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Fenske-Hall Approximate Molecular Orbital Analysis of the Chelating Carbene Complex eta5-Cp'(CO)Mn{C(OEt)CH2PPh2}

John P. Graham
Arkansas Tech University

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Subterranean Biodiversity of Arkansas, Part 1: Bioinventory and Bioassessment of Caves in the Sylamore Ranger District, Ozark National Forest, Arkansas

G. O. Graening*
The Nature Conservancy
Arkansas Field Office
601 North University Avenue
Little Rock, AR 72205

Michael E. Slay
Department of Biological Sciences
University of Arkansas
601 Science-Engineering
Fayetteville, AR 72701

Karen K. Tinkle
Sylamore Ranger District
U.S. Forest Service
P.O. Box 1279
Mountain View, AR 72560

*Corresponding Author

Abstract

Inventory and assessment of subterranean ecosystems of the Sylamore Ranger District (within Baxter, Marion, Searcy, and Stone counties), Ozark National Forest, was performed 2000 to 2002. The Sylamore District, completely underlaid in karst topography (occurring in Mississippian to Ordovician carbonates), contains approximately 10% of the known caves in Arkansas. Thirty-five sites were inventoried, six of which were sampled for environmental quality. These were combined and analyzed with previous studies, creating a database of 1,238 total species occurrences, 230 species, and 61 total sites. Most common were cave crickets, pipistrelle bats, woodrats, mosquitoes, and spiders. Fourteen species obligate to caves or groundwater were found, including four new to science, although a collector's curve showed that sampling effort to date has not reached maximum species richness. Richness was significantly greater in caves developed in Ordovician carbonates, in caves with organic inputs (especially bat guano), and as cave passage length increased. Richness was not significant between watersheds (Buffalo versus White Rivers), nor by water resource, nor by degree of recreational use. Caves were ranked by passage length, total and obligate richness, and overall biological significance. Blanchard Springs Caverns ranked highest and is the most biologically rich cave in Arkansas with 96 total and nine obligate species. Recommendations include continuation of physical and biological inventories, increased protection of high-ranking sites, and increased public education/outreach. The US Forest Service has invested 0.6 million dollars in cave research, monitoring, and protection on the Sylamore District to date.

Introduction

The subterranean fauna of Arkansas are inadequately documented and protected, yet are important for many reasons. These animals are extremely rare and highly endemic, and are a significant part of the natural heritage of the region and nation. In the United States, cave-limited fauna (troglobites) and ground-water-limited fauna (stygobites) represent more than half of the imperiled (heritage ranks of G1 and G2) species listed in the Natural Heritage Program, yet less than 4% are under federal protection (Culver et al., 2000; NatureServe, 2002). Furthermore, these animals, with their unique morphological adaptations to subterranean habitats, are important subjects of medical and evolutionary research. These animals can also serve as ground water quality indicators (Malard et al., 1996), and ground water is a major water resource for communities, agriculture, and industry in Arkansas. To address these data deficiencies, a regional inventory of subterranean habitats was initiated by a multi-agency consortium (the Ozark Subterranean Biodiversity Project), the results of which are being presented in this manuscript series. This study focused upon one of the most cave-dense areas of the Ozark plateaus ecoregion.

Public lands managed by the US Department of Agriculture, Forest Service (USFS) harbor the greatest number of populations of imperiled and endangered species of any federal agency - 40% of imperiled species and 50% of federally listed species (Stein et al., 2000). Of all of the national forests in the US, the Ozark National Forest (ONF) is one of the richest in caves. The Sylamore Ranger District of the ONF (Sylamore District) is located within Baxter, Marion, Searcy, and Stone counties (Fig. 1). It contains the majority of caves on the ONF, and an estimated 10% of all reported caves in Arkansas, a state that is itself very rich in caves, ranking 13th in cave richness by state in the US (Harris, 2003). Thus, the Sylamore District has a unique resource and management challenge with its diversity of subterranean habitats and fauna.

Methods

The objectives of this study were as follows: to bioinventory as many caves as possible in a two-year period, with special focus upon caves containing endangered species; in select sites, assess environmental quality,

