GRAY AND INDIANA BAT POPULATION TRENDS IN MISSOURI

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Abstract

Since 1975 the Missouri Department of Conservation (MDC) has systematically censused the endangered bats, *Myotis sodalis* (Indiana bat) and *M. grisescens* (Gray bat). A recent statewide reestimate of about 15,812 indicates that Indiana bats declined by 95% since 1979. Pilot Knob Mine, a National Wildlife Refuge, had 80,000-100,000 Indiana bats in 1958, but only 1,678 were found there in February 2008, a 98% decline. At other sites they declined or abandoned one cave for another, seeking protection and more optimal temperatures. Their decline probably was caused by multiple factors, including human disturbance, the partial collapse of Pilot Knob Mine in 1979, warming of hibernacula, and possibly by pesticides and loss of summer habitat in northern Missouri. White Nose Syndrome has not been found in Missouri.

Missouri's Gray bat population declined, but it is now stable or increasing in some protected caves. Many other caves remain abandoned for various reasons. At bottom, Gray bats lost at least 67% of their maximum past population, as measured in 56 important caves, and 53% of the caves were abandoned. The maternity population of Gray bats is currently estimated at approximately 635,000, but it may have been >1,700,000 in the past. The three largest Gray bat hibernacula were censused in 2006 and totalled 773,850. The Gray bat is a key species in Missouri ecosystems, providing nutrient input to cave animal communities and significant control of night-flying insects, some of which are agricultural or health pests. Although there has been a general increase, many maternity colonies are still threatened by intruders and vandals, so further conservation work is needed.

Key words: *Myotis sodalis*, Indiana bat, *Myotis grisescens,* Gray bat, population trends, disturbance of bats, cave temperatures, mine collapse, pesticides, cave gates, White Nose Syndrome, Missouri, Onyx Cave/Crawford County, Bear Cave/Franklin, Copper Hollow Sinkhole, Brooks Cave, Great Spirit Cave, Ryden Cave, Bat Cave/Shannon, Martin Cave, Great Scott Cave, Scotia Hollow Cave, Pilot Knob Mine, Devils Icebox Cave/Boone, Rocheport Cave, Coffin Cave, Mary Lawson Cave, Slaven Cave, Cookstove Cave, Hamilton Cave, Powder Mill Creek Cave, McDowell Cave, Mary Lawson Cave, Toby Cave, Moles Cave, Smittle Cave, Marvel Cave, Mose Prater Cave, Coffin Cave, Bat Cave #1/Franklin, Blackwell Cave, Grandpa Chippley Cave, Lower Burnt Mill Cave, Tumbling Creek Cave

Introduction and Literature Review

In this paper I focus on the status of the endangered bats, *Myotis sodalis* (Indiana bat) and *M. grisescens* (Gray bat) in "Missouri," by which I mean the Missouri region, insofar as we must be censusing some bats migrating to and from neighboring states. We know from previous work that these

species migrate fairly long distances seasonally, and among different hibernacula, transient, bachelor, and maternity sites.

Caves provide important habitat to ten Missouri bat species and three other species have been found in caves. Colonies of Grays and Indianas hibernate in "cold air trap" caves, which have descending floors, deep pits, or large entrances that accept large amounts of winter air. Maternity colonies of Grays prefer warm caves with high ceilings to raise their young in spring/summer. Gray bats roost exclusively in various caves in different seasons for maternity, hibernation, bachelor, and transient colonies. Indiana bats primarily hibernate in caves and mines, are transient via other caves, then females leave caves for riparian forests, particularly snags, to raise their young during the summer.

To census these interesting animals is to track a moving target, literally and figuratively. The colonies are dynamic, even fluctuating significantly night to night at some Gray bat caves in late summer.

Richard F. Myers (1964) pioneered the study of myotine bats in Missouri. On February 22, 1958, Myers visited Pilot Knob Mine, Iron County, with three local men to photograph the hibernating Indianas (Figure 1). He visited the abandoned iron mine again on April 11 and December 27, 1958. In December the "Devils Icebox," as the lower mine was called, contained about 80,000 *M. sodalis* by Myers' conservative estimate, based on a density of 2,367 bats/m^2 (220 bats/$ft.^2$). Another photograph appeared to have about 3,229 bats/m^2 (300 bats/$ft.^2$), estimated from the size of a man's hand near the bats and by counting bats inside a frame drawn by Elliott and Kennedy (2008). Myers also estimated at least 35,000 *M. lucifugus* in the mine. Elliott and Kennedy (2008) concurred with the U.S. Fish and Wildlife Service (USFWS) that 100,000 may be a reasonable reestimate for 1958, especially since the upper mine was not visited during Myers' trips, but it is now known to harbor bats. In February, 1958, the interior of the mine appeared to be stable, with old wooden roof supports mostly in place. By December Myers noticed that boulders had shifted, and there had been some rock falls in the entrance area and on the route to the hibernaculum. Myers last visited the mine in March 1960.

In 1975 Richard and Margaret LaVal from the Missouri Department of Conservation (MDC) began harp-trapping estimates of *M. sodalis, M. lucifugus* and *M. septentrionalis* at the lower mine entrance, but they did not enter the mine, owing to its "dangerous" reputation. Richard Clawson

