# ZOOGEOGRAPHY AND BIODIVERSITY OF MISSOURI CAVES AND KARST

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Abstract: The Missouri Cave Life Database contains 927 species and about 12,500 observation and collection records. About 1,038 (17%) of Missouri's 6,200 caves and cave springs are biocaves with at least one species record, but only 491 sites (8%) have five or more species recorded. Missouri has 82 troglobites (67 described, 15 undescribed), including 49 aquatic and 33 terrestrial species. The aquatics include 30 described and six undescribed stygobites, plus 13 described phreatobites. The terrestrials include 24 described and nine undescribed species. Six of the troglobites (four described) may actually be troglophiles, edaphobites or neotroglobites. There are about 215 troglophiles (17 aquatic), 203 trogloxenes (20 aquatic) and 407 accidentals or of uncertain ecological classification (27 aquatic).

Karst zoogeographic regions include the broad Springfield and Salem plateaus; the Boone, Hannibal, St. Louis, Jefferson-Ste. Genevieve, and Perryville karsts; and an isolated area, Caney Mountain. Troglobites are currently known from 728 Missouri sites, including 597 caves (10% of known caves). Twenty-five troglobites, eight of which are new species, occur at single sites only. Missouri shares 48 troglobites with other states, exhibiting relatively low diversity in terrestrial troglobites compared to areas east of the Mississippi River, but high aquatic biodiversity.

Values for species richness (SR), troglobites, site endemism (SE) and biodiversity (B) were derived to rank and compare caves for conservation planning. Many species and biologically important biocaves were added to the Missouri Natural Heritage Database and the Comprehensive Wildlife Conservation Strategy, a long-range, statewide conservation plan. Further work should focus on poorly known regions.

## Introduction

The purpose of this paper is to summarize and analyze data derived from the Cave Life Database (CLD), which the author developed at the Missouri Department of Conservation (MDC) to track Missouri's cave fauna. Peck and Lewis (1978) compared the eastern Missouri cave fauna to Illinois and other regions, and they extensively discussed the origins and relations of the faunas. An updated overview of the State's cave zoogeography is provided, but the focus of this paper is more on cave biodiversity and how to prioritize caves for conservation planning.

The purpose of the CLD is to bring together all pertinent checklists and data sources into a relational database. The CLD draws on published and unpublished records from the scientific literature, agency reports, speleological literature, databases (such as the Missouri Natural Heritage Database), and unpublished records from experienced observers and biologists. The database is used to track collections and observations, to produce checklists for any cave, county, or taxon, and to study zoogeography, biodiversity and conservation issues. The analyses help in recognizing knowledge gaps, planning studies and wildlife conservation work, drawing species range maps, updating the Natural Heritage Database and developing educational materials and publications.

The CLD is too large to publish here, so summary statistics, analyses, tables, maps, photographs and species checklists are provided for the top three caves for biodiversity. Readers may contact the author for checklists and specialized reports.

## Literature Review

Missouri caves (Figs. 1 and 2) are mentioned in some of the earliest American biospeleological literature. Girard (1852, 1859) reported on cave crayfishes and described *Typhlichthys subterraneus* (the Southern cavefish) from Kentucky; the species was later found in Missouri. Ruth Hoppin (Hoppin, 1889) sent her collection of Ozark cavefish from Sarcoxie Cave, Jasper County, in 1888 to Harvard professors Samuel Garman (Garman, 1889) and Walter Faxon. Faxon (1889) described *Cambarus setosus*, the Bristly Cave Crayfish (Fig. 3). Schwarz (1891) described the beetle, *Ptomaphagus cavernicola*, from Marvel (Marble) Cave, Stone County, and it also was collected in 1897 by C. H. Merriam in Hamilton Cave, Washington County. Stejneger (1892) described the Grotto salamander, *Typhlotriton spelaeus* (now *Eurycea spelaea* according to

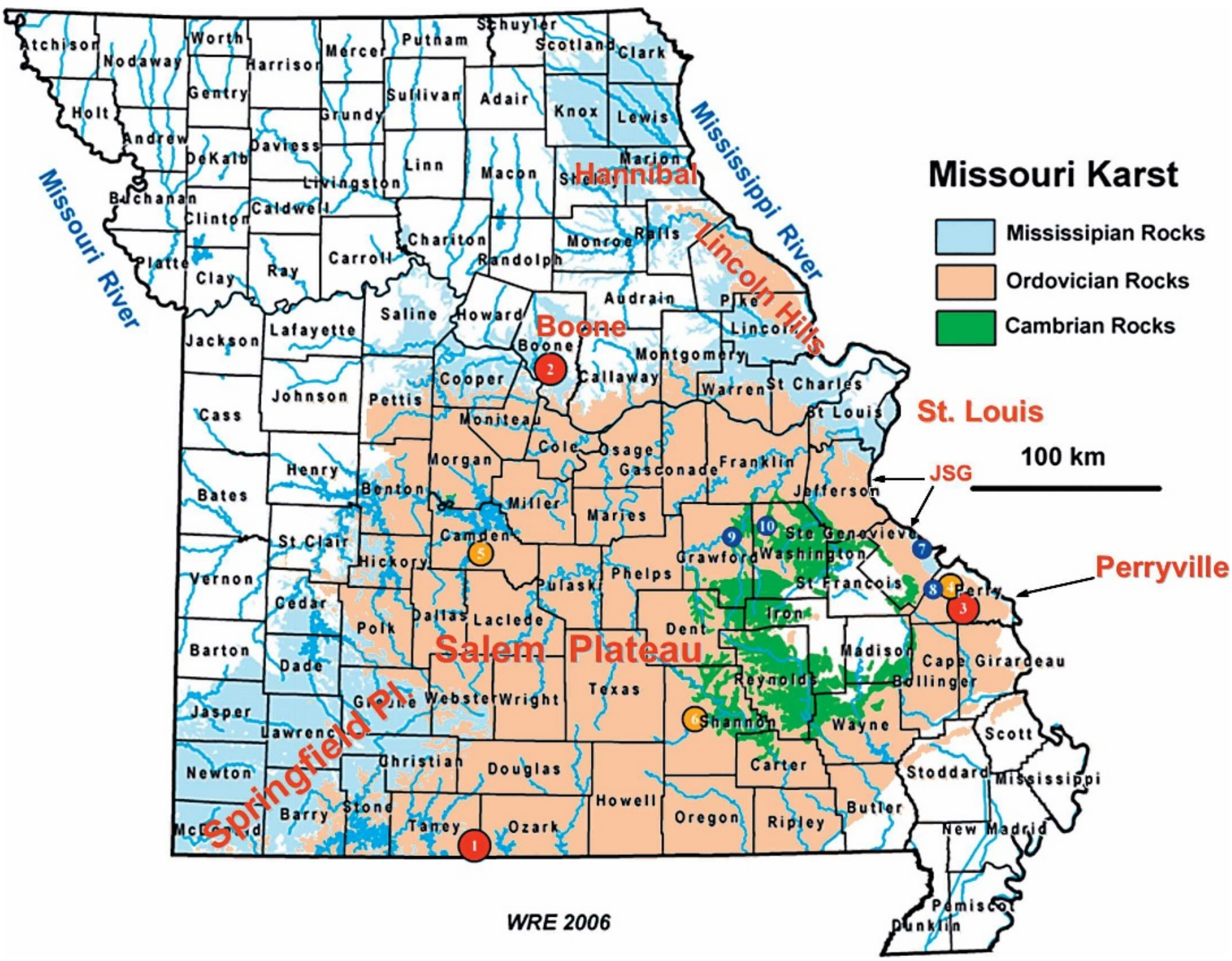


**Figure 1. Missouri karst map showing the three principal ages of dolomites and limestones, karst zoogeographic regions and the top ten biocaves. 1) Tumbling Creek Cave, Taney County; 2) Devil's Icebox Cave, Boone County; 3) Mystery Cave, Perry County; 4) Berome Moore Cave, Perry County; 5) River Cave, Camden County; 6) Branson Cave, Shannon County; 7) Kohms Cave, Ste. Genevieve County; 8) Tom Moore Cave, Perry County; 9) Jagged Canyon Cave, Crawford County; 10) Great Scott Cave, Washington County.**

Bonett and Chippindale, 2004). Eigenmann (1898, 1899, 1901, 1909) described the Ozark cavefish, *Amblyopsis rosae* (Fig. 4), and published many other papers on Missouri cavefish and salamanders.

The first third of the 20th century saw few reports on Missouri cave life. A troglophilic spider was reported by Crosby (1905) from Rocheport (Boone) Cave, Boone County; later it was described as *Cicurina cavealis* by Bishop and Crosby (1926). J. W. Mackelden collected the Grotto salamander from Marble Cave, Oregon County, in 1906. A. D. Newman collected amphipods from a well at Harrisonville, Cass County, from 1915–1917. Unknown collectors worked in Talking Rocks Cavern (Fairy Cave), Stone County, in 1919. Grotto salamanders were taken in Sarcoxie Cave in 1927, apparently by B. C. Marshall, and by E. P. Creaser and E. B. Williamson from several caves in 1929–1930. These early records came from several museum catalogs.

In the second third of the 20th century, Hubbell (1934, 1936) published many descriptions of *Ceuthophilus* crickets (Fig. 5), including five species in Missouri caves. The legendary Leslie Hubricht studied many caves and springs from 1931 to 1969. He found and described numerous new species of amphipods, isopods, and aquatic snails (Hubricht, 1940, 1941, 1942, 1943, 1950, 1959, 1971, 1972; Hubricht and Mackin, 1940, 1949). Kenneth Dearolf and Hubricht collected four species of millipedes in 1938, which were described by Loomis (1939), including *Causeyella*

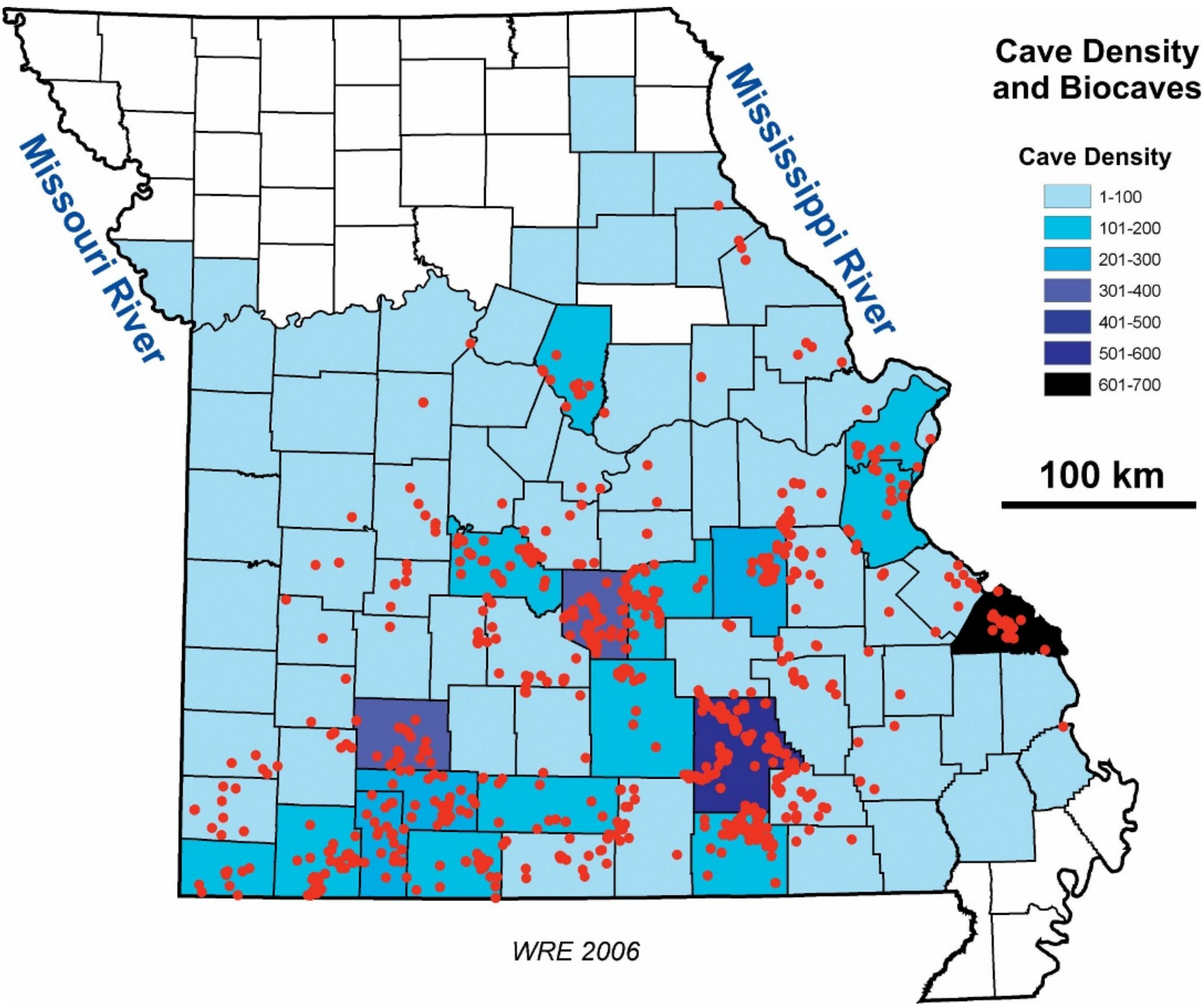


**Figure 2. Cave density by county (about 6,000 caves) and biocaves (about 900).**

*dendropus* (Fig. 6), a widespread troglobite. Hubricht published the first general paper on Ozark cave invertebrates in 1950. Hyman (1945, 1956) described the flatworms *Sphalloplana hubrichti* from Illinois and Missouri, and *Macrocotyla glandulosa* from Devil's Icebox Cave, Boone County. *Macrocotyla* was placed under the older genus name, *Kenkia* (Sluys and Kawakatsu, 2006). Kenneth Christiansen collected springtails in 42 Missouri caves between 1950 and 1986, and he provided many other identifications (Christiansen, 1964, 1966) (Table 1). Thomas C. Barr, Jr. studied seven caves in 1958 and 1965, and he described and identified numerous beetles. Causey (1960) provided a key to six species of millipedes, two of them troglobites.

In the last third of the 20th century cave research increased as more speleologists became active. John R. Holsinger made four collecting trips to Missouri between 1964 and 1988, visiting 30 caves and springs in search of amphipods and hydrobiid snails, at times with Rusty Norton and Robert Hershler (Holsinger, 1967, 1971, 1989). In 1999 the author worked in the field with Holsinger's Ph.D. student, Stefan Koenemann, and Ulrike Englisch in search of *Bactrurus* amphipods (Koenemann and Holsinger, 2001). These trips and papers provided a monograph on the systematics of *Stygobromus* (then *Stygonectes*); descriptions of *S. barri, S. ozarkensis, Allocrangonyx hubrichti* and *Bactrurus pseudomucronatus*; the new family Allocrangonyctidae; and new locality records for

**Figure 3.** ***Cambarus setosus*, Bristly cave crayfish, Turnback Cave, Lawrence County, Missouri.**

**Figure 5.** ***Ceuthophilus gracilipes*, a female camel cricket.**

*S. alabamensis, S. clantoni* and *B. brachycaudus*. New species of Missouri *Stygobromus* will be described in the near future.

In 1966 Thomas J. Aley purchased Tumbling Creek Cave (Bear Cave), Taney County, and began the Ozark Underground Laboratory, which sponsored many scientific studies over the next 40 years (Aley and Thomson, 1971; Thomson and Aley, 1971; Hershler et al., 1990; Elliott et al., 2005; Elliott and Aley 2006). John L. Craig studied cave invertebrates, focusing on caves threatened by the proposed Meramec Park Lake in eastern Missouri (Craig, 1975, 1977). LaVal et al. (1977) completed an evaluation of bat caves in the proposed Meramec Park Lake and Union Lake project areas. Many important caves would have been inundated by the Meramec Lake. These studies, along with reports from caver Don Rimbach and others, influenced public opinion, and the projects died for several reasons, including imminent loss of scenic and recreational values.

Lewis (1974) extensively studied Mystery Cave, Perry County, one of the top three Missouri caves for biodiversity. Kenk (1975, 1977) described the flatworms *Macrocotyla* (now *Kenkia*) *lewisi* and *Sphalloplana evaginata* from Perry County; the latter was later found in Camden County by Slay et al. (2006). Peck and Lewis (1978) compared the richness of eastern Missouri caves to Illinois and other areas. Christiansen (1983) analyzed cave Collembola patterns across the eastern USA.