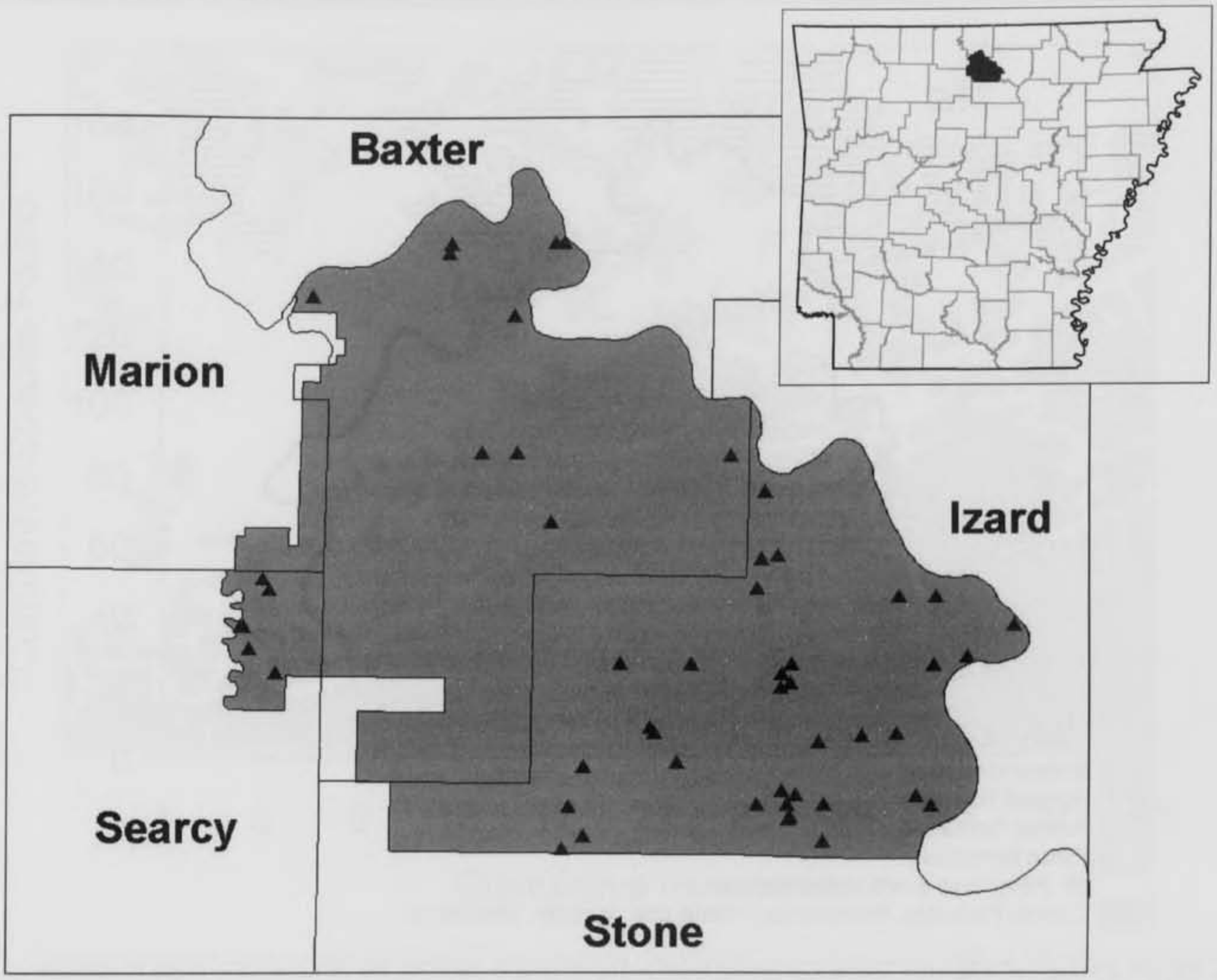

Fig. 1. Inset map shows the location of the Sylamore District within Arkansas. Larger map shows the Sylamore District shaded in gray in relation to Baxter, Marion, Searcy, and Stone counties. Black triangles demarcate the locations of 61 total sites inventoried in this study or previous studies.

focusing upon parameters that might indicate pollution from land-use practices; assemble this new data into a database and, combined with historic information, discern patterns in the distribution of cave fauna, their limiting factors, and the effect of any habitat stressors.

The Sylamore District lies within a dramatic geologic setting – the entire district (*circa* 130,000 acres) lies in karst topography (Fig. 2), a landscape formed by acidic ground water dissolving the carbonate bedrock. This creates a system of voids and conduits that transport enormous amounts of ground water and sediment. The Eureka Springs Escarpment divides the Sylamore District and demarcates the abrupt change from the Springfield Plateau down into the Salem Plateau. Three rivers (the White River, Sylamore Creek, and Big Creek) divide the Sylamore District into the Middle White River Basin and the Buffalo River Basin and have dissected deeply the plateaus that contain them.

Sites were assessed for the following parameters: level of human visitation - none, little, moderate, and heavy use; presence/absence of vandalism, defined as spray paint or other graffiti, damage to speleothems or fauna, refuse, or smoke damage; presence/absence of organic matter, including leaf and woody debris or guano and other feces; and water resource - dry, drip pool, intermittent stream, or perennial stream. Water samples were taken on 19 - 20 February 2000 at Bald Scrappy Cave, Biology Cave, Blanchard Springs Caverns, Clark Spring, Hell Creek Cave, Nesbitt Spring, and Rowland Cave. Water and sediment samples were taken on 7-8 April 2001 at Blanchard Springs Caverns, Clark Spring, Gunner Cave, Hell Creek Cave, Nesbitt Spring, and Rowland Cave and again on 29 March 2002 at Blanchard Springs Caverns, Clark Spring, and

