

ZOOGEOGRAPHY AND BIODIVERSITY OF MISSOURI CAVES AND KARST

WILLIAM R. ELLIOTT

Missouri Department of Conservation, Resource Science Division, 2901 West Truman Boulevard, Jefferson City, MO 65102-0180, Bill.Elliott@mdc.mo.gov

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 troglaphiles, edaphobites or neotroglobites. There are about 215 troglaphiles (17 aquatic), 203 troglaxenes (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-St. 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

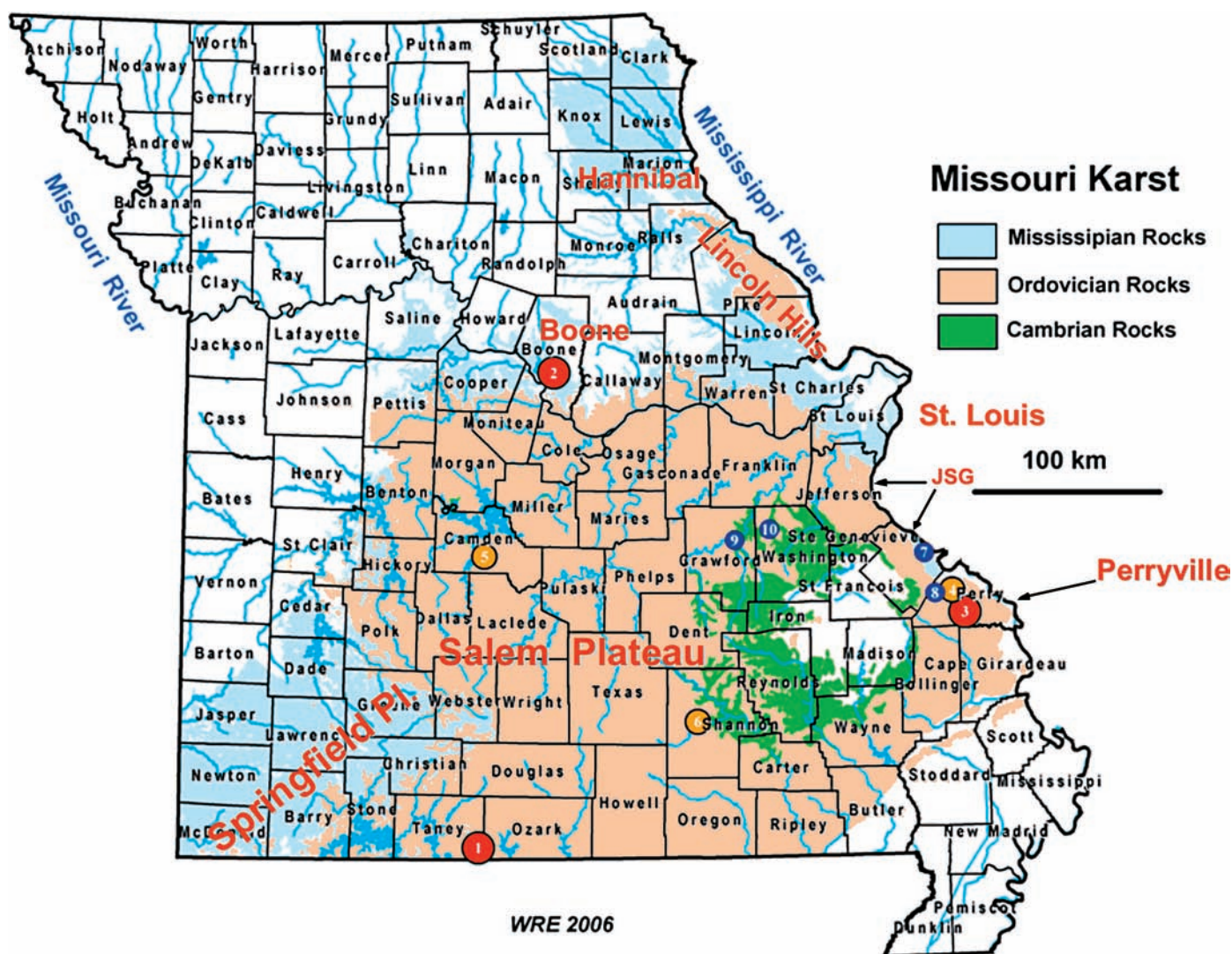


Figure 1. Missouri karst map showing the three principal ages of dolomites and limestones, karst zoogeographic regions and the top ten biocaves. 1) Tumbling Creek Cave, Taney County; 2) Devil's Icebox Cave, Boone County; 3) Mystery Cave, Perry County; 4) Berome Moore Cave, Perry County; 5) River Cave, 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 (Fair 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*