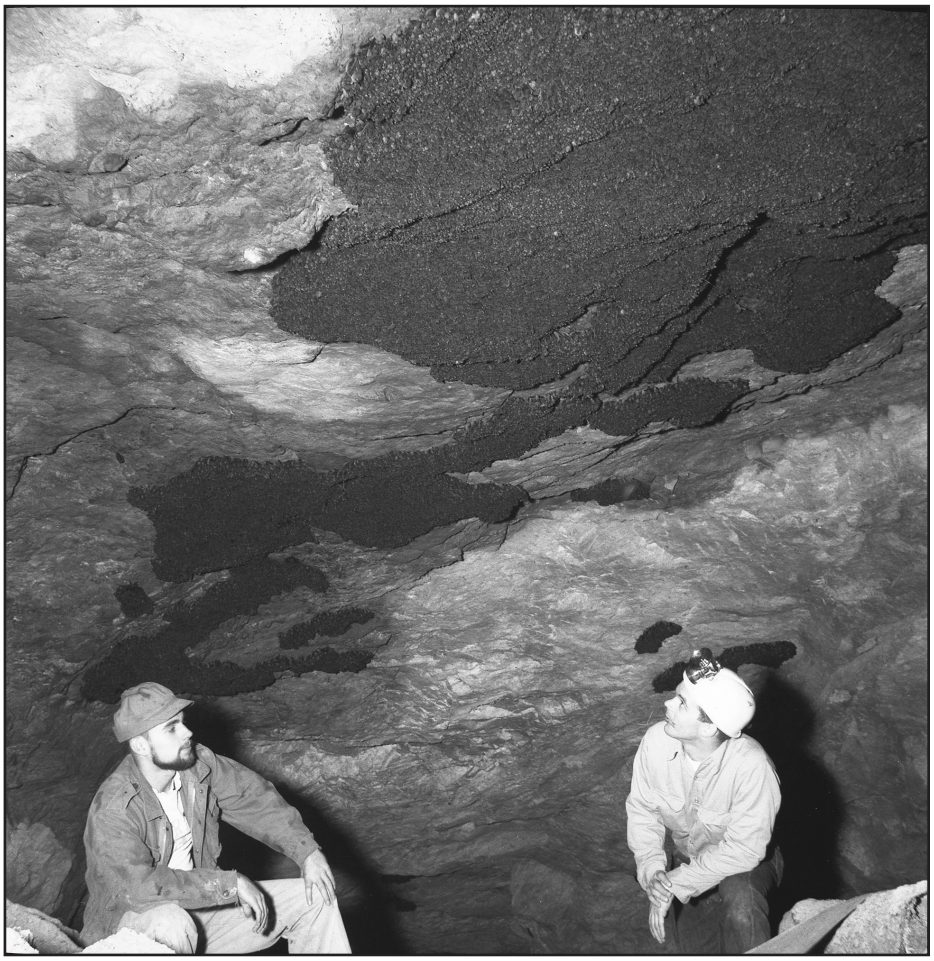

Figure 1 *Hibernating Indiana bats in the lower part of Pilot Knob Mine, February 22, 1958. Photo by Richard F. Meyers.*

soon joined their project, and they continued the effort until 1978 (Clawson and Titus 1988). Trapping usually was done in late September or early October during the fall mating swarm. The great majority of bats captured and released, usually over a two-hour period in two rounds or "bags," were *M. sodalis*, with some *M. lucifugus* (Little brown bat) and *M. septentrionalis* (Northern bat). They were identified to species, most were sexed, and some were weighed and examined in detail.

MDC continued to census cave bats after 1975 (Clawson and Titus 1988, Clawson et al. 1992, McGimsey and Johnson 1994, Clawson 2002, Clawson, Elliott and Burns 2006, Elliott 2005, Elliott 2007, Sasse et al. 2007). 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, but it was not built (Elliott 2007).

On May 25, 1979, at Pilot Knob Mine, LaVal reported that "a colossal collapse has occurred, blocking the two entrances used by bats. Cold air is blowing out of the rocks above the old main exit site, it appears a person could still get in by climbing among newly fallen giant boulders. The higher main entrance that was being used by nearly half the bats earlier this spring appears to be completely blocked. The entire south wall of the 'Devils Icebox' has collapsed, partially filling the icebox ... We suspect foul play, but saw no evidence of same." A federal agent was sent to investigate, but he reported no evidence of violations. After the collapse there were no harp-trapping trips until 1992. Intruders may have affected the bats, but much of the subsequent decline probably was the result of this partial collapse of the lower mine, which may have killed many bats. Furthermore, it probably caused changes in airflow and the availability of habitat (Elliott and Kennedy 2008).

In 1986, a local boy was trapped and injured in the lower mine while exploring with a friend. He was rescued after a two-day ordeal, in which he barely survived and nearly lost his legs. Some called for permanent closure of the mine, but its value as a bat refuge also was publicized. Within a year the U.S. Fish and Wildlife Service received a donation of the mine and 90 acres from the Pilot Knob Ore Co., and the area was fenced (Elliott and Kennedy 2008). In 1992, Clawson and others resumed harp-trapping studies at Pilot Knob Mine, but they did not enter the mine. These studies continued through September 2007.

From 1978 to 1984, Gardner (1986) collected numerous invertebrate specimens from 436 caves and 10 springs, providing important baseline information on subterranean biodiversity. No comprehensive list of Missouri's cave vertebrates has been published, but a 1984 computer printout with a large number of bat observations was contributed by Gardner to the author's Cave Life Database (CLD). The author joined MDC as cave biologist in 1998, and he worked with other researchers to study Missouri's cave life. Bat census and cave protection were important duties of the cave biologist, shared with Clawson. Since 1978 Clawson contributed voluminous census data on bats from 103 caves and three mines in 38 counties, primarily of Grays and Indianas (Elliott 2007). A year-long study of 40 caves was led by MDC and the Missouri Caves and Karst Conservancy, in which common species were recensused 20 years after Gardner recorded them. A possible decline in *Eptesicus fuscus*, Big brown bat, was noted at some caves (Elliott and Ireland 2002).

For spot temperature readings and data logger checks, Clawson and Elliott used digital thermometers, with accuracy ±0.1C°, calibrated in freezing water to measure air and rock temperatures during hibernaculum surveys. In 1998, the author and others installed Hobo® H8 Pro temperature data loggers in seven caves and Pilot Knob Mine for a joint study by Bat Conservation International (BCI) and MDC. The study sites were Great Scott Cave and Scotia Hollow Cave, Washington County, Bat Cave, Shannon County, Pilot Knob Mine, Iron County, Onyx Cave, Crawford County, and Brooks Cave, Great Spirit Cave, and Ryden Cave, Pulaski County (Elliott and Clawson 2001). They obtained weather data from 1975 through 1998 for several Missouri cities from the Department of Soil and Atmospheric Sciences, University of Missouri–Columbia. The data set from Waynesville, Pulaski County, is geographically close to most of the study sites. They examined the secular trend of annual means, extreme lows, and extreme highs.

On February 7, 1999, Jim Kennedy and Sheryl Ducummon of Bat Conservation International (BCI) visited the lower part of Pilot Knob Mine, but found only 303 *M. sodalis.* MDC's harp-trapping results were used to estimate as many as 50,545 Indiana bats in the mine until 2007. This method

was not calibrated against a count in the mine, but against catch rates at Great Scott Cave in the 1970s. Concern about the true number of bats in the mine continued, especially as the harp-trapping results decreased. Elliott and Kennedy (2008) found only 1,678 *M. sodalis* there in February 2008.

Missourians have built at least 67 cave gates, 55 of which were for Grays, Indianas or both. MDC built 22 cave gates on Conservation lands, and they assisted ten other landowners with cave gates. Forty-six caves were gated for Grays, 38 for hibernating Indiana bats, significantly helping endangered and other bats. Two gates were destroyed by flash floods and two were removed because they were not helping bats. In the last 30 years the downward trend in Gray bats was reversed at many caves where the landowner was involved or where MDC helped with signs and appropriate cave gates. However, Indiana bats continue to decrease at most sites, despite good protection of the larger colonies since the 1970s and 1980s.

Materials and Methods

General bat activity can be gauged with mist netting and Anabat detectors, but those methods are not used for censusing. In Missouri various methods have been used to census bats, listed below in generally increasing order of accuracy:

- Harp trap with catch rate calibrated against in-cave count,
- Measurements of guano or ceiling stains, with area times density (Figure 2),
- Roost counts: direct counts, measured area times density, counting virtual rows and columns, or counting from photographs (Figure 3),
- Stopwatch visual exit counts with spreadsheet estimate (Elliott et al. 2006),
- Near-infrared (NIR) videography with statistical counts or thermal infrared (TIR) videography with computer count (Sabol and Hudson 1995, Melton et al. 2005, Elliott et al. 2006).