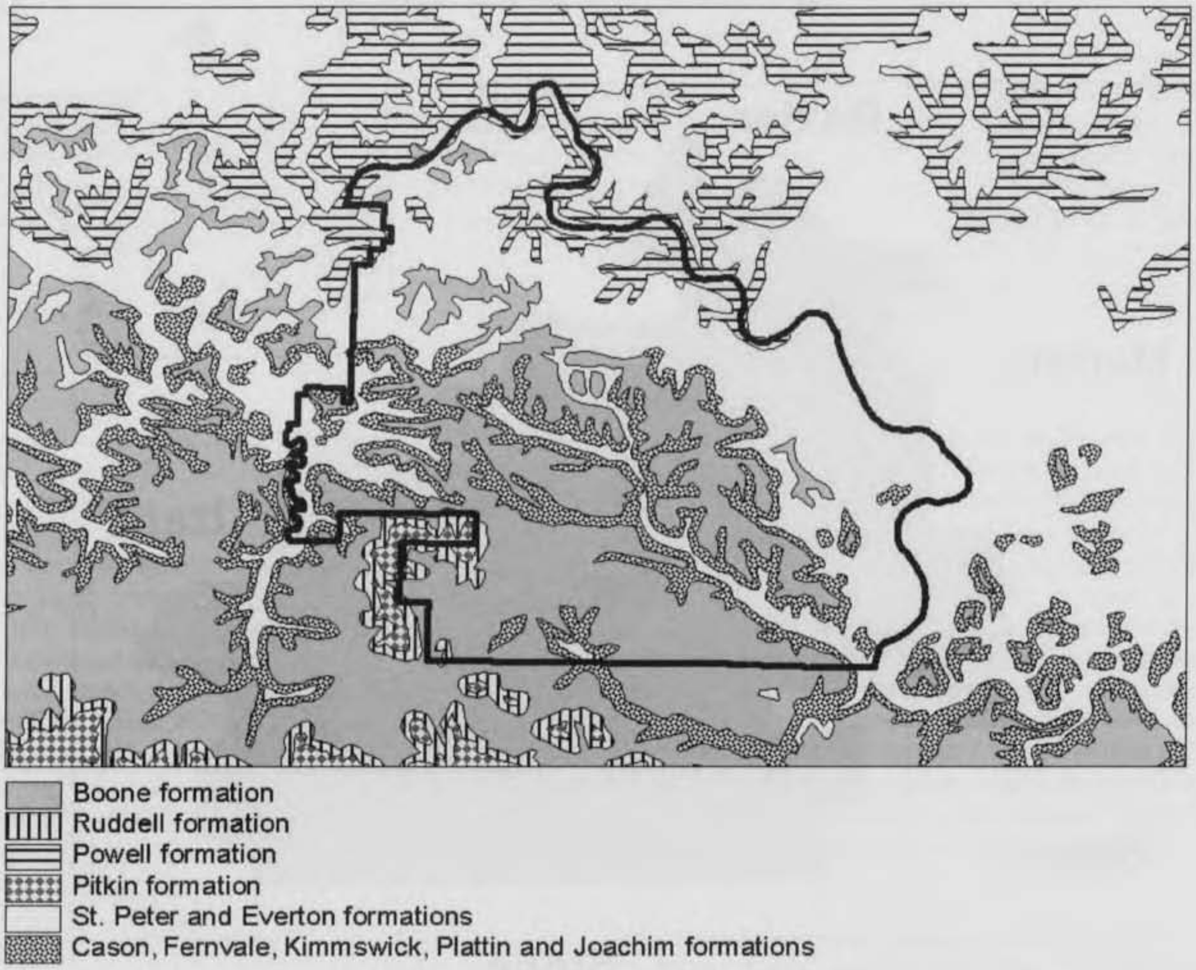

Fig. 2. Surface geology of Sylamore District, adapted from a digital map created by the Arkansas Geologic Commission.

Partee Spring. For flowing cave streams, water samples were collected manually where discharge was greatest for the stream cross-section, and for still water, the samples were collected in the largest accessible pool. The following parameters were analyzed: metals in sediments and water column; nitrate and ammonia-nitrogen, total and orthophosphate, chloride, fluoride, sulfate, and hardness (all in mg/L); total coliform and *Escherichia coli* densities (each as colony-forming unit / 100 mL), temperature (± 0.5 °C); pH (± 0.5 unit); turbidity (± 0.5 Nephlometric Turbidity Unit); and specific conductivity (± 1 µSiemens/cm). Sampling techniques and analytical procedures followed approved US Environmental Protection Agency methods. Analyses were performed at the Arkansas Department of Environmental Quality's Environmental Chemistry Laboratory, the Arkansas Water Resources Center's Water Quality Laboratory, and the Center of Excellence in Poultry Science's Central Analytical Laboratory. Appropriate quality assurance and quality control measures were taken.

Biological inventories of macrofauna were performed from September 2000 to December 2002. During this two-year study, over 40 field trips were taken and at least 35 caves and springs were inventoried (Fig. 1). They are: Albino Orchid Cave, Alexander Cave, Almus Knob Cave, Almus Knob Annex Cave, Bald Scrappy Cave, Barfing Vulture Cave, Big Creek Cave, Biology Cave, Bird's Nest Cave, Black Gum Cave, Blanchard Springs Caverns, Blowing Spring Cave, Bonanza Cave, Breakdown Cave, Bud Wallis Cave, Clark Spring – Alexander Cave, Dead Bear Cave, Double Barrel Cave, Gunner Cave, Gustafson Cave, Hammer Springs Cave, Hanger Cave, Herald Hollow Cave, Hidden Spring Cave, Lower Shelter Cave, Norfork Bat Cave, Optimus Cave, Partee Spring, Rowland Cave, Saltpeter Cave, Shelter Cave, Thruway Cave, Upper Shelter Cave, and Wood's Hollow Caves No. 1 and No. 2. Sites were georeferenced in Universal Transverse Mercator

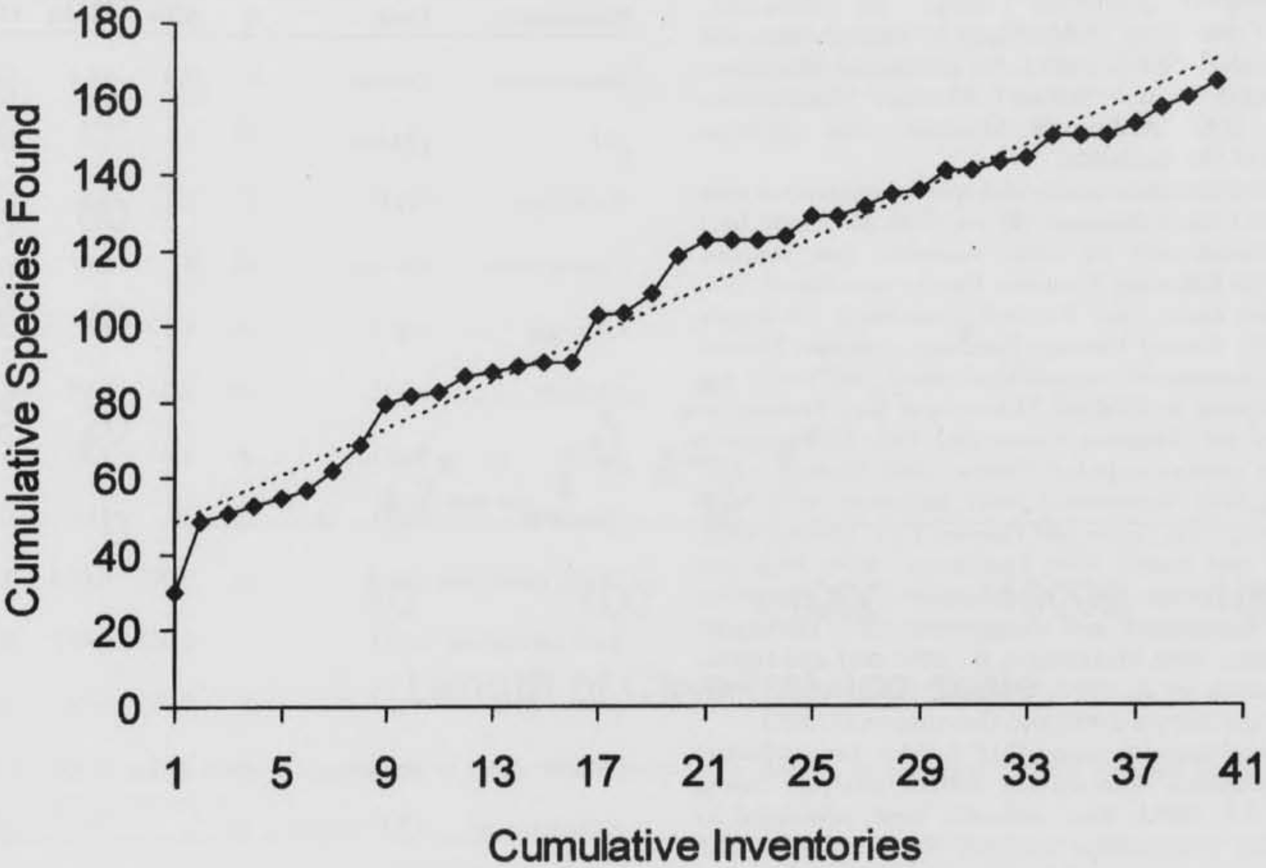

Fig. 3. Collector's curve for this inventory effort (40 bioinventories performed from September 2000 to December 2002), where cumulative number of inventories were plotted against cumulative number of unique species found, with a line fitted to the curve.

