

# SUBTERRANEAN BIODIVERSITY PROJECT

Research Proposal Submitted to the Arkansas Game and Fish Commission



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## PROJECT SUMMARY

Subterranean ecosystems harbor a rich diversity of life that is critically imperiled and poorly documented. Using a multi-scalar approach, this research project will integrate information from cave bioinventories and habitat assessments into a dynamic model of subterranean biodiversity in the Ozark Plateaus. Many cave systems, several containing federally listed endangered species, are being investigated, focusing upon disturbance impacts and other factors that may structure these communities and explain pattern on an ecoregional scale. The data from these bioinventories of Ozark cave life will also be used to test a prototype index of biotic integrity of cave ecosystems. A geographical information system will integrate data from these investigations and from state cave databases, and a modified Gap Analysis will be initiated. This prototype *Underground Gap Analysis* will elucidate zoogeographical patterns in the distribution of these endemics and identify the gaps in the protection of subterranean biodiversity. The Arkansas Natural Heritage Commission, Arkansas Soil & Water Conservation Commission, Arkansas Department of Environmental Quality, *The Nature Conservancy*, U.S. Forest Service, U.S. Geological Survey, and U.S. Fish and Wildlife Service are cooperators in this effort to understand and preserve the underground biodiversity of the Ozarks. Progress from the first year of funding includes: bioinventories of 77 caves; water quality analyses of 38 caves; identification of over 46 species (including new occurrence records on the county and state level, and the discovery of new populations of endangered cave crayfishes); design of the Arkansas Cave Database and the entry of data from previous surveys and databases; and implementation of a geographical information system to examine zoogeographical patterns in the distribution of cave fauna.

## PROBLEM STATEMENT

**Introduction:** Groundwater supplies 62% of the overall water demands of the United States, yet little is known about groundwater ecosystems (Job and Simons, 1994). Phreatic habitats provide crucial ecological services and sustain rich endemic communities, 90% of which remain undescribed (Culver and Hobbs III, 2000). Despite the importance of subterranean habitats, they have received very little study by the scientific community (Cullimore, 1993): little is known about the distribution of species and their limiting factors (Strayer, 1994); very few food webs have been described (Culver, 1994); and the nutrient dynamics are poorly understood (Gibert *et al.*, 1994). Knowledge of subterranean ecosystem dynamics is needed not only for the protection of the groundwater resource, but because its denizens are among the world's most rare and endangered freshwater fauna, and are under-protected in the existing network of preserves (IUCN, 1996). This project addresses these needs by implementing a multi-scalar approach: habitat-scale assessments of cave communities and environmental quality; a regional-scale comparison of disturbance impacts of cave complexes; and an ecoregion-scale computer analysis of subterranean biodiversity of the Ozark Plateaus.

**Habitat Assessments and Pollution Threats:** Subterranean food webs are fundamentally detrital communities, relying upon microbes and invertebrates to assimilate and enhance the few organics present (Culver, 1982). Yet some of these cave habitats are experiencing rapid nutrient enrichment, which may have devastating effects upon the cave community (Danielopol, 1981; Notenboom *et al.*, 1994). Organic pollutants alter the oligotrophic nature of groundwater ecosystems and severely alter their food webs (Notenboom *et al.*, 1994). The groundwater quality of the Ozark Plateaus ecoregion of Arkansas is severely compromised by pollution from

confined animal operations and septic systems (Steele, 1985). Cave Springs Cave Natural Area is home to the federally endangered Gray bats and Ozark cavefish, as well as two globally imperiled species (G1,S1), the Ozark cave amphipod and a cave isopod. Brown and colleagues have been performing studies there for the last 15 years (Willis and Brown, 1985), and Graening and Brown (1999) have identified certain habitat stressors (eutrophication, intoxication) and conservation needs. While the cavefish population appears to be recovering, the gray bats are declining and the cave amphipod is no longer found in this cave complex. It is thought that many other karst ecosystems are under similar stresses. Phase 1 will assess the environmental quality of several other priority cave habitats and determine the status of their endangered fauna. This will fulfill several goals of the cavefish and cave crayfish Recovery Plans (US FWS 1988, 1989, 1996) and provide much needed information for future conservation actions, as well as provide baseline information for studies on larger scales.

