KARST CONSERVATION IN THE OZARKS: FORTY YEARS AT TUMBLING CREEK CAVE

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Abstract

In this paper we detail nearly 40 years of scientific work and land management in and around Tumbling Creek Cave, Missouri. Tumbling Creek Cave is a famous educational and research cave on a rural property called the "Ozark Underground Laboratory." Tumbling Creek Cave has the highest cave biodiversity west of the Mississippi River, with about 112 species, including 12 troglobites and three endangered species: gray bats, Indiana bats and Tumbling Creek cavesnail. The cavesnail began declining in the 1990s, which prompted more intensive work towards land restoration and recovery of cavesnails and gray bats. The gray bat population has increased again, but the cavesnail will require more time and effort to recover. Land and cave remediation work have taught us many lessons that should be useful to others who manage large caves with rich resources.

Introduction

Tumbling Creek Cave, in Taney County, Missouri, has many interesting and valuable resources (Figure 1). A 1,032-hectare (2,550-acre) tract in southern Missouri karst serves as the home of the Ozark Underground Laboratory, established in 1966 and operated by Tom and Cathy Aley and their staff of six. Ozark Underground Laboratory conducts water tracing studies and consults on cave and karst problems in many locations. The cave's catchment area is 2,349 hectares (5,804 acres). The nonprofit Tumbling Creek Cave Foundation now owns 106 hectares (263 acres) around the natural entrance, to continue protection of the cave into the future.

Tumbling Creek Cave (Figure 1) is a famous educational and research cave and a National Natural Landmark (Aley and Thomson 1971, Elliott *et al*. 2005) Tumbling Creek Cave has the highest recorded biodiversity of any American cave west of the Mississippi River, rivaled only by Tooth Cave and Stovepipe Cave in Austin, Texas. Currently 112 species are listed in the Missouri Cave Life Database from Tumbling Creek Cave, including 12 species of troglobites (Table 1, Figure 2,4). Tumbling Creek Cave has appeared in a National Geographic special, other TV programs, news and scientific articles. The cave harbors three endangered species: gray bats (*Myotis grisescens*), Indiana bats (*M. sodalis*) and the Tumbling Creek cavesnail (*Antrobia culveri*, Figure 4). The latter is nearly extinct. Scientists have studied this cave in cooperation with the Aleys for nearly 40 years. The Aleys lead low-impact educational tours of the epikarst and the attractive cave for college and professional groups. Tumbling Creek Cave is protected and only light agriculture is practiced on the land.