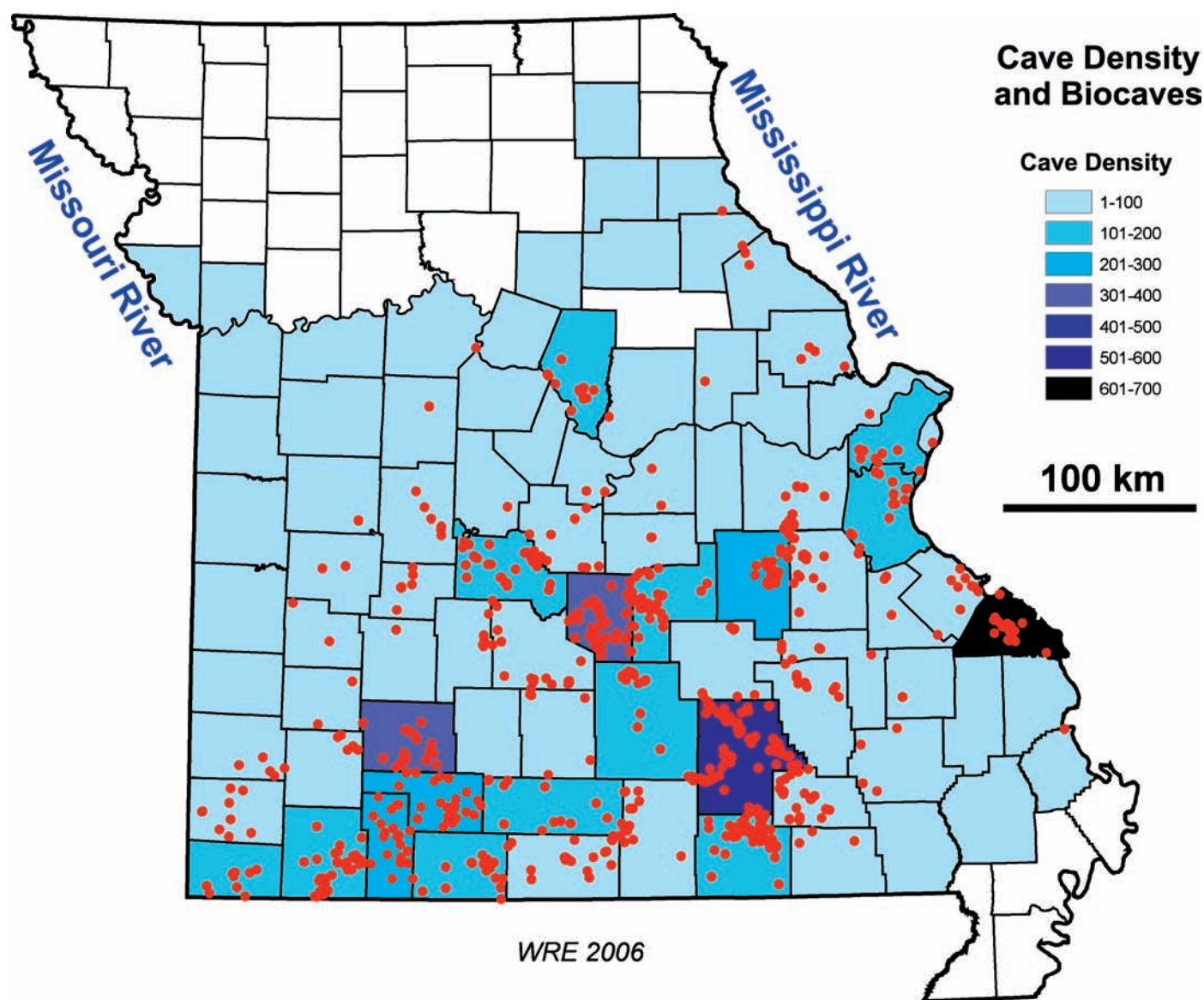


Figure 2. Cave density by county (about 6,000 caves) and biocaves (about 900).

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 *Batrurus* 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 *Batrurus pseudomucronatus*; the new family Allocrangonyctidae; and new locality records for



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

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.



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



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

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*) *lewisii* 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 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
<u>Exclusive totals</u>	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 troglaphiles (25–31%), 135–167 troglaxenes (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 troglaphiles, edaphobites or neotroglobites. Included in the troglaphile category are 35 possible troglaxenes and 3 possible stygaxenes.