coordinates using North America Datum 1983 with a global positioning system handheld unit (Garmin III Plus GPS), and the estimated position error was recorded (range of 1 - 20 m). In each cave surveyed, fauna were inventoried using the most unobtrusive methods possible and at times when endangered bats were not hibernating or birthing. Macrofauna were counted visually with helmet-mounted lights, using snorkeling gear and dive lights for deep pools. For submerged passages, SCUBA was necessary, and those portions of the surveys were sub-contracted to certified cave divers as funds permitted. Collections were limited to those fauna that were impossible to identify on site and were made possible by the following permits: Federal Fish and Wildlife Permits PRT-834518, TE834518-3, TE834518-2 and TE834518-1, Arkansas Natural Heritage Commission Permit S-NHCC-98-009 and S-NHCC-97-009, and Arkansas Game and Fish Commission Educational Collecting Permits 1082 and 1476. Voucher specimens were collected by hand, aspirator, or net, preserved in 75% ethanol, and brought back to the University of Arkansas at Fayetteville (UAF) for identification and cataloging. Specimens were identified at UAF by Graening and Slay, by Jeffrey Barnes (UAF Dept. of Entomology), or sent to taxonomic specialists, including the following: Kenneth Christiansen (Grinnell College) and Jeffrey Battigelli (Earthworks Research Group) for collembolans; Horton Hobbs III (Wittenburg Univ.) for decapods; John Holsinger (Old Dominion Univ.) for amphipods; Jerry Lewis (Lewis Consulting, Inc.) for isopods; William Shear (Hampdra-Sydney College) for diplopods; Jeffrey Battigelli for acari; William Muchmore (University of Rochester) for pseudoscorpions; Henry Robison (Southern Arkansas Univ.) for fishes; Stewart Peck (Carleton Univ.) for coleopterans; James Cokendolpher (Museum of Texas Tech

Univ.) and Darrell Ubick (California Academy of Sciences) for opilionids; Lynn Ferguson (Longwood College) and Mark Muegge (Texas Cooperative Extension) for diplurans; Anne Hampton (Castleton College) for planarians; Theodore Cohn (Univ. of Michigan) for orthopterans; and Gerald Walsh (USEPA, retired) for gastropods. Specimens were curated in the National Museum (Smithsonian Institute), UAF Arthropod Museum, and personal collections of the specialists.

The environmental quality and species' occurrence data were entered into a database (Access 2000, Microsoft, Inc.) and combined with all other available data sources, including the following: Sylamore District cave files (USFS, unpublished data); Cave Research Foundation (Welbourn 1980, 1983); Natural Heritage Database (Arkansas Natural Heritage Commission, unpublished data); and yearly bat surveys (reports by Michael Harvey and Ron Redman to USFS and the Arkansas Game and Fish Commission). Other data sources included: Wilson, 1967; Dickson, 1971; Flemming, 1972; Schuier et al., 1972; McIntosh, 1973; Peck, 1973; Grove, 1974; Grove and Harvey, 1974; Harvey, 1975; McDaniel and Smith, 1976; Muchmore, 1976; Peck and Russell, 1976; Stotler and Crandall-Stotler, 1977; Saugey et al., 1978; Youngsteadt and Youngsteadt, 1978; Darlington and Chandler, 1979; McDaniel et al., 1979; Beck and Dorris, 1982; Dunivan et al., 1982; Waddell, 1982; Smith, 1984; Graening and Brown, 2000; and Graening et al., 2001.

Statistical analyses (using JMP 5, SAS, Inc., software) and geographical information system analyses (using ArcView 3.2, ESRI, Inc., software) were performed to discern any relationships between the distribution and richness of cave fauna and factors such as geologic setting and watershed, water quality, level of disturbance, *etc.* Statistics used included linear and logistic regression, pair-wise correlation, *t*-test, and the chi-square test (where water and sediment quality parameters that were below detection were set to the detection limit). For some of the analyses in this study, data for Rowland Cave and Blanchard Springs Caverns were analyzed separately, and in other instances data were combined. Dye tracing has shown that these two cave systems are hydrologically connected by sharing the same subterranean stream (Aley, 1980), and mapping surveys have converged the systems within 300 feet of a traversable connection. Similarly, data for Clark Spring and Alexander Cave were combined for some analyses because divers have connected the spring resurgence owned by USFS (Clark Spring) to the upstream cave system owned privately (Alexander Cave).

Results

Summary of water and sediment quality analyses are presented in Tables 1 and 2, and the complete data set is available in Graening et al. (2003). Surficial geology was determined for 208 solution caves, one crevice cave, three springs, one sinkhole, two pits, and one bluff shelter by site reconnaissance and by using GIS analyses upon the Arkansas Geologic Commission's digital version of the 1976 Geologic Map of Arkansas, scale 1:500,000 (Fig. 2). Sixty caves were formed in Mississippian Period limestone (Boone formation), 51 were formed in Ordovician limestones and dolomites (Fernvale, Plattin, and Joachim formations), and 96 were formed in Ordovician limestone (Everton formation) with a few caves each in other carbonates (Cotter, Jefferson City, Powell formations). Of the 52 mapped caves, mean total passage length was 637 m, the longest cave in the data set was the Rowland – Blanchard Springs Caverns complex at over 17,000 m of combined, mapped passages, and the shortest was Partee Spring at 5 m.

Table 1. Summary statistics of water quality parameters of select cave streams and springs on the Sylamore District.