High Biodiversity

Tumbling Creek Cave's biodiversity is mea-

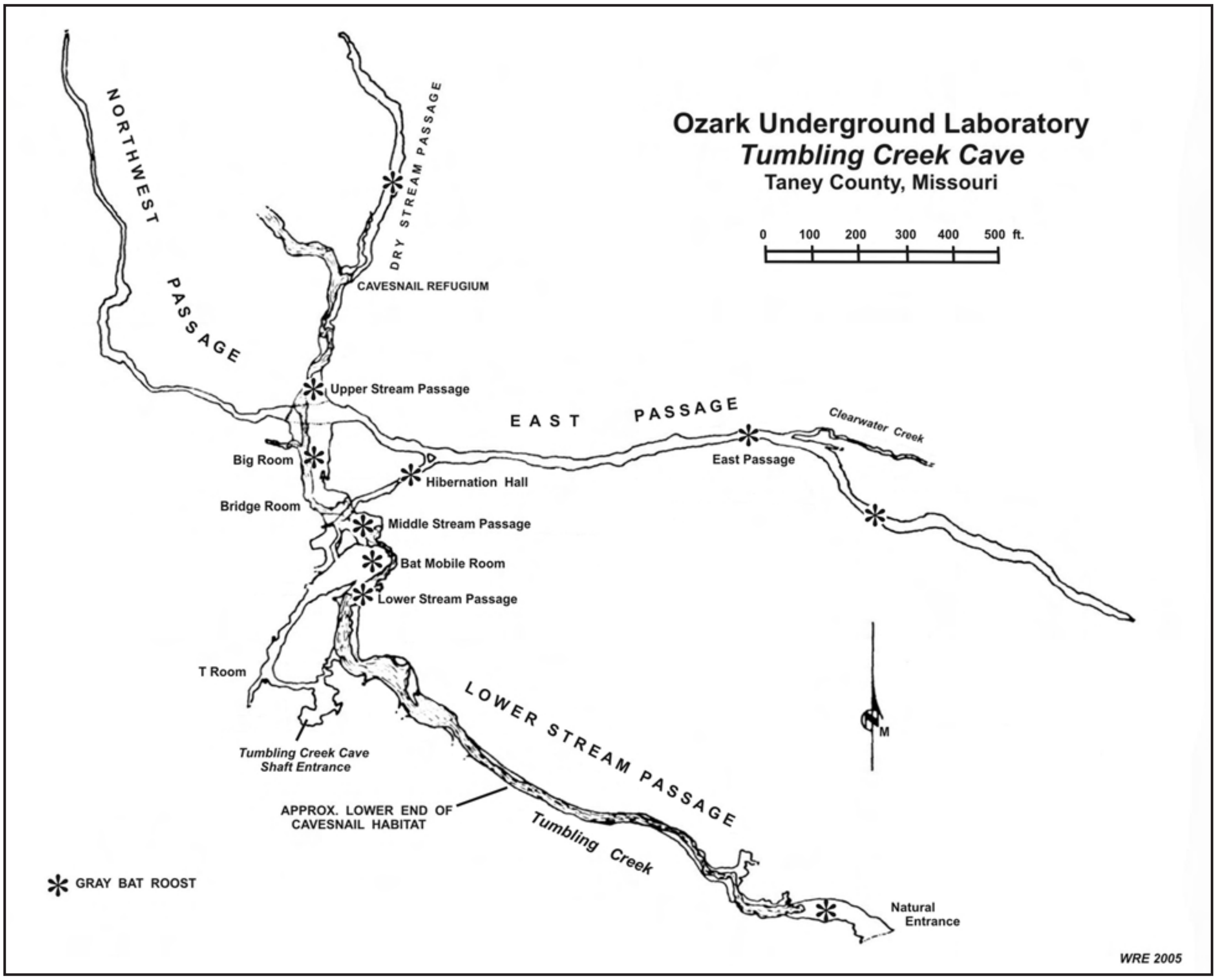

Figure 1. Map of Tumbling Creek Cave showing the extent of the cavesnail's range and major gray bat roosts.

sured not only in terms of its species richness, but in the rarity of its troglobites. Elliott has developed a biodiversity index for Missouri caves that accounts for the number of species, number of troglobites, and how endemic or rare those troglobites are (Elliott and Ashley 2005, Elliott 2006b). Some are unique to Tumbling Creek Cave, such as the cavesnail, a new millipede named after the Aleys, and a new isopod named after Dr David C. Ashley, biology professor at Missouri Western State University (Table 1).

Figure 2. The Grotto salamander, commonly seen in Tumbling Creek Cave, is the trademark troglobite of the Ozark Region. Formerly known as Typhlotriton spelaeus, *the species is now* Eurycea spelaea *(see Bonnett and Chippindale 2004).*

Antrobia culveri	Tumbling Creek cavesnail
Arrhopalites clarus	cave springtail
Brackenridgia ashleyi	trichoniscid isopod
Caecidotea antricola	Antricola cave isopod
Causeyella dendropus	Causeyella cave millipede
Chaetaspis aleyorum	Aleys' cave millipede
Eurycea spelaea	Grotto salamander
*Islandiana sp.**	cave spider
*Phalangodes flavescens**	harvestman

Spelobia tenebrarum	Cave dung fly
Stygobromus onondagaensis	Onondaga cave amphipod
Stygobromus ozarkensis	Ozark cave amphipod

*Table 1. About 10% of Tumbling Creek Cave's species are troglobites Species in bold are unique to this cave, while two marked with an * may be troglophiles, which are less cave-adapted.*

Besides its biological resources, Tumbling Creek Cave is an attractive cave with a perennial stream, called "Tumbling Creek" for its polished chert pebbles similar to ones produced in a rock polishing tumbler. The Aleys lead occasional educational tours for college and professional groups. Each group gets an introduction to karst on the surface, views sinkholes, then enters the artificial shaft entrance, which has two airlock doors to keep the cave from drying out. The visitors bring their own lights and follow a rudimentary trail. The cave has been disturbed very little by this educational use.

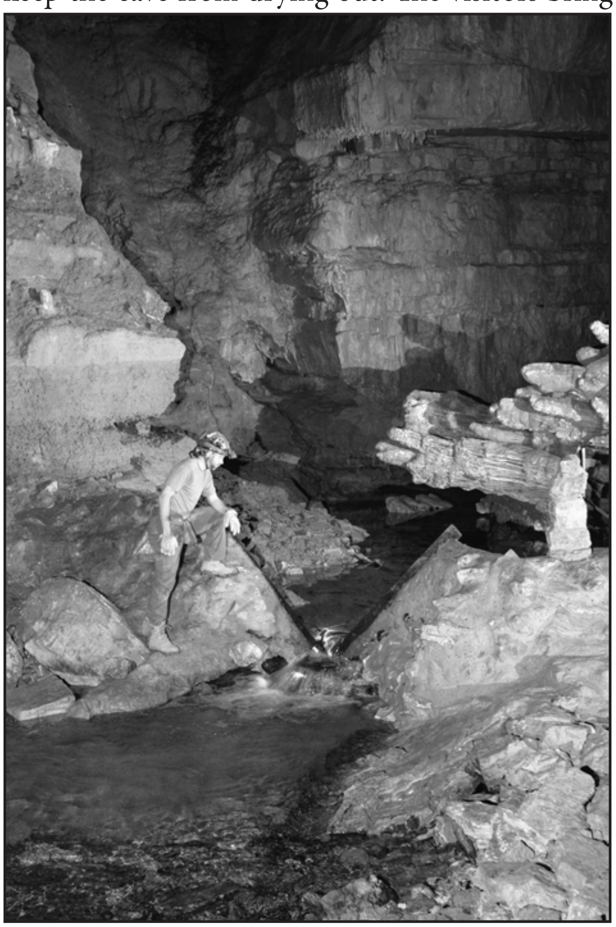

Figure 3. Steve Samoray at the weir in the Big Room, Tumbling Creek Cave, Missouri. This structure is used to visually gauge stream flow. Sensors in the pool beyond the weir register water quality paramaters to a data logger.