Since 1978 MDC's Richard Clawson contributed voluminous census data on bats from 103 caves and three mines in 38 counties, primarily of endangered Gray and Indiana bats (Table 1).

From 1978 to 1984, MDC's James E. (Gene) Gardner collected numerous invertebrate specimens from 436 caves and 10 springs, providing important baseline information on subterranean biodiversity and the core data in the CLD

**Figure 4.** ***Ambyopsis rosae*, Ozark cavefish, Ben Lassiter Cave, McDonald County.**

**Figure 6.** ***Causeyella dendropus* (formerly *Scoterpes*), Smallin Cave, Christian County.**

**Table 1. Principal contributors to the Cave Life Database, starting with Gardner's 1986 study. Christiansen collected an unknown number of Collembola representing 28 species.**

| Collector | Observed | Collected | Sites | Counties |
|---|---|---|---|---|
| D. Ashley and students | 5,200 | 1,200 | 57 | 17 |
| K. Christiansen (Collembola) | | | 42 | 24 |
| R. Clawson (Chiroptera) | 9,680,000 | | 106 | 35 |
| W. R. Elliott and assistants | 1,525,000 | 1,800 | 130 | 36 |
| J. E. Gardner | 390,000 | 4,500 | 446 | 41 |
| M. Sutton | 483,000 | >1,000 | 174 | 21 |
| Exclusive totals | 16,207,494 | >12,500 | 960 | 63 |
| Caves | 647 | 615 | | |
| Counties | 54 | 61 | | |

(Gardner, 1985, 1986) (Table 1). Gardner worked with many agencies and landowners to study their cave life and provide management recommendations. He listed 414 invertebrate species, of which 52 species (13%) were considered troglobites (39 described, 13 undescribed). The numbers of other ecological types were uncertain because of limited ecological data, but were in the range of 90–130 troglophiles (25–31%), 135–167 trogloxenes (32–40%) and 142 accidentals (34%). No comprehensive list of Missouri's cave vertebrates has been published, but a computer printout with a large number of observations was contributed by Gardner to the CLD.

MDC's Natural History Division provided many observations to the Natural Heritage Database from 1985–2006, and these were imported into the CLD. Koppelman and Figg (1993) published a preliminary study on the genetics of cave crayfish. William Pflieger published important summaries of Missouri crayfishes (Pflieger, 1996) and fishes (Pflieger, 1997), including cave forms. Many other MDC staff participated in cave studies (see Acknowledgments).

Oesch and Oesch (1986) studied caves at Fort Leonard Wood, Pulaski County. Elliott and Clawson (2001) studied the temperatures of Indiana and Gray bat caves, including Fort Leonard Wood. Taylor and Slay (pers. comm.) conducted detailed cave invertebrate surveys at Fort Leonard Wood.

Michael J. Sutton studied at least 174 caves in 21 counties for the Cave Research Foundation, mostly in the Mark Twain National Forest and the Ozark National Scenic Riverways (Sutton, 1993, 1998, 1999). He also conducted a census study (2004) of the Pink Planarian, *Kenkia glandulosa,* in Devil's Icebox Cave, Boone County, a stygobite unique to that cave. The species is threatened by water pollution, and it appears to have variable population size. Sutton contributed many invertebrate identifications and observations (Table 1). In 2005 and 2006, Sutton and Sue Hagan (*pers. comm.*) discovered an undescribed species of trechine beetle, *Pseudanophthalmus,* about 5 mm long, in Branson Cave and Round Spring Cavern, Shannon County. Thomas C. Barr, Jr. is studying this species, which would be the third species of troglobitic beetle in Missouri.

David C. Ashley studied at least 57 caves in 17 counties with his students from Missouri Western State University and others since 1993 (Ashley, 1993, 1996, 2003). The studies included bioinventory, community ecology, and many cavesnail censuses of the endangered *Antrobia culveri* in Tumbling Creek Cave, Taney County (Table 1). Ashley and Elliott (2000) provided an overview of Missouri cave life.

Lewis (2002, 2004) described *Chaetaspis aleyorum*, a polydesmoid millipede, and *Brackenridgia ashleyi,* a trichoniscid isopod, from Tumbling Creek Cave. Shear (2003) redescribed *Scoterpes dendropus*, placing it in the new genus *Causeyella*, which contains two other species in Arkansas.

Population estimates of the endangered *Antrobia culveri,* Tumbling Creek Cavesnail (Fig. 7), by Ashley and Paul McKenzie, United States Fish and Wildlife Service (USFWS), have documented their decline since 1996 (Ashley 2003, U.S. Department of the Interior 2001, 2003). The Tumbling Creek Cavesnail Working Group was founded by Paul McKenzie to bring together experts from the region.

Elliott (2000a, 2000b, 2001, 2003a, 2003b, 2004, 2005, 2006b) joined MDC in 1998, and he worked with eight research partners and others to study Missouri's cave life (see Acknowledgments). He collected about 1,800 invertebrate specimens in 130 caves, springs, wells and mines in 36 Missouri counties, and he observed an aggregate of 860,000 animals (1,525,000 with assistants). In 1999 his team discovered a new species of cave crayfish, *Orconectes stygocaneyi* (Fig. 8), from Caney Mountain Conservation Area, a significant addition to our understanding of cave crayfish systematics and zoogeography (Hobbs, 2001). Elliott and Ireland (2002) led a year-long study of 40 caves, involving members of the Missouri Caves and Karst Conservancy. Elliott and Ashley (2005) characterized Missouri cave and karst communities. MDC

**Figure 7.** ***Antrobia culveri*****, Tumbling Creek cavesnail, Taney County.**

**Figure 8.** ***Orconectes stygocaneyi*****, Caney Mountain cave crayfish, Ozark County.**

cave biology interns, Michael E. Slay, Stephen T. Samoray, Sara Gardner, and resident cave ecologist, James E. Kaufmann, contributed 860 invertebrate specimens and counted a total of 1,050,000 bats, mostly using near-infrared video (Elliott et al., 2006); they also counted about 260 other vertebrates. Slay et al. (2006) and Graening et al. (2006) provided new data on planarians and *Cambarus setosus* in the Ozarks.

## Materials and Methods

### Database Design

In 1998 the author began work on the CLD for MDC using a species database that he had previously designed in Texas. Significant amounts of data were added with the help of research partners and assistants since 1999 (Table 1). Additional research partners recently joined the project. The design is frequently upgraded, and the author is interested in collaborating with other states that may want to expand the database to their areas.

A large database of cave life images also was developed, some of which is posted on the *Biospeleology* web site (Elliott, 2007). The image database consists of hundreds of scanned and digital photographs, mostly in jpeg format, maintained in the ACDSee® program by ACD Systems, Inc. A description field holds pertinent data about each image, including the cave, county, state, subject, photographer, date and keywords. Images may be found by searching folders, file names, or words in the description field. This program has a self-maintaining database function. Many of these photos are available for scientific and educational use.

The CLD was developed using Microsoft Access®, a Windows® application. The CLD is a relational database with three central relations: the tables Species and Localities, and a query object, Unique Cave Names, which is based on the Localities table. This query could be replaced in the future by a table of official cave names derived from the Missouri Speleological Survey; however, the query functions well in tracking known county/cave name combinations, new cave names that are not yet registered with the Missouri Speleological Survey (MSS), and 279 noncaves, such as wells, mines, smaller springs, and some epigean (surface) sites.

A relational database is a software system that ties together related data through certain key fields held in common, such as county and cave name, species number, cave accession number and so on. This type of database is used for everything from parts inventories to biological data. Space does not allow a complete description of all the many fields and objects in the CLD, but such is available from the author on request.

The Species table, with 31 fields, contains extensive taxonomic and ecological information about each species, including published remarks of various authors. Notations can be added. The conservation status of the species in the *Missouri Species and Communities of Conservation Concern* (Missouri Department of Conservation, 2005) checklist is noted in the Status field, including whether it is a threatened or endangered species on the Missouri or Federal lists. The Status field matches information in NatureServe's national Natural Heritage Database, and proposed data can be recorded there for species that are not yet in the Heritage system. If a species is revised taxonomically, those changes are made one time in the appropriate fields. Each species is assigned a unique Spnum (species number), which is used to relate it to the Localities table in a one-to-many relationship. Thus, basic taxonomic information does not

**Table 2. Ecological types of cave-dwelling species, described and undescribed. Included as troglobites are 36 stygobites, 13 phreatobites and 6 possible troglophiles, edaphobites or neotroglobites. Included in the troglophile category are 35 possible trogloxenes and 3 possible stygoxenes.**

| Ecological Type | Terrestrial | Aquatic | Total |
|---|---|---|---|
| troglobites | 33 | 49 | 82 |
| troglophiles | 198 | 17 | 215 |
| trogloxenes | 203 | 20 | 223 |
| accidentals | 380 | 27 | 407 |
| Totals | 814 | 113 | 927 |

have to be repeated for each new locality record. Another field, ITIS, contains the Integrated Taxonomic Information System's Taxonomic Serial Number (TSN), if such has been assigned (U.S. Department of Agriculture 2006). Currently 979 species are in the Species table, 51 of which are placeholders for generic identifications, such as unsorted collection or *Stygobromus sp.* About 927 species are known from Missouri caves, 82 of which are troglobites (Table 2), and 57 Spnums were added for cooperative work with Arkansas. The author, as data manager, maintains the CLD with data from colleagues and the literature. A new version is issued on compact disc to the partners once a year.

The Localities table, with 59 fields, contains data on observations and collections. Each partner enters new data through data entry forms, viewing either one species or one cave at a time. One can find a species and its Spnum in several ways, then enter its Spnum for a new record within a cave, in which case the county and cave name are automatically inserted in the record. If one uses a species form, one can fill in the county and cave name, then the Spnum for that species is automatically inserted, thereby insuring that the proper relation is maintained. New data records are automatically tagged so that the data manager can separate them from old data when the users send in their data. The user can input the date, number observed, number collected, temperatures, names of observers, field notes and other fields, which allow one to record if an identification is tentative, specimen and vial numbers, taxonomist, date collections were sent to a taxonomist, museum catalog number, identification date, and other data. This provides a complete tracking system for field collections until they are indentified and curated. A special query allows the printing of small specimen labels. Literature records may be entered and the references included.

Another table, Cave Trips, is related to Unique Cave Names, and is used for trip reports and preliminary data. These can be used for inputting a preliminary report, from which a user can then copy data into the main tables via forms on the same screen.

Many queries were created for special purposes, and they can be copied to spreadsheets or a geographic information system (GIS) for analysis and reformatting. The queries can select fewer fields or composite multiple species records into presence/absence form. Trends in bat colony size can be graphed from such queries. Report forms can be printed for a particular cave, area or taxon, or sent to a word processor for editing. The design allows expansion of the database to other states or countries.

The CLD does not include precise cave location data, but only the county, cave name and cave accession number. Ongoing collaboration with the MSS and the Missouri Caves & Karst Conservancy (MCKC) enables the CLD to be temporarily related to a state cave database, for zoogeographic analysis and cave management. Such data tables are used only in a secure GIS. Potential uses would be creating species range maps and mapping biodiversity and conservation problems. Such products are important for environmental review of construction projects that may threaten cave resources and ground water. In Missouri these tools were used for mapping Cave Focus Areas for long-term wildlife conservation planning (Elliott, 2006). The end products were maps at scales that do not reveal precise cave locations. Many caves are degraded by individuals who have discovered cave locations on their own, but it is not necessary to worsen the problem by publicizing precise cave locations.

## Biodiversity Computations

For biodiversity computations in this paper, I include stygobites (aquatic troglobites) and phreatobites under the general term troglobite or troglobiont, which some authors now reserve for terrestrial troglobites. In Elliott (2003a) and this paper, I consider a phreatobite an inhabitant of ground water, exhibiting troglomorphy, but not necessarily limited to karst systems. Many authors may prefer the term stygobite or stygobiont for all subterranean, aquatic, troglomorphic species, and avoid the term phreatobite.

Limited funding for cave conservation work requires that we prioritize caves. One goal was to identify caves rich in species and high in endemism for long-range, statewide, wildlife conservation planning (Elliott, 2003b, 2006). Generally, Missouri caves with rare, endemic species also have many other species, but that is not always the case. Troglobites generally are the most endemic cave dwellers, whereas troglophiles often have large ranges, therefore the focus was on troglobites and species richness.

For MDC's Missouri Comprehensive Wildlife Conservation Strategy project in 2004, important bat caves and large karst springs also were taken into account because they represent important components in the karst ecosystem (Elliott, 2006).

There are various methods for measuring biodiversity. The author developed a cave biodiversity index for individual caves based on three elements that could be computed with queries in the CLD: *SR* (species rich-

**Table 3. Troglobites and phreatobites in Missouri (82 total, 15 undescribed in bold). A = aquatic, T = terrestrial. Endemism is the inverse of the number of sites.**

| Sciname | Author | Year | Common Name | Eco Type | Habitat | Sites | Endemism |
|---|---|---|---|---|---|---|---|
| *Allocrangonyx hubrichti* | Holsinger | 1971 | Hubricht's long-tailed amphipod | PB | A | 8 | 0.13 |
| *Amblyopsis rosae* | (Eigenmann) | 1897 | Ozark cavefish | TB | A | 44 | 0.02 |
| *Amnicola stygia* | Hubricht | 1971 | Stygian cavesnail | TB | A | 2 | 0.50 |
| *Antrobia culveri* | Hubricht | 1971 | Tumbling Creek cavesnail | TB | A | 1 | 1.00 |
| *Apochthonius colecampi* | Muchmore | 1967 | Colecamp pseudoscorpion | TP or TB | T | 3 | 0.33 |
| *Apochthonius mysterius* | Muchmore | 1976 | Mystery Cave pseudoscorpion | TB | T | 1 | 1.00 |
| *Apochthonius typhlus* | Muchmore | 1967 | Stone County cave pseudoscorpion | TB | T | 2 | 0.50 |
| *Arrhopalites clarus* | Christiansen | 1966 | Clarus cave springtail | TB | T | 8 | 0.13 |
| *Bactrurus brachycaudus* | Hubricht and Mackin | 1940 | Short-tailed ground-water amphipod | PB | A | 88 | 0.01 |
| *Bactrurus hubrichti* | Shoemaker | 1945 | Sword-tailed amphipod | TB | A | 1 | 1.00 |
| *Bactrurus pseudomucronatus* | Koenemann and Holsinger | 2001 | False sword-tailed cave amphipod | PB | A | 23 | 0.04 |
| *Brackenridgia ashleyi* | Lewis | | trichoniscid isopod | TB | T | 7 | 0.14 |
| *Caecidotea ancyla* | (Fleming) | 1972 | Ancyla cave isopod | TB | A | 11 | 0.09 |
| *Caecidotea antricola* | Creaser | 1931 | Antricola cave isopod | TB | A | 106 | 0.01 |
| *Caecidotea beattyi* | Lewis and Bowman | 1981 | Beatty's cave isopod | TB | A | 2 | 0.50 |
| *Caecidotea dimorpha* | Mackin and Hubricht | 1940 | Dimorphic ground water isopod | PB | A | 2 | 0.50 |
| *Caecidotea extensolinguala* | Fleming | 1972 | St. Francois ground water isopod | PB | A | 1 | 1.00 |
| *Caecidotea fustis* | Lewis | 1981 | Fustis cave isopod | TB | A | 16 | 0.06 |
| *Caecidotea kendeighi* | Steeves and Seidenberg | 1971 | Kendeigh's ground water isopod | PB | A | 1 | 1.00 |
| ***Caecidotea n. sp.*** | | | Devil's Icebox Cave isopod | TB | A | 1 | 1.00 |
| *Caecidotea packardi* | Mackin and Hubricht | 1940 | Packard's cave isopod | TB | A | 1 | 1.00 |
| *Caecidotea salemensis* | Lewis | 1981 | Salem cave isopod | TB | A | 31 | 0.03 |
| *Caecidotea serrata* | (Fleming) | 1972 | Serrated cave isopod | TB | A | 2 | 0.50 |
| *Caecidotea steevesi* | (Fleming) | 1972 | Steeves' cave isopod | TB | A | 1 | 1.00 |
| *Caecidotea stiladactyla* | (Mackin and Hubricht) | 1940 | Slender-fingered cave isopod | TB | A | 4 | 0.25 |
| *Caecidotea stygia* | Packard | 1871 | Stygian cave isopod | TB | A | 7 | 0.14 |
| *Cambarus aculabrum* | Hobbs & Brown | 1987 | cave crayfish | TB | A | 1 | 1.00 |
| *Cambarus hubrichti* | Hobbs | 1952 | Salem cave crayfish | TB | A | 23 | 0.04 |
| *Cambarus setosus* | Faxon | 1889 | Bristly cave crayfish | TB | A | 44 | 0.02 |
| *Causeyella dendropus* | (Loomis) | 1939 | Causeyella cave millipede | TB | T | 14 | 0.07 |
| *Chaetaspis aleyorum* | Lewis | 2002 | Aleys' cave millipede | TB | T | 3 | 0.33 |
| ***Cottus sp. 8*** | | | Grotto sculpin | TB | A | 8 | 0.13 |
| *Crangonyx packardi* | Smith | 1888 | Packard's ground water amphipod | PB | A | 5 | 0.20 |