MDC has used most of the above methods, but most of the data on Gray maternity colonies have been from guano estimates until we began using NIR in 2004. Both methods were used until we were satisfied that they were comparable.

Figure 2 *MDC biologists measure Gray bat guano in Smittle Cave, Wright County, Missouri.*

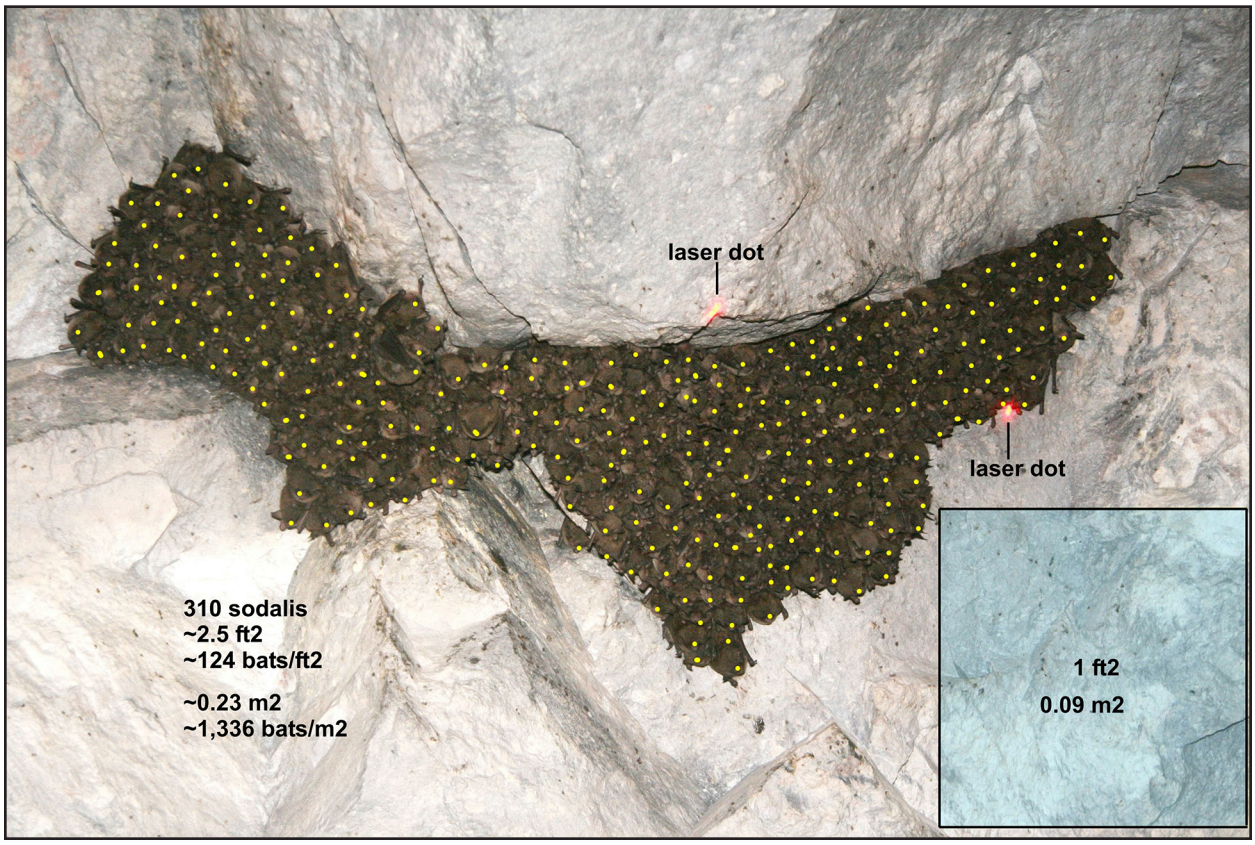

Figure 3 *Pilot Knob Mine, February 25, 2008, view of about 310 Indiana bats. Visual counts were later corrected by adding digital dots on the photos. The two laser dots from a laser caliper are 30.48 cm (1 ft.) apart, yielding about 1,336 bats/m^2 (124 bats/ft.^{2}).*

TIR became available experimentally in 2006, and we used it extensively in the summer of 2008. We may discontinue guano measurements after 2008. Winter visits used roost counts, to which we added high-resolution digital photographs in 2007.

Census data from many sources were entered into the Missouri Natural Heritage Database and the CLD, a Microsoft Access® database. Special queries were made to view and edit the data, export it to Excel® and graph it.

From 1975 to 1977 Indiana bat surveys were done yearly at some sites, but starting in 1979 most were biennial. To examine long-term trends, data from a few dates were moved to the nearest year in the same winter to put all on the same basis, and the 1978 Pilot Knob Mine harp-trap estimate was placed in 1979 for graphing. Five data for Great Spirit in 1981, Scotia Hollow in 1983, Brooks and Ryden in 1989, and Onyx Cave in 2003 were absent, so they were calculated as a mean of the previous two years to fill the cells for graphing. Most of the data for Pilot Knob mine are based on one harp-trap estimate from 1978 and two in-mine counts in 1999 and 2008, the rest were interpolated linearly between these anchor points. However, these estimates do not affect the overall estimate of decline since "1979." Although some hibernaculum surveys began in 1975, I focused on trends since 1979, when more data were available for the 11 major and 8 minor hibernacula. This did not ignore any significant 1975–1979 trends that I could see. I examined the trends for the major and minor sites separately.

Results

Overall results are provided in Table 1, and details are provided in Tables 2-6 and Figures 1-16.

Indiana bats. *M. sodalis* is known from 75 caves and 2 mines, about 1% of the 6,200 known caves in Missouri. Of these, 53 sites are hibernacula and 24 others are used by transients in spring or fall on their way to or from forest habitat, mostly in northern Missouri. The 1979 population was 315,045 as measured at 11 major sites, but it declined to 8,632 at the same 11 sites in 2007, a

Table 1 *Status of Gray bats and Indiana bats in Missouri. MPP is "maximum past population." The recent data are from 2006–2008. The recent hibernating populations were an aggregate of 31 caves.*

	Grays	Indianas
Past population	1,700,000 (MPP)	315,045 (1979)
Maternity caves	49	0
Hibernacula	13	53
Other sites	157	24
Total sites	219	77
Recent maternity colonies	635,000	---
Recent hibernating colonies	784,000	15,812
Percent of past population	37-46%	5%

drop of 97%. Two (18%) of the sites were essentially abandoned. Many additional, minor sites were found in 30 years, so in 2006-2008 there was a total of 15,812 Indianas counted in 31 important sites, but still only 5% of the past, known population.

The overall trend for 11 major Indiana bat hibernacula is shown in Table 2 and Figure 4. All of the major sites lost a large number, whether or not they also had large numbers of Gray bats hibernating nearby. The decline in Pilot Knob Mine, which contained 36-44% of the state population in 1979, was 98% depending on which estimate used.