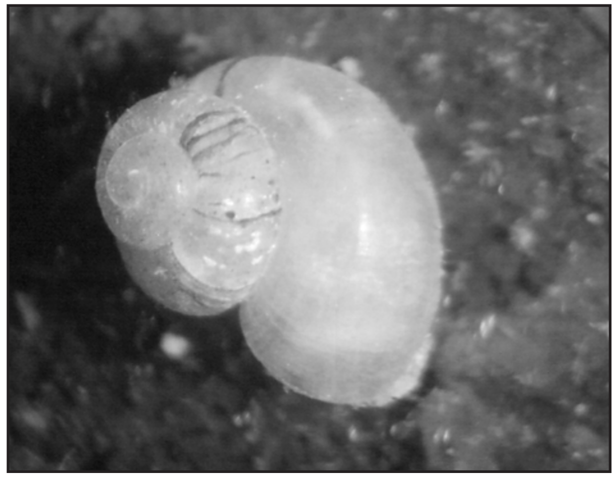

Figure 4. The Tumbling Creek cavesnail, Antrobia culveri *(by David C. Ashley)*

Review of Studies

Ozark Underground Laboratory has sponsored many studies of the cave and its life. The Aleys did extensive dye tracing to delineate the recharge area of the cave, and they studied groundwater infiltration rates to the cave. A state-of-the-art data logging system, designed by Ralph Ewers and Peter Idstein, is collecting water quality data from the cave stream. The Aleys also studied the potential long-term impacts of using bleach to control plant growth in show caves and natural alpha radiation concentrations on behalf of the National Caves Association. Other projects have included extensive studies of Tumbling Creek Cave's cavesnail and stream fauna by David Ashley (2003). Several biologists have estimated bat numbers since 1964, but the most detailed work has been since 2004 (Elliott *et al.* 2006c).

Four graduate theses were based on studies at Tumbling Creek Cave. Fair (1974) wrote a PhD dissertation on variations in water quality and quantity in stalactite drippage. Martin (1980) wrote a master's thesis on the arthropods of guano piles, greatly increasing the size of the fauna list. Fletcher (1982) wrote a thesis on the microbial succession on guano piles. Neill (2003) prepared a thesis on the effects of land use on Tumbling Creek Cave.

Figure 5. This neighboring farm was cleared and converted to little more than a cattle feedlot.

Recovery of the Cavesnail

Even though Tumbling Creek Cave is appreciated and protected well, something unexpected happened in recent years. In the 1990s a cattle operation was developed on a nearby farm (Figure 5), resulting in overgrazing and forest clearing, which loaded the groundwater with sediments. The cave has no open swallowhole upstream, but the sediments worked down through losing streams into the cave. Muck visibly built up in the cave stream, which is normally floored with cobbles. Some areas are so mucky now that one cannot pull up rocks that used to be loose. Now the tiny cavesnail, *Antrobia culveri* (Figure 4), is nearly extinct. In 1973, 15,118 cavesnails were estimated to live in the stream (Greenlee 1974), but a decline became noticeable by 1991. Population estimates of the cavesnails by Dr Ashley and Dr Paul McKenzie, United States Fish and Wildlife Service, have documented the decline since 1996 (Ashley 2003, Department of the Interior 2001, 2003, Figures 6 and 7).

The Tumbling Creek Cavesnail Working Group was founded by Paul McKenzie to bring together experts from the region (Department of the Interior 2001, 2003). We are studying the cave with other scientists to determine what happened. Sediments probably hurt the cavesnail and other life, but we also are checking for chemical contaminants with Semi-permeable Membrane Devices and Polar Organic Chemical Interactive Samplers that mimic live organisms in absorbing waterborne chemicals. Dr John Besser of the U.S. Geological Survey is analyzing sediment samples for heavy metals and organic contaminants.