**Table 3. Continued.**

| Sciname | Author | Year | Common Name | Eco Type | Habitat | Sites | Endemism |
|---|---|---|---|---|---|---|---|
| *Diacyclops clandestinus* | Yeatman | | Copepod | PB | A | 1 | 1.00 |
| ***Eumesocampa n. sp.*** | | | cave dipluran | TB | T | 6 | 0.17 |
| *Eurycea spelaea* | (Stejneger) | 1892 | Grotto salamander | TB | A | 200 | 0.01 |
| *Fontigens antroecetes* | (Hubricht) | 1940 | Enigmatic cavesnail | TB | A | 8 | 0.13 |
| *Fontigens proserpina* | (Hubricht) | 1940 | Proserpine cavesnail | TB | A | 5 | 0.20 |
| ***Haplocampa or Litocampa n. sp. 1*** | | | cave dipluran | TB | T | 5 | 0.20 |
| ***Haplocampa or Litocampa n. sp. 2*** | | | cave dipluran | TB | T | 1 | 1.00 |
| ***Haplocampa or Litocampa n. sp. 3*** | | | cave dipluran | TB | T | 1 | 1.00 |
| *Islandiana speophila* | Ivie | | cave spider | TB | T | 2 | 0.50 |
| *Kenkia glandulosa* | (Hyman) | 1956 | Pink planarian | TB | A | 1 | 1.00 |
| *Kenkia lewisi* | Kenk | 1975 | Lewis' cave planarian | TB | A | 3 | 0.33 |
| *Mundochthonius cavernicolus* | Muchmore | 1968 | cave pseudoscorpion | TB | T | 1 | 1.00 |
| ***Mundochthonius n.sp. near cavernicolus*** | | | cave pseudoscorpion | TB | T | 1 | 1.00 |
| *Oncopodura hoffi* | Christiansen & Bellinger | 1980 | Hoff's cave springtail | TB | T | 2 | 0.50 |
| *Oncopodura iowae* | Christiansen | 1961 | Springtail | TP or TB | T | 4 | 0.25 |
| ***Onychiurus n. sp. nr. paro*** | | | cave springtail | TB or TP? | T | 1 | 1.00 |
| ***Onychiurus n.sp., nr. pseudofimetarius*** | | | cave springtail | TB or TP? | T | 5 | 0.20 |
| *Onychiurus obesus* | Mills | 1934 | Obese springtail | TP or TB | T | 1 | 1.00 |
| *Orconectes stygocaneyi* | Hobbs | 2001 | Caney Mountain cave crayfish | TB | A | 1 | 1.00 |
| *Phanetta subterranea* | (Emerton) | 1875 | cave spider | TB | T | 3 | 0.33 |
| *Porrhomma cavernicola* | (Keyserling) | 1886 | cave spider | TB | T | 10 | 0.10 |
| ***Pseudanophthalmus n. sp.*** | Barr (in ms) | | blind trechine beetle | TB | T | 2 | 0.50 |
| *Pseudosinella espana* | Christiansen | 1961 | Espana cave springtail | TB | T | 5 | 0.20 |
| ***Pseudosinella sp. 1, argentea group*** | | | cave springtail | TB | T | 8 | 0.13 |
| *Sinella avita* | Christiansen | 1960 | Avita cave springtail | TB | T | 3 | 0.33 |
| *Sinella barri* | Christiansen | 1960 | Barr's cave springtail | TB | T | 3 | 0.33 |
| *Sinella cavernarum* | (Packard) | | Cavern springtail | TP or TB | T | 5 | 0.20 |
| *Spelobia tenebrarum* | (Aldrich) | 1897 | Cave dung fly | TB | T | 90 | 0.01 |
| *Sphalloplana evaginata* | Kenk | 1977 | Perryville cave planarian | TB | A | 4 | 0.25 |
| *Sphalloplana hubrichti* | (Hyman) | 1945 | Hubricht's cave planarian | TB | A | 3 | 0.33 |
| ***Stygobromus n. sp. a*** | Holsinger (in ms) | | cave amphipod | TB | A | 1 | 1.00 |

**Table 3. Continued.**

| Sciname | Author | Year | Common Name | Eco Type | Habitat | Sites | Endemism |
|---|---|---|---|---|---|---|---|
| *Stygobromus alabamensis alabamensis* | (Stout) | 1911 | Alabama cave amphipod | PB | A | 23 | 0.04 |
| *Stygobromus barri* | (Holsinger) | 1967 | Barr's ground-water amphipod | PB | A | 3 | 0.33 |
| *Stygobromus clantoni* | (Creaser) | 1934 | Clanton's ground-water amphipod | PB | A | 2 | 0.50 |
| ***Stygobromus n. sp. g*** | Holsinger (in ms) | | Gardner's cave amphipod | TB | A | 27 | 0.04 |
| *Stygobromus heteropodus* | (Hubricht) | 1943 | Pickle Springs amphipod | PB | A | 1 | 1.00 |
| ***Stygobromus n. sp. 2, onon. gp.*** | | | cave amphipod, to be revised | TB | A | 1 | 1.00 |
| ***Stygobromus n. sp. 3, onon. gp.*** | | | cave amphipod, to be revised | TB | A | 1 | 1.00 |
| *Stygobromus onondagaensis* | (Hubricht and Mackin) | 1940 | Onondaga Cave amphipod | TB | A | 38 | 0.03 |
| *Stygobromus ozarkensis* | (Holsinger) | 1967 | Ozark cave amphipod | TB | A | 10 | 0.10 |
| *Stygobromus subtilis* | (Hubricht) | 1943 | Subtle ground-water amphipod | PB | A | 1 | 1.00 |
| *Tingupa pallida* | Loomis | 1939 | Tingupa cave millipede | TB | T | 72 | 0.01 |
| *Tomocerus missus* | Mills | 1949 | Missus cave springtail | TB | T | 6 | 0.17 |
| *Typhlichthys subterraneus* | Girard | 1859 | Southern cavefish | TB | A | 29 | 0.03 |
| *Uncinocythere pholetera* | (Hart and Hobbs) | 1961 | cave ostracod | TB | A | 1 | 1.00 |
| *Uncinocythere xania* | (Hart and Hobbs) | 1961 | cave ostracod | TB | A | 1 | 1.00 |
| *Xenotrechus condei* | Barr and Krekeler | 1967 | Northern Xenotrechus cave beetle | TB | T | 2 | 0.50 |
| *Xenotrechus denticollis* | Barr and Krekeler | 1967 | Southern Xenotrechus cave beetle | TB | T | 2 | 0.50 |
| *Zosteractis interminata* | Loomis | 1943 | Zosteractis cave millipede | TB | T | 5 | 0.20 |

**Table 4. Species checklist for Tumbling Creek Cave, Taney County, Missouri.**

| Rank | Species | Common Name | Type | Status |
|---|---|---|---|---|
| 1 | *Agkistrodon contortrix* | Copperhead | AC | |
| 2 | *Antrobia culveri* | Tumbling Creek cavesnail | TB | S1 G1G2 |
| 3 | *Arctoseius cetratus* | Long-leg small shiny longsnout mite | AC | |
| 4 | *Arrhopalites clarus* | Clarus cave springtail | TB | S3 G4 |
| 5 | *Arrhopalites pygmaeus* | springtail | TP | |
| 6 | *Arrhopalites whitesidei* | springtail | TP | |
| 7 | *Atheta troglophila* | rove beetle | TP | |
| 8 | *Bakerdania sp.* | hairy mite | AC | |
| 9 | *Banksinoma sp.* | slender knobby-legged oribatid mite 2 | AC | |
| 10 | *Bembidion sp.* | small black ground beetle | TP | |
| 11 | *Brackenridgia ashleyi* | Ashley's isopod | TB | S2 G2 |
| 12 | *Bradysia sp.* | dark-winged fungus gnat | TP | |
| 13 | *Caecidotea ancyla* | Ancyla cave isopod | TB | S1 G1G3? |
| 14 | *Caecidotea antricola* | Antricola cave isopod | TB | S4 G5 |
| 15 | *Calvolia sp.* | mite | AC | |
| 16 | *Carpelimus sp.* | rove beetle | | |
| 17 | *Castor canadensis* | Beaver | TX | |
| 18 | *Causeyella dendropus* | Causeyella cave millipede | TB | SU GNR |
| 19 | *Ceratozetes sp.* | winged oribatid mite | AC | |
| 20 | *Ceuthophilus seclusus* | Secluded camel cricket | TX | |
| 21 | *Ceuthophilus silvestris* | Forest camel cricket | TX | |
| 22 | *Ceuthophilus uhleri* | Uhler's camel cricket | TX | |
| 23 | *Chaetaspis aleyorum* | Aleys' cave millipede | TB | S1 GNR |
| 24 | *Cicurina cavealis* | Cicurina spider | TP | |
| 25 | *Crosbyella sp.* | harvestman | TP or TB? | |
| 26 | *Cottus bairdi* | Mottled sculpin | TX | |
| 27 | *Dendrolaelaps near latior* | short-leg small shiny longsnout mite | AC | |
| 28 | *Eptesicus fuscus* | Big brown bat | TX | |
| 29 | *Ereynetes sp.* | small velvet mite | AC | |
| 30 | *Eurycea longicauda* | Dark-sided salamander | TP | |
| 31 | *Eurycea lucifuga* | Cave salamander | TP | |
| 32 | *Eurycea spelaea* | Grotto salamander | TB | S2S3 G4 |
| 33 | *Ferrissia fragilis* | limpet | TX | |
| 34 | *Folsomia candida* | springtail | TP | |
| 35 | *Hesperochernes occidentalis* | guano pseudoscorpion | TP | S3 G4G5 |
| 36 | *Histiosoma sp.* | small lumpy mite | AC | |
| 37 | *Hoploscirus sp.* | longsnout velvet mite | AC | |
| 38 | *Hydra sp.* | freshwater hydra | | |
| 39 | *Hypena humili* | quadrifid moth | | |
| 40 | *Hypoaspis sp.* | large shiny longsnout mite | AC | |
| 41 | *Iphidozercon reticaelatus* | small squat mite | AC | |
| 42 | *Islandiana sp.* | cave spider | TP or TB? | |
| 43 | *Ixodes sp.* | tick | | |
| 44 | *Lasiurus borealis* | Eastern red bat | TX | |
| 45 | *Lasiurus cinereus* | Hoary bat | TX | |
| 46 | *Leptocera sp.* | small dung fly | | |
| 47 | *Leptocera tenebrarum* | dung fly | TP? | |
| 48 | *Limonius flavomarginatus* | click beetle | TP | |
| 49 | *Lirceus sp.* | Lirceus isopod | TP or TX? | |
| 50 | *Macrocera nobilis* | webworm, fungus gnat | TP | |
| 51 | *Macrocheles penicilliger* | brown shiny mite | AC | |
| 52 | *Macronyssus jonesi* | black squat or hairy shiny bat mite | AC | |

**Table 4. Continued.**

| Rank | Species | Common Name | Type | Status |
|---|---|---|---|---|
| 53 | *Monunguis near streblida* | large velvet mite | AC | |
| 54 | *Multioppiea sp.* | slender knobby-legged oribatid mite 1 | AC | |
| 55 | *Myotis grisescens* | Gray bat | TX | S3 G3 SE FE |
| 56 | *Myotis lucifugus* | Little brown bat | TX | |
| 57 | *Myotis septentrionalis* | Northern long-eared bat | TX | S3 G4 |
| 58 | *Myotis sodalis* | Indiana bat | TX | S1 G2 SE FE |
| 59 | *Neobisnius sp.* | rove beetle | AC | |
| 60 | *Onychiurus sp.* | springtail | TP | |
| 61 | *Orconectes neglectus neglectus* | Ringed crayfish | TX | |
| 62 | *Palaeacarus sp.* | black-hair oribatid mite | AC | |
| 63 | *Physa gyrina* | physid snail | TP? | |
| 64 | *Pipistrellus subflavus* | Eastern pipistrelle | TX | |
| 65 | *Platynus tenuicollis* | large black ground beetle | TP | |
| 66 | *Plesiodamalus sp.* | hairy knobby-legged oribatid mite | AC | |
| 67 | *Plusiocampa sp.* | cave dipluran | | |
| 68 | *Poecilochirus necrophori* | Split-back shiny mite | | |
| 69 | *Poecilophysis weyerensis* | rhagidiid mite | TP | |
| 70 | *Polyaspis sp.* | large squat mite | AC | |
| 71 | *Proctolaelaps hypudaei* | pale shiny mite | AC | |
| 72 | *Pseudopolydesmus pinetorum* | polydesmid millipede | TP | |
| 73 | *Pseudosinella argentea* | springtail | TP | |
| 74 | *Pseudozaona sp.* | pseudoscorpion | | |
| 75 | *Psyllipsocus ramburii* | book louse | TP | |
| 76 | *Ptomaphagus cavernicola* | cave leiodid beetle | TP | |
| 77 | *Rana palustris* | Pickerel frog | TX | |
| 78 | *Rhizoglyphus sp.* | large oval mite | AC | |
| 79 | *Sancassania? sp.* | tiny oval mite | AC | |
| 80 | *Semotilus atromaculatus* | Creek chub | AC | |
| 81 | *Spelobia tenebrarum* | Cave dung fly | TB | |
| 82 | *Stigmaeus sp.* | hairy medium oval mite | AC | |
| 83 | *Stygobromus onondagaensis* | Onondaga Cave amphipod | TB | S3? G5 |
| 84 | *Stygobromus ozarkensis* | Ozark cave amphipod | TB | S3? G4 |
| 85 | *Trichocera sp.* | winter crane fly | TX | |
| 86 | *Trombidium sp.* | thin-legged chigger mite | AC | |
| 87 | *Tyrophagus sp.* | side-dot mite | AC | |
| 88 | *Undetermined sp.* | generic amphipod, crangonyctid | | |
| 89 | *Undetermined sp.* | generic ant, black | AC | |
| 90 | *Undetermined sp.* | generic ant, red | AC | |
| 91 | *Undetermined sp.* | generic beetle, antlike flower | AC | |
| 92 | *Undetermined sp.* | generic beetle, click | AC | |
| 93 | *Undetermined sp.* | generic beetle, darkling | AC | |
| 94 | *Undetermined sp.* | generic beetle, dermestid larva | AC | |
| 95 | *Undetermined sp.* | generic beetle, ground | TP, TX or | |
| 96 | *Undetermined sp.* | generic beetle, rove | TP? | |
| 97 | *Undetermined sp.* | generic beetle, wrinkled bark | AC | |
| 98 | *Undetermined sp.* | generic bug, bed | PR | |
| 99 | *Undetermined sp.* | generic bug, jumping ground | | |
| 100 | *Undetermined sp.* | generic bug, true | | |
| 101 | *Undetermined sp.* | generic centipede | TX | |
| 102 | *Undetermined sp.* | generic crayfish | | |
| 103 | *Undetermined sp.* | generic dipluran | ED | |
| 104 | *Undetermined sp.* | generic fluke, Mongenea | PR | |
| 105 | *Undetermined sp.* | generic fly, moth | TX | |

**Table 4. Continued.**

| Rank | Species | Common Name | Type | Status |
|---|---|---|---|---|
| 106 | *Undetermined sp.* | generic gnat, fungus | TX or TP? | |
| 107 | *Undetermined sp.* | generic leafhopper | AC | |
| 108 | *Undetermined sp.* | generic midge 446 | TX | |
| 109 | *Undetermined sp.* | generic millipede | | |
| 110 | *Undetermined sp.* | generic mite, large velvet | AC | |
| 111 | *Undetermined sp.* | generic mite, spinturnicid star | PR | |
| 112 | *Undetermined sp.* | generic pseudoscorpion, small, white | | |
| 113 | *Undetermined sp.* | generic spider, pale | | |
| 114 | *Undetermined sp.* | generic springtail, huge pigmented | AC? | |
| 115 | *Wespus sp.* | harvestman | AC | |

Many of the common names given are informal working names. Ecological types: TB = troglobite (including stygobites), PB = phreatobite (groundwater forms), TP = troglophile, TX = trogloxene, AC = accidental, ED = edaphobite (soil-dweller), PR = parasite. Status is that given in the Missouri Natural Heritage Database and the annual Missouri Species and Communities of Concern Checklist: S1 is critically imperiled in the nation or state because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation from the state, with typically five or fewer occurrences or very few remaining individuals ($<$1000). G1 is similar on the global scale. S2 and G2 are imperiled, S3 and G3 are vulnerable, S4 and G4 are apparently secure. SE and FE refer to state and federal endangered status. Those without Status have not been listed or rated.

ness or number of all species in the cave), *T* (number of troglobites, stygobites and phreatobites), and *SE* (site endemism, which is the aggregate of troglobite endemism at the site). Lacking troglobite population estimates in most cases, a simple metric was found for comparing how endemic a species is within Missouri, as follows.

$$SE = \sum e \qquad (1)$$

where *e* (endemism) represents the reciprocal of the number of known Missouri sites. For example, the Grotto salamander, *Eurycea spelaea*, has 200 known sites in Missouri, so

$$e = \frac{1}{200} = 0.005 \qquad (2)$$

The total number of sites for *E. spelaea*, which ranges through four states in the Ozark region, is not currently published, however, for such a species the endemism value becomes so small as to be relatively unimportant in calculating a cave's *SE*. One could also use the *S* or *G* values from the Natural Heritage Database, but these values are not as up-to-date and do not take into account the many undescribed species that are known to cave biologists.