**Subterranean Biodiversity:** In North America, the number of known cave-adapted species (troglobites and stygobites) has increased exponentially since the late 1800's, as shown in Figure 1. Culver and Holsinger (1992) estimated that there are 1000 troglobitic species in the Ozark Plateaus, yet less than 100 cave-adapted species have been described from this ecoregion (Culver and Hobbs III, 2000). In an attempt to understand the true biodiversity of the Ozarks, Graening and Brown have begun a statewide inventory of cave fauna with current funding by the Arkansas Game and Fish Commission. The data from this first year of the state survey are being assembled into a new database (Arkansas Cave Database), which will eventually be dynamically linked to a geographical information system (GIS) to discern patterns in the distribution of cave fauna and identify the gaps (*sensu* Scott *et al.*, 1993) in protected habitats.

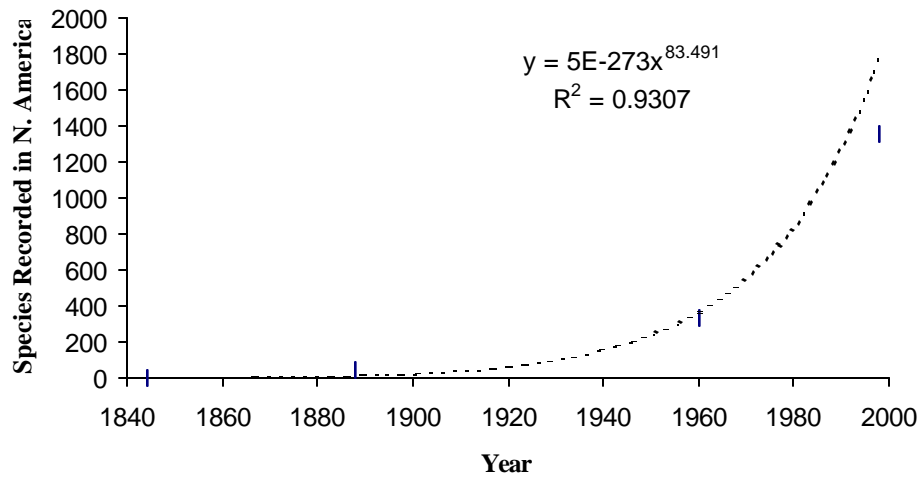


Figure 1. Graph showing exponential increase in the number of known obligate, cave-dwelling species in North America (DeKay, 1844; Nicholas, 1960; Packard, 1888; Peck, 1998) and a power function trend line fitted to the data.

**Zoogeographic Patterns and Underground GAP:** Little is known about the zoogeography of stygobites (cave-limited aquatics), especially their modes of colonization and factors that limit their distribution (Strayer, 1994). One pattern that has emerged from our preliminary analyses of cavefish and cave crayfish distribution is a hypothesis known as the “karst subway.” Cave passages in northwest Arkansas parallel the trend of the area’s major faults (Fanning, 1994), and our bioinventory indicates that cave-adapted organisms are found predominantly in cave conduits (or *karst subways*) near or on these major faults. The karst hydrologist Van Brahana (Geosciences, U. of A.), has postulated that these underground conduits have been used by cave fauna as colonization routes. Collaborating with Dr. Brahana, this study will attempt to determine if this hypothesis is geostatistically significant. Other distribution patterns that will be investigated include: vicariance zoogeography (Willis and Brown, 1985); the limitation of cave organisms to particular aquifers or biogeographic regions in the Ozarks; and the necessity of

interconnection of faults or surface streams to cave colonization. Such knowledge about underground habitat connectivity and fragmentation is crucial to proper management and the long-term viability of Ozark cave fauna. This GIS will also constitute the backbone of a prototype conservation tool – *Underground Gap Analysis*. Using the extensive information layers of the Arkansas Gap Analysis Project, the species' occurrence data of the Arkansas Cave Database (and the Natural Heritage database), and other information layers including geological features and the national hydrography dataset, a new gap analysis will be developed that meets the unique requirements of subterranean life. Underground Gap will focus upon geologic features rather than vegetation, emphasize site connectivity via phreatic conduits, and weigh biological factors such as trophic status, disturbance level, and community structure as well as conservation management factors such as cost, ownership, and site connectivity.