Parameter	Unit	n	Min.	Mean	Max.
Temperature	Celsius	8	9.0	13.4	15.0
pH	pH unit	13	5.5	6.5	7.0
Turbidity	NTU	7	1.5	2.7	7.0
Conductivity	µS/cm	16	8	190	305
Chloride	mg/L	16	1.5	3.9	6.1
Fluoride	mg/L	10	0.05	0.06	0.08
Sulfate	mg/L	16	2.45	4.97	8.44
Hardness	mg/L	15	26	115	175
Ortho-phosphate	mg/L	16	0.007	0.024	0.084
Total phosphate	mg/L	7	0.056	0.077	0.111
Ammonia	mg/L	3	0.01	0.01	0.02
Nitrate	mg/L	16	0.07	0.91	3.78
Escherichia coli	CFU/100mL	16	4	79	199
Total coliforms	CFU/100mL	16	20	524	2540

Species occurrence data obtained from our study and others produced a total of 1,238 species occurrences, 230 unique species reported, 61 sites with some amount of species occurrence data, and 40 sites with intensive

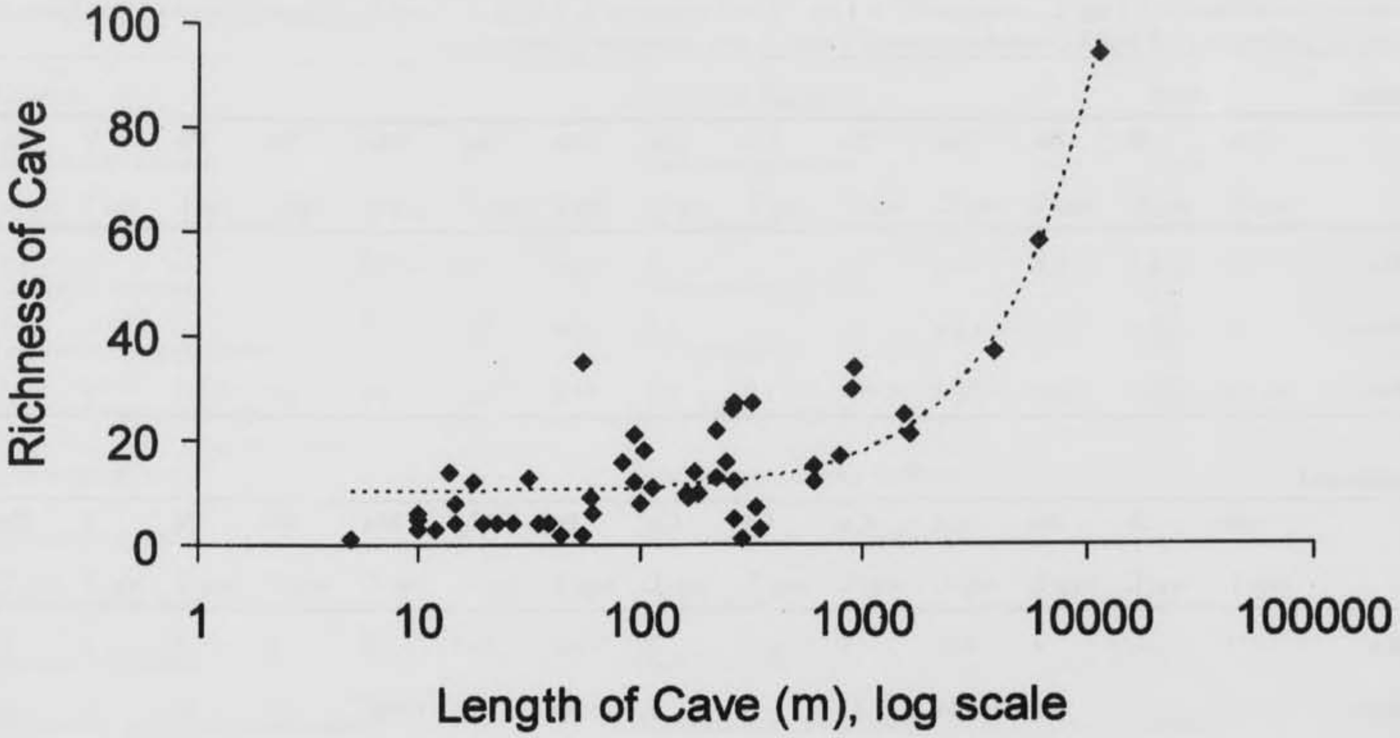

Fig. 4. Total mapped passage lengths (m) of caves in this study were directly proportional to their richness (total number of unique species per cave).

bioinventories - see Graening et al. (2003) for a detailed faunal list. A collector's curve was created, whereby each novel species found during consecutive collecting trips was added to the cumulative number of species found and plotted against cumulative number of collecting trips (Fig. 3) and assuming consistent search effort. The number of cumulative species found increased linearly with every additional inventory (species = 45.235 + 3.111 x number of inventories, $r^2 = 0.973$, $P < 0.001$), suggesting that this study did not exhaustively inventory all animals inhabiting Sylamore District caves.

Of 52 cave habitats with at least partial inventory data, the mean species per habitat (alpha diversity) was 15, with a maximum of 81 (Blanchard Springs Caverns), a median of 12, and a mode of 4. The Rowland Cave - Blanchard Springs Cavern complex was the richest with 96 species, and second was Bud Wallis Cave with 34 species. The relationship between species richness and number of caves having that richness was significant, indicating that an exponentially fewer number of caves have an increasingly greater number of species [log (number of caves) = 0.703 – (0.013 x richness), n = 29, $P = 0.006$, $r^2 = 0.252$]. Regional species richness (gamma diversity) was difficult to estimate, but at least 14 stygobites and troglobites and at least 215 other, non-cave adapted species occurred on the Sylamore District (Table 3). The Rowland-Blanchard Springs Caverns complex had the most obligates per cave with a count of nine. Second were the Clark Spring - Alexander Cave complex and Gunner Cave, both with six, followed by Hammer Spring Cave, Biology Cave, Breakdown Cave, Norfork Bat Cave, and Woods Hollow Cave No. 1, all with four.

