial variation. Some finely defined compositional types, including only a narrow range of characteristic species, such as white oak-black oak forests, are distributed in large blocks over much of the park's area.

1. Within the "xeric-subxeric conifer-oak" formation, there is considerable variation in composition related to geology or soil pH.

    1A. On acid, sandy soils, generally near sandstone clifftops, there is probably much potential for fire to open up the forest and create denser grassy ground vegetation. However, there has been relatively little survey in these narrow zones of the remote NW sector of the park. In analogous Appalachian systems, fire is well known to promote open grassy woodlands with much *Piptochaetium avenaceum*, *Danthonia* spp., *Panicum* spp., *Schizachyrium scoparius*, etc. (e.g., Campbell et al. 1991, Campbell 1996). It would be particularly interesting to know if *Piptochaetium* exists in the park, since there is a record from further up the Nolin River, and this grass is often one of the most rapidly responsive to fire in Appalachian pine-oak systems. Several other uncommon to rare species may be expected in such cases, as discussed below in the floristic section. It is also possible that shrublands (e.g., *Vaccinium arboreum*, *Kalmia latifolia*, *Gaylussacia baccata*), or open rocky grassland zones could be maintained by fire close to the sandstone outcrops, but more inventory and experimentation is needed to explore this potential.

1B. On basic, calcareous soils, generally near limestone outcrops, the frequent sites with thin woods and small rocky glades often have a distinctively high diversity of species that require open sunny conditions to prosper and reproduce. From scattered records of such species, often suppressed in the shade of denser forest, it seems likely that most of the S/SW-facing moderate to steep calcareous slopes did have open red cedar-oak woodland before settlement. For further indications of such vegetation in historical descriptions of the region 100-200 years ago, see Appendix 2B, especially Owen (1856, p. 81), and Dicken & Bowen (1938, p. 39). Common graminoids in these openings include *Schizachyrium scoparius*, *Sporobolus clandestinus*, *Panicum oligosanthes*, *Carex meadii*, etc. On the purest limestone soils, on lower slopes closer to the Karst Plain, there may have been a distinct variant, with locally abundant *Bouteloua curtipendula*, but this species is currently unknown in the park. There are many uncommon to rare species associated with remnants of these openings today in the park or nearby (see "Rare Plants" section below, p. 31).

2. Within the "non-hydric oak plains" formation, there is variation related to geology and soil pH, and to further differences in soil depth and hydrology.

2A. The acid, infertile extreme, generally on sandy soils, may have little representation at the park. In Appalachian regions, there would be much gradation into pine-oak forest on such sites. However, the forest type generally known as "southern red oak-scarlet oak" (*Quercus falcata*-*Q. coccinea*) does appear to reflect at least a transition to this extreme. In more open, pyric phases of this type, distinct grassy ground vegetation can be expected, perhaps with such rare species as *Buchnera americana*, *Cirsium carolinianum*, *Phlox amoena*, *Rhynchosia tomentosa*, etc. (for further rare species, see Appendix 2C, 5). More xeric variants could grade into open pine (*Pinus virginiana*) woodland, and there needs to be more survey of sites near sandstone cliffs where this might occur. On more xerohydric sites, other distinctive species such as *Aletris farinosa*, *Platanthera lacera* and *Spiraea tomentosa* may be expected in open, pyric phases, but there are no good remnants of such systems in the park today (see Appendix 4B for further notes on such phases within this formation).

2B. On intermediate soils, with mixed bedrock, and locally with much loess, there is a widespread, broadly defined forest or open woodland type typified by locally dominant *Quercus falcata*, *Q. stellata* or *Q. marilandica*. However, with fire-suppression after park formation, there appears to have been much loss of *Q. marilandica*, which is typical of the more xeric variants, and a general trend towards *Q. velutina* and *Q. alba*, which are typical of subxeric sites with less stressful soils (Appendix 4B). Many uncommon or rare herbs and graminoids were probably associated with more open phases of this woodland, including the globally threatened or declining *Helianthus eggertii* and *Trifolium reflexum*. More xeric, or xerohydric variants of this open woodland phase may also be tentatively recognized in vegetational (Appendix 4B) and floristic patterns (Appendix 5), but experimentation with fire will probably be needed for proper definition of these variants.

2C. On basic, calcareous soils, or transitions to such soils, there is little evidence remaining of distinct open woodland on the upland ridges of the park. On these ridges, more acid soils, with bases leached and loess eroded, generally predominate even on calcareous bedrock. However, on the gentle karst valley slopes and bottoms, it is likely that such vegetation did exist before settlement, maintained by fires and perhaps by browsing of deer and other herbivores. There are very few sites where presettlement composition can be estimated directly from modern remnants. The outstanding Wondering Woods site is truly exceptional in showing the native grassland potential. It is difficult to judge what tree species existed in the open woodland that may have prevailed over this land type, though it seems that locally abundant *Quercus imbricaria* may have been a distinctive feature. On typical submesic to subxeric variants, it seems likely that *Andropogon gerardii* and *Sorghastrum nutans* were abundant in grassy openings. On more xeric variants, *Schizachyrium scoparius*-(*Sorghastrum nutans*) grassland may have been extensive in some sections, especially where connected to the frequent fire regime of the Karst Plain. On more xerohydric sites, it is possible that some features of *Tripsacum dactyloides*-*Panicum virgatum* grassland were present before settlement, but this type has virtually disappeared from the region today (for further notes on possible composition before settlement, see Appendix 4B).

3. The "hydric oak flats" formation is typical of more or less poorly drained sites within the "non-hydric oak plains" formation. These sites are much less extensive, and there are no good remnants of open woodland or grassland phases in the park. However, highly distinct composition may have occurred in open phases before settlement, especially in drier transitions with more fire and grassland history. Some concept of such vegetation may be gleaned from historical and modern floristic data.

3A. On extremely acid infertile sites, or transitions to such soil, open phases may well have resembled the vegetation known on similar sites elsewhere in the Interor Low Plateaus (e.g., at Hazel Dell in Pulaski Co., KY; and May Prairie in Coffee Co., TN). These sites have highly significant concentrations of Coastal Plain plant species and others. Sadie Price's 1890s collections (at Missouri Botanical Garden, cited by Medley 1993) of *Drosera intermedia*, *Ludwigia hirtella*, *Platanthera ciliaris* and *Polygala cruciata* from the Chalybeate area, five miles west of the park, have great relevance here, since these are some of the same uncommon to rare taxa that occur at those more eastern sites. It is unclear what tree species were most closely associated with such sites before settlement, other than pin oak (*Quercus palustris*) and perhaps scarlet oak (*Q. coccinea*). [On the Coastal Plain, one would expect longleaf pine (*Pinus palustris*) to occur in open, pyric woodlands on such sites.]