**Developing a Biotic Index for Subterranean Ecosystems :** In general, moderate nutrient pollution results in a loss of biodiversity and an increase in the standing crop (Sinton, 1984). In Cave Springs Cave, which may be impacted by both septic and animal waste, the cave amphipods have apparently disappeared while the cave isopods are numerous. Simon and Buikema Jr. (1997) suggested that the different pollution tolerances of amphipods and isopods could be useful in biomonitoring. Alternatively, Ronneberger (1975) reports that the ratio between epigeal and hypogean fauna in wells could be used as an indicator of ground water quality. In Greece, Danielopol (1981) found that in polluted, unprotected wells, where organic matter inputs and pumping rates are high, the fauna were epigeal, cosmopolitan and more abundant than in protected wells, with lower organic inputs and pumping rates, where the fauna were primarily hypogean. This study will determine whether differences exist in the community

structure of disturbed and undisturbed cave habitats, and an index of biotic integrity for cave ecosystems will be designed and tested using community structure factors such as alpha diversity, abundance and diversity of epigeal and hypogean invertebrates, and nutrient inputs/trophic status.

## **REPORT OF PROGRESS**

The first year of this study (1999-2000), funded by AGFC, has made considerable progress in the Underground Biodiversity Project. A cave survey team has been assembled, and consists of the two PI's, 14 undergraduate students, and several state and federal employees, including Brian Wagner and Stan Todd (AGFC), Ron Redman (ASWC), Karen Tinkle (USFS), and Tim Snell (TNC). To date, 77 caves have been inventoried and over 46 species have been identified, with many new occurrence records at the county and state levels, and several new species have been discovered that are awaiting description and publication. The appendix contains a full list of the caves and species studied. Of special note is the discovery of 4 new populations of cave crayfishes, which are either new species of *Cambarus*, or range extensions of the endangered *C. aculabrum* or *C. setosus*. Additional funding from ANHC and chemical analyses provided by Arkansas Department of Environmental Quality without charge enabled 38 caves to be analyzed for water quality. An Access 2000 (Microsoft) database has been designed to record all of these findings (Arkansas Cave Database), and an ArcView 3.2 (ESRI) GIS project has been initiated to perform the zoogeographical analyses.

## STUDY OBJECTIVES

**Objective 1:** To assess the environmental quality of cave ecosystems, and specifically to determine if pollutant stressors detected in Cave Springs Cave are present in other endangered species' habitats.

- Test hypothesis: Heavy metal concentrations are bioaccumulating in the food web.
- Test hypothesis: Only caves near mining districts have high levels of heavy metals.

**Objective 2:** To update the status of Arkansas' endangered cave fauna, and to understand the distribution of cave fauna by performing bioinventories of as many caves as possible.

**Objective 3:** To detect zoogeographic patterns that explain the distribution and abundance of Ozark cave fauna; to develop a biotic index of the integrity of subterranean ecosystems by analyzing community structure and geographic factors.

- Test hypothesis: Species occur significantly more near major faults than far from faults.
- Test hypothesis: Community structure is correlated to pollution type and magnitude.
- Test hypothesis: The ratio of isopods to amphipods increases with pollution level.
- Test hypothesis: Cave-adapted species occur only in pristine cave ecosystems.

**Objective 4:** To promote conservation of subterranean biodiversity through the identification of rare species' habitats which are under-represented in the existing network of preserves.

## STUDY METHODS AND APPROACH

This study is being performed under the following permits: Federal Fish and Wildlife Permits #PRT-834518, #TE834518-2 and #TE834518-1; Arkansas Natural Heritage Commission Permit #S-NHCC-99-005; and Arkansas Game and Fish Commission Educational Collecting Permit #1082.

**Cave Bioinventories:** Bioinventories are being performed of caves in the Ozark Plateaus of Arkansas, with the total number of caves inventoried depending upon funding levels from the agencies involved. A goal of 50 new caves was set for the level of funding requested in the AGFC budget. Records are being kept of all biota encountered, including troglomorphic and epigean species (which may compete with or predate upon the endangered species). Caves known or suspected to contain the Ozark cavefish (*A. rosae*) or cave crayfishes (*C. aculabrum* or *C. zophonastes*), and which have suitable habitat within the range will be surveyed for their presence. The visual surveys will be performed by the same method as previous surveys: using bright lights, one to three people will move slowly upstream and count cavefish and crayfish as they are sighted. For submerged passages, SCUBA gear is necessary, and those portions of the surveys will be sub-contracted to certified cave divers as funds permit. This ocular survey method can produce fairly reliable quantitative population information with minimal impact on the cave habitats and their inhabitants, endangered or otherwise. Searches will be discontinued any time endangered bats of any species are encountered. Plankton nets, kick nets and/or vacuum samplers will be used where possible for sampling of protists, meiofauna, and other microinvertebrates. When possible and permitted, specimens that are difficult to identify will be

collected and brought back to the laboratory (University of Arkansas). Note that US Fish and Wildlife Permit #TE834518-3 allows the lethal take of *A. rosae*, *C. aculabrum*, and *C. zophonastes* as voucher specimens to document new populations outside of their published ranges. When appropriate and permitted, collected specimens will be curated in suitable museum collections (e.g. Smithsonian, University of Arkansas, etc.).