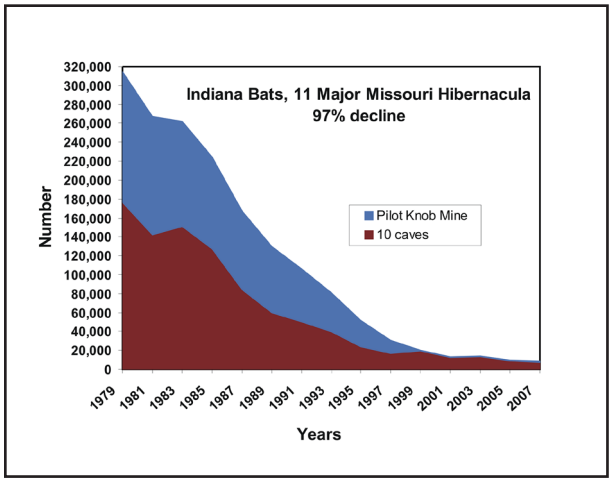

Figure 4 *Population trends at 11 major Indiana bat hibernacula, 1979-2007. The Pilot Knob data are stacked on the data for 10 caves.*

The trends for eight minor *M. sodalis* hibernacula are more difficult to assess numerically because all have not been followed completely for many years. Table 3 shows that four have been

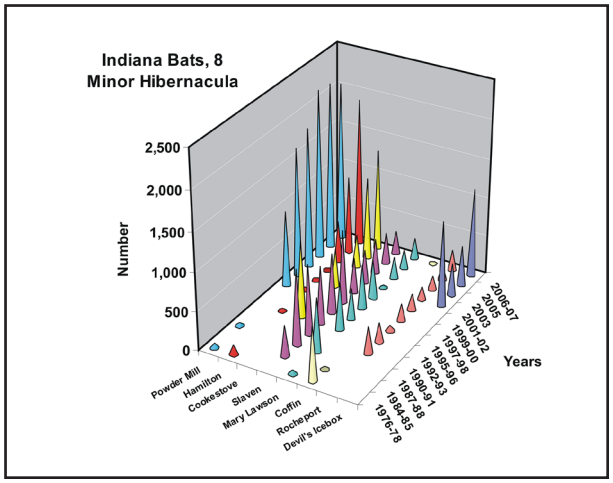

Figure 5 *Population trends at eight minor Indiana bat hibernacula, 1976–2007.*

censused since the 1970s, and most of the others since 1990-1991. Four of the colonies were up by 2006-2007, two were stable, and two were down (Figure 5). The largest increase was at Powder Mill Creek Cave, which was gated in 1995, after which the colony increased to >2,000 despite temperatures >10°C in the late 1990s. These bats may have moved from Bat Cave, Shannon County, about 28 km away, which essentially was abandoned, perhaps because of extremely variable temperatures, often below freezing (Elliott and Clawson 2001), and an increase in Gray bats there, but the true cause is uncertain (Figure 6). At Bat Cave the Grays usually moved up to the 10-meter-high ceiling where it is warmer, but the Indianas stayed under ledges and domes close to the floor where it was colder.

Gray bats are present at some of the sites that

Table 2 *Indiana bats in 11 major Missouri hibernacula, 1975–2007. Trends were examined and graphed from 1979-2007. Missing data (bold) were inserted from means of the previous two years (caves), or from a linear function between anchor points at Pilot Knob Mine. The 1979 estimate for Pilot Knob Mine was actually from October 1978, and the 2007 count was from February 2008. Since 1979 there was a 97% decline in the bats at the major hibernacula, and all lost a large number, whether they also had large numbers of Gray bats hibernating nearby or not.*

Year	Onyx Cave, Crawford	Bear Cave, Franklin	Copper Holow Sinkhole	Brooks Cave	Great Spirit Cave	Ryden Cave	Bat Cave, Shannon	Martin Cave	Great Scott Cave	Scotia Hollow Cave	10 caves	Pilot Knob Mine	Totals
1975	10,800	3,000	15,550						38,860	5,480	73,690	59,695	
1976	21,625	2,100	12,600				46,000		46,600	93	129,018	100,357	
1977	12,700	1,800	9,050				20,670		59,500	3,450	107,170	85,361	
1979	11,100	3,250	8,850	19,375	549	10,550	42,821	8,100	68,700	2,750	176,045	139,000	315,045
1981	5,325	1,750	5,200	11,850	1,792	5,800	32,800	2,425	72,350	3,100	142,392	125,130	267,522
1983	3,267	1,100	3,150	11,150	1,171	4,950	30,750	5,350	85,700	4,550	151,138	111,261	262,398
1985	2,250	650	1,050	5,500	500	2,000	30,450	3,550	77,950	3,400	127,300	97,391	224,691
1987	2,050	525	600	4,900	40	700	4,150	4,900	60,650	5,300	83,815	83,521	167,336
1989	1,575	400	250	5,200	35	1,350	4,275	2,600	38,875	5,150	59,710	69,652	129,362
1991	1,275	300	160	2,700	8	160	4,275	2,975	32,125	6,225	50,203	55,782	105,985
1993	700	225	125	1,550	625	80	6,175	2,250	22,750	4,550	39,030	41,912	80,942
1995	325	190	140	750	450	40	941	2,125	14,850	3,600	23,411	28,042	51,453
1997	260	95	175	600	195	14	450	1,500	11,875	1,615	16,779	14,173	30,952
1999	155	80	155	400	175	14	6,175	1,000	9,100	2,375	19,629	303	19,932
2001	265	105	185	235	285	10	89	2,460	8,250	450	12,334	647	12,981
2003	210	90	250	130	160	13	1,020	2,100	8,875	290	13,138	991	14,129
2005	180	100	250	70	40	10	0	1,300	6,450	150	8,550	1,334	9,884
2007	180	110	380	65	60	3	16	950	5,100	90	6,954	1,678	8,632

Table 3 *Indiana bats in eight minor Missouri hibernacula, 1975–2007.*

Year	Devils Icebox Cave	Rocheport Cave	Coffin Cave	Mary Lawson Cave	Slaven Cave	Cookstove Cave	Hamilton Cave	Powder Mill Creek Cave	Totals
1976–78			714	60			119	60	893
1984–85			0		405				405
1987–88				700	975			50	1,675
1990–91		350			900				1,250
1992–93		250		625	750	1,000	6		2,631
1995–96		80		400	775				1,255
1997–98		220		570	950		44	975	1,784
1999–00		215		500	450	500	1	1,660	3,326
2001–02	1,100	170		5	425			1,800	1,700
2003–04	420	180		280	440	430	530	2,175	2,280
2005–06	520	180		240	400	1,062	1,000	2,150	3,402
2007	1,140	259	17	275	290	1,300	1,900	2,050	5,181

had declines, but not all. Grays are absent at Pilot Knob Mine, which had the worst decline, so if crowding from Gray bats is a factor in the decline of Indianas, it is not the most important factor. New, minor hibernacula of Indiana bats have been found, most notably at Devils Icebox Cave, Boone County, in 2002, but they do not make up the large decline in the major hibernacula. Small colonies of transients are found in additional caves from time to time, they are not represented here, but their conservation also is important.