3B. On intermediate soils, pin oak (*Quercus palustris*) is locally dominant around several small ephemeral ponds on broad ridges in the park, but there is also much intermixing with surrounding forest of swamp red maple (*Acer rubrum* var. *trilobum*), southern red oak (*Q. falcata*, white oak (*Q. alba*), etc. Again, one can only speculate about the composition of such forest when it was more frequently burned and more open. From other sites in the Interior Low Plateaus (as in 3A, also Fort Campbell and Arnold Airforce Base), it is likely that *Erianthus* spp., *Panicum* spp., *Rhynchospora* spp., *Carex* spp., *Juncus* spp., etc., are potentially abundant in wetter places, or mix with the typical upland grasses in drier transitions. Uncommon to rare species that may have typified such sites before settlement are noted below in the section on rare plants.

3C. On base-rich, calcareous sites, or transitions to such soil, swamp white oak (*Quercus bicolor*) is generally more typical than pin oak (*Q. palustris*) in Kentucky, and shumard oak (*Q. shumardii*) is often associated in drier transitions. It is possible that small areas of such forest could occur at MCNP, but none are known currently. The closest examples may be a few miles to the west, near Beaver Dam Creek. Although distinctive uncommon or rare species might be expected in open phases further west (e.g., *Tripsacum dactyloides*, *Panicum virgatum*, *Calamagrostis canadensis*, *Spartina pectinata*), it is possible that the small size and isolation of such sites limited native diversity in the park area even before settlement.

Within formations less strongly associated with fire before settlement, there are still many interesting questions about the role of fire. From recent experiences in Daniel Boone National Forest (Campbell et al. 1996, and unpublished data), it is clear that even within typical subxeric oak forests and submesic to subhydric forests fires can promote certain distinctive species in the ground vegetation. More research will be needed to provide an overlay of ground-vegetation patterns for these burned woods, for placing over the water- and soil-related gradients of tree composition.

Rare Plants

Appendix 5 (see also Map ID) presents a detailed annotated list of rare species known from the park, or nearby, or within the park's whole region, defined as the Pennyrile Karst Plain, Southern Dripping Springs Hills, plus Pottsville Escarpment. This is an attempt to represent the pool of rare species that can be expected in the park. However, further taxonomic work and inventory will be needed before a definitive list can be produced. The list indicates globally rare species (estimated G1/2/3), other state-rare species (estimated S1/2/3), and other species of interest within the state (estimated S3/4 intermediates).

Globally Rare Species

There are about eight globally rare species known from the park. Four of these are largely restricted to openings and edges in the park, and are clearly dependent on disturbance of some kind:

Helianthus eggertii, Eggert's Sunflower (Interior Low Plateaus endemic)

Prenanthes crepidinea, Giant Wood-lettuce (mid-western range)
Silphium pinnatifidum, Pinnate-leaved Prairie-dock (largely endemic to ILP)
Trifolium reflexum, Buffalo Clover (southeastern; almost extinct in northern range).

None of these are globally endangered, but, from a general knowledge of their ecology, they have probably declined greatly since settlement. *T. reflexum*, in particular, being a biennial, appears to be highly dependent on fire or soil disturbance to expose new ground for germination and growth (D. Boone, Bartlett Tree Care, Cincinnati, pers. comm.). It is probably the most significant indicator species for the lost native grasslands and open woodlands on typical upland habitats in the park. The three others are more long-lived perennials, and can survive for several years without flowering, in more brushy or forested habitats.

The other globally rare species in the park include two herbs restricted to rocky ravines on subxeric to mesic sites, and which probably have had little relationship with fire:

Aureolaria patula, Spreading False-foxglove: open woods along the river;
Dodecatheon frenchii, French's Shooting Star: under sandstone cliffs.

Also, there are two trees that have declined drastically due to diseases, but it is possible that fires promoted these two trees in the past:

Castanea dentata, chestnut, is known to be fire-tolerant and there is some regional evidence from pollen cores that native people increased its proportion in Appalachian forests through frequent burning (Delcourt et al. 1998).

Juglans cinerea, butternut (or "white walnut") was locally abundant in thickets and young woods before settlement in Kentucky, especially on fertile bottoms, lower slopes and even some ridges, where native peoples may have farmed and burned the land (e.g., Campbell 1989; see also Hibbard's (1934b, 21 Dec) note on the Great Onyx Cave area in Appendix 2).

There are about seven other globally rare plants known in the region, and most of these are restricted to rocky glades, grasslands, open woodlands or ephemeral ponds (see Appendix 5). It is possible that some of these occurred in the park before settlement, and efforts might be made restore a few eventually, e.g., *Leavenworthia torulosa* (Necklace Glade-cress) and *Silene regia* (Royal Catch-fly).

State-rare Species

About 24 additional species known from the park, plus another nine from within ten miles of the park, should be considered rare (S3), threatened (S2) or endangered (S1) in Kentucky (Appendix 5). About 17 of these 33 species are largely restricted to open rocky glades, grasslands or ponds and shores, and another 10 or so are concentrated in open woods or brushy edges. Only about three species are typical of undisturbed, closed forests:

Circaea alpina, Small Enchanter's Nightshade
Trichomanes boscianum, Filmy Fern
Veratrum woodii (= Melanthium w.), False Hellebore

A few others are typical of partly open woods but rarely grassland:

Lilium michiganense, Mid-western Wood-lily
Quercus nigra, Water Oak
Solidago patula, Swamp Goldenrod
Tragia cordata, Heart-leaf Noseburn.

The following state-rare species are most typical of deeper soils with native grassland or open non-hydric oak woodland, where fires were probably most influential (in addition to the few globally rare species listed above):

Aureolaria pectinata, Southern Annual Yellow-foxglove
Bartonia virginica, Yellow Screwstem
Buchnera americana, Blue-hearts
Gentiana puberulenta, Prairie Gentian
Gymnopogon ambiguus, Bearded Skeleton Grass
Helianthemum bicknellii, Plains Frostweed
Oenothera fruticosa, Bushy Sundrops
Rhynchosia tomentosa, Hairy Snout-bean
Silphium integrifolium, Prairie Rosin-weed
Solidago speciosa var. *angustata*, Western Showy Goldenrod.

These species are all very rare in the park, with no more than two or three records each, and they probably continue to be threatened with further declines or local extinction, as the forest is allowed to become denser, with fire-suppression.

On more rocky ground, typically in more stable (less fire-dependent) open phases of red cedar-oak woodland, state-rare species recorded in or near the park include the following:

Aster sericeus, Western Silky Aster
Krigia occidentalis, Western Dwarf Dandelion
Liatris cylindracea, Slender Blazingstar
Melica nitens, Glade Melic-grass
Muhlenbergia capillaris, Glade Hairgrass
Phlox bifida ssp. *bifida*, Cleft (Sky-blue) Phlox
Ranunculus fascicularis, Silky-leaved Buttercup
Viola egglestonii, Glade Violet.

Even though these species may be somewhat less fire-dependent, they appear to be very rare in the park, with no more than two or three records each (except perhaps A. sericeus). It is likely that their remaining populations have been constrained to only the most xeric rocky sites where forest succession is the slowest.

On wetter ground, state-rare species that were probably typical of open hydric oak woodland or its drier transitions include:

Drosera intermedia, Spoon-leaved Sundew
Hypericum canadense, Narrow-leaved St. John's Wort
Ludwigia hirtella, Hairy Water-primrose
Polygala cruciata, Cross-leaf Milkwort.