Ecological Type	Terrestrial	Aquatic	Total
troglobites	33	49	82
troglaphiles	198	17	215
troglaxenes	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 identified 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 troglaphiles 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
<i>Allocrangonyx hubrichti</i>	Holsinger	1971	Hubricht's long-tailed amphipod	PB	A	8	0.13
<i>Amblyopsis rosae</i>	(Eigenmann)	1897	Ozark cavefish	TB	A	44	0.02
<i>Ammicola stygia</i>	Hubricht	1971	Stygian cavesnail	TB	A	2	0.50
<i>Antrobia culveri</i>	Hubricht	1971	Tumbling Creek cavesnail	TB	A	1	1.00
<i>Apochthonius colecampi</i>	Muchmore	1967	Colecamp pseudoscorpion	TP or TB	T	3	0.33
<i>Apochthonius mystereus</i>	Muchmore	1976	Mystery Cave pseudoscorpion	TB	T	1	1.00
<i>Apochthonius typhlus</i>	Muchmore	1967	Stone County cave pseudoscorpion	TB	T	2	0.50
<i>Arrhopalites clarus</i>	Christiansen	1966	Clarus cave springtail	TB	T	8	0.13
<i>Batrachus brachycaudus</i>	Hubricht and Mackin	1940	Short-tailed ground-water amphipod	PB	A	88	0.01
<i>Batrachus hubrichti</i>	Shoemaker	1945	Sword-tailed amphipod	TB	A	1	1.00
<i>Batrachus pseudomucronatus</i>	Koenemann and Holsinger	2001	False sword-tailed cave amphipod	PB	A	23	0.04
<i>Brackenridgia ashleyi</i>	Lewis		trichoniscid isopod	TB	T	7	0.14
<i>Caecidotea ancyla</i>	(Fleming)	1972	Ancyla cave isopod	TB	A	11	0.09
<i>Caecidotea antricola</i>	Creaser	1931	Antricola cave isopod	TB	A	106	0.01
<i>Caecidotea beattyi</i>	Lewis and Bowman	1981	Beatty's cave isopod	TB	A	2	0.50
<i>Caecidotea dimorpha</i>	Mackin and Hubricht	1940	Dimorphic ground water isopod	PB	A	2	0.50
<i>Caecidotea extensolinguala</i>	Fleming	1972	St. Francois ground water isopod	PB	A	1	1.00
<i>Caecidotea fustis</i>	Lewis	1981	Fustis cave isopod	TB	A	16	0.06
<i>Caecidotea kendeighi</i>	Steeves and Seidenberg	1971	Kendeigh's ground water isopod	PB	A	1	1.00
<i>Caecidotea n. sp.</i>			Devil's Icebox Cave isopod	TB	A	1	1.00
<i>Caecidotea packardii</i>	Mackin and Hubricht	1940	Packard's cave isopod	TB	A	1	1.00
<i>Caecidotea salemensis</i>	Lewis	1981	Salem cave isopod	TB	A	31	0.03
<i>Caecidotea serrata</i>	(Fleming)	1972	Serrated cave isopod	TB	A	2	0.50
<i>Caecidotea steevesi</i>	(Fleming)	1972	Steeves' cave isopod	TB	A	1	1.00
<i>Caecidotea stilodactyla</i>	(Mackin and Hubricht)	1940	Slender-fingered cave isopod	TB	A	4	0.25
<i>Caecidotea stygia</i>	Packard	1871	Stygian cave isopod	TB	A	7	0.14
<i>Cambarus aculabrum</i>	Hobbs & Brown	1987	cave crayfish	TB	A	1	1.00
<i>Cambarus hubrichti</i>	Hobbs	1952	Salem cave crayfish	TB	A	23	0.04
<i>Cambarus setosus</i>	Faxon	1889	Bristly cave crayfish	TB	A	44	0.02
<i>Causeyella dendropus</i>	(Loomis)	1939	Causeyella cave millipede	TB	T	14	0.07
<i>Chaetaspis aleyorum</i>	Lewis	2002	Aleys' cave millipede	TB	T	3	0.33
<i>Cottus sp. 8</i>			Grotto sculpin	TB	A	8	0.13
<i>Crangonyx packardii</i>	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
<i>Diacyclops claudestinus</i>	Yeatman		Copepod	PB	A	1	1.00
<i>Eumesocampa n. sp.</i>			cave dipluran	TB	T	6	0.17
<i>Eurycea spelaea</i>	(Stejneger)	1892	Grotto salamander	TB	A	200	0.01
<i>Fontigens antroecetes</i>	(Hubricht)	1940	Enigmatic cavesnail	TB	A	8	0.13
<i>Fontigens proserpina</i>	(Hubricht)	1940	Proserpine cavesnail	TB	A	5	0.20
<i>Haplocampa</i> or <i>Litocampa n. sp.</i> 1			cave dipluran	TB	T	5	0.20
<i>Haplocampa</i> or <i>Litocampa n. sp.</i> 2			cave dipluran	TB	T	1	1.00
<i>Haplocampa</i> or <i>Litocampa n. sp.</i> 3			cave dipluran	TB	T	1	1.00
<i>Islandiana speophila</i>	Ivie		cave spider	TB	T	2	0.50
<i>Kenkia glandulosa</i>	(Hyman)	1956	Pink planarian	TB	A	1	1.00
<i>Kenkia lewisi</i>	Kenk	1975	Lewis' cave planarian	TB	A	3	0.33
<i>Mundochthonius cavernicolus</i>	Muchmore	1968	cave pseudoscorpion	TB	T	1	1.00
<i>Mundochthonius n.sp. near cavernicolus</i>			cave pseudoscorpion	TB	T	1	1.00
<i>Oncopodura hoffi</i>	Christiansen & Bellinger	1980	Hoff's cave springtail	TB	T	2	0.50
<i>Oncopodura iowae</i>	Christiansen	1961	Springtail	TP or TB	T	4	0.25
<i>Onychiurus n. sp. nr. parvo</i>			cave springtail	TB or TP?	T	1	1.00
<i>Onychiurus n.sp., nr. pseudofinetarius</i>			cave springtail	TB or TP?	T	5	0.20
<i>Onychiurus obesus</i>	Mills	1934	Obese springtail	TP or TB	T	1	1.00
<i>Orconectes stygocaneyi</i>	Hobbs	2001	Caney Mountain cave crayfish	TB	A	1	1.00
<i>Phanetta subterranea</i>	(Emerton)	1875	cave spider	TB	T	3	0.33
<i>Porrohonna cavernicola</i>	(Keyserling)	1886	cave spider	TB	T	10	0.10
<i>Pseudanophthalmus n. sp.</i>	Barr (in ms)		blind trechine beetle	TB	T	2	0.50
<i>Pseudosinella espana</i>	Christiansen	1961	Espana cave springtail	TB	T	5	0.20
<i>Pseudosinella sp. 1, argentea group</i>			cave springtail	TB	T	8	0.13
<i>Sinella avita</i>	Christiansen	1960	Avita cave springtail	TB	T	3	0.33
<i>Sinella barri</i>	Christiansen	1960	Barr's cave springtail	TB	T	3	0.33
<i>Sinella cavernarum</i>	(Packard)		Cavern springtail	TP or TB	T	5	0.20
<i>Spelobia tenebrarum</i>	(Aldrich)	1897	Cave dung fly	TB	T	90	0.01
<i>Sphalloplana evaginata</i>	Kenk	1977	Perryville cave planarian	TB	A	4	0.25
<i>Sphalloplana hubrichti</i>	(Hyman)	1945	Hubricht's cave planarian	TB	A	3	0.33
<i>Stygobromus n. sp. a</i>	Holsinger (in ms)		cave amphipod	TB	A	1	1.00

Table 3. Continued.