The pooled faunal occurrences (n = 1,238) were examined for most abundantly occurring species, irrespective of habitat. Overall, arthropods dominated the cave habitats, especially crickets, mosquitoes, spiders, and springtails. The most common invertebrates were cave crickets of the genus *Ceuthophilus* with 59 site occurrences. The most common vertebrates were eastern pipistrelle bats (*Pipistrellus subflavus*) with 41 occurrences and eastern woodrats (*Neotoma floridana*) with 31 occurrences. In aquatic habitats, plethodontid salamanders and crustaceans dominated. Significant species found and their number of occurrences include the following: cave salamander (*Eurycea lucifuga*) - 23 occurrences; grotto salamander (*Typhlotriton*

Table 2. Summary statistics of metals concentrations in water samples (n = 15) and sediment samples (n = 9) in select cave streams and springs on the Sylamore District. Other metal concentrations measured were below detectable limits in water samples - beryllium (< 0.3 µg/L), cadmium (< 0.4 µg/L), and selenium (< 3.0 µg/L) - and in sediment samples - beryllium (< 1 mg/L), cadmium (< 1 mg/L), molybdenum (< 2 mg/L), and selenium (< 0.6 mg/L).

Water

	As	B	Ba	Ca	Co	Cr	Cu	Fe	Mg	Mn	Ni	Pb	V	Zn
	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Min.	---	< 4.5	< 8.8	6.4	---	---	< 0.5	< 15.0	0.8	< 0.5	---	---	---	3.3
Mean	---	69.0	15.2	42.4	---	---	1.5	17.0	2.2	1.0	---	---	---	11.1
Max.	< 1.0	203.8	22.6	53.2	< 0.5	< 1.0	3.9	44.2	13.4	3.4	< 2.5	< 0.6	< 1.0	39.3

Sediment

	As	B	Ba	Ca	Co	Cr	Cu	Fe	Mg	Mn	Ni	Pb	V	Zn
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Min.	< 1	---	4	647	1	< 1	3	1152	260	59	2	2	6	4
Mean	4	---	60	15284	11	5	7	18915	512	10087	27	14	62	33
Max.	11	< 1.0	99	37373	27	15	17	91261	1541	84501	81	27	96	62

spelaeus) - 16 occurrences; cave isopods (*Caecidotea* spp.) - 10 occurrences; and cave amphipods (*Stygobromus* spp.) - 10 occurrences.

Logistic regression of surface geology category by species richness revealed that sites underlaid by Ordovician Period formations (Fernvale, Kimmswick, Plattin, and Joachim carbonates) were significantly richer in species than sites underlaid by other formations (Boone, Cotter, Jefferson City, or Everton) (n = 52, $P = 0.030$, $r^2 = 0.169$). Analysis revealed that species richness was significantly greater when organics were present (n = 52, $P = 0.001$, $r^2 = 0.222$, $t = -3.795$) and when bat guano was present (n = 52, $P = 0.001$, $r^2 = 0.220$, $t = -3.753$). Species richness did not significantly differ between Buffalo River and Middle White River watersheds ($P = 0.547$), nor by water resource category ($p = 0.383$), nor by degree of recreational use ($P = 0.100$). Species richness of a site was directly proportional to its passage length (m) (richness = 10.067 + 0.007 x length, n = 52, $r^2 = 0.76$, $t = 12.71$, $P < 0.001$); approximately one more species is added for every additional 100 m of cave passage (Fig. 4).

Discussion

A diverse array of arachnids, crustaceans and insects dominate the species composition of cave faunas in Arkansas (Graening et al., 2001) and in the U.S. in general (Culver et al., 2000). In a survey of cave streams of the Springfield plateau, Willis and Brown (1985) found that isopods (*Caecidotea* spp.) were the most common benthic invertebrates, and chironomids were second. Graening et al. (2001) also found isopods to be the most abundant benthic invertebrates in a survey of Arkansas cave streams, while cave crickets were the most common terrestrial invertebrates and bats and salamanders were the most abundant vertebrates. Similar findings are reported here. The Sylamore District is one of the most biologically important karst areas of the Ozark Plateaus ecoregion. Several species with federal status under the Endangered Species Act rely upon subterranean habitats of the Sylamore District: two endangered bat species, the gray bat (*Myotis grisescens*) and the Indiana bat (*M. sodalis*), utilize many caves for hibernation and reproduction; the endangered Ozark big-eared bat (*Corynorhinus townsendii ingens*) has occasionally been reported in crevice and solution caves; and the endangered Hell Creek cave crayfish (*Cambarus zophonastes*) is rumored to exist in Blanchard Springs Caverns, and its designated habitat (Hell Creek Cave recharge zone) is contiguous with the district boundary. At least 14 subterranean-obligate species exist on the Sylamore District, including two new species of troglobitic diplurans

Table 3. At least 16 species are known to be limited to, or adapted to, groundwater habitats (stygobites) or caves (troglobites) on the Sylamore District. Also shown are the global heritage status ranks assigned by The Nature Conservancy and NatureServe: G1- critically imperiled; G2 – imperiled; G3 – vulnerable; G4 – apparently secure; G5 – demonstrably secure; GU - unranked (NatureServe, 2002).

Species	Common Name	Rank
Apochthonius titanicus	Cave false scorpion	G1G2
Caecidotea antricola	Cave isopod	G3G4
Causeyella causeyae	Cave milliped	GU
Causeyella youngsteadtorum	Cave milliped	GU
Hesperochernes occidentalis	Cave false scorpion	G4G5
Litocampa sp. nov. 1	New species of cave dipluran	GU
Litocampa sp. nov. 2	New species of cave dipluran	GU
Phanetta subterranea	Cave spider	G4
Spelobia tenebrarum	Cave dung fly	GU
Stygobromus alabamensis alabamensis	Alabama cave amphipod	G4G5
Stygobromus sp. nov.	Undescribed amphipod	GU
Tricladida	Unidentified cave flatworm	GU
Typhlichthys subterraneus	Southern cavefish	G4
Typhlotriton spelaeus	Grotto salamander	G4

(*Litocampa* spp.) that await taxonomic description. However, the bioinventory effort is far from complete, and much taxonomic study remains to be done. Continuation of biologic and geologic inventories is highly recommended in order to accurately assess and manage these karst resources.