Most of these were recorded only once, by S.F. Price in the 1890s near Chalybeate ("Kalibeet"), and they may well be locally extinct (Medley 1993).

Other Species of Interest

About 64 additional species known from the park or nearby are uncommon enough to be considered in general conservation planning, and they can also be used to indicate special vegetational features. These would mostly be considered as "watch-list" species in the Natural Heritage System, and typically they should be given the "S3S4" state rank. About 45 of these species are largely restricted to open rocky glades, grasslands or ponds or shores, and another 12 or so are more typical of open woods and brushy edges. Only about seven species are typical of undisturbed, closed forest.

About 34 of these species are typical of grasslands or open non-hydric oak woodlands on deep upland soils where fires were probably most influential. These include the following:

Agalinis gattingeri, Western Small Purple-foxglove
Asclepias amplexicaulis, Clasping Milkweed
Asclepias exaltata, Stately Milkweed
Carex crawei, Damp-glade Sedge
Desmodium cuspidatum, Large Tick-trefoil
Desmodium obtusum, Stiff Tick-trefoil
Desmodium sessilifolium, Tall Sessile-leaf Tick-trefoil
Cirsium altissimum, Tall Wild Thistle
Cirsium carolinianum, Early Wild Thistle
Echinacea purpurea, Broad-leaf Purple Coneflower

Eryngium yuccifolium, Rattlesnake-master
Helianthus mollis, Downy Sunflower
Helianthus occidentalis, Naked-stemmed Sunflower
Hypericum denticulatum, Barrens St. John's Wort
Lespedeza capitata, Dense-headed Bush-clover
Liatris spicata, Sessile Blazing-star
Liatris squarrulosa, Southern Blazing-star
Panicum malacophyllum, Soft-leaved Barrens Panic-grass
Panicum ravenellii, Hard-leaved Barrens Panic-grass
Phaseolus polystachios, Wild Bean
Phlox amoena, Charming Phlox
Phlox pilosa, Prairie Phlox
Platanthera lacera, Ragged Summer Orchid
Polygala incarnata, Fleshy Milkwort
Pycnanthemum pilosum, Hairy Mountain-mint
Ratibida pinnata, Yellow Coneflower
Rudbeckia tenax, Western Brown-eyed Susan
Tripsacum dactyloides, Gama-grass
Veronicastrum virginicum, Culver's Root.

Most of these may still have viable populations in some the best grassland or open woodland remnants in the park. But some only have one or two records, or may already be locally extinct (e.g., *Echinacea purpurea*, *Phlox amoena*, *Tripsacum dactylodes*).

In more rocky openings, other species "of interest" include the following:

Bumelia lycioides, Smooth Southern Buckthorn
Carex meadii, Dry-glade Sedge
Crotonopsis elliptica (= *Croton wildenovii*), Common Rushfoil
Echinacea simulata, Narrow-leaved Purple Coneflower
Hexalectris spicata, Crested Coral-root Orchid
Leavenworthia uniflora, Common Glade-cress
Liatris aspera, Lacerate Blazing-star
Liatris squarrosa, Small Blazing-star
Linum sulcatum, Glandular Flax
Paronychia fastigiata, Hairy Annual Whitlow-wort
Scutellaria leonardii, Smooth Small Skullcap
Sporobolus clandestinus, Rough Dropseed
Thaspium barbinode var. angustifolium, Narrow-leaved Meadow-parsnip

Some of these have fairly large populations in some rocky openings (e.g., *Carex meadii*, *Echinacea simulata*, *Liatris squarrosa*, *Sporobolus clandestinus*), but others appear to be quite rare in the park or nearby.

On wetter ground, there appear to be few additional species typical of open hydric oak woodland or its transitions. Only *Juncus coriaceus* (Shining Rush) and Viola lanceolata (Lance-leaved White-violet) seem to fit this category. There is also a historical record of *Platanthera ciliaris* (Orange Fringed Orchid) from the Chalybeate area (S.F. Price collection at Missouri Botanical Garden). Was there once a more diverse flora on such sites before settlement, or were openings much less extensive? Further floristic research in this region might help answer such questions.

Zoological Data

Insects

Because most easily observed animals are more mobile than plants, it is more difficult to argue that supposed "relic" animal occurrences form evidence of presettlement environments. Nevertheless, some entomologists have made such arguments based on data for rare insects that are restricted to open grassy woods and grassland (e.g., Panzer et al. 1995, Bess 1992-98). Moreover, any fire management plan should ideally consider effects on rare species, and it is important to know if any such species exist at MCNP. For these reasons, an introductory survey of lepidopterans and hemipterans was conducted for this plan by C. Covell (Appendix 6). Discussions concerning the significance of insect records were also conducted with J. Bess (OTIS Enterprises, Wanatah IN, pers. comm.). Problems in deciding exactly how to define "rarity" or "grassland remnant-dependent" species continue, but at least some preliminary results have been obtained.

During June to September, 1998, C. Covell and his assistants (Appendix 6) sampled four sites with grassy openings: Wondering Woods area (NE of Resource Management Building) with 134 species recorded; Great Onyx Cave area (old fields on ridge) with 130 species recorded; Crystal Cave area (old fields on ridge) with 59 species recorded; and the Cedar Sink area (rocky openings and nearby roadsides) with 58 species recorded. Lower numbers in the latter two sites partly reflect less intensive sampling, but they did appear to be less diverse sites. The following species are considered rare or uncommon in Kentucky.

Butterflies: Hesperiidae

Erynnis baptisiae; at Wondering Woods; though listed as a prairie specialist by Panzer (1988), this species has become more common in this region due to its larval feeding on the alien crown vetch (*Coronilla varia*) in addition to its native food plants, wild indigos (*Baptisia* spp.).

Moths: Torticidae

Epiblema sp. nov. (aff. *infelix*); at Wondering Woods; Covell is planning to name this.

Moths: Crambidae

Compacta capitalis; at Wondering Woods; third KY record, "very rare" in KY.

Herpetogramma sp. (aff. *aeglealis*); at Great Onyx Cave; undetermined, but possible new state record.

Moths: Geometridae

Glena plumosaria; at Cedar Sink

Hypagyrtis brendae; at Great Onyx Cave

Lophosis labeculata; at Crystal Cave and Great Onyx Cave; third KY record, but common further south in USA.

Moths: Sphingidae

Sphinx franckii; at Wondering Woods; "fairly rare" in KY.

Moths: Artiidae

Grammia arge; at Crystal Cave area; "rather uncommon" in KY.

Moths: Noctuidae

Phlogophora iris; at Cedar Sink; "uncommon in our experience" in KY.
Magusa orbifera; at Great Onyx Cave; "uncommon in our experience" in KY.
Leucania phragmatidicola; at Crystal Cave and GOC; "grassland specialist although generally common" in KY; "remnant-dependent" (Bess).
Leucania multilinea; at GOC; "grassland specialist although generally common" in KY.
Leucania pseudargyria; at GOC; "grassland specialist although generally common" in KY.