Dr Paul Johnson, formerly of the Tennessee Aquarium Research Institute and now of the Alabama Aquatic Biodiversity Center, is an expert in propagating aquatic snails. Johnson is culturing two surrogate species of hydrobiid snails in his laboratory. If the methods are successful, and if enough *Antrobia culveri* can be

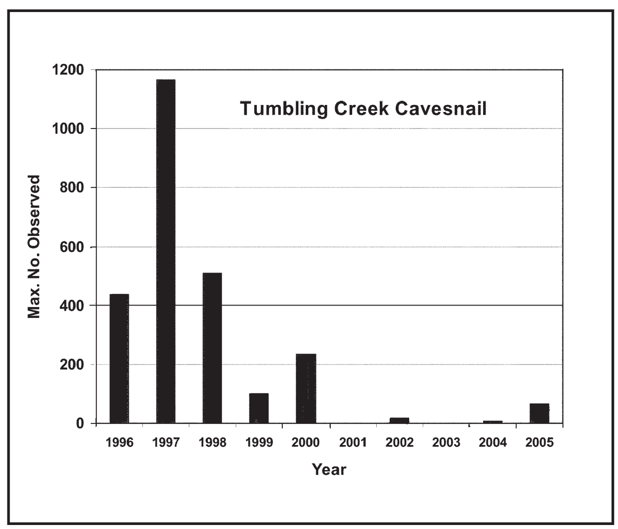

Figure 6. Bar graph showing the maximum number of Tumbling Creek cavesnails observed or estimated since estimates were begun in 1996 by Ashley and McKenzie. Greenlee had estimated 15,118 cavesnails in 1973.

Figure 7. Cavesnail census using a random quadrat method, August 31, 2001. Left to right are David Ashley, Paul McKenzie, and Andy Roberts.

found again, it may be possible to propagate them in a laboratory in Tumbling Creek Cave, and then put them back into a repaired Tumbling Creek. Funding has been provided by the U.S. Fish and Wildlife Service to set up a small culture system in the cave and construct a culture rack in a laboratory in Alabama. Ceramic tiles will be placed in Tumbling Creek to provide substitute reproductive habitat for *Antrobia culveri*. Dr Johnson will develop a basic culture and in-stream propagation plan for the cavesnails (Paul Johnson and Paul McKenzie, pers comm).

Land Management and Restoration

Light agriculture can be compatible with a karst system, and the Aleys do some cattle raising and hay cropping on parts of their land. The Missouri Department of Conservation and the U.S. Fish and Wildlife Service are assisting the Aleys, who bought the nearby abused property with their own funds. With cost-share funds they replanted 70,000 trees to restore the land. They have overseen the planting of native species, such as black oak, northern red oak, white oak, black gum, black walnut, green ash, dogwood, redbud, sycamore, and a few short-leaf pines (Figure. 8). They expect that sassafras, hickories, and persimmons will re-establish naturally from the surrounding areas.

Another cost-share project with the National Park Service is helping to identify and characterize old dumps in the recharge area for the cave. A total of 23 dumps have been discovered to date, and work is underway to remove the trash. To date about 65 tons of scrap steel have been shipped to a recycling facility and another 40 tons awaits shipment, but the work is not yet finished. These efforts

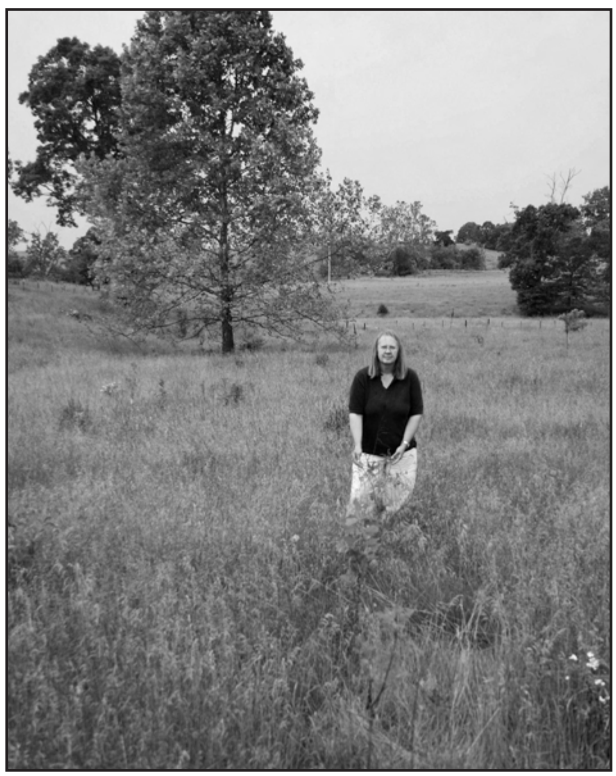

Figure 8. Cathy Aley shows one of 70,000 young trees planted in an effort to restore the abused land near the Ozark Underground Laboratory.