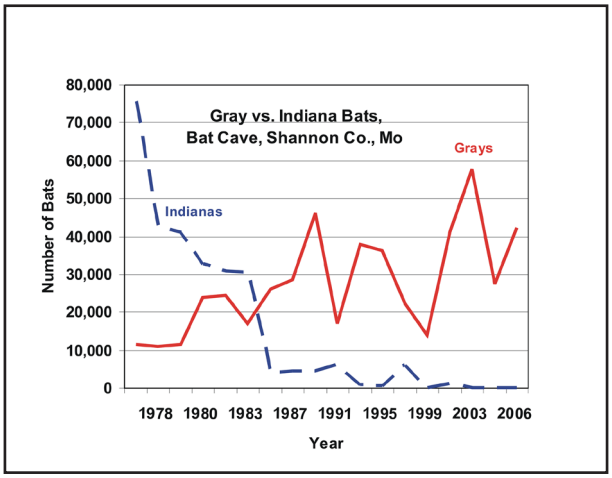

Figure 6 *Gray bats increased in Bat Cave, Shannon County, while Indiana bats declined since 1978. The trends are inversely correlated, but the true cause is uncertain.*

Gray bats. *M. grisescens* has been recorded from at least 219 caves, about 3.5% of Missouri caves (Table 1). Of these 49 are maternity caves, 13 are hibernacula (three with >30,000), 125 are transient and/or bachelor sites and 32 (15%) are abandoned. Additional sites likely exist, especially transient and minor maternity caves.

Table 4 and Figure 7 depict the trends at nine, priority 1, Gray bat maternity caves with a long census record: Devils Icebox, Great Spirit, McDowell, Mary Lawson, Toby (formerly confused with Mauss Cave), Moles, Rocheport, and Smittle caves. Data were placed in five-year bins for analysis. Overall, these colonies increased by 21% from about 1980 to 2005, and were at roughly 37% of their MPP (maximum past populations). Gray bats bottomed out between 1970 and 1985, but increased at many protected caves since then.

Table 5 and Figure 8 illustrate the trends at four, major, Gray bat hibernacula: Marvel, Mose Prater, Coffin, and Bat/Shannon caves. Marvel Cave, a show cave, lost most of its hibernating Grays because of warming trends in the cave caused by man-made alterations at the entrance, which decreased the influx of winter air. The other three hibernacula, which are protected without artificial alterations of airflow, have had increases in Gray bats.

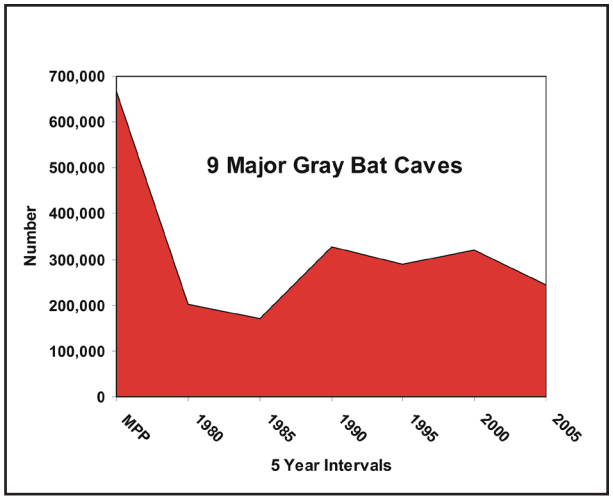

Figure 7 *Trends at nine, priority 1, Gray bat maternity caves with a long census record. See Table 4. Overall, these colonies increased by 21% about 1980 to 2005, and were at roughly 37% of their MPP (maximum past populations).*

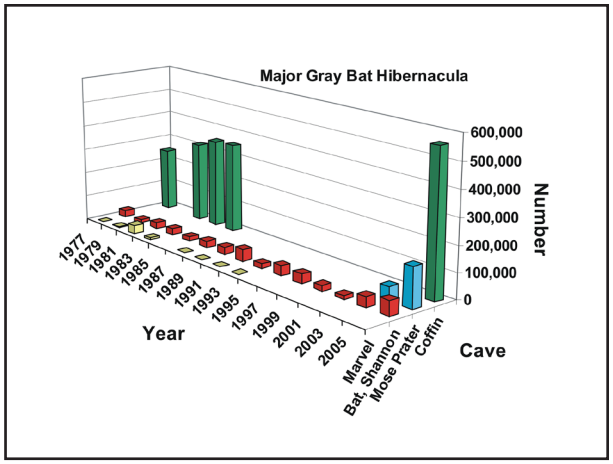

Figure 8 *Trends at four major, Gray bat hibernacula, 1977-2006. Some data have been shifted a year for graphing.*

Table 4 *Trends at nine, priority 1, Gray bat maternity caves with a long census record. Data were placed in five-year bins, bold numbers had no data so numbers were inserted from adjacent cells from the same cave. Overall, these colonies increased by 21% about 1980 to 2005, and were at roughly 37% of their MPP (maximum past populations). Toby was up to 97,000 and Smittle was currently down to 12,800 in the 2008 TIR census.*

	Devils Icebox, Boone	Great Spirit, Pulaski	Mc-Dowell, Miller	Mary Lawson, Laclede	Toby, Camden	Moles, Camden	Roche-port, Boone	Smittle, Wright	Totals
MPP	5,000	250,000	11,000	97,000	54,000	100,000	100,000	50,000	667,000
1980	5,000	10,000	12,000	21,500	42,800	40,000	25,000	46,000	202,300
1985	2,300	11,600	12,000	19,000	54,500	49,000	385	22,200	170,985
1990	9,350	10,200	10,200	36,700	71,400	67,320	16,320	105,500	326,990
1995	9,200	24,000	10,200	36,550	73,450	73,450	26,000	33,650	290,188
2000	13,050	22,000	7,800	34,300	76,700	93,840	41,000	33,650	320,815
2005	12,150	10,900	13,898	71,000	17,000	43,500	50,000	24,500	243,848

Table 5 *Trends at four major Gray bat hibernacula, 1977–2006. Some data have been shifted by one year for graphing. See Figure 8.*

	Marvel	Bat, Shannon	Mose Prater	Coffin
1977	86	27,299		250,000
1979	3,380	11,000		
1981	34,200	23,850		316,300
1983	8,850	24,400		349,500
1985		17,150		355,450
1987	2,425	26,050		
1989	1,286	28,725		
1991	1,300	46,300		
1993	900	17,030		
1995		37,945		
1997		36,400		
1999		22,400		
2001		14,100		
2003		41,100	52,000	
2005		57,850	155,000	561,000

Discussion and Conclusions

Indiana bats. Indiana bats have declined drastically in the Missouri region. The recent, statewide reestimate of about 15,812 indicates that Indiana bats declined by 95% since 1979. Some probably abandoned one cave for another, such as Powder Mill Creek Cave, seeking protection and more optimal temperatures. Pilot Knob Mine, a National Wildlife Refuge since 1987, had 80,000-100,000 Indiana bats in 1958, but only 1,678 were found there in February 2008, a 98% decline.