Sciname	Author	Year	Common Name	Eco Type	Habitat	Sites	Endemism
<i>Stygobromus alabamensis alabamensis</i>	(Stout)	1911	Alabama cave amphipod	PB	A	23	0.04
<i>Stygobromus barri</i>	(Holsinger)	1967	Barr's ground-water amphipod	PB	A	3	0.33
<i>Stygobromus clantoni</i>	(Creaser)	1934	Clanton's ground-water amphipod	PB	A	2	0.50
<i>Stygobromus n. sp. g</i>	Holsinger (in ms)		Gardner's cave amphipod	TB	A	27	0.04
<i>Stygobromus heteropodus</i>	(Hubricht)	1943	Pickle Springs amphipod	PB	A	1	1.00
<i>Stygobromus n. sp. 2, onon. gp.</i>			cave amphipod, to be revised	TB	A	1	1.00
<i>Stygobromus n. sp. 3, onon. gp.</i>			cave amphipod, to be revised	TB	A	1	1.00
<i>Stygobromus onondagaensis</i>	(Hubricht and Mackin)	1940	Onondaga Cave amphipod	TB	A	38	0.03
<i>Stygobromus ozarkensis</i>	(Holsinger)	1967	Ozark cave amphipod	TB	A	10	0.10
<i>Stygobromus subtilis</i>	(Hubricht)	1943	Subtle ground-water amphipod	PB	A	1	1.00
<i>Tingupa pallida</i>	Loomis	1939	Tingupa cave millipede	TB	T	72	0.01
<i>Tomocerus missus</i>	Mills	1949	Missus cave springtail	TB	T	6	0.17
<i>Typhlichthys subterraneus</i>	Girard	1859	Southern cavefish	TB	A	29	0.03
<i>Uncinocythere pholetera</i>	(Hart and Hobbs)	1961	cave ostracod	TB	A	1	1.00
<i>Uncinocythere xania</i>	(Hart and Hobbs)	1961	cave ostracod	TB	A	1	1.00
<i>Xenotrechus condei</i>	Barr and Krekeler	1967	Northern Xenotrechus cave beetle	TB	T	2	0.50
<i>Xenotrechus denticollis</i>	Barr and Krekeler	1967	Southern Xenotrechus cave beetle	TB	T	2	0.50
<i>Zosteractis interminata</i>	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	<i>Agkistrodon contortrix</i>	Copperhead	AC	
2	<i>Antrobia culveri</i>	Tumbling Creek cavesnail	TB	S1 G1G2
3	<i>Arctoseius cetratus</i>	Long-leg small shiny longsnout mite	AC	
4	<i>Arrhopalites clarus</i>	Clarus cave springtail	TB	S3 G4
5	<i>Arrhopalites pygmaeus</i>	springtail	TP	
6	<i>Arrhopalites whitesidei</i>	springtail	TP	
7	<i>Atheta troglaphila</i>	rove beetle	TP	
8	<i>Bakerdania sp.</i>	hairy mite	AC	
9	<i>Banksinoma sp.</i>	slender knobby-legged oribatid mite 2	AC	
10	<i>Bembidion sp.</i>	small black ground beetle	TP	
11	<i>Brackenridgia ashleyi</i>	Ashley's isopod	TB	S2 G2
12	<i>Bradysia sp.</i>	dark-winged fungus gnat	TP	
13	<i>Caecidotea ancyla</i>	Ancyla cave isopod	TB	S1 G1G3?
14	<i>Caecidotea antricola</i>	Antricola cave isopod	TB	S4 G5
15	<i>Calvolia sp.</i>	mite	AC	
16	<i>Carpelimus sp.</i>	rove beetle		
17	<i>Castor canadensis</i>	Beaver	TX	
18	<i>Causeyella dendropus</i>	Causeyella cave millipede	TB	SU GNR
19	<i>Ceratozetes sp.</i>	winged oribatid mite	AC	
20	<i>Ceuthophilus seclusus</i>	Secluded camel cricket	TX	
21	<i>Ceuthophilus silvestris</i>	Forest camel cricket	TX	
22	<i>Ceuthophilus uhleri</i>	Uhler's camel cricket	TX	
23	<i>Chaetaspis aleyorum</i>	Aleys' cave millipede	TB	S1 GNR
24	<i>Cicurina cavealis</i>	Cicurina spider	TP	
25	<i>Crosbyella sp.</i>	harvestman	TP or TB?	
26	<i>Cottus bairdi</i>	Mottled sculpin	TX	
27	<i>Dendrolaelaps near latior</i>	short-leg small shiny longsnout mite	AC	
28	<i>Eptesicus fuscus</i>	Big brown bat	TX	
29	<i>Ereynetes sp.</i>	small velvet mite	AC	
30	<i>Eurycea longicauda</i>	Dark-sided salamander	TP	
31	<i>Eurycea lucifuga</i>	Cave salamander	TP	
32	<i>Eurycea spelaea</i>	Grotto salamander	TB	S2S3 G4
33	<i>Ferrissia fragilis</i>	limpet	TX	
34	<i>Folsomia candida</i>	springtail	TP	
35	<i>Hesperochnes occidentalis</i>	guano pseudoscorpion	TP	S3 G4G5
36	<i>Histiosoma sp.</i>	small lumpy mite	AC	
37	<i>Hoploscirus sp.</i>	longsnout velvet mite	AC	
38	<i>Hydra sp.</i>	freshwater hydra		
39	<i>Hypena humili</i>	quadrid moth		
40	<i>Hypoaspis sp.</i>	large shiny longsnout mite	AC	
41	<i>Iphidozercon reticaelatus</i>	small squat mite	AC	
42	<i>Islandiana sp.</i>	cave spider	TP or TB?	
43	<i>Ixodes sp.</i>	tick		
44	<i>Lasiurus borealis</i>	Eastern red bat	TX	
45	<i>Lasiurus cinereus</i>	Hoary bat	TX	
46	<i>Leptocera sp.</i>	small dung fly		
47	<i>Leptocera tenebrarum</i>	dung fly	TP?	
48	<i>Limonius flavomarginatus</i>	click beetle	TP	
49	<i>Lirceus sp.</i>	Lirceus isopod	TP or TX?	
50	<i>Macrocera nobilis</i>	webworm, fungus gnat	TP	
51	<i>Macrocheles penicilliger</i>	brown shiny mite	AC	
52	<i>Macronyssus jonesi</i>	black squat or hairy shiny bat mite	AC	

Table 4. Continued.

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

Table 4. Continued.

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

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

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

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

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

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

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

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

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

Table 5. Continued.