In contrast, the Tumbling Creek cavesnail, *Antrobia culveri*, is an endangered species known from one cave, so

$$e = \frac{1}{1} = 1 \qquad (3)$$

Tumbling Creek Cave has an *SE* value of 2.92, representing the aggregate endemism of 12 species of troglobites, at least two of which are unique to that cave. So, the more endemic a cave's fauna is, the higher the *SE* value.

To represent all three factors in one score for each cave, they were multiplied to obtain a Biodiversity Index *B*

$$B = SR \times T \times SE \qquad (4)$$

which is used for ranking caves for biodiversity. *B* is dimensionless, and minor differences between caves probably are not significant. *B* simply is a way of digesting complex information into one index for broad comparisons. *SE* scores also were computed for certain counties and karst zoogeographic regions, which one could call area endemism, to examine the suite of troglobites within broader areas.

One also could add *SR, T* and *SE* to create a biodiversity index, however, they do not scale the same and *SR* usually would be overemphasized. One can transform *SE* by multiplying it by 10 or 100 to obtain a value in the same order of magnitude as *SR* and *T*. However, the ranks for the top three caves would be the same as multiplying the three factors, although some low scoring caves would rank differently. Multiplication of the factors provides a fairly balanced emphasis of *SR, T*, and *SE*.

The relations of *SR, T*, and *SE* were examined with linear regressions and one-way ANOVA. All regressions were highly significant ($p < 0.001$), indicating that *SE* is highly dependent on high *SR* and *T*. However some interesting outliers resulted, which did not conform well to general trends. Some caves with high *SR* and *T* have much higher *SE* than the general trend would predict; examples are Devil's Icebox Cave, Boone County; Mystery Cave and Berome Moore Cave, Perry County; River Cave, Camden; Kohm's Cave, Ste. Genevieve County; and Branson Cave, Shannon County. Three of these caves are in eastern Missouri, where there is high cave

**Table 5. Species checklist for Devil's Icebox Cave, Boone County, Missouri.**

| Rank | Species | Common Name | Type | Status |
|---|---|---|---|---|
| 1 | *Agabus sp.* | predaceous diving beetle | TP | |
| 2 | *Agkistrodon contortrix* | Copperhead | AC | |
| 3 | *Ambystoma maculatum* | Spotted salamander | AC | |
| 4 | *Ambystoma texanum* | Smallmouth salamander | TX | |
| 5 | *Arrhopalites pygmaeus* | springtail | TP | |
| 6 | *Arrhopalites whitesidei* | springtail | TP | |
| 7 | *Bactrurus brachycaudus* | Short-tailed groundwater amphipod | PB | S4 G4 |
| 8 | *Bembidion sp.* | small black ground beetle | TP | |
| 9 | *Brachinus americanus* | ground beetle | AC | |
| 10 | *Bufo americanus* | Eastern American toad | TX | |
| 11 | *Caecidotea brevicauda* | Short-tailed groundwater isopod | TP | |
| 12 | *Caecidotea sp.* | Caecidotea isopod, troglobite | TB | |
| 13 | *Cantharis? sp.* | soldier beetle | TX | |
| 14 | *Ceuthophilus seclusus* | Secluded camel cricket | TX | |
| 15 | *Ceuthophilus silvestris* | Forest camel cricket | TX | |
| 16 | *Chrysemys picta bellii* | Western painted turtle | AC | |
| 17 | *Crangonyx forbesi* | amphipod | TP | |
| 18 | *Crangonyx packardi* | Packard's groundwater amphipod | PB? | |
| 19 | *Crangonyx sp., forbesi group* | amphipod | TP | |
| 20 | *Dina microstoma* | leech | TP? | |
| 21 | *Dineutus sp.* | whirligig beetle | AC | |
| 22 | *Dugesia dorotocephala* | planarian | AC | |
| 23 | *Eptesicus fuscus* | Big brown bat | TX | |
| 24 | *Etheostoma spectabile* | Orange-throat darter | AC | |
| 25 | *Eurycea longicauda* | Dark-sided salamander | TP | |
| 26 | *Eurycea lucifuga* | Cave salamander | TP | |
| 27 | *Eurycea sp.* | Eurycea salamander | TP | |
| 28 | *Gammarus pseudolimnaeus* | amphipod | TX | |
| 29 | *Hyla versicolor* | Eastern gray treefrog | TX | |
| 30 | *Kenkia glandulosa* | Pink planarian | TB | S12G3 |
| 31 | *Lampropeltis calligaster calligaster* | Prairie kingsnake | AC | |
| 32 | *Lepomis megalotis* | Longear sunfish | AC | |
| 33 | *Macrocera nobilis* | webworm, fungus gnat | TP | |
| 34 | *Mustela vison* | mink | TX | |
| 35 | *Myotis grisescens* | Gray bat | TX | S3 G3 SE FE |
| 36 | *Myotis lucifugus* | Little brown bat | TX | |
| 37 | *Myotis septentrionalis* | Northern long-eared bat | TX | S3 G4 |
| 38 | *Myotis sodalis* | Indiana bat | TX | S1 G2 SE FE |
| 39 | *Oncopodura iowae* | springtail | TP or TB | |
| 40 | *Ondatra zibethicus* | Muskrat | AC | |
| 41 | *Onychiurus reluctus* | springtail | TP | |
| 42 | *Orconectes virilis* | Northern crayfish | TX | |
| 43 | *Physa sp.* | physid snail | TP | |
| 44 | *Pipistrellus subflavus* | Eastern pipistrelle | TX | |
| 45 | *Placobdella sp.* | leech | TX | |
| 46 | *Plethodon glutinosus* | Slimy salamander | TX | |
| 47 | *Porrhomma cavernicola* | cave spider | TB | S2 G5 |
| 48 | *Procyon lotor* | Raccoon | TX | |
| 49 | *Pseudacris crucifer crucifer* | Northern spring peeper | TX | |
| 50 | *Pseudacris triseriata triseriata* | Western chorus frog | AC | |
| 51 | *Pseudopolydesmus sp.* | polydesmid millipede | TP | |
| 52 | *Pseudosinella argentea* | springtail | TP | |
| 53 | *Ptomaphagus cavernicola* | cave leiodid beetle | TP | |

**Table 5. Continued.**

| Rank | Species | Common Name | Type | Status |
|---|---|---|---|---|
| 54 | *Rana catesbiana* | Bullfrog | AC | |
| 55 | *Rana clamitans* | Green frog | TX | |
| 56 | *Rana palustris* | Pickerel frog | TX | |
| 57 | *Scalopus aquaticus* | Eastern mole | AC | |
| 58 | *Semotilus atromaculatus* | Creek chub | AC | |
| 59 | *Spelobia tenebrarum* | Cave dung fly | TB | |
| 60 | *Thamnophis sirtalis sirtalis* | Common garter snake | AC | |
| 61 | *Tingupa pallida* | Tingupa cave millipede | TB | S4 G4 |
| 62 | *Tomocerus missus* | Missus cave springtail | TB | SU G4 |
| 63 | *Undetermined sp.* | generic amphipod | | |
| 64 | *Undetermined sp.* | generic beetle | | |
| 65 | *Undetermined sp.* | generic beetle, darkling | AC | |
| 66 | *Undetermined sp.* | generic beetle, ground | TP, TX or | |
| 67 | *Undetermined sp.* | generic beetle, hister | | |
| 68 | *Undetermined sp.* | generic beetle, predaceous diving | AC | |
| 69 | *Undetermined sp.* | generic beetle, rove | TP? | |
| 70 | *Undetermined sp.* | generic crane fly | TX | |
| 71 | *Undetermined sp.* | generic earthworm, lumbricid | ED | |
| 72 | *Undetermined sp.* | generic fly | | |
| 73 | *Undetermined sp.* | generic fly, sciarid | | |
| 74 | *Undetermined sp.* | generic mite | | |
| 75 | *Undetermined sp.* | generic mite, oribatid | AC? | |
| 76 | *Undetermined sp.* | generic mite, rhagidiid | | |
| 77 | *Undetermined sp.* | generic spider | | |
| 78 | *Undetermined sp.* | generic spider, pale | | |
| 79 | *Undetermined sp.* | generic springtail, entomobryid | | |
| 80 | *Vonones sayi* | harvestman | AC | |

Many of the common names given are informal working names. Ecological types: TB = troglobite (including stygobites), PB = phreatobite (groundwater forms), TP = troglophile, TX = trogloxene, AC = accidental, ED = edaphobite (soil-dweller), PR = parasite. Status is that given in the Missouri Natural Heritage Database and the annual Missouri Species and Communities of Concern Checklist: S1 is critically imperiled in the nation or state because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation from the state, with typically five or fewer occurrences or very few remaining individuals (<1000). G1 is similar on the global scale. S2 and G2 are imperiled, S3 and G3 are vulnerable, S4 and G4 are apparently secure. SE and FE refer to state and federal endangered status. Those without Status have not been listed or rated.

endemism, however, they have received extensive study by cave biologists, so they probably have higher values as a result. On the other hand, some prominent caves are deficient in *SE* despite having a high *SR*, such as Great Scott Cave, Washington County; Jagged Canyon Cave, Bear Cave and Onondaga Cave, Crawford County; and Great Spirit Cave, Pulaski County. Four of the five latter caves are in the Meramec River basin, but that may not be significant, and they probably have not received as much study as deserved.

## Results

### High Biodiversity Caves

Currently there are about 12,500 observation and collection records. About 1,038 (17%) of Missouri's approximately 6,200 caves and cave springs are biocaves (at least one species), but only 491 sites (8%) have five or more species recorded. The CLD has data on 279 other localities, such as springs, wells, mines and some surface sites.

Missouri has 82 troglobites (67 described, 15 undescribed), including 49 aquatic and 33 terrestrial species (Tables 2 and 3). The aquatics include 30 described and six undescribed stygobites, plus 13 described phreatobites. The terrestrials include 24 described and nine undescribed species. Six of the troglobites (four described) may be troglophiles, edaphobites or neotroglobites. There are about 215 troglophiles (17 aquatic), 203 trogloxenes (20 aquatic) and 407 species of uncertain ecological type (27 aquatic).

Species checklists are provided for three important biocaves: Tumbling Creek Cave, Taney County (Table 4); Devil's Icebox Cave, Boone County (Table 5); and Mystery Cave, Perry County (Table 6). Tumbling Creek Cave ranks first in Missouri for species richness (115 species), number of troglobites (12), and site endemism (2.9154), giving it an overall Biodiversity Value of 4,023.25

**Table 6. Species Checklist for Mystery Cave, Perry County, Missouri.**

| Rank | Species | Common Name | Type | Status |
|---|---|---|---|---|
| 1 | *Agonum extensicolle* | ground beetle | AC | |
| 2 | *Ambystoma tigrinum tigrinum* | tiger salamander | | |
| 3 | *Amoebaleria defessa* | heleomyzid fly | TX | |
| 4 | *Anisodactylus opaculus* | ground beetle | AC | |
| 5 | *Apochthonius mysterius* | Mystery Cave pseudoscorpion | TB | S1 G1G2 |
| 6 | *Armadillidium vulgare* | pillbug isopod | TX | |
| 7 | *Arrhopalites clarus* | Clarus cave springtail | TB | S3 G4 |
| 8 | *Arrhopalites pygmaeus* | springtail | TP | |
| 9 | *Atheta sp. 3* | rove beetle | TP | |
| 10 | *Atheta sp.* | rove beetle | TP | |
| 11 | *Atranus pubescens* | ground beetle | TP | |
| 12 | *Austrotyla specus* | conotylid millipede | TP | |
| 13 | *Bactrurus brachycaudus* | Short-tailed groundwater amphipod | PB | S4 G4 |
| 14 | *Bembidion texanum* | ground beetle | TP | |
| 15 | *Bimastos tumidus* | earthworm | ED | |
| 16 | *Brachinus fumans* | ground beetle | AC | |
| 17 | *Caecidotea antricola* | Antricola cave isopod | TB | S4 G5 |
| 18 | *Caecidotea brevicauda* | Short-tailed groundwater isopod | TP | |
| 19 | *Caecidotea n. sp.* | Caecidotea isopod | TB | |
| 20 | *Caloglyphus sp.* | acarid mite | TP? | |
| 21 | *Ceuthophilus elegans* | Elegant camel cricket | TX | |
| 22 | *Cottus sp. 8* | Grotto sculpin | TB | S2 G1Q |
| 23 | *Crangonyx forbesi* | amphipod | TP | |
| 24 | *Cunaxa sp.* | cunaxid mite | TP? | |
| 25 | *Dactylolabis montana* | crane fly | TP | |
| 26 | *Dina microstoma* | leech | TP? | |
| 27 | *Diplocardia sp.* | earthworm | ED | |
| 28 | *Eumesocampa n. sp.* | cave dipluran | TB | |
| 29 | *Fallicambarus fodiens* | digger crayfish | TX | |
| 30 | *Folsomia candida* | springtail | TP | |
| 31 | *Fontigens antroecetes* | Enigmatic cavesnail | TB | S2 G2G3 |
| 32 | *Fontigens sp.* | cavesnail | TP | |
| 33 | *Galerita bicolor* | ground beetle | AC | |
| 34 | *Gammurus troglophilus* | amphipod | TP | |
| 35 | *Harpalus fulgens* | ground beetle | AC | |
| 36 | *Hawaiia miniscula* | zonitid snail | TX | |
| 37 | *Hypogastrura denticulata* | springtail | TP | |
| 38 | *Hypogastrura matura* | springtail | AC or TX? | |
| 39 | *Hypogastrura sp., denticulata complex* | springtail | TP | |
| 40 | *Isotoma notabilis* | springtail | TP | |
| 41 | *Isotoma sp.* | springtail | TP | |
| 42 | *Isotoma viridis* | springtail | TX | |
| 43 | *Kenkia lewisi* | Lewis' cave planarian | TB | S1 G1 |
| 44 | *Lycoriella sp.* | sciarid fly | TX | |
| 45 | *Meta ovalis* | Cave orb weaver | TP | |
| 46 | *Neobisnius sp.* | rove beetle | AC | |
| 47 | *Oncopodura hoffi* | Hoff's cave springtail | TB | S1S3 G1G2 |
| 48 | *Paratachys sp., corruscus* | ground beetle | AC | |
| 49 | *Pardosa sp.* | lycosid spider | TX | |
| 50 | *Patrobus longicornis* | ground beetle | TX? | |
| 51 | *Phagocata gracilis* | planarian | TP | |
| 52 | *Physa halei* | Hale's Physa snail | TP | |
| 53 | *Pseudosinella argentea* | springtail | TP | |

**Table 6. Continued.**

| Rank | Species | Common Name | Type | Status |
|---|---|---|---|---|
| 54 | *Pseudosinella sp. 1, argentea group* | cave springtail | TB | |
| 55 | *Rugilus dentatus* | rove beetle | AC | |
| 56 | *Stratiolaelaps sp.* | laelapid mite | TP? | |
| 57 | *Undetermined sp.* | generic beetle, ground | TP, TX or | |
| 58 | *Undetermined sp.* | generic mite, laelapid | TP? | |
| 59 | *Zonitoides arboreus* | snail | TP or TX? | |

Many of the common names given are informal working names. Ecological types: TB = troglobite (including stygobites), PB = phreatobite (groundwater forms), TP = troglophile, TX = trogloxene, AC = accidental, ED = edaphobite (soil-dweller), PR = parasite. Status is that given in the Missouri Natural Heritage Database and the annual Missouri Species and Communities of Concern Checklist: S1 is critically imperiled in the nation or state because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation from the state, with typically five or fewer occurrences or very few remaining individuals (<1000). G1 is similar on the global scale. S2 and G2 are imperiled, S3 and G3 are vulnerable, S4 and G4 are apparently secure. SE and FE refer to state and federal endangered status. Those without Status have not been listed or rated.