Tuttle and Kennedy (1999) analyzed 15 cave systems and found a strong correlation between

increasing cave temperatures and declining populations of *M. sodalis*. Elliott and Clawson (2001) analyzed temperature data from Missouri caves and surface weather. From 1975 to 1999 the mean annual temperature (calculated from daily highs and lows) at Waynesville, Missouri, was 12.9°C (55.3°F). The standard deviation was 1.4°C and the range was 11.7 to 14.4°C (53 to 58°F). There appeared to be no significant change in mean annual temperature between 1975 and 1999. However, in examining extreme lows in January, they found a possible warming trend since 1975 from about -21 to -18°C (-7 to 0°F). The author believes that extremely low temperatures from severe cold fronts could influence hibernaculum temperatures all year, probably more than mean annual temperatures. Severe cold fronts are usually associated with strong winds and barometric pressure drops, which cause more cold air invasion into caves than weaker fronts. It is possible that the loss of extreme winter lows magnifies the warming at some cold-air traps in Missouri.

We have no continuous temperature records in the hibernacula for 30 years, but we do have spot readings taken with a digital thermometer on every winter trip. Figures 9–13 are selected graphs depicting trends in Indiana bat populations with the simultaneous air and rock spot temperatures. The data were not controlled for exact date, so there may be some hidden variance related to January vs. February visits, generally, and a few December and March dates. However, the rock temperature changes slowly. These graphs illustrate that temperatures were generally above the optimal 5°C for hibernation of *M. sodalis,* found by Dzurick (2007). However, the populations began plummeting generally without much change in hibernaculum temperature. Brooks Cave (Figure 9) is interesting in that it is located on Fort Leonard Wood with only a little disturbance, lacks Gray bats, was never gated, had little temperature change, and yet the bats declined. Ryden Cave (Figure 10) was gated, lacks Gray bats, had little warming and a recent cooling, and the Indianas declined. Great Scott Cave (Figure 11) warmed up mostly because its second entrance was blocked off, but it cooled again after a second cave gate was installed in 1999. Indianas increased there until 1983, then they declined despite the later cooling. Bat Cave, Shannon County (Figure 12), is extremely variable in temperature, and it has had a cooling trend since 1995. Yet Grays increased there while Indianas essentially abandoned the cave (Figure 6). Indianas may have moved from the latter cave to Powder Mill Creek Cave (Figure 13). In the author's opinion, these five examples indicate that the decline in Missouri's Indiana bats has not been caused by temperature changes alone.

Disturbance during hibernation was one of the important, early factors in the decline of Indiana bats, and it still is a threat at unprotected sites. Improperly designed cave gates have been implicated in some population declines, but all such gates have been removed or replaced at Missouri Indiana bat caves. Loss or reduction of roosting or foraging habitat during the warm season also has been suspected.

Pesticide residues were detected in Indianas, Grays, and other bats in Missouri (Clark et al. 1978, 1980, 1983, Clawson et al. 1983, 1989, 1991, McFarland 1998, O'Shea and Clark 2002, Schmidt and Glueck 2002). O'Shea and Clark (2002) provided a review and examined temporal and spatial patterns of agricultural pesticide use in Missouri and Indiana. Some Grays and Indianas died from organochlorine (OC) insecticides prior to their discontinuance in the 1980s. Dieldrin in carcasses of Indiana bats from Missouri in the 1970s was one to two orders of magnitude higher than the norm and reached lethal concentrations in brains of

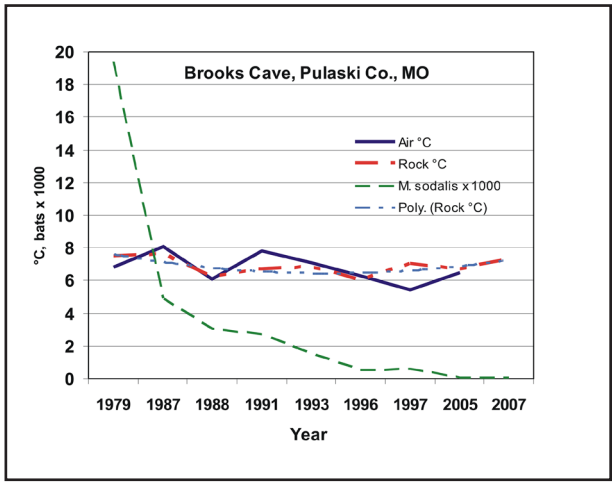

Figure 9 *Indiana bat population trend in Brooks Cave, Pulaski County, combined with concomitant air and rock temperature readings. A polynomial trend line (dot-dash line) has been fitted to the rock temperatures in this and Figures 10–13.*

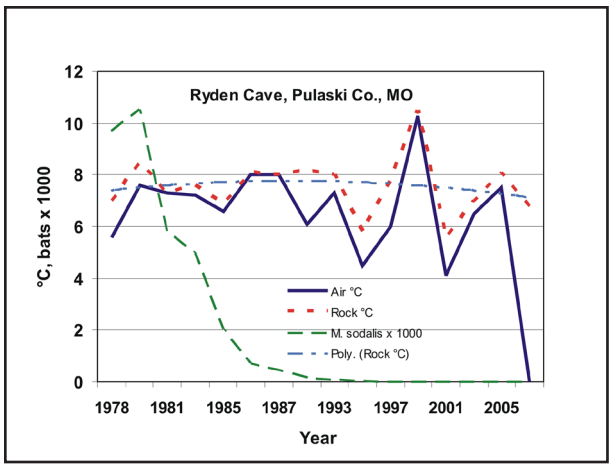

Figure 10 *Indiana bat population trend in Ryden Cave, Pulaski County, combined with concomitant air and rock temperature readings.*

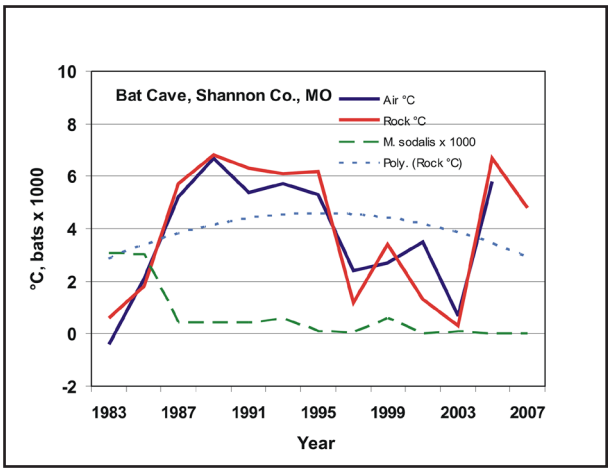

Figure 12 *Indiana bat population trend in Bat Cave, Shannon County, combined with concomitant air and rock temperature readings. This cave has extremely variable winter temperatures.*