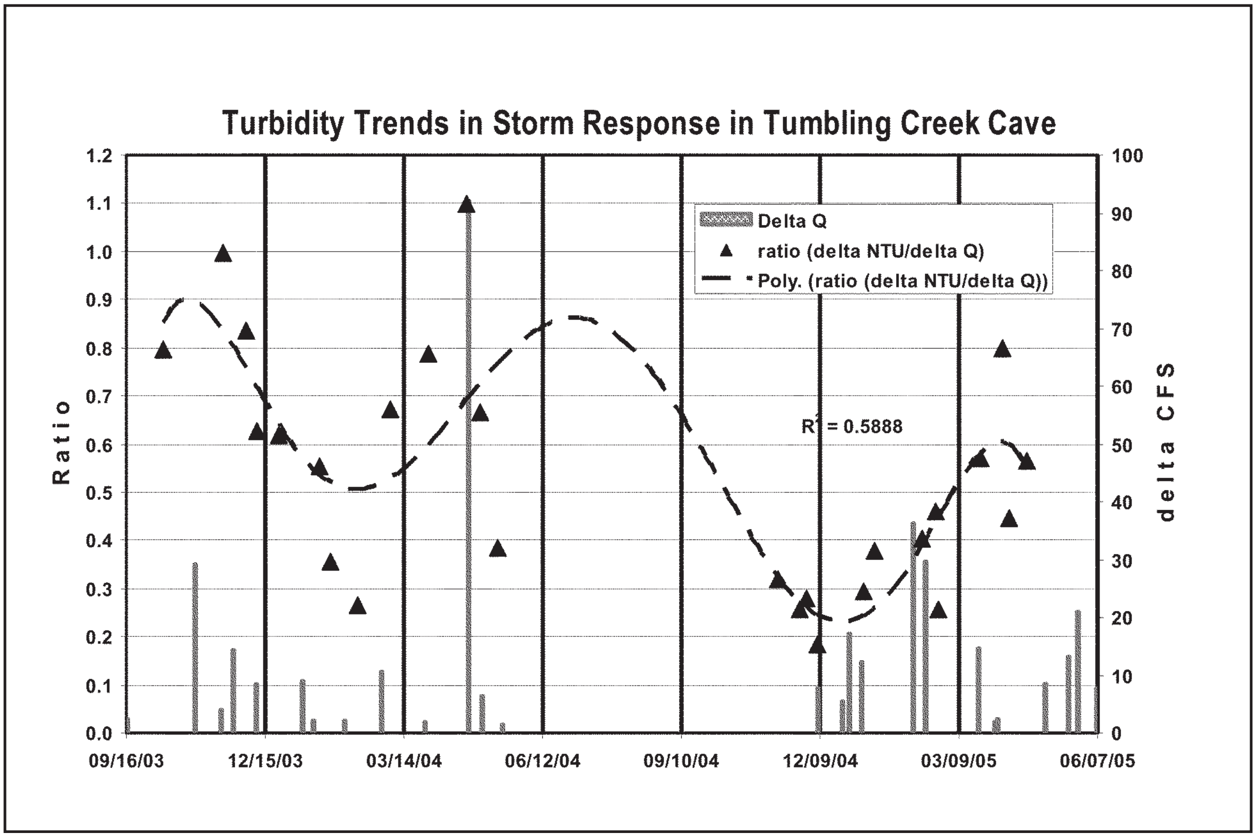

Figure 9. Turbidity trends in storm response in Tumbling Creek, using the delta values for both turbidity and discharge, as measured with in-stream sensors and a data logger. There are two apparent trends: more intense storms and turbidity in the summer and a trend towards lower ratios of turbidity to discharge from 2003 to 2004. These trends are based on few data points and more work is needed.

may already be paying off. Figure 9 depicts a possible decline in turbidity in Tumbling Creek, as measured with in-stream sensors and a data logger.

In 2005 major improvements to the Ozark Underground Laboratory sewage systems were constructed. The new system collects all sewage effluent generated on-site and transports it through a combination of pressure and gravity systems to a large disposal field located outside of the recharge area for the cave. Prior to construction of the field two dye traces were conducted that demonstrated that the new field area did not contribute water to any of the springs associated with the cave. Most of the funding for the project was provided as a demonstration project by the U.S. Fish and Wildlife Service through the Arkansas Chapter of The Nature Conservancy.

Recovery of the Gray Bat

Tumbling Creek Cave provides habitat for eight species of bats. The Indiana bat (*Myotis sodalis*) has been reported in Tumbling Creek Cave on a limited number of occasions, though early anecdotal accounts indicate that the bat used the cave as a hibernation site in the past. The latest observation was in February 2005, more than ten years since the previous report. With the new cave gate (discussed below), fewer disturbances may lead to more frequent winter use of the cave by these endangered bats.

The gray bat (*Myotis grisescens*) forms large colonies in caves both in the summer and winter, which makes cave protection for this species especially important. The Missouri Department of Conservation's recovery program for gray bats involves many key caves. Tumbling Creek Cave's gray bats have been studied extensively because of their large numbers and the importance of the nutrient input provided by their guano (possibly 95% of the energy input to this cave is from bat guano). Indeed, gray bats may be a keystone species for many