Several other species found by Covell are considered "remnant-dependent" by Panzer et al. (1995) and Bess (1992-98), as marked in Appendix 6. To quote Bess (1998): "Remnant-dependent insects are defined as occurring only on remnants of pre-European settlement plant communities and being absent from the highly altered landscape surrounding these remnants. Studies conducted on Kentucky glades and barrens (Bess 1003, 1996a-b, 1998c) found that approximately 35% of the insects occurring in these native grasslands and woodlands fall into [this] category." However, it may be difficult to decide clearly whether a species is "remnant-dependent or not. Several of Bess's examples do occur in old fields with diverse native vegetation that may partly contain animal and plant species present before settlement, but also partly made up of recent immigrants to farmland (P. Palmer-Ball, KSNPC, pers. comm.). There is continuing debate among entomologists about these definitions, but the basic observation is clear--that a considerable proportion (perhaps 10-30% on average) of insects in remnants of natural grassy openings are largely restricted to such habitats. Some of these species are undoubtedly rare and their occurrences are probably relics from presettlement ecosystems at those locations or nearby. Such species should be considered sensitive in management plans. [Although precise statistics have not yet been calculated from botanical data, it is clear that a similar proportion of plant species are rare or "conservative", including the broadly defined "S3S4" category of state heritage programs.]

In addition to providing possible evidence of presettlement conditions, the presence of rare or uncommon insects in remnants of grassy openings provides further justification for applying prescribed burns, in order to restore their habitats. However, it is also very important not to plan a burn that covers a complete grassy opening, which could cause local extinction of overwintering insects. Either such openings should be divided into blocks for rotational burning in a multi-year sequence; or small unburned patches should be left among the burn units (Bess 1998).

Vertebrates

There are relatively few vertebrates in this region that can be reasonably used as evidence of grassy openings maintained by fire before settlement (J. MacGregor, USFS/DBNF, and P. Palmer-Ball, KSNPC, pers. comm.). The most obvious example is the eastern slender glass lizard (*Ophisaurus attenuatus longicaudis*), which was reported to be "common in the park area" by Hibbard (1934). There have been virtually no records during the past 10-20 years. This species is known to be almost completely restricted to grassy openings (often rights-of-way with native vegetation) in limited disjunct western and southeastern sections of the state. The pattern of open grassy conditions before settlement is probably related to these disjunctions, in addition to the sandy soil conditions that this species seems to prefer. There is, however, some danger of circularity in this argument, and there is a need for more definitive study of this species.

Several other rare or uncommon herptiles recorded from the Mammoth Cave area are concentrated in grassy openings or open woodlands, but to a lesser extent than the glass lizard. Some of them may be relics from presettlement openings, but there is a need for further study. Such species may include pine snake, corn snake, scarlet king snake, scarlet snake, southeastern five-line skink, and northern coal skink. Birds probably have little or no use as evidence for presettlement conditions, because they are so mobile and can move into farmland (B. Palmer-Ball, pers. comm.). Even the globally rare Bachman's sparrow, which requires open grassy woodland for breeding, may have moved into some areas of the state after settlement. This species was not recorded in Kentucky by Audubon. There are a few records of the federally endangered red-cockaded woodpecker from the Mammoth Cave area (Palmer-Ball 1996). This species is strongly associated with open grassy pine or pine-oak woodlands, and the narrow strips of pine along sandstone clifftops are probably inadequate for stable populations. It is possible that fires before settlement expanded the zone of pine woodland from cliffs onto adjacent ridges.

Nevertheless, many vertebrates do benefit from open grassy conditions, and will probably respond to fire in the park (see Part II), enhancing native biodiversity. Some of these species appear to have declined since settlement, especially in areas where the forest has not been kept open with fire or other means.

FIRE HISTORY

Unfortunately, there is little good direct evidence of fire-history in the park, aside from records of fires in recent decades. Initially, it was hoped that this study would include some further examination of physical evidence that would provide substantial support for hypotheses of pyric patterns before settlement. However, the techniques employed and the resources available did not allow this. Nevertheless, it is important to review all possible sources of information, and to provide guidance for future research into this subject. This final section of Part I summarizes these sources, and provides whatever overall conclusions about fire history seem to be justified. Much of this information has already been referenced and reviewed above, and the following is a more condensed summary.

Sediments and Soils

There have only been two complete studies of fossil pollen in the natural ponds of Kentucky--one in the west (Wilkins et al. 1991) and one in the east (Delcourt et al. 1998), which also examined charcoal. These studies, and other partial studies, provide very important data for inferring fire history. As noted above (p. 11-13), they suggest that after about 3000-3500 years ago there was a shift in the forests from relatively fire-intolerant, mesophytic or hydrophytic trees to more fire- and drought-tolerant oak, ash, hickory and chestnut (plus pine in the Appalachian site). About the same time, there was an increase in grass pollen percentage at the western site (in Larue County at the edge of the karst plain), and there was an increase in deposition of larger charcoal dust. From these studies and others in the region (P. & H. Decourt, Univ. of Tennessee, pers. comm.), there is now clear evidence that fires increased during this period. Moreover, correlated archeological and paleoclimatological suggest that changes in human culture were the major cause, rather than a general climatic change. These changes occurred after the "hypsithermal" period of 5000-8000 years ago, when a maximum in warmth and dryness occurred throughout much of eastern North America.

Archeological data from cave deposits, as also reviewed above (p. 11-16), suggests that about the same period, ca. 3000-3500 years ago, there was a shift to more cultivation of garden plots. This corresponds to the general transition from "Archaic" to "Woodland" cultural eras. Although there is no direct evidence of population trends, it is reasonable to suppose that during this period there was an increase in the residential human population, with more agricultural activity and more burning to clear ground and increase game production.

In preparation for this plan, an effort was made to analyze soil samples for traces of charcoal, distinctive phytoliths (silica bodies left by grassland vegetation), and other evidence of pre-park or pre-settlement environments. P. Kalisz (Dept. of Forestry, Univ. of Kentucky) was contracted to do this analysis and his report is attached as Appendix 7. He took samples from throughout the park, but stratified by the Olson & Franz land types, in the hope that differences in grassland history would be detected. However, no identifiable charcoal particles or phytoliths were found in the samples. Possible reasons for this absence of evidence are that fire-maintained grassy openings may not have been present for long enough to leave evidence in the samples, or that not enough well located samples were fully analyzed, or that too much erosion of presettlement topsoil has occurred.

The total mass of opal (organic silica) was determined for 17 samples at Mammoth Cave. This parameter has been used in previous studies (e.g., Kalisz & Boettcher 1990) to indicate presettlement grassland, though Kalisz (pers. comm.) now considers it to have little value for such interpretation. The Mammoth Cave opal masses were reported as mostly 0.69-0.83%, but four were distinctly higher: Raymond Hollow/broad sandy ridge (0.94), Sand Cave/karst-slope transition below broad sandy ridge (0.97), Brooks Knob/broad sandy ridge (1.05), and Maple Springs/broad sandy ridge (1.46). These higher values appear similar to values found in grassland and open woodland transition by Kalisz & Boettcher (1990), but an exact comparison need more details of soil mass per square meter. Because these sites are mostly on or near sandy ridges, one might speculate that warm-season (C4) grasses have been able to redeposit more silica on such sites. It may also be useful to note that higher values did not come from typical limestone karst or slope sites, where distinct types of grassy openings might have occurred, but where much erosion probably occurred after settlement.