(Table 7), but its ranking could change with further studies. Depending on biodiversity measures, Tumbling Creek Cave may have the highest biodiversity for a single cave west of the Mississippi River, rivaled by Tooth Cave and Stovepipe Cave, Travis County, Texas, and perhaps others (Elliott, 1997; Elliott and Aley, 2006). However, the entire Edwards Aquifer in Texas ranks higher in biodiversity (Longley, 1981).

## Karst Zoogeography

Although karst regions and cave faunal units were named by earlier authors, such areas were conceived differently by each. Peck and Lewis (1978), Dom (2002) and Nigh and Schroeder (2002) discussed karst regions, but karst zoogeographic regions in this paper are based on a combination of troglobite zoogeography, physiography, geology and karst type. These regions lack sharp boundaries because of wide-ranging troglobites.

Troglobites are currently known from 728 Missouri sites, including 597 caves (9% of known caves). Twenty-five troglobites, eight of which are new species, occur at single sites only. An interesting example is *Orconectes stygocaneyi* (Fig. 8), the Caney Mountain cave crayfish, known only from a small cave with a perched aquifer on a high hill, geologically and hydrologically isolated from the main Springfield and Salem plateaus. As the only stygobitic *Orconectes* west of the Mississippi, its nearest relative is *O. pellucidus* from Kentucky (Ashley and Elliott, 2000; Hobbs, 2001).

Some aquatic species are wide-ranging. The most ubiquitous troglobite is *Eurycea spelaea*, the Grotto salamander (Fig. 9), with 200 known sites in Missouri, many others in Arkansas and Oklahoma, and one in Kansas. The author considers the Grotto salamander as the trademark cave species of the Ozark Region. It is a neotroglobite that may have evolved from an ancestor ecologically similar to *Eurycea lucifuga* (Fig. 10), but within the *E. multiplicata* complex (Bonett and Chippindale, 2004). Other wide-ranging forms are the millipede *Tingupa pallida* and the amphipod *Stygobromus ozarkensis* (Fig. 11); the latter ranges across most of the Ozarks (mostly caves) into Kansas (wells), more as a phreatobite than a strict stygobite. The isopod *Caecidotea antricola* (Fig. 12) has an even larger range. The amphipod *Allocrangonyx hubrichti* was considered a rare stygobite, but Robison and Holsinger (2000) found it in an Arkansas well and Sarver and Lister (2004) found it in 16 epigean streams in 14 Missouri counties. Individuals from caves typically were larger than those from epigean sites, which usually were gravel substrates in pools.

Missouri shares 48 troglobites with other states (Table 8), has relatively low diversity in terrestrial troglobites compared to areas east of the Mississippi River, but has high aquatic biodiversity. There is nearly equal similarity to faunas east and west of the Mississippi River. Missouri ranks about seventh among the United States in troglobite richness (Table 9).

## Springfield Plateau

This broad karst and physiographic region (Fig. 1) comprises limestones of Mississipian age, but it has smaller springs than the Salem Plateau. The plateau stretches into northern Arkansas, northeastern Oklahoma and the southeastern corner of Kansas. Representative species are *Amblyopsis rosae*, the Ozark cavefish (44 sites, Fig. 4), and *Cambarus setosus*, the Bristly cave crayfish (44 sites, Fig. 3), which co-occur in 16 sites (22%). Subpopulations of these species are found in semi-isolated parts of the aquifer. The geologic influence on cavefish distributions was discussed by Noltie and Wicks (2001). There are 21 troglobites in this large area, with the second highest area endemism in Missouri. However, none of the top 10 biocaves are in this region. Turnback Cave, Lawrence County, is the most biodiverse, with 40 species, seven troglobites (including Ozark cavefish and Bristly cave crayfish), but relatively low *SE* (Table 7).

## Boone Karst

This karst is formed in Mississippian limestones, and it might be considered an extension of the Springfield Plateau, along the Missouri River in Boone and adjacent counties. This karst was not glaciated during the latest (Wisconsin) glacial, but it may have been glaciated during the Illinoian and earlier. The Boone Karst lacks cavefish

**Table 7. The top 50 biocaves in Missouri ranked by overall Biodiversity Index (B).**

| Rank | Cave | County | *SR* | *T* | *SE* | *B* |
|---|---|---|---|---|---|---|
| 1 | Tumbling Creek Cave | Taney | 115 | 12 | 2.9154 | 4,023.25 |
| 2 | Devil's Icebox Cave | Boone | 80 | 9 | 2.7530 | 1,982.18 |
| 3 | Mystery Cave | Perry | 59 | 11 | 2.6875 | 1,744.16 |
| 4 | Berome Moore Cave | Perry | 28 | 10 | 2.0205 | 565.75 |
| 5 | River Cave | Camden | 41 | 8 | 1.6800 | 551.05 |
| 6 | Branson Cave | Shannon | 54 | 7 | 1.1997 | 453.48 |
| 7 | Kohms Cave | Ste. Genevieve | 38 | 7 | 1.5208 | 404.53 |
| 8 | Tom Moore Cave | Perry | 33 | 7 | 1.1811 | 272.82 |
| 9 | Jagged Canyon Cave | Crawford | 64 | 7 | 0.4478 | 200.63 |
| 10 | Great Scott Cave | Washington | 55 | 6 | 0.4222 | 139.34 |
| 11 | Bear Cave | Crawford | 62 | 5 | 0.4125 | 127.88 |
| 12 | Brawley Cave | Shannon | 27 | 7 | 0.6110 | 115.47 |
| 13 | Kelly Hollow Cave | Oregon | 21 | 7 | 0.7829 | 115.09 |
| 14 | Chimney Rock Cave | Barry | 40 | 7 | 0.4079 | 114.22 |
| 15 | Bounds Branch Cave | Shannon | 23 | 4 | 1.0623 | 97.73 |
| 16 | Turnback Cave | Lawrence | 40 | 7 | 0.3318 | 92.90 |
| 17 | Possum Trot Hollow Cave | Shannon | 18 | 4 | 1.0513 | 75.69 |
| 18 | Bat Cave | Crawford | 42 | 4 | 0.4354 | 73.14 |
| 19 | Round Spring Cavern | Shannon | 25 | 5 | 0.5394 | 67.43 |
| 20 | Panther Cave | Ripley | 10 | 5 | 1.2585 | 62.93 |
| 21 | Zorumski Cave | Phelps | 30 | 2 | 1.0323 | 61.94 |
| 22 | Creech Cave | Lincoln | 27 | 2 | 1.0114 | 54.61 |
| 23 | Hamilton Spring Cave | Washington | 15 | 6 | 0.6016 | 54.14 |
| 24 | Turner Spring Cave | Oregon | 38 | 5 | 0.2628 | 49.93 |
| 25 | Fisher Cave | Franklin | 20 | 4 | 0.5817 | 46.54 |
| 26 | Old Spanish Cave | Stone | 11 | 5 | 0.7859 | 43.22 |
| 27 | Upper Camp Yarn Cave | Carter | 22 | 5 | 0.3728 | 41.00 |
| 28 | Mushroom Cave | Franklin | 25 | 4 | 0.4058 | 40.58 |
| 29 | Smallin Cave | Christian | 9 | 4 | 1.1086 | 39.91 |
| 30 | Mushroom Rock Cave | Barry | 16 | 4 | 0.6161 | 39.43 |
| 31 | Lewis Cave | Ripley | 8 | 4 | 1.0918 | 34.94 |
| 32 | Camp Branch Cave | Washington | 11 | 3 | 1.0357 | 34.18 |
| 33 | Davis Cave | Shannon | 27 | 5 | 0.2519 | 34.00 |
| 34 | Powder Mill Creek Cave | Shannon | 35 | 5 | 0.1842 | 32.24 |
| 35 | Cooks Cave | Reynolds | 27 | 2 | 0.5769 | 31.15 |
| 36 | Running Bull Cave | Perry | 8 | 5 | 0.7756 | 31.03 |
| 37 | Great Spirit Cave | Pulaski | 46 | 4 | 0.1657 | 30.50 |
| 38 | Onondaga Cave | Crawford | 52 | 5 | 0.1171 | 30.46 |
| 39 | Mossy Spring Cave | Washington | 28 | 5 | 0.1965 | 27.51 |
| 40 | Pipe Spring Cave | Oregon | 23 | 6 | 0.1907 | 26.32 |
| 41 | Lone Hill Onyx Cave | Franklin | 37 | 3 | 0.2250 | 24.98 |
| 42 | Bat Cave | Shannon | 19 | 5 | 0.2606 | 24.76 |
| 43 | Woods Cave | St. Louis | 23 | 4 | 0.2568 | 23.62 |
| 44 | Martin Cave | Shannon | 17 | 4 | 0.3394 | 23.08 |
| 45 | Wood Cave | Christian | 29 | 5 | 0.1554 | 22.53 |
| 46 | Green Cave | Washington | 27 | 3 | 0.2627 | 21.28 |
| 47 | Mud Cave | Ozark | 10 | 2 | 1.0435 | 20.87 |
| 48 | Crevice Cave | Perry | 12 | 4 | 0.3958 | 19.00 |
| 49 | New Liberty Cave | Oregon | 23 | 6 | 0.1199 | 16.55 |
| 50 | Rice Cave | Jefferson | 8 | 5 | 0.4024 | 16.09 |

*SR* = total number of species or species richness, *T* = number of troglobites and phreatobites, *SE* = site endemism value, $B = SR \times T \times SE$.

**Figure 9.** ***Eurycea spelaea*****, Grotto salamander, Tumbling Creek Cave, Taney County.**

and cave crayfish and its cave fauna is different. Devil's Icebox Cave is a large cave with an extensive sinkhole plain feeding its stream, with two endemics, *Kenkia glandulosa*, the Pink Planarian, and a new, undescribed species of *Caecidotea* (Table 5). The system is nutrient-enriched from sinkhole ponds, suburban development and livestock, and it has a large Gray bat colony and abundant cave life. Other large caves, such as Hunter's Cave and Rocheport (Boone) Cave, have few troglobites and are largely fed by epigean waters (Lerch et al., 2000). The area has 10 troglobites and moderate endemism.

## Hannibal Karst

This karst is formed in Mississippian rocks and some Devonian and Silurian rocks near Hannibal, Marion County. Somewhat isolated from the other karsts, it has two common troglobites, *Bactrurus brachycaudus* (Fig. 13) and *Tingupa pallida*, but it has received little study.

**Figure 10.** ***Eurycea lucifuga*****, the troglophilic Cave salamander, Keyhole Cave, Shannon County.**

**Figure 11.** ***Stygobromus ozarkensis*****, Tumbling Creek Cave, Taney County, is a stygobite found in the Springfield Plateau of southwestern Missouri and adjacent parts of Arkansas and Oklahoma.**

## Lincoln Hills Karst

Formed in Mississippian rocks along the Lincoln Fold in Pike and Lincoln counties, this region has three troglobites and a moderate amount of endemism: *Bactrurus brachycaudus, Caecidotea packardi* and *Mundochthonius cavernicolus.*

## Salem Plateau

This broad area is mostly a dolomitic karst of Ordovician age, with Cambrian rocks ringing the central Ozark Dome, a structural, igneous feature known as the St.

**Figure 12.** ***Caecidotea antricola*****, a widespread phreatobite/stygobite, Cooks Cave, Reynolds County.**

**Table 8. Troglobites and phreatobites shared between Missouri and other states. Numbers shared with regions east and west of the Mississippi are for those regions as a whole.**

| State | Species |
|---|---|
| Arkansas | 22 |
| Iowa | 4 |
| Kansas | 7 |
| Oklahoma | 14 |
| West of Mississippi | 31 |
| West of Mississippi only | 23 |
| Illinois | 22 |
| Indiana | 10 |
| Kentucky | 10 |
| Tennessee | 9 |
| West Virginia | 1 |
| East of Mississippi | 26 |
| Widespread both sides | 6 |
| Missouri only | 34 |
| Total shared with Missouri | 48 |

Francois Mountains. This plateau could be divided into many karst zoogeographic regions, particularly river basins such as the Meramec, Gasconade, Osage, Niangua, Current/Jacks Fork, Eleven Point and others. However, interbasin transfer of ground water is common, and there are very large recharge areas, therefore stygobites can cross from one basin to another. For example, the record-holding, long-distance dye trace in the USA ran for 64 km to Big Spring, Carter County (Aley, 2000).

High biodiversity is found in some caves such as Tumbling Creek Cave, Taney County, and Branson Cave, Shannon County. A cavefish/crayfish pair co-occurs in nine (21%) of 52 caves: *Typhlichthys subterraneus*, Southern cavefish (29 sites), and *Cambarus hubrichti*, Salem cave crayfish (23 sites). These two stygobites are absent from

**Figure 13. *Bactrurus brachycaudus*, a phreatobite, Devil's Icebox Cave.**

some stream caves, even though they may occur in springs nearby (e.g., Powder Mill Creek Cave, Shannon County). A new species of troglobitic carabid beetle, Tribe Trechini, was recently found in two caves near the Current River, the first *Pseudanophthalmus* west of the Mississippi River and a link to eastern faunas (Michael J. Sutton and Tom Barr, Jr., pers. comm.). The three karst regions below can be considered eastern subdivisions of the main Salem Plateau, separated from it by the St. Francois Mountains.

## St. Louis Karst

Nigh and Schroeder (2002) recognized the Florissant Karst and the St. Louis Karst, based on surface vegetation, soils and geology, but they are lumped together here, as there is no distinction in cave zoogeography. Woods Cave contains a widespread species that is rare in Missouri, *Caecidotea stygia.* Many of the caves have been obliterated by urbanization. Nevertheless, there are 11 troglobites and

**Table 9. The top ten states in troglobite biodiversity (described species). Data from Hobbs, Culver and Elliott (2006) and the CLD. Missouri has a total of 82 troglobites (67 described, 15 undescribed), including 49 aquatic and 33 terrestrial species. The aquatics include 31 described and 6 undescribed stygobites, plus 13 described phreatobites. The terrestrials include 24 described and 9 undescribed species.**

| Rank | State | Stygobites | Phreatobites | Terrestrial Troglobites | Total |
|---|---|---|---|---|---|
| 1 | Texas | 58 | 2 | 119 | 179 |
| 2 | Tennessee | 40 | 1 | 120 | 161 |
| 3 | Alabama | 23 | 2 | 120 | 145 |
| 4 | Virginia | 38 | 12 | 89 | 139 |
| 5 | Kentucky | 29 | 0 | 90 | 119 |
| 6 | West Virginia | 32 | 1 | 42 | 75 |
| 7 | Missouri | 31 | 13 | 24 | 68 |
| 8 | Indiana | 22 | 3 | 32 | 57 |
| 9 | California | 8 | 7 | 42 | 57 |
| 10 | Georgia | 16 | 0 | 24 | 40 |