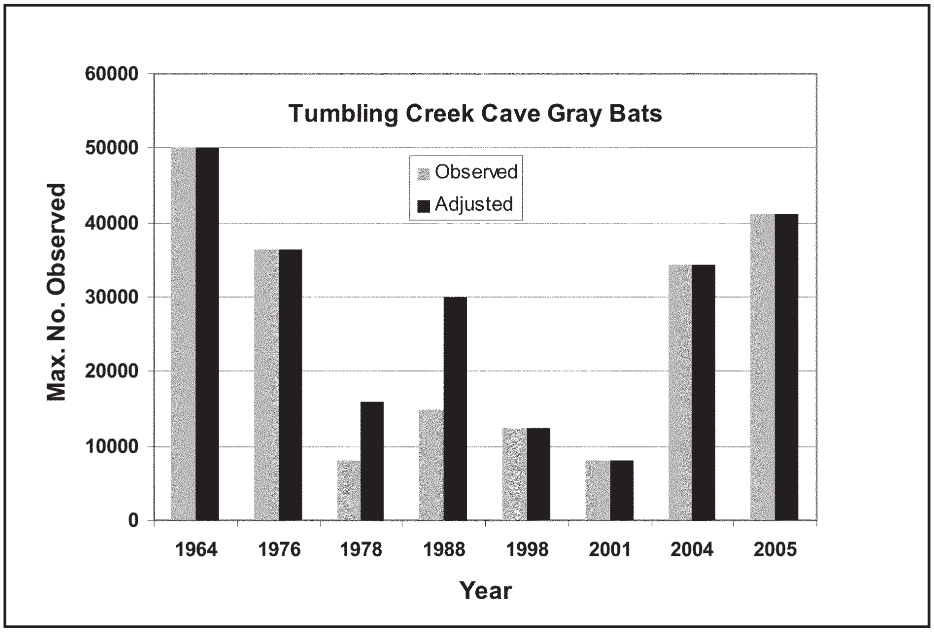

Figure 10. Bar graph showing the maximum number of gray bats observed in Tumbling Creek Cave in mid-summer, after the young are volant. The estimates for 1978 and 1988 were in May or June, and and have been adjusted by a factor of two to approximate the number that would have been observed in July–August.

eastern cave ecosystems (Elliott and Ashley 2005, Elliott 2006a).

The earliest known gray bat population estimate at Tumbling Creek Cave was 50,000 by Richard Meyers in 1964, who also observed 135,000 transient grays in September 1969. In 1976 there were 36,000. Over the next 20 years the numbers varied, but generally did not exceed 15,000. The last emergence count before the new gate was built was about 12,000 in 1998 (Figure 10).

Explaining this decline of Tumbling Creek Cave's gray bats is difficult. Elliott *et al.* (2005) think that the contributing causes of the decline might have been (1) grays declined throughout their range and locally over several decades, (2) an internal cave gate may have hindered movements of the bats, (3) disturbance by intruders via the natural entrance (not then owned and protected by the Aleys), and (4) disturbance and decline at the bat's hibernation sites some distance away.

Samoray and Gardner monitored the gray bats from May to October 2004. They used internal visual surveys, guano estimates, and near-infrared video counts of emergences, the "Missouri Department of Conservation Method" (Elliott *et al.* 2006c). This is by far the most intense monitoring effort of this population, and it consequently revealed several interesting aspects of this species' use of Tumbling Creek Cave.

We found large fluctuations in the number of bats roosting in the cave throughout the summers of 2004 and 2005. Emergence counts ranged from a low of about 19,000 in May 2004 to a high of about 34,000 in August 2004. In May 2005 about 29,000 bats emerged, and in August 2005, about 41,000 emerged. This indicates a net increase of 7,000–10,000 in one year, and the gray bats are approaching the population size observed in 1964.

In 2004, the bats had more erratic emergence patterns during the first two months of the study when compared to the final few months, possibly a result of the new gate. Internal surveys of the cave and the fresh guano (as measured with guano-collecting plates on wooden stakes, Figure. 11), revealed frequent movements among several roosts in the cave; a rare observation for this species, which has very strict temperature and humidity preferences.

This in-cave movement prompted Samoray, Gardner, Elliott, and Kaufmann to study the cave's internal temperature variation (Elliott *et al.* 2005, Samoray *et al.* in press). In March, 2005, we installed Onset® Hobo Pro® temperature data loggers on the roost ceilings in the Bat Mobile Room, East Passage, Lower Stream Passage, and Hibernation Hall and we continued monitoring guano plates. When the bats roosted near the data loggers the ambient temperature increased from about 13.5–14.5°C up to 24–30°. The temperature peaks did not overlap, and with the guano plates they indicated that the bats switched roosts at least five times from April to September 2005 (Figures 1 and 12). In the meantime there was minimal human disturbance of the cave. We hope to answer several questions