Rank	Species	Common Name	Type	Status
54	<i>Rana catesbiana</i>	Bullfrog	AC	
55	<i>Rana clamitans</i>	Green frog	TX	
56	<i>Rana palustris</i>	Pickerel frog	TX	
57	<i>Scalopus aquaticus</i>	Eastern mole	AC	
58	<i>Semotilus atromaculatus</i>	Creek chub	AC	
59	<i>Spelobia tenebrarum</i>	Cave dung fly	TB	
60	<i>Thamnophis sirtalis sirtalis</i>	Common garter snake	AC	
61	<i>Tingupa pallida</i>	Tingupa cave millipede	TB	S4 G4
62	<i>Tomocerus missus</i>	Missus cave springtail	TB	SU G4
63	<i>Undetermined sp.</i>	generic amphipod		
64	<i>Undetermined sp.</i>	generic beetle		
65	<i>Undetermined sp.</i>	generic beetle, darkling	AC	
66	<i>Undetermined sp.</i>	generic beetle, ground	TP, TX or	
67	<i>Undetermined sp.</i>	generic beetle, hiser		
68	<i>Undetermined sp.</i>	generic beetle, predaceous diving	AC	
69	<i>Undetermined sp.</i>	generic beetle, rove	TP?	
70	<i>Undetermined sp.</i>	generic crane fly	TX	
71	<i>Undetermined sp.</i>	generic earthworm, lumbricid	ED	
72	<i>Undetermined sp.</i>	generic fly		
73	<i>Undetermined sp.</i>	generic fly, sciarid		
74	<i>Undetermined sp.</i>	generic mite		
75	<i>Undetermined sp.</i>	generic mite, oribatid	AC?	
76	<i>Undetermined sp.</i>	generic mite, rhagidiid		
77	<i>Undetermined sp.</i>	generic spider		
78	<i>Undetermined sp.</i>	generic spider, pale		
79	<i>Undetermined sp.</i>	generic springtail, entomobryid		
80	<i>Vonones sayi</i>	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 = troglaxene, 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 troglaxenes (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	<i>Agonum extensicolle</i>	ground beetle	AC	
2	<i>Ambystoma tigrinum tigrinum</i>	tiger salamander		
3	<i>Amoebaleria defessa</i>	heleomyzid fly	TX	
4	<i>Anisodactylus opaculus</i>	ground beetle	AC	
5	<i>Apochthonius mysterius</i>	Mystery Cave pseudoscorpion	TB	S1 G1G2
6	<i>Armadillidium vulgare</i>	pillbug isopod	TX	
7	<i>Arrhopalites clarus</i>	Clarus cave springtail	TB	S3 G4
8	<i>Arrhopalites pygmaeus</i>	springtail	TP	
9	<i>Atheta</i> sp. 3	rove beetle	TP	
10	<i>Atheta</i> sp.	rove beetle	TP	
11	<i>Atramus pubescens</i>	ground beetle	TP	
12	<i>Austrotyla specus</i>	conotylid millipede	TP	
13	<i>Bactrurus brachycaudus</i>	Short-tailed groundwater amphipod	PB	S4 G4
14	<i>Bembidion texanum</i>	ground beetle	TP	
15	<i>Bimastos tumidus</i>	earthworm	ED	
16	<i>Brachinus fumans</i>	ground beetle	AC	
17	<i>Caecidotea antricola</i>	Antricola cave isopod	TB	S4 G5
18	<i>Caecidotea brevicauda</i>	Short-tailed groundwater isopod	TP	
19	<i>Caecidotea</i> n. sp.	Caecidotea isopod	TB	
20	<i>Caloglyphus</i> sp.	acarid mite	TP?	
21	<i>Ceuthophilus elegans</i>	Elegant camel cricket	TX	
22	<i>Cottus</i> sp. 8	Grotto sculpin	TB	S2 G1Q
23	<i>Crangonyx forbesi</i>	amphipod	TP	
24	<i>Cunaxa</i> sp.	cunaxid mite	TP?	
25	<i>Dactylolabis montana</i>	crane fly	TP	
26	<i>Dina microstoma</i>	leech	TP?	
27	<i>Diplocardia</i> sp.	earthworm	ED	
28	<i>Eumesocampa</i> n. sp.	cave dipluran	TB	
29	<i>Fallicambarus fodiens</i>	digger crayfish	TX	
30	<i>Folsomia candida</i>	springtail	TP	
31	<i>Fontigens antroecetes</i>	Enigmatic cavesnail	TB	S2 G2G3
32	<i>Fontigens</i> sp.	cavesnail	TP	
33	<i>Galerita bicolor</i>	ground beetle	AC	
34	<i>Gammurus troglophilus</i>	amphipod	TP	
35	<i>Harpalus fulgens</i>	ground beetle	AC	
36	<i>Hawaiia miniscula</i>	zonitid snail	TX	
37	<i>Hypogastrura denticulata</i>	springtail	TP	
38	<i>Hypogastrura matura</i>	springtail	AC or TX?	
39	<i>Hypogastrura</i> sp., <i>denticulata</i> complex	springtail	TP	
40	<i>Isotoma notabilis</i>	springtail	TP	
41	<i>Isotoma</i> sp.	springtail	TP	
42	<i>Isotoma viridis</i>	springtail	TX	
43	<i>Kenkia lewisi</i>	Lewis' cave planarian	TB	S1 G1
44	<i>Lycoriella</i> sp.	sciarid fly	TX	
45	<i>Meta ovalis</i>	Cave orb weaver	TP	
46	<i>Neobisnius</i> sp.	rove beetle	AC	
47	<i>Oncopodura hoffi</i>	Hoff's cave springtail	TB	S1S3 G1G2
48	<i>Paratachys</i> sp., <i>corruscus</i>	ground beetle	AC	
49	<i>Pardosa</i> sp.	lycosid spider	TX	
50	<i>Patrobus longicornis</i>	ground beetle	TX?	
51	<i>Phagocata gracilis</i>	planarian	TP	
52	<i>Physa halei</i>	Hale's Physa snail	TP	
53	<i>Pseudosinella argentea</i>	springtail	TP	

Table 6. Continued.