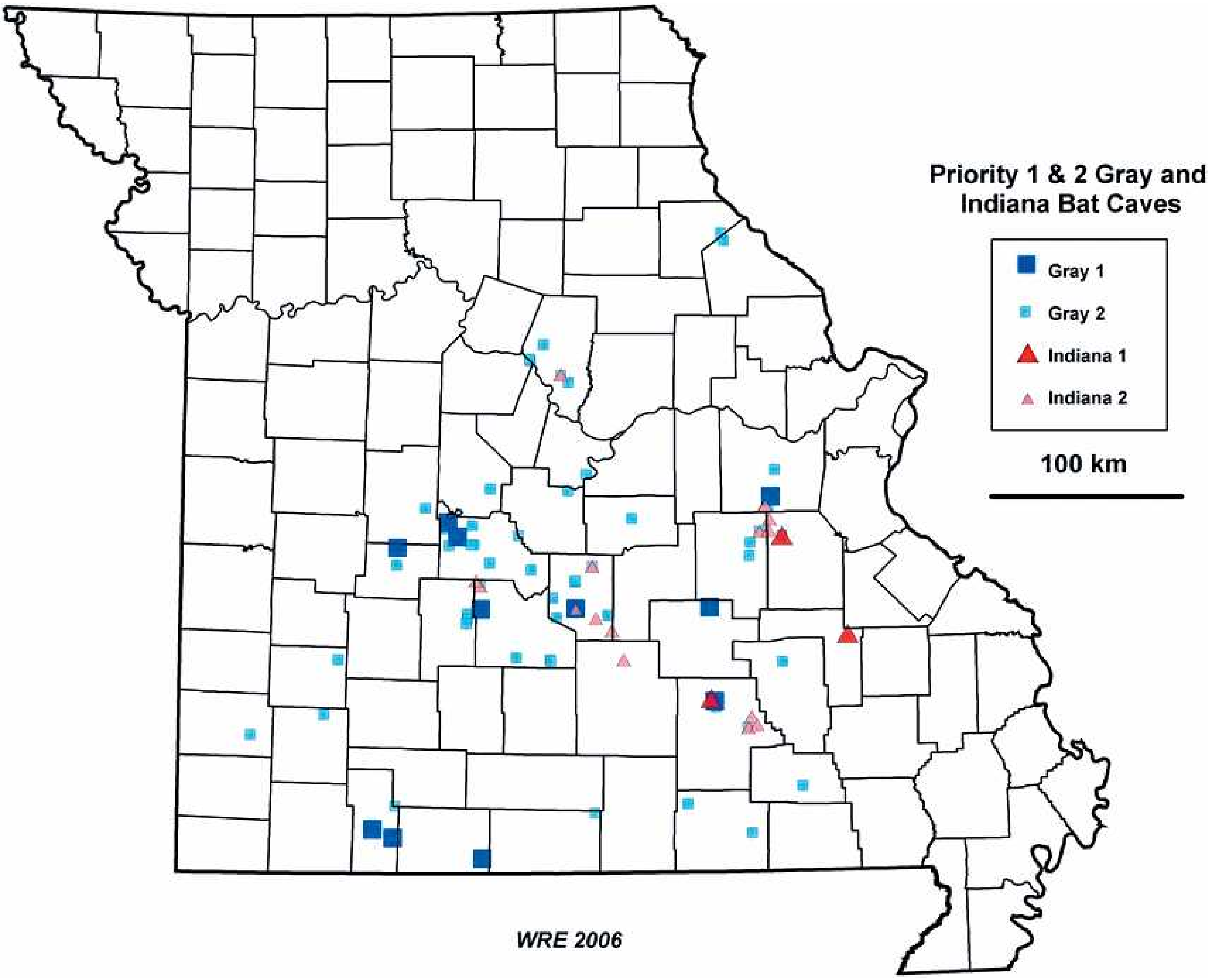


**Figure 14. Priority 1 and 2 Gray and Indiana bat caves.**

slightly more area endemism than the Lincoln Hills to the north. Peck and Lewis (1978) recognized a St. Louis-Ste. Genevieve County Fauna, which are separated here into the St. Louis and Jefferson-Ste. Genevieve karsts.

## Jefferson Ste. Genevieve Karst

This karst is formed in Mississippian and Ordovician rocks in Jefferson and Ste. Genevieve counties, south of St. Louis. There are faunistic similarities to the St. Louis and Perryville karsts. Mississippian rocks crop out in northern and southern blocks containing most of the caves, but a few important biocaves, such as Friedman's and Pleasant Valley, lie in Ordovician rocks in northern Jefferson County. Two endemic cave beetles occur: *Xenotrechus condei*, Northern Xenotrechus cave beetle, and *X. denticollis*, Southern Xenotrechus cave beetle, with only two known caves each. A stygobite, *Sphalloplana hubrichti*, Hubricht's cave planarian, occurs in Illinois and in this area, in two Ordovician springs and in Kohm's Cave, a large stream system with abundant cave life. Kohm's also has *X. denticollis*, a trechine beetle about 3.6 mm long, which may feed on tubificid oligochaete worms on stream banks. *Xenotrechus* is most closely similar to *Chaetoduvalius* and *Geotrechus* from southern Europe (Barr and Krekeler 1967). Extensive bat stains on the edges of domes indicate that a large colony of Gray bats may have roosted in Kohm's Cave, but no longer. No Gray bats are currently known from caves in eastern Missouri. With 19 troglobites, this karst has the highest area endemism in Missouri. Peck and Lewis (1978) thought the Ste. Genevieve Fault separated this area from the Perryville County Fauna to the south.

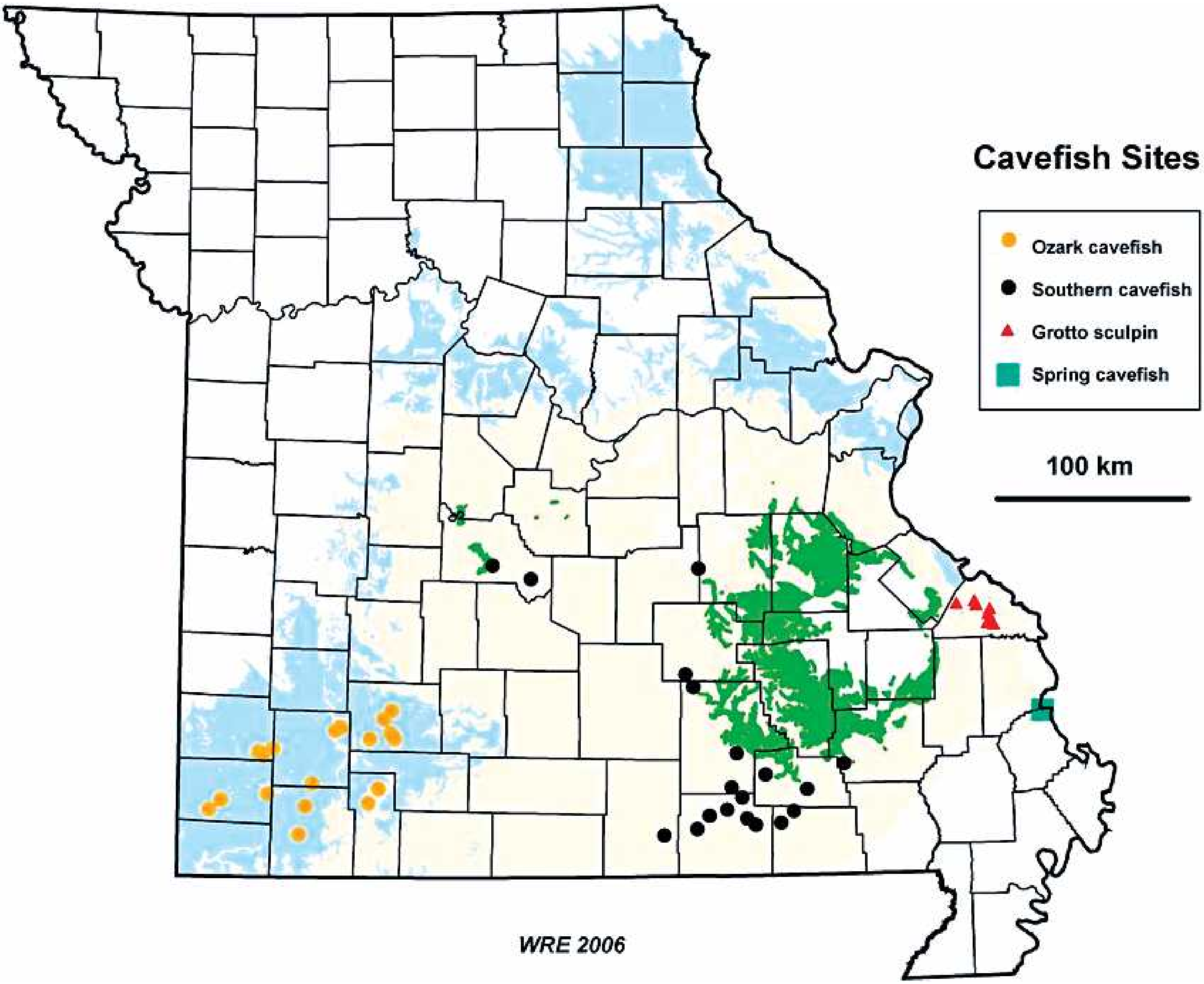


**Figure 15. Cavefish sites.**

### PERRYVILLE KARST

Some of the densest known karst development in the USA occurs in Perry County, in limestones of middle Ordovician age or older. About 700 cave entrances are recorded in the large sinkhole plain, with many large river caves, such as Crevice Cave, the longest in Missouri at 45 km. Large stream caves are especially developed in the Cinque Hommes Creek area. The uplands are covered with up to 10 m of loess derived from the Mississippi River flood plain (Vandike, 1985), and there is heavy row crop agriculture. Biologically similar to the Jefferson-Ste. Genevieve Karst, the Perryville Karst has its own endemics and lacks trechine beetles. Endemic species include *Sphalloplana evaginata,* Perryville cave planarian, *Kenkia lewisi,* Lewis' cave planarian, and *Cottus* sp. 8, the undescribed but distinct Grotto sculpin (Burr et al., 2001), now on Missouri's Species of Concern List. Mystery Cave ranks as third in cave biodiversity in Missouri (Table 7). With 18 troglobites, this karst has high area endemism.

### CONSERVATION

Many species and biologically important caves were added to the Missouri Natural Heritage Database and the Comprehensive Wildlife Conservation Strategy, a long-range, statewide conservation plan (Elliott, 2006b).

The term biocave is a cave for which at least one species was recorded in the CLD. Five was considered the minimum number of species indicating that there had been an actual bioinventory instead of a cursory check or a single-species survey. Beginning with a set of about 1200 caves with biological records, a subset of 862 biocaves was

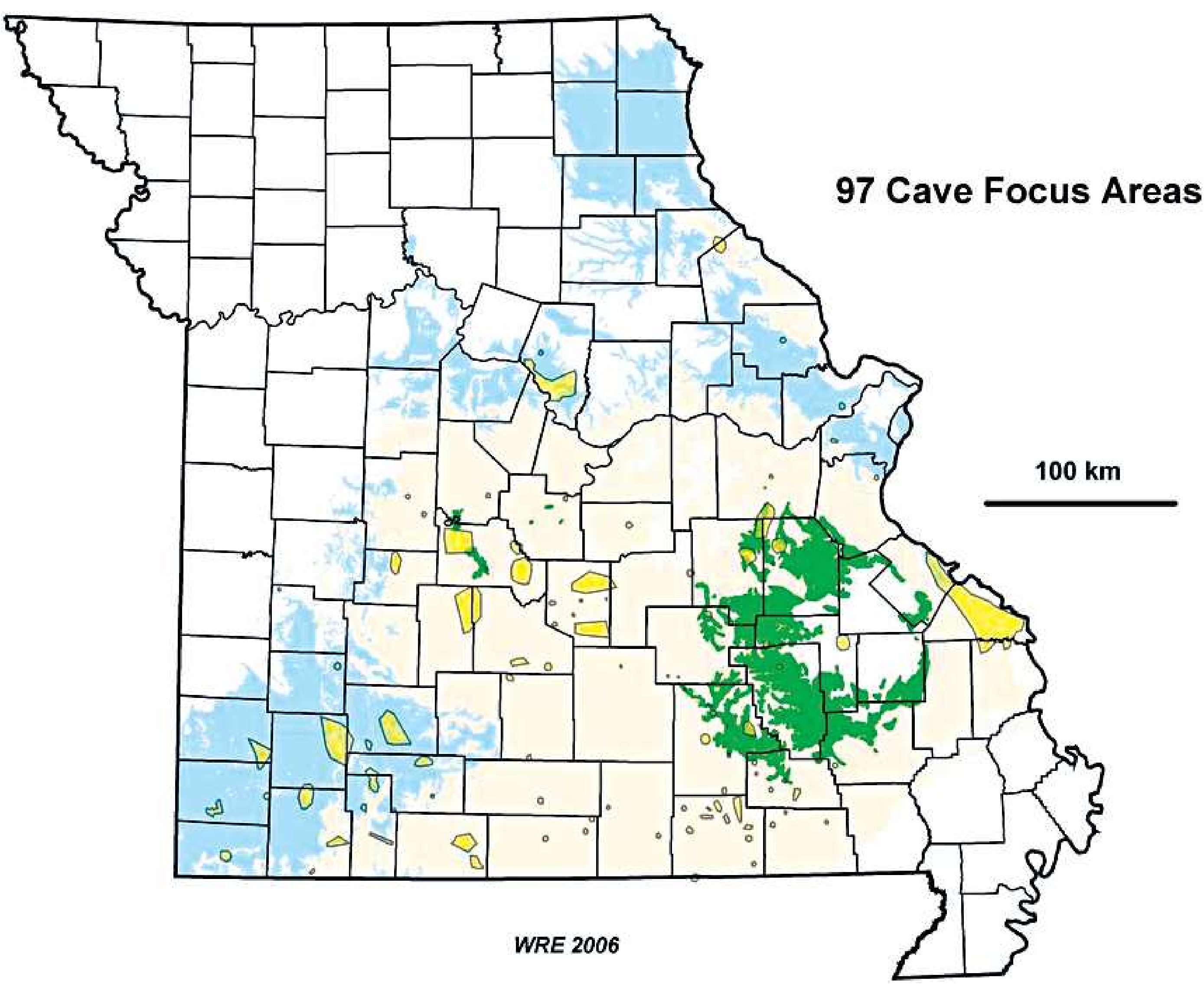


**Figure 16. Ninety-seven Cave Focus Areas comprising high biodiversity caves, important bat and cavefish caves, and first magnitude springs.**

derived (Fig. 2), then a relation between a table of biocaves and a table of cave locations was temporarily created using decimal-degree coordinates, developed with the help of the Missouri Natural Heritage Database and Hal Baker, Missouri Caves & Karst Conservancy.

The Cave Focus Areas that were derived do not pinpoint caves, but are polygons typically four to eight kilometers in diameter, including one or more important caves or springs. Once the polygon shapefiles were created in ESRI's ArcMap®, the Cave Focus Areas could be included in an overall GIS project for wildlife planning without revealing specific cave locations. Researchers and conservationists may obtain individual cave locations from the Heritage Database or the Missouri Speleological Survey on a need-to-know basis, with written justification.

Caves were ranked for *B* (biodiversity index), as an attribute in ArcMap to examine the geographic distribution of important biocaves (Fig. 1). Figure 14 shows 11 Priority 1 (>25,000–30,000 bats) and 55 Priority 2 (<25,000–30,000) Gray bat caves, and three Priority 1 and 16 Priority 2 Indiana bat caves. These priorities are used by MDC to rate the caves for larger, more important colonies of Gray bats (maternity and hibernacula) and Indiana bats (hibernacula only). See Clawson et al. (2006). Figure 15 depicts cavefish sites.

The final step in delineating Cave Focus Areas (Fig. 16) was to create data layers in ArcMap of the above elements. Polygon shapefiles were drawn around clusters of important caves and first magnitude karst springs, which flow $>2.83\ m^3\ s^{-1}$ ($100\ ft^3\ s^{-1}$). The latter springs often contain

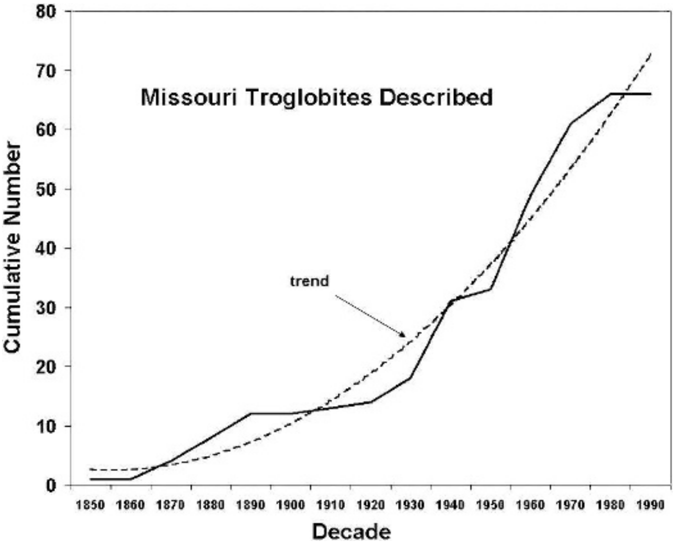


**Figure 17. The rate of description of new troglobitic species from Missouri, with fitted polynomial curve.**

important ground water species and represent hydrological connections over long distances. The largest, Big Spring, Carter County, flows about 12 $m^3 s^{-1}$ (424 $ft^3 s^{-1}$), with a peak flow of 37 $m^3 s^{-1}$ (1,307 $ft^3 s^{-1}$).