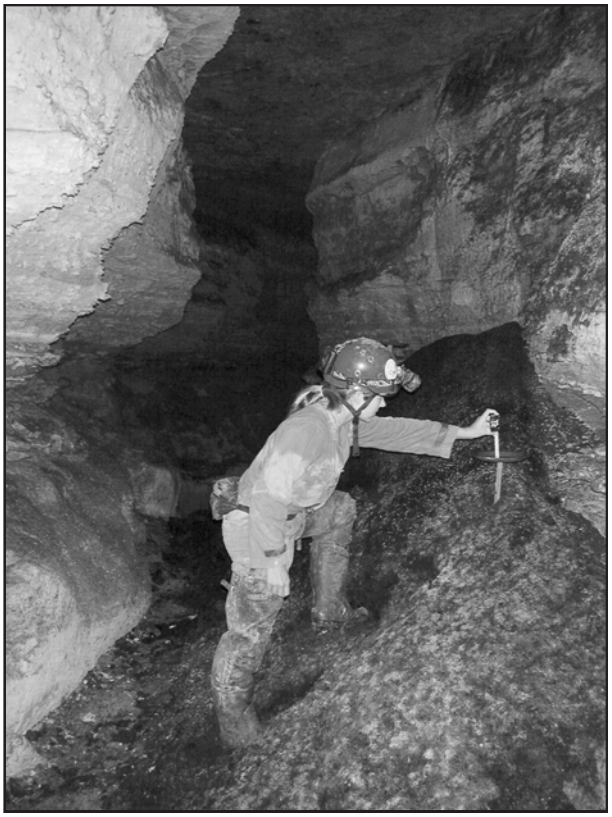

Figure 11. Sara Gardner checks guano accumulated on a staked plate.

about the cave temperatures and the gray bats' use of the cave. Ultimately we hope to predict where the bats may be located at certain times of the year, allowing more cautious visitation to specific areas of the cave.

Cave Protection

A team of 18 conservationists built the world's largest chute gate on the natural entrance in 2004 (Figure 13). A chute gate's function is to keep intruders out of the cave to protect the bats and the other cave resources; the bats fly in and out of the chute. We do not gate a cave for one species, but for an entire cave community. A chute gate is a type developed by Roy Powers of the American Cave Conservation Association since 1996 in Missouri and Tennessee. It allows us to construct gates on some gray bat cave entrances where we could not do so before. A chute gate is used for low, wide entrances, where there is not enough height to build the usual half gate, or flyover gate, for a maternal colony of gray bats. In most of its range, gray bat maternal colonies do not tolerate a full gate that completely covers the cave passage, even when it is properly spaced for bats. However, we can construct a rect-

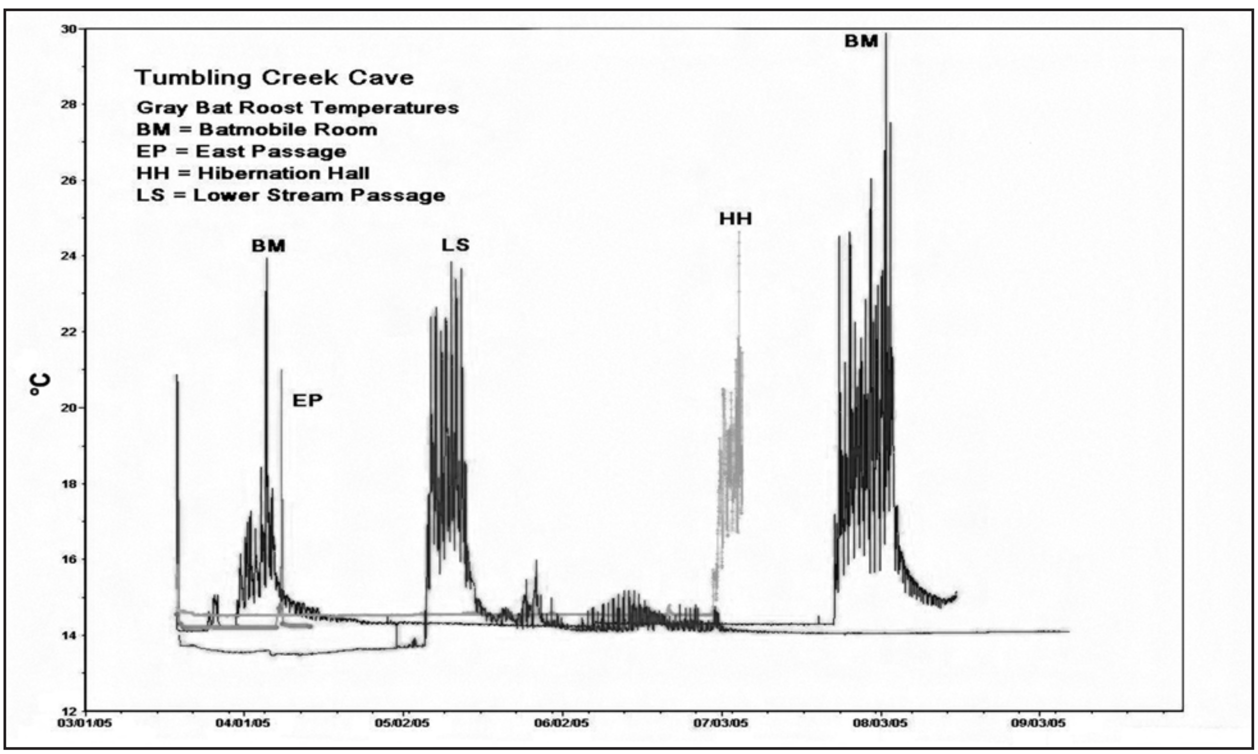

Figure 12. Ambient temperatures measured with Onset® Hobo Pro® data loggers in five gray bat roosts in Tumbling Creek Cave, March–September, 2005. The bats switched roosts at least five times during this period.