**Environmental Quality Assessments:** In each cave habitat that is surveyed, environmental quality parameters will be measured (where possible) and entered into the cave database. These parameters include: level of human visitation and disturbance; type of organic matter input; and physical measurements such as air temperature and humidity, water temperature, dissolved oxygen, conductivity, and turbidity. The water quality of approximately twenty-five caves will be analyzed intensively, focusing upon habitats that contain federally listed species (e.g. Cave Springs, Logan, Rootville, Nesbitt, Cave River, Bear Hollow, and Hell Creek Caves). For flowing cave streams, all water samples will be collected manually where discharge is greatest for the stream cross-section, and for stillwater, the samples will be collected in the largest accessible pool. The following water quality parameters will be analyzed as appropriate: dissolved metals, nitrate-nitrogen, nitrite-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, total phosphorous, ortho-phosphate, total organic carbon, dissolved organic carbon, total coliform and *Escherichia coli* densities. Sampling techniques and analytical procedures will follow approved U.S. Environmental Protection Agency methods, and appropriate quality assurance and quality control measures will be taken. Some of the water quality analyses will be performed by the ADEQ as a project participant, and others will be performed under sub-contract with the Arkansas Water Resources Center.

**Zoogeographical Analyses and Computer Modeling:** The environmental quality and species' occurrence data are being entered into the Arkansas Cave Database (Access 2000, Microsoft, Inc.), and combined with all other possible data sources, including data from previous surveys, the Natural Heritage database (ANHC), and data from the US Forest Service (Ozark/St. Francis National Forests). A geographical information system (ArcView 3.2), begun with current funding from AGFC, will be dynamically linked to the Arkansas Cave Database. The extensive resources of HSI-Geotrans, Inc., and the UA Center for Advanced Spatial Technologies ([http://www.cast.uark.edu/index\\_main.html](http://www.cast.uark.edu/index_main.html)) significantly improve our GIS analyses. Range maps of each cave species will be generated using the following: latitude/longitude point data from field GPS locations (III-Plus, Garman, Inc.); a database query of current, historic, and rumored occurrences, and a background layer of the county boundaries of Arkansas. Geostatistical analyses will be performed upon the data from these surveys to determine if patterns exist between the distribution of cave fauna and factors such as geologic setting and aquifer, water quality, level of disturbance, distance to fault, community composition, stewardship/ownership, etc. The geostatistics that will be used include descriptive statistics, auto-correlation, logistic regression, pair-wise correlations, and the chi-square test. In this process, the proposed biotic index of cave ecosystem integrity will be tested. Finally, a prototype gap analysis that meets the unique requirements of subterranean life will be designed to identify habitats of high diversity that are not protected in the existing network of preserves. The most crucial data layer is the cave species' range maps described previously. The extensive information layers of the Arkansas Gap Analysis Project, created by CAST (<http://web.cast.uark.edu/gap/>), will be used. Other information layers that will be used include the digitized version of the Geology of Arkansas map, the national hydrography dataset (<http://nhd.usgs.gov/data.html>), and layers from

the Arkansas Cave Database. Coarse filters used for this gap analysis will include: cave habitats of high diversity ranked by total number of species (alpha diversity), number of listed species (federal and Natural Heritage designations), and number of obligate cave-dwellers (stygobites and troglobites); cave habitats underneath surface habitats of high biodiversity (identified by the Arkansas GAP); site connectivity, identified by a map of the faults of Arkansas; ownership and stewardship; and any restrictions designated by the land managers involved, including cost, minimum/maximum acreage, etc. A final ranked map and table will be generated ranking the “gaps,” or habitats remaining after filtering. Several information layers must be manually digitized, such as the faults of Arkansas, and the cost for these tasks are estimated in the budget.