Fire-scars in Trees

At the outset of this study there was some hope that dead trees in the park could yield evidence of fire scars 150-200+ years ago. However, insufficient numbers were located. Moreover, further consultation with Albert Meier (Dept. of Biology, Western Kentucky Univ.) indicated that by far the best chances to get useful data from old fire-scars would be to focus strictly on post oak and red cedar. Post oak is a long-lived, fire-tolerant species that was probably dependent on fire for much of its abundance before settlement (see above, p. 17-22), and it has been used in successful studies of fire-scars within the Ozark region. Red cedar is fire-sensitive but it can also be long-lived in natural stands on the driest rocky, limestone exposures where fires may have been less intense because of less oak-leaf or tall-grass fuel on the ground. Meier is currently conducting a study of fire-scars in the Conservancy's Mantle Rock preserve (Livingston County, Kentucky), and preliminary results indicate that there are clear signs of fires in older stems dating from the settlement era or earlier.

In Mammoth Cave National Park, there are many fire-scars on trees that date from recent decades. Some initial notes on these were made by T. Simmons and others during this study, there has not yet been a comprehensive attempt to analyze such data for a substantial area of the forest. Such data could be useful in showing what sections of the park have had the most chance of burning within the past 50-100 years, and such patterns could help guide fire management in the future.

Written Records

The written record of vegetation in the region (see above, p. 17-20 and Appendix 2) provides some indirect evidence of fire, because the extensive grasslands and open woodlands with post oak and blackjack oak must have been dependent on fire. Moreover, there were several early observers who noted annual burning on the karst plain (in the Big Barrens). More recent records have clearly demonstrated the shift towards more densely forested vegetation in this region when fire is reduced. Further details of interpretation have already been suggested above (p. 17-29), but suggestions about variation in fire-frequencies and topographic patterns cannot be considered conclusive.

There is an extensive body of fire data from recent decades in Mammoth Cave National Park. Fires have been mapped, and there are files with details of each incident (R. Caldwell, pers. comm.). There is a need to summarize the patterns from these data, since they will aid in predicting where wild fires are most likely to occur. Moreover, further study of the burned areas will aid in determining fire effects.

Ray (1997) presented a study of lightning fire data from Mammoth Cave National Park. From historical data, and comparisons with other regions, he suggested that about 15-20 fires per year would have been started by lightning in the presettlement vegetation that covered the 850 square miles of the Mammoth Cave area and adjacent karst plain. However, it is difficult to judge how extensively these fires would have burned, and how important they would have been compared to fires started by people. Most of the recorded lightning fires in the park occurred on ridges south of the river, but this pattern may just reflect a greater chance of fires being observed here.

Biological Patterns

In addition to general observations of grassy open vegetation and fires during the pioneer period and the first few decades of settlement, there are many details of distribution patterns in vegetation types and individual species that may be partly explained by fire history. Although such data cannot be considered good direct evidence of fire history, they do form a fairly substantial body of supporting circumstantial evidence. Key points to be made from the information presented above are as follows.

Although most of the park was probably well forested before settlement, a significant proportion of the natural woodland in the park area appears to have had abundant post oak, together with associated blackjack oak, southern red oak, black oak and other species. From general knowledge of eastern North American ecology, such vegetation is probably maintained in large part by fire. A typical fire interval of 3-5 years may be expected in relatively natural, open grassy stands of such woodland (see Table 1 in Part II and references cited therein). Especially after park formation and modern fire suppression, the 3000+ acres of woodland with abundant post oak, southern red oak or blackjack oak that existed in the 1930s (Appendix 3) has dwindled to only a few hundred acres today. White oak appears to have gradually invaded much of this woodland.

The remnants of this post oak woodland and other indicators of natural openings, based on data mapped after 1930, appear to have been concentrated on broad ridges and S/SW-facing slopes in the southeast sector of the park, south of the river (Map IE). This distribution pattern may be explained in terms of patterns in fire frequency before settlement, as discussed above (p. 17-20). Ray (1997, with fold-out map) suggested a similar distribution of open woodland in the

Mammoth Cave area before settlement, based on general considerations of fire behavior. Further south, on the karst plain annual fires appear to have maintained most of the area as grassland. Further north, especially on the north side of the river, there is relatively little evidence that open woodland existed before settlement.

In the subxeric oak forests on more sloping ground north of the river, there was probably a typical fire interval of 5-25 years (see Table 1 in Part II). Post oak and blackjack oak, in particular, are remarkably rare there today, except perhaps on a few broader ridges along the northern edges of the park and in narrow zones along xeric bluffs of the river. It is likely that the river valley, and its tributary ravines, acted to break the spread of large fires from the karst plain grasslands into the Shawnee Hills. However, some exceptions to this pattern might well have occurred on sandy ridges and clifftops with chestnut oak and pine, which are more fire tolerant than white oak. It is possible that narrow zones of slightly open woodland were maintained by fire on these sandstone ridges, perhaps influenced by lightning strikes more than human burning.

On uplands of the park, truly xeric open woodland and glades are likely to have been influenced by fire before settlement, but these are restricted to relatively narrow zones along rocky S/SW-facing slopes. Because of thinner fuels and more interrupted rocky ground, fires are likely to have been less intensive on such sites, allowing more sensitive species such as red cedar to survive. As well as fire, the shallow soils and rock outcrops must have been a major factor in maintaining natural openings here. Even today, after 60 years with little or no fire, there are numerous small openings and thin woodlands on these sites.

On poorly drained upland flats, with xerohydric to hydric conditions, there may have been distinctive open grassy woodlands with some influence from fire (p. 28). However, there are virtually no remnants of such vegetation in the region today.

There are several rare plant species in the park that are largely dependent on open conditions, and which are probably relics from open grassy woodland before settlement (p. 30-34). Several of these species are strongly associated with more stable rocky openings. But other species are not associated with unusual soil conditions, and their occurrence before settlement may have been largely associated with openings maintained by fire. It must be emphasized that these species do not exhibit "weedy" tendencies by spreading into newly disturbed clearings here or elsewhere in the region, and general botanical knowledge has often labelled them as "conservative" (Wilhelm & Ladd 1988). The best examples of these species that are recorded from the park area (p. 30-31) include *Helianthus eggertii* (Eggert's sunflower), *Silphium pinnatifidum* (pinnate-leaved prairie-dock), *Trifolium reflexum* (buffalo clover), *Aureolaria pectinata* (southern annual yellow-foxglove), *Buchnera americana* (blue-hearts), *Gentiana puberulenta* (prairie gentian), *Gymnopogon ambiguus* (bearded skeleton grass), *Oenothera fruticosa* (bushy sundrops), *Rhynchosia tomentosa* (hairy snout-bean), *Silphium integrifolium* (prairie rosin-weed) and *Solidago speciosa* var. *angustata* (western showy goldenrod). The distribution of such species can aid in suggesting where the most open grassy woodlands occurred before settlement (Map IE).