## Discussion and Conclusions

High troglobite endemism occurs in some areas, such as the Jefferson-Ste. Genevieve Karst, Springfield Plateau, Perryville Karst, and the Salem Plateau. Area endemism is generally low north of the Missouri River, Boone County being an exception. Endemism generally increases to the south and the east, but high biodiversity caves occur over a broad area. The top three caves are widely separated by 260–320 km, but more top biocaves are found in eastern Missouri than elsewhere (Fig. 1).

The Ozark Region lacks the rich troglobitic beetle fauna that is common in the eastern United States. Until recently the only trechines in Missouri were the two *Xenotrechus* found in the Jefferson-Ste. Genevieve Karst. The discovery of a new species of relatively small *Pseudanophthalmus* in Shannon County re-opens the question of the low number of troglobitic beetles in the Ozarks, discussed by Barr and Krekeler (1967) and Peck and Lewis (1978). Perhaps we only need to look for smaller beetles to have success. However, Missouri caves lack large colonies of rhaphidoporid crickets, with just four instances in the CLD where an observer counted more than 100 crickets, the maximum being 500 *C. gracilipes.* In contrast, cricket populations often number in the thousands in Texas (several *Ceuthophilus*) and Kentucky (*Hadenoecus* and *Ceuthophilus*), where there are many troglobitic and troglophilic carabid beetles, such as *Rhadine*, *Pseudanophthalmus*, and *Neaphaenops* preying on cricket eggs (Lavoie et al., 2007). Missouri rhaphidophorids are less cave-loving, which may have prevented the co-evolution of cricket-egg-predators, along with a possible lack of ancestral carabids invading the Ozarks from the Appalachians (Peck and Lewis, 1978).

Christiansen (1983) analyzed the distributions and troglomorphy of cave Collembola east of the Great Plains. The greatest biodiversity of troglobites was in the heartland of the nonglaciated Appalachians and Interior Low Plateaus, particularly among the Entomobryinae. The Ozarks have intermediate biodiversity, and caves in glaciated areas have the lowest level of cave adaptation.

Hobbs et al. (2003) provided a list troglobitic species for the United States. Culver et al. (1999, 2003) analyzed regional patterns of troglobites, stygobites and phreatobites across the entire USA. The analysis of Culver et al. looked at the Ozark Region and not Missouri *per se*. For both stygobites and troglobites, only number of caves was a significant predictor, and that seems to be borne out in this study, at least in eastern Missouri. Distance to Pleistocene glacial edges was not important, but there was some influence from proximity to late Cretaceous sea margins, an ancient source of aquatic colonizers. There was no effect from surface productivity (vegetation type).

In this study somewhat different conclusions were drawn than by Culver et al., (2003), but without statistical testing. In this study, high biodiversity as measured in some Missouri caves seems to be related to several factors:

1) Areas with larger and numerous caves with numerous aquatic and terrestrial microhabitats,
2) Location generally south of the Missouri River (away from Pleistocene glaciation),
3) Moderate to high, natural nutrient loads from recharge (essential) and Gray bat guano (not always essential, as in Mystery Cave), as opposed to vegetation type, and
4) High scientific and conservationist interest by the owner or manager, and access by qualified biologists.

The top three biocaves provide excellent examples of the factors given above. Tumbling Creek Cave, the leading Missouri biocave at this time, has received 40 years of study but is still yielding new species (Elliott and Aley, 2006). Martin (1980) studied the extreme arthropod diversity of Tumbling Creek Cave, tabulating 28 mite species, most of which were associated with Gray bat guano. Insofar as half (58) of the 115 species in Tumbling Creek Cave are morphospecies not yet identified to species, including 27 that are not yet identified to genus, there is still some potential for additional, new, endemic species there. Tom Aley (*pers. comm.*) observed troglobitic crayfishes on five occasions in the cave, but no specimens have been obtained yet for identification.

Another example of the above four factors is Devil's Icebox Cave, managed by Rock Bridge Memorial State Park as a wildlife refuge and wild caving venue, where

**Table 10. Cave biodiversity in 46 Missouri counties, based on the approximate number of caves known in 2005–2006. Sorted by Success 5, which is the countywide number of troglobites divided by Effort 5 (the number of biocaves with at least five species divided by the number of caves).**

| County | Caves | Biocaves 1 | Biocaves 5 | Troglobites | Effort 1 | Success 1 | Effort 5 | Success 5 |
|---|---|---|---|---|---|---|---|---|
| Perry | 656 | 23 | 9 | 19 | 0.0351 | 542 | 0.0137 | 1385 |
| Jefferson | 160 | 51 | 3 | 15 | 0.3188 | 47 | 0.0188 | 800 |
| Newton | 57 | 20 | 1 | 7 | 0.3509 | 20 | 0.0175 | 399 |
| Lawrence | 43 | 12 | 1 | 9 | 0.2791 | 32 | 0.0233 | 387 |
| Greene | 360 | 29 | 4 | 4 | 0.0806 | 50 | 0.0111 | 360 |
| St. Louis | 130 | 56 | 5 | 12 | 0.4308 | 28 | 0.0385 | 312 |
| Stone | 283 | 31 | 10 | 11 | 0.1095 | 100 | 0.0353 | 311 |
| Douglas | 108 | 17 | 2 | 5 | 0.1574 | 32 | 0.0185 | 270 |
| Ste. Genevieve | 72 | 17 | 4 | 12 | 0.2361 | 51 | 0.0556 | 216 |
| Shannon | 535 | 158 | 65 | 24 | 0.2953 | 81 | 0.1215 | 198 |
| Pulaski | 350 | 70 | 25 | 14 | 0.2000 | 70 | 0.0714 | 196 |
| Dade | 55 | 2 | 1 | 3 | 0.0364 | 83 | 0.0182 | 165 |
| Dent | 96 | 12 | 3 | 5 | 0.1250 | 40 | 0.0313 | 160 |
| McDonald | 103 | 20 | 4 | 6 | 0.1942 | 31 | 0.0388 | 155 |
| Taney | 137 | 27 | 14 | 15 | 0.1971 | 51 | 0.1022 | 147 |
| Christian | 220 | 45 | 18 | 11 | 0.2045 | 54 | 0.0818 | 134 |
| Crawford | 205 | 45 | 24 | 13 | 0.2195 | 59 | 0.1171 | 111 |
| Camden | 146 | 44 | 20 | 15 | 0.3014 | 50 | 0.1370 | 110 |
| Jasper | 26 | 7 | 1 | 4 | 0.2692 | 15 | 0.0385 | 104 |
| St. Francois | 19 | 9 | 1 | 5 | 0.4737 | 11 | 0.0526 | 95 |
| Benton | 42 | 5 | 2 | 4 | 0.1190 | 34 | 0.0476 | 84 |
| Phelps | 146 | 41 | 23 | 13 | 0.2808 | 46 | 0.1575 | 83 |
| Boone | 105 | 32 | 14 | 11 | 0.3048 | 36 | 0.1333 | 83 |
| Washington | 81 | 28 | 16 | 15 | 0.3457 | 43 | 0.1975 | 76 |
| Franklin | 97 | 54 | 23 | 17 | 0.5567 | 31 | 0.2371 | 72 |
| Wright | 57 | 10 | 7 | 8 | 0.1754 | 46 | 0.1228 | 65 |
| Barry | 134 | 60 | 28 | 13 | 0.4478 | 29 | 0.2090 | 62 |
| Laclede | 78 | 28 | 9 | 7 | 0.3590 | 20 | 0.1154 | 61 |
| Reynolds | 66 | 16 | 6 | 5 | 0.2424 | 21 | 0.0909 | 55 |
| Lincoln | 36 | 4 | 2 | 3 | 0.1111 | 27 | 0.0556 | 54 |
| Oregon | 140 | 81 | 47 | 18 | 0.5786 | 31 | 0.3357 | 54 |
| Ozark | 80 | 25 | 14 | 9 | 0.3125 | 29 | 0.1750 | 51 |
| Miller | 64 | 18 | 5 | 4 | 0.2813 | 14 | 0.0781 | 51 |
| Texas | 178 | 46 | 21 | 6 | 0.2584 | 23 | 0.1180 | 51 |
| Madison | 20 | 8 | 2 | 5 | 0.4000 | 13 | 0.1000 | 50 |
| Carter | 75 | 45 | 26 | 14 | 0.6000 | 23 | 0.3467 | 40 |
| Pike | 38 | 4 | 1 | 1 | 0.1053 | 10 | 0.0263 | 38 |
| Maries | 36 | 3 | 2 | 2 | 0.0833 | 24 | 0.0556 | 36 |
| Howell | 39 | 19 | 9 | 8 | 0.4872 | 16 | 0.2308 | 35 |
| Morgan | 30 | 3 | 1 | 1 | 0.1000 | 10 | 0.0333 | 30 |
| Dallas | 27 | 12 | 2 | 2 | 0.4444 | 5 | 0.0741 | 27 |
| Ripley | 9 | 3 | 3 | 6 | 0.3333 | 18 | 0.3333 | 18 |
| Cole | 18 | 3 | 1 | 1 | 0.1667 | 6 | 0.0556 | 18 |
| Iron | 25 | 14 | 8 | 5 | 0.5600 | 9 | 0.3200 | 16 |
| Hickory | 21 | 12 | 2 | 1 | 0.5714 | 2 | 0.0952 | 11 |
| Pettis | 5 | 5 | 2 | 2 | 1.0000 | 2 | 0.4000 | 5 |

visiting scientists and park staff often conduct faunal surveys and contribute data to the CLD. Mystery Cave received intensive study by Lewis (1974). Few high-biodiversity caves received only cursory study.

The trend of discovering and describing new troglobitic species in Missouri has varied since the 19$^{th}$ Century, but it is gradually increasing (Fig. 17). With a backlog of 15 undescribed troglobites, the pace of description still will increase if there is funding for the few skilled invertebrate taxonomists. The ongoing taxonomic crisis does not encourage the training of new invertebrate taxonomists (Wheeler et al., 2004, Elliott, 2006). If the Missouri trend of discovery continues, we could see many more troglobites eventually, or else an ever-increasing backlog of undescribed species and unrecognized biodiversity.

Additonal work is needed in many areas. Many Missouri caves are good candidates for having high biodiversity, but they have not yet received adequate study. Three examples are Carroll Cave, Camden County; Crevice Cave, Perry County; and Bruce Cave, Pulaski County. All are large, with extensive streams and terrestrial habitats, large recharge areas and reportedly abundant cave life. Table 10 shows cave biodiversity in 46 Missouri counties, based on the number of caves known in 1998. Of the 1,274 sites with biological records, 1,038 are caves or cave springs and 491 are caves with five or more recorded species. Effort1 is the number of Biocaves1 (with at least one recorded species) divided by the number of caves in that county. A similar calculation was done for Effort5 (caves with at least five species). Success1 is the number of troglobites divided by Effort1 for a county (similarly for Success5). The list is ranked in descending order of Success5, a measure of success in finding troglobites in caves that have been studied somewhat adequately. Perry and Jefferson counties rank high because many troglobites were found with relatively little effort, indicating the high endemism found in those karst areas. Table 10 is a guide to where future work should be concentrated. Besides the three prominent caves mentioned above, counties with many caves, but modest success to date, probably are good candidates for intensive study. An exception may be the urban areas of Greene and St. Louis counties, but the more rural areas may yet contain high biodiversity. Some counties have received little cave exploration, but still may have high speleological potential (e.g., Stone and Douglas counties).

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## REFERENCES

Aley, T.J., and Thomson, K.C., 1971, Ozark Underground Laboratory, Part II. Ozark Caver, Southwest Missouri State College, Springfield, Missouri, v. 3, no. 6, p. 1–19, + appendix.

Aley, T.J., 2000, Karst groundwater: Missouri Conservationist, v. 61, no. 3, p. 6–9. Reprinted in Conserving Missouri's Caves and Karst, 2002, Missouri Department of Conservation.

Ashley, D.C., 1993, Field studies in Missouri on Cave-dwelling snails of the genus *Fontigens*: Transactions of the Missouri Academy of Science, Abstracts, v. 27, 92 p.

Ashley, D.C., 1996, Adding cave ecology to the college curriculum: A description of BIO398 at Missouri Western State College, *in* Rea, G.T., ed., Proceedings of the 1995 National Cave Management Symposium, Abstracts, Spring Mill State Park, Mitchell, Indiana, October 25–28, 1995, Indiana Karst Conservancy, Inc., 318 p.

Ashley, D.C., 2003, A final report on the monitoring project to evaluate the population status of the Tumbling Creek cavesnail, *Antrobia culveri* (Gastropoda: Hydrobiidae): Progress report to the U.S. Fish and Wildlife Service, Columbia, Mo., 93 p.

Ashley, D.C., and Elliott, W.R., 2000, Missouri cave life, Missouri Conservationist, v. 61, no. 3, p. 12–17. Reprinted in Conserving Missouri's Caves and Karst, 2002, Missouri Department of Conservation.

Barr, Jr., T.C., and Krekeler, C.H., 1967, *Xenotrechus*, a new genus of cave trechines from Missouri (Coleoptera: Carabidae): Annals of the Entomological Society of America, v. 60, no. 6, p. 1322–1325.

Bishop, S.C., and Crosby, C.R., 1926, Notes on the spiders of the southeastern United States with descriptions of new species: Journal of the Elisha Mitchell Scientific Society, v. 41, no. 3–4, p. 165–212, pls. 20–25.

Bonett, R.M., and Chippindale, P.T., 2004, Speciation, phylogeography and evolution of life history and morphology in plethodontid salamanders of the *Eurycea multiplicata* complex: Molecular Ecology, v. 13, p. 1189–1203.

Burr, B.M., Adams, G.L., Krejca, J.K., Paul, R.J., and Warren, M.L. Jr., 2001, Troglomorphic sculpins of the *Cottus carolinae* species group in Perry County, Missouri: Distribution, external morphology, and conservation status: Environmental Biology of Fishes, v. 62, p. 279–296.

Causey, N.B., 1960, Troglobitic millipeds in Missouri: Missouri Speleology, Missouri Speleological Survey, v. 2, p. 60–65.

Christiansen, K.A., 1964, A revision of the Neartic members of the genus *Tomocerus* (Collembola: Entomobryidae): Revue d'Ecologie et de Biologie du Sol, v. 1, p. 639–678.

Christiansen, K.A., 1966, The genus *Arrhopalites* (Collembola: Sminthuridae) in the United States and Canada: International Journal of Speleology, v. 2, p. 43–73.

Christiansen, K.A., 1983, Zoogeography of cave Collembola east of the Great Plains: National Speleological Society Bulletin, v. 44, p. 32–41.

Clawson, R.L., Elliott, W.R., and Burns, D., 2006, A bat management plan for the Missouri Department of Conservation, 68 p.

Craig, J.L., 1975, A checklist of the invertebrate species recorded from Missouri subterranean habitats: Missouri Speleology, v. 15, no. 2, p. 1–10.

Craig, J.L., 1977, Invertebrate faunas of caves to be inundated by the Meramec Park Lake in eastern Missouri: National Speleological Society Bulletin, v. 39, no. 3, p. 80–89.

Crosby, D.R., 1905, The spiders of the Rochport Cave, Mo.: Canadian Entomology, v. 37, p. 367–369.

Culver, D.C., Master, L.L., Christman, M.C., and Hobbs, III, H.H., 1999, Obligate cave fauna of the 48 contiguous United States: Conservation Biology, v. 14, p. 386–401.

Culver, D.C., Christman, M.C., Elliott, W.R., Hobbs, III, H.H., and Reddell, J.R., 2003, The North American obligate cave fauna: Regional patterns. Biodiversity and Conservation, v. 12, p. 441–468.

Dom, J.E., 2002, A study of the cave morphology in Missouri [M.S. thesis]: Columbia, University of Missouri, 126 p.

Eigenmann, C.H., 1898, A new blind fish, Proceedings of the Indiana Academy of Science, Abstracts, v. 8, p. 231.

Eigenmann, C.H., 1899, Explorations in the caves of Missouri and Kentucky, Proceedings of the Indiana Academy of Science, v. 9, p. 58–61.

Eigenmann, C.H., 1901, Description of a new cave salamander, *Spelerpes stejnegeri*, from the caves of southwestern Missouri: Transactions of the American Microscopical Society, v. 22, p. 189–192, pls. XXVII–XXVIII.

Eigenmann, C.H., 1909, Cave vertebrates of America. A study in degenerative evolution, Carnegie Institute of Washington Publications, 104 ix + 241 pp., frontispiece, pls. A, 1–29.