Caves have often been likened to islands due to their insular features, especially their hydrologic and geologic barriers (e.g., Culver, 1970). As a general pattern, larger islands carry more species than smaller ones, and this species-area relationship is well documented in diversity studies (e.g., MacArthur and Wilson, 1967). Similarly, the largest caves (measured as passage length) are often the most diverse - the world's longest cave, Mammoth Cave, at over 571 km of passage, has the greatest known number of stygobites and troglobites (Culver and Sket, 2000). Longer caves imply more habitat types and trophic resources, which may increase the few niches available and increase carrying capacity (Culver and Sket, 2000). Cave length was significantly correlated to richness in this study and in Arkansas caves in general (Graening et al., 2001). For this reason, length was used as the primary criterion for biological significance ranking. However, this constitutes a significant management challenge because the longest caves are usually the most attractive for recreational caving. The richness of obligate species is often used to rank the importance of the world's caves (*e.g.* Culver and Sket, 2000), and this criterion was also used in this study. The third criterion was total species richness, which is a common measure of biological significance, and in this study, significantly fewer caves had high species counts. The 61 caves that had been bioinventoried adequately were ranked according to these three criteria if they had a minimum of at least two obligate species, at least 20 total species, and at least 600 m of cave passage (Table 4). The Rowland Cave-

Blanchard Springs Caverns complex ranked highest with 96 species (Table 5), nine of which were stygobites or troglobites.

The best-studied caves tend to be the most biologically rich caves (see summary by Graening et al., 2001). Blanchard Springs Caverns is undoubtedly Arkansas' most thoroughly studied cave, although we agree with McIntosh (1973) who states, "*The inventory of biologic features of Blanchard Springs Caverns will never be complete.*" Ignoring this and other biases, this cave complex is the most species rich cave documented in Arkansas to date and second only to Tumbling Creek Cave, Taney County, Missouri, for the entire Ozark plateaus ecoregion; Tumbling Creek Cave has approximately 105 species, 12 of which are stygobites or troglobites (William Elliot, pers. comm.). Blanchard Springs Caverns also has at least two single-site endemics - a liverwort, *Plagiochila acanthophylla ciliigera*, (Stotler and Crandall-Stotler, 1977) and a cellular slime mold, *Dictyostelium caveatum*, (Waddell, 1982). Surprisingly, it is also a very impacted cave. Blanchard Springs Caverns is the most visited cave in Arkansas with an estimated 88,000 visitors per year (Bob Reeves, Caverns Administrator, pers. comm.). It has been modified in many ways including the paving of passages, extensive illumination of surfaces, and the creation of two artificial entrances and other tunnels and shafts by use of explosives.

The impact of trespass, archaeological looting, and vandalism in caves of the Sylamore District is of special concern. Approximately 30 recreational caving permits per year and 50 scientific study permits per year are issued, and Tinkle estimates over 100 recreational caving trips per year are undertaken illegally (without permits). The Arkansas Cave Resources Protection Act of 1989 affords limited protection to caves, and subterranean fauna are protected by Arkansas Game and Fish Commission Regulation No.1817 - Wildlife Pet Restrictions and the federal Endangered Species Act of 1973. Protection for Arkansas caves also necessitates the enforcement of state and federal water quality and solid waste disposal regulations, although water and sediment analyses of the study caves did not reveal any major pollution concerns on the Sylamore District. The Federal Cave Resources Protection Act protects caves designated as "significant" on federal lands by allowing federal land managers to keep cave locations and names confidential and assign a penalty of up to $10,000 for abuses. All surveyed caves on the Sylamore District have been designated "significant." All caving and related activities on Forest Service lands are by permit only and permits can be acquired by contacting the District Office.

Other management recommendations include increasing protection of vulnerable, high-ranking sites, such as Alexander Cave which is not under public ownership, and the improvement of public outreach regarding wise use of karst resources. The USFS has invested approximately 0.6 million dollars in protection of karst resources on the Sylamore District, including the following: endangered bat species monitoring and research at approximately $10,000 per year for at least 12 years; four cave gates at approximately $50,000 each; monitoring, research, and educational products at approximately $15,000 per year for the last 10 years; and $102,000 spent on the protection, development, and maintenance of Blanchard Springs Caverns since its dedication, and another $35,000 was spent for research and continuing water and air quality monitoring.

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Table 4. Ranking of the top 20 most biologically significant caves on the Sylamore District, with and without Blanchard Springs Caverns and Rowland Cave combined. Sites were scored according to the following formula: (number of obligate species x 10) + (number of total species) + (square root of length in meters).

Site Name	No. of obligates	No. of Species	Length	Score	Rank
Rowland – BSC Cave complex	9	96	17381	318	1st
Blanchard Springs Caverns	8	81	11265	267	1st
Rowland Cave	7	58	6116	206	2nd
Clark Spring – Alexander Cave	6	29	5633	164	3rd
Gunner Cave	6	31	3891	153	4th
Norfork Bat Cave	4	27	900	97	5th
Biology Cave	4	17	789	85	6th
Bonanza Cave	2	24	1536	83	7th
Gustafson Cave	2	33	906	83	7th
Hammer Springs Cave	4	25	321	83	7th
Hidden Spring Cave	2	21	1629	81	8th
Breakdown Cave	4	15	605	80	9th
Big Creek Cave	3	27	265	73	10th
Saltpeter Cave	3	11	900	71	11th
Herald Hollow Cave	3	24	262	70	12th
Woods Hollow Cave No. 1	4	18	105	68	13th
Bud Wallis Cave	2	34	55	61	14th
Bald Scrappy Cave	2	22	220	57	15th
Woods Hollow Cave No. 2	3	16	84	55	16th
Double Barrel Cave	2	21	94	51	17th
Panther Mountain Cave	2	9	167	42	18th

Table 5. All known animal species (96) found in Rowland – Blanchard Springs Cavern complex, with obligate species emboldened (data from this study and those cited in Methods). Columns are scientific name of species, common name of species, degree of adaptation to subterranean environments (obligate – troglobite or stygobite; tolerant – troglophile or stygophile; intolerant or transitory – incidental; or unknown), and site of species' occurrence – Blanchard Springs Caverns (BSC), Rowland Cave, or both caves.