There are a few animal species that may be relics from open grassy conditions before settlement, especially some insect species (Bess 1992-98). Preliminary surveys at the park by C. Covell (Appendix 6) indicates that significant concentrations of such species may occur in the grassy openings at Wondering Woods, Crystal Cave and Great Onyx Cave. These sites are also important for rare plant species and appear to be have remnants of presettlement ecosystems in their biota. However, much more research into such distribution patterns is needed for definitive conclusions about presettlement conditions.

Overall Conclusions

The most important conclusion of this preparation (Part I) for the fire management plan (Part II) is that before settlement open grassy woodland characterized by abundant post oak, blackjack oak and southern red oak was widespread in the southeast (Drippping Springs Hills) sector of the park, especially south of the river. Based on vegetational data after 1930, this woodland is presumed to have been concentrated on most broad ridges and S/SW-facing slopes in this sector of the park (Map IE; see also Ray 1997). The river valley probably tended to break the spread of annual fires from the karst plain grasslands into the Shawnee Hills. The Dripping Springs Hills are transitional between the sandstone-dominated Shawnee Hills to the north and the Pennyrile Karst Plain to the south, and it is likely that a mosaic of forest and open grassy woodland existed before settlement.

The typical fire interval in the post oak woodlands was probably about 3-5 years. In more densely forested uplands, especially north of the river, fire intervals may have been about 5-25 years. This would have allowed white oak forest to dominate much of the land. However, narrower sandstone ridges and clifftops might have been subject to more frequent fires (partly due to lightning strikes), and there may have been open woodland with chestnut oak and pine. In mesic ravines, especially on N/NE-facing colluvial slopes, fire intervals were probably about 25-50+ years, allowing fire-sensitive sugar maple and beech to dominate.

More detailed analysis of presettlement conditions in the park area may eventually come from further study of sediments in natural ponds of the region. Such work has great potential for great insight to fire ecology, especially if charcoal deposition is studied in addition to pollen (P. & H. Delcourt, Univ. of Tennessee, pers. comm.). Further insight may also come from more detailed analysis of early property surveys--with much painstaking work it is probably possible to reconstruct the pattern of early property boundaries, with the trees noted at each corner. Although not forming a systematic sample, such data could be very useful in relating forest composition to topography and fire history--the most useful parameter to examine might be the concentration of post oak versus white oak.

Further analysis of the existing vegetation and recent fire history can also provide much more information about burning patterns and responses. Although not directly relevant to reconstructions of presettlement conditions, such analysis could be very useful in understanding the general relationship between fire and vegetation in this region. Moreover, direct experimental observation on future effects of fire on the vegetation, when prescribed burning is applied, will eventually provide the most definitive results for understanding of the ecological effects of fire. Only then, by combining thorough modern observations with the fragmentary historic and prehistoric evidence, may we achieve the best possible interpretation of fire history in the park, and the best possible plan for future fire management.

LITERATURE CITED

Abrams, M.D. 1992. Fire and the development of oak forests. Bioscience 42:346-353.

Applegate, H.L. (ed.) 1965. A Tour of the South: Travel Diary of Moses Dewitt Burnet 1815-1816. Carnegie Library, Syracuse University, Syracuse, New York.

Bailey, R.G., P.E. Avers, T. King and W.H. McNab. 1994. Ecoregions and subregions of the United States (1:7,500,000 map). U.S. Geological Survey, Washington, DC. [linked with: W.H. McNab and P.E. Avers. Ecological subregions of the United States: section descriptions. U.S.D.A. Forest Service.]

Barton, J.E. 1919. The Mineral and Forest Resources of Kentucky. Department of Geology and Forestry. [Kentucky State Government.] Vol. 1, Series 5.

Baskin, J.M. and C.C. Baskin. 1981. The Big Barrens of Kentucky not a part of Transeau's Prairie Peninsula. Pages 43-48 in R.L. Stuckey & K.J. Reese (eds.). The Prairie Peninsula - in the "shadow" of Transeau: Proceedings of the Sixth North American Prairie Conference, Ohio State University, Columbus, Ohio, 12-17 August 1978. Ohio Biological Survey Notes No. 15, 278 pp.

Baskin, J.M., C.C. Baskin & E.W. Chester. 1994. The Big Barrens Region of Kentucky and Tennessee: further observations and considerations. Castanea 59:226-254.

Baskin, J.M., E.W. Chester & C.C. Baskin. 1997. Forest vegetation of the Kentucky Karst Plain (Kentucky and Tennessee): review and synthesis. Journal of the Torrey Botanical Society 124:322-335.

Bess, J. 1992. A survey of the insect fauna of Kentucky remnant grasslands. Prepared for The Nature Conservancy, Lexington, KY.

Bess, J. 1996a. A report on insect population monitoring at two Kentucky grassland preserves. Prepared for The Nature Conservancy, Lexington, KY.

Bess, J. 1996b. A report on surveys for *Papaipema eryngii* and other insects at Lapland Barrens Wildlife Management Area, Meade County, Kentucky. Report to Kentucky Dept. of Fish & Wildlife Resources. Weaver Boos Consultants, Inc., Chicago, IL.

Bess, J. 1998. A report on insect surveys at Mantle Rock Nature Preserve, Livingston County, Kentucky. Prepared for The Nature Conservancy, Lexington, KY.

Bolstad, P., W. Swank & J. Vose. 1998. Predicting Southern Appalachian overstory vegetation with digital terrain data. Landscape Ecology 13:271-....

Braun, E.L. 1950. Deciduous Forests of Eastern North America. Blakiston, Philadelphia.

Campbell, J.J.N. 1987. Gradients of tree species composition in the Central Hardwood Region. In P.L. Hay, F.W. Woods & H. DeSelm (eds.). Sixth Central Hardwood Forest Conference, Proceedings. University of Tennessee, Knoxville, TN.

Canpbell, J.J.N., M. Evans, M.E. Medley & N.L. Taylor. 1988. Buffalo clovers in Kentucky (*Trifolium stoloniferum* and *T. reflexum*): historical records, presettlement environment, rediscovery, endangered status, cultivation and chromosome number. Rhodora 90:399-418.

Campbell, J.J.N. 1989. Historical evidence of forest composition in the Bluegrass Region of Kentucky. Pages 231-246 in G. Rink & C.A. Budelsky. Seventh Central Hardwood Forest Conference, Proceedings. North Central Forest Experiment Station, USDA Forest Service.

Campbell, J.J.N., D.D. Taylor, M.E. Medley & A.C. Risk. 1991. Floristic and historical evidence of fire-maintained grassy pine-oak barrens before settlement in southeastern Kentucky. Pages 359-375 in S.C. Nodvin & T.A. Waldrop. Fire and the Environment: Ecological and Cultural Perspectives. Proceedings of an International Symposium. Southeastern Forest Experiment Station, Asheville, NC.