Rank	Species	Common Name	Type	Status
54	<i>Pseudosinella sp. 1, argentea group</i>	cave springtail	TB	
55	<i>Rugilus dentatus</i>	rove beetle	AC	
56	<i>Stratiolaelaps sp.</i>	laelapid mite	TP?	
57	<i>Undetermined sp.</i>	generic beetle, ground	TP, TX or	
58	<i>Undetermined sp.</i>	generic mite, laelapid	TP?	
59	<i>Zonitoides arboreus</i>	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 = troglaxene, 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 Mississippian 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	<i>SR</i>	<i>T</i>	<i>SE</i>	<i>B</i>
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



Figure 10. *Eurycea lucifuga*, the trogliphilic 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.

two common troglobites, *Batrachus brachycaudus* (Fig. 13) and *Tingupa pallida*, but it has received little study.

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: *Batrachus 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. *Batrachus 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

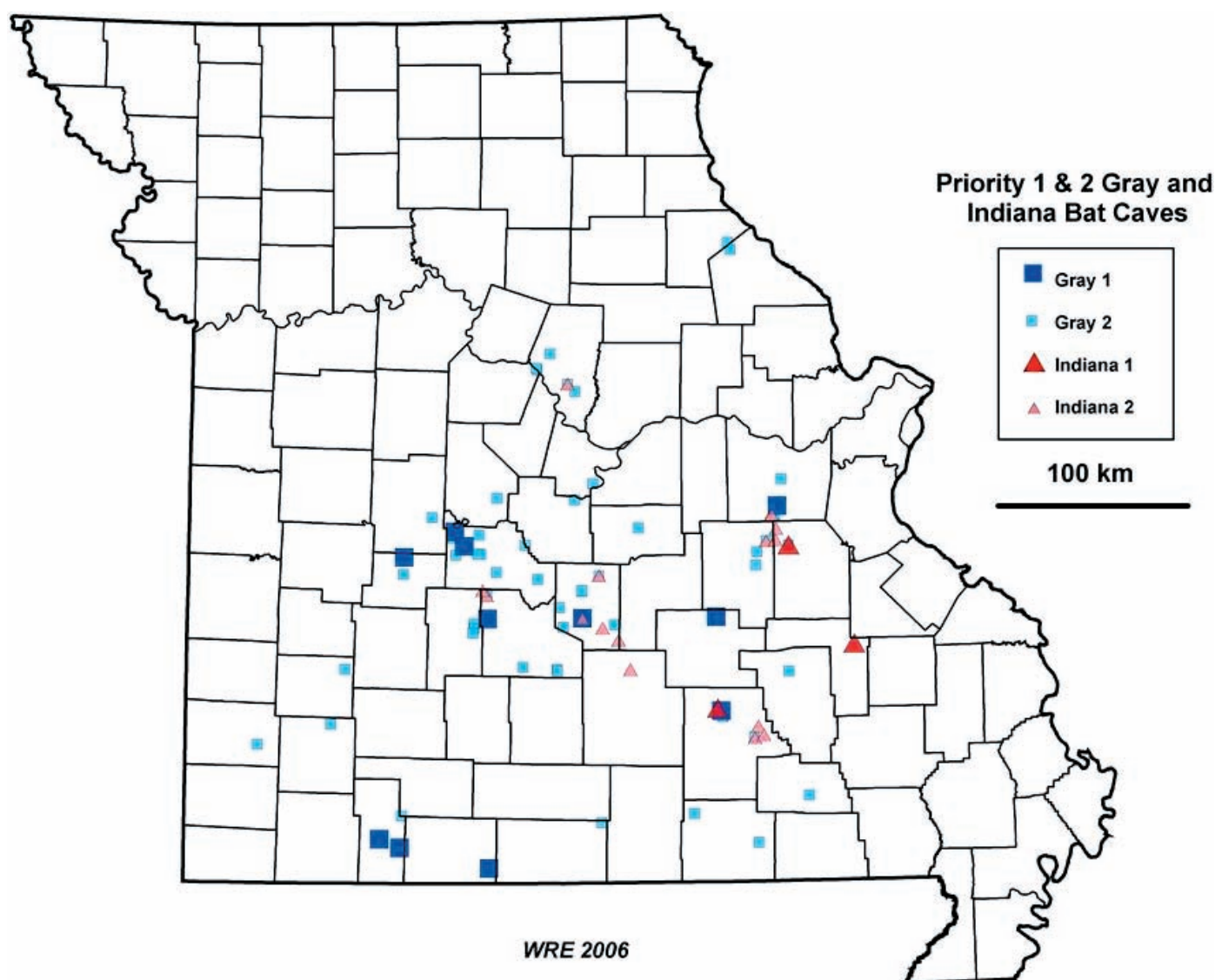


Figure 14. Priority 1 and 2 Gray and Indiana bat caves.

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.