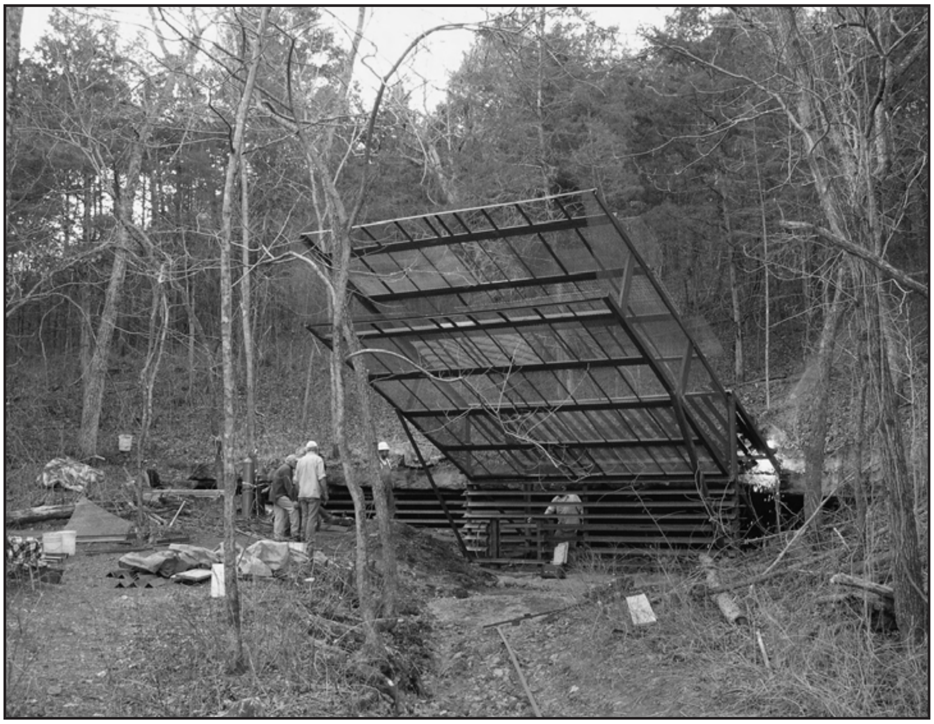

Figure 13. Construction of the Tumbling Creek Cave chute gate, March 2004. Roy Powers and Tom Aley, lower left. The open chute allows pregnant gray bats to use the entrance freely, but excudes human intruders. Bats have increased since the gate was built.

angular metal chute, sheathed in expanded metal (mesh), that angles up from the vertical wall of the gate, high enough to be out of the reach of most intruders.

We built the chute gate in March and April 2004 under the direction of Roy Powers and Jim Kaufmann (Caves & Karst, Inc). Staff from Ozark Underground Laboratory, Missouri Department of Conservation, and some volunteers constructed the 9-ton gate. The Aleys provided food and lodging, saving us travel in this remote part of the Ozarks. The cost of the gate was about $25,000, paid from a Missouri Department of Conservation "State Wildlife Grant." The price does not include in-kind services and volunteer time.

Kenny Sherrill fabricated the strong locking door on the gate. Jim Kaufmann returned several times to complete the welding and add strengthening members to the gate. The gate withstood about 4 m^3/sec. (150 ft^3/sec.) of water outflow in May 2004, a 25-year record. Meanwhile, the old internal gate was removed to expand the flyway for the bats. We observed returning gray bats using the chute gate before it was even finished, a good sign. Our emergence counts from infrared video indicated a large increase in the colony over the 1998 visual count, even before the full maternity season. In August 2005 the population increased further to a peak of 41,153. The gate appears to be a success.

The Missouri Department of Conservation is increasing its efforts to help Missouri cave owners and provide public education about caves and karst. The Department is working with Ozark Underground Laboratory, several government agencies, and the Mark Twain School to replace a sewage lagoon that presently loses about 88% of its contents into the groundwater system that feeds Tumbling Creek Cave. A modern septic system will be installed and the students will learn about karst, groundwater, and caves. Missouri Department of Conservation's new "Cave Trunk" for teachers and conservationists will be available to the school. It contains books, curriculum guides, videos, posters, bat models, and a three-dimensional karst groundwater model that illustrates how interconnected cave systems and the surface of the land can be.

Discussion and Lessons Learned

It is troubling that one of the most protected private caves in the Ozarks, in a rural area with little industry or row crops, still developed such ecological problems. However, the following lessons learned and the methods we have developed will be useful to others restoring cave communities or living on karst.

- Noticeable changes can occur in 2–40 years in a cave and on the land.

- Baseline physical and biological data are extremely important to document trends.
- Keep a good logbook inside the entrance if it is secure. A record of visitors, dates, destinations, work, and observations may be invaluable later.
- Multiple, overlapping studies may reinforce or provide interesting correlations.
- A cave in a remote rural setting may be impacted by poor land use on other property in the cave's recharge area.
- Stream and bat communities are dynamic.
- There are many sources of funding and help.

Acknowledgments

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