Campbell, J.J.N. 1996. Forest, Soil and Land Types in Daniel Boone National Forest. Technical Report submitted to Daniel Boone National Forest, Winchester, Kentucky.

Carroll, R. ????. Edmonson County 1825-1900: the Past History and the People who Made it. [Published by the author; available at Edmonson County Public Library, Brownsville.]
Cronquist, A. 1991. Manual of Vascular Plants of Northeastern United States and Adjacent Canada. New York Botanical Garden, Bronx, NY.
Cutter, B.E., & R.P. Guyette. 1994. Fire frequency on an oak-hickory ridgetop in the Missouri Ozarks. American Midland Naturalist 132:393-398.
Davidson, Rev. Robert. 1840. An Excursion to the Mammoth Cave and the Barrens of Kentucky. A.T. Skillman and Son, Lexington, KY. (C. Sherman & Co., Printers, Philadelphia, PA).
Defriese, L.H. 1880. Report on a Belt of Kentucky Timbers from Columbus to Pound Gap. Geological Survey of Kentucky, Part X, Vol. V, Second Series (p. 287-348). [Reprinted 1884. Pages 171-232 in Timber and Botany B.]
Delcourt, H.R., P.A. Delcourt, G.R. Wilkins and E.N. Smith. 1986. Vegetational history of the Cedar Glade Regions of Tennessee, Kentucky, and Missouri during the past 30,000 years. Association of Southeastern Biologists Bulletin 33:128-137.
Delcourt, P.A., & H.R. Delcourt. 1997. Report of paleoecological investigations: Cliff Palace Pond, Jackson County, Kentucky, in the Daniel Boone National Forest. Submitted to USDA Forest Service.
Delcourt, P.A., & H.R. Delcourt. 1998. Forest dynamics and fire history at Curt Pond, Pulaski County, Kentucky. Report to Daniel Boone National Forest.
Delcourt, P.A., H.R. Delcourt, C.R. Ison, W.E. Sharp & K.J. Gremillion. 1998. Prehistoric human use of fire, the Eastern Agricultural Complex, and Appalachian oak-chestnut forests: paleoecology of Cliff Palace Pond, Kentucky. Journal of the Society for American Anthropology, in press.

Dicken, S.N. 1935. The Kentucky Barrens. Bulletin of the Geographical Society of Philadelphia 33:42-51.

Dicken, S.N., & H.B. Brown. 1938. Soil erosion in the karst lands of Kentucky. USDA Circular No. 490.

Drake, D. 1850. Systematic Treatise, Historical, Etiological, and Practical, on the Principal Diseases of the Interior Valley of North America as they appear in the Caucasian, African, Indian, and Esquimaux Varieties of its Population. Winthrow B. Smith & Co., Cincinnati.

ECOMAP (Ecological Classification and Mapping Task Team). 1993. National Hierarchical Framework of Ecological Units. U.S.D.A. Forest Service, Washington, D.C. [Unpublished administrative paper.]

Ellsworth, I.J. 1934. Forest Cover Type Map Survey of Proposed Mammoth Cave National Park. U.S. Dept. of the Interior, Office of National Parks, Buildings and Reservation. [Original maps in archives at MCNP.]

Ellsworth, I.J. 1938. Report to Supplement Forest Cover Type Map Survey of Proposed Mammoth Cave Park. Mammoth Cave National Park.

Faller, A. 1972. Testimony on the Master Plan and Wilderness Proposals for Mammoth Cave National Park. Filed in archives at the park.

Faller, A. 1975. The plant ecology of Mammoth Cave National Park, Kentucky. Ph.D. dissertation, Indiana State University, Terre Haute.

Flint, J. 1822. Letters from America. W. & C. Tait, Edinburgh. Reprinted 1970 by Johnson Reprint Corporation, New York.

Fowells, H.A. (ed.). 1965. Silvics of Forest Trees of the United States. U.S.D.A. Agriculture Handbook 271, 762 p.

Fralish, J.S., S.B. Franklin, P.A. Robertson, S.M. Kettler & F.B. Crooks. 1993. An ordination of compositionally stable and unstable forest communities at Land Between the Lakes, Kentucky and Tennessee. Pages 247-267 in J.S. Fralish, R.P. McIntosh & O.L. Loucks (eds.). John T. Curtis: Fifty Years of Wisconsin Plant Ecology. Wisconsin Academy of Science, Arts and Letters, Madison.

Franklin, S.B., P.A. Robertson, J.A. Fralish & S.M. Kettler. 1993. Overstory vegetation and successional trends of Land Between The Lakes, USA. Journal of Vegetation Science 4:509-520.

Franklin, S.B. 1994. Late Pleistocene and Holocene Vegetation History of Land Between the Lakes, Kentucky and Tennessee. Transactions of the Kentucky Academy of Science 55:6-19.

Gardiner, F.E. 1940. Cyrus Edwards' Stories of Early Days and Others in What is Now Barren, Hart and Metcalfe Counties. Standard Printing Company, Louisville.

Gray, A. (revised by S. Watson & J.M. Coulter) 1889. Manual of The Botany of the Northern United States, Sixth Edition. American Book Company, New York.

Gorin, F. 1929. The Times of Long Ago: Barren County, Kentucky. J.P. Morton & Co., Louisville, KY.

Hibbard, C.W. 1934a. Report to the Wildlife Division, National Park Service: Mammoth Cave National Park. Vertical file 1391.0 at the park administration [C.W. Hibbard was Naturalist Assistant during park formation].

Hibbard, C.W. 1934b-35. Field Notes of Claude W. Hibbard, Naturalist Assistant. Vertical file 1741.0 at the park administration.

Horn, H.S. 1971. The Adaptive Geometry of Trees. Princeton University Press, Princeton, NJ.

Hussey, John. 1876. Report on the Botany of Barren and Edmonson Counties. Kentucky Geological Survey Part II, Vol. I, Second Series, 32 pages.

Jenkins, S.E., & A.J. Rebertus. 1994. Spatial demography of an oak savanna in the Ozarks. Pages 107-111 in Proceedings of the North American Conference on Savannas and Barrens: Living in the Edge. Illinois State University, Normal, IL.

Jones, T.H. 1932. Letter to C.E. Peterson, Chief Eastern Division, Branch Plans and Design. Vertical file 2096.1 at Mammoth Cave National Park [T.H. Jones was Assistant Landscape Architect at the park].

Keys, J., C. Carpenter, S. Hooks, F. Koenig, W.H. McNab, W. Russell and M.L. Smith. 1995. Ecological units of the eastern United States - first approximation (1:3,500,000 map and booklet). U.S,D.A. Forest Service, Atlanta, GA. [Linked with McNab & Avers, 1994.]

King, M.E. 1974. The Salts Cave textiles: a preliminary account. Pages 31-40 in P.J. Watson (ed.). Archaeology of the Mammoth Cave area. Academic Press, New York.