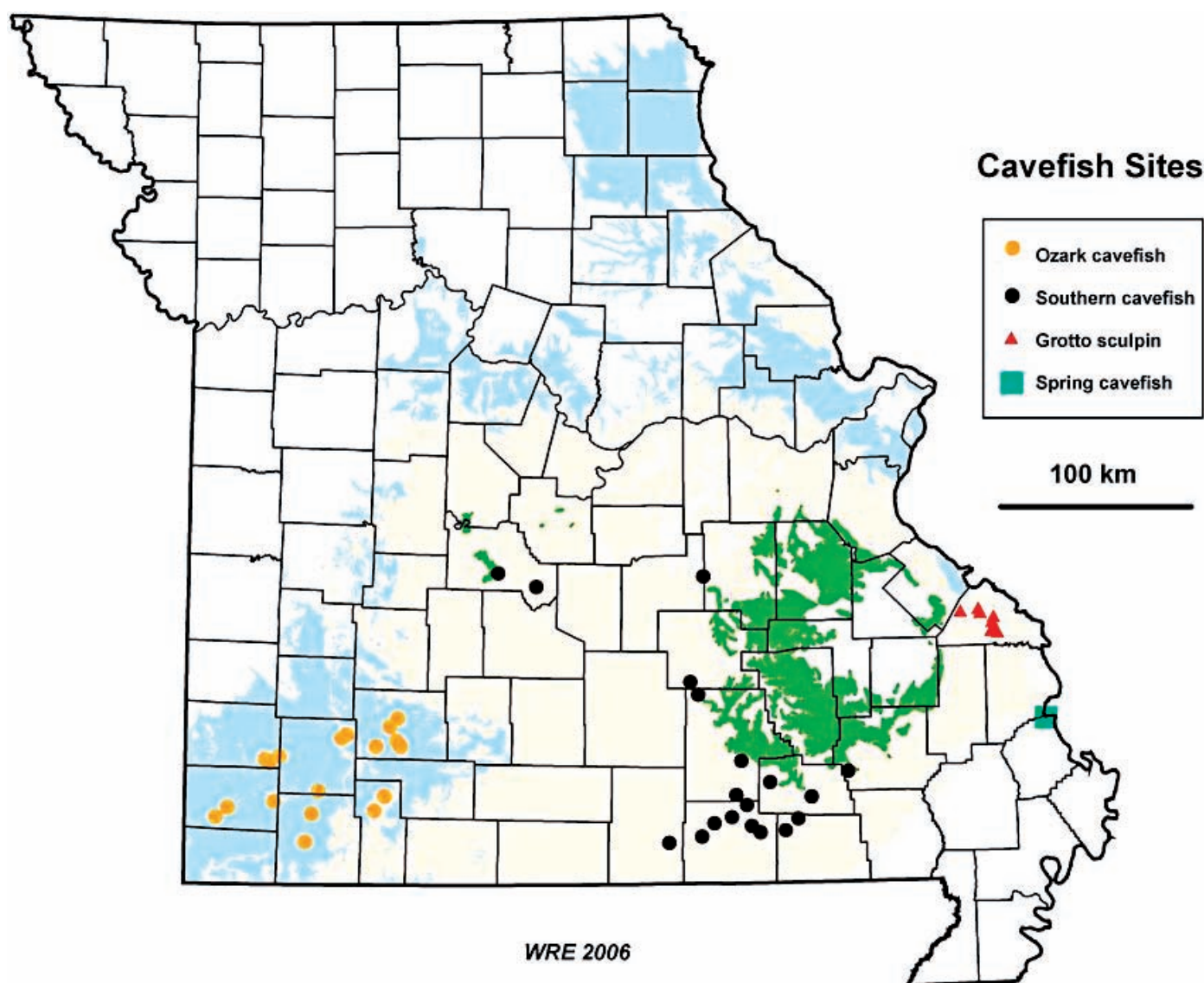


Figure 15. Cavefish sites.

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

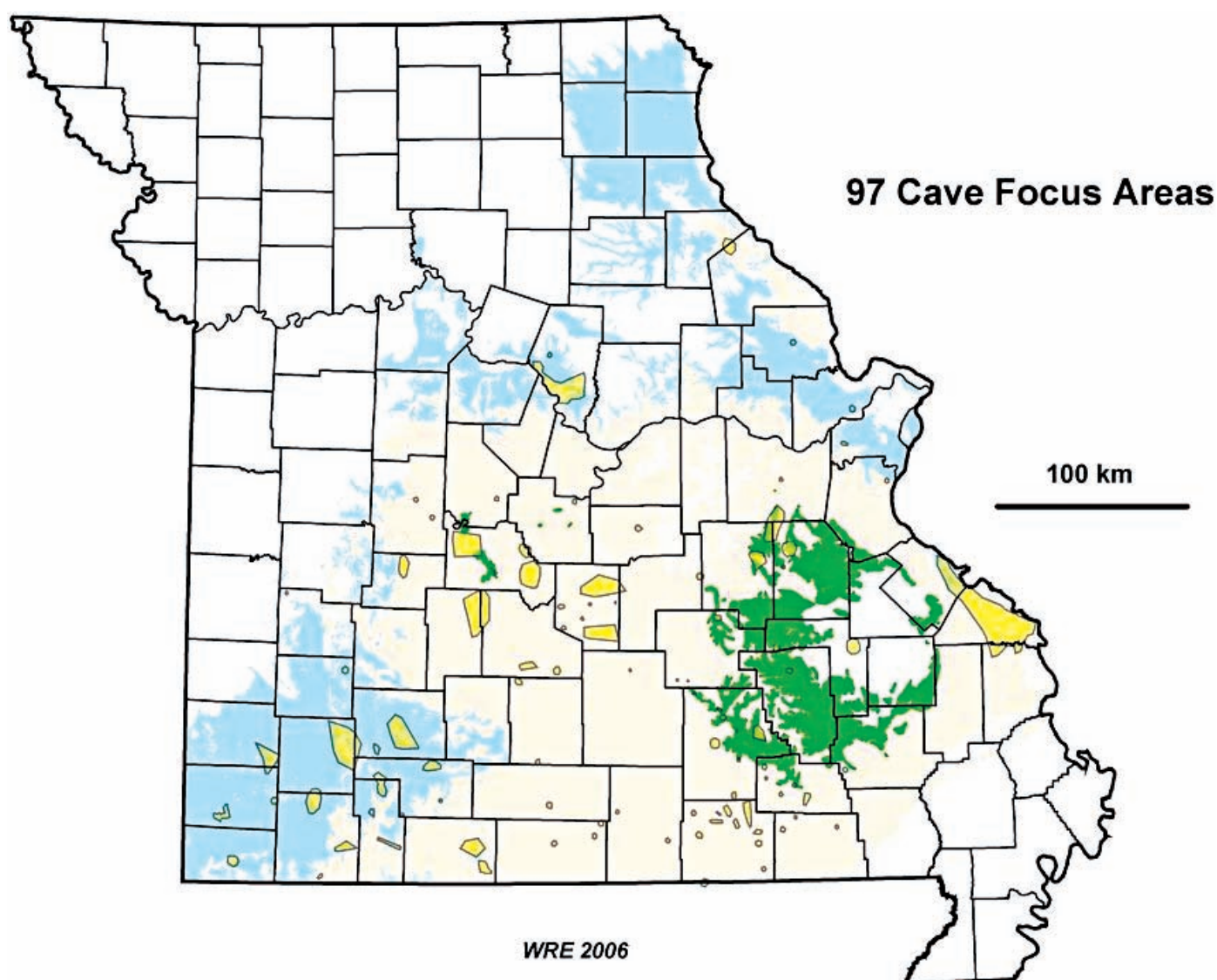


Figure 16. Ninety-seven Cave Focus Areas comprising high biodiversity caves, important bat and cavefish caves, and first magnitude springs.