Species	Common Name	Adaptation	Site
Achaearanea tepidariorum	Common house spider	Troglophile	BSC
Aecothea specus	Cave fly	Troglophile	BSC
Agkistrodon contortrix contortrix	Southern copperhead	Incidental	Rowland Cave
Ambystoma maculatum	Spotted salamander	Troglophile	BSC
Amoebalaria defessa	Fly	Troglophile	Both
Amphipoda - stygophilic	Surface amphipod	Stygophile	BSC
Apochthonius titanicus	**Cave false scorpion**	**Troglobite**	**BSC**
Arrhopalites clarus	Springtail	Troglophile	Rowland Cave
Athetini sp.	Rove beetle	Unknown	Rowland Cave
Bibio albipennis	Beetle	Unknown	BSC
Brevicornu sp.	Fungus gnat	Unknown	BSC
Caecidotea antricola	**Cave isopod**	**Stygobite**	**Rowland Cave**
Calliphoridae	Unidentified blow fly	Unknown	BSC
Camponotus americanus	Ant	Unknown	BSC
Causeyella causeyae	**Cave milliped**	**Troglobite**	**Both**
Ceuthophilus gracilipes	Cave cricket	Troglophile	Both
Chironomidae	Unidentified blood worm	Unknown	Both
Chrysomelidae sp. 1 and 2	Unidentified beetles	Unknown	BSC
Corynoptera sp.	Dark-winged fungus gnat	Troglophile	Both
Curculionidae	Unidentified weevil	Unknown	BSC
Decapoda - crayfish	Unidentified crayfish	Stygophile	BSC
Drosophila melanogaster	Fruit fly	Unknown	BSC
Elaphe obsoleta	Black rat snake	Incidental	BSC

Species	Common Name	Adaptation	Site
Eptesicus fuscus	Big brown bat	Troglophile	Both
Eurycea longicauda melanopleura	Dark-sided salamander	Troglophile	Both
Eurycea lucifuga	Cave salamander	Troglophile	Both
Eurycea multiplicata multiplicata	Many-ribbed salamander	Troglophile	BSC
Exechia sp.	Fungus gnat	Unknown	BSC
Exechiopsis sp.	Fungus gnat	Unknown	Rowland Cave
Formicidae	Unidentified ant	Unknown	BSC
Gastropoda - aquatic snail	Unidentified aquatic snail	Unknown	BSC
Ichneumonidae	Unidentified wasp	Incidental	BSC
Lasionycteris noctivagans	Silver-haired bat	Troglophile	Rowland Cave
Lasiurus borealis	Eastern red bat	Troglophile	Both
Lasiurus cinereus	Hoary bat	Troglophile	Both
Leiobunum sp.	Eastern harvestman	Troglophile	BSC
Lepidoptera	Unidentified moth	Unknown	BSC
Leptocera caenosa	Small dung fly	Unknown	BSC
Leptoneta arkansa	Spider	Troglophile	BSC
Ligidium elrodii elrodii	Sow bug	Troglophile	BSC
Lithobiomorpha	Unidentified centipede	Unknown	BSC
***Litocampa* sp. nov. 1 and 2**	**New species cave diplurans**	**Troglobite**	**Rowland Cave**
Lumbricidae	Unidentified earthworm	Troglophile	Both
Macrocera nobilis	Fungus gnat	Troglophile	Both
Megapallifera ragsdalei	Ozark mantleslug	Unknown	BSC
Megaselia cavernicola	Humpbacked fly	Troglophile	Rowland Cave
Mephitis mephitis	Striped skunk	Incidental	Rowland Cave
Microtus pinetorum	Woodland vole	Troglophile	BSC
Mus musculus	House mouse	Troglophile	BSC

Species	Common Name	Adaptation	Site
Myotis grisescens	Gray bat	Troglophile	Both
Myotis lucifugus	Little brown bat	Troglophile	Both
Myotis septentrionalis	Northern long-eared bat	Troglophile	Both
Myotis sodalis	Indiana bat	Troglophile	Both
Nematomorpha	Horsehair worm	Unknown	BSC
Neotoma floridana	Eastern woodrat	Troglophile	Rowland Cave
Nycticeius humeralis	Evening bat	Troglophile	Rowland Cave
Patera perigrapta	Engraved bladetooth snail	Unknown	BSC
Pentatomidae	Unidentified stinkbug	Unknown	BSC
Pericoma signata	Dark-winged fungus gnat	Unknown	BSC
Phagocata gracilis	Flatworm	Stygophile	BSC
Phoridae	Humpbacked fly	Unknown	BSC
Pipistrellus subflavus	Eastern pipistrelle	Troglophile	Both
Platynus sp.	Ground beetle	Troglophile	BSC
Plecoptera	Stonefly larva	Unknown	BSC
Plethodon albagula	Slimy salamander	Troglophile	BSC
Plethodon angusticlavius	Ozark zigzag salamander	Troglophile	BSC
Procyon lotor	Northern raccoon	Troglophile	Rowland Cave
Pseudopolydesmus pinetorum	Milliped	Troglophile	BSC
Psychoda satchelli	Moth fly	Unknown	BSC
Ptomaphagus cavernicola	Round fungus beetle	Troglophile	Rowland Cave
Rana catesbeiana	BullFrog	Incidental	BSC
Rana clamitans melanota	Green frog	Incidental	BSC
Rana sphenocephala	Southern leopard frog	Incidental	BSC
Rana sylvatica	Wood frog	Incidental	BSC
Rhagidia sp.	Mite	Unknown	Rowland Cave

Species	Common Name	Adaptation	Site
Sabacon cavicolens	Harvestman	Troglophile	Rowland Cave
Sayornis phoebe	Eastern phoebe	Troglophile	Both
Sciaridae	Dark-winged fungus gnat	Unknown	BSC
Sciurus carolinensis	Eastern gray squirrel	Incidental	BSC
Soricidae	Shrew	Troglophile	BSC
Spelobia tenebrarum	**Cave dung fly**	**Troglobite**	**Rowland Cave**
Sphingidae	Unidentified sphinx moth	Unknown	BSC
Storeria occipitomaculata	Red-belly snake	Incidental	BSC
Stygobromus a. alabamensis	**Alabama cave amphipod**	**Stygobite**	**BSC**
***Stygobromus* sp. nov.**	**Undescribed cave amphipod**	**Stygobite**	**Rowland Cave**
Tamias striatus	Eastern chipmunk	Incidental	BSC
Tipulidae	Unidentified crane fly	Troglophile	Both
Tomoceridae	Unidentified springtail	Unknown	BSC
Trichoceridae	Winter crane fly	Incidental	BSC
Turbellaria	Stream flatworm	Stygophile	BSC
Typhlotriton spelaeus	**Grotto salamander**	**Troglobite**	**Both**
Ventridens ligera	Globose dome snail	Unknown	BSC
Virginia valeriae	Smooth earth snake	Incidental	BSC
Zonitoides arboreus	Quick gloss snail	Unknown	Rowland Cave