### **DELIVERABLES AND EXPECTED BENEFITS**

This project will produce the following: assessments of the status of endemic cave species and their habitats; a biologic index of cave ecosystem integrity; the elucidation of zoogeographic patterns in the distribution and limiting factors of cave-adapted organisms; community classifications for the Ozark Plateau Ecoregion; and a new, prototype gap analysis that prioritizes subterranean habitats for conservation actions. This research project will enhance the Non-game Aquatics Program by focusing new conservation methodologies on understudied and underprotected ecosystems – subterranean streams. This research will produce information that is vital to writing successful Site Conservation Plans for these and other cave complexes in the U. S., and will give land managers baseline information needed to measure conservation success at these and other priority sites. The creation of an index of ecological integrity for subterranean ecosystems is crucial for the rapid bioassessment of cave habitats, many of which are experiencing multiple stresses. The Underground Gap Analysis, dynamically linked to an

expanding cave database, will integrate these research findings into an expert system that will reveal biogeographical patterns and gaps in the protection of subterranean biodiversity. A final report will be submitted on completion of this study, as well as CD-ROM's of the data, GIS, and final maps. An attempt will be made to use appropriate data from this study to generate one or more publications in appropriate scientific journals to inform the scientific public of the status of aquatic cave biodiversity in Arkansas, and provide a durable record. The final report will include a summary of all known previous population and habitat data for aquatic cave fauna, a summary of all population and habitat data generated in this study, statistical analyses of all data, range maps of each species, and conclusions and recommendations for future studies and for management of these ecosystems. No cave location data will be made available to the public.

### **TIMETABLE**

<b>BEGIN</b>	<b>END</b>	<b>DESCRIPTION OF WORK</b>
6/2000	4/2001	Perform biological surveys of the 6 priority cave habitats and as many other caves as possible.
6/2000	3/2001	Perform literature review; take and analyze cave water samples, statistically compare new data to existing data.
1/2001	5/2001	Enter data into database, perform geostatistical analyses, perform GIS analyses and design and test prototype Underground Gap analysis.
4/2001	6/2001	Preparation and delivery of final report and GIS project.

### **PERSONNEL**

#### **Vita of Arthur Brown**

#### **Education**

1974	Ph.D. University of North Texas	Major: Biology-Ecology
1966	M.S. Sam Houston State University	Major: Biology-Chemistry
1962	B.S. Sam Houston State University	Major: Biology-Chemistry

#### **Research**

Primary Research Interests: observational and experimental evaluation of the structure and functioning of watershed (stream) ecosystems with emphasis on those of the Interior Highlands

(Ozark and Ouachita Mountains). Current Research Topics: impacts of various methods of forest harvest on headwater streams; influences of aquatic mosses on particulate organic carbon dynamics and as invertebrate habitat; dissolved and ultrafine particulate organic carbon dynamics in headwater streams; meiofauna dynamics in gravelbed streams; use of meiofauna by larval Coho salmon; trophic dynamics of an Ozark cave stream; abundance and distribution of endangered and threatened Ozark cave organisms.

### **Professional Affiliations**

Ecological Society of America, American Fisheries Society, North American Benthological Society, Sigma Xi Scientific Society, American Association of University Professors, Great Plains Limnology Association

### **Selected Publications, etc.**

Graening, G. and A. Brown. 1999. Cavefish Population Status and Environmental Quality in Cave Springs Cave, Arkansas. Report to the Arkansas Natural Heritage Commission. Publication No. 276, Arkansas Water Resources Center, University of Arkansas, Fayetteville, AR.

Brown, A., G. Graening, and P. Vendrell. 1998. Monitoring cavefish population and environmental quality at Cave Springs Cave, Arkansas. Report to the Arkansas Natural Heritage Commission. Misc. publication no. MSC-214. AWRC, University of Arkansas, Fayetteville, AR.

Brown, A.V., M.M. Lyttle, and K.B. Brown. 1998. Impacts of gravel mining on gravelbed streams. *Transactions of the American Fisheries Society* 127:981-996.

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Brown, A.V. and W.J. Matthews. 1995. Streams of the central United States. In Cushing, C.E., K.W. Cummins, and G.W. Minshall (eds.). *River and Stream Ecosystems*. Elsevier Press, Amsterdam.

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Resh, V.H., A.V. Brown, A.P. Covich, M.E. Gurtz, H.W. Li, G.W. Minshall, S.R. Reice, A.L. Sheldon, J.B. Wallace, and R. Wissmar. 1988. The role of disturbance theory in stream ecology. *Journal of the North American Benthological Society* 7:433-455.