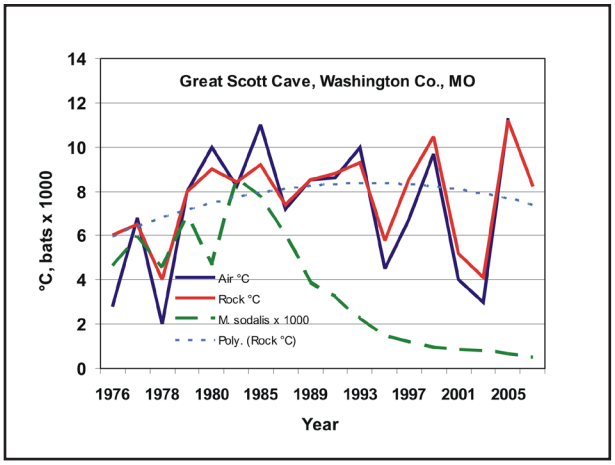

Figure 11 *Indiana bat population trend in Great Scott Cave, Washington County, combined with concomitant air and rock temperature readings. A blocked, secondary cave entrance was regated in 1999, which cooled the cave to somewhat normal temperatures.*

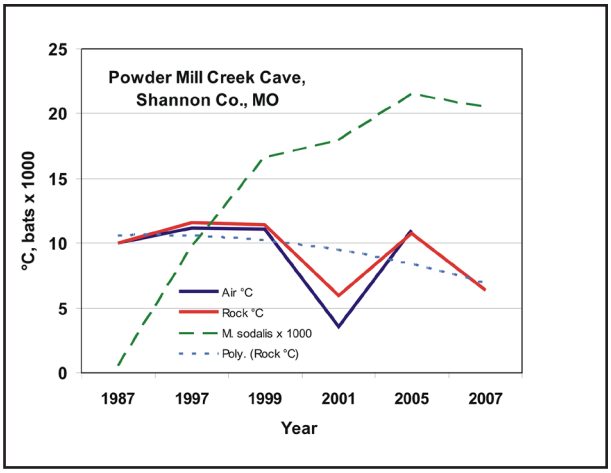

Figure 13 *Indiana bat population trend in Powder Mill Creek Cave, Shannon County, combined with concomitant air and rock temperature readings. Although temperatures were >10°C in the late 1990s, the population increased, possibly because they abandoned Bat Cave, Shannon.*

some individuals. Chronic mortality was suggested in these two endangered species even in the 1980s. McFarland (1998) found persistent OC residues in Little brown bats and Northern bats, long after OCs were discontinued.

Some studies found organophosphates (OP) and carbamates in Missouri bats. These insecticides are not as persistent as OCs, but they may cause acute toxicity, death, or sublethal intoxication leading to inability to fly, which is certain death in flying mammals. Other sublethal effects on thermoregulation, food consumption, and reproduction could lead to population declines. Pyrethroid use increased later in Missouri, and would also be toxic to bats.

No systematic surveys are currently being done

in Missouri that would find pesticides in Indiana and Gray bats, or other suitable surrogate species. O'Shea and Clark's (2002) suggestion that Indianas may forage over cotton fields in southeastern Missouri, heavily treated with insecticides, is an unlikely scenario because cotton is >100 km from the nearest, known hibernaculum. A more realistic hypothesis of a cause of Indiana bat decline would be pesticide contamination of prey insects in northern Missouri, where there is much more pesticide use in row-crop agriculture than within the range of foraging Indiana bats in most of southern Missouri. Circumstantial evidence in favor of this hypothesis is the continued increase of Gray bats, which range more in the southern part of the state, in forest, pasture, and hay areas with little pesticide use. The Missouri Natural Heritage Database has no current records of Indiana or Gray bats in the row-crop areas of southeastern Missouri, such as Perry County, which has many caves, but is also farmed for corn and soybeans. No caves occur in the cotton-growing areas of the Missouri Bootheel, comprising Dunklin, Pemiscot, New Madrid, Stoaddard, and Scott counties (Elliott 2007).

Another hypothesis would be crowding by increasing Gray bats, but I do not believe that to be an important factor based on two observations

(1) Indiana bats declined at most sites, even without Gray bats present, and (2) I have not observed agonistic behavior between Grays and Indianas, although I have photographed Grays crawling on the edges of Indiana bat clusters several times, and even on top of Indiana bats (Figure 14). Grays do this in their own clusters, but I have not observed Indiana bats leaving as a result of such behavior, although our visits are brief.

Disease is another hypothesis of decline that has not been eliminated. White Nose Syndrome, which had a recent outbreak in bats in the north-

Figure 14 *A cluster of 43* Myotis sodalis *with five* M. grisescens *on the edge, indicated by white dots. Onyx Cave, Crawford County, Missouri, January 19, 2007.*

eastern U.S., has not been found in Missouri to date, and it probably was not involved in declines 30 years ago. Several Missouri bat caves were checked in the winter of 2007–2008 and, although some bats were seen with mold on their skin, they did not fly outside during the day or appear to be starving, which are characteristic of this syndrome.

I suggest that Indiana bats in Missouri have been adversely affected by several factors: disturbance by humans (especially 30 years ago, but at some sites even today), the partial collapse of Pilot Knob Mine in 1979, some effect from global warming at some hibernacula, (especially from the loss of extreme winter lows), and possibly pesticides and loss of summer habitat in northern Missouri.

Gray bats. Missouri's Gray bat population declined, but is now stable or increasing in some protected caves. Many other caves remain abandoned for various reasons. At bottom, Gray bats had lost at least 67% of their maximum past population, as measured in 56 important caves, and 53% of the caves were abandoned. The maternity population of Gray bats in Missouri is currently estimated at approximately 635,000. This is compared to evidence (guano and ceiling stains) suggesting that historic populations in the same set of caves once numbered over 1,700,000 (Table 1).

Thirty-one Gray bat hibernacula totaled 784,000 in recent years. The three major hibernacula were censused in 2006 and totaled 773,850. While Marvel Cave declined, Bat Cave, Shannon, was at 337% in 20 years, and Coffin Cave was at 157% (Tables 1 and 5).

Although there has been a general increase in Gray bats, many maternity colonies are still threatened by intruders and vandals. Table 6 summarizes events and population trends at 13 selected caves. These examples illustrate the typical problems that MDC has seen in managing these caves, and there are a few extreme examples as well. Figures 15 and 16 illustrate the vagaries of management at Blackwell and McDowell caves, whose bat populations have fluctuated with archaeological looting and breaches of the otherwise effective gates built in 2001.

The conclusion that I draw from ten years of bat cave management in Missouri, is that it requires a major effort by many people to keep Gray bat colonies stable or increasing, and to keep the few remaining Indiana bat colonies from being disturbed by intruders. One cannot gate a cave and consider it safe for long. Each cave gate must be checked and maintained periodically. It is common to find a breach in even the strongest cave gate within a few years. The more cave gates that are built, whether on state or private land, the more long-term commitment we have to maintain the gates. The gates may have an expected lifetime of 30 to 50 years in a relatively dry entrance, but at caves that are prone to flash flooding the gate may only last two to four years. Many lessons have been learned by wildlife agencies who build cave gates. Having lost three cave gates to floods in the last 11 years persuades the author to be cautious about building any more, unless they are built to higher engineering standards at greater cost.