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 $>2.83 \text{ m}^3 \text{ s}^{-1}$ ($100 \text{ ft}^3 \text{ s}^{-1}$). The latter springs often contain

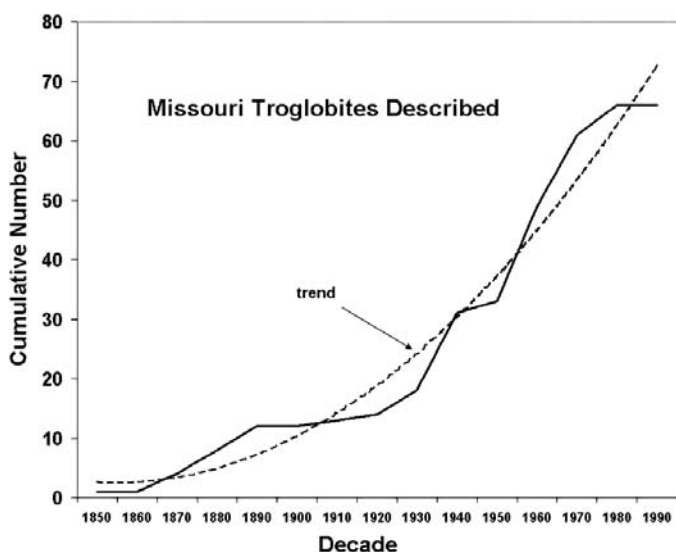


Figure 17. The rate of description of new trogllobitic species from Missouri, with fitted polynomial curve.

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

DISCUSSION AND CONCLUSIONS

High trogllobite 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 trogllobitic beetle fauna that is common in the eastern United States. Until recently the only trechine 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 trogllobitic 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 raphidopodid 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 (*Hadenoeus* and *Ceuthophilus*), where there are many trogllobitic and troglophilic carabid beetles, such as *Rhadine*, *Pseudanophthalmus*, and *Neaphaenops* preying on cricket eggs (Lavoie et al., 2007).

Missouri raphidophorids 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 trogllobites 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 trogllobitic species for the United States. Culver et al. (1999, 2003) analyzed regional patterns of trogllobites, 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 trogllobites, 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 trogllobitic 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 19th 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.

Additional 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).

ACKNOWLEDGMENTS

Support for this study came from the Missouri Department of Conservation, Natural History and Resource Science divisions. I am grateful to my research partners in the CLD, David C. Ashley, Richard L. Clawson, Scott House, Lawrence Ireland, James E. Kaufmann, Steven Samoray, Michael E. Slay and Michael J. Sutton, who contributed thousands of observations and specimens to the shared database. I want to specifically thank Jim Rathert for the

photograph that appears in Figure 4 and David Ashley for the photograph that appears in Figure 7. Dr. Frederick Hartwig is especially acknowledged for his generous support of cave protection, as are conservationist landowners Cathy and Tom Aley, Judy and LesTurilli, and others. I thank the Missouri Caves & Karst Conservancy, whose members participated in the Missouri Cave Life Survey of 2001–2002, and the MVOR (Mississippi Valley Ozark Region), National Speleological Society, who assisted in cave restoration. I thank the many biologists, cavers, students and volunteers who contributed field work, observations, taxonomic identifications and labor while studying cave life, building cave gates and restoring caves; this can only be a partial list: Cathy Aley, Tom Aley, Sybil Amelon, Hal Baker, Thomas C. Barr Jr., Jonathan Beard, Jeff Briggler, Leonard Butts, Roxie Campbell, Stephanie Clark, Kenneth Christiansen, James Cokendolpher, Bob Currie, Katie Derr, Jeff Dierking, Dan Drees, Jody Eberly, Ulrike Englisch, Dennis Figg, Anna Ford, Gene Gardner, Sara Gardner, Bob Gillespie, G.O. Graening, Sue Hagan, Paul Hauck, Kevin Hedgpeth, A.J. Hendershott, Joe Hobbs, John R. Holsinger, Peggy Horner, Mike Hubbard, Paul Johnson, David Kampwerth, Jim Kennedy, Stefan Koenemann, Janeen Laatsch, Steve Laval, Bob Lerch, Julian J. Lewis (special thanks for editorial review), Kenneth Lister, Kim Livengood, Brian Loges, Randy Long, Paul McKenzie, Jean Mayer, Richard Meyers, Mark McGimsey, Paul McKenzie, Tom Meister, Philip Moss, Ron Oesch, Steve Paes, Justin Pepper, Brad Pobst, Barry Rabe, Joseph Reznik, Rhonda Rimer, Melissa Shiver Scheperle, Scott Schulte, Mike Skinner, Tim Snell, Steve Taylor, Rick Thom, Gayle A. Unruh and David Urich.

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, Troglotic millipeds in Missouri: Missouri Speleology, Missouri Speleological Survey, v. 2, p. 60–65.
- Christiansen, K.A., 1964, A revision of the Nearctic 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., Encyclopedia 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/troglist.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 *Ammicola 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 Contributions 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 myotone 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 species 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 *Trigenotyia* 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.