In addition, 33 articles in refereed journals, 20 final reports to various granting agencies, 22 invited and 52 refereed papers at various international, national, and regional meetings.

## **Vita of Geo Graening**

### **Education**

- 5/2000 Ph.D. in Biology, University of Arkansas, Fayetteville, AR.  
5/1994 Master of Science in Biological and Agricultural Engineering, University of Arkansas, Fayetteville, AR.  
3/1991 Bachelor of Arts, University of California, Santa Barbara, CA.

### **Research**

Primary Research Interests: groundwater ecosystem dynamics, including the description of the impact of anthropogenic disturbance upon the food web and community structure of groundwater fauna, and the population dynamics of rare and endangered cave fauna.

### **Professional Affiliations**

American Fisheries Society, the American Society of Agricultural Engineers, the National Speleological Society, the North American Benthological Society, and Sigma Xi Scientific Research Society.

### **Publications**

Graening, G. and A. Brown. 1999. Cavefish Population Status and Environmental Quality in Cave Springs Cave, Arkansas. Report to the Arkansas Natural Heritage Commission. Publication No. 276, Arkansas Water Resources Center, University of Arkansas, Fayetteville, AR.

Brown, A., G. Graening, and P. Vendrell. 1998. Monitoring cavefish population and environmental quality at Cave Springs Cave, Arkansas. Report to the Arkansas Natural Heritage Commission. Miscellaneous Publication no. MSC-214. Arkansas Water Resources Center, University of Arkansas, Fayetteville, AR.

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<b>CAVES SURVEYED</b>		<b>SPECIES IDENTIFIED</b>
3 Be 532	John Eddings Cave	Amblyopsis rosae
Above the Waterfall Cave	Joyce Cemetary Cave	3 Arachnid spp.
Baker Spring Cave	Little Mouth Cave	2 Beetle spp.
Bear Hollow Cave	Logan Cave	Caecidotea ancyla
Beckham Creek Cave	Marshall Caves	Caecidotea antricola
Big Mouth Cave	Martin Hollow Cave	Caecidotea steevesi
Blanchard Springs Cavern	Nesbitt Springs Cave	Caecidotea stiladactyla
Blanchard Springs Cavern	Nursery Pond	Cambarus aculabrum
Brock Spring	Old Pendergrass Cave	Cambarus sp.
Cave River Cave	Pfaff's Cave	Cambarus zophonastes
Cave Spring	Picnic Cave	Ceuthophilus sp.
Cave Springs Cave	Pigeon Roost	3 Collembola spp.
Chilly Bowl	Pine Creek Cave	Cottus sp.
Civil War Cave	Prairie Creek Cave	Dendrocoelopsis americana
Copperhead Cave	Pregnant Nun Cave	Dugesia sp.
Cosmic Cavern	Pretty Clean Cave	Eurycea longicauda
Covington's Cave	Reed's Spring	Eurycea lucifuga
Crystal Cave	Richardson Cave	Flatworm sp.
Crystal Dome Cave	Road Cave Pit	Gammarus sp.
Devil's Den Cave	Rootville Cave	2 Gordian worm spp.
Devil's Kitchen Cave	Rory Cave	Lepomis sp.
Dickerson Cave	Rowland Cave	Lirceus hoppinae
Dozen Den Cave	Tanyard Creek Cave	Lirceus sp.
Eagle Hollow Cave	War Eagle Cave	3 Millipede spp.
Eden's Bluff Cave	War Eagle Cavern	Myotis grisescens
Fantastic Caverns	Whippoorwill Cave	Myotis sodalis
Farmer's Cave	Wildcat Hollow Cave	Orconectes neglectus
Fitton Cave	Withrow Springs Cave	Orconectes punctimanus
Galena Spring	Wolf Creek Cave	Pipistrellus subflavus
Gentry Cave	Wonderland Cave	Plethodon glutinosus
Hell Creek Cave	No name #1 thru #10	2 Snail spp.
Hickory Creek Cave		Stygobromus clantoni
Hurricane River Cave		Stygobromus ozarkensis
Indian Creek Cave		Synurella bifurca
Indian Rockhouse Cave		Typhlichthys subterraneus
Ivy Springs Cave		Typhlotriton spelaeus
James Ditto		Webworm