Kite, T. 1847. Journal of a Trip through Kentucky and Visit to Mammoth Cave, May and June 1847, by Thomas Kite, Cincinnati, Ohio. Typewritten copy of the manuscript ["Cincinnati, Ohio, 1943"] housed at Manuscripts and Folklife Archives, Kentucky Building, Western Kentucky University.

McCune, B., and C.L. Henckel. 1993. Tree mortality rates in two contrasting forests in Mammoth Cave National Park. Natural Areas Journal 13:115-123.

McKinney, L., M. Evans & K. Nicely. 1991. A floristic list for Mammoth Cave National Park (unpublished). Kentucky State Nature Preserves Commission.

McNab, W.H., & P.E. Avers. 1994. Ecological Subregions of the United States: Section Descriptions. WO-WSA-5, U.S.D.A. Forest Service (Ecosystem Mamangement), Washington, D.C. [Linked with Keys et al., 1995.]

Medley, M.E. 1993. An Annotated Catalog of the Known and Reported Vascular Flora of Kentucky. Ph.D. dissertation, University of Louisville, kentucky.

Meloy, H. (ed.) 1985. Rambles in the Mammoth Cave during the Year 1844 by a Visiter [attributed to "Alexander Clark Bullitt"]. Cave Books, St. Louis, MO. [Originally printed in 1845 by Morton & Griswold, Louisville, KY; catalogued in Special Collections at University of Kentucky with "John Croghan" as the supposed author.]

Michaux, Andre. 1793-96. Journal of Andre Michaux [translated from French]. In R.G. Thwaites (ed.). 1904. Early Western Travels, 1748-1846. Volume III. Arthur Clark Co., Cleveland, OH.

Michaux, F.A. 1805. Travels to the West of the Allegheny Mountains in the States of Ohio, Kentucky, and Tennessee [reprint]. In R.G. Thwaites (ed.). 1904. Early Western Travels, 1748-1846. Volume III. Arthur Clark Co., Cleveland, OH.

Mitchell, M.J. 1993. Soil Survey of Hart County, Kentucky. U.S.D.A. Soil Conservationm Service

Musselman, L.J., & W.F. Mann. 1978. Root Parasites of Southern Forests. U.S.D.A. Forest Service, General Technical Report SO-20, Southern Forest Experiment Station, New Orleans, Louisiana.

Nature Conservancy, The. 1998. International Classification of Ecological Communities: Terrestrial Vegetation of the Southeastern United States. The Nature Conservancy, Southeast Regional Office, Chapel Hill, NC.

Olson, R. 1998. Torch fuels used by prehstoric Indian cavers: their utility and botanical significance. Pages 5-8 in Proceedings of Mammoth Cave National Park's Seventh Science Conference. Mammoth Cave National Park, KY.

Olson, R., & M. Franz. 1998. A vegetation habitat classification for Mammoth Cave National Park. Pages 19-25 in Proceedings of Mammoth Cave National Park's Seventh Science Conference. Mammoth Cave National Park, KY.

Owen, D.D. 1856. [First] Report of the Geological Survey of Kentucky, made during the years 1854 and 1855. [Series 1, Vol. 1.] A.G. Hodges, State Printer, Frankfort, KY.

Owen, D.D. 1857. Second Report of the Geological Survey of Kentucky, made during the years 1854 and 1855. [Series 1, Vol. 2.] A.G. Hodges, State Printer, Frankfort, KY.

Palmer-Ball, B.L. 1996. The Kentucky Breeding Bird Atlas. University Press of Kentucky, Lexington, KY.
Panzer, R., D. Stillwaugh, R. Gnaedinger and G. Derkovitz. 1995. Prevalence of remnant dependence among the prairie- and savanna-inhabiting insects of the Chicago region. Natural Areas Journal 15:101-116.
Prentice, G. 1993. Archaeological Overview and Assessment of Mammoth Cave National Park. National Park Service, Southeastern Archaeological Service, Tallahassee, FL.
Price, S.F. 1893. Flora of Warren County. C.F. Carr, New London, Wisconsin.
Quarterman, E., and R.L. Powell. 1978. Potential ecological/natural landmarks on the Interior Low Plateaus. U.S. Department of the Interior, Washington, DC.
Rafinesque, C.S. 1819. Botany of Kentucky[:] on its principal features. Western Review & Miscellaneous Magazine 1(2):92-95; 1(3):128 (Errata).
Ray, J.A. 1997. Natural vegetation patterns of the Mammoth Cave region as maintained by lightning fires and aboriginal burning prior to settlement. Pages 179-197 in Proceedings of the Sixth Mammoth Cave Science Conference, National Park Service.
Ross, J. 1882. Life and Times of Elder Reuben Ross [1776-1860]. Grant, Faires & Rodgers, Philadelphia.
Sargent, C.S. 1884. Report on the Forests of North America (exclusive of Mexico). Department of the Interior Census Office. Government Printing Office, Washington, D.C.
Schoenwetter, J. 1974. Pollen analysis of sediments from Salts Cave vestibule. Pages 97-105 in Watson, P.J. (ed.). Archaeology of the Mammoth Cave Area. Academic Press, New York.
Shaler, N.S. 1884. Kentucky. A Pioneer Commonwealth. Houghton Mifflin Co., Boston & New York.
Society of American Foresters. 1980. Forest cover types of the United States and Canada. SAF. Washington, D.C.

Stuckey, R.L., & J.S. Pringle. 1997. Common names of vascular plants reported by C.S. Rafinesque in an 1819 descriptive outline of four vegetation regions of Kentucky. Transactions of the Kentucky Academy of Science 58:9-19.

Ulack, R., K. Raitz and G. Pauer. 1997. Atlas of Kentucky. The University Press of Kentucky, Lexington, Kentucky.

Watson, P.J. (ed.) 1969. The Prehistory of Salts Cave, Kentucky. Illinois State Musuem Reports of Investigations, No. 16.

Watson, P.J. (ed.) 1974. Archaeology of the Mammoth Cave Area. Academic Press, New York.

Weakley, A.S., K.D. Patterson, S. Landaal and M. Pyne. 1998. International Classification of Ecological Communities: Terrestrial Vegetation of the Southeastern United States. The Nature Conservancy, Chapel Hill, NC.

Wilhelm, G., & D. Ladd. 1988. Natural area assessment in the Chicago region. Pages 361-375 in Transactions of the 53rd North American Wildlife & Natural Resources Conference.

Wilkins, G.R., P.A. Delcourt, H.R. Delcourt, F.W. Harrison and M.R. Turner. 1991. Paleoecology of central Kentucky since the last glacial maximum. Quaternary Research 36:224-239.

Winstead, J.E., & F.P. Stone. 1996. Stability of the Big Woods, Hart County (abstract). Kentucky Academy of Science Annual Meeting.

Wright, H.E., B. Spross & R.A. Watson. 1966. Pollen analysis of the sediment from sinkhole ponds in the central Kentucky Karst. National Speoleological Society Bulletin 28:185-188.

Yarnell, R.A. 1974. Plant food and cultivation of the Salt Cavers. Pages 113-122 in Watson, P.J. (ed.). Archaeology of the Mammoth Cave area. Academic Press, New York.