Obtaining accurate census data also is a large task, now involving several experienced biologists, weeks of field time every year, high-quality digital cameras, flash units, infrared video gear, specialized software, and many hours for analysis. As pointed out by Martin (2007) and Sasse et al. (2007), more accurate and standardized census data are needed across the range of Gray bats before one could downlist or delist them from the U.S. Endangered Species List.

The Gray bat is a key species in Missouri cave ecosystems, providing nutrient input to animal communities. Conservation work has returned Gray bats in Missouri to about 46% (784,000) of the state population decades ago. I have calculated that the average colony of 10,000 Gray bats consumes about 45 kg (100 pounds) of insects each night between March and October, based on eating half their weight each night, or up to their weight each night for pregnant or nursing mothers. That translates to about 10 metric tons per year, about 4.3 billion insects. They eat a variety of species, such as aquatic insects—especially mayflies, caddisflies, and stoneflies—but also beetles and moths, some of which are agricultural pests. Statewide, Gray bats are eating 490 metric tons (223 billion) of insects per year. This is a major economic and environmental benefit to humans. We should also consider how much insect control we have lost by losing 300,000 Indiana bats in 30 years.

We have found that Grays and Indianas are unlikely to return to long-abandoned roosts, but this does not mean that restoration of caves and cave gating should not be tried where the potential payoff may be great. For Grays and Indianas, cave gates

Table 6 *Examples of management problems and population trends at selected Gray bat maternity caves.*

Cave, County	History	Population Trend
Bat Cave #1, Franklin	Upper entrance bulldozed 1970s, lower entrance full gate1989, airflow reduced, cave cooled, pigeons infested lower entrance. MDC opened upper entrance and gated 2005, temperatures more natural. Upper gate breached and repaired 2007.	MPP 91,800 in 1976. Abandoned before 1990. Colony in nearby suboptimal cave might recolonize. MDC monitors for bats yearly.
Blackwell, Hickory	Difficult to monitor. Full rebar gate in 1979 hindered bats, modified to flyover in 1980. Break-ins by looters and abandonment 2000. New flyover gate 2001. Intrusions and break-in in 2004–2005, bats dropped to 700 in 2005.	Varies with intrusions.
Devils Icebox, Boone	No gate, intruders are infrequent because of strict park management, scheduled caving trips and long, cold water passage.	Stable since 1995.
Grandpa Chippley, Camden	MDC aquired 1997. Some intrusions, flyover gate 2004. Gate fell down April 2008 because of flooding and too few pins to walls.	Probably stable. Guano washes out, difficult to census until NIR and TIR.
Great Spirit, Pulaski	Show cave 1950s, MDC acquired 1981 and installed inadequate chain-link fence. Intense looting and bat disturbance. Large flyover gate 2002 for multiple resources.	Nearly abandoned. Struggling maternity colony.
Lower Burnt Mill, Camden	Frequent intruders from river recreators until April 2008 when MDC built chute gate and acquired land. Bats absent summer 2008, may be at Toby 5 km away.	Struggling maternity colony varied 0–30,600 since 1978 with intrusions.
Mary Lawson, Laclede	Good private protection for many years, MDC acquired and gated with flyover, 2004.	Up since gating
McDowell, Miller	Isolated area of park, frequent looting and visitors disturbed bats despite signs, chute gate 2001, breached 2003 or 2004, breached 2006 or 2007. More maintenance needed.	Varies with intrusions. Censused most summers since 2001.
Moles, Camden	In remote area, full constricted gate 1978, removed 1979 when it hindered bats.	Stable for long time, down in 2005, colony exchanges with Toby Cave.
Rocheport, Boone	Show cave 1965, owner tried to smoke out bats. MDC acquired 1995, flyover gate 1996, washed out 1997. New, very large flyover gate 2002, washed out 2004-2007. Second gate too heavy for structure, inadequately anchored, flood debris clean out a problem. Perimeter fence installed 2008.	Varies with flash floods, intrusions.
Smittle, Wright	Show cave 1950s. Acquired by MDC and fenced 1988. Flyover gate 1997. Some intrusions and two breaches. Open to permit caving in May and September. Key may have been copied by some permittees. Guano difficult to measure in cave stream.	Peaked at 105,500 in 1985 (guano). Down to 12,800 in 2008 (TIR).
Toby (Mauss), Camden	Large cave in remote area, protected well by private owner. Some caving allowed during appropriate times.	17,000–81,600 in 1977–2003, 97,000 in 2008.
Tumbling Creek, Taney	Intrusions led to constricted internal barrel gates 1966. Gates removed and large chute gate built 2004.	Declined 36,450–12,400 from 1976–2004. Up to 36,000 since regating.

are still important, and they must be checked and maintained periodically (Elliott 2006).

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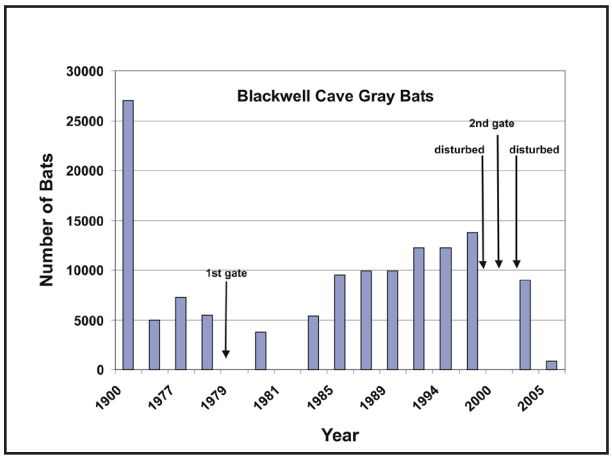

Figure 15 *Blackwell Cave's Gray bats have been repeatedly disturbed by archaeological looters and vandals. The flyover gate, built in 2001, was breached and a ladder was used to gain entry. Only 98 bats were seen in July 2008.*

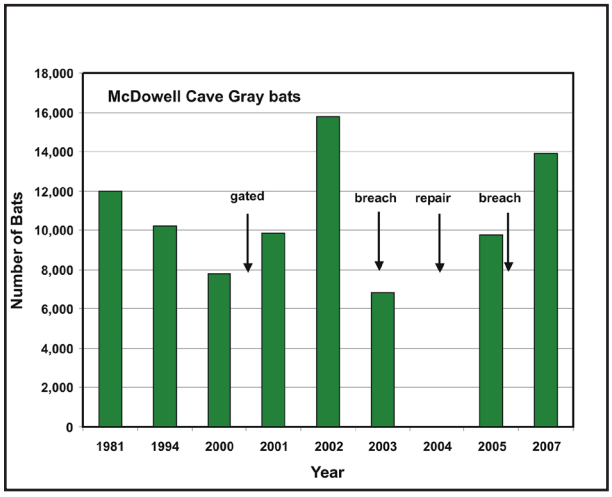

Figure 16 *A chute gate was built on McDowell Cave in 2001. No census was done in 2004. Small breaches of the chute were repaired, but the Gray bat colony was affected sometimes.*

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