Elliott, W.R., 1997, The Caves of the Balcones Canyonlands conservation plan, Report to Travis County, Transportation and Natural Resources Department, Balcones Canyonlands Conservation Plan, 156 p.

Elliott, W.R., 2000a, Conservation of the North American cave and karst biota, *in* Wilkens, H., Culver, D.C., and Humphreys, W.F., eds., Subterranean ecosystems: Ecosystems of the World, 30, Amsterdam, Elsevier, p. 665–689 [Electronic reprint on Biospeleology web site].

Elliott, W.R., 2000b, Below Missouri karst: Missouri Conservationist, v. 61, no. 3, p. 4–7. [Reprinted, in Conserving Missouri's Caves and Karst, 2002, Missouri Department of Conservation]

Elliott, W.R., 2003a, A Guide to Missouri's cave life. Missouri Department of Conservation. 40 p.

Elliott, W.R., 2003b, Missouri cave biogeography and biodiversity: Journal of Cave and Karst Studies, Abstracts, v. 65, no. 3, p. 174.

Elliott, W.R., 2004, Protecting caves and cave life, *in* Culver, D.C., and White, W.B., eds., Encylopedia of caves: Amsterdam, Elsevier, p. 458–467.

Elliott, W.R., 2005, Gray bat trends in Missouri: Gated vs. ungated caves, *in* G.T. Rea, ed., Proceedings of the 2003 National Cave and Karst Management Symposium, Gainesville, Fla., Abstracts, p. 43–44.

Elliott, W.R., 2006a, Critical issues in cave biology, *in* Rea, G.T., ed., Proceedings of the 2005 National Cave and Karst Management Symposium, Albany, New York, p. 35–39.

Elliott, W.R., 2006b, Missouri's Cave Focus Areas, *in* Rea, G.T., ed., Proceedings of the 2005 National Cave and Karst Management Symposium, Albany, New York, p. 48–52.

Elliott, W.R., 2007, Biospeleology: The Biology of Caves, Karst, and Groundwater. University of Texas at Austin, http://www.utexas.edu/tmm/sponsored_sites/biospeleology [accessed March 21, 2007].

Elliott, W.R., and Aley, T.J., 2006, Karst conservation in the Ozarks: Forty years at Tumbling Creek Cave, *in* Rea, G.T., ed., Proceedings of the 2005 National Cave and Karst Management Symposium, Albany, New York, p. 204–214.

Elliott, W.R., and Ashley, D.C., 2005, Caves and karst, *in* Nelson, P., ed., The terrestrial natural communities of Missouri, 3rd., Missouri Natural Areas Committee, p. 474–491.

Elliott, W.R., and Clawson, R.L., 2001, Temperature data logging in Missouri bat caves, *in* G.T. Rea, and G.T., eds., Proceedings of the 1999 National Cave and Karst Management Symposium, Chattanooga, Tennessee, p. 52–57.

Elliott, W.R., and Ireland, L., 2002, The Missouri cave life survey, *in* Rea, G.T., ed., Proceedings of the 2001 National Cave and Karst Management Symposium, Tucson, Ariz., p. 123–130.

Elliott, W.R., Sutton, M.J., and Ashley, D.C., 2000, Stygobite distribution in Missouri: Journal of Cave and Karst Studies, Abstracts, v. 62, p. 31.

Elliott, W.R., Samoray, S.T., Gardner, S.E., and Aley, T.J., 2005, Tumbling Creek Cave: An ongoing conservation and restoration partnership: American Caves, v. 19, no. 1, p. 8–13.

Elliott, W.R., Samoray, S.T., Gardner, S.E., and Kaufmann, J.E., 2006, The MDC Method: Counting bats with infrared video, *in* Rea, G.T., ed., Proceedings of the 2005 National Cave and Karst Management Symposium, Albany, New York, p. 147–153.

Faxon, W., 1889, [Description of] *Cambarus setosus* and *Asellus hoppinae*, *in* Garman, S., ed., Cave animals from southwestern Missouri: Bulletin of the Museum of Comparative Zoology, v. 17, p. 237–238.

Gardner, J.E., 1985, Invertebrate fauna from Missouri caves: Missouri Speleology, v. 25, no. 1–2, p. 172–177.

Gardner, J.E., 1986, Invertebrate fauna from Missouri caves and springs. Missouri Department of Conservation, Natural History Series, no. 3, p. i–vi, 1–72.

Garman, S., 1889, Cave animals from southwestern Missouri: Bulletin of the Museum of Comparative Zoology, v. 17, no. 6, p. 225–240, pls. I–II.

Girard, C., 1852, A revision of the North American Astaci, with observations on their habits and geographical distribution: Proceedings of the Academy of Natural Sciences, Philadelphia, v. 6, p. 87–91.

Girard, C., 1859, Ichthyological notices. XIII: Proceedings of the Academy of Natural Sciences, Philadelphia, v. 13, p. 56–68.

Graening, G.O., Hobbs, H.H. III, Slay, M.E., Elliott, W.R., and Brown, A.V., 2006, Status update for Bristly Cave Crayfish, *Cambarus setosus* (Decapoda: Cambaridae), and range extension into Arkansas: The Southwestern Naturalist, v. 51, no. 3, p. 382–392.

Hershler, R., Holsinger, J.R., and Hubricht, L., 1990, A revision of the North American freshwater snail genus *Fontigens* (Prosobranchia: Hydrobiidae). Smithsonian Contributions to Zoology, no. 509, 49 p.

Hobbs, H.H. III, 2001, A new cave crayfish of the genus *Orconectes*, subgenus *Orconectes*, from southcentral Missouri, U.S.A., with a key to the stygobitic species of the genus (Decapoda, Cambaridae): Crustaceana, v. 74, p. 635–646.

Hobbs, III., H.H., Culver, D.C., and Elliott, W.R., 2003, A list of cave-limited species in the United States and Canada, Karst Waters Institute, http://www.karstwaters.org/trogslist.htm [accessed January 1, 2003].

Holsinger, J.R., 1967, Systematics, speciation, and distribution of the subterranean amphipod genus *Stygonectes* (Gammaridae): United States National Museum Bulletin, v. 259, 176 p.

Holsinger, J.R., 1971, A new species of the subterranean amphipod genus *Allocrangonyx* (Gammaridae), with a redescription of the genus and remarks on its zoogeography: International Journal of Speleology, v. 3, no. 3–4, p. 317–331, pls. 104–110.

Holsinger, J.R., 1989, Allocrangonyctidae and Pseudocrangonyctidae, two new families of Holarctic subterranean amphipod crustaceans (Gammaridea), with comments on their phylogenetic and zoogeographic relationships: Proceedings of the Biological Society of Washington,, v. 102, no. 4, p. 947–959.

Hoppin, R., 1889, [Letters to Samuel Garman], *in* Samuel, G., ed., Cave animals from southwestern Missouri: Bulletin of the Museum of Comparative Zoology, v. 17, no. 6, p. 225–240, pls. I–II.

Hubbell, T.H., 1934, Rhaphidophorinae, *in* Hebard, M., ed., The dermaptera and orthoptera of Illinois: Illinois Natural History Survey Bulletin, v. 20, p. 125–279.

Hubbell, T.H., 1936, A Monographic Revision of the Genus *Ceuthophilus* (Orthoptera, Gryllacrididae, Rhaphidophorinae): University of Florida Publication, Biological Science Series, v. 2, no. 1, 551 p. + 38 pl.

Hubricht, L., 1940, The Ozark Amnicolas: The Nautilus, v. 53, no. 4, p. 118–122, pl. 14.

Hubricht, L., 1941, The cave Mollusca of the Ozark region: The Nautilus, v. 54, no. 4, p. 111–112.

Hubricht, L., 1942, A new locality for *Amnicola proserpina* Hubricht: Nautilus, v. 55, p. 105.

Hubricht, L., 1943, Studies on the nearctic freshwater Amphipoda, III: Notes on the freshwater Amphipoda of eastern United States, with description of ten new species: The American Midland Naturalist, v. 29, no. 3, p. 683–712.

Hubricht, L., 1950, The invertebrate fauna of Ozark caves: National Speleological Society Bulletin, v. 12, p. 16–17.

Hubricht, L., 1959, Malacostraca: Amphipoda, *in* Edmondson, W.T., ed., Fresh-water biology. 2nd ed.: New York, John Wiley & Sons, p. 876–878.

Hubricht, L., 1971, New Hydrobiidae from Ozark caves: The Nautilus, v. 84, no. 3, p. 93–96.

Hubricht, L., 1972, *Gastrocopta armifera* (Say): Nautilus, v. 85, p. 73–78.

Hubricht, L., and Mackin, J.G., 1940, Descriptions of nine new species of fresh-water amphipod crustaceans with notes and new localities for other species: The American Midland Naturalist, 23, p. 187–218.

Hubricht, L., and Mackin, J.G., 1949, The freshwater isopods of the genus *Lirceus* (Asellota, Asellidae): The American Midland Naturalist, v. 42, no. 2, p. 334–349.

Hyman, L.H., 1945, North American triclad Turbellaria XI, New, chiefly cavernicolous, planarians: The American Midland Naturalist, v. 34, no. 2, p. 75–484.

Hyman, L.H., 1956, North American triclad Turbellaria 15, Three new species: American Museum Novitates, no. 1808, p. 1–14.

Kenk, R., 1975, Fresh-water triclads (Turbellaria) of North America VII, The genus *Macrocotyla*: Transactions of the American Microscopical Society, no. 94, p. 324–339.

Kenk, R., 1977, Freshwater triclads (Turbellaria) of North America IX, The genus *Sphalloplana*: Smithsonian Contribtions to Zoology, no. 246, p. 1–38.

Koenemann, S., and Holsinger, J.R., 2001, Systematics of the North American subterranean amphipod genus *Bactrurus* (Crangonyctidae): Beaufortia Bulletin Zoological Museum University of Amsterdam, v. 51, no. 1, p. 1–56.

Koppelman, J.B., and Figg, D.E., 1993, Genetic estimates of variability and relatedness for conservation of an Ozark cave crayfish species complex: Conservation Biology, v. 9, no. 5, p. 1288–1294.

LaVal, R.K., Clawson, R.L., Caire, W., Wingate, L.R., and LaVal, M.L., 1977, An evaluation of the status of myotine bats in the proposed Meramec Park Lake and Union Lake project areas, Missouri: St. Louis District, U.S. Army Corps of Engineers, 136 p.

Lavoie, K.H., Helf, K.L., and Poulson, T.L., 2007, The biology and ecology of North American cave crickets: Journal of Cave and Karst Studies, [this issue].

Lerch, R.N., Erickson, J.M., Wicks, C.M., Elliott, W.R., and Schulte, S.W., 2000, Water quality in two karst basins of Boone County, Missouri: Journal of Cave and Karst Studies, Abstracts, v. 62, p. 187.

Lewis, J.J., 1974, The invertebrate fauna of Mystery Cave, Perry County, Missouri: Missouri Speleology, v. 14, no. 4, p. 1–19.

Lewis, J.J., 2002, *Chaetaspis aleyorum*, a new specis of milliped from Tumbling Creek Cave, Missouri, with a synopsis of the cavernicolous species of Chaetaspis (Diplopoda: Polydesmida): Myriapodologica, v. 7, no. 11, p. 101–111.

Lewis, J.J., 2004, *Brackenridgia ashleyi*, a new species of terrestrial isopod from Tumbling Creek Cave, Missouri (Crustacea, Isopoda: Trichoniscidae): Proceedings of the Biological Society of Washington, v. 117, no. 2, p. 176–185.

Longley, G., 1981, The Edwards Aquifer: Earth's most diverse groundwater ecosystem?: International Journal of Speleology, v. 11, no. 1–2, p. 123–128.

Loomis, H.F., 1939, The millipeds collected in Appalachian caves by Mr. Kenneth Dearolf: Bulletin of the Museum of Comparative Zoology, v. 86, p. 165–193.

Martin, B.J., 1980, The community structure of arthropods on bat guano and bat carcasses in Tumbling Creek Cave [M.S. thesis]: Chicago Circle, University of Illinois, 178 p.

Missouri Department of Conservation, 2005, Missouri Species and Communities of Conservation Concern, 53 p.

Nigh, T.A., and Schroeder, W.A., 2002, Atlas of Missouri Ecoregions, Missouri Department of Conservation, 212 p.

Noltie, D., and Wicks, C.M., 2001, How hydrogeology has shaped the ecology of Missouri's Ozark cavefish (*Amblyopsis rosae*) and Southern cavefish (*Typhlichthys subterraneus*): Insights on the sightless from understanding the underground: Journal of the Environmental Biology of Fishes. v. 62, p. 171–194.

Oesch, R.A., and Oesch, D.W., 1986, Cave resources of Fort Leonard Wood, Missouri Department of Conservation, 159 p.

Peck, S.B., and Lewis, J.J., 1978, Zoogeography and evolution of the subterranean invertebrate faunas of Illinois and southeastern Missouri: The National Speleological Society Bulletin, v. 40, no. 2, p. 39–63.

Pflieger, W.L., 1996, The crayfishes of Missouri, Missouri Department of Conservation, 152 p.

Pflieger, W.L., 1997, The fishes of Missouri, Missouri Department of Conservation, 382 p.

Robison, H.W., and Holsinger, J.R., 2000, First record of the subterranean amphipod crustacean *Allocrangonyx hubrichti* (Allocrangonyctidae) in Arkansas: Journal of the Arkansas Academy of Science, v. 54, p. 153.

Schwarz, E.A., 1891, A list of the blind or nearly eyeless Coleoptera found in North America: Proceedings of the Entomological Society of Washington, v. 2, p. 23–27.

Sarver, R.J., and Lister, K.B., 2004, Surface stream occurrence and updated distribution of *Allocrangonyx hubrichti* Holsinger (Amphipoda: Allocrangonyctidae), an endemic subterranean amphipod of the Interior Highlands: Journal of Freshwater Ecology, v. 19, no. 2, p. 165–168.

Shear, W.A., 2003, The milliped family Trichopetalidae, Part 1: Introduction and genera *Trigenotyla* Causey, *Nannopetalum* n. gen., and *Causeyella* n. gen. (Diplopoda: Chordeumatida, Cleidogonoidea): Zootaxa, v. 321, p. 1–36. www.mapress.com/zootaxa/, [accessed 2003]

Slay, M.E., Elliott, W.R., and Sluys, R., 2006, Cavernicolous Missouri triclad (Platyhelminthes: Turbellaria) records: The Southwestern Naturalist, v. 51, no. 2, p. 251–252.

Sluys, R., and Kawakatsu, M., 2006, Towards a phylogenetic classification of dendrocoelid freshwater planarians (Platyhelminthes): A morphological and eclectic approach: Journal of Zoological Systematics and Evolutionary Research, v. 44, no. 4, p. 274–284.

Stejneger, L., 1892, Preliminary description of a new genus and species of blind cave salamander from North America: Proceedings of the United States National Museum, v. 15, no. 894, p. 115–117, pl. IX.

Sutton, M.J., 1993, Caves and cave wildlife in a mineral prospecting area, Oregon and Shannon counties, Missouri: Missouri Speleology, v. 33, no. 1–4, p. 1–138.

Sutton, M.J., 1998, Baseline mapping and biological inventory of caves on the Mark Twain National Forest, Doniphan-Eleven Point District, Missouri: Phase 2: Cave Research Foundation, 105 p.

Sutton, M.J., 1999, Cave documentation in an Ozark prospecting area: NSS News, v. 57, no. 5, p. 138–140.

Sutton, M.J., 2004, The Pink Planarians of Devil's Icebox Cave–Census protocols: Cave Research Foundation, 35 p.

Thomson, K.C., and Aley, T.J., 1971, Ozark Underground Laboratory, Part I: Ozark Caver, v. 3, no. 5, p. 1–24.

Vandike, J., 1985, Movement of shallow groundwater in the Perryville Karst Area, southeastern Missouri: Water Resources Report, Missouri Department of Natural Resources, Division of Geology and Land Survey, Rolla, Missouri.

U.S. Department of Agriculture, 2006, Integrated Taxonomic Information System. http://www.itis.usda.gov/

U.S. Department of the Interior, Fish and Wildlife Service, 2001, Endangered and threatened wildlife and plants; List the Tumbling Creek cavesnail as endangered. [Emergency rule] Federal Register, v. 66, no. 248), p. 66803–66811.

U.S. Department of the Interior, Fish and Wildlife Service, 2003, Tumbling Creek Cavesnail Recovery Plan. 97 p.

Wheeler, Q.D., Raven, P.H., and Wilson, E.O., 2004, Taxonomy: Impediment or Expedient?: Science, 303(